Coquitlam-Buntzen Project Water Use Plan

Lower Coquitlam River Substrate Quality Assessment

Implementation Year 8

Reference: COQMON-8

LOWER COQUITLAM RIVER SUBSTRATE QUALITY ASSESSMENT

Study Period: 2012-2015

Submitted to:
BC Hydro and Power Authority
5911 Southpoint Drive
Burnaby, BC
V3N 4X8

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EXECUTIVE SUMMARY

G3 Consulting Ltd. (G3) was retained by BC Hydro to complete a Lower Coquitlam River Substrate Quality Assessment in salmonid spawning and rearing habitat of the Lower Coquitlam River from 2012 to 2017. A primary objective of this study is to evaluate the effectiveness of flushing flow provisions intended to increase fish productivity through improved substrate quality in the Lower Coquitlam River.

As part of the *Coquitlam River Water Use Plan* (WUP), eight (8) separate monitoring programs have been implemented with the objectives and monitoring indicators reported to BC's Comptroller of Water Rights. The *Lower Coquitlam River Substrate Quality Assessment* is the focus of this report and provides an update on project activities and results of three (3) years of monitoring surveys undertaken between October 2012 and May 2015.

Substrate quality was assessed at six (6) sampling sites in the Lower Coquitlam River by measuring percent (%) particle size distribution for surficial and subsurface samples collected using a modified Hess sampling method. Sampling was conducted at the start of the salmon spawning season (September or October [autumn]), during the mid-incubation period (January [winter]) and at the end of emergence (May [spring]). During each sampling event at each site, an assessment of dominant and subdominant substrate type, percent (%) embeddedness, D_{95}, D_{50}, water depth, turbidity and water velocity was done.

Mean percent (%) embeddedness, mean D_{50} and mean D_{95} were generally comparable over the three (3) years of monitoring and among sites and season. Mean turbidity ranged between 0.35 NTU (Site 5) and 3.86 NTU (Site 3) across study years. Higher turbidity at Site 3 compared to other sites was noted in January 2014 (10.44 NTU) and January 2015 (10.47 NTU). A visible sediment plume at Site 3 was noted during winter sampling events in 2014 and 2015, arising potentially from an adjacent gravel mining operation immediately upstream of Site 3.

For the October 2012 to May 2015 program, results of 3-way (year, season and site) ANOVA showed significant differences over years ($p<0.001$) and between seasons ($p<0.0001$) in surface sand, silt and clay fractions and among sites ($p<0.01$) in sand and silt fractions. There were no significant interaction effects noted for any surface particle size fractions. Results of 3-way (year, season and site) ANOVA showed significant differences over years ($p<0.0001$), between seasons ($p<0.01$) and among sites ($p<0.0001$) in all subsurface particle sizes (<10 mm) except clay, in which there was significant difference only between seasons. There were significant interaction effects on all subsurface particle sizes (<10 mm) for clay ($p<0.05$) and all others fractions ($p<0.0001$). For coarse (>10 mm) subsurface particles, results of 3-way (year, season and site) ANOVA showed significant differences between years for all grain sizes ($p<0.05$ to $p<0.0001$), between seasons for pebbles ($p<0.05$ to $p< 0.001$) and among sites only for very coarse pebble ($p<0.001$). Significant interaction effects were noted on medium pebble ($p<0.01$), very coarse pebble ($p<0.001$) and medium cobble ($p<0.05$). Comparatively higher turbidity levels at Site 3 suggest possible contribution of fine sediment inputs upstream of Site 3.

Suitable substrates for spawning and rearing were observed at the sampling sites; however, data from which to determine whether flushing flows were effective at mobilizing sediments and whether sediment particle size profiles at each site are a reflection of discharge or other environmental factors remains inconclusive at this time due to the lack of intentional flushing flows from Coquitlam Dam during the study period. Analysis of substrate quality results will require several years of data to develop robust correlations between substrate quality results and fish productivity and have not been considered in this report.

1.0 INTRODUCTION

On behalf of the British Columbia Hydro and Power Authority (BC Hydro), G3 Consulting Ltd. (G3) was retained to complete a Lower Coquitlam River Substrate Quality Assessment program (COQMON #8) in salmonid spawning and rearing habitat of the Lower Coquitlam River from 2012 to 2017. The *Lower Coquitlam Substrate Quality Assessment* program (COQMON #8) is part of comprehensive monitoring program established by BC Hydro to address uncertainties related to the effectiveness of the *Coquitlam-Buntzen Water Use Plan* (LB1 WUP) operating constraints. The overall objective of the monitoring program is to produce information required for future water planning processes on the Coquitlam-Buntzen system in support of a Coquitlam Dam release regime that fits within the parameters of the LB1 WUP agreement.

As part of the LB1 WUP, eight (8) separate monitoring programs (COQMON #1-8) were implemented with objectives and monitoring indicators reported to BC's Comptroller of Water Rights. *The Lower Coquitlam River Substrate Quality Assessment* (COQMON#8) study is the focus of this report for Years 1 to 3 (October 2012 to May 2015) of this monitoring program. The primary objective of COQMON#8 is to evaluate the effectiveness of flushing flow provisions as outlined in the LB1 WUP to increase fish productivity through improved substrate quality in the Lower Coquitlam River.

This chapter (Chapter 1) outlines study objectives and summarizes important information on the morphology, ecology and substrate of the study area within the Lower Coquitlam River. Chapter 2 provides an overview of the study design and methodology for field and laboratory work. Chapter 3 provides results and discussion. Summary and recommendations are provided in Chapter 4 with references in Chapter 5. Appendices provide figures (Appendix 1), charts (Appendix 2), tables (Appendix 3), photographs (Appendix 4), laboratory and raw data (Appendix 5), the *Emergency Action and Safety Management Plan* (Appendix 6) and a sample of field forms (Appendix 7).

1.1 Background

1.1.1 1 Physiography of the Coquitlam River Watershed

The Coquitlam River watershed is one of many watersheds on the north shore of the Fraser River in southwestern British Columbia. The river drains 261 km^2 in the southern Coast Mountains (McPhee, 2003), part of the traditional territory of the Kwikwetlem First Nation. The Coquitlam River watershed can be subdivided into two sections, namely the Headwaters (including the Coquitlam Reservoir above the Coquitlam Lake Dam) and the lower watershed. The lower watershed drains 79 km^2 and includes at least thirty watercourses draining into the Lower Coquitlam River. The Lower Coquitlam River is over 18 km long from the Coquitlam Lake Dam to its mouth into the Fraser River, near the estuary on Georgia Strait (McPhee, 2003; Figure A1-2, Appendix 1).

The present-day channel of the Lower Coquitlam River carved through glaciofluvial outwash sands and gravels, deltaic silts and fine sands, glaciomarine and glaciolacustrine clays and silts and boulder glacial till deposited during late Quaternary glacial advances (Armstrong, 1990; NHC, 2012). Presently, river confinement decreases downstream of Galette Avenue towards Lougheed Highway and channel substrate is characterized by glacial till overlain by stony glaciomarine clays and sandy beach sediments deposited during elevated sea levels at the time of the last glacial retreat (NHC, 2012).

Three (3) sources provide the primary bulk of sediment contribution to the Lower Coquitlam River: tributary inputs, mass wasting of glaciolacustrine deposits and gravel mining activities (NHC, 2012). Or Creek drains an area approximately 23.5 km^2 and enters the Lower Coquitlam River approximately 1.5 km downstream of the dam. Considered to be the largest contributor of sediment to the Lower Coquitlam River, Or Creek carries cobbles and boulders from the mountainous headwaters and supplies silts and clays from high eroding glaciolacustrine terrace scarps near the creek mouth (NHC, 2001 and 2012). Scott and Hoy Creeks were not considered as notable contributors in this study given that they join the Lower Coquitlam River downstream of the monitoring reaches.

Gravel operations adjacent to the Coquitlam River began in the 1950s and three (3) mines were active in the watershed at the time of writing (Coquitlam River Watershed, 2016). Exposed glacial deposits have been mined for gravel on the west side of the broad bedrock canyon between the dam and Lougheed Highway and wastewater from gravel operations was treated in settling ponds prior to being discharged into the river (McPhee, 2003). Most of the sediment introduced to the river from the gravel mines consisted of fine sand, silt and clays creating frequent turbidity events below the point of discharge. Past discharges from the mines have also included coarser sediments. Occasional settling pond failures have resulted in greater contributions of coarser sediment to the river (NHC, 2007).

1.1.2 2 Hydrology of the Coquitlam River Watershed

Water contributions to the Lower Coquitlam River watershed are sourced from precipitation, upper watershed flow (released from the Coquitlam Lake reservoir), inflows from tributaries (Or Creek being the most important), runoff from surface flows, stormwater discharges and subsurface flows (McPhee, 2003). Dam releases and tributary inflows supply the majority of water to the system. Construction of the Coquitlam Lake dam in the early 1900s and urbanization have had the largest influences on the watershed hydrology.

Since the early 1900s the river has been dammed to provide consistent water supply and power generation to support the growing communities of the Lower Mainland. An early history (pre-1914) of hydroelectric development in the lower reaches of the Coquitlam River was outlined in Koop (2001).

Fine sediment infiltration into surface and subsurface river substrates depends on several factors, including local hydraulics, size distribution of the bed material and size distribution and volume of sediment supplied to a reach (Evans and Wilcox, 2013). The larger grain sizes (e.g., large gravels and cobbles) found in the Lower Coquitlam River have greater porosity between grains for infiltrating sediment (Wooster *et al*., 2008). The largest fraction of infiltrating fine particles (<4 mm; granule, sand, silt and clay) typically originates from bedload (not settled suspended load) and less frequently mobilized channel beds can preserve fine sediment loadings for longer residence times (Lisle, 1989; Venditti *et al*., 2010). Scour and fill events winnow fines from the channel bed, exposing deeper layers of the substrate and managing sand deposition (Lisle, 1989). Fine sediment infiltration can decrease the mobility of coarse particles in the channel bed, increase cohesion between grains and increase bottom current velocity by smoothing protrusion of coarse particles (Evans and Wilcox, 2013).

1.1.3 3 Climate of the Lower Coquitlam River Watershed

The Lower Coquitlam River watershed is characterized by the coastal western hemlock (CWH) biogeoclimatic (BEC) zone and west coast maritime climate. Pressure systems travel in an easterly direction, contributing high annual precipitation to the mountainous terrain of the Coquitlam River headwaters. Average precipitation doubles between the mouth of the river (1,869 mm) and the reservoir (3,468 mm) due to elevation changes and precipitation is greatest between November and March (McPhee, 2003).

1.1.4 4 Fish Resources of the Lower Coquitlam River

Fish are important ecological, cultural and economic resources in a watershed. Twenty-four (24) fish species are known to inhabit tributaries of the Coquitlam River Watershed. Several species of anadromous Pacific salmon (Coho salmon [*Oncorhynchus kisutch*], Chum salmon [*Oncorhynchus keta*], Chinook salmon [*Oncorhynchus tshawytscha*] and Pink salmon [*Oncorhynchus gorbuscha*]) as well as sea-run and resident trout (steelhead/rainbow [*Oncorhynchus mykiss*], Coastal cutthroat trout [*Oncorhynchus clarki clarki*]) and char (Dolly Varden [*Salvelinus malma*] and bull trout [*Salvelinus confluentus*]) use the Lower Coquitlam River to complete their life cycles (McPhee, 2003).

Fine sediment infiltration can reduce habitat quality for macroinvertebrates, salmonids and other aquatic organisms (Evans and Wilcox, 2013). Excessive fine sediment loadings can create a community shift towards burrowing macroinvertebrates, thereby reducing prey availability for juvenile salmonids (Suttle *et al*., 2004). Incubation success of salmonids is inhibited by reduced intergravel flow which decreases ambient oxygen availability below concentrations necessary for diffuse exchange across egg membranes (Greig *et al*., 2005). Fine-textured substrata (e.g., 5 to 8 mm diameter) can also create physical barriers to emerging posthatch salmonids migrating to open water from the interstitial zone and reduce overall survival rate (Sternecker and Geist, 2010).

1.2 Study Objectives & Monitoring Program Rationale

In 2003, the LB1 WUP Consultative Committee (CC) agreed to a set of operating conditions for the review period set to end in 2017. The agreement included the release of two (2) flow regimes (Treatment 1 and Treatment 2) from Coquitlam Dam.

- Treatment 1 (1999 - autumn 2008): releases between 0.8 m^3/s to 1.7 m^3/s; and,
- Treatment 2 (autumn 2008 – 2017): releases between 1.1 m^3/s to 5.9 m^3/s (seasonally variable).

Treatment 1 adhered to the release schedule from two fully open fish valves (2FVC), whereas Treatment 2 adhered to the alternate release schedule described as “Share the Pain #6” (STP6). Treatment 2 was implemented following dam seismic upgrade completion in 2008.

To address uncertainties related to the effectiveness of LB1 WUP operating constraints, a monitoring program was recommended by the CC and implemented for the duration of the review period (BC Hydro, 2003, 2006, 2007, 2009). The monitoring program objective was to provide necessary information required for future water planning processes and recommend a Coquitlam Dam release regime within the parameters of the LB1 WUP agreement (i.e., whichever annual water budget between Treatment 1 and Treatment 2 would be more beneficial to fish). In general, the program attempted to address key uncertainties and evaluate the effectiveness of WUP operations using fish productivity in the Lower Coquitlam River as the primary indicator of effectiveness. Although the lower reaches (i.e., Reaches 0 and 1) are known to be highly productive areas for fish in the Coquitlam River, the effect size used in analysis showed that these sites would be less reliable indicators of response to upstream dam releases (Higgins *et al*., 2002). As a result, the monitoring program was focused on the upper reaches (i.e., Reaches 2 to 4).

Two (2) factors affecting fisheries productivity in the Lower Coquitlam River were highlighted during WUP proceedings:

- *Instream flows*: the timing and magnitude of flow releases from Coquitlam Dam were evaluated in terms of habitat benefits; and,
- *Substrate quality*: the fine sand content and availability of substrate suitable for spawning and overwintering.

The CC recognized that improving substrate quality could enhance habitat quality. Consequently, a study was commissioned to investigate the use of flow releases to improve substrate quality. The investigation determined that short-term, high magnitude flow releases (“flushing flows”) from Coquitlam Dam would be highly effective at mobilizing fines from the channel bedload and recruiting gravel through erosion and bedload movement.

Recommendations from the *Fisheries Technical Committee* (FTC) advocated annual flushing flow releases of 30-50 m^3/s from the Coquitlam Dam for 3 to 5 days a year, coinciding with peak inflows from Or Creek to produce total flows of 70-100 m^3/s, herein referred to as regulated flushing flows. The objective of these flows was to mobilize and reduce fine sediment fractions (e.g., diameter <10 mm) from the top 10-20 cm of river substrate. Implications and effectiveness of this operation were not fully assessed by the CC, leading to the decision to monitor substrate quality on a seasonal basis throughout the review period to investigate linkages between fish productivity and substrate quality.

1.3 Program Requirements & Objectives

1.3.1 1 Management Questions

Future water use decisions require that the following question be addressed in this monitoring program:

Question: Will recommended flushing flow operations result in improvements to substrate quality and fish productivity in the Lower Coquitlam River?

The procedures used to assess the relationships between substrate composition, habitat quality and fish productivity in the Lower Coquitlam River involve the review of fish productivity results in conjunction with substrate quality monitoring data. Substrate quality indicators and methods of data collection can vary according to dominant channel and substrate forms; therefore, for the purpose of this program and to maintain interpretive consistency, substrate quality using volumetric and particle size analysis was applied. Given that natural inflow in the Coquitlam River can result in notable channel disruption, an analysis of both regulated and unregulated flushing flow events will also be undertaken. Regulated flushing flows are generated by additional flow releases from Coquitlam Dam coinciding with elevated tributary inflows to the Lower Coquitlam River and unregulated flushing flows are generated by high tributary inflows without additional flow releases from Coquitlam Dam.

Substrate quality can influence spawning and rearing success of salmonids in coastal rivers (Bjornn and Reiser, 1991; Suttle *et al*., 2004; Greig *et al*., 2005). An assessment of this influence in the Lower Coquitlam River would be conducted by assessing any correlation between substrate quality data and fish productivity and comparing field monitoring results with established biostandards (i.e., relating spawning and rearing success to substrate quality). This correlation will be undertaken in the final interpretive report of the monitoring program.

1.3.2 2 Key Water Use Decision Affected

One objective of the COQMON#8 Lower Coquitlam River Substrate Quality Assessment study was to assess the effectiveness of the flushing flow provisions in the water use plan to enable BC Hydro to provide recommendations to re-instate, modify or eliminate the flushing flow provisions in the WUP following the 2015 Substrate Quality Assessment report. In addition, the evaluation of both flow releases outlined in the Coquitlam-Buntzen WUP will be completed by 2016 and based on the results from this and other studies, BC Hydro will recommend a base flow regime to the *Water Planning Committee*. The flow recommendations will meet the objective of optimizing fish interests in the Lower Coquitlam River and be constrained within the two (2) releases being tested in consideration of Metro Vancouver's (previously known as GVRD) planning requirements (BC Hydro, 2002). Any recommendation from BC Hydro will be vetted through the monitoring committee to ensure it has their understanding and support.

1.3.3 3 Flushing Flows

Monitoring potential effects of flushing flow events (regulated or unregulated) occurs separately from scheduled seasonal monitoring of substrate quality. Flushing flows are defined as short-term, high magnitude flow releases that mobilize fines from the channel bedload and recruit gravel through erosion and bedload movement (NHC, 2002). Flushing flows recommended by the *Fisheries Technical Committee* were defined as flows between 70-100 m^3/s for a duration of 3 to 5 days (BC Hydro, 2006). Regulated flushing flows were to be generated by releasing 30-50 m^3/s from the Coquitlam Dam, coinciding with peak inflows from Or Creek, to maintain discharges of 70 m^3/s to 100 m^3/s for 3 to 5 days. Regulated flushing flows (generated by increased flow releases from Coquitlam Dam coinciding with elevated tributary inflow) are expected to occur one (1) out of every four (4) years (BC Hydro, 2005). In addition, unregulated flushing flows (without increased Coquitlam Dam flow releases) of the same magnitude (70 to 100 m^3/s) or greater may occur in the Lower Coquitlam River resulting from elevated inflows from tributaries, in particular Or Creek. The bulk-sieve subsurface sampling method described by Northwest Hydraulics Consultants (2008) and Church *et al*. (1987) was originally proposed for sampling substrate following a flushing flow event; however, following discussion with BC Hydro in 2015, the modified Hess surface and subsurface sampling method used during the regular triannual sampling program and described in this report (Chapter 2) will be used to assess future flushing flows to provide for consistency in data comparisons.

1.3.4 4 Sampling Timing

Monitoring of substrate quality is to be conducted during three (3) surveys each year to coincide with the start of the salmon spawning period (week of October 15th), mid-incubation period (week of January 15th) and end of emergence (week of May 1st), though environmental factors influence the timing of sampling events. During October 2012 and 2013 sampling events, active salmon redds were observed on-site and avoided during sampling. Subsequently, advance sampling in mid-September was implemented in 2014 to avoid disturbing spawning salmons. Fluctuating water levels and fast-flowing water pose a logistical challenge for sampling in the Lower Coquitlam River. A river level of eight (8) meters or less at the Water Survey of Canada (WSC) streamflow gauging station (08MH002; Coquitlam River at Port Coquitlam) located at the CP Rail Bridge, 0.4 km downstream of Lougheed Highway is required for safe access and successful sampling. Real-time water depth and discharge data at WSC Station 08MH002 is monitored in the days leading up to the anticipated sampling events and timing of sampling adjusted if required to ensure a successful sampling event.

1.4 Past Results & Recommendations

1.4.1 1 Bulk-Sieve Subsurface Sampling

Bulk-sieve subsurface sampling (bulk sampling) occurred in the Lower Coquitlam River between 2000 – 2009 at sites monitored by Northwest Hydraulics Consultants (NHC; PSS 3, 7, 9 and 10; Figure A1-1, Appendix 1). Excavation pits remained visible in several gravel bars during the study period, providing evidence that insufficient flows for bulk sediment transport occurred (NHC, 2012). Bulk-sieve subsurface sampling was recommended to continue for the same sites in the event of bedload-mobilizing flushing flows (NHC, 2012).

1.4.2 2 Photogrammetric Analysis

Photogrammetric sampling occurred from 2006 to 2011 and provided no clear temporal or spatial trends in sediment composition (NHC, 2012). Natural variability in sediment composition appeared to be unrelated to flushing flows. Two (2) unregulated flushing flows (i.e., flows that met the flushing flow criteria) and two (2) dam releases (regulated) approaching flushing flow criteria occurred between 2006 and 2011 (NHC, 2012). The quantities of fines temporarily decreased within an expected range of natural variability following flushing events (NHC, 2010 and 2012). Photo sampling was unsuccessful in addressing management objectives and was discontinued.

1.4.3 3 Freeze-Core Sampling

Freeze-core sampling was attempted by NHC between 2000 and 2009 as an alternative to bulk sampling. The method requires the injection of liquid nitrogen or liquid carbon dioxide into the stream core sample, enabling sediment collection within the wetted channel and retaining the fine particle fractions that may be lost during manual extraction; however, coarse substrates throughout the riverbed interrupted corer insertion and partial samples were only obtained from a few isolated spots within the channel. Given the challenges associated with the method in the Lower Coquitlam River, results of the field sampling effort were not reported, the technique was discontinued and not recommended for future use.

2.0 METHODS

2.1 Review of Existing Information

Prior to the initiation of office and field activities, a project start-up meeting between G3 and BC Hydro representatives was convened in October 2012, during which the project schedule and milestones were established. A review of existing information, including previous Lower Coquitlam River substrate monitoring reports (NHC, 2001, 2004, 2006, 2007, 2008, 2010 and 2012) was completed.

2.2 Environmental and Field Safety Plan

Prior to conducting assessments, G3 developed a project-specific *Emergency Action and Safety Management Plan* in accordance with BC Hydro Standard Operating Procedures (SOPs) and Occupational Safety and Health (OSH) guidelines. The *Emergency Action and Safety Management Plan* (Appendix 6) was accepted by BC Hydro prior to field crew deployment and included detailed protocols on:

- Radio and communication;
- Job hazards;
- Field emergencies;
- Emergency Action Plans;
- Water rescue;
- Field mobility and activities;
- Field check-in procedures; and,
- Emergency and program contacts (e.g., local fire, SAR, police, medical, BC Hydro, G3, etc.).

2.3 Site Reconnaissance & Selection

In October 2012, field reconnaissance of the Lower Coquitlam River (reaches 1 to 4) evaluated potential sampling sites with increased focus on reaches 2 and 3 (as discussed in Section 1.2 and Higgins *et a*l., 2002), identified previous NHC substrate monitoring sites and salmon spawning and rearing areas. Site selection was adapted from those studied in prior substrate analysis completed by Northwest Hydraulics Consultants (NHC 2012; Figure A1-1, Appendix 1) and represent Lower Coquitlam River main channel and side channel habitat. Sites were selected for representativeness of substrate type, suitability for salmonid spawning and rearing as well as consistent accessibility to staff. Based on these observations, six (6) sampling sites were established for the monitoring program and identifying markers placed for the upstream and downstream transects at each site.

2.4 Sampling Sites

Six (6) sampling sites were monitored in the Lower Coquitlam River (Figure A1-1, Appendix 1): Site 1 (Reach 2a), Sites 2, 3 and 4 (Reach 2b) and sites 5 and 6 (Reach 3). Every sampling site (6) consists of two (2) transects (upstream and downstream), each with three (3) random replicate sampling points, generating 36 surface and 36 subsurface particle samples per sampling event.

2.5 Site Description

In October 2013, detailed site descriptions were completed for the six (6) sites selected for the study. Habitat classification and mapping, vegetation (aquatic and terrestrial), presence of wildlife, erosional and depositional areas, slope of stream banks, propensity for banks to erode or be undercut, general water flow and depth and assessment of confounding influences. A photographic inventory of sites was assembled and characteristics affecting stream morphology and fish habitat (e.g., islands, gravel bars, large woody debris, etc.) were noted. Public access, constructed side channels and changes in riparian vegetation were also described. An assessment of fish habitat was conducted at each site following *Resources Inventory Standards Committee* (RISC) protocols (MOE, 2008).

2.6 Water Level Monitoring

Water levels in the Lower Coquitlam River were monitored through hydrographic data from the Water Survey of Canada (WSC) and two (2) water level loggers installed by G3 in December 2012.

2.6.1 1 Streamflow Gauging Station (08MH002)

G3 obtained water depth and discharge data from the Water Survey of Canada (WSC) streamflow gauging station (08MH002; Coquitlam River at Port Coquitlam) at the CP Rail Bridge, 0.4 km downstream of Lougheed Highway.

2.6.2 2 Water Level Loggers

One (1) HOBO U20 water level logger was installed in each of Reach 2b and 3 and data were uploaded during each monitoring event using Onset's HOBO Waterproof Shuttle to G3's project database. HOBO water loggers capture hourly fluctuations in local water depth using water temperature and barometric pressure. Loggers were camouflaged and identified with contact information in the event that they are discovered. The data logger in Reach 2b went missing prior to the October 2013 sampling event and was replaced in November 2014.

2.6.3 3 Precipitation Data

Precipitation data was obtained from Environment and Climate Change Canada (ECCC) weather station Coquitlam Como Lake Avenue for the period 2012 to 2015 reviewed and compiled for comparison with river flow data.

2.7 Substrate Quality

Evaluation of substrate quality involved the collection of surface and subsurface substrate samples using a modified Hess sampler. For this sampling program, surface substrate is defined as the particles on the surface of the river bed which are easily dislodged and transported by river flow. Dislodged particles (within the confine of the Hess sampler) collected in the Hess sampler mesh sock (20 µm mesh) and collection cup were considered as the surface sample for this program. Subsurface samples were defined as material remaining on the river bed after the collection of the surface sample (to a depth of 6.5 cm within the confine of the Hess sampler) and collected in sample pails. Subsurface samples were separated in two (2) size groups: particles <10 mm and coarse particles (>10 mm).

2.7.1 1 Timing of Sampling

For each year of the study (Years 1 to 3; October 2012 to May 2015) monitoring of substrate quality occurred during three (3) surveys in autumn (September [2014] or October [2012 and 2013]), winter (January) and Spring (May). The autumn sampling was advanced to mid-September starting in Year 3 (September 2014) to avoid disturbing spawning salmons in the river. Year 1 monitoring for this program was completed between October 2012 and May 2013, Year 2 monitoring during October 2013 to May 2014 and Year 3 monitoring between September 2014 and May 2015.

Fluctuating water levels and fast-flowing water pose a logistical challenge for sampling in the Lower Coquitlam River. River levels of eight (8) meters or less at the Water Survey of Canada (WSC) streamflow gauging station (08MH002) are required for safe and efficient sampling in the upper reaches of the Lower Coquitlam River. G3 monitored water depth and discharge using real-time hydrometric data at WSC Station 08MH002 in the days leading up to anticipated sampling events to ensure water depth was acceptable to allow a successful sampling event.

2.7.2 2 Field measurements & Substrate Sampling (2012-current)

Field collected data and observations were recorded on a project-specific *In situ Sediment Data Form* (Appendix 6). Site and sample characteristics were documented, including sample ID, dominant and subdominant substrate type, percent (%) embeddedness, measure of D_{50} and D_{95}, sampler depth of penetration, water depth, water velocity, turbidity, weather and a site sketch. Scaled photographs of the substrate within the Hess sampler were taken and identified with pre-labelled photo cards. To ensure consistency recording tasks were assigned to specific technicians for the duration of each sampling event.

A modified Hess stream bottom sampler was used to collect surface and subsurface samples at six (6) sites within the Lower Coquitlam River. The Hess (33 cm in diameter) was placed at each sampling location along established transects (upstream and downstream transects) and the location of each replicate (three [3] per transect) determined using a GPS unit and recorded on the field form. The penetration depth of the Hess samples was 6.5 cm into the substrate where possible and was recorded on the project-specific field form. Water depth and velocity was also measured at the time of collection. The mesh screen was aimed upstream to allow water flow through the sampler with the modified 20µm mesh sock trailing downstream.

2.7.3 3 Field Measurements

Visual assessments of dominant and subdominant substrate type, percent (%) embeddedness, measure of D_{50} and D_{95} were recorded for each sample within the confine of the Hess sampler prior to collecting substrate samples. Photographs of each sample were also taken. Water velocity and turbidity were measured at each site and recorded on the project specific *In situ* Sediment Data Form (Appendix 6).

Dominant & Subdominant Substrate Type

The dominant substrate type was visually determined for each sample within the confine of the Hess sampler (prior to any disturbance) and recorded as the most abundant particle size (sand, gravel [pebble], cobble or boulder). Similarly, the subdominant substrate type was determined as the second most abundant particle size. Substrate dominance was determined by the same technician throughout a sampling event to ensure consistency.

Embeddedness

Cobble embeddedness was developed as a method to measure the amount of fine sediment enveloping larger particles (Sylte and Fischenich, 2002) and is used as a surrogate measurement to estimate the interstitial spaces of streambed cobble habitats (Burton & Harvey, 1990). The visual method was used to determine percent embeddedness *in situ* for each sample. Percent embeddedness of the substrate within the confine of the Hess sampler, prior to any substrate disturbance, was visually estimated independently and simultaneously by all three (3) technicians and data recorded on the field form.

D_{50} & D_{95}

D_{95} is the size of a particle larger than 95% of all substrate materials larger than sand (identified in-field as the second largest particle within the sample). Similarly, D_{50} is the size of a particle larger than 50% of all substrate materials larger than sand. Two (2) particles from within the Hess sampler (D_{95}, D_{50}) were collected and measured along the intermediate axis and placed in the pre-labelled sample pail. The intermediate axes of large inextricable particles identified for the determination of the D_{95} or D_{50} were measured *in-situ* with noted reduced precision. D_{95} or D_{50} determination was done by the same technician for each sampling event to ensure consistency among samples.

Photo Documentation

Photographs and supporting documentation were collected at each monitoring site during each sampling event (Appendix 4) using a waterproof camera and site-specific photo cards. Photo cards included information on sample ID, sampling date and gray scale and were included in their respective sample pails for further confirmation of sample identification. Site photos were taken to capture images of cardinal directions and substrate for each sample. Any relevant observations were recorded made from monitoring sites and surrounding areas.

Water Velocity

Water velocity has been measured at each site for the substrate quality assessment program. More recently, detailed water velocity measurements were taken at each sampling location since May 2015. Water velocity was measured for each sample just above substrate and just below the water surface using a Swoffer current velocity meter.

Turbidity

At each site one sample was collected for turbidity and measured using a La Motte 2020we Turbidity Meter. Triplicate readings were taken and averaged.

2.7.4 4 Substrate Sample Collection

A trowel was used to stir the substrate within the Hess sampler twenty (20) times to dislodge surface fines into the mesh collection sock. The sample was washed down into the collection cup using river water filtered through the mesh and transferred to pre-labelled sampling bags. The sample bags were placed in a cooler.

Subsurface substrate within the Hess sampler to a depth of 6.5cm was collected manually (larger substrate) and using the trowel and placed into a pail pre-labelled with external and internal sample identification codes.

2.7.5 5 Substrate Sampling Following Flushing Flow Events

Sampling following flushing flow events will be conducted using the same methods as for the regular substrate quality assessment sampling described above.

2.8 Sample Processing & Analysis

For each sampling event (September/October, January and May) a total of 36 samples were collected from six (6) sites from the Lower Coquitlam River (three [3] replicate samples were obtained at an upstream and a downstream transect at each site). For each sample, the surface and the subsurface fraction was processed separately.

2.8.1 1 Surface Samples

Surface fines collected in-stream in the Hess sampler mesh sock and collection cup were submitted to Maxxam Analytics (Burnaby, BC), a CALA accredited laboratory, for percent (%) particle size distribution analysis (texture analysis by hydrometer). Labelled and inventoried samples were shipped in coolers with accompanying Chain of Custody (COC) forms.

2.8.2 2 Subsurface Samples

Subsurface samples collected in-stream and placed into pails were transported to G3's warehouse for processing. Samples were inventoried and checked against in-house COCs upon receipt. Samples were drained, weighed (wet weight), then lain to dry on clean polyethylene sheets in individual cells on a custom-built drying rack (Appendix 4). Sample cells were mapped for process inventory and left to dry completely at ambient temperature. Air circulation was improved to reduce drying time using drywall fans aimed away from samples.

Dry samples were weighed (total dry weight), photographed with sample-specific photo ID card and then sieved through a 10mm mesh sieve. The fine particle fraction (<10mm) was weighed and sent to Maxxam for percent (%) particle size distribution analysis (texture analysis by hydrometer and gravel analysis). Samples were placed in pre-labelled sample bags and shipped to the lab in coolers accompanying COC form. The coarse particle fraction (>10mm) was weighed, sorted by grain size (Wentworth, 1922; Table 2-1) and particles counted for each class (Wolman, 1954).

Table 2-1: Particle Size Categories

Particle Diameter (mm)	Phi (ϕ)	Wentworth Grade	
< 0.0039	>8.0	Clay	Clay
0.0039-0.0625	8.0 to 4.0	Silt	Silt
0.0625-2	4.0 to -1.0	Sand	Sand
2-4	-1.0 to -2.0	Very Fine Gravel or Granule	Gravel
4-8	-2.0 to -3.0	Fine Gravel	
8-16	-3.0 to -4.0	Medium Gravel	
16-32	-4.0 to -5.0	Coarse Gravel	
32-64	-5.0 to -6.0	Very Coarse Gravel	
64-90	-6.0 to -6.49	Small Cobble	
90-128	-6.49 to -7.0	Medium Cobble	
128-256	-7.0 to -8.0	Large Cobble	
>256	< -8.0	Boulder	

2.9 Data Entry & Archiving

Data entry was subjected to rigorous QA/QC protocols prior to archiving as described in Section 2.4. Manual data entry and data uploads were cross-checked and verified by alternating staff members. Verified data sets were compiled into a project-specific database and managed using Microsoft Access. Project databases were archived and backed up regularly on G3's server.

2.10 Data Assessment & Analysis

Surface, subsurface and pebble count data were analyzed using JMP statistical software. Particle distributions were tested for significant differences using 3-way Analysis of Variance (ANOVA; year, season, site). One-way ANOVA tests were applied to each factor (year, season, site) with subsequent post-hoc Student's t-test. Particle size distribution sample statistics were generated using GRADISTAT version 8 software package (Blott and Pye, 2001).

2.11 QA/QC & Data Management

Procedures for quality assurance and quality control (QA/QC) were applied throughout the study period to ensure program integrity at every stage and incorporated into work plans, management strategy, protocols for handling and recording information and sample processing. Instrumentation used in surveys was calibrated regularly to ensure accuracy and secondary units were used to verify measurements. Transcription and/or data entry errors were checked by cross referencing with original documentation and entries reviewed by alternate staff members. Data was compiled into an Access database and rigorously verified prior to inclusion. If errors exceeding 5% of data set were encountered, then the entire data set was reexamined.

2.11.1 .1 Laboratory QA/QC

Maxxam Analytics (Burnaby, BC) a CALA accredited laboratory, adhered to a comprehensive Quality Assurance/Quality Control (QA/QC) protocols. Quality control measures used by the analytical laboratory included testing of Quality Control (QC) Standards and laboratory duplicates (Appendix 4).

3.0 RESULTS & DISCUSSION

3.1 Sampling Site Descriptions

3.1.1 1 Site 1

Site 1 is accessed from Westwood Park, Coquitlam and is located at 49° 16' 35.4937" N 122° 46' 34.7520" W in Reach 2a of the Lower Coquitlam River. The upstream transect is located approximately 60 m upstream of the downstream transect, immediately adjacent to the Trans-Canada Trail Footbridge (Figure A2-1, Appendix 1).

Riparian vegetation at Site 1 consisted of a mix of deciduous and coniferous species in a mature forest. Understory composition included salmonberry (*Rubus spectabilis*), Indian plum (*Oemleria cerasiformis*), sword fern (*Polystichum munitum*) and thimbleberry (*Rubus parviflorus*). No sidebars or islands were present in the river, though cover was available with overhanging vegetation, boulders, undercut banks and some in-stream vegetation. Channel width was 35 m at the monitoring site with a 3% gradient. Instream cover was available as overhanging vegetation (20%), boulders (10%, undercut banks (5%) and some instream vegetation (2%). Pink salmon have been observed at this site.

3.1.2 2 Site 2

Site 2 is located at 49° 18' 13.8384" N 122° 46' 10.2540" W in Reach 2b of the Lower Coquitlam River and is accessible through Galette Park at the north end of Galette Avenue, Coquitlam (Figure A2-3, Appendix 1). The upstream reach is adjacent to the east shore of the river immediately upstream of the in-channel gravel bar. The downstream reach is located on the submerged gravel bar, approximately 15 m downstream of the upstream transect.

Riparian vegetation at Site 2 consisted of a mix of coniferous and deciduous species in mature forest with a shrub understory composed of salmonberry, alder (*Alnus sp*.), vine maple (*Acer circinatum*), sword fern, huckleberry (*Vaccinium sp*.) and rhododendron (*Rhododendron sp*.). Channel width was 47 m at the monitoring site with a 2% gradient. Sidebars were present in the channel. Approximately 20 m upstream of the monitoring site is the confluence of the Coquitlam River bifurcated by an island and about 20 m downstream of the downstream transect is the confluence of Kelly Creek with the Coquitlam River (Figure A1-2, Appendix 1). Instream cover was provided by overhanging vegetation (15%), boulders (10%), undercut banks (10%), small woody debris (5%) and some instream vegetation (2%). Evidence of predators (bear sign, blue heron), salmon eggs and spawning behavior have been observed near the monitoring site.

3.1.3 3 Site 3

Site 3 is located at 49° 18' 50.0579" N 122° 46' 9.3432" W in Reach 2b of the Lower Coquitlam River, adjacent to Pipeline Rd, Coquitlam (Figure A2-5, Appendix 1). The upstream and downstream transects are situated approximately 45 m apart in riffles along the edge of the main river channel.

Riparian vegetation at Site 3 consisted of a mix of deciduous and coniferous mature forest with a dense shrub layer composed of salmonberry, alder, willow (*Salix sp*.), vine maple and thimbleberry. Channel width was 35 m at the monitoring site with a 2% instream gradient. Instream cover was provided by overhanging vegetation (35%), boulders (25%), large woody debris (5%), undercut banks (5%) and some instream vegetation (5%). Sidebars and occasional islands were present at the monitoring site. Spawning pink salmon and piscivorous species (kingfisher) were observed at the monitoring site.

Site 3 is downstream of the active gravel excavation operations on the Westwood Plateau escarpment; most turbidity events observed in the river not attributable to high flows are regarded as being direct consequences of the nearby mining activities (NHC, 2007). Previous reports have suggested that turbidity levels downstream of the mines have been in excess of 13 times the ambient record levels measured at the GVRD gate (Quilty, 2003). Pollution management systems have been successfully implemented by Operators in the gravel mines, but some problems have arisen historically during rainfall events (Urban Systems, 2009).

3.1.4 4 Site 4

Site 4 is located at 49° 19' 31.0945'' N 122° 46' 15.9816'' W, in a side channel of Reach 2b in the Lower Coquitlam River, accessed from Upper Coquitlam River Park (Figure A2-7, Appendix 1). The site is approximately 350 m downstream of Coquitlam Sand and Gravel staging yard and across from the gravel operations to the west of Pipeline Rd. The upstream and downstream transects are approximately 40 m apart.

Riparian vegetation at Site 4 consisted of a mix of deciduous and coniferous forest with dense riparian shrub layers composed of alder, salmonberry, willow, thimbleberry, huckleberry, sword fern, elderberry and Indian plum. Instream cover to spawning salmon was available as overhanging vegetation (25%), undercut banks (20%), large woody debris (10%), boulders (10%), small woody debris (5%) and some instream vegetation (5%). Mature pink and chinook salmon as well as unidentified fry have been observed at this site.

Site 4 is adjacent to Archery Pond, a site which has been subjected to enhancement and rehabilitation projects since the early 1990's. The Archery Pond Habitat Improvement Project, a joint effort between land owners, the City of Coquitlam Leisure and Parks Services, DFO and BC Hydro, was created in 1994 and included the creation of a 50 m flood protection dyke, excavation of a 95 m outlet channel and a flood-limiting side channel in order to increase spawning habitat. Off-channel habitat maintenance and upgrades were completed in 2005 and 2006 to remove deposits of fine sediment restricting flow at the intake, reposition large woody debris (LWD) dislodged during floods and reposition migrating spawning gravel back into the spawning reach.

3.1.5 5 Site 5

Site 5 is located at 49° 20' 10.3055'' N 122° 46' 7.6440'' W in Reach 3 of the Lower Coquitlam River, in riffles along the edge of the main river bed (Figure A2-9, Appendix 1). Access to the site is from the shoulder of Pipeline Road. The upstream and downstream transects are situated approximately 15 m apart and dominant substrate is typically cobble, according to estimates of in-field substrate dominance.

Riparian vegetation at Site 5 consisted of mixed deciduous and coniferous mature forest with a shrub layer composed of salmonberry, sword ferns, vine maple, licorice fern (*Polypodium glycyrrhiza*) and willows. Channel width was 26 m at the monitoring site with a 3% instream gradient. Instream cover to spawning salmon was available through large woody debris (20%), boulders (20%), overhanging vegetation (10%), instream vegetation (5%) and some observed small woody debris (2%). Coho and pink salmon have been observed at Site 5.

3.1.6 6 Site 6

Site 6 is located at 49° 20' 15.1440'' N 122° 46' 16.1724'' W in Reach 3 of the Lower Coquitlam River (Figure A2-11, Appendix 1). The upstream transect is located in the riffle of a side channel, immediately downstream of the BC Hydro Operations access and is immediately downstream from the confluence with Or Creek. The downstream transect is located in a riffle approximately 50 m from the upstream transect, immediately below the Al Grist Memorial Hatchery near the junction with Slade Creek, where the side channel joins the main channel of the river.

Riparian vegetation at Site 6 consisted of mature mixed deciduous and coniferous forest with a developed understory shrub layer composed of ferns, Indian plum, willow, salmon berry, skunk cabbage (*Lysichiton americanus*) and alders. Several snags were visible in the canopy of the left bank near the site. Channel width was 37 m at the monitoring site with a 3% gradient. Instream cover was provided by boulders (30%), overhanging vegetation (15%), small woody debris (5%) and large woody debris (2%). Coho, chum and chinook salmon have all been observed at the site.

Slade Creek has historically been stocked with coho fry by *Port Coquitlam District Hunting and Fishing Club* (PCDHFC) volunteers and successfully yields a significant population of spawning coho. The creek also serves as an alternative water source for the hatchery. In-field observations state dominant and subdominant substrates as cobble and gravel, respectively, though grain size distributions were skewed to medium gravels (56.8%).

3.1 Precipitation into the Lower Coquitlam River

The Lower Coquitlam River receives contributions of rainfall and snowfall in the annual precipitation budget (Charts A1-1, Appendix 2). Total precipitation between October 2012 and May 2015 in the Lower Coquitlam River was 5,298 mm, or 5,505 mm including summer 2012 precipitation (Table A1-1, Appendix 3). November (272 mm), March (252 mm), December (245 mm) and January (239 mm) were the wettest months on average (Chart A1-2, Appendix 2). Total precipitation in Year 1 of the monitoring study was 31.5% higher than Year 2 (1,560 mm), the driest of the monitoring period, and accounted for 37.3% of all precipitation across the monitoring years (Years 1 to 3).

3.2 Lower Coquitlam River Hydrometric Data

3.2.1 Daily Discharge

Water discharge into the Lower Coquitlam River was assessed using Water Survey of Canada (WSC) historic and real-time hydrometric data measured at the streamflow gauging Station 08MH002 (Coquitlam River at Port Coquitlam (Charts A2, Appendix 2). Mean daily water discharges in the Lower Coquitlam River for Treatment 1 and Treatment 2 were compared. Treatment 1 (1999 to September 2008) involved Coquitlam Dam flow releases between 0.8 m^3/s to 1.7 m^3/s and Treatment 2 (October 2008 to 2017) involves Coquitlam Dam flow releases between 1.1 m^3/s to 5.9 m^3/s (seasonally variable). Mean daily discharges for each monitoring year (October to May) for Year 1 (October 2012 to May 2013), Year 2 (October 2013 to May 2014) and Year 3 (October 2014 to May 2015) were also compared. Comparisons of mean daily flows per season for each of the three (3) annual sampling events (autumn, winter and spring) was also done. Flows preceding the substrate sampling events were compiled for each season. For the autumn sampling event mean daily flows for June to September were summarized, for the winter sampling event mean daily flows for October to January were included and for the spring sampling event mean daily flows for February to May were included.

Mean daily water discharges were greatest preceding the winter sampling (16.0 m^3/s and 12.7 m^3/s for Treatment 1 and 2, respectively) and least preceding the autumn sampling event (4.1 m^3/s and 6.3 m^3/s for Treatment 1 and 2, respectively; Table A2-1, Appendix 3).

Mean daily discharge for Treatment 1 (January 2000 to September 2008) was on average 9.7% lower than mean daily discharge for Treatment 2 (October 2008 to May 2015; Chart A2-1, Appendix 2). The range between maximum and minimum daily discharges was 26.9% greater in Treatment 1 than Treatment 2. Under Treatment 2, river discharge exhibited a smaller range in mean daily flow and greater volumes of water than observed under Treatment 1 (Chart A2-1, Appendix 2). Generally, spikes in river discharge occurred in January, March, October, November and December in Treatment 1 (January 2000 to September 2008). For Treatment 2 (October 2008 to May 2015) flow above 15 m^3/s were generally noted in January, March, September and November. Flows preceding the winter sampling events were historically greater during Treatment 1 (16.0 m^3/s) than Treatment 2 (12.7 m3/s), though flows preceding the spring and autumn sampling events were greater on average during Treatment 2 (8.8 m^3/s and 6.3 m^3/s, respectively) than Treatment 1 (6.7 m^3/s and 4.1 m^3/s for spring and autumn, respectively; Table A2-1, Appendix 3).

Mean daily discharge in the Lower Coquitlam River was greatest in Year 1 of the monitoring period, on average (Table A2-2, Appendix 3). Mean daily discharge decreased by 25% on average between Year 1 and Year 3 of the monitoring period, mirroring similar trends in precipitation inputs to the river (Table A1-1, Appendix 3).

Variability in timing, quantity and magnitude of discharge spikes existed between years (Chart A2-2, Appendix 2). In 2012, pulses between 30-50 m^3/s occurred in January, October and November, with pulses in excess of 50 m^3/s occurring in October, 2012. Pulses between 30-50 m^3/s lasting 3-5 days occurred four (4) times between October 18 and November 8, 2012, with the last three events separated by single days averaging exceedances of 50 m^3/s. In 2013, pulses between 30-50 m^3/s occurred in February, March, April, May and September, with spikes exceeding 50 m^3/s occurring in February and March. Pulses between 30-50 m^3/s occurred in January, March and October in 2014, with the largest spike of the 2012-2015 period (93 m^3/s) occurring on November 6, 2014. Elevated flows in November 2014 (mean daily discharge of 93 m^3/s and 76 m^3/s on November 6 and 7, 2014, respectively) approached flushing flows recommended by the *Fisheries Technical Committee* (BC Hydro, 2006); however, the flows exceeded 70 m^3/s for a shorter period than required to meet the flushing flow definition (only two [2] days rather than three [3] to five [5] days). No mean daily discharges in excess of 30 m^3/s were recorded January to May 2015, though a single spike in excess of 20 m^3/s (22.48 m^3/s) occurred in January 14th, 2015.

Actual sampling events in relation to river discharges are depicted in Chart A2-3 (Appendix 2) as timing of scheduled sampling events (autumn, winter and spring) was adjusted based on water levels to ensure safe and successful sampling (see Section 2.7.1).

3.2.2 Daily Water Level

Hourly water level measurements using HOBO U20 water loggers (based on water temperature and barometric pressure) were recorded near Sites 3 and 5 and data compiled and summarized as mean daily water levels. Measurements are depicted for one (1) logger near Site 5 in 2014 (Chart A3-1, Appendix 2). Mean daily water levels near Site 5 ranged from 0.21 m (July 18, 2014) to 0.80 m (March 6, 2014). Another HOBO logger is located near Site 3; however, the data logger was lost in October 2013 and replaced in November 2014. Data records for these two (2) loggers were incomplete for 2013 given the loss of the logger at Site 3 and incomplete record at Site 5 due to instrument malfunction. Partial data for 2015 (to May 2015) is not presented. Data is being examined and a more complete data set will be presented in subsequent reports. Results for these two (2) loggers will be applied with hydrographic data in the river to develop an understanding of flow dynamics on substrate mobilization in the Lower Coquitlam River using available data records for 2014 to 2016.

3.3 Field parameters

Field parameters used to support the substrate quality assessment included measurements of embeddedness, D_{95} and D_{50}, turbidity and water velocity.

3.3.1 Embeddedness

Embeddedness ranged from 5% to 100% in the Lower Coquitlam River, with a mean of 43% (Chart A4-1, Appendix 2). Mean embeddedness was comparable among seasons ranging from 41% (winter) to 46% (autumn) for monitoring Years 1 to 3 (October 2012 to May 2015) and all six (6) sites (Chart A4-1, Appendix 2; Tables A3-1 and A3-3, Appendix 3). Mean percent (%) embeddedness for all six (6) sites was comparable among monitoring years (Year 1 to 3) ranging from 36% (Year 3) to 47% (Year 2; Table A3-2, Appendix 3). Site 5 had the greatest mean embeddedness (48%) and Site 6 the smallest (38%) for Years 1 to 3 (Table A3-1, Appendix 3 and

Chart A4-2, Appendix 2). Differences in river morphology at Sites 5 and 6 may be attributable to differences in percent (%) embeddedness at these sites. Site 6 is located off-channel immediately upstream and downstream of the Al Grist Memorial hatchery, whereas Site 5 is located along the edge of the main river channel further downstream.

3.3.2 D_{50} & D_{95}

Mean D_{50} was comparable among seasons ranging from 28 mm (coarse gravel; winter) to 35 mm (very coarse gravel; spring) for monitoring Years 1 to 3 (October 2012 to May 2015) and all six (6) sites. (Tables A4-1 and A4-5, Appendix 3, Chart A5-2, Appendix 2). Site 6 had the greatest mean D_{50} (35 mm, very coarse gravel) and Site 5 the smallest (28 mm, coarse gravel) for Years 1 to 3 (Tables A4-1 and A4-2, Appendix 3; Chart A5-1, Appendix 2). Mean D_{50} for all six (6) sites was comparable among monitoring years (Years 1 to 3) ranging from 29 mm (coarse gravel; Year 1 and 3) to 32 mm (coarse gravel; Year 2; Table A4-2, Appendix 3). Maximum D_{50} was noted at Site 2 in autumn 2012 (110 mm, medium cobble) and minimum D_{50} (10 mm, medium gravel) at Site 1 in autumn 2012 and Sites 2, 3, 4 and 5 in winter 2013.

Mean D_{95} was comparable among seasons ranging from 78 mm (small cobble; winter) to 89 mm (small cobble; spring) for monitoring Years 1 to 3 and all six (6) sites (Tables A4-3 and A4-5, Appendix 3 and Chart A5-2, Appendix 2). Site 3 had the highest mean D_{95} (94 mm, medium cobble) and Sites 1 and 4 the smallest (78 mm, small cobble) for monitoring Years 1 to 3 (Table A4-3, Appendix 3; Chart A5-1, Appendix 2). Mean D_{95} was greatest in Monitoring Year 3 (88 mm, small cobble) and least in Year 2 (80 mm, small cobble; Table A4-4, Appendix 3). Max D_{95} was noted at Site 2 in autumn 2012 (170 mm, large cobble) and min D_{95} at Site 6 in autumn 2013 (34 mm, very coarse gravel). Generally, mean D_{50} and D_{95} were comparable across all sites and season for monitoring Years 1 to 3 (Charts A4-1 and A4-2, Appendix 2).

3.3.3 3 Turbidity

For monitoring Years 1 to 3, mean turbidity was lowest in the spring (0.57 NTU) and greatest in the winter (1.82 NTU; Table A5-1, Appendix 3 and Chart A6-1, Appendix 2). Mean turbidity for all six (6) sites in the Lower Coquitlam River ranged from 0.21 NTU in autumn of Year 2 to 2.49 NTU in winter of Year 2 (Table A5-3, Appendix 3). Mean turbidity ranged from 0.35 NTU (Site 5) to 3.86 NTU (Site 3) across study years (Table A5-2, Appendix 3 and Chart A6-2, Appendix 2). High mean turbidity was noted at Site 3 in January 2014 (10.44 NTU) and January 2015 (10.47 NTU). A visible sediment plume originating from a discharge channel entering the Lower Coquitlam River immediately upstream of Site 3 was noted during winter sampling events in 2014 and 2015, arising potentially from adjacent gravel mining operations immediately upstream of Site 3.

3.3.4 4 Water Velocity

Velocity data for October 2012 to May 2015 is presented in Appendix 5. Mean water velocity in May 2015 was measured for each replicate sample and data summarized by site. Water velocity was lowest at Site 4 (0.15 m/s) and highest at Site 1 (0.44 m/s; Table A6, Appendix 3). Water velocity and substrate quality data in the river will be assessed to develop an understanding of flow dynamics on substrate mobilization in the Lower Coquitlam River and results presented in subsequent reports.

3.4 Substrate Particle Size Distribution

Substrate quality results for October 2012 to May 2015 (monitoring Years 1 to 3) were compiled and analyzed. Three (3) sampling events (autumn [September or October], winter [January] and spring [May]) were conducted for each year. In monitoring Year 1, sampling was conducted in October 2012 (autumn), January 2013 (winter) and May 2013 (spring). Year 2 sampling was done in October 2013, January 2014 and May 2014 and Year 3 sampling in September 2014, January 2015 and May 2015. Six (6) sites were assessed in the Lower Coquitlam River and at each site three [3] replicate samples were collected at two [2] transects. For each sampling event, a total of 36 surface and subsurface (<10mm and >10mm) samples were analysed for percent (%) particle size distribution. Particle size data were compared between sites, seasons and monitoring years.

3.4.1 1 Surface Particles

For monitoring Years 1 to 3, surface sediments were dominated by sand (particles 0.0625 mm to 2 mm; Charts A6, Appendix 2). Overall mean sand content at the six (6) sites in three (3) seasons over three (3) year was 76.9% (ranging from 18% to 100%), mean silt content (particles 0.0039 mm to 0.0625 mm) was 16.9% (<2% to 82%) and mean clay content (particles 0.002 mm to 0.0039 mm) was 6.4% (<2% to 44%). The results of 3-way (year, season and site) Analysis of Variance (ANOVA) showed a statistically significant difference over years ($p<0.001$) and between seasons ($p<0.0001$) in sand, silt and clay fractions and among sites ($p<0.01$) in sand and silt fractions. There were no significant interaction effects on any particle size.

In surface samples for all six (6) sites and all seasons, the mean annual sand content ranged from 65.1% (Year 3) to 83.9% (Year 1), silt from 10.9% (Year 2) to 27.5% (Year 3) and clay from 4.8% (Year 1) to 7.5% (Year 3; Chart A7-1, Appendix 2). Sand was statistically lower in Year 3 than Year 1 or Year 2 ($p<0.0001$, Student's t-test); silt was statistically higher in Year 3 than in Year 1 or Year 2 ($p<0.0001$); and, clay was statistically lower in Year 1 than in Year 2 or Year 3 ($p<0.01$).

Seasonal average of surface particle fractions at six (6) sites for monitoring Years 1 to 3 varied from 72.0% in autumn to 83.8% in winter for sand, from 13.0% in winter to 19.3% in autumn for silt and from 3.6% in winter to 9.0% in autumn for clay (Chart A7-2, Appendix 2). For Years 1 to 3, the sand fraction was statistically higher in winter than in autumn or spring ($p<0.0001$, Student's t-test); the silt fraction was statistically lower in winter than in autumn or spring ($p<0.001$); and, clay was statistically higher in autumn than in winter or spring ($p<0.0001$).

Spatially, the average of surface particle fractions per site for monitoring Years 1 to 3 ranged from 71.0% (Site 3) to 80.4% (Site 2) for sand, from 14.0% (Site 1) to 21.8% (Site 3) for silt and from 4.7% (Site 4) to 7.4% (Site 6) for clay (Chart A7-3, Appendix 2). There were no significant differences in sand among all sites except Site 3 where sand was statistically lower compared to Sites 1, 2, 4 and 5 ($p<0.05$, Student's t-test). There were no significant differences in the silt fraction among all sites except Site 3 where the silt fraction was statistically higher compared to Sites 1, 2 and 5 ($p<0.05$). There were no significant differences in clay content among all sites except Site 4 where clay was statistically lower compared to Sites 3 and 6 ($p<0.05$). There were no clear patterns in distribution of surface particle sizes among the six (6) sites except Site 3 with relatively higher silt-clay content and lower sand content, possibly associated to higher turbidity noted at this Site in January 2014 and 2015.

3.4.2 2 Subsurface Particles (<10 mm)

Subsurface sediments (<10 mm) were dominated by gravel and sand in monitoring Years 1 to 3 (Charts A7, Appendix 2). Over the three (3) monitoring years, mean gravel content (particles 2 mm to <10 mm) in subsurface sediments was 55.4% (ranging from 11% to 99%); mean sand content (particles 0.0625 mm to 2 mm) was 42.3% (<2% to 89%); mean silt content (particles 0.0039 mm to 0.0625 mm) was 1.5% (<2% to 7%); and, mean clay content (particles < 0.0039 mm) was 1.1% (<2% to 5%). The results of 3-way (year, season and site) ANOVA showed statistical differences over years ($p<0.0001$), between seasons ($p<0.01$) and among sites ($p<0.0001$) in all particle sizes except clay, in which there was a significant difference only between seasons. There were significant interaction effects on all particle sizes ($p<0.05$ for clay and $p<0.0001$ for all others).

In subsurface samples from all six (6) sites, the annual mean percent (%) gravel ranged from 43.8% (Year 2; October 2013 to May 2014) to 62.0% (Year 1; October 2012 to May 2013), sand from 36.3% (Year 1) to 53.0% (Year 2), silt from 0.8% (Year 1) to 2.3% (Year 2) and clay from 1.0% (Year 1) to 1.2% (Year 3; September 2014 to May 2015; Chart A8-1, Appendix 2). Gravel was statistically lower in Year 2 than Year 1 or Year 3 (p<0.0001, Student's t-test). Sand and silt fractions were statistically higher in Year 2 compared to Year 1 or Year 3 (p<0.0001) and there was no significant difference in clay fraction between years.

For all six (6) sites in monitoring Years 1 to 3, seasonal averages of subsurface particle fractions varied from 50.5% (spring) to 62.5% (autumn) for gravel, 35.8% (autumn) to 46.4% (spring) for sand, 1.2% (autumn) to 1.8% (spring) for silt and 0.8% (winter) to 1.4% (spring) for clay; Chart A8-2, Appendix 2). Gravel content was statistically higher in autumn than in winter or spring (p<0.001, Student's t-test); sand content was statistically lower in autumn than in winter or spring (p<0.01); and, silt and clay content were significantly higher in spring than in autumn or winter (p<0.05 and p<0.01, respectively) in monitoring Years 1 to 3.

Subsurface particle fraction averages per site for monitoring Years 1 to 3 ranged from 42.5% (Site 2) to 61.4% (Site 3) for gravel, from 36.4% (Site 4) to 55.8% (Site 2) for sand, from 1.0% (Site 3) to 2.0% (Site 1) for silt and from 0.9% (Site 2) to 1.4% (Site 3) for clay (Chart A8-3, Appendix 2). For monitoring Years 1 to 3, gravel was statistically higher at Sites 3 to 6 than Sites 1 and 2 (p<0.01 to <0.0001, Student's t-test), with no significant differences among Sites 3 to 6 and between Sites 1 and 2. Sand was statistically lower at Sites 3 to 6 compared to Sites 1 and 2 (p<0.01 to <0.0001), with no significant differences among Sites 3 to 6 and between Sites 1 and 2. Silt was statistically higher at Site 1 compared to Sites 2, 3, or 6 (p<0.05 to <0.001). There were no significant differences in clay among all sites, except Site 3, where clay was statistically higher than Sites 1 and 2.

3.4.3 .3 Coarse Particles (>10 mm)

For monitoring Years 1 to 3 (October 2012 to May 2015), subsurface coarse particles (>10 mm) were predominantly pebbles (Charts A8, Appendix 2). Overall, for all six (6) sites in Years 1 to 3, mean medium pebbles content (>10-16 mm) was 57.0% (ranging from 11.8% to 91.9%), coarse pebbles (>16-32 mm) was 31.7% (6.2% to 53.1%) and very coarse pebbles (>32-64 mm) was 8.5% (1.9% to 29.2%). Mean small cobbles content (>64-90 mm) was 1.8% (ranging from 0% to 19.6%), medium cobbles (>90-128 mm) was 0.8% (0% to 9.6%) and large cobbles (>128-256 mm) was 0.3% (0% to 16.7%). The results of 3-way (year, season and site) ANOVA showed statistical differences between Years 1 to 3 for all coarse particles (>10 mm) grain sizes (p<0.05 to <0.0001), between seasons for pebbles (p<0.05 to p<0.001) and among sites only for very coarse pebble (p<0.001). There were significant interaction effects on medium pebble (<0.01), very coarse pebble (p<0.001) and medium cobble (p<0.05).

For subsurface coarse particles from all six (6) sites and all seasons, the mean annual medium pebble content ranged from 49.7% (Year 2) to 63.7% (Year 3), coarse pebble from 26.9% (Year 3) to 35.3% (Year 2) and very coarse pebble from 7.1% (Year 3) to 11.0% (Year 2; Chart A9-1, Appendix 2). Mean annual small cobble content ranged from 1.0% (Year 3) to 2.5% (Year 2), medium cobble from 0.6% (Year 3) to 1.0% (Year 2) and large cobble from 0.2% (Year 3) to 0.6% (Year 2) for all six (6) sites and all seasons (Chart A9-1, Appendix 2). Medium pebble content was statistically higher in Year 3 than Year 1 or Year 2 (p<0.0001, Student's t-test) and higher in Year 1 than Year 2 (p<0.0001). Coarse pebble content was statistically higher in Years 1 and 2 than Year 3 (p<0.0001) and very coarse pebble and small cobble content higher in Year 2 than Years 1 and 3 (p<0.001 to <0.0001). Medium cobble was statistically higher in Year 2 than Year 3 (p<0.05) and medium cobble lower in Years 1 and 3 compared to Year 2 (p<0.05).

For all six (6) sites over the duration of the monitoring program (Years 1 to 3), seasonal mean medium pebble content ranged from 55.6% (autumn) to 58.3% (spring), coarse pebble from 31.0% (spring) to 32.4% (autumn) and very coarse pebble from 7.1% (winter) to 11.0% (spring; Chart A9-2, Appendix 2). Seasonal mean small cobble content ranged from 1.7% (winter) to 1.8% (spring), medium cobble from 0.6% (winter) to 1.0% (spring) and large cobble from 0.2% (winter) to 0.6%

(spring; Chart A9-2, Appendix 2). Results of a one-way ANOVA and *post-hoc* Student's t-test show no statistically significant difference in fractions of pebble and cobble sizes between seasons due to interaction effects of year, season and site.

For subsurface coarse particles for each site for monitoring Years 1 to 3, mean medium pebble content ranged from 54.3% (Site 6) to 63.3% (Site 1), coarse pebble from 30.6% (Site 1) to 32.3% (Site 6) and very coarse pebble from 6.9% (Site 1) to 9.8% (Site 4). Mean small cobble content ranged from 1.4% (Site 5) to 2.1% (Site 6), medium cobble from 0.5% (Site 1) to 1.1% (Site 6) and large cobble 0.2% (Site 1) to 0.6% (Site 6) for monitoring Years 1 to 3 (Chart A9-3, Appendix 2). Very coarse pebble content was statistically higher at Sites 4 and 6 than Sites 1, 3 and 5 ($p<0.05$ to $p<0.001$) and higher at Site 2 compared to Site 1 ($p<0.05$). Medium cobble was statistically higher at Site 6 compared to Sites 1, 4 and 5 ($p<0.05$) and higher at Site 3 than Site 1 ($p<0.05$). There were no statistically significant differences in fraction of medium pebble, coarse pebble, small cobble and large cobble. In general, there were no clear patterns in distribution of coarse particles among the six (6) sites.

3.5 Flushing Flow Events

Only one event approaching a non-regulated flushing flow occurred between October 2012 and May 2015. Elevated flows (93 m^3/s and 76 m^3/s) occurred on November 6 and 7, 2014; however, flows did not exceed 70 m^3/s for the required duration (three [3] to five [5] days) to be defined as a flushing flow based on the Fisheries Technical Committee recommendation as described in the *Coquitlam-Buntzen Water Use Plan Monitoring Program Terms of Reference* (BC Hydro, 2006). This event was unregulated (i.e., did not involve additional flow release from Coquitlam Dam). No sampling was conducted following this event.

3.6 QA/QC

Quality assessment and quality control (QA/QC) measures employed for this program included analytical and procedural protocols implemented in the field and laboratory.

3.6.1 1 Field QA/QC

Rigorous QA/QC procedures (described in Section 2.11) were applied during field measurements, sample collection and sample processing, storage and shipping of samples to ensure samples were properly identified and to maintain a record of field notes, including sampling date, site name, sample ID, waypoint and photographs. Field instruments were calibrated prior to use.

3.6.2 2 Laboratory QA/QC

Maxxam (Burnaby, BC), a CALA accredited laboratory, followed established protocols for conducting laboratory analyses. Laboratory QC results were within the acceptable limit for duplicate samples (≤35% RPD) and recovery of QC Standard (75% to 125% [clay content], 86% to 114% [[percent silt] or 84% to 116% [percent sand]). A reliable RPD could not be calculated for some parameters when the level was <5X the Reported Detection Limit (RDL).

4.0 SUMMARY & RECOMMENDATIONS

4.1 Summary

G3 Consulting Ltd. (G3) was retained by BC Hydro to complete a Lower Coquitlam River Substrate Quality Assessment in salmonid spawning and rearing habitat at the Lower Coquitlam River from 2012 to 2017. A primary objective of this monitoring program is to evaluate the effectiveness of flushing flow provisions intended to increase fish productivity through improved substrate quality in the Lower Coquitlam River. The program involved sampling three (3) times a year, and opportunistic sampling of flushing flow events when they occur, to evaluate substrate particle size distribution and habitat quality as part of an ongoing study under the Coquitlam River Water Use Plan (WUP). At the conclusion of the program results will be compared with fisheries data and habitat quality requirements for spawning and rearing of juvenile salmonids to evaluate the effectiveness of flushing flow provisions as outlined in the Coquitlam-Buntzen Water Use Plan (LB1 WUP) to increase fish productivity through improved substrate quality in the Lower Coquitlam River.

Sampling was conducted at the start of the salmon spawning season (September or October [autumn]), during the mid-incubation period (January [winter]) and at the end of emergence (May [spring]). For each sampling event (autumn, winter and spring) a total of 36 surface and subsurface substrate samples were collected from six (6) sites in the Lower Coquitlam River using a modified Hess sampler to a depth of 6.5 cm into substrates. At each site an assessment of dominant and subdominant substrate type, percent (%) embeddedness, D_{95}, D_{50}, water depth, turbidity and water velocity was done. Fine surface particles on the surface of the river bed were dislodged and collected using the Hess sampler (surface samples). Subsurface substrate remaining on the river bed following surface sample collection (within the confine of the Hess sampler) was placed in sample pails (subsurface samples). Subsurface samples were separated in two (2) separate size class: subsurface particles (<10mm) and coarse subsurface particles (>10mm). Surface and subsurface particles <10 mm were submitted to Maxxam Analytics for particle size analysis. Coarse subsurface substrate (>10mm) was weighed and assessed by pebble count.

Mean percent (%) embeddedness, mean D_{50} and mean D_{95} were generally comparable over the three (3) years of monitoring and among sites and season. Mean turbidity ranged between 0.35 NTU (Site 5) and 3.86 NTU (Site 3) across study years. Higher turbidity at Site 3 compared to other sites was noted in January 2014 (10.44 NTU) and January 2015 (10.47 NTU). A visible sediment plume at Site 3 was noted during winter sampling events in 2014 and 2015, possibly from adjacent gravel mining operations immediately upstream of Site 3.

The results of 3-way (year, season and site) ANOVA showed significant differences over all program years ($p<0.001$) and between seasons ($p<0.0001$) in sand, silt and clay surface sediment fractions and among site ($p<0.01$) in sand and silt fractions. There were no statistically significant interaction effects noted for any particle size fractions. For Years 1 to 3, the sand fraction was statistically higher in winter than in autumn or spring ($p<0.0001$, Student's t-test), silt was statistically lower in winter than in autumn or spring ($p<0.001$) and clay was statistically higher in autumn than in winter or spring ($p<0.0001$). There were no significant differences in the clay fraction among sites except Site 4, where the clay fraction was statistically lower than Sites 3 and 6 ($p<0.05$). In general, there were no clear patterns in distribution of surface particle sizes among the six (6) sites except Site 3 which had higher silt-clay and lower sand content possibly associated with comparatively higher winter turbidity at Site 3 compared to other sites as discussed above.

For the monitoring Years 1 to 3 (October 2012 to May 2015), subsurface sediments were dominated by gravel and sand. A 3-way (year, season and site) ANOVA showed significant differences over years ($p<0.0001$), between seasons ($p<0.01$) and among sites ($p<0.0001$) in all particle sizes except clay, for which only seasonal differences were significant. There were significant interaction effects on all particle sizes ($p<0.05$ for clay and $p<0.0001$ for all others). Gravel was statistically lower in Year 2 than Years 1 or 3 ($p<0.0001$, Student's t-test); sand and silt fractions higher in Year 2 than Year 1 or Year 3 ($p<0.0001$); and, no significant difference noted in clay between years. Gravel fraction was statistically higher in autumn than in winter or spring ($p<0.001$, Student's t-test); sand was statistically lower in autumn than winter or spring ($p<0.01$) and, silt and clay fractions were statistically higher in spring than autumn or winter ($p<0.05$ and $p<0.01$, respectively). There were no significant differences in clay among all sites, except Site 3, where percent (%) clay was statistically higher compared to Sites 1 and 2.

Coarse particles (>10 mm) collected from the Lower Coquitlam River were predominantly pebbles. A 3-way (year, season and site) ANOVA showed significant differences between all monitoring years for all grain sizes ($p<0.05$ to <0.0001), between seasons for pebbles ($p<0.05$ to $p< 0.001$) and among sites only for very coarse pebble ($p<0.001$). There were significant interaction effects on medium pebble (<0.01), very coarse pebble ($p<0.001$) and medium cobble ($p<0.05$). The medium pebble fraction was statistically higher in Year 3 than Years 1 or 2 ($p<0.0001$, Student's t-test) and higher in Year 1 than Year 2 ($p<0.0001$). Coarse pebbles were statistically higher in Years 1 and 2 compared to Year 3 ($p<0.0001$) and fractions of very coarse pebbles and small cobbles were statistically higher in Year 2 compared to Years 1 and 3 ($p<0.001$ to $p<0.0001$). Medium cobble was statistically higher in Year 2 versus Year 3 ($p<0.05$) and medium cobble was lower in Years 1 and 3 than Year 2 ($p<0.05$). One-way ANOVA and post-hoc Student's t-test showed no significant differences in fractions of pebble and cobble sizes between seasons due to interaction effects of year, season and site. The very coarse pebbles were statistically higher at Sites 4 and 6 than Sites 1, 3 and 5 ($p<0.05$ to $p<0.001$) and statistically higher at Site 2 than Site 1 ($p<0.05$). Medium cobble was statistically higher at Site 6 versus Sites 1, 4 and 5 ($p<0.05$) and higher at Site 3 than Site 1 ($p<0.05$). There were no significant differences in the medium pebble, coarse pebble, small cobble and large cobble fractions. In general, there were no clear patterns in distribution of coarse particles among the six (6) sites.

Suitable substrates for spawning and rearing were observed at the sampling sites; however, data from which to determine whether flushing flows were effective at mobilizing sediments and whether sediment particle size profiles at each site are a reflection of discharge or other environmental factors remains inconclusive at this time. Analysis of substrate quality results will require several years of data to develop robust correlations between substrate quality results and fish productivity and have not been considered in this report.

4.2 Limitations

There were only one (1) event approaching an unregulated flushing flow event (93 m^3/s and 76 m^3/s on November 6 and 7, 2014, respectively) during the October 2012 to May 2015 monitoring period but no flushing flow sampling was conducted as the duration did not meet the definition of a flushing flow. Flushing flows in the magnitude of 70 m^3/s to 100 m^3/s should be maintained for a duration of 3 to 5 days to be considered a flushing flow as described in the *Coquitlam- Buntzen Water Use Plan Monitoring Program Terms of Reference* (BC Hydro, 2006). Yearly regulated flushing flows (70 m^3/s to 100 m^3/s for 3 to 5 days) generated by Coquitlam Dam flow releases of 30 m^3/s to 50 m^3/s coinciding with elevated inflows from Or Creek were recommended by the *Fisheries Technical Committee* (BC Hydro, 2016). Correlations between flushing flow events and substrate quality could not be done to assess the effectiveness of flushing given the lack of data.

4.3 Recommendations

The following are recommended for assessment of substrate quality in the Lower Coquitlam River based on the findings of this October 2012 to May 2015 monitoring program:

- continue using the modified Hess sampling method to collect surface and subsurface substrate samples;
- continue to monitor river flows in the Lower Coquitlam River to identify opportunities to sample river substrate following regulated or unregulated flushing flows in the Coquitlam River;
- continue to sample sites opportunistically following a regulated or unregulated flushing or near flushing flow event;
- correlate river velocity measurements taken at time of sampling with reservoir release data and stream discharge data to establish a statistical correlation with substrate particle profiles at different times of year;

- incorporate fish productivity indices measured in COQMON#7-*Lower Coquitlam River Fish Productivity Index Study* in future substrate quality assessments for the Lower Coquitlam River; and,
- obtain data from other river programs to assess if there is a correlation with substrate particle profiles at different times of year.

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APPENDICES

Appendix 1: Figures
Appendix 2: Charts
Appendix 3: Tables
Appendix 4: Photographs
Appendix 5: Laboratory and Raw Data
Appendix 6: Emergency Action and Safety Management Plan
Appendix 7: Field Form

Appendix 1

Figures

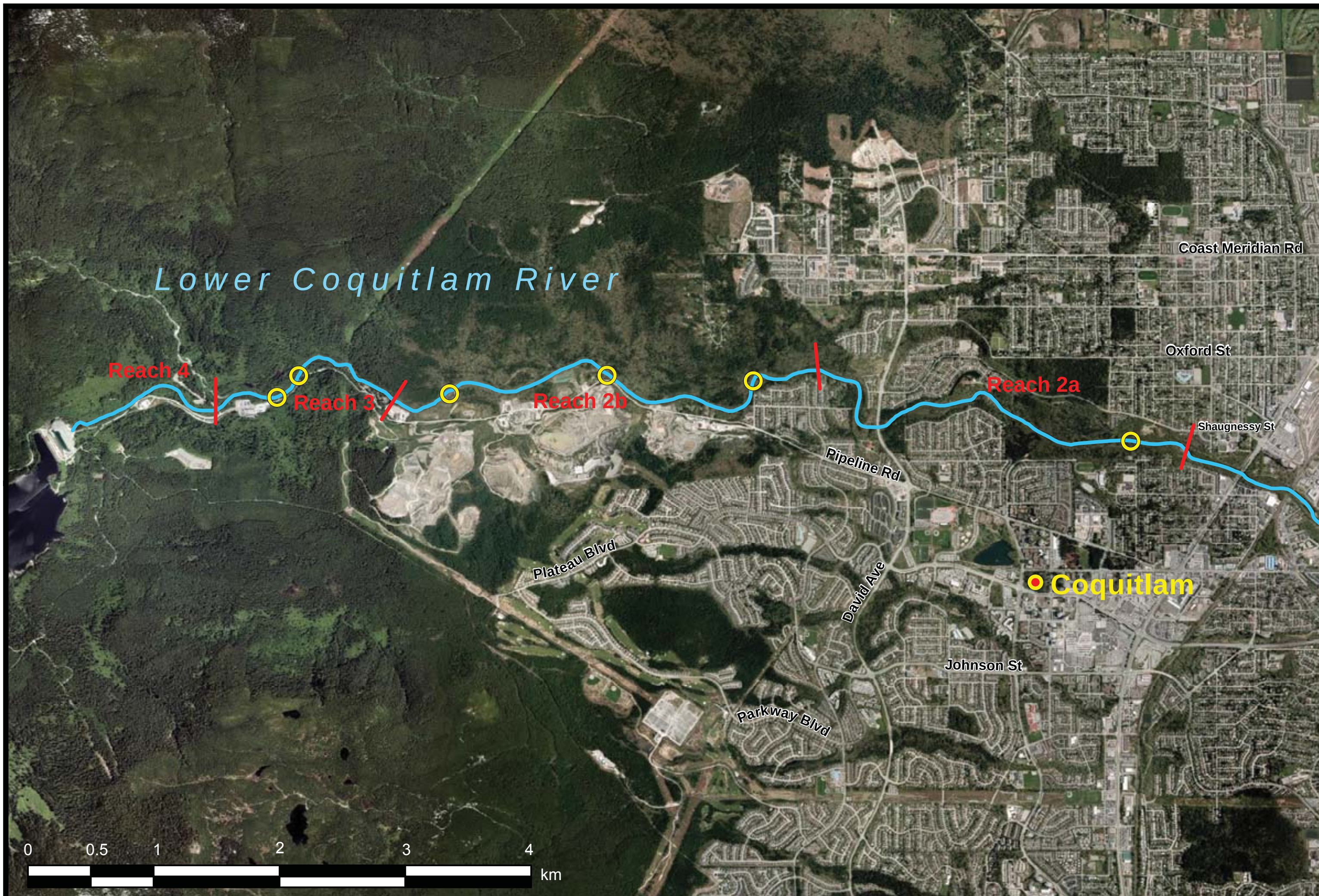

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Figure A1-1: COQMON Overview Map

Date: 01/12/2016

Coordinate System: WGS 84 UTM Zone 10N

Scale: 1:40,000

Source: City of Coquitlam Aerials Jan 15, 2012

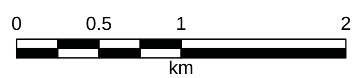

Figure A1-2: Lower Coquitlam River Creeks and Tributaries

Date: February 16, 2016
Scale: 1:23,000
Coordinate System: NAD 83 UTM Zone 10N
Date Sources: City of Coquitlam Partridge, Mantle and Fulawka Creeks Watershed Review, ESRI, DigitalGlobe

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Figure A2-1: Site 1 Sampling Locations

Date, Author: 01/12/2016, Chris Adamson
Coordinate System: WGS 84 UTM Zone 10N
Scale: 1:500
Source: City of Coquitlam Aerials Jan 15, 2012

0 12.5 25 50 Metres

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Figure A2-2: Site 1 Sampling Locations

Date, Author: 01/12/2016, Chris Adamson
Coordinate System: WGS 84 UTM Zone 10N
Scale: 1:1,500
Source: City of Coquitlam Aerials Jan 15, 2012

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Figure A2-3: Site 2 Sampling Locations

Date, Author: 01/12/2016, Chris Adamson
Coordinate System: WGS 84 UTM Zone 10N
Scale: 1:500
Source: City of Coquitlam Aerials Jan 15, 2012

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Figure A2-4: Site 2 Sampling Locations

Date, Author: 01/12/2016, Chris Adamson
Coordinate System: WGS 84 UTM Zone 10N
Scale: 1:1,500
Source: City of Coquitlam Aerials Jan 15, 2012

0 37.5 75 150 Metres

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Figure A2-5: Site 3 Sampling Locations

Date, Author: 01/12/2016, Chris Adamson
Coordinate System: WGS 84 UTM Zone 10N
Scale: 1:500
Source: City of Coquitlam Aerials Jan 15, 2012

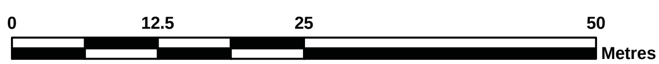

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Figure A2-6: Site 3 Sampling Locations

Date, Author: 01/12/2016, Chris Adamson
Coordinate System: WGS 84 UTM Zone 10N
Scale: 1:1,500
Source: City of Coquitlam Aerials Jan 15, 2012

0 37.5 75 150 Metres

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Figure A2-7: Site 4 Sampling Locations

Date, Author: 01/12/2016, Chris Adamson
Coordinate System: WGS 84 UTM Zone 10N
Scale: 1:750
Source: City of Coquitlam Aerials Jan 15, 2012

0 12.5 25 50 Metres

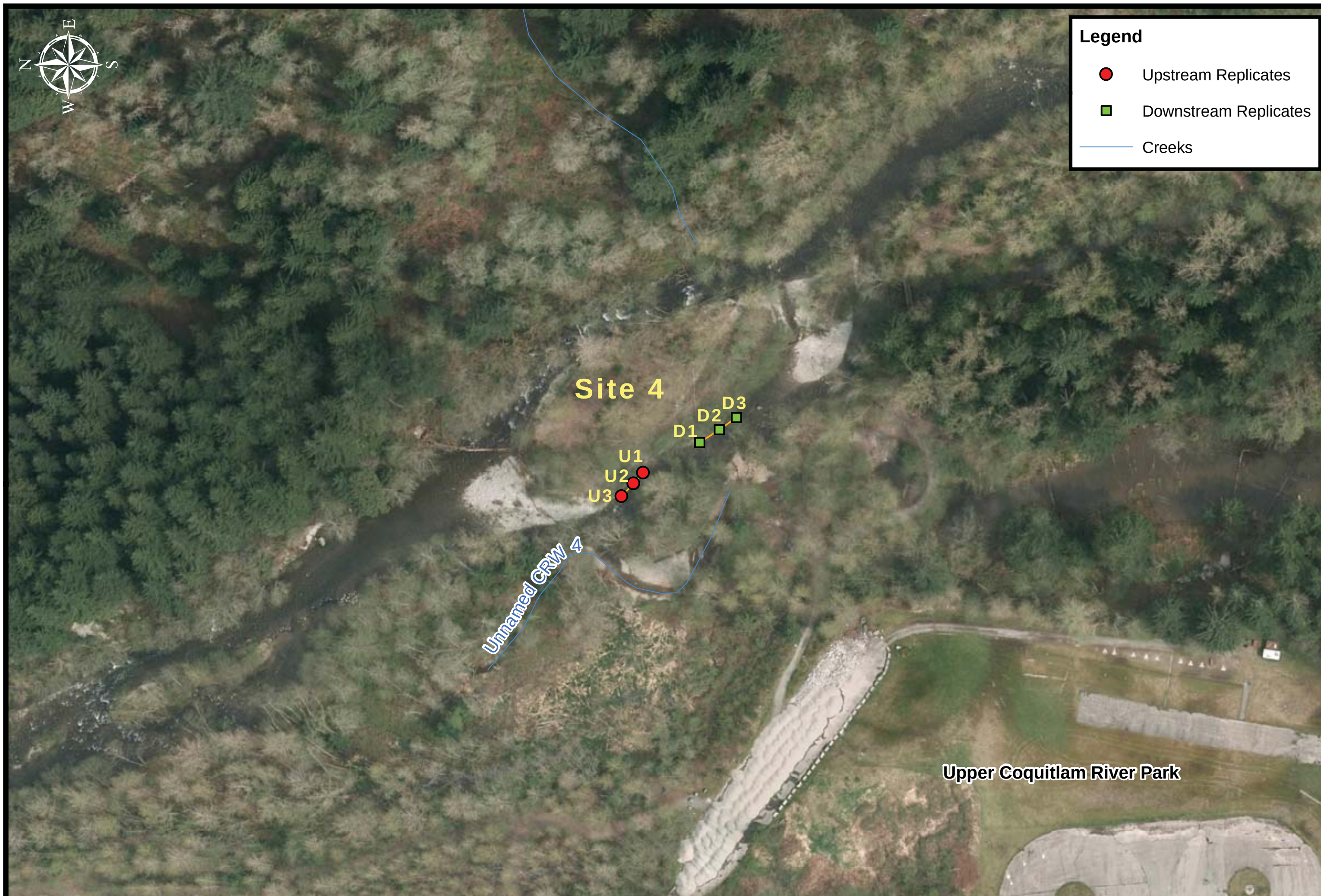

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Figure A2-8: Site 4 Sampling Locations

Date, Author: 01/12/2016, Chris Adamson
Coordinate System: WGS 84 UTM Zone 10N
Scale: 1:1,500
Source: City of Coquitlam Aerials Jan 15, 2012

0 37.5 75 150 Metres

Figure A2-9: Site 5 Sampling Locations

Date, Author: 01/12/2016, Chris Adamson
Coordinate System: WGS 84 UTM Zone 10N
Scale: 1:500
Source: City of Coquitlam Aerials Jan 15, 2012

0 12.5 25 50 Metres

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Figure A2-10: Site 5 Sampling Locations

Date, Author: 01/12/2016, Chris Adamson
Coordinate System: WGS 84 UTM Zone 10N
Scale: 1:1,500
Source: City of Coquitlam Aerials Jan 15, 2012

0 37.5 75 150 Metres

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Figure A2-11: Site 6 Sampling Locations

Date, Author: 01/12/2016, Chris Adamson
Coordinate System: WGS 84 UTM Zone 10N
Scale: 1:500
Source: City of Coquitlam Aerials Jan 15, 2012

0 12.5 25 50 Metres

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Figure A2-12: Site 6 Sampling Locations

Date, Author: 01/12/2016, Chris Adamson
Coordinate System: WGS 84 UTM Zone 10N
Scale: 1:1,500
Source: City of Coquitlam Aerials Jan 15, 2012

0 37.5 75 150 **Metres**

Appendix 2

Charts

Chart A1-1: Mean Daily Precipitation (mm) in the Lower Coquitlam River during Monitoring Years 1-3 (2012-2015)

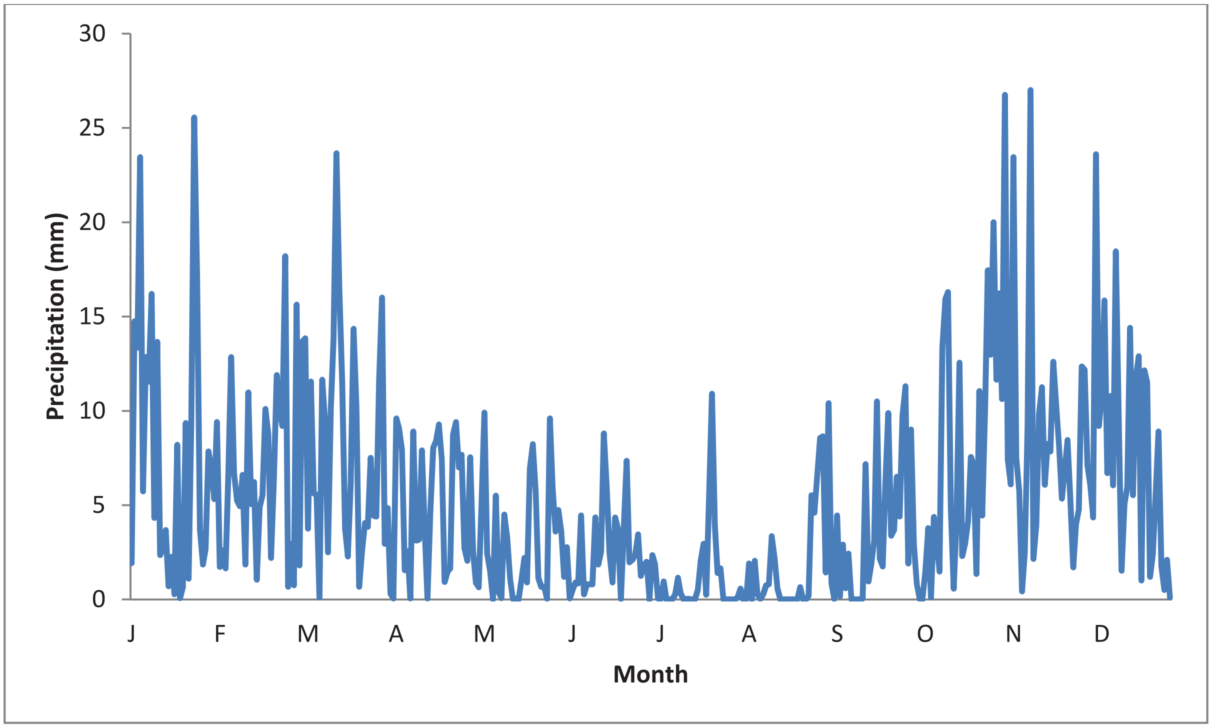


Chart A1-2: Mean Total Precipitation (mm) in the Lower Coquitlam River during Monitoring Years 1-3 (2012 – 2015)

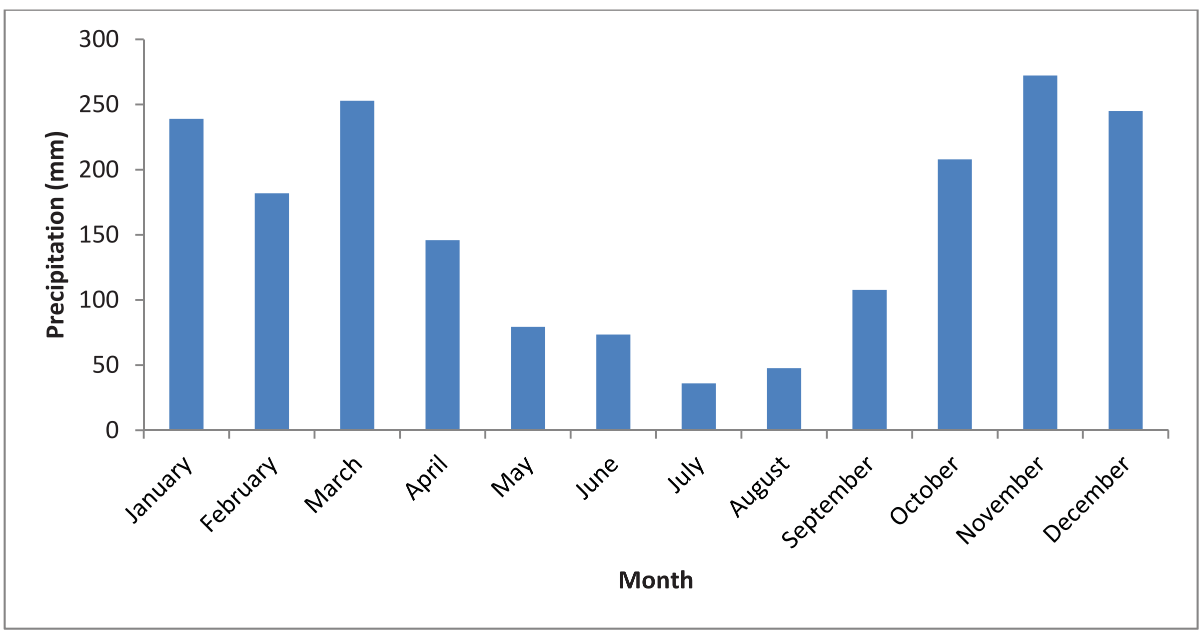
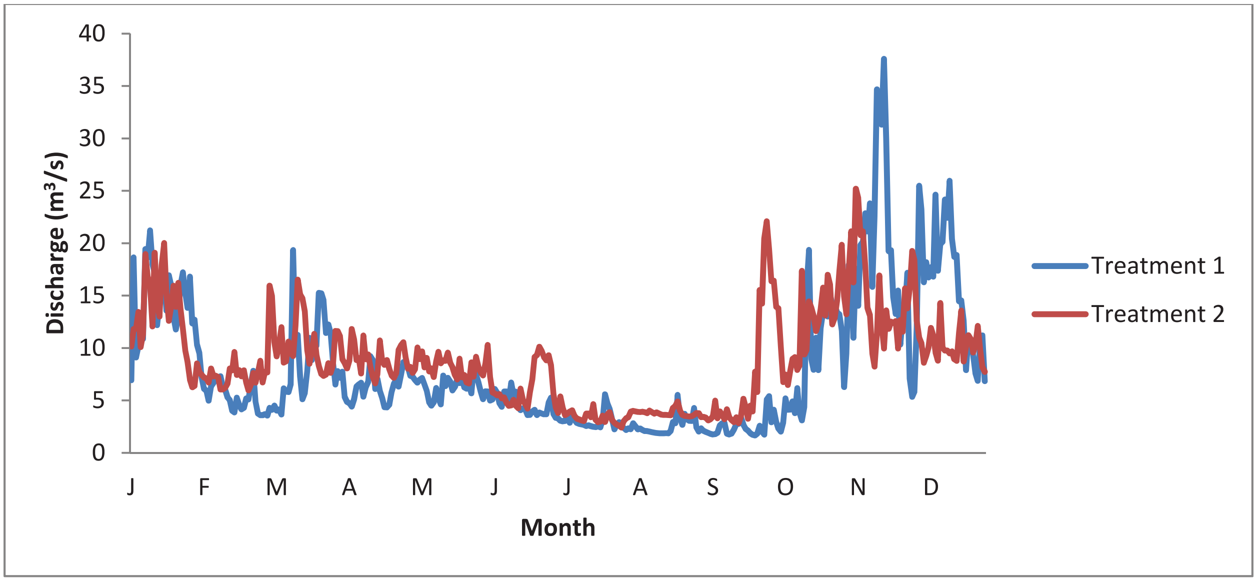


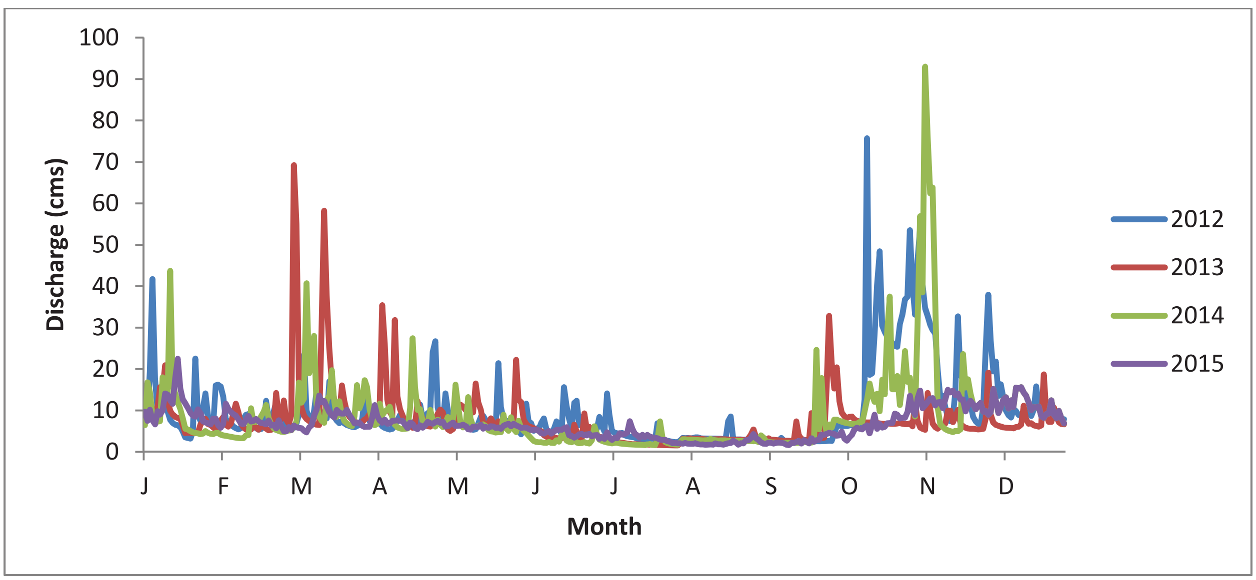
Chart A2-1: Mean Daily Discharge (m^3/s) in the Lower Coquitlam River during Treatment 1 & Treatment 2



Note:

Discharge measured at Water Survey of Canada streamflow gauging station 08MH002 (Coquitlam River at Port Coquitlam)
Treatment 1 includes data from January 2000 to September 2008 and Treatment 2 from October 2008 to May 2015

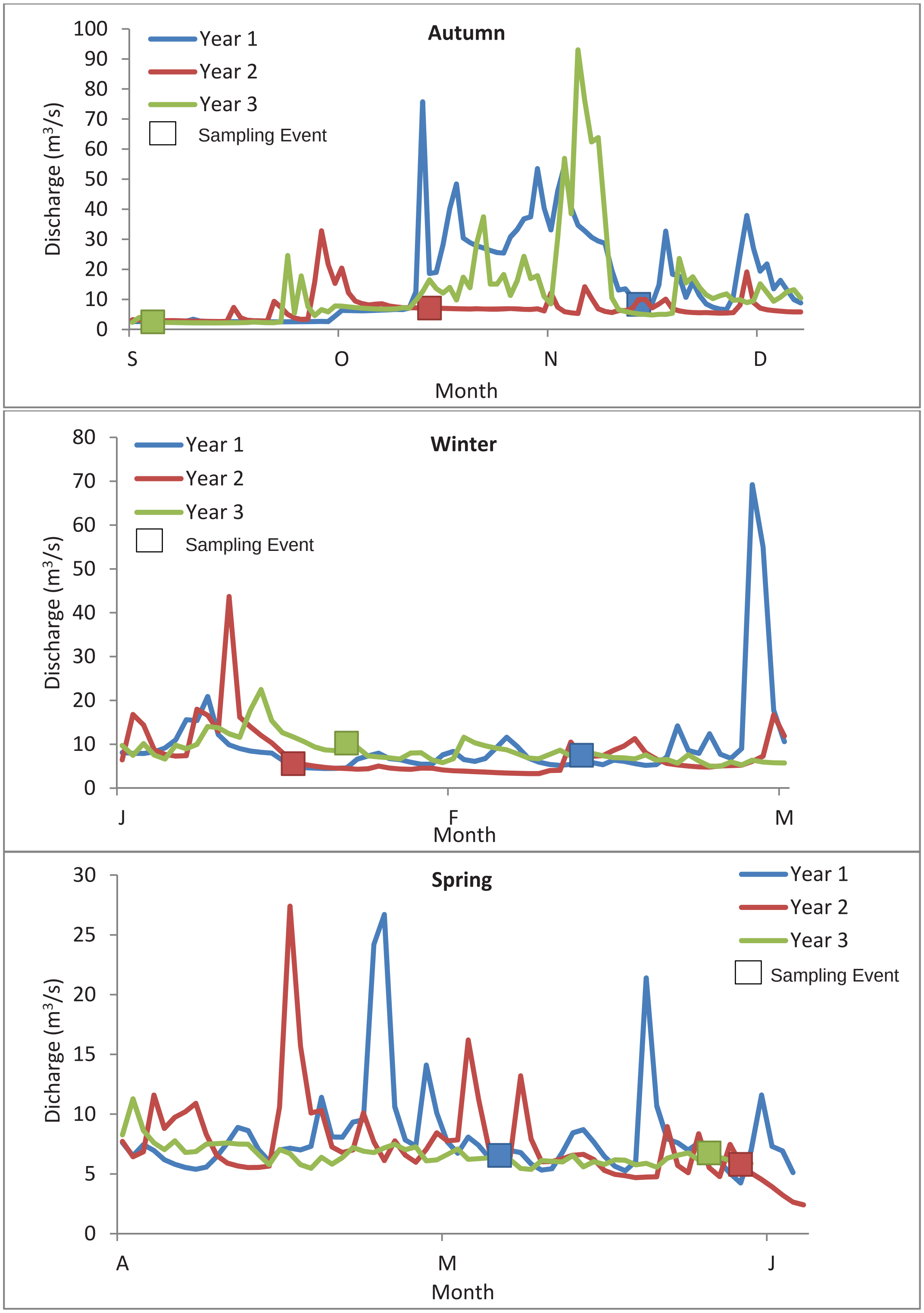
Chart A2-2: Mean Daily Discharge (m^3/s) in the Lower Coquitlam River during Monitoring Years 1-3 (2012-2015)



Note:

Discharge measured at Water Survey of Canada streamflow gauging station 08MH002 (Coquitlam River at Port Coquitlam)

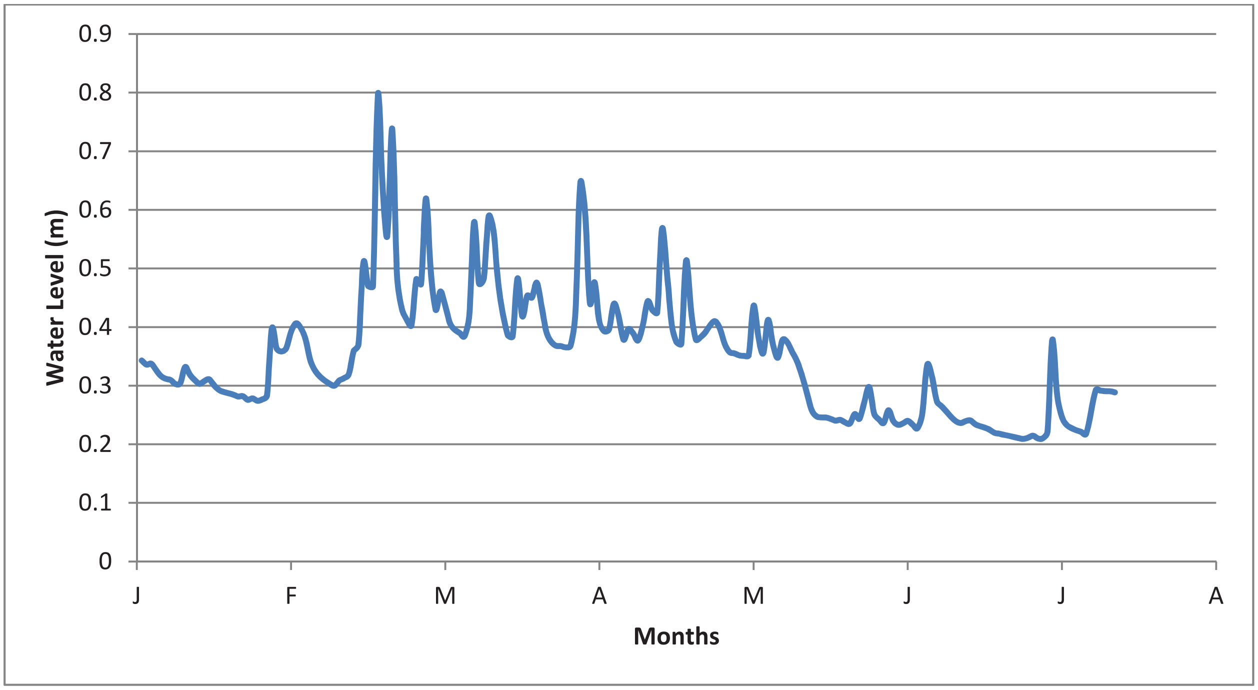
Chart A2-3: Daily Discharge (m^3/s) in the Lower Coquitlam River prior to Seasonal (Autumn, Winter, Spring) Sampling Events



Note:

Discharge measured at Water Survey of Canada streamflow gauging station 08MH002 (Coquitlam River at Port Coquitlam)

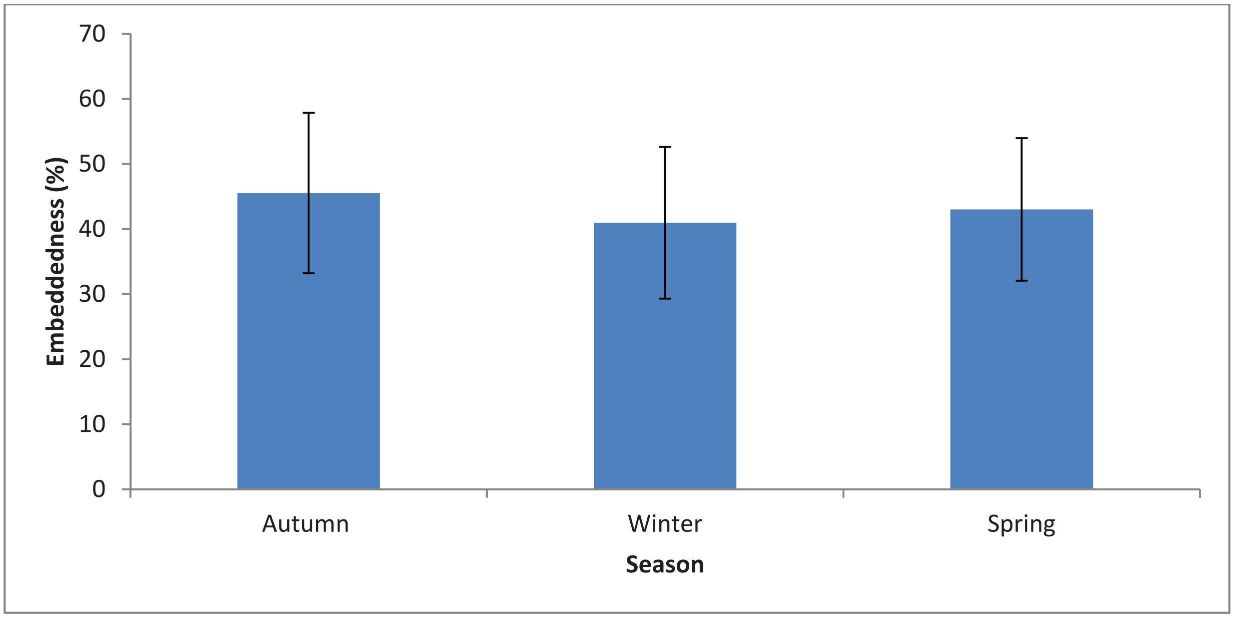
Chart A3: Mean Daily Water Level (m) near Site 5 in the Lower Coquitlam River (2014)



Note:

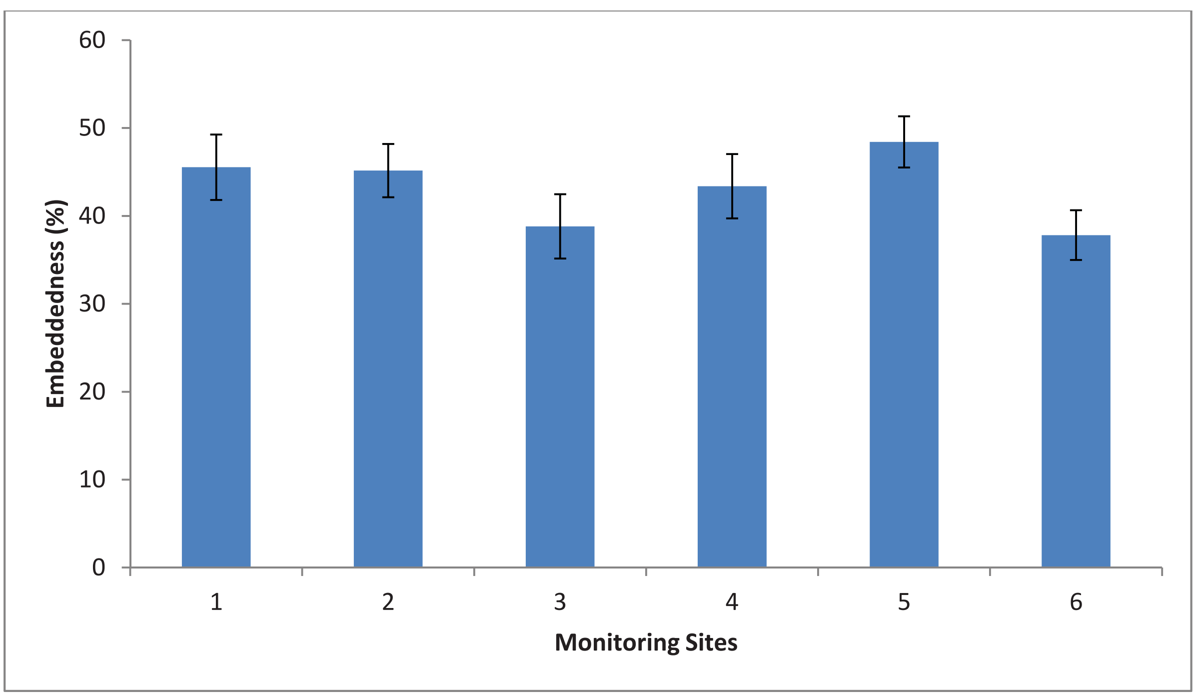
Water level measured using a HOBO U20 water logger

Chart A4-1: Seasonal Average Embeddedness (%) in the Lower Coquitlam River during Monitoring Years 1-3 (2012- 2015)



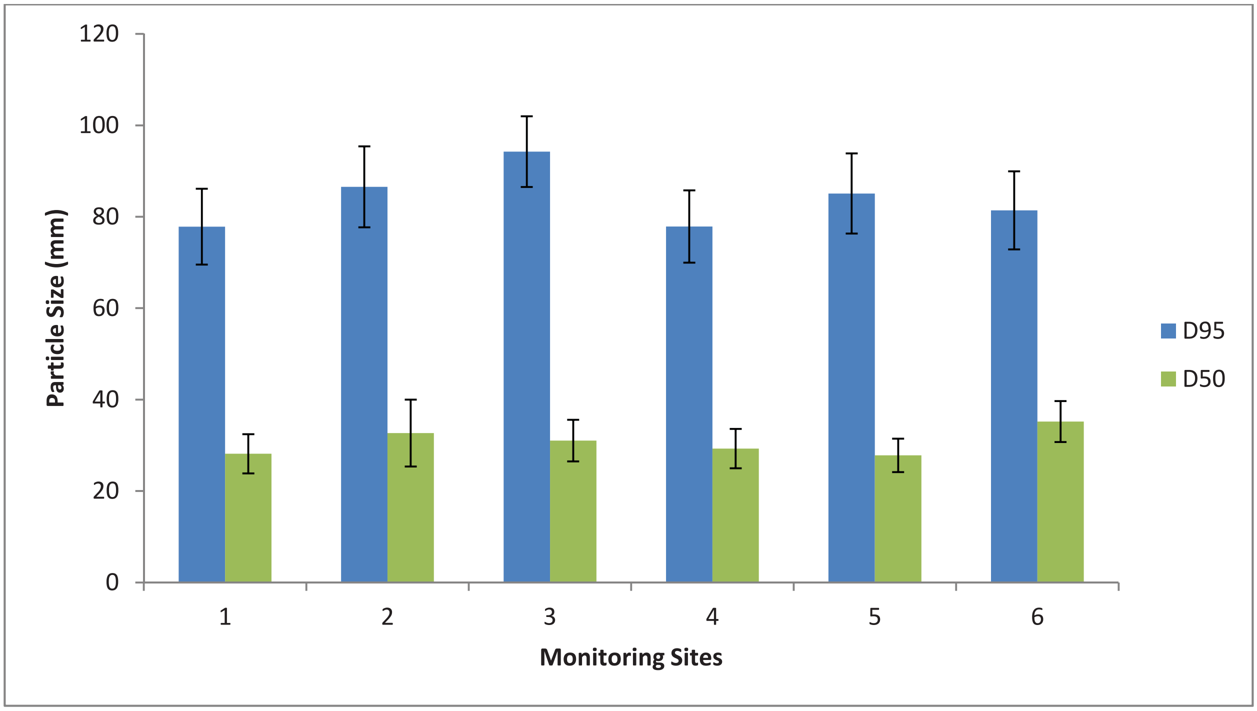
Note:
Values are average ± standard error

Chart A4-2: Average Embeddedness (%) in the Lower Coquitlam River during Monitoring Years 1-3 (2012- 2015)



Note:
Values are average ± standard error

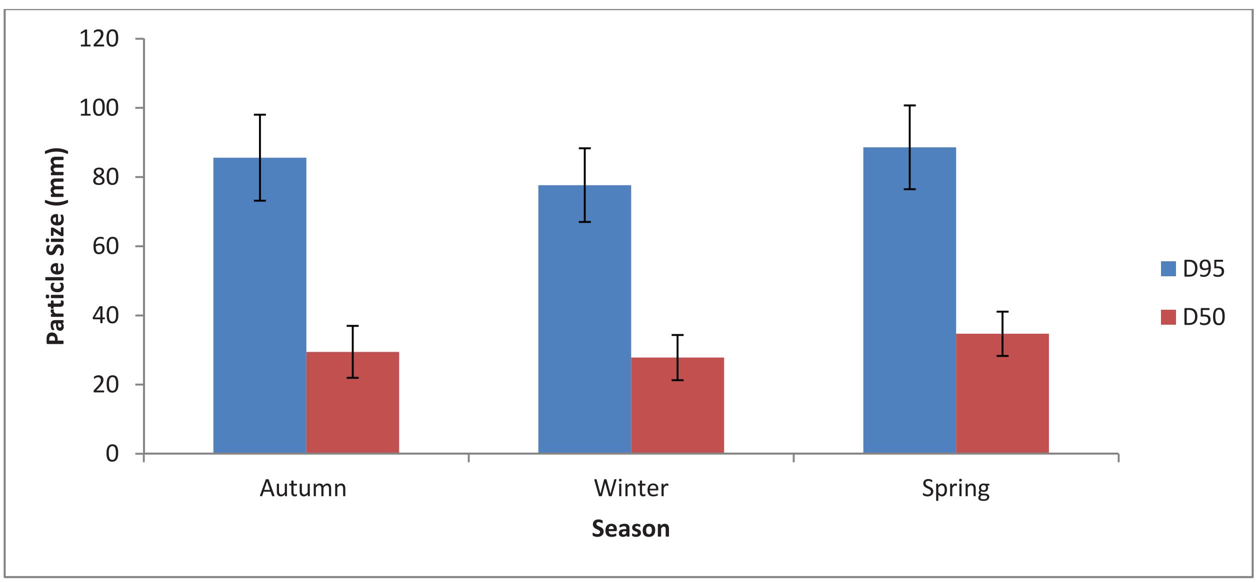
Chart A5-1: Average D_{95} and D_{50} (mm) in the Lower Coquitlam River during Monitoring Years 1-3 (2012- 2015)



Note:

Values are average ± standard error

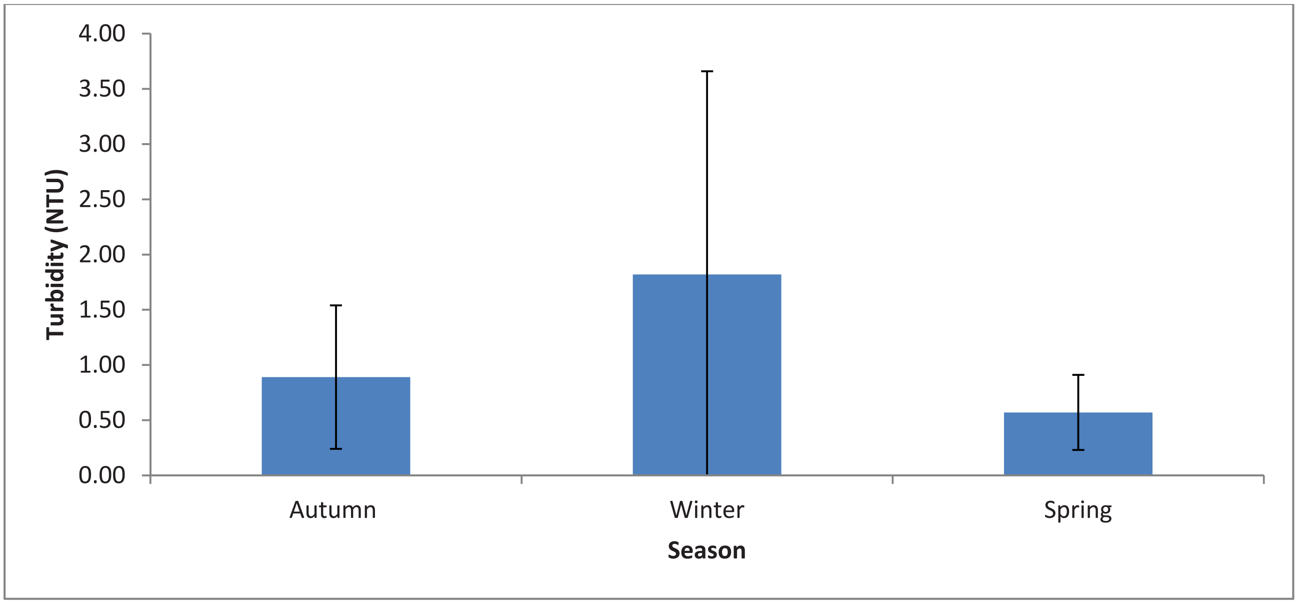
Chart A5-2: Seasonal Average D_{95} and D_{50} (mm) in the Lower Coquitlam River during Monitoring Years 1-3 (2012-2015)



Note:

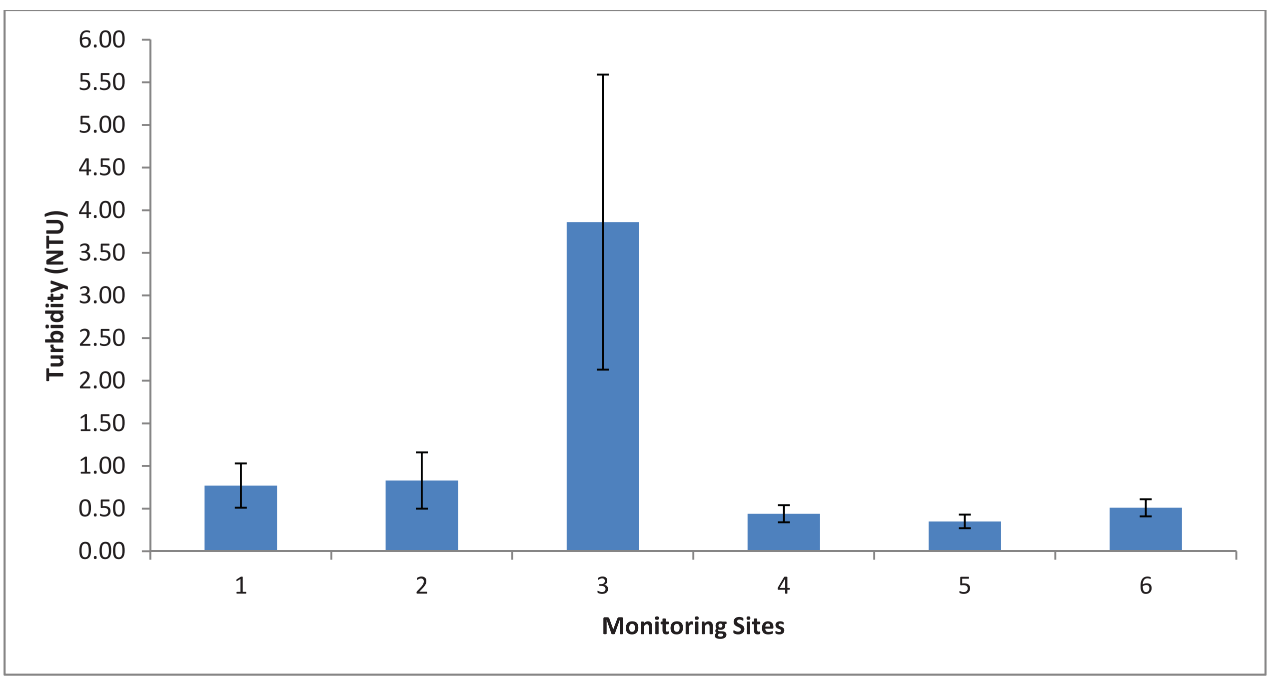
Values are average ± standard error

Chart A6-1: Seasonal Average Turbidity (NTU) in the Lower Coquitlam River during Monitoring Years 1-3 (2012-2015)



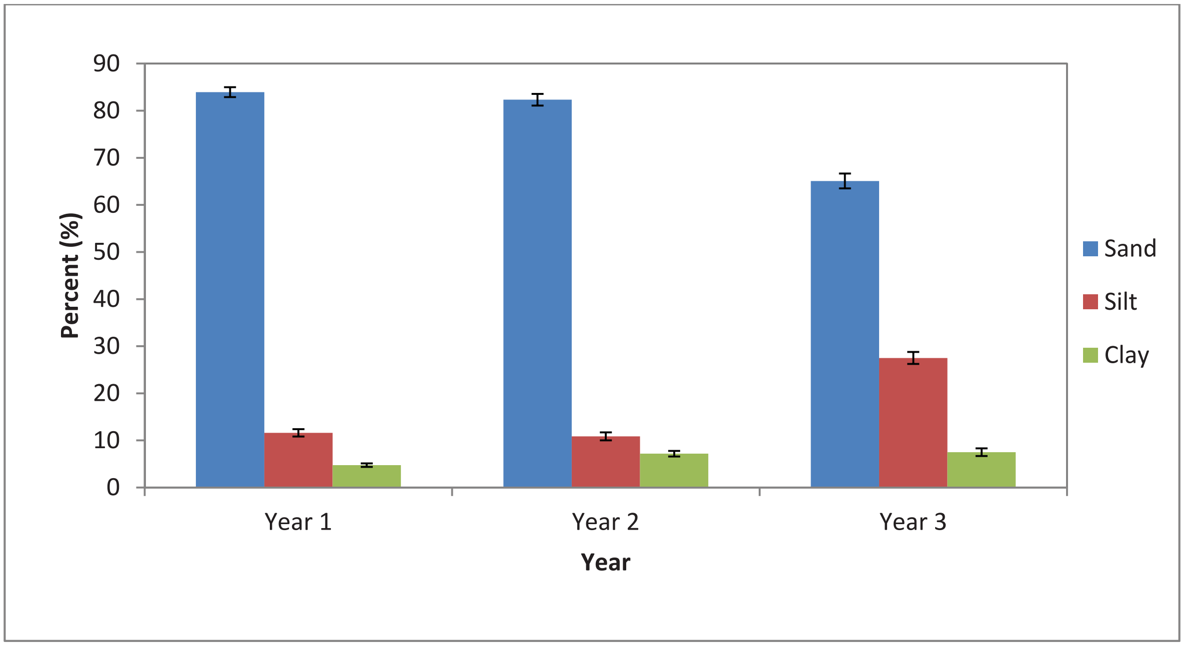
Note:
Values are average ± standard error

Chart A6-2: Average Turbidity (NTU) in the Lower Coquitlam River during Monitoring Years 1-3 (2012- 2015)



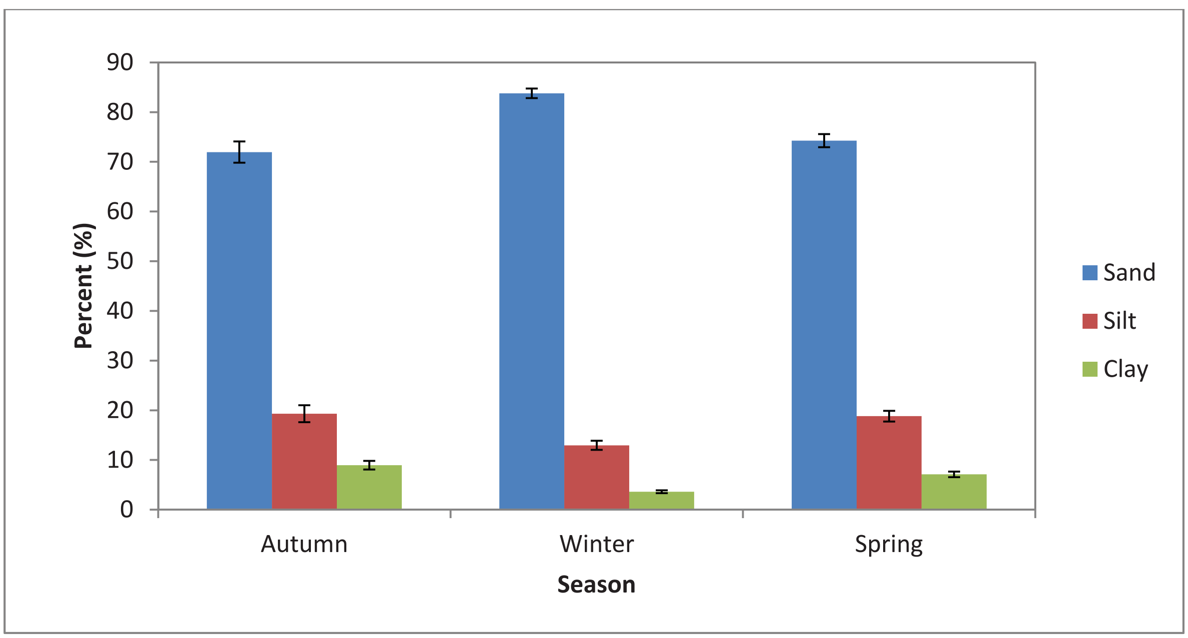
Note:
Values are average ± standard error

Chart A7-1: Particle size percent (%) Distribution of Surface Sediment in the Lower Coquitlam River for Monitoring Years 1 - 3 (2012-2015)



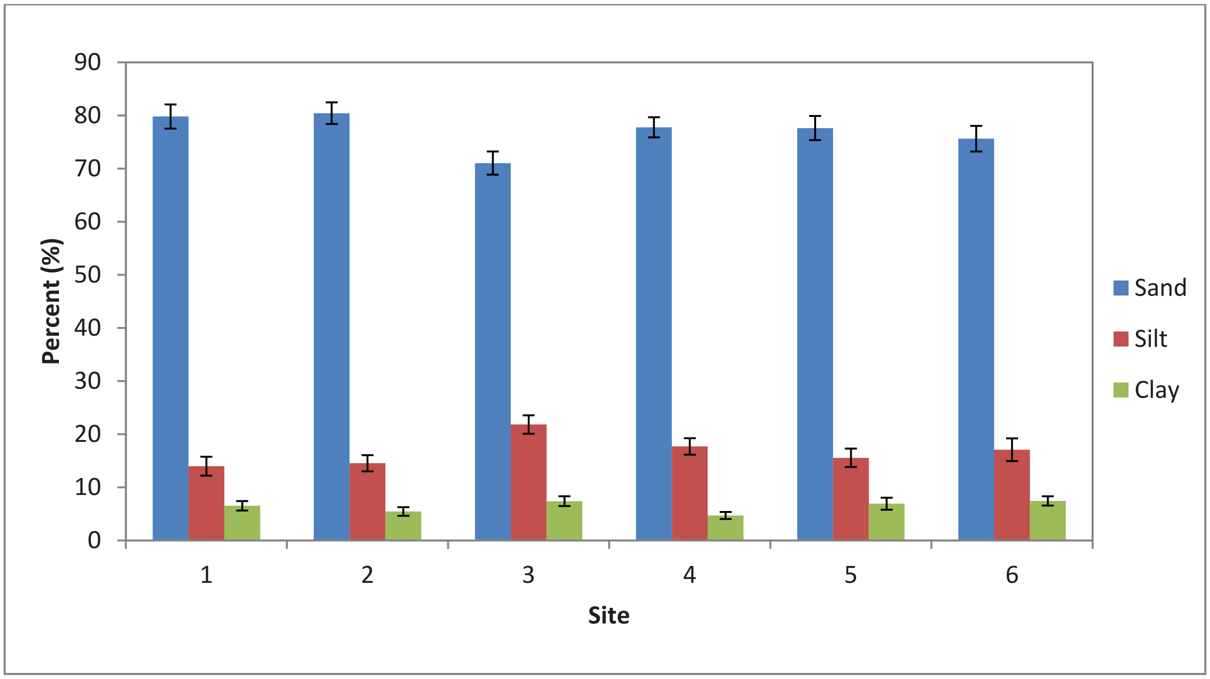
Note:
Values are average ± standard error

Chart A7-2: Seasonal Particle size percent (%) Distribution of Surface Sediment in the Lower Coquitlam River during Monitoring Years 1-3 (2012-2015)



Note:
Values are average ± standard error

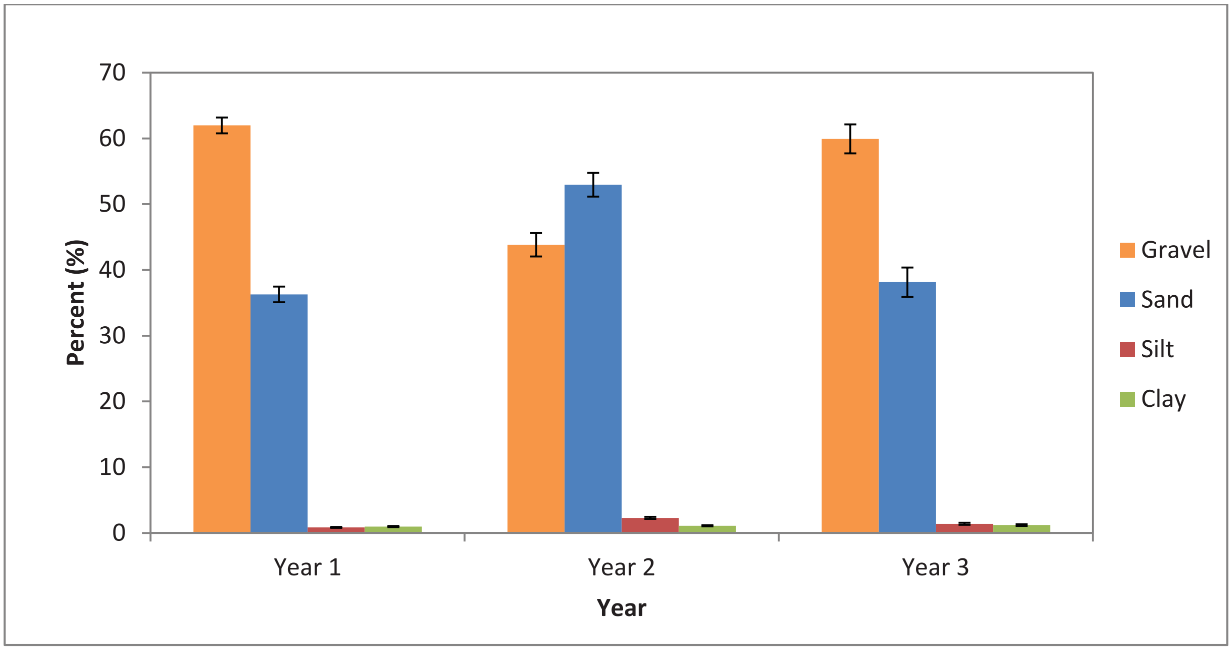
Chart A7-3: Average Particle Size Percent (%) Distribution in the Lower Coquitlam River during Monitoring Years 1-3 (2012-2015)



Note:

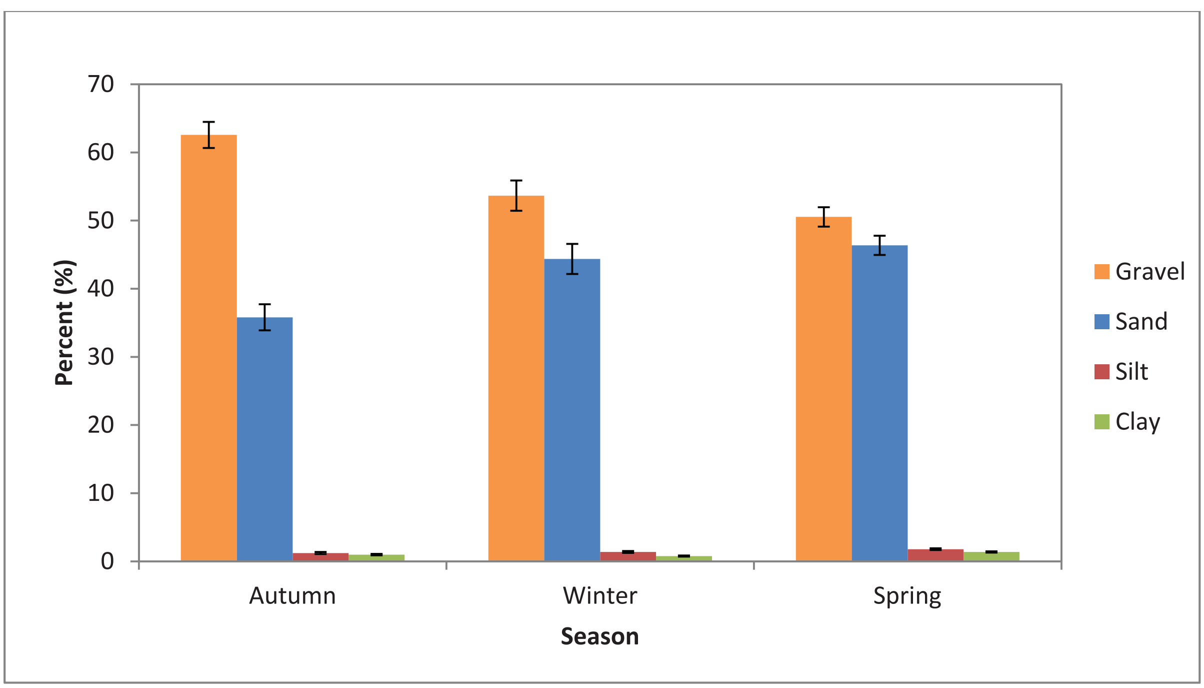
Values are average ± standard error

Chart A8-1: Particle Size Percent (%) Distribution of Subsurface Sediment in the Lower Coquitlam River for Monitoring Years 1 - 3 (2012-2015)



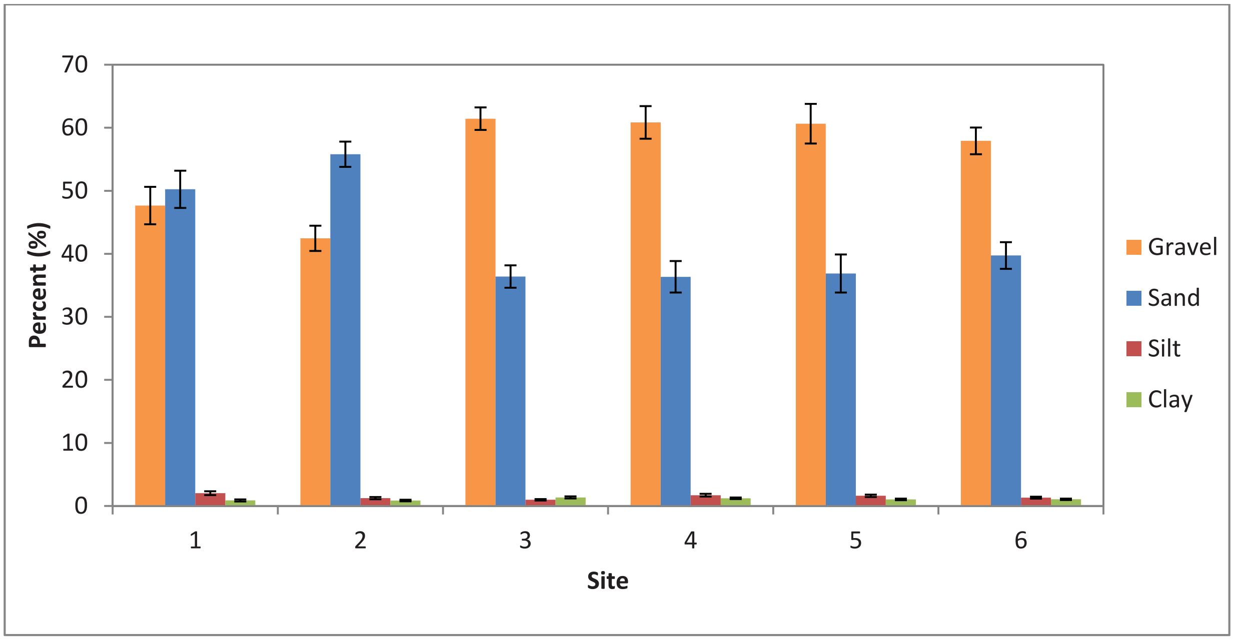
Note:
Values are average ± standard error

Chart A8-2: Seasonal Particle Size Percent (%) distribution of Subsurface Sediment in the Lower Coquitlam River during Monitoring Years 1-3 (2012-2015)



Note:
Values are average ± standard error

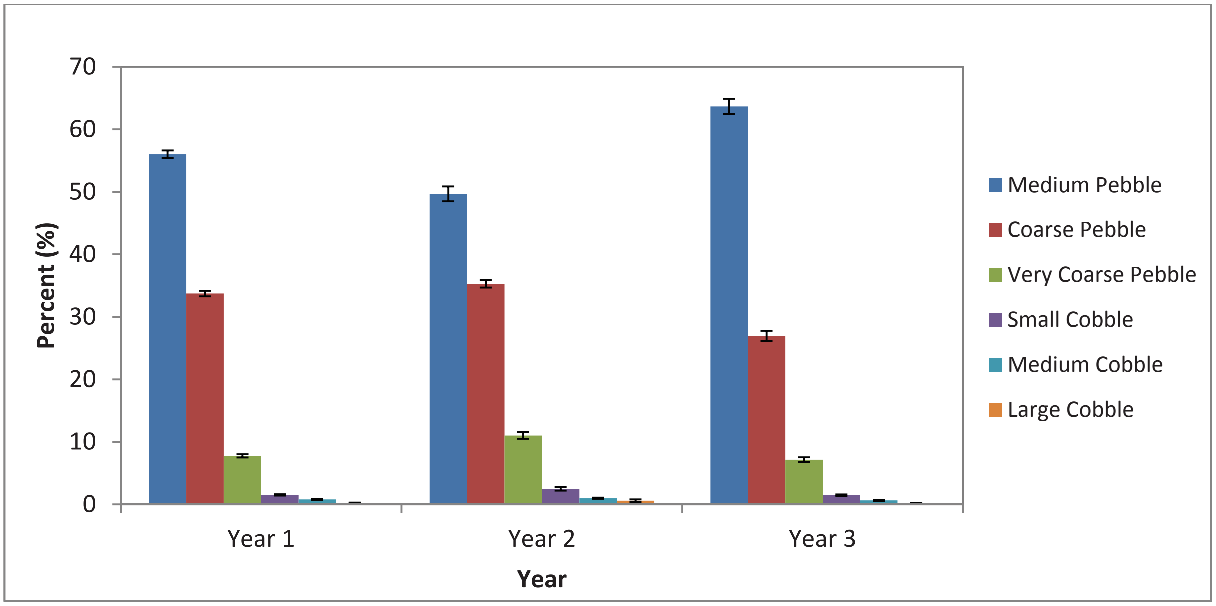
Chart A8-3: Average Particle Size Percent (%) Distribution of Subsurface Sediment in the Lower Coquitlam River during Monitoring Years 1-3 (2012-2015)



Note:

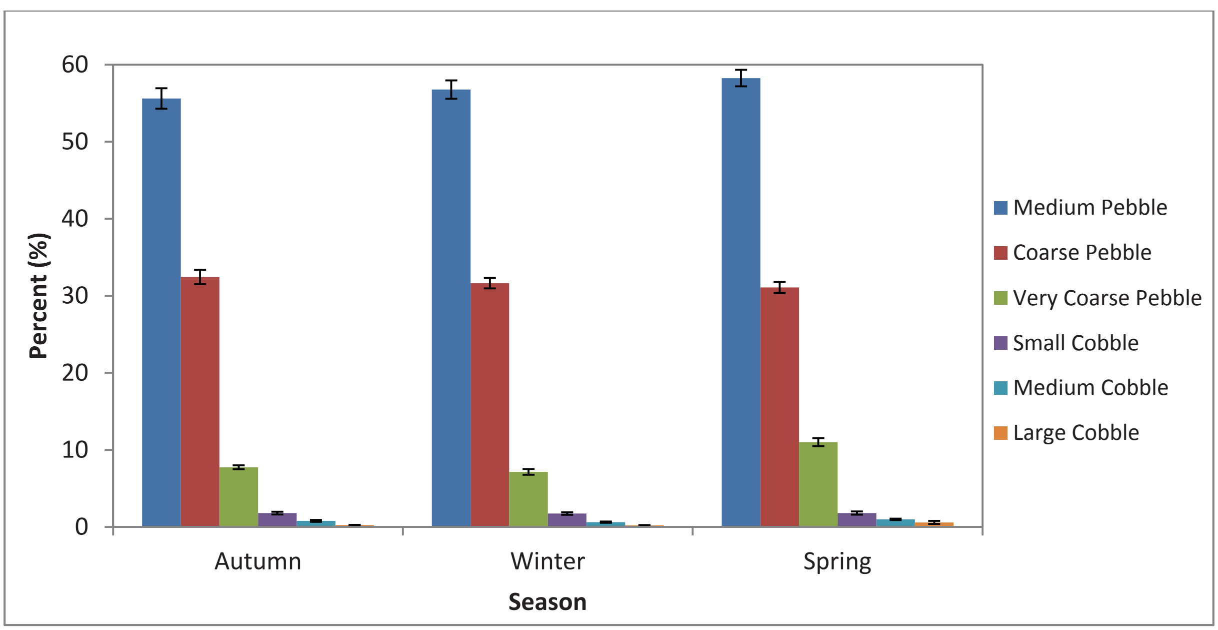
Values are average ± standard error

Chart A9-1: Average Particle Size Percent (%) Distribution of Coarse Subsurface Particles in the Lower Coquitlam River during Monitoring Years 1-3 (2012-2015)



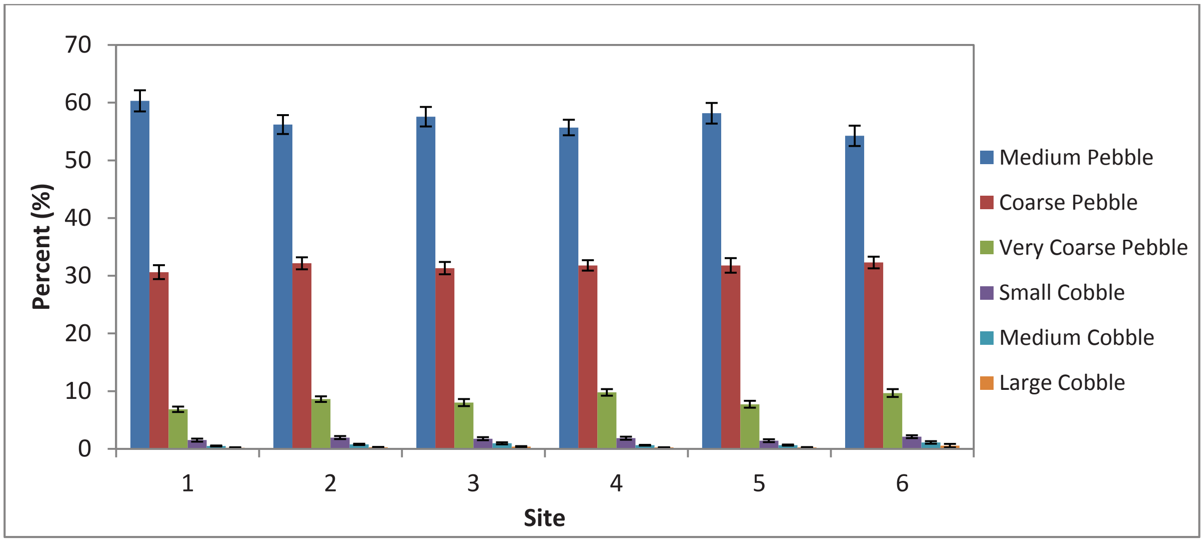
Note:
Values are average ± standard error

Chart A9-2: Seasonal Average Particle Size Percent (%) Distribution of Coarse Subsurface Particles in the Lower Coquitlam River during Monitoring Years 1-3 (2012- 2015)



Note:
Values are average ± standard error

Chart A9-3: Average Particle Size Percent (%) Distribution of Coarse Subsurface Particles in the Lower Coquitlam River during Monitoring Years 1-3 (2012-2015)



Note:

Values are average ± standard error

Appendix 3

Tables

Table A1-1: Seasonal Total Precipitation (mm) in the Lower Coquitlam River during Monitoring Years 1-3				
Season	Monitoring Years			Total
	1	2	3	
Autumn	527	371.6	560.2	1458.8
Winter	734.8	481.5	831.9	2048.2
Spring	790.8	707.3	499.9	1998
Total	2052.6	1560.4	1892.0	5505.0

Table A2-1: Seasonal Mean Daily Discharge (m^3/s) during Treatments 1 & 2 in the Lower Coquitlam River		
Season	Treatments	
	1	2
Autumn	4.1	6.3
Winter	16.0	12.7
Spring	6.7	8.8
Mean	8.9	9.3

Note:

Discharge measured at Water Survey of Canada streamflow gauging station 08MH002 (Coquitlam River at Port Coquitlam)
Treatment 1 was from January 2000 to September 2008 and Treatment 2 from October 2008 to May 2015

Table A2-2: Seasonal Average Daily Discharge (m^3/s) in the Lower Coquitlam River during Monitoring Years 1-3				
Season	Monitoring Years			Mean
	1	2	3	
Autumn	8.0	4.7	5.1	5.9
Winter	13.8	8.1	13.0	11.6
Spring	11.0	8.7	7.2	8.9
Mean	10.4	6.9	7.8	N/A

Notes:

Discharge measured at Water Survey of Canada streamflow gauging station 08MH002 (Coquitlam River at Port Coquitlam)
N/A: Not Applicable

Table A3-1: Seasonal Average Embeddedness (%) at 6 Sites in the Lower Coquitlam River (2012-2015)							
Season	Site						Mean
	1	2	3	4	5	6	
Autumn	44 (±29)	52 (±20)	40 (±22)	47 (±18)	50 (±20)	43 (±21)	46 (±21)
Winter	41 (±17)	40 (±18)	35 (±26)	45 (±24)	49 (±17)	36 (±15)	41 (±20)
Spring	52 (±22)	46 (±16)	41 (±17)	38 (±24)	46 (±16)	34 (±14)	43 (±19)
Mean	46 (±22)	45 (±18)	39 (±22)	43 (±22)	48 (±17)	38 (±17)	N/A

Notes:
Values are average ± standard deviation
N/A: Not Applicable

Table A3-2: Average Embeddedness (%) at 6 Sites in the Lower Coquitlam River during Monitoring Years 1-3 (2012-2015)							
Monitoring Year	Site						Mean
	1	2	3	4	5	6	
1	47 (±26)	50 (±18)	45 (±19)	49 (±18)	54 (±16)	33 (±18)	46 (±20)
2	49 (±21)	46 (±18)	49 (±24)	51 (±22)	47 (±21)	42 (±15)	47 (±20)
3	42 (±22)	40 (±18)	23 (±12)	31 (±21)	44 (±14)	38 (±18)	36 (±19)
Mean	46 (±22)	45 (±18)	39 (±22)	43 (±22)	48 (±17)	38 (±17)	N/A

Notes:
Values are average ± standard deviation
N/A: Not Applicable

Table A3-3: Seasonal Average Embeddedness (%) in the Lower Coquitlam River during Monitoring Years 1-3				
Season	Monitoring Years			Mean
	1	2	3	
Autumn	42 (±24)	54 (±23)	44 (±18)	46 (±21)
Winter	52 (±15)	40 (±21)	31 (±19)	41 (±20)
Spring	44 (±20)	51 (±16)	34 (±17)	43 (±19)
Mean	46 (±20)	47 (±20)	36 (±17)	N/A

Notes:
Values are average ± standard deviation
N/A: Not Applicable

Table A4-1: Seasonal Average D_{50} (mm) at 6 Sites in the Lower Coquitlam River (2012-2015)							
Season	Site						Mean
	1	2	3	4	5	6	
Autumn	27 (±11)	37 (±28)	27 (±5)	29 (±6)	26 (±6)	33 (±13)	29 (±13)
Winter	25 (±9)	25 (±10)	28 (±10)	24 (±11)	28 (±13)	37 (±11)	28 (±11)
Spring	32 (±11)	38 (±14)	39 (±13)	35 (±11)	29 (±6)	36 (±9)	35 (±11)
Mean	28 (±11)	33 (±18)	31 (±11)	29 (±11)	28 (±9)	35 (±11)	N/A

Notes:
Values are average ± standard deviation
N/A: Not Applicable

Table A4-2: Average D_{50} (mm) at 6 Sites in the Lower Coquitlam River during Monitoring Years 1-3 (2012-2015)							
Monitoring Year	Site						Mean
	1	2	3	4	5	6	
1	27 (±11)	37 (±26)	31 (±15)	31 (±16)	24 (±10)	34 (±11)	29 (±14)
2	28 (±9)	32 (±10)	30 (±9)	30 (±6)	33 (±8)	41 (±13)	32 (±10)
3	29 (±11)	29 (±11)	32 (±9)	28 (±8)	27 (±6)	31 (±5)	29 (±9)
Mean	28 (±11)	33 (±18)	31 (±1)	29 (±11)	28 (±9)	35 (±11)	N/A

Notes:
Values are average ± standard deviation
N/A: Not Applicable

Table A4-3: Seasonal Average D_{95} (mm) at 6 Sites in the Lower Coquitlam River (2012-2015)							
Season	Site						Mean
	1	2	3	4	5	6	
Autumn	76 (±22)	87 (±27)	95 (±17)	85 (±21)	87 (±20)	82 (±17)	86 (±22)
Winter	75 (±16)	77 (±12)	86 (±19)	67 (±15)	79 (±19)	82 (±24)	78 (±18)
Spring	82 (±23)	95 (±19)	102 (±18)	82 (±18)	90 (±24)	81 (±22)	89 (±21)
Mean	78 (±20)	87 (±22)	94 (±19)	78 (±19)	85 (±21)	81 (±21)	N/A

Notes:
Values are average ± standard deviation
N/A: Not Applicable

Table A4-4: Average D_{95} (mm) at 6 Sites in the Lower Coquitlam River during Monitoring Years 1-3 (2012-2015)							
Monitoring Year	Site						Mean
	1	2	3	4	5	6	
1	74 (±20)	87 (±27)	94 (±17)	85 (±26)	78 (±23)	82 (±22)	83 (±23)
2	69 (±15)	82 (±15)	86 (±21)	72 (±14)	87 (±22)	82 (±26)	80 (±20)
3	87 (±21)	90 (±20)	102 (±15)	76 (±15)	92 (±17)	80 (±14)	88 (±19)
Mean	78 (±20)	87 (±22)	94 (±19)	78 (±19)	85 (±21)	81 (±21)	N/A

Notes:

Values are average ± standard deviation
N/A: Not Applicable

Table A4-5: Seasonal Average D_{50} and D_{95} (mm) in the Lower Coquitlam River during Monitoring Years 1-3								
Season	Monitoring Years						Mean	
	1		2		3			
	D_{50}	D_{95}	D_{50}	D_{95}	D_{50}	D_{95}	D_{50}	D_{95}
Autumn	31 (±18)	89 (±25)	32 (±11)	85 (±23)	26 (±6)	83 (±16)	30 (±15)	85 (±22)
Winter	24 (±11)	72 (±17)	34 (±12)	77 (±19)	26 (±7)	84 (±18)	28 (±11)	78 (±18)
Spring	37 (±15)	89 (±23)	31 (±7)	81 (±20)	36 (±9)	89 (±20)	35 (±11)	86 (±22)
Mean	31 (±16)	83 (±23)	32 (±10)	81 (±20)	29 (±9)	85 (±19)	N/A	N/A

Notes:

Values are average ± standard deviation
N/A: Not Applicable

Table A5-1: Seasonal Average Turbidity (NTU) at 6 Sites in the Lower Coquitlam River (2012-2015)							
Season	Sites						Mean
	1	2	3	4	5	6	
Autumn	0.79 (±0.050)	1.54 (±1.61)	1.83 (±1.77)	0.29 (±0.23)	0.22 (±0.09)	0.25 (±0.13)	0.89 (±1.12)
Winter	1.07 (±1.03)	0.82 (±0.37)	7.34 (±5.40)	0.49 (±0.35)	0.45 (±0.31)	0.73 (±0.25)	1.82 (±3.18)
Spring	0.45 (±0.17)	0.35 (±0.19)	1.68 (±1.56)	0.5 (±0.21)	0.33 (±0.04)	0.47 (±0.11)	0.57 (±0.59)
Mean	0.77 (±0.63)	0.83 (±0.81)	3.86 (±4.23)	0.44 (±0.25)	0.35 (±0.19)	0.51 (±0.25)	N/A

Notes:

Values are average ± standard deviation
N/A: Not Applicable

Table A5-2: Average Turbidity (NTU) at 6 Sites in the Lower Coquitlam River during Monitoring Years 1-3 (2012-2015)							
Monitoring Year	Sites						Mean
	1	2	3	4	5	6	
1	0.58	1.16 (±1.34)	2.41 (±1.85)	0.36 (±0.09)	0.3 (±0.06)	0.51 (±0.29)	0.83 (±1.01)
2	1.37 (±1.22)	0.89 (±0.52)	4.48 (±5.32)	0.52 (±0.30)	0.29 (±0.01)	0.51 (±0.09)	0.84 (±0.83)
3	0.59 (±0.29)	0.45 (±0.10)	4.2 (±5.45)	0.48 (±0.39)	0.42 (±0.34)	0.52 (±0.38)	0.56 (±0.36)
Mean	0.77 (±0.63)	0.83 (±0.81)	3.86 (±4.23)	0.44 (±0.25)	0.35 (±0.19)	0.51 (±0.25)	N/A

Notes:

Values are average ± standard deviation
N/A: Not Applicable

Table A5-3: Seasonal Average Turbidity (NTU) in the Lower Coquitlam River during Monitoring Years 1-3 (2012-2015)				
Season	Monitoring Year			Mean
	1	2	3	
Autumn	1.37 (±1.46)	0.21	0.53 (±0.57)	0.7 (±1.12)
Winter	0.57 (±0.35)	2.49 (±3.97)	2.39 (±3.96)	1.82 (±3.18)
Spring	0.36 (±0.15)	2.03 (±0.93)	0.41 (±0.12)	0.93 (±0.59)
Mean	0.77 (±0.96)	1.58 (±2.78)	1.11 (±2.36)	N/A

Notes:

Values are average ± standard deviation
N/A: Not Applicable

Table A6: Average Velocity (m/s) at 6 Sites in the Lower Coquitlam River (May 2015)

	Site						Mean
	1	2	3	4	5	6	
Surface Velocity	0.50	0.40	0.25	0.18	0.27	0.07	0.28
Bottom Velocity	0.37	0.28	0.22	0.11	0.24	0.27	0.25
Mean Velocity	0.44	0.34	0.24	0.15	0.24	0.27	0.28

Appendix 4

Photographs

Photos A1 – 1-12: Representative Site Photos
Photos A2 – 1-12: Methods

Photos A1–1-12: Representative Site Photos

Photo A1-1: Looking downstream (south) from Site 1 (27 May 2015)

Photo A1-2: Substrate at Site 1 (22 January 2015)

Photo A1-3: Looking downstream (southeast) from Site 2 (27 May 2015)

Photo A1-4: Substrate at Site 2 (27 May 2015)

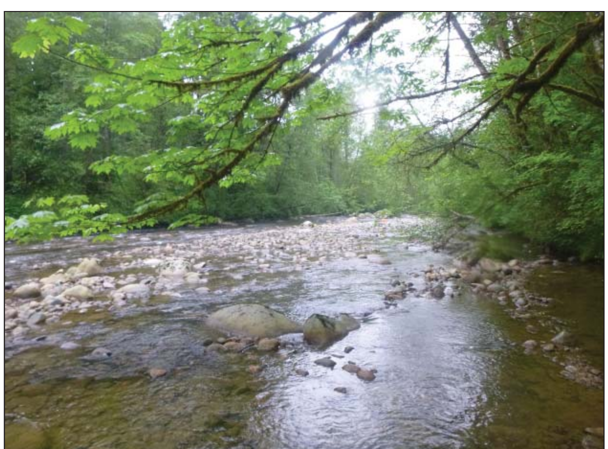


Photo A1-5: Looking downstream (southwest) from Site 3 (27 May 2015)

Photo A1-6: Substrate at Site 3 (27 May 2015)

Photo A1-7: Looking downstream (southeast) from Site 4 (26 May 2015)

Photo A1-8: Substrate at Site 4 (22 January 2015)

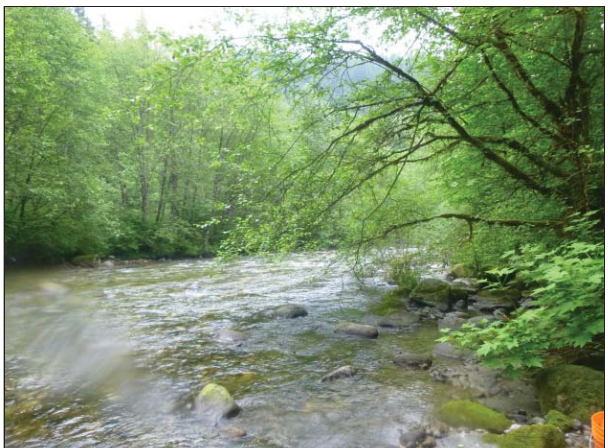


Photo A1-9: Looking downstream (southeast) from Site 5 (26 May 2015)

Photo A1-10: Substrate at Site 5 (27 January 2015)

Photo A1-11: Looking downstream (26 May 2015) from Site 6

Photo A1-12: Substrate at Site 6 (26 May 2015)

Photos A2–1-12: Methods

Photo A2-1: Placing Hess sampler in stream

Photo A2-2: Hess sampler embedded in substrate

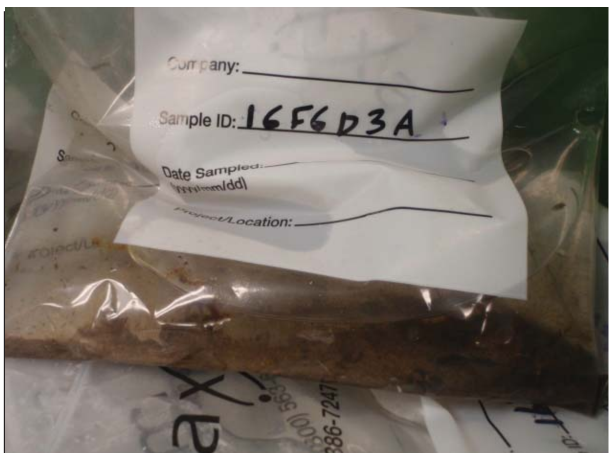


Photo A2-3: Surface fines collected from Hess sampler

Photo A2-4: Substrate being removed from Hess sampler

Photo A2-5: Wet sample in bucket being weighed

Photo A2-6: Subsurface samples placed on clean polyethylene sheets on drying rack

Photo A2-7: Second layer of drying rack being constructed

Photo A2-8: Sample dried and ready to be measured

Photo A2-9: Dry sample in bucket being weighed

Photo A2-10: Sample placed in sifter box, preparing for sorting

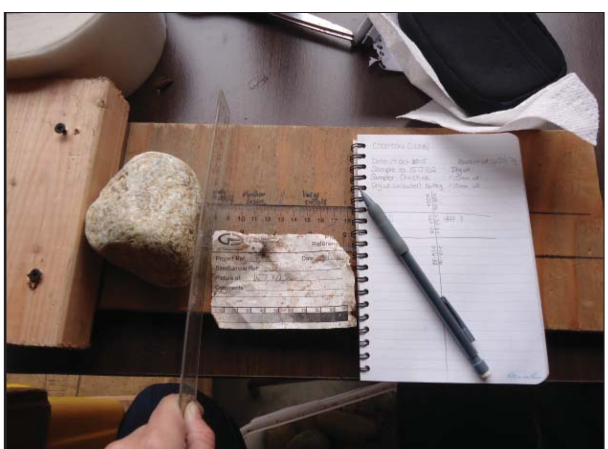


Photo A2-11: Rock >10 mm measured and recorded as small cobble

Photo A2-12: Subsurface <10 mm sample weighed before sending to laboratory for particle size analysis