Coquitlam-Buntzen Project Water Use Plan

Lower Coquitlam River Substrate Quality Assessment

Implementation Year 10

Reference: COQMON #8

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G3 Consulting Ltd.

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LOWER COQUITLAM RIVER SUBSTRATE QUALITY ASSESSMENT

COQMON #8

Final Report 2018

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Statement of Limitations

This report was prepared for the exclusive use of BC Hydro and Power Authority. Any third party decisions made based on this report are the responsibility of such third parties. This report is based on data collected by G3 Consulting Ltd. and site conditions at the time of survey. Samples were collected at discrete locations. Site conditions between sampling locations have been inferred based on conditions at specific sampling locations. G3 makes no other representations whatsoever, including the legal significance of its findings, or other legal matters including, but not limited to, ownership of any property, or the application of any law to the facts set forth in this report. G3 assumes no liability with respect to use of the information contained in this report other than its intended purpose.

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I. 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. The original intent of the program was to assess the effectiveness of a defined flushing flow with an annual 'opportunistic' flow from Coquitlam Dam between 30 m^3/s to 50 m^3/s for a duration of 3 to 5 days to improve fish habitat quality through substrate size. No defined flushing flows had occurred since the Water Use Plan (WUP) had begun (2005); therefore, in 2015 an amendment (TOR; addendum 3) was created to assess the effectiveness of managed and unmanaged flow exceeding 70 m^3/s on improving fish habitat quality. The program evaluated substrate size distribution and habitat quality objectives to address specific management questions as part of one of eight (8) studies under the Coquitlam River WUP.

Substrate quality was assessed at six (6) sites in the Lower Coquitlam River by measuring percent (%) particle size distribution for surficial (0 to 2 mm) and subsurface (<10 mm and >10 mm) substrate as collected using a modified Hess sampler. Sampling was conducted over a five (5) year period and during three (3) seasons (autumn, winter and spring) each year, coinciding with salmon spawning season, mid-incubation and end of emergence periods. During each sampling event at each site an assessment of dominant and subdominant substrate, embeddedness, water depth, turbidity and velocity was measured, as well as a biophysical assessment done in the first year (2013).

Mean embeddedness varied between years, season and sites. Site 3 embeddedness was statistically lower than Site 1, 4 and 5. Embeddedness in autumn was statistically higher than winter suggesting natural flows from increased rainfall were effective in reducing average seasonal embeddedness. D_{50} and D_{95} were comparable among seasons and site measurements varied throughout monitoring years. Velocity varied throughout the years, season and site. Winter velocity was statistically significant and higher than spring and higher at Site 1 compared to Sites 4 and 6. Turbidity at Site 3 was statistically higher than all other sites and was higher in winter. A visible sediment plume at Site 3 was noted during winter sampling events in 2014, 2015 and 2016, and may be attributed to an adjacent upstream, gravel mining operation.

Surficial substrate samples were dominated by sand (0.0625 mm – 2 mm) in all monitoring years. Surficial sand, silt and clay had statistically significant variability among years, seasons and sites and had significant inter relationships (i.e. interaction effects). Site 3 had statistically significantly higher silt and clay content and lower sand content than all other sites.

Subsurface samples throughout all monitoring years were dominated by gravel (2 mm – 10 mm), with the exception of Year 2 (2013 to 2014) which was generally dominated by sand. Subsurface gravel, sand, silt and clay had significant variability among, Years, Seasons and Sites and statistically significant relationships (i.e. interaction effects). Sand was statistically higher in spring than autumn and there were statistically significant differences in subsurface substrate (<10 mm) composition between sites for all size fractions (except clay).

Coarse subsurface particles collected from the Lower Coquitlam River were dominated by three (3) gravel size classes. Statistically significant differences were noted between years for all six (6) size classes, between seasons for all gravel sizes and between sites for medium cobble. In addition there were statistically significant relationships between Year, Season and Site (i.e. interaction effects).

Year 2 (2013 to 2014) had the least precipitation and lowest releases from the Coquitlam Dam which likely influenced river substrates. Year 2 had an increase in smaller sediment of sand and silt in the subsurface (<10 mm) and a decrease in gravel and increase in cobble in the subsurface (>10 mm) sample.

Precipitation and dam discharge was positively correlated with river discharge showing river flow is highly influenced by water inputs. Three (3) high flow events occurred shortly before sampling in November 2012, December 2015 and February 2016. Regression analysis was used to compare percent (%) particle size and averages of mean daily discharge prior to sampling using seasonal (4 months prior), monthly (30 days prior) and weekly (7 days prior) river flows. Statistically significant positive correlation was found between surficial sand and weekly flow and a statistically significant negative correlation was found between silt and clay and weekly flow (three [3] regulated high flow events excluded). As flow increased sand increased and silt and clay decreased. No statistically significant trends were noted between flow and various size fractions of subsurface samples. Similarly, no statistically significant trends were noted between flow prior to sampling and embeddedness or turbidity.

Comparison between number of steelhead and coho redds and outmigration abundance identified no statistically significant trends between surficial substrate fractions and number of redds and Coho outmigration abundance in the Lower Coquitlam River. Coho and steelhead outmigration abundances were compared to embeddedness results one winter prior to the salmon survey. Coho outmigration abundance in Reach 3 showed a statistically significant negative correlation with winter embeddedness.

With flow regimes occurring over the monitoring period, suitable habitat for spawning and rearing were observed at each sampling site and compared to biostandards (e.g. Groot and Margolis, 1991) from literature. Over the years an increase in small particle sizes in the river was not observed; however, variability over years, season and site was noted.

From program observations and results it is suggested that there is suitable spawning and rearing habitat in the system and flows, occurring naturally and associated with the Coquitlam Dam releases, are effective at reducing fines (silt and clay). Unless there is a significant change in dam release operations it is recommended that this study be considered complete. It is recommended if dam operations change, substrates be monitored opportunistically. Although not a BC Hydro related impact, turbidity at Site 3 downgradient from gravel operations, should be continually monitored. In addition, data from Reach 1 should be assessed for substrate composition and salmon surveys be better correlated in the future. Lastly, river velocity during high releases from Coquitlam Dam should be assessed near salmon spawning grounds to determine whether velocities are favorable for spawning salmon where releases occur during the spawning season.

II. MANAGEMENT QUESTIONS

Management Question	Supportive Questions	Status or Conclusion
Are flow events that are occurring on the Coquitlam River effective at improving fish habitat quality?	Is there a correlation between substrate composition and flow mechanism in Coquitlam River that meet criteria defined during the Coquitlam-Buntzen WUP?	An increase in small particle sizes surficial and subsurface was not observed in the Coquitlam River over the monitoring period. Under the current flow regime, suitable substrate and fish habitat for spawning and rearing was observed at each sampling site and seem to be effective at keeping fine sediments at a minimal level over the five-year program. Substrate varied by year, site and season. (Section 3.0)
	Is there a correlation between substrate quality and fish productivity?	Correlations were assessed for sediment particle size and secondary indicators (i.e., embeddedness, velocity, turbidity) with Coho and Steelhead outmigration and Steelhead redd counts. Correlation with respect to substrate and fish data were limited given it was collected independently (i.e. separate programs) and not at comparable sites; however, substrate and fish data were compared for each reach (Reach 2 and 3), as opposed to individual sites and a small sample size (n=5) was available for analysis (Section 3.7): • a significant relationship was noted between Coho outmigration abundance and percent (%) embeddedness; • total number of redds decreased as percent (%) silt increased, not statistically significant and; • Coho smolt to fry outmigration abundance in Reach 2 decreased as the percentage (%) of silt increased, not statistically significant. Although data was limited results suggest that fish productivity is negatively correlated with fine sediments (increased embeddedness and silt).
	Are substrate particle size fractions in the Coquitlam river comparable to literature biostandards for successful salmon incubation?	Percent (%) particle sizes within the Lower Coquitlam River were comparable to available literature on salmonids and suitable substrate for successful salmon incubation at all sites (Section 3.7).

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* (COQMON #8) on salmonid spawning and rearing habitat of the Lower Coquitlam River from 2012 to 2017 and provide a final report on results in 2018. This *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 was to produce information required for future water planning processes on the Coquitlam-Buntzen system in support of a Coquitlam Dam release regime within the criteria 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. This is the final report (2012-2017) for *The Lower Coquitlam River Substrate Quality Assessment* (COQMON #8) monitoring program.

Initially, the primary objective of COQMON #8 was to evaluate the effectiveness of "flushing flows" as outlined in the *LB1 WUP Monitoring Program Terms of Reference* (BC Hydro, 2006) to increase fish productivity through improved substrate quality in the Lower Coquitlam River. Flushing flows as defined in the T*erms of Reference,* did not occur during the current monitoring program (2012–2017). The *Terms of Reference* have been revised with several addenda, with the most recent, *Addendum 3 (* BC Hydro, 2016), amending the assessments required for COQMON #8 to evaluate the effectiveness of flow events occurring in the Coquitlam River (and not specifically flushing flows) to improve fish habitat quality. The flow regime on the Coquitlam River assessed between 2012 and 2017 included natural river flows and elevated flows generated by Coquitlam Dam releases of 30-50 m^3/s which did not meet yet approached "flushing flows" as defined in the *Terms of Reference* and were referred to as regulated high flow events in the assessment.

This chapter (Chapter 1) outlines study objectives and summarizes important information on river morphology, ecology and substrate of the study area within the Lower Coquitlam River. Chapter 2 provides an overview of study design and methodology for field and laboratory work and Chapter 3 includes results and discussion. Chapter 4 provides a summary and recommendations, with references in Chapter 5. Appendices at the back of this report provide figures (Appendix 1), charts (Appendix 2), tables (Appendix 3), photographs (Appendix 4), laboratory and raw data (Appendix 5), *Safety and Environmental Management Plan* (Appendix 6), a sample of field forms (Appendix 7) and the G3 2016 report on comparison of freeze-core versus modified Hess sampler methodologies (Appendix 8).

1.1 Background

1.1.1 Coquitlam River Watershed Physiography

The Coquitlam River watershed is one of many watersheds on the north shore of the Fraser River in southwestern British Columbia. The river drains approximatly 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 lower watershed. The lower watershed drains approximately 79 km^2 and includes at least thirty (30) watercourses that drain into the Lower Coquitlam River. The Lower Coquitlam River is approximately 18 km long from Coquitlam Lake Dam to Fraser River, near the estuary on Georgia Strait (McPhee, 2003; Figure A1-1, 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 which were deposited during late Quaternary glacial advances (Armstrong, 1990; NHC, 2012). Presently, downstream of Galette Avenue towards Lougheed Highway channel substrate is characterized by glacial till overlain by 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 majority 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 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, 2018). 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 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 sediment to the river (NHC, 2007).

1.1.2 Coquitlam River Watershed Hydrology

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 relevant), runoff from surface flows, storm water 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 influences on watershed hydrology (McPhee, 2003).

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) 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 remove 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 Lower Coquitlam River Watershed Climate

The Lower Coquitlam River watershed is characterized as a coastal western hemlock (CWH) biogeoclimatic (BEC) zone and west coast maritime climate. Pressure systems arising from a peak in the sea level pressure distribution, travel in an easterly direction, and 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. Precipitation is greatest annually between November and March (McPhee, 2003).

1.1.4 Lower Coquitlam River Fish Resources

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*]), char (Dolly Varden [*Salvelinus malma*] and bull trout [*Salvelinus confluentus*]) use the Lower Coquitlam River to complete their life cycles (McPhee, 2003). Sockeye Salmon (*Oncorhynchus nerka*) inhabited the river in the past and efforts are being made to restore this species (Coquitlam River Watershed, 2018).

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, 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 post hatch 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 with 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.

Treatment 1 was to adhere to the release schedule from two (2) fully open fish valves (2FVC), whereas Treatment 2 was to adhere to the alternate release schedule described as “Share the Pain #6” (STP6). Treatment 2 was implemented following dam seismic upgrades completed 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, 2016). The monitoring program objective was to provide necessary information required for future water planning processes and to 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, monitoring focused on 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*: timing and magnitude of flow releases from Coquitlam Dam evaluated in terms of habitat benefits; and,
- *Substrate quality*: fine sand content and availability of substrate suitable evaluated for spawning and overwintering.

The CC recognized that improving substrate quality could potentially 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 could potentially 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 per year, coinciding with peak inflows from Or Creek to produce total flows of 70-100 m^3/s for 3 to 5 days, 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 a potential correlation between fish productivity and substrate quality (i.e. the objectives of this study).

The original intent of the program was to assess the effectiveness of a defined flushing flow with an annual 'opportunistic' flow from Coquitlam Dam to improve fish habitat quality through substrate size. No defined flushing flows had occurred since the Water Use Plan (WUP) had begun (2005); therefore, in 2015 an amendment (TOR; addendum 3) was created evolving the program to assess the effectiveness of managed and unmanaged flows on improving fish habitat quality. The program evaluated substrate size distribution and habitat quality objectives to address specific management questions as part of one of eight (8) studies under the Coquitlam River WUP.

1.3 Program Requirements & Objectives

1.3.1 Management Questions

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

Question: Are flow events that are occurring in the Lower Coquitlam River effective at improving fish habitat quality in the Lower Coquitlam River?

The procedures used to assess the relationships between substrate compositions, habitat quality and fish productivity in the Lower Coquitlam River involved the review of fish productivity results in conjunction with substrate quality monitoring data. Substrate quality indicators and methods of data collection vary according to dominant channel and substrate forms; therefore, for the purpose of this program and to maintain interpretive consistency, substrate quality using particle size analysis and dry weight was applied as well as secondary indicators (i.e., embeddedness). High tributary inflows, leading to elevated flows, occur naturally in the Lower Coquitlam River. Elevated flow can also be generated by additional flow releases from Coquitlam Dam coinciding with high tributary inflows to the Lower Coquitlam River, referred to as "regulated high flows" (or "regulated flushing flows" as defined in the *Terms of Reference* for specified duration and flow level [Section 1.2]) and were recommended by *Fisheries Technical Committee*. Coquitlam River discharge varied seasonally during the sampling Program (2012 to 2017) and regulated high flows were part of the flow regime assessed.

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 was conducted by assessing potential correlations between substrate quality data and fish productivity and comparing monitoring results with established biostandards (i.e., relating spawning and rearing success to substrate quality in the literature).

1.3.2 Key Water Use Decision Affected

Initially one objective of the COQMON #8 Lower Coquitlam River Substrate Quality Assessment study in the *LB1 WUP Monitoring Program Terms of Reference* (BC Hydro, 2006) was to assess the effectiveness of “flushing flow” provisions in the Water Use Plan (WUP) to enable BC Hydro to provide recommendations to re-instate, modify or eliminate the flushing flow provisions in the WUP following this 2018 Substrate Quality Assessment report. 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, 2001). 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 opportunistically every year 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 (BC Hydro, 2006). Flows greater than 70 m^3/s occurred in the Lower Coquitlam River during the study period (2012 to 2017); however, were of shorter duration (<3 days) than defined for a flushing flow event. Given that flushing flows had not occurred since 2005, in 2016 an amendment was made (*Addendum 3* of the *LB1 WUP Monitoring Program Terms of Reference;* BC Hydro, 2016) to the scope of work for this monitoring program to assess the effectiveness of “flow events” (rather than flushing flows) occurring on the Coquitlam River to improve fish habitat quality. Elevated flows in the Coquitlam River generated by releases of 30-50 m^3/s from the Coquitlam Dam were noted and part of the flow regime on the Coquitlam River assessed between 2012 and 2017.

BC Hydro is to recommend a base flow regime to the *Water Planning Committee* based on the results from this and other monitoring studies (COQMON #1 to #7), including evaluation of both flow releases (Treatment 1 and Treatment 2), outlined in the Coquitlam-Buntzen WUP (BC Hydro, 2005) in several of the studies. The flow recommendations are to 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). Recommendations from BC Hydro will be vetted through the Monitoring Committee to ensure it has their understanding and support. The study presented in this report (2012-2017) was undertaken during Treatment 2 only; previous work for COQMON #8 (2006-2011) was conducted using different and unsuccessful methodologies (photogrammetric method) and results are not directly comparable.

1.3.3 Sampling Timing

Monitoring of substrate quality was conducted during five (5) monitoring years (November 2012-June 2017) over three (3) seasons (autumn, winter and spring) annually to assess substrate quality coinciding with the start of the salmon spawning period, mid-incubation period and end of emergence, though environmental factors such as river velocity also influenced timing of sampling events.

1.4 Past Results & Recommendations

1.4.1 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 A1-2, Appendix 1). Excavation pits remained visible in several gravel bars during the current study period, providing evidence that insufficient flows for bulk sediment transport occurred (NHC, 2012).

1.4.2 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 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 (through freezing to the core) 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.

In 2016, during the current project, a comparison of the modified Hess stream bottom sampler versus a Tri-tube freeze-corer (report presented in Appendix 8) was undertaken as requested by the BC Ministry of Environment. The tri-tube freeze corer was efficient within a specific particle size; however, the method was not recommended for substrate sampling in the Lower Coquitlam River given the limited ability to represent all substrate classes in the river bed, required level of effort, ability to address management questions, safety, sample size, processing and cost considerations (G3, 2016).

2.0 METHODS

2.1 Review of Existing Information

Following a project start-up meeting between G3 and BC Hydro representatives in October 2012 to discuss project schedule and milestones. 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 & Field Safety Plan

G3 developed a project-specific *Safety and Environmental Management Plan* in accordance with BC Hydro Standard Operating Procedures (SOPs) and Occupational Safety and Health (OSH) guidelines. The *Safety and Environmental 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 an 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 NHC (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 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 (BCMOE, 2008) with results reported herein (Section 3.1).

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 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 Water Level Loggers

One (1) HOBO U20 water level logger was installed near the substrate in each of Reach 2b (Site 3) and Reach 3 (Site 5) to capture hourly fluctuations in local water depth and one (1) logger was installed for barometric compensation at Reach 3 (Site 5). Data were uploaded during each monitoring event using Onset's HOBO Waterproof Shuttle to G3's project database. The data logger in Reach 2b (Site 3) went missing prior to the October 2013 sampling event and was replaced in November 2014.

2.6.3 Precipitation Data

Precipitation data were obtained from *Environment and Climate Change Canada* (ECCC) weather station *Coquitlam Como Lake Avenue* from January 2012-June 2017, reviewed and compiled for comparison with river flow data.

2.6.4 Coquitlam Dam Release Data

Coquitlam Dam releases (m^3/s) to the Lower Coquitlam River from November 2012 to June 2017 were obtained from *BC Hydro*, reviewed and compiled for comparison with river flow data.

2.7 Substrate Quality Sampling

2.7.1 Timing of Sampling

Monitoring of substrate quality was conducted during five (5) years in three (3) seasons, autumn (September to November), winter (December to early March) and spring (May and early June; Table 2-1). Sampling events were intended to coincide with the start of the salmon spawning period, mid-incubation period and end of emergence, though other environmental factors (e.g. river flow) influenced timing of sampling events. 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) was required for safe access and successful sampling. Real-time water depth and discharge data at WSC Station 08MH002 was monitored in days leading up to the anticipated sampling events and timing of sampling adjusted as required to ensure a successful sampling event.

2.7.2 Field Measurements & Substrate Sampling (2012-2017)

Evaluation of substrate quality involved the collection of surficial and subsurface substrate samples using a modified Hess sampler and associated measurements and field observations.

Field collected data and observations were recorded on a project-specific *In situ Sediment Data Form* (Appendix 7). Site and sample characteristics were documented, including sample ID, GPS coordinate for each sample, dominant and subdominant substrate type, percent (%)

embeddedness, measure of D_{50} and $D_{95,}$ sampler depth of penetration (to a maximum of 6.5 cm), 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.

Table 2-1: Sampling Start Date for Each Season in the Five Monitoring Years (2012-2017)

Season	Monitoring Years				
	1	2	3	4	5
Autumn	Nov 15 2012	Oct 15, 2013	Sept 4, 2014	Oct 20, 2015	N/A
Winter	Dec 20, 2012 Feb 13, 2013	Jan 6, 2014	Jan 22, 2015	Dec 22, 2015 Feb 3, 2016	Dec 15, 2016 Mar 8, 2017
Spring	May 7, 2013	May 29, 2014	May 26, 2015	May 4, 2016	June 6, 2017

2.7.3 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 and monitoring site were also taken. Turbidity and water velocity were measured at each site and recorded on the project specific *In situ Sediment Data Form* (Appendix 7).

Dominant & Subdominant Substrate Type

Dominant substrate types were 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, cobble or boulder). Similarly, subdominant substrate type was determined as the second most abundant particle size. Substrate dominance was determined by the same field personnel throughout a given 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 each field personnel and averaged.

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, then 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* to the closest millimeter. D_{95} or D_{50} determination was done by the same field personnel 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 included in each individual sample pail for further confirmation of sample identification. Site photos were taken to capture images of all four cardinal directions and substrates for each sample. Any relevant observations of sites and surrounding areas were recorded.

Turbidity

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

Water Velocity

Water velocity was 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.

2.7.4 Substrate Sample Collection

A modified Hess stream bottom sampler (0.33 m wide and 0.4 m high with a purposer-made 20 µm mesh sock) was used to collect surficial and subsurface samples at six (6) sites within the Lower Coquitlam River. The Hess was placed at each sampling location along established transects (upstream and downstream transects) and the GPS location of each replicate (three [3] per transect) recorded on the field form. 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 as discussed in Section 2.7.3. The mesh screen was aligned upstream to enable water flow through the sampler with the modified 20 µm mesh sock trailing downstream.

Surficial Samples

For the purposes of this sampling program, surficial substrate is defined as the particles on the surface of the river bed which are easily dislodged and transported by river flow. Surficial samples for this program were comprised of dislodged particles collected in the Hess sampler mesh collection bag (20 µm mesh) following a standardized stirring of the substrate within the confine of the Hess sampler. 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 then placed in a cooler for transport to the laboratory with accompanying Chain of Custody (COC) form.

Subsurface Samples

Subsurface samples were defined as material remaining on the river bed after the collection of the surficial sample (to a depth of 6.5 cm within the confine of the Hess sampler). Subsurface samples were collected in pre-labelled sample pails (with external and internal sample identification codes) manually (larger substrate) and using the trowel. Following drying of the samples, subsurface samples were separated in two (2) size groups: particles <10 mm and coarse particles (>10 mm) and analyzed separately.

2.7.5 Substrate Sampling Following High Flow Events

Sampling following ‘high flow’ events were conducted when river flow in the Coquitlam River decreased to a safe level (see Section 2.7.1), using the same methods done for the regular substrate quality assessment sampling described above. Three (3) sampling events followed high flow events (approximately 70 m^3/s) during this sampling program (2012 to 2017): December 20, 2012, December 22, 2015 and February 3, 2016.

2.8 Sample Processing & Analysis

For each sampling event (autumn, winter and spring for 5 years; Table 2-2) a total of 36 surficial and subsurface 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, surficial and subsurface samples were processed separately. Laboratory analyses for the surficial samples and subsurface fraction <10 mm were conducted by Maxxam Analytics [2012 to 2015] and Caro Analytical Services [2016 and 2017] both CALA accredited laboratories.

2.8.1 Surficial Samples

Surface fines collected in-stream in the Hess sampler mesh sock were analyzed for percent (%) particle size distribution (texture analysis by hydrometer) and dry weight (2015 to 2017). Labelled and inventoried, samples were shipped to the laboratory in coolers with accompanying Chain of Custody (COC) forms.

2.8.2 Subsurface Samples

Subsurface samples collected in-stream were placed into pails and transported to G3’s warehouse for processing. Samples were inventoried and checked against COCs upon receipt. Samples were drained and dried on polyethylene sheets in individual cells on custom-built drying racks (Photo A2-7; Appendix 4). Sample cells were mapped for process inventory and left to dry completely at ambient temperature.

Dry samples were weighed (total dry weight), photographed with sample-specific photo ID cards, then sieved through a series of mesh sizes 10 mm, 16 mm, 32 mm, and 64 mm (Photo A2-9 to A2-12; Appendix 4). The fine particle fraction (<10 mm) was placed in pre-labelled sample bags, weighed then sent to the laboratory for analysis of percent (%) particle size distribution (clay, silt, sand and gravel) using sieve and texture analysis (by hydrometer). Samples were shipped to the lab in coolers with accompanying COC form. The coarse particle fraction (>10 mm) was weighed, sorted by grain size (Wentworth, 1922; Table 2-2) and particles counted for each class (pebble count; Wentworth, 1922).

Table 2-2: 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	Cobble
90-128	-6.49 to -7.0	Medium Cobble	
128-256	-7.0 to -8.0	Large Cobble	
>256	< -8.0	Boulder	Boulder

2.9 Data Entry & Archiving

Data entry was subjected to rigorous QA/QC protocols prior to archiving. 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. Project databases were archived and backed up regularly on G3's server.

2.10 Data Assessment & Analysis

Percent (%) particle size distribution and dry weight data collected at each site (6 sites), in three (3) seasons (autumn, winter and spring) for five (5) monitoring years were assessed for surficial, fine subsurface (<10 mm) and coarse subsurface (>10 mm; pebble count) samples separately. Monitoring years were as follows:

- Year 1: November 2012 to May 2013;
- Year 2: October 2013 to May 2014;
- Year 3: September 2014 to May 2015;
- Year 4: October 2015 to May 2016;
- Year 5: December 2016 to June 2017.

Statistical analyses were carried out in JMP and R statistical software. Surficial, subsurface and pebble count data were tested for significant differences using 3-way Analysis of Variance (ANOVA; Year, Season, Site). A 3-way ANOVA was conducted to determine if there were relationships between the three (3) independent variables (Year, Season, Site). One-way ANOVA tests were applied to each factor (Year, Season, Site), to assess if there were significant differences with each factor. Subsequent post-hoc Tukey's HSD (Honest Significant Difference) tests were conducted following the one-way ANOVA to assess differences of means (Year, Season, Site) where differences occurred (i.e. what year, season or site was different). Linear and best fit modeling was performed on substrate data (percent [%] clay, silt, sand or gravel) and secondary indicators (embeddedness, turbidity, velocity) compared to Coquitlam River discharge data one (1) week, one (1) month and four (4) months (seasonal) before sediment sampling events in 2012 to 2017, to determine if flow rates preceding sample collection had a significant influence on percent substrate composition. Correlations between yearly Coho and Steelhead outmigration abundance (COQMON #7) and Steelhead redd counts (COQMON #3), for overlapping locations with COQMON #8 were performed.

In Year 4 (Oct 2015 to May 2016), percent (%) gravel was absent from the laboratory particle size analysis for subsurface particles <10 mm for October 2015, December 2015 and February 2016 with the exception of twelve (12) samples (10 from February 2016, 1 from October 2015 and 1 from December 2015). Whole sample dry weight for subsurface particles <10 mm was available for all samples. Percent gravel, sand, silt and clay were estimated using linear regression models using other years and the 12 samples from Year 4. Percent error was calculated using percent (%) gravel for the twelve (12) available samples from Year 4 and calculated as 11.616%. When Year 4 generated values were removed from the ANOVA analyses results were identical or very similar, therefore generated values for Year 4 were included in further analysis for the subsurface fraction <10 mm.

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 a database and rigorously verified prior to inclusion. If errors exceeding 5% of data set were encountered, then the entire data set was re-examined.

2.11.1 Laboratory QA/QC

Maxxam Analytics and Caro Analytical Services (Burnaby, BC and Richmond, BC, respectively), CALA accredited laboratories, 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 5). Results are presented in Section 3.8.

3.0 RESULTS & DISCUSSION

3.1 Sampling Site Descriptions

3.1.1 Site 1

Site 1 was accessed from Westwood Park, Coquitlam and is located in Reach 2a of the Lower Coquitlam River (Table 3-1). 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%). Adult pink salmon have been observed at this site (October 2013).

3.1.2 Site 2

Site 2 was located at in Reach 2b of the Lower Coquitlam River and is accessible through Galette Park at the north end of Galette Avenue, Coquitlam (Table 3-1; Figure A2-2, 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 in October 2013. 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. Adult salmon were observed at this site in October 2013 and 2015. Juvenile Pink salmon were observed at this site (June 2017).

3.1.3 Site 3

Site 3 was located at in Reach 2b of the Lower Coquitlam River, adjacent to Pipeline Rd, Coquitlam (Table 3-1; Figure A2-3, Appendix 1). The upstream and downstream transects were 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. Main channel width was 35 m at the monitoring site with a 2% instream gradient in October 2013. 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. Pink salmon and piscivorous species (Kingfisher) were observed at the monitoring site (October 2013).

Site 3 was 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; however problems have arisen historically during rainfall events (Urban Systems, 2009). The turbidity levels in the current program agree with previous work, noting high turbidity (Chart A6-1, Appendix 2; Table A5-1, Appendix 3).

3.1.4 Site 4

Site 4 was located in a side channel of Reach 2b in the Lower Coquitlam River, accessed from Upper Coquitlam River Park (Table 3-1; Figure A2-4, Appendix 1). The site is approximately 350 m downstream of Coquitlam Sand and Gravel staging yard, across from the gravel operations to the west of Pipeline Rd. The upstream and downstream transects were 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 were observed in October 2013, as well as unidentified fry in February 2017.

Site 4 was 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, created in 1994 and with the creation of a 50 m flood protection dyke, excavation of a 95 m outlet channel and a flood-limiting side channel 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 Site 5

Site 5 was located in Reach 3 of the Lower Coquitlam River, in riffles along the edge of the main river bed (Table 3-1; Figure A2-5, Appendix 1). Access to the site is from the shoulder of Pipeline Road. The upstream and downstream transects were 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, pink salmon and fertilized eggs have been observed at in October 2013. Pink and chinook and/or Coho salmon parr were observed in June 2017.

3.1.6 Site 6

Site 6 was located in Reach 3 of the Lower Coquitlam River (Table 3-1; Figure A2-6, 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 were 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 in October 2013. Instream cover was provided by boulders (30%), overhanging vegetation (15%), small woody debris (5%) and large woody debris (2%). Coho, chum and chinook salmon were all observed at the site in October 2013. In May 2013 50+ chinook and Coho parr were observed at Site 6. In March 2017 unidentified yolk-sac larvae and alevin were observed as well as in June 2017 salmon eggs and Coho parr were observed at Site 6.

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.

Table 3-1: Site Coordinates for COQMON #8

Site	Reach	Location	Latitude	Longitude
1	2a	Near Trans-Canada Trail Footbridge	49° 16' 35.4937" N	122° 46' 34.7520" W
2	2b	Near Galette Park	49° 18' 13.8384" N	122° 46' 10.2540" W
3	2b	Adjacent to Pipeline Road Downstream of gravel operation	49° 18' 50.0579" N	122° 46' 9.3432" W
4	2b	Near Upper Coquitlam River Park	49° 19' 31.0945" N	122° 46' 15.9816" W
5	3	Adjacent to Pipeline Road	49° 20' 10.3055" N	122° 46' 7.6440" W
6	3	Near Al Grist Memorial Hatchery	49° 20' 15.1440" N	122° 46' 16.1724" W

3.2 Lower Coquitlam River Precipitation

The Lower Coquitlam River receives contributions of rainfall and snowfall in the annual precipitation budget (Chart A1-1 Appendix 2). Total precipitation in the Lower Coquitlam River was, on average, 1,762 mm for autumn, winter and spring (Table A2-1, Appendix 3). Year 2 (2013-2014) had the least amount of annual total precipitation (1,531 mm), while Year 1 (2012-2013) had the most (1,932 mm). December 2015 (374 mm), November 2016 (352 mm) and November 2014 (330 mm) were the three (3) highest total precipitation months throughout the five (5) monitoring years (Chart A1-2, Appendix 2). Annual average daily discharge was compared to average monthly total precipitation and showed a similar trend. When precipitation increased, daily river discharge increased (Chart A1-2, Appendix 2).

3.3 Lower Coquitlam River Hydrometric Data

3.3.1 Daily Discharge

Lower Coquitlam River discharge was assessed using the Water Survey of Canada (WSC) historic and real-time hydrometric data measured at the streamflow gauging Station 08MH002 (Coquitlam River at Port Coquitlam). Mean daily water discharges in the Lower Coquitlam River during the monitoring program (October 2012 to June 2017) were depicted on Chart A2-1, Appendix 2.

Mean daily discharge in the Lower Coquitlam River was highest in Year 4 (2015 to 2016; 12.33 m^3/s) and lowest in Year 2 (2013 to 2014; 8.03 m^3/s; Table A2-2, Appendix 3). Mean daily discharge in the Lower Coquitlam River and Coquitlam Dam mean daily releases (Table A2-3, Appendix 3) were greatest in autumn for all monitoring years (13.55 m^3/s [river flow], 7.14 m^3/s [dam release]) and lowest in spring (6.55 m^3/s [river flow], 2.78 m^3/s [dam release]). Average river daily discharge and dam release data throughout the monitoring years were significantly positively correlated (correlation= 0.82, R^2= 0.67, $p<0.00001$; Chart A2-2, Appendix 2).

For each monitoring year, mean daily flows preceding each substrate sampling event were compiled and depicted for each season (autumn, winter and spring; Charts A2-3 to A2-5, Appendix 2). Timing of scheduled sampling events were adjusted based on water levels to ensure safe and successful sampling (see Section 2.7.1). Variability in timing, quantity and magnitude of discharge spikes existed between years. In 2012, pulses between 50-70 m^3/s occurred in October and November, with pulses in excess of 70 m^3/s occurring in October, 2012. In 2014, pulses above 50 m^3/s occurred from November 4 to November 10 and December 9 to December 16. In 2015 pulses >50 m^3/s occurred from November 12 to 17 and December 9 to 18. In 2016, pulses between 50-70 m^3/s occurred from January 28 to February 1 and March 11 to 15. High flow events were influenced by Coquitlam Dam releases.

Table 3-2: High River Flow Periods with influences from Coquitlam Dam Discharges

Year	Date	Duration (days)	Average River Discharge (m^3/s)	Average Dam Releases (m^3/s)
2012	Oct 27th to Nov 8th	14	38.8	21.5
2014	Nov 4th to 10th	7	52.3	30.2
2014	Dec 9th to 16th	8	58.0	36.5
2015	Nov 12th to 17th	6	58.7	30.2
2015	Dec 9th to 18th	10	52.8	33.9
2016	Jan 28th to Feb 1st	5	56.3	32.4
2016	Mar 11th to 15th	5	53.0	36.6

Sampling was conducted after high flow events in November 2012 (approximately 30 m^3/s to 70 m^3/s over an extended period in October and November 2012), in December 2015 (approximately 40 m^3/s to 70 m^3/s) and in February 2016 (approximately 30-70 m^3/s (Charts A2-3 and A2-4, Appendix 2).

3.3.2 Daily Water Level

Data available for Site 3 and 5 were complete from January 2015 (Year 3) to March 2017 (Year 5); therefore, this data was used to compare water depth with river discharge. Daily water depth was significantly positively correlated with daily river discharge (R^2=0.91, $p<0.05$ [Site 5]; R^2= 0.95, $p<0.05$ [Site 3]; Chart A3-1, Appendix 2). Water depth reached a maximum of approximately 1.2 m at Site 5 (December 2015, January 2016 and November 2016) and a low of approximately 0.1 m at Sites 3 and 5 during summer 2016 (Chart A3-1, Appendix 3).

3.4 *In Situ* Field Parameters

In situ field parameters, used to support the substrate quality assessment, included measurements of embeddedness, D_{50} (size of a particle larger than 50% of all substrate material in Hess sampler), D_{95} (size of a particle larger than 95% of all substrate material within the Hess sample), turbidity and water velocity.

3.4.1 Embeddedness

Embeddedness ranged from 0% to 100% in the Lower Coquitlam River during the monitoring program. Mean embeddedness was comparable among seasons ranging from 39% (winter), 41% (spring), 47% (autumn) for all monitoring years and all six (6) sites (Table A3-2, Appendix 3; Chart A4-1 and A4-2, Appendix 2). Site 4 (Year 4; 2015 to 2016) had the greatest mean embeddedness (55%) and Site 3 (Year 3; 2014 to 2015) had the least (23%; Table A3-1, Appendix 3; Chart A4-2, Appendix 2). Differences in river morphology at Sites 3 and 4 may be attributable to differences at these sites. Site 3 was located in the main channel downstream of the active gravel excavation operations whereas Site 4 was located in a side-channel further upstream.

A 3-way ANOVA, done for embeddedness, showed statistically significant differences between Year ($p<0.0001$), Season ($p<0.0001$) and Site ($p<0.0001$). Significant interactions effects, meaning relationships with one another, were identified between Season and Year ($p<0.0001$), as well as between Year and Site ($p<0.0001$).

One-way ANOVA and *post-hoc* Tukey's HSD test done for embeddedness, noted that Year 3 (2014 to 2015) and 5 (2016 to 2017) were significantly lower than Year 1 (2012 to 2013), 2 (2013 to 2014) and 4 (2015 to 2016; $p<0.01$ to $p<0.0001$), autumn was higher than winter ($p<0.01$) and, Site 3 was lower compared to Sites 1, 4 and 5 ($p<0.05$ to $p<0.0001$).

Embeddedness was noted to be lower in winter during high rainfall and river flow and in spring after high rainfall, indicating embeddedness decreased during higher managed and unmanaged high flows. Higher discharges were generally released from Coquitlam Dam during the winter season adding to the increase in river flows (Table 3-2). In autumn after the dry low flow season embeddedness was higher.

3.4.2 D_{50} & D_{95}

D_{50} (size of a particle larger than 50% of all substrate material in Hess sampler) was comparable among seasons, ranging from 26 mm (coarse gravel; autumn and winter; Year 3; 2014 to 2015) to 38 mm (very coarse gravel; spring; Year 5 (2016 to 2017); Table A4-3, Appendix 3; Chart A5-1, Appendix 2). Sites 2 and 3 (Year 5) had the greatest mean D_{50} (47 mm, very coarse gravel) and Site 4 (Year 4) had the smallest (23 mm, coarse gravel; Table A4-1, Appendix 3; Chart A5-1, Appendix 2). Maximum D_{50} was noted at Site 3 in winter 2016 (112 mm, medium cobble) and minimum D_{50} (5 mm, fine gravel) at Site 4 (autumn 2015).

D_{95} (size of a particle larger than 95% of all substrate material within the Hess sample) was comparable among seasons, ranging from 77 mm (small cobble; winter Year 2 [2013 to 2014]) to 89 mm (small cobble; autumn Year 1 [2012 to 2013]) for all monitoring years and at all six (6) sites (Tables A4-3, Appendix 3; Chart A5-4, Appendix 2). Site 3 had the highest mean D_{95} (102 mm, medium cobble) and Site 4 the smallest (67 mm, small cobble) over all monitoring years (Table A4-2, Appendix 3; Chart A5-3, Appendix 2). Maximum D_{95} was noted at Site 2 in autumn 2012 (170 mm, large cobble) and minimum D_{95} at Site 3 in autumn 2015 (19 mm, coarse gravel). Generally, mean D_{50} and D_{95} were comparable across all sites and seasons for all monitoring years (Charts A5-1 to A5-4, Appendix 2).

3.4.3 Turbidity

During all years monitored mean turbidity was lowest in the spring of Year 3 (2014 to 2015; 0.41 NTU) and highest in the winter of Year 2 (2013 to 2014; 2.49 NTU; Table A5-2, Appendix 3; Chart A6-1, Appendix 2). Mean turbidity across six (6) sites ranged from 0.29 NTU (Site 5; Year 2) to 4.19 NTU (Site 3; Year 3; Table A5-1, Appendix 3; Chart A6-2, Appendix 2). Site 3 was most turbid of all sites over all years, reaching a high of 10.6 NTU (January 2014), attributed to its location downstream of an active gravel excavation operation. Turbidity measures as low as 10 NTU may have negative effects on salmon (Berg, 1982; Sigler *et al*., 1984; Berg and Northcote, 1985).

A 3-way ANOVA done for turbidity showed statistically significant differences between Year ($p<0.05$), Season ($p<0.001$) and Site ($p<0.0001$). Significant interactions effects, meaning relationships with one another, were found between Season and Site ($p<0.01$) as well as between Year and Site ($p<0.05$).

A One-way ANOVA and *post-hoc* Tukey's HSD test showed no statistically significant differences between sampling years for turbidity. Winter was higher and statistically more significant than spring ($p<0.05$). Site 3 was statistically higher than other sites ($p<0.05$ to $p<0.0001$). Site 3, downstream of gravel mining operations (as noted during winter sampling events in 2014 and 2015) had increased turbidity compared to upstream sites. On January 14, 2014 and January 22, 2015 turbidity at Site 3 (10.46 NTU and 10.47, respectively) may have exceeded *British Columbia Approved Water Quality Guidelines* for turbidity (change from background of 8 NTU at any one time for a duration of 24 h in all waters during clear flows or in clear waters [BCMOE, 2001]) where measured levels were maintained for a 24 hour duration. Turbidity upstream of Site 3 in January 2014 and 2015 were 0.30 NTU and 0.9 NTU, respectively.

3.4.4 Water Velocity

Mean water velocity in all monitoring years was measured at each upstream and downstream location with data summarized by site and monitoring year (Chart A7-1, Appendix 2; Table A6-1, Appendix 3). Mean yearly water velocity was consistently highest at Site 1 compared to other sites, except in Year 1 (2012 to 2013; Table A6-1, Appendix 3 and Chart A7-1, Appendix 2). Mean velocity ranged from 0.36 m/s (Site 6) to 0.53 m/s (Site 1) for all monitoring years (Table A6-1, Appendix 3). Velocity data is provided in Appendix 5.

A 3-way ANOVA was conducted for velocity and showed statistically significant differences between Year ($p<0.0001$) and Site ($p<0.0001$). No significant interactions effects (relationships between year, site and season) were identified.

One-way ANOVA and *post-hoc* Tukey's HSD tests for velocity indicated that Year 1 (2012 to 2013)was statistically higher than Year 2 (2013 to 2014), 3 (2014 to 2015), 4 (2015 to 2016) and 5 (2016 to 2017; $p<0.0001$), Year 3 was lower than Year 4 and 5 ($p<0.01$) and winter was higher than spring ($p<0.01$). Site 1 was statistically higher than Sites 4 and 6 ($p<0.01$).

3.5 Substrate Particle Size Distribution

Particle size distribution for all sites over all five (5) monitoring years were compiled and analyzed. Tri-annual sampling events (autumn, winter and spring) were conducted for each monitoring year. Six (6) sites were assessed in the Lower Coquitlam River and at each site three (3) replicate samples collected along two (2) transects. For each sampling event, a total of 36 surface surficial and subsurface (<10 mm and >10 mm) samples were analysed for percent (%) particle size distribution. Particle size data were compared between sites, seasons and years, and with flow conditions, prior to sampling events.

3.5.1 Surficial Particles

During all years monitored (November 2012 to June 2017), surficial samples were dominated by sand (0.0625 mm to 2 mm; Charts A8-1 to A8-3, Appendix 2 and Tables A7-1 to A7-3, Appendix 3). Overall, six (6) sites and all seasons, mean sand content was 75.7%, mean silt content (0.0039 mm to 0.0625 mm) 17.2% and mean clay content (0.0625 mm to 0.0039 mm) was 7.5% (Table A7-1, Appendix 3 and Chart A8-1, Appendix 2).

A 3-way ANOVA was done for surficial substrate and identified statistically significant differences between Year ($p<0.0001$), Season ($p<0.0001$) and Site ($p<0.0001$) for sand, silt and clay. Significant interactions effects, relationships with one another, between Season and Year ($p<0.0001$) and Year, Season and Site ($p<0.0001$) were noted for sand, silt and clay. Significant interactions/relationships between Year and Site ($p<0.0001$) were noted for silt and clay.

A one-way ANOVA and *post-hoc* Tukey's HSD test indicated that sand in Year 1 (2012 to 2013) and 2 (2013 to 2014) were statistically higher than Year 3 (2014 to 2015), 4 (2015 to 2016) and 5 (2016 to 2017; $p<0.01$ to $p<0.0001$) and Year 3 was lower than all other years ($p<0.0001$). Silt fractions were statistically higher in Year 3 than all other years ($p<0.0001$) and Year 1 and 2 were lower than Year 3, 4 and 5 ($p<0.001$ to $p<0.0001$). Clay fractions were statistically lower in Year 1 than Year 3 and 5 ($p<0.05$ to $p<0.0001$) and Year 5 was significantly higher than Year 1, 2 and 4 ($p<0.05$ to $p<0.0001$).

Seasonal averages for surficial particle fractions at all sites over the duration of monitoring ranged from 73.6% (autumn) to 77.7% (winter) for sand, 15.8% (winter) to 20.2% (spring) for silt and 6.4% (spring) to 9.0% (autumn) for clay (Table A7-2, Appendix 3; Chart A8-2, Appendix 2). A one-way ANOVA and post-hoc Tukey's HSD test indicated that sand was statistically higher in winter than in autumn ($p<0.001$), silt was lower in winter than in autumn or spring ($p<0.05$ and $p<0.001$, respectively) and clay was higher in autumn than all other seasons ($p<0.05$).

Surficial particle fraction site averages over the duration of the monitoring program ranged from 65.5% (Site 3) to 79.6% (Site 5) for sand, 13.8% (Site 1) to 24.6% (Site 3) for silt and 4.8% (Site 4) to 11.3% (Site 3) for clay (Table A7-3, Appendix 3; Chart A8-3, Appendix 2). A one-way ANOVA and post-hoc Tukey's HSD test indicated no statistically significant differences in sand amongst sites, except Site 3 where sand was statistically lower ($p<0.05$ to $p<0.0001$). Silt was statistically higher at Site 3 compared to all other sites ($p<0.05$ to $p<0.0001$) and clay was statistically higher at Site 3 compared to other sites ($p<0.01$ to $p<0.0001$) except Site 6. Site 3 had a relatively higher silt-clay content and lower sand content compared to other sites, attributed to higher turbidity noted at this site in December (2016), January (2014 and 2015), February (2016) and March (2017).

3.5.2 Subsurface Particles (<10 mm)

Over the duration of the monitoring program (November 2012 to June 2017), subsurface sediments (<10 mm) were dominated by gravel (<10 mm to 2 mm) except in Year 2 (October 2013 to May 2014) which was dominated by sand (0.0625 mm to 2 mm; Charts A9-1, Appendix 2 and Table A8-1, Appendix 3). For all sites over all seasons and years, mean gravel content was 57.8%, ranging from 43.8% (Year 2) to 65.0% (Year 5), mean sand was 40.7% (33.8% [Year 4] to 52.9% [Year 2]), mean silt (0.0039 mm to 0.0625 mm) was 2.3% (2.1% [Year 1 and 5] to 2.8% [Year 2]) and mean clay (particles 0.0625 mm to 0.0039 mm) was 2.1% (2.0% [Year 4 and 5] to 2.2% [Year 3]; Table A8-1, Appendix 3).

A 3-way ANOVA was conducted for fine subsurface substrate and indicated statistically significant differences between Year ($p<0.0001$), Season ($p<0.0001$, except for silt $p=0.9$) and Site ($p<0.0001$ to $p<0.05$) for gravel, sand, silt and clay size fractions. Significant interactions effects indicating relationships between Season and Year ($p<0.0001$ to $p<0.05$), Year and Site ($p<0.0001$ to $p<0.05$), Season and Site ($p<0.0001$ to $p<0.001$), and Year, Season and Site ($p<0.0001$ to $p<0.05$) were noted for gravel, sand, silt and clay.

A one-way ANOVA and *post-hoc* Tukey's HSD test indicated that gravel was statistically lower in Year 2 (2013 to 2014) than all other years ($p<0.001$), statistically higher in Year 1 (2013 to 2013) than Year 2 and 3 (2014 to 2015), and statistically lower in Year 3 than Year 4 (2015 to 2016) and 5 (2016 to 2017). Sand was statistically higher in Year 2 than all other years ($p<0.0001$) and significantly higher in Year 3 compared to Year 1, 4 and 5 ($p<0.0001$ to $p>0.05$). Silt was statistically higher in Year 2 ($p<0.0001$) compared to all other years and statistically higher in Year 3 than Year 1 and 5 ($p<0.05$). Clay was statistically higher in Year 3 compared to Year 4 and 5 ($p<0.05$). Year 2 had the least amount of precipitation, and lowest river discharge and releases from Coquitlam Dam. These factors may have influenced an increase in fractions of sand and silt in subsurface substrates throughout Year 2.

Seasonal average of subsurface particle fractions at all sites over the duration of the monitoring program varied from 57.2% (winter) to 61.3% (autumn) for gravel, 39.2% (autumn) to 41.1% (spring) for sand, 2.3% in all seasons for silt and 2.0% (winter) to 2.1% (autumn and spring) for clay (Table A8-2, Appendix 3; Chart A9-2, Appendix 2). A one-way ANOVA and post-hoc Tukey's HSD test noted that sand was statistically higher in spring than autumn ($p<0.05$), clay was statistically higher in autumn compared to winter ($p<0.05$), and gravel and silt showed no significant differences among seasons.

Site averages of subsurface particle fractions over the duration of the program ranged from 46.9% (Site 2) to 65.2% (Site 5) for gravel, from 33.0% (Site 5) to 51.6% (Site 2) for sand, from 2.1% (Site 3) to 2.5% (Site 1) for silt and from 2.0% (Site 5 and 6) to 2.2% (Site 3) for clay (Table A8-3, Appendix 3; Chart A9-3, Appendix 2). A one-way ANOVA and post-hoc Tukey's HSD test indicated that gravel was statistically lower at Site 1 compared to Sites 3, 4 and 5 ($p<0.0001$), Site 2 was lower than all other sites ($p<0.001$) and Site 6 was significantly lower ($p<0.05$) than Sites 3, 4 and 5. Sand was statistically higher ($p<0.001$) at Site 1 than Sites 3, 4 and 5, statistically higher ($p<0.0001$) at Site 2 compared to Sites 3, 4, 5 and statistically higher at Site 6 ($p<0.05$) than Sites 3, 4 and 5. The silt fraction was statistically higher at Site 1 compared to Sites 2 and 3 ($p<0.05$) and, clay was not statistically different at any site.

A 3-way ANOVA for total sample weight of fine subsurface particles (<10 mm) showed significant differences between Year ($p<0.0001$) and Site ($p<0.0001$) and significant interaction (meaning relationships with one another) between Season and Year ($p<0.001$), Year and Site ($p<0.05$) and, Year, Season and Site ($p<0.001$). A one-way ANOVA and *post-hoc* Tukey's HSD test for total sample weight identified that Year 1 (2012 to 2013) was statistically higher than other years ($p<0.001$), Year 5 (2016 to 2017) was statistically lower than Year 1, 2 and 4 and Site 1 was significantly higher than Sites 5 and 6 ($p<0.01$).

As discussed above, subsurface samples were dominated by gravel and sand. The presence of silt and clay was minimal or at laboratory detection limits throughout all monitoring years indicating that the presence of fine sediment was minimal in the sampling area of the Coquitlam River, potentially due to the flow regime; therefore, silt and clay content was not statistically assessed further.

3.5.3 Subsurface Coarse Particles (>10 mm)

Over all monitoring years (November 2012 to June 2017), subsurface coarse particles (>10 mm) were predominantly gravel (>10 mm-64 mm; Charts A10-1 to A10-3, Appendix 2 and Table A9-1, Appendix 3). Overall, for all six (6) sites and all seasons over the five (5) monitoring years, mean medium gravel content (>10-16 mm) was 62.0%, coarse gravel (>16-32 mm) 27.8% and very coarse gravel (>32-64 mm) 7.6% (Table A9-1, Appendix 3). Mean small cobble content (>64-90 mm) was 1.5%, medium cobble (>90-128 mm) 0.8% and large cobble (>128-256 mm) 0.3% (Table A9-1, Appendix 3; Chart A10-1, Appendix 2).

A 3-way (Year, Season and Site) ANOVA of coarse (>10 mm) subsurface particles, showed statistically significant differences between years for all size classes ($p<0.001$ to $p<0.0001$), between seasons for all gravel ($p<0.001$ to $p< 0.0001$) and between sites for medium gravel, very coarse gravel and medium gravel ($p<0.001$ to $p< 0.0001$). Significant relationships (i.e. interaction effects) between Season and Year were noted on all size classes, with the exception of large cobbles ($p<0.05$ to $p<0.0001$). Significant relationships were noted between Year and Site for all size classes ($p<0.05$ to $p<0.0001$). Significant relationships for Season and Site were noted for medium gravel, very coarse gravel and medium cobble ($p<0.05$) and for Season, Site and Year for all size classes ($p<0.001$ to $p<0.0001$).

One-way ANOVA and *post-hoc* Tukey's HSD tests, done for Year, indicated that medium gravel content was statistically lower in Year 2 (2013 to 2014; $p<0.001$) than all other years, statistically higher in Year 1 (2012 to 2013) than Year 2 ($p<0.0001$) and lower than Years 3 (2014 to 2015), 4 (2015 to 2016) and 5 (2016 to 2017; $p<0.0001$), Year 4 was statistically higher than Year 1, 2 and 3 ($p<0.0001$), and Year 5 was significantly higher than 1, 2 and 3 ($p<0.0001$). Coarse gravel content in Year 1 was statistically higher than Year 3, 4 and 5 ($p<0.0001$) and Year 2 was statistically higher than Year 3, 4 and 5 ($p<0.0001$). Year 3 was significantly higher than Year 4 and 5 ($p<0.0001$). Very coarse gravel in Year 1 was statistically higher than Year 4 ($p<0.0001$) and Year 2 was significantly higher than all years ($p<0.0001$). Small cobble content was statistically higher in

Year 2 than all other years ($p<0.0001$). Medium cobble content was statistically higher in Year 2 compare to Year 3 and 4 ($p<0.05$, $p<0.001$) and Year 5 was statistically higher than Year 4 ($p<0.01$). Large cobble content was statistically higher in Year 2 compared to all other years ($p<0.0001$ to $p<0.05$) and Year 4 was significantly lower than Year 1 ($p<0.05$). Year 2 had the least amount of precipitation, and lowest daily river discharge and releases from the Coquitlam Dam. Fine and medium gravel did not flow readily down stream and the percentage of cobbles in the Hess sampler increased.

Subsurface coarse particles (>10 mm) at all six (6) sites over the duration of the monitoring program, seasonal mean medium gravel content was 62.7%, coarse gravel 27.4% and very coarse gravel from 7.5% (Table A9-2, Appendix 3). Seasonal mean small cobble content at all sites was 1.5%, medium cobble 0.7% and large cobble from 0.2% (Table A9-2, Appendix 3). One-way ANOVA and *post-hoc* Tukey's HSD tests conducted for Season indicated that medium gravel content in spring was statistically higher than autumn ($p<0.05$) and coarse gravel in autumn was statistically higher than spring and winter ($p<0.05$). Very coarse gravel in autumn was statistically higher than spring ($p<0.05$).

For subsurface coarse particles over all five (5) monitoring years and seasons, mean medium gravel content ranged from 61.3% (Site 2) to 64.9% (Site 5), coarse gravel 26.2% (Site 3) to 28.2% (Site 2) and very coarse gravel 6.6% (Site 5) to 8.0% (Site 6; Table A9-3, Appendix 3; Chart A10-2, Appendix 2). Mean small cobble content ranged from 1.2% (Site 5 and 1) to 1.8% (Site 6), medium cobble from 0.4% (Site 1) to 1.0% (Site 3) and large cobble from 0.1% (Site 1) to 0.3% (Site 2, 3 and 6) for all five (5) years and all seasons (Table A9-3, Appendix 3; Chart A10-2, Appendix 2).

Medium cobble at Site 1 was statistically lower than Sites 2, 3 and 6 ($p<0.001$) and Site 3 was significantly higher than Site 4 ($p<0.001$) as assessed using one-way ANOVA and post-hoc Tukey's HSD tests. There was no significant difference for gravel or large cobbles among sites in all years.

3.6 High Flow Events

Three (3) high flow events, associated with releases from Coquitlam Dam, occurred prior to sampling in November 2012, December 2015 and February 2016. Elevated river discharge was noted in October 27 to November 8 2012, November 4 to 10 2014, December 9 to 16 2014, November 12 to 17 2015, December 9 to 18 2015, January 29 to February 1, 2016, March 11 to 15 2016 and November 6 to 11 2016. These high flow events were regulated by flow release from Coquitlam Dam (Chart A2-2, Appendix 2).

3.7 Daily Discharge & River Substrates

3.7.1 Limitations with High Flow Data

Over the duration of the project there were three (3) substrate sampling events conducted less than 30 days following a regulated high flow event. Regulated high flows in the Lower Coquitlam River generated by releases of 30 m^3/s–50 m^3/s at Coquitlam Dam coinciding with high tributary inflow occurred opportunistically and did not follow a specific schedule. Substrate sampling was conducted when river level was eight (8) meters or less at the Water Survey of Canada (WSC) streamflow gauging station (08MH002; Coquitlam River at Port Coquitlam) to ensure safe and successful sampling events (Section 2.7.1); therefore a sufficient decrease in river flow was required for sampling and timing of sampling varied with river flow conditions. Data were limited to three (3) high flow events; however, correlations between river flow and river substrate percent (%) particle size were performed to determine potential trends on substrate quality following regulated high flow events.

3.7.2 Surficial Particles

Linear regression was used to compare percent (%) particle size and mean daily discharge averages prior to sampling seasonally (4 months prior), monthly (30 days prior) and weekly (7 days prior). Site 3 was found to be statistically significantly different than other sites in the one-way ANOVA (Section 3.5.2); therefore, the same analysis for seasonal, monthly and weekly was performed separately.

There was a statistically significant, positive correlations between sand (0.0625 mm to 2 mm) and weekly flow when the three (3) dam regulated high flow events were removed ($p=0.003$ [without Site 3], $p=0.03$ [only Site 3]); as well as monthly flow with regulated high flows removed ($p=0.04$ [no site 3]). As flow increased percentage (%) of sand also increased (Chart A11-1, Appendix 2). Conversely, statistically significant negative correlations were found between weekly flow and silt (0.0039 mm to 0.0625 mm) and weekly flow and clay (<0.0039 mm) when the three (3) regulated high flow events were removed ($p=0.01$ and $p=0.038$, respectively; [without site 3]; Charts A11-2 and A11-3, Appendix 2). Trends were not statistically significant for the three (3) regulated high flow events as data points were limited (Chart A11-3, Appendix 2). Similarly, the trend between weekly flow and surficial sample weight was statistically insignificant (correlation= 0.53, $R^2= 0.28$, $p>0.05$; without site 3). As river discharge increased whole sample weight of the surficial samples indicated an increasing trend, based on six (6) data points and weights from December 2015 to June 2017 (Chart A11-4, Appendix 2). Site 3 whole sample weights were analyzed individually and showed an opposite trend than the other sites with a slight decrease in whole weight with increasing river discharge (correlation= -0.36, $R^2=0.13$, $p>0.05$).

3.7.3 Subsurface Particles (<10 mm)

Linear regression was used to compare percent (%) gravel, percent (%) sand and total sample weight with mean daily discharge averages prior to sampling each season (using data from 4 months prior), monthly (30 days prior) and weekly (7 days prior). No clear trend was identified for percentages (%) of sand and gravel with discharge prior to sampling. Similarly, no trend was noted between flow and subsurface (<10 mm) sample weights.

3.7.4 Coarse Particles (>10 mm)

Linear regression was used to compare percent (%) particle size with mean daily discharge averages prior to sampling seasonally (using data from 4 months prior), monthly (30 days prior) and weekly (7 days prior). No statistically significant trends were noted for cobble, coarse gravel (16 mm -32 mm) or medium gravel (>10 mm -16 mm) and flow.

3.7.5 Secondary Indicators

Linear regression and qualitative diagrams were used to compare secondary indicators (i.e. embeddedness, velocity and turbidity) and mean daily discharge prior to sampling seasonally (using data from 4 months prior), monthly (30 days prior) and weekly (7 days prior).

Trends between embeddedness and flow were not statistically significant (Chart A12-1, Appendix 2). Velocity showed an increase with increasing discharge when compared to discharge on the day of sampling ($p<0.001$, $R^2=0.56$; Chart A12-2, Appendix 2). Site 1 was removed from the analysis as velocity at Site 1 was significantly different from the rest of the sites likely due to channel morphology at Site 1 being a more uniform strait channel compared to other sites located in proximity to sidebars, islands or with presence of large boulders. Pacific salmonid species actively search for spawning habitat with velocities ranging from 0.2 m/s to 0.8 m/s (Groot and Margolis, 1991; Kondolf, 1993). Coho salmon favour velocities that range from 0.3 m/s to 0.55 m/s (Gribanov, 1948) and pink salmon from 0.6 m/s to 0.8 m/s (Groot and Margolis, 1991). When velocity is too low fine sediment, such as silt and clay can build up due to colmation and smoother eggs. When velocities are too high eggs could potentially be washed away. When daily discharge increased in Lower Coquitlam River velocities also increased and tended to produce rates favourable to salmonids.

Turbidity showed no statistically significant trend with daily discharge at all sites (Chart A12-3, Appendix 2).

3.8 Salmon

3.8.1 Data Limitations

Results from the COQMON #3 and #7 monitoring projects were used to identify potential correlations with substrate composition and salmon survival and redd counts. These comparisons were limited given that the two (2) data sets were collected independently of one another, data was not collected at the exact same location and sample size was small (n=5). Data from the salmon studies were based on locations that were not directly comparable to this study; therefore, comparisons of Reach 2 and 3 were done and individual substrate sampling sites (1-6) were not used separately. Salmon program information was assessed for all years since 2005; however, substrate quality in the current program began in 2012; therefore, only a small sample size was available for comparison.

3.8.2 Sediment & Salmon

The potential effects of sedimentation in river systems and reduction of fish populations has been researched for over a century (Waters, 1995). Suitable substrate in the current study was found for spawning and rearing at all sampling sites although salmonid substrate requirements differ with species and life stage. In general salmonids spawn on substrate with gravel sizes with a size range of 2 mm to 42 mm (Kondolf, 1993). Sites in the current study were dominated by gravel (2 mm to <10 mm) at all sites in all years as assessed in samples of the subsurface fraction <10 mm and in the >10 mm fraction sites were dominated by medium gravel (>10-16 mm) also suitable substrate for salmon.

Salmon survival during incubation is dependent on many factors (i.e. habitat, water quality, predators, flow, freezing, heavy silt loads and infection ect.). High levels of suspended sediment (0 mm to 2 mm; sand, silt and clay) can lead to secondary negative effects on adult fish (i.e. avoidance, reduced feeding and growth, respiratory impairment, reduced tolerance to disease ect.) and primary negative effects (i.e. death of eggs and fry) through depletion of oxygen in water (Waters, 1995). In Tagart's research, when fine sediment (<0.85 mm) in spawning redds is >50%, survival was also greatly reduced for coho salmon (Tagart, 1984). Substrate quality thresholds for embryonic survival of steelhead showed embryonic survival was substantially reduced when a >30% fine less than 0.85 mm (sand, silt and clay) were present (Tappel and Bjornn, 1983). In the same study, steelhead and chinook salmon embryos had a survival rate of 90% when the substrate geometric mean was >10 mm (Tappel and Bjornn, 1983).

In this study, percentage of sand (<2 mm) >50% in the subsurface fraction primarily occurred in Year 2 (2013 to 2014) of the monitoring program (Chart A9-1, Appendix 2). Lowest precipitation was noted in monitoring Year 2 (October 2013 to Spring 2014; Chart A1-1, Appendix 2) and there were no high flow releases from the Coquitlam Dam. Spawning and incubation times in the Lower Coquitlam River occur from October to June, based on COQMON #7 spawning and incubation results (Figure 1.1 from COQMON #7, 2015). In the Lower Coquitlam River this likely influenced coho, chum, pink and chinook salmon though no direct correlations was identified between salmon and outmigration abundances or redd counts during COQMON #8 by G3 consulting or other COQMON studies.

In this study surficial substrate composition and weights were compared to salmon survival and redd counts for corresponding areas. No statistically significant correlations were found between surficial silt and number of redds and coho smolt to fry outmigration. Statistically insignificant negative correlations were identified between percentage (%) of silt in surficial samples compared to number of redds (correlation = -0.76, R^2= 0.58, p=0.07; Chart A13-1, Appendix 2) and coho smolt to fry outmigration abundance in Reach 2 (correlation= -0.39, R^2= 0.15, p>0.05; Chart A13-2, Appendix 2). The average percentage (%) of silt was used for the entire year as coho salmon could be most influenced from October to January during spawning and November to June during incubation. No strong correlations with subsurface fractions were identified.

Velocity results were compared to salmon survival and redd counts during the spawning and incubation period for coho and steelhead. No clear correlations were identified; however, velocities in the Coquitlam

River during G3 sampling were favorable for salmonids (Groot and Margolis, 1991). Sampling was not conducted during high flows in the Coquitlam River for safety reasons and to ensure successful sampling (see Section 2.7.1); therefore, there is no velocity data for high flow conditions for this program.

Embeddedness is the measure of the amount of interstitial space between the cobble substrate. An increase in embeddedness can have less interstitial space with cobble becoming surrounded by, covered or sunken into the silt, clay or sand. Interstitial space is a key habitat for salmonids during rearing, especially when they overwinter in the river (Chapman and McLeod, 1987). Overwintering salmon are generally seen in habitats with slow velocities, deeper depths, and more cover than the summer months (Riehle and Griffith, 1993). Slow velocities, deeper water and cover are all characteristics of interstitial space. An increase in embeddedness has been shown to decrease rearing habitat for salmonids (Bjornn and Reisser, 1991). An embeddedness greater than 50% has been shown to reduce fry in the habitat (Chapman and McLeod, 1987). In the current study program embeddedness on average remained below 50% and was generally higher in autumn after the dry season (June to September).

Coho and steelhead outmigration abundances were compared to embeddedness results during winter, prior to salmon surveys. Coho in Reach 3 showed a statistically significant negative correlation with increased winter embeddedness (correlation= -0.98, R^2= 0.97, p=0.01; Chart A14-1, Appendix 2). Steelhead outmigration in Reach 3 also showed a negative correlation with embeddedness, though not statistically significant (correlation= -0.73, R^2= 0.54, p>0.05).

3.9 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.

3.9.1 Field QA/QC

Rigorous QA/QC procedures (described in Section 2.11) were applied during field measurements, sample collection and sample processing.

3.9.2 Laboratory QA/QC

Maxxam and Caro (Burnaby, BC and Richmond, BC, respectively), followed established protocols for conducting laboratory analyses. Laboratory QC results were within the acceptable limit of ≤35% Relative Percent Difference (RPD) for duplicate samples and recovery of QC Standard (75% to 125% [clay content], 86% to 114% [percent silt] or 84% to 116% [percent sand]).

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 of the Lower Coquitlam River from 2012 to 2017. The original intent of the program was to assess the effectiveness of a defined flushing flow with an annual ‘opportunistic’ flow from Coquitlam Dam between 30 m^3/s to 50 m^3/s for a duration of 3-5 days to improve fish habitat quality through substrate size. No defined flushing flows had occurred since the Water Use Plan (WUP) had begun (2005); therefore, in 2015 an amendment (TOR; addendum 3) was created evolving the program to assess the effectiveness of managed and unmanaged flow exceeding 70 m^3/s on improving fish habitat quality. The program evaluated substrate size distribution and habitat quality objectives to address specific management questions as part of one of eight (8) studies under the Coquitlam River WUP.

Sampling was conducted over a five (5) year period and during three (3) seasons (autumn, winter and spring) each year, coinciding with salmon spawning season, mid-incubation and end of emergence periods. For each sampling event (autumn, winter and spring) a total of 36 surficial and subsurface substrate samples were collected from six (6) sites in the Lower Coquitlam River using a modified Hess sampler. At each site an assessment of dominant and subdominant substrate type, embeddedness, water depth, turbidity and velocity was recorded. Fine surficial substrate on the surface of the river bed was dislodged and collected. Subsurface substrate, remaining on the river bed following surficial sample collection (within the confine of the Hess sampler), was then then removed and placed in sample pails. Subsurface samples were separated in two (2) size classes, subsurface particles (<10 mm) and coarse subsurface particles (>10 mm). Surficial and subsurface particles <10 mm were submitted for particle size analysis and coarse subsurface substrate (>10 mm) was weighed and counted by G3.

Mean embeddedness varied between years, season and sites. Site 3 embeddedness was statistically lower than Site 1, 4 and 5. Embeddedness in autumn was statistically higher than winter suggesting natural flows from increased rainfall were effective in reducing average seasonal embeddedness. D_{50} and D_{95} were comparable among seasons and sites varied throughout monitoring years. Velocity varied throughout the years, season and site: winter was statistically significant and higher than spring and higher at Site 1 compared to Sites 4 and 6. Mean turbidity ranged between 0.29 NTU (Site 5) and 4.19 NTU (Site 3) across all years. Turbidity at Site 3 was statistically higher than all other sites and higher in winter. High turbidity events were noted in January 2014 (10.44 NTU), January 2015 (10.47 NTU), February 2016 (5.30 NTU) and March 2017 (4.02 NTU). A visible sediment plume at Site 3 was noted during winter sampling events in 2014, 2015 and 2016, and may be attributed to discharge from a gravel mining operation upstream.

Surficial substrate samples were dominated by sand (0.0625 mm – 2 mm) in all monitoring years. Surficial sand, silt and clay had statistically significant variability among, years, seasons and sites and had significant interaction effects. Site 3 had statistically significantly higher silt and clay content and lower sand content than all other sites.

Subsurface (<10 mm) samples throughout all monitoring years were dominated by gravel (2 mm – 10 mm), with the exception of Year 2 (2013 to 2014) which was generally dominated by sand. Subsurface gravel, sand, silt and clay had significant variability among, years, seasons and sites and statistically significant relationships (i.e. interaction effects). Sand was statistically higher in spring than autumn and there were statistically significant differences in subsurface substrate (<10 mm) composition between sites for all size fractions (except clay).

Coarse subsurface particles (>10 mm) collected from the Lower Coquitlam River were dominated by the three (3) gravel size classes. Statistically significant differences were noted between years for all six (6) size classes, between seasons for all gravel sizes and between sites for medium cobble. In addition there were statistically significant relationships between Year, Season and Site (i.e. interaction effects).

Year 2 (2013 to 2014) had the least amount of precipitation, river discharge and releases from Coquitlam dam which may have had an influence on the river substrate. In Year 2, an increase in sand and silt, a decrease in fine and medium gravel (2 mm - 16 mm) and an increase in cobble were noted in subsurface samples.

Precipitation and dam discharge were positively correlated with river discharge showing that river flow is highly influenced by water inputs. Three (3) high flow events occurred shortly before sampling in November 2012, December 2015 and February 2016. Regression and correlation analyses were used to compare percent (%) particle size and average of mean daily discharge prior to sampling seasonally (4 months prior), monthly (30 days prior) and weekly (7 days prior).

There was a statistically significant positive correlation between surficial sand and weekly flow and negative correlation between silt and clay and weekly flow (with three [3] regulated high flow events excluded). As flow increased sand increased and silt and clay decreased. No statistically significant trends were noted between flow and various size fractions of subsurface samples (<10 mm or >10 mm). Similarly, no statistically significant trends were noted between flow prior to sampling with embeddedness or turbidity.

Comparison between number of steelhead and coho redds and outmigration abundance identified no statistically significant trends between surficial substrate fractions and number of redds and coho outmigration abundance in the Lower Coquitlam River. Coho and steelhead outmigration abundances were compared to embeddedness results one winter prior to the salmon survey. Coho outmigration abundance in Reach 3 showed a statistically significant negative correlation with winter embeddedness.

With flow regimes occurring over the monitoring period, suitable habitat for spawning and rearing were observed at each sampling site and compared to biostandards (e.g. Groot and Margolis, 1991) from literature. Over the years an increase in small particle sizes in the river was not observed; however, variability over years, season and site was noted.

In conclusion under the current flow regime for unmanaged (i.e. rainfall) and managed (i.e. Coquitlam Dam releases) flows, the Coquitlam River has quality habitat suitable for salmonid spawning and rearing,

4.2 Recommendations

The following recommendations are made in the event that any significant changes are made to the Coquitlam Dam operations or release scenarios and additional monitoring is being considered for the Lower Coquitlam River. Recommendations are based on observations and results of the current monitoring program;

1. collect substrate and salmon data for Reach 1 given the absence of information and potential for sediment deposition in the that reach;
2. future substrate quality assessments should be better correlated with salmon surveys; and,
3. river velocity, during high releases from Coquitlam Dam, should be assessed nearer salmon spawning grounds to determine whether velocities are favourable for spawning salmon, when occurring during the spawning season.

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