A Literature Review and Data Analysis of Benthic Macroinvertebrate Habitat Suitability for the Coquitlam River

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1 Introduction

BC Hydro, the Department of Fisheries and Oceans and the Ministry of Environment, Lands and Parks have initiated the creation of a water use plan (WUP) for the Coquitlam River. Recognition of the importance of every trophic level to stream ecosystem health has led the group to consider flow affects on the macroinvertebrate population downstream of the dam. The invertebrate population forms the key food source for fish and their inclusion in water use plans is encouraged as they can be affected to a greater degree than their predators by changes in flow (Orth and Maughan 1983; Gore 1989).

This literature review was originally commissioned to explore three objectives: (i), to determine the benthic fauna of the Coquitlam, (ii), to determine the habitat preferences of those species and (iii) to explore how other projects had used the Instream Incremental Flow Methodology (IFIM) to model for the benthic community.

It was determined early that the literature would not support these objectives. A general lack of specific study on the aquatic macroinvertebrates of southwestern British Columbia, coupled with species specific life histories, forced a more general approach to this review. Objectives were modified and are now as follows:

i. To perform a general review of macroinvertebrate life history with local emphasis where possible.

ii. To analyse samples recently collected from the Coquitlam River and discuss them in terms of river health and possible invertebrate prediction models

iii. To discuss the general effect of physical parameters on microhabitat suitability for macroinvertebrates with an accompanying table, generated from the literature of physical parameter preferences for macroinvertebrate indexes.

iv. To review methods for building macroinvertebrate habitat suitability models.

A list of available references is provided at the end of this report.

2 Life Histories of Aquatic Insects

The life history of aquatic macroinvertebrates is species specific. Identification to genera does not provide enough resolution to differentiate patterns of development or habitat preferences. The classification of the Fraser River basin benthic community has not been determined in large part, so identification can be taken only to genera in the majority of cases (Rempel *et al.* 2000). It follows that limited work has been done on invertebrate life history in this region. Further, for species identified from rivers in B.C. it is misleading to assume that life history work done elsewhere is applicable, as variation within species has been shown to occur among streams in the same region (Teage *et al.* 1985; Gore 1989). Therefore, this review will have to remain general with the exception of a few species which have been researched locally.

Life history is briefly discussed in the context of insect development, both general, and three specific life history strategies are covered as well as the introduction and role of functional feeding groups on life history timing. All orders and families discussed in this review have been identified through recent sampling in the Coquitlam River.

2.1 Development

There are three types of development; ametabolous, hemimetabolous, and holometabolous. Insect life history begins with the oviposition of eggs (Figure 1). Larvae hatch and go through stages of successive growth with little development, referred to as instars. This type of growth without further development characterizes ametabolous insects, which are not discussed in this review. Important aquatic insects belong to the two latter categories. Both hemimetabolous and holometabolous development includes a final shedding of the exoskeleton, referred to as ecdysis, resulting in an adult form. Stoneflies (Order: Plecoptera), and mayflies (Order: Ephemeroptera) go through a hemimetabolous development where larvae are referred to as nymphs or naiads and final ecdysis results in a winged adult form, which resembles the larval stage. Holometabolous development occurs in the true flies (Order: Diptera), and caddisflies (Order: Trichoptera). Adoption of a pupal

stage between larvae and adult forms characterizes this group. In the pupal stage dramatic morphological changes occur so that adults do not resemble their larval forms (Merritt and Cummins 1996).
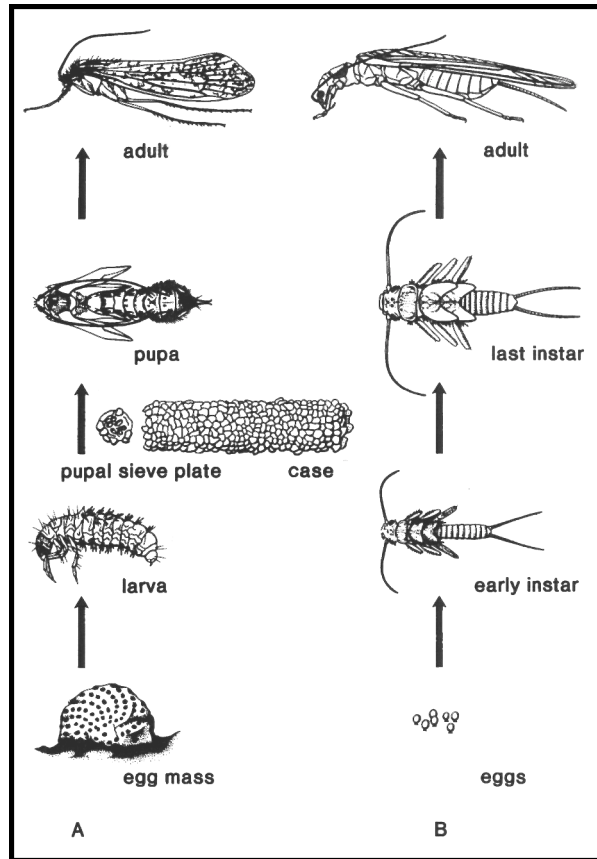
Figure 1 Examples of the development stages in the holometabolous caddisfly (Trichoptera) (A), and the hemimatabolous stonefly (plecoptera) (B). (Merritt and Cummins 1996)

2.2 General Life Histories

Hynes (1970) separated life history strategies into three distinct categories for Northern Temperate streams: slow seasonal, fast seasonal and non-seasonal. Histograms for each of the three strategies, built on frequency of occurrence of each developmental stage, are given in Figure 2.

Eggs that hatch soon after deposition characterize slow seasonal cycles. The larvae grow slowly and mature almost a year later. This strategy is popular in cool streams. It is typical of stoneflies, but can be adopted by mayflies and caddisflies.

Fast seasonal cycles are characterized by rapid growth after an extended egg or larval diapause. Cycles of this type tend to emerge as adults and oviposit during spring/early summer or late summer/fall. Generations of some species will follow each other in rapid succession within a single year, such as *Baetis* sp.(Baetidae: Ephemeroptera) and *Simulium* sp.(Simuliidae: Diptera). Seasonal cycles result in a distinct and synchronous growth in larval cohorts over time.

Presence of all life history stages or size classes in any given season is indicative of non-seasonal cycles. This may be the result of a merovoltine life history (less than one generation per year), or overlapping generations such as in the chironomid family Chironomidae (Order: Diptera).
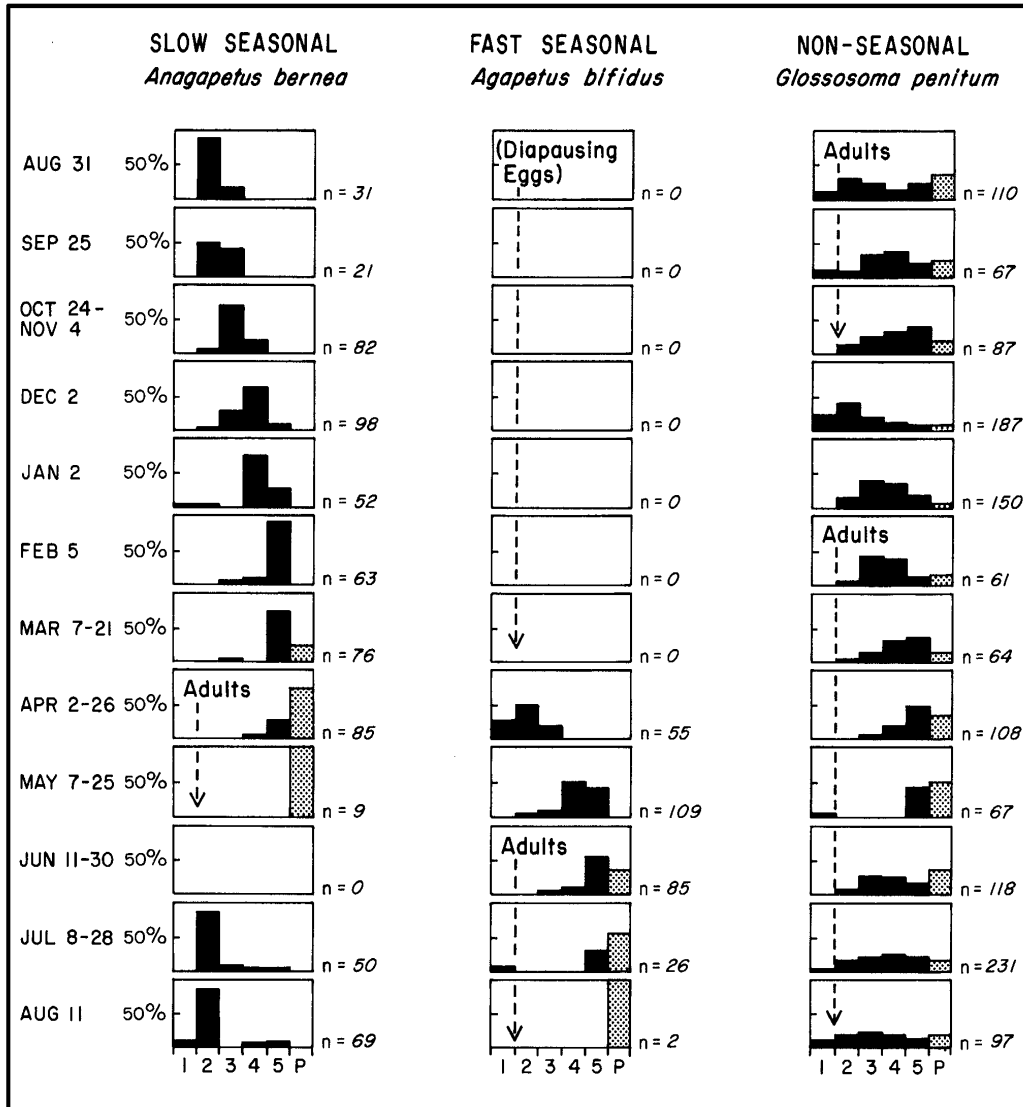
Figure 2 Life cycle illustrated with three glossamatid caddisflies. The numbers represent the five larval instars or growth stages, P; prepupa and pupa, n; number per sample (adapted by Merritt and Cummins (1996) from Anderson and Bourne (1974)).

For Northern Temperate streams such as the Coquitlam River, a univoltine strategy (one generation per year) is common. Invertebrates which exploit the summer season (e.g. Baetidae , Chironomidae and Simuliidae), however, can employ multivoltine (more than one generation per year) life histories, and species in the beetle family Elmidae (Order: Coleoptera) and some caddisflies and stoneflies have adopted a merovoltine life history strategy. Some of the larger predatory stoneflies, such as Perlidae, can have life cycles that last up to three years (Merritt and Cummins 1996).

2.3   Functional Feeding Groups (FFG)

Benthic invertebrates can be partitioned into functional feeding groups based on food aquiring mechanisms (Table 1), which represent different trophic levels. Examination of the FFG composition of benthic macroinvertebrates can assist with the understanding of physical requirements of the population. The designations used for this review are taken from Merritt and Cummins (1996).

Collector-gatherers exploit fine particulate organic matter (FPOM) deposition, while collector-filterers trap organic sediments suspended in the water column. The scrapers main source of nutrition is periphyton and associated detritus, while shredders make use of the coarse particulate organic matter (CPOM) in the form of living vascular hydrophytes or as detrivores consuming dead plant material. Predator diet consists mainly of living animal tissue through either engulfing or piercing.

The existence of functional feeding groups may facilitate temporal and spatial partitioning of resources. For example, shredder abundance may increase in the fall and winter to exploit the coarse particulate material (CPOM) from leaf accumulation while periphyton scraper abundance declines. Further partitioning may occur between species of the same FFG by offsetting the timing of rapid growth intervals so as to avoid competition (Mackay 1972). A rapid seasonal succession of stonefly species occurs in temperate regions. There is an overlap in species emergence but timing of maximum abundance differs in species, which would otherwise compete for similar niches (Jewett 1959).

Determination of life history timing involves not only the adoption of slow, fast or non-seasonal life history cycles but is also a function of the resources that a particular species is best suited to exploit. This results in an extremely varied array of life history strategies and ensures the existence of benthic macroinvertebrates in all stages of life through all seasons.

Table 1 A list of the functional feeding groups and their representative genera found in the Coquitlam River (adapted from Merritt and Cummins (1996))

FFG	Dominant Food	Invertebrates found in the Coquitlam River				
		Oligocheates (Worms)	Ephemeroptera (Mayflies)	Plecoptera (Stoneflies)	Trichoptera (Caddisflies)	Diptera (True Flies)
Collector - Gatherers	Loose surface fine particulate organic matter (FPOM)	Oligocheates	*Beatis* sp., *Serratella* sp., *Cinygma* sp., *Cynigmula* sp., *Rithrogena* sp., *Paraleptophlebia* sp.			Tanytarsini, Orthocladiinae, *Dixa* sp., Antocha
Scrapers	Periphyton - attached algae and associated material		*Beatis* sp., *Drunella* sp., *Cynigma* sp., *Cynigmula* sp., *Rithrogena* sp.			
Predators	Living animal tissue			*Utaperla* sp.*, *Sweltsa* sp., *Neaviperla* sp.*, *Skwala* sp.	*Rhyacophila* sp.	*Probezzia* sp., Oreogeton, *Dicranota* sp., *Hexatoma* sp.,*Chelifera* sp.*
Shredders	Living vascular hydrophytes, Decomposing vascular plant tissue, coarse particulate matter (CPOM), Wood			*Capnia* sp., *Zapada* sp.	*Glossosoma* sp., *Chyranda* sp.	
Collector - Filterers	Suspended FPOM				*Hydropsyche* sp.	Simulium sp.

* Predator designation given because all other genera in family are predators.

2.4 Local Life Histories

Three invertebrate species life histories were determined from work on Spring, and Mayfly creek and the North Alouette River in the Malcolm Knapp Research Forest (Figure 4) (Reece and Richardson 1998). The abundance and size of three taxa; *Drunella doddsi* and *D. spinifera* (Ephemerellidae: Ephemeroptera) and *Zapada cinctipes* (Nemouridae: Plecoptera), were monitored through five sampling dates spread over a single year and

timing of major events is given in Table 2. These specific species were chosen because they existed in large numbers in all streams studied.

Both *D. spinifera* and *D. doddsi* were emerging and hatching in July with greatest growth rates between July and October. *Z. cinctipes* began emergence in December and hatching occurred mid March to early April. Highest growth rates occurred between October and December. Abundance of all three taxa was highest during July sampling. Abundance of both *Drunella spp.* was highest during coinciding emergence and hatching while *Z. cinctipes* was in greatest abundance after hatching (Reece and Richardson 1998).

A general life history and biomass timing curve was established by Hynes (1970) for temperate streams dominated by insects (Figure 3). This speculative curve indicates highest numbers in late autumn and early winter due to recruitment and growth of young. Highest biomass occurs in the early spring as the winter species have achieved growth and summer species are hatching. Spring and summer are the months of lowest total numbers and biomass respectively, due to deaths and emergence.

Table 2 Comparison of four events in the life history of species from coastal streams (Reece and Richardson 1998)

Species	Life History Stage	J	F	M	A	M	J	J	A	S	O	N	D
Drunella spinifera	emerging							*					
	hatching							*					
	greatest growth rates							*	*	*	*		
	highest abundance							A					
Drunella doddsi	emerging							*					
	hatching							*					
	greatest growth rates							*	*	*	*		
	highest abundance							A					
Zapada cinctipes	emerging												*
	hatching			*	*								
	greatest growth rates										*	*	*
	highest abundance							A					

Reece and Richardson's (1998) studies of seasonal variation on the coast of British Columbia indicate that highest abundance occurs in summer and corresponds with the variable peak indicated by Hynes (1970) not the winter peak expected in Hynes model (Figure 3). This was attributed to both summer multivoltine, and hatching univoltine species. Invertebrate recruitment occurred in late spring through summer. This differed

from the Hynes model where highest recruitment occurred in late summer and autumn. Reece and Richardson (in press), found abundance was low in the autumn and winter.

2.5   Effects of Flow Regimes on Life History Timing

Two large rivers, the Thompson and Fraser, and three interior streams from the Nicola drainage, Mellin, Glimpse and Beak creek, were sampled concurrently with Mayfly and Spring creek and the North Allouette River of the Malcolm Knapp Research Forest (Reece and Richardson 1998). All differed markedly in their flow regimes. Reece and Richardson (1998) determined that flow had little effect on timing of life history events of the species under observation. Possible reasons include: flood predictability was not sufficient to develop adaptations around it; other environmental constraints may have limited life history timing; the invertebrates studied may be generalists; other adaptations may be employed to avoid the seasonal scouring effects of flooding; and finally, bankful discharge may not represent a significant disturbance for which life history timing should be altered.

Life history timing is determined by a complex set of variables including photoperiod, temperature, food availability and competition (Anderson and Cummins 1979). Cohort splitting of the cranefly (Family: Tipulidae) has revealed that individuals from the same cohort can vary their life cycles from 1 to 3 years when food and temperature were manipulated (Pritchard 1983). Mayflies have adapted to warmer water at all life stages whereas stoneflies seem to have adapted strategies which exploit cooler temperatures. Brittian (1990) suggested that stoneflies are not dependent on temperature but instead food and Hynes (1970) believed their increase in winter months was partly a response to the relative lack of predators.

Studies of mayflies in drainage basins from the south eastern United States to Quebec revealed temperature as the predictor of development, not flow regime (Newbold *et al*. 1994).   More flexible timing of life histories are seen in areas of unpredictable environmental conditions (Merritt and Cummins 1996). This might indicate that flow conditions are able to alter life history timing over the long term, however if changes in flow are not dramatic life history timing does not appear to be affected.

3   Characterization of the Coquitlam

The Coquitlam is a fourth order river with a drainage basin of 269.6 km^2 and an elevation gain at the dam of approximately 130m. It is characteristic of coastal streams in that it runs over slow weathering, quartzite rock. This results in soft water, low alkalinity, low conductivity and slightly acidic conditions (Reece and Richardson 1998, Dr. John Richardson pers. comm.).   Rivers of this order have a reduced dependence on allochthonous, terrestrial organic input characteristic of lower order streams, and an enhanced dependence on autochthonous primary production and organic production from upstream (Vannote *et al.* 1980). Fourth order rivers can expect to receive quantities of fine particulate organic matter (FPOM) from the upstream processing of dead leaves and woody debris.

This shift in the food base coincides with a shift in the macroinvertebrate community. Fourth order streams are characteristically dominated by grazers and collectors, with a small and relatively constant population of shredders and predators (Vannote *et al.* 1980). Shredder abundance will be in direct relation with the amount of CPOM, generally in the form of allochthonous material, a river receives and retains. Shredders are most strongly represented during the winter months as they exploit the autumn leaf fall.

The North Alouette River has been suggested as a system that might parallel the Coquitlam (Dr. John Richardson pers. comm.). It is a second order stream with a 9.58 km^2 drainage basin and an elevation gain of 315m. Recent work focusing on the macroinvertebrate population would be the closest comparable data set for reference.

4 Sampling of the Coquitlam River

4.1 Methods of Collection

All samples were taken within a 200m downstream range, beginning approximately 50m downstream from the depth gauge at Reach 2b (Figure 4). Samples were collected September 19th and October 2nd of this year. Eight riffles, seven runs and five pools were selected by observation for a total of 20 sites. Stream depth, velocity and substrate type were measured and recorded at each site. Substrate was visually assessed and the first two dominant substrate types were recorded from boulder, cobble, gravel and/or fines designations.

A 30 X 30 cm net with 0.49 mm mesh, was fixed in place with rebar and the 0.75 m^2 area immediately in front was disturbed for approximately 1 minute. The net remained in place for 5 minutes after the substratum was disturbed. All contents of the net were placed in jars and preserved in 5% formalin.

Samples were washed with water to allow for processing and were picked on a white 30X40 cm tray with no magnification. Invertebrates were removed to labeled glass vials containing 80% isopropanol.

Most insects were identified to genus, with the exception of Diptera in which Chironomidae subfamilies were distinguished. A reference collection for each genus (lowest taxonomic designation) was established with five individuals each. Ten individuals were set aside for each of the Chironomidae Subfamilies. The remainder were placed back in their original vials.

4.2 Results

Seven orders were identified of which three were non-insect; Arachnida, Oligocheata and Hydracarina. Of the twelve Nearctic aquatic and semiaquatic insect orders Ephemeroptera, Plecoptera, Trichoptera, and Diptera were sampled from the Coquitlam River. Eighteen families and twenty-eight genera were further identified from these four orders. Ten adult

and 18 Diptera pupae remained unidentified (data is given in Appendix A and summarized in Tables 3 and 4). The genus *Baetis* sp. (Order: Ephemeroptera) made up 47% of the entire sample followed by two subfamilies of the family Chironomidae at 17% and a single genus of Heptegeniidae (Order: Ephemeroptera) at 8%. Eight genera were represented by less than 5% each, Oligocheates represented 3.5%, and the remaining sixteen genera were present at a frequency of less than 1% each.

Genera were divided into functional groups as designated by Merritt and Cummins (1996) (Table 1). Collector-gatherers and scrapers were dominant, representing 80.1% of the total fauna. Predators were represented at 14.6% and shredders and collector-filterers were both fairly uncommon at 3.9% and 1.4% respectively.

Total number of macroinvertebrates sampled was plotted as a function of depth (Figure 5A) and velocity (Figure 5B). Both total numbers and functional groups were plotted against depth and velocity increments as a three dimensional histogram (Figure 6). A rough example of a probability distribution function based on water depths was also plotted and is represented in Figure 7

Figure 5   The total number of invertebrates per sample as a function of **A**: depth and **B**: velocity.

Invertebrates sampled as a function of depth

A

Invertebrates sampled as a function of velocity

B
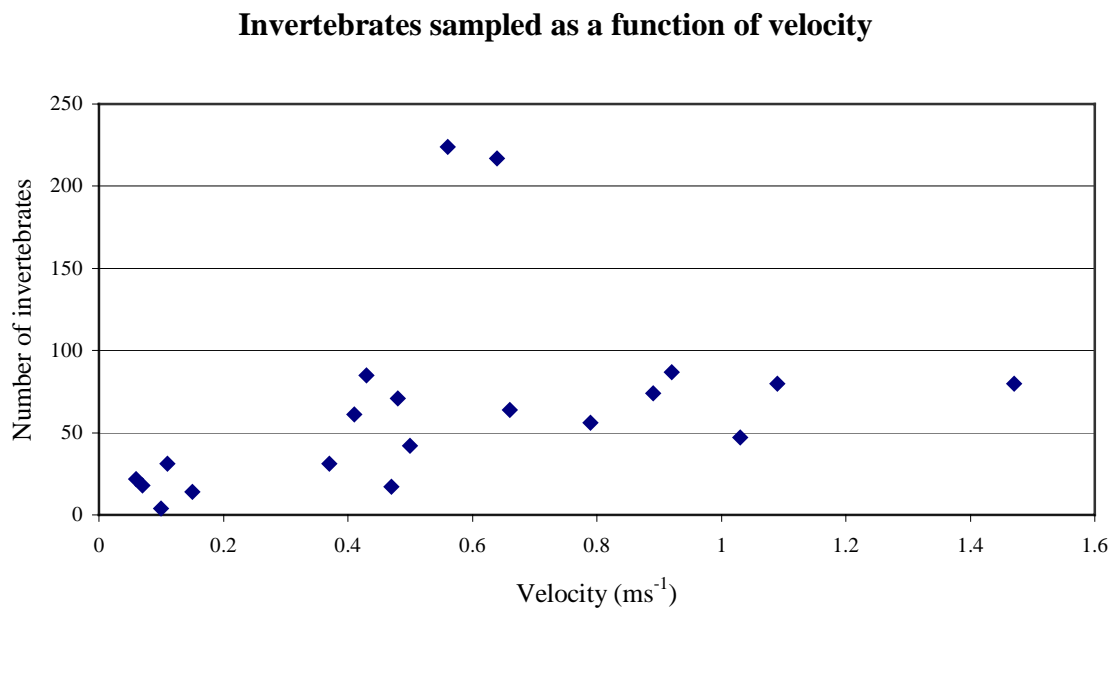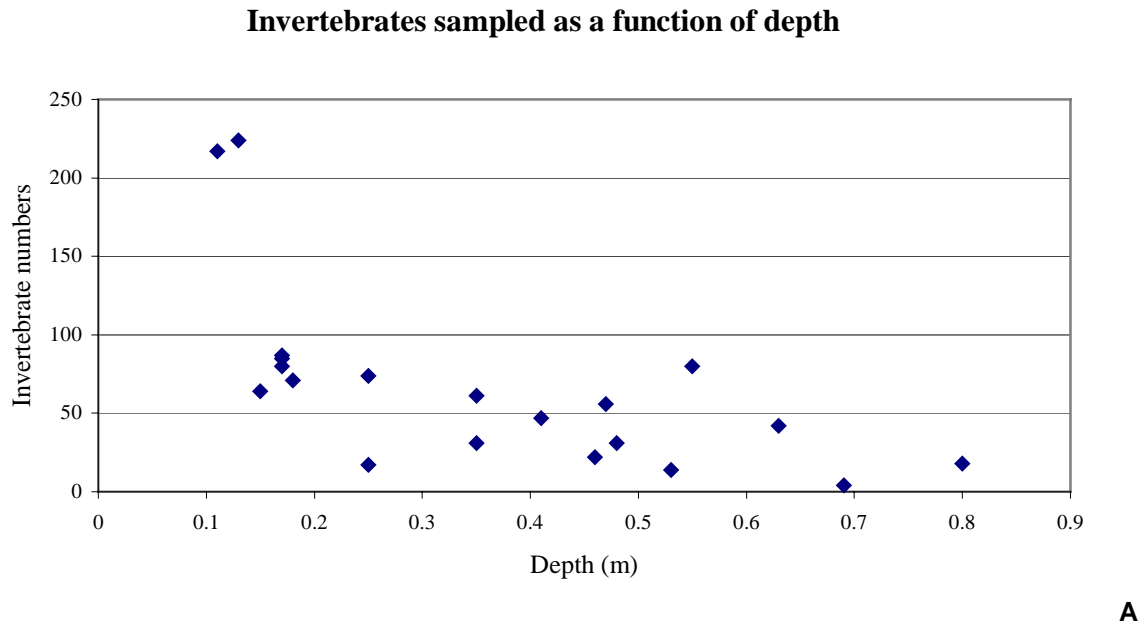
Figure 6 Two way histogram plotting the frequency of total invertebrates as a function of both depth and velocity (generated by Josh Korman)
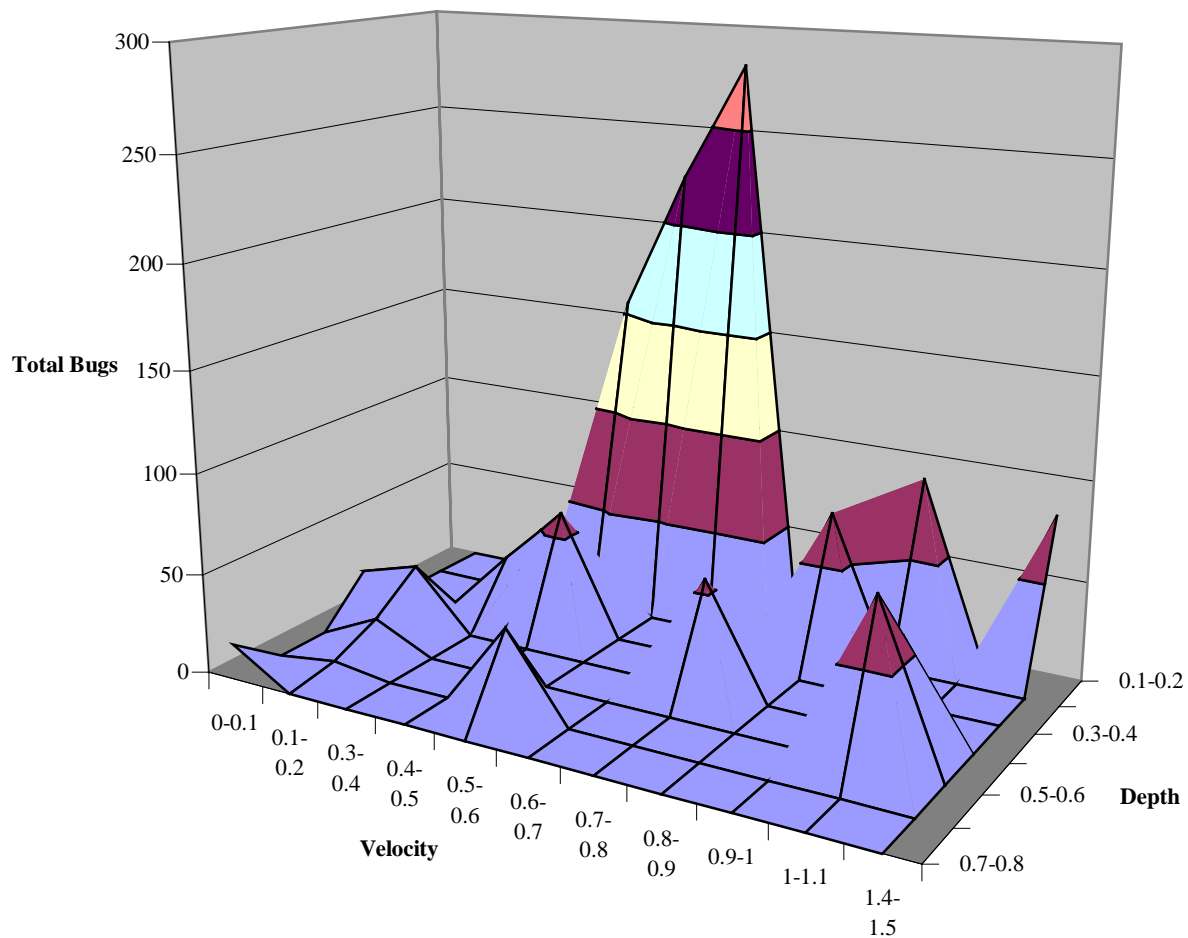
Figure 7 An example of a probability distribution function based on water depths of **A**; greater than 30 cm and **B**; less than 30 cm (generated by Josh Korman)

Probability Distribution Function for Depths Greater Than 30 cm

A

Probability Distribution Function for Depths Less Than 30 cm
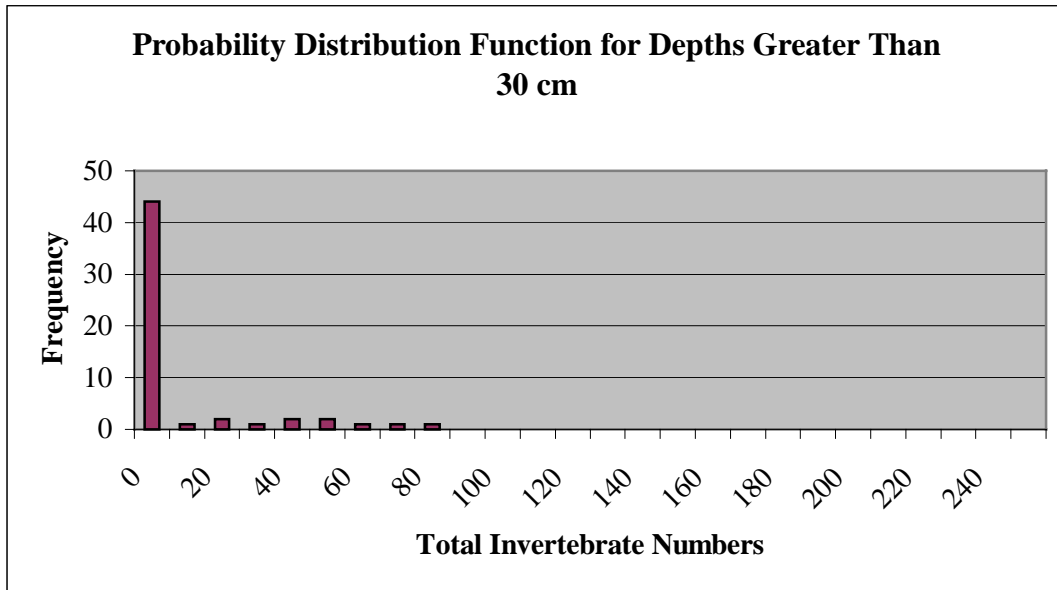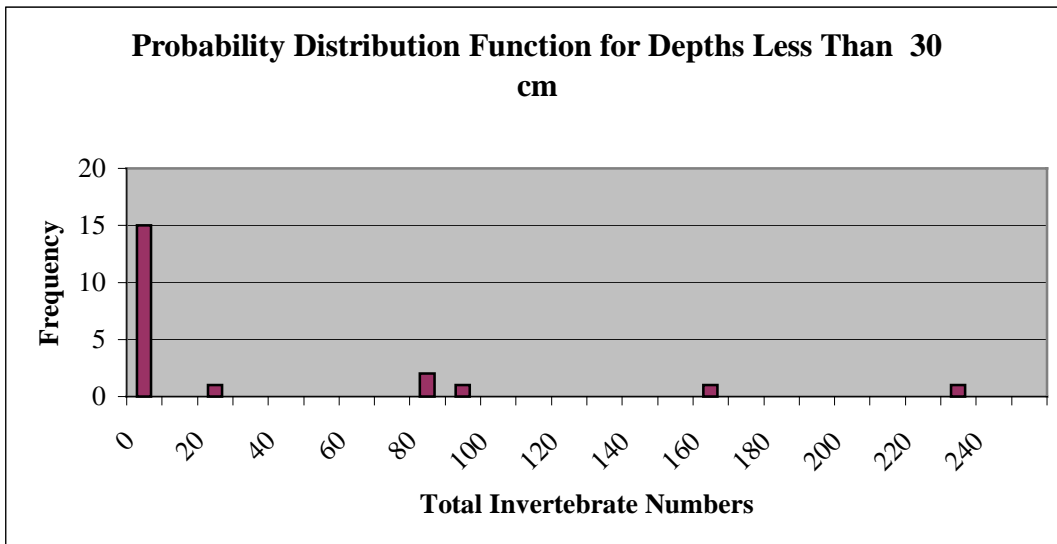
B

4.3   Discussion

Examination of FFGs was consistent with expectations from the stream order of the Coquitlam River (Vannote *et al.* 1980). Collector-gather and scraper types ranked highest, making up 80 % of the total sample. Ranking of invertebrate order by abundance produced different results from those found by Reece and Richardson (in press), where Ephemeroptera, Plecoptera and Trichoptera were found in greater abundance than Diptera in coastal streams. Ephemeroptera, Diptera, Plecoptera and Oligocheates were more abundant than Tricoptera in the Coquitlam River samples. A general measure of system health is the ratio EPT (Epheroptera, Plecoptera and Trichoptera numbers to total or chironomid numbers). EPT scores from the Coquitlam should be compared with caution to standards in the literature as no such ratios have been developed for the Fraser River Basin. **Still working on this**

Absence of the beetle family Elmidae, and the small number of individuals from the Heptagenidae family (Order: Ephemeroptera) were noted on initial examination of the Coquitlam River data (Dr. John Richardson pers. comm.). Overall numbers from the Coquitlam River, especially Diptera numbers look low (Dr. John Richardson pers. comm.). An average of five, three minute kick samples from the North Alouette River yielded 557 ± 220.7 (± 1SE) invertebrates while average one minute riffle kick samples, yielded a mean of 113 ± 66.9 (±1 SD) invertebrates in the Coquitlam River (Reece and Richardson 2000). Implications of the numbers on statements of system health is hard to determine as factors such as the experience of the sampler can have a large effect (pers com. Dr. John Richardson).

Initially sampling was undertaken to have a preliminary look at the composition of the Coquitlam River. Because the sampling objectives did not include the development of habitat suitability curves for this river, sampling techniques are inadequate to fulfill objectives of this type. The combination of low sampling intensity and large mesh size allowing the passage of early instars, limited coverage of the river, and single season sampling accompanied by a deficiency of data across hydraulic variable continuums, has

compounded to result in a real lack of information with regard to invertebrate preferences in the Coquitlam River.

4.4 Recommendations for Modeling

The traditional approach to developing habitat capability models has been to rely on parametric, multivariate statistical tools, e.g. linear regressions that relate habitat attributes to an index of fish or aquatic insect abundance. The use of these tools require that certain assumptions be met regarding the form of the habitat capability function and the distribution of errors among habitat attributes and across the range of abundance measurements. These assumptions however are rarely met (James and McCulloch 1990; Rice 1993) and as a consequence, tend to have weak predictive ability. Of even greater concern are the estimates of certainty about these predictions (Rice 1993). Confidence interval calculations require even stronger adherence to modeling assumptions.

Consider the distribution of total bug abundances in the Coquitlam River as a function of water depth and velocity. There is no obvious relationship between depth and total insect abundance (Figure 5A), but the highest abundances were found in some of the shallowest locations. Apparently, deeper water puts a 'limit' on attaining maximum abundance. Velocity appears to control insect abundance in a parabolic fashion; very slow and very fast water limit abundance levels (Figure 5B). When the effect of these variables is examined together (Figure 6), maximum densities are attained at moderate velocities (ca. 0.5 m/sec) at shallow depths (10-20 cm).

The functional forms of habitat-abundance data are certainly not simple. To paraphrase Rice (1993);

Although ecological theories can yield predictions of how animals should use habitats, theory predicts in only general ways the shape of specific abundance-habitat functions.

When abundance and habitat data are plotted, the relationships commonly show combinations of thresholds, floor and ceiling effects, asymmetric ascending and descending limbs, marked skewness or kurtosis, differing variability in abundance at different positions along a habitat gradient and other diverse statistical problems. Curvilinear models may fit the data better than linear models, but they do not necessarily fit the data well.

To overcome these problems, Rice (1993) suggested that a non-parametric density approach be used to predict abundance from habitat data. In particular, Rice (1993) advocates the use of kernel density estimation to predict or forecast probability distribution functions (pdf) of animal abundance for a given set of habitat attributes. A probability density function in this application is simply a frequency histogram showing the probability (y-axis) of different insect abundance levels (x-axis). Perhaps the greatest advantage of using a pdf to estimate habitat capability in this application is that it does a good job of capturing the uncertainty in capability predictions.

An example of a pdf based on water depth is provided in Fig. X (Figure 7). If the Coquitlam invertebrate data are lumped into samples collected at depths ≤30 cm and those collected at greater depths, it is clear that there is a greater chance of finding high invertebrate abundance in shallower sites than in deeper ones. However, under either habitat condition, there is considerable range of potential densities although the mean in shallower sites (41.8) is considerably higher than in deeper ones (7.4). Multivariate kernel density estimation, predicts the shape of a pdf for any site given its habitat characteristics (e.g. depth, velocity) in relation to those in the reference data set. In this application, the reference dataset is the 20 samples analyzed in this report. The multivariate procedure creates a new pdf by weighting each abundance record in the reference set based on the similarity of its habitat characteristics to those in the site where predictions are required. An algorithm for the procedure has been developed by James Bruce at BC Hydro. If the WUP process demands predictive models of insect abundance as function of depth and velocity, we recommend the use of the multivariate kernel density estimation approach described

here. The approach will predict a pdf for every site in question that reflects the degree of uncertainty in abundance associated with the habitat attributes used in the model. One can at least present predictions in a probabilistic way. For example, the pdf's in Fig. 2 (JK) could be summarized by saying that there is a 10% chance (2 out of 19) of obtaining high insect abundance if depth ≤30 cm compared to a 0% change if depth ≥30 cm.

5 Effect of Various Physical Parameters on The Benthic Community

No single parameter exerts its influence in isolation. The microdistribution of aquatic macroinvertebrates is the result of an interaction between many variables including sediment size, current velocity, turbulence, temperature, dissolved oxygen and water chemistry (Appendix B) (Culp *et al.* 1983; Collier 1993; Degani *et al.* 1993; Bouckaert and Davis 1998).

Substrate acts indirectly on invertebrates as a modifier of their environment and directly as the medium on or in which they live (Minshall 1984). It is generally accepted that macroinvertebrate density increases as grain size increases to large cobble, then begins to decline on larger substrates (Minshall 1984). Further studies have found substrate heterogeneity supports higher density and, as discussed below, studies have found preferences for substrates which interact with flow in such a way as to accumulate particulate organic matter. Beisel *et al.* (1998) found highest numbers of taxa at sites with the greatest microheterogeneity (e.g. roots and bryophytes). These substrates are assumed to be important to microdistribution as they provide a wide range of refugia against abiotic and biotic factors. Hydrophytes provide oviposition sites, protective nurseries for early instars, refugia during spates and can interact with flow to collect detritus or periphyton (Beisel *et al.* 1998). Mineral substrate influence includes its ability to restrict or enhance an invertebrate's ability to adhere, cling or burrow. It provides for case construction and is also a medium for egg deposition as well as shelter from predators and current disturbances (Minshall 1984).

Stability of substrate forms the presence or absence of refugia during spates and scouring events (Cobb *et al.* 1992). Substrate stability, the presence of large woody debris acting as refugia, and stable diel flow patterns have all been linked to increased insect density (Cobb *et al.* 1992; Borchardt 1993; Death 1995).

An insect's respiration changes according to the substrate it inhabits. When all other parameters are equal insects will choose the substrate on which their respiration is lowest

(Minshall 1984). Fine sediment cover increases invertebrate respiration as more energy is expended to simply maintain position. Early study has argued few effects on insect density as a result of sedimentation (Chutter 1969; Barton 1977). More recent study has refuted these findings. Quinn and Hickey (1990) found lowest abundance and richness in rivers with beds of silt or substrate overlain with sand deposits. Rabeni and Minshall (1977) found that the addition of a light layer of silt (approximately one mm thick) on coarse substrate reduced abundance of taxa. De March (1976) determined silting to be a limiting factor to the number and types of invertebrates and a more important indicator of insect distribution than mean substrate size.

Fine sediment around substrate can form a "gasket effect", creating a seal which serves to restrict access of burrowing forms, to the interstitial region (e.g. midge and crane fly larvae) (Brusven and Prather 1974). Net fouling and decrease in larval growth of filter feeders has been linked to sedimentation in microcosm studies but sedimentation may not play as large a role as was demonstrated due to organisms greater ability to avoid sediments in a natural setting (Strand and Merritt 1998).

Food depletion in the form of coarse and fine particulate matter (CPOM and FPOM respectively) has been demonstrated as a limiting factor in the distribution of collector-gathers and shredders. An experiment isolating food source from substrate type found that density and biomass were not significantly different between substrate types (Culp *et al.* 1983). Bouckaert and Davis (1998) found that macroinvertebrate richness and abundance were significantly higher in the wake of boulders even though near bed velocities were reduced in both the front and wake regions. Because highly variable shear stress and turbulence throughout the water column existed in the wake of the boulder, Bouckaert and Davis (1998) reasoned that macroinvertebrates were responding to the effect this had on increasing deposition of particulate organic matter and increasing dissolved gases. Chironomid velocity and depth preference were also attributed to the effects of the interactions between a suite of various physical parameters on food deposition and dissolved oxygen (Collier 1993).

Light attenuation, and therefore depth, have an effect on invertebrate collector-browsers via effects on periphyton growth. Quinn and Hickey (1994) found a marked reduction in

chlorophyll a at depths greater than one meter. They suggested that decreased light penetration, and the increased scouring affect on periphyton mats due to higher shear stress at greater depths, were the causes. Degree of shading due to canopy was a better indicator than substrate character of total abundance and guild structure (Hawkins *et al.* 1982). Streams without shading had higher invertebrate abundances than shaded streams.

Many aquatic macroinvertebrates have an inherent need for current as well as upper velocity tolerances (Beisel 1998). This may be due to oxygen requirements or the rate at which water passes through filtering apparatus for the purpose of FPOM collection. Again heterogeneity at the mesoscale is linked to density as many flow requirements can be met due to variation about a patch (Jowett and Richardson 1990). Structurally complex habitats are expected to support greater abundance and diversity than simple ones (Beisel 1998)

6 How Other Studies Have Accounted for Invertebrates in Their IFIM Models

"IFIM is based on the assumption that fish and/or benthic species exhibit discrete and quantifiable preferences (as habitat suitability curves) for a range of velocities, depths and cover/substrate characteristics. If these physical habitat characteristics can be predicted at a variety of discharges, a relationship between available habitat (expressed as weighted usable area, WUA) and altered flow regimes can be determined." (Gore 1989).

All instream flow techniques are based upon instantaneous measurements of habitat conditions at a single discharge. This implies that there is a proportional or "linear" response of macroinvertebrates to changes in discharge for predictive purposes; however, this may not present a problem over a narrow range of discharge (Gore 1989)

Data gathered to generate curves for IFIM models have been collected from surrounding watersheds (Gore *et al.* 1998) or gathered over a minimum of one year from the system in question (Gore and Judy 1981; Orth and Maughan 1983; Gore *et al.* 1998). To generate accurate preference criteria, curve development data from the specific system in question, or systems extremely close by, is encouraged as requirements of aquatic insects can vary from system to system (Orth and Maughan 1983; Gore 1989). This is why a catalogue of suitability curves for benthic species will likely be inadequate for useful instream flow assessments and development of release strategies (Gore 1989).

Curve development has centered on specific species with disparate habitat requirements which represent species guilds. Visual analysis of curves generated for a number of species is used to select the smallest number of species with the narrowest tolerances, which fit into the greatest number of other preferences curves. Density and community metrics which are associated with ecosystem health, such as diversity, richness and biomass, are also used in the development of curves for IFIM modelling (Quinn and Hickey 1994; Gore *et al.* 1998).

6.1   Use of Simple Variables: Depth, Velocity and Substrate

Gore and Judy (1981), using incremental curve fitting, generated initial curves by plotting cumulative means against single variables such as depth, velocity and substrate. A fourth order polynomial was fit to the data and its first derivative generated a normalized curve with the peak indicating habitat preference (Gore 1978).

Criticism for the incremental curve fitting methodology cited its inability to account for variance within means. Modification by Orth and Maughan (1983) applied log transformation to raw data in order to minimize variance. This can skew curves toward the lower end of the physical parameter range (Gore 1989).

An attempt to analyze depth and velocity dependencies using exponential polynomial curve fitting, indicated that this cross product term does affect the prediction of densities at various velocities and depths but its use was recommended only as an instrument for "fine-tuning" (Gore and Judy 1981). The exponential polynomial curve contained the joint velocity-depth term:

F=exp[- (a1v + a2d + a3v2 + a4d2 + a5vd)][1]

Mathur et al. (1985) believed this approach to be critical to take into account interrelatedness of variables such as the turbulence and shear stresses created by certain flows over certain substrates.

When all three models were used; single variable, log transformed and exponential polynomial curves, to predict habitat suitability for *Simulium* sp., it was found that exponential polynomial curves had the effect of minimizing variances and were better predictors of density (Morin *et al.* 1986).

6.2   Use of Complex Variables: Turbulence and Stress Models

There is little doubt that IFIM modeling on single hydraulic variables produces error in the estimation of physical habitat (Gore and Judy 1981; Morin *et al.* 1986; Gore 1989; Quinn and Hickey 1994). Interactions between the variables depth, velocity and substrate produce

turbulence and shear stress that more accurately describe the local conditions in which invertebrates exist. Exponential polynomial models have been shown to be acceptable predictors of benthic invertebrate density (Morin *et al.* 1996). Concerns however, have been raised over their lack of ability to replicate true hydraulic conditions, as well as statistical problems arising from multiplication of individual habitat suitability data to produce WUA values (Gore 1998). Alternatives involve the use of more complex variables which use depth-velocity-substrate interactions to explain hydraulic habitat (Table 5). Any single index of hydraulic habitat can be incorporated into the PHABSIM model.

Quinn and Hickey (1994) tested single variables, multiple regression models incorporating depth, mean velocity and substrate and complex hydraulic variables (Froude number, shear velocity, and water column and boundary Reynolds numbers (Table 5)) for their ability to predict invertebrate density and community metrics in both systems with both uniform and heterogeneous substrate. For streams of uniform substrate, invertebrate variables were similarly correlated with mean velocity, and the complex near bed hydraulic variables. Invertebrate variables in streams of heterogeneous substrate were correlated 25 – 45 % more accurately with Froude number, inferred shear velocity and boundary Reynolds number, than with velocity alone. Of the complex hydraulic variables, boundary Reynolds number was the best predictor. The overall strongest correlations however, were with the multiple regression model incorporating depth, mean velocity and substrate. Statzner et al (1988) reported greater accuracy of estimates for small samples sizes when boundary Reynolds number or sublayer thickness values were used in IFIM.

Table 5 Some complex hydraulic variables used to measure the microdistribution of aquatic macroinvertebrates (adapted from Rempel *et al.* (2000)).

Name	Symbol	Units	Formula	Description
Hydraulic measures: near-bed				
Shear velocity	U_*	cm s^{-1}	$\dfrac{1}{slope \times 5.57}$	Slope of vertical velocity log profile
Bed roughness	k_s	mm	$3.5 \times D_{84}$	Bed roughness, topographic variation
Boundary Reynolds number	Re_*	None	$\dfrac{U_* k_s}{\nu}$	Nature of flow close to the bed, near-bed turbulence
Hydraulic measures: depth - averaged				

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[1] a_i is constant and derived from multiple regression of frequency distributions of velocity and depth (Gore, 1989)

Froude number	Fr	None	$(U2/g\,d)^{1/2}$	Turbulence close to water surface
Reynolds number	Re	None	$\dfrac{U\,d}{\nu}$	Turbulence of free flow

Simple variables involved in the calculation of complex variables

Mean Velocity	U	cm s^{-1}		Velocity measured at 0.6 depth below water surface
Acceleration due to gravity	g	cm s^{-1}		
Water depth	d	cm		
Kinematic viscosity of water	ν	None		

7 Conclusions and Recommendations

Unfortunately, time is a key factor in the decisions made by the fisheries technical committee. It is important to proceed cautiously. Rather than developing a model from existing data, maximizing habitat heterogeneity is recommended, using the preferences, and maximum and minimum requirements gathered from the literature as a guide (presented in Appendix B) (Dr. John Richardson pers. comm.).

Benthic macroinvertebrate life histories are species and sometimes system specific. This, along with a lack of species identification for the entire Fraser River basin makes it impossible to develop habitat suitability criteria for the Coquitlam River based on a literature review. To properly manage for secondary production more sampling with sound objectives needs to take place. Data from the length of the Coquitlam River should be gathered, from four seasons, along with the physical parameters that enable macroinvertebrate preference to be discussed in terms of the joint preference factor developed by Gore and Judy (1981) or boundary Reynolds numbers. If modeling of habitat suitabilities is necessary then the use of probability distribution functions is recommended as its strength is its ability to describe the likelihood of its own error (Josh Korman pers. comm.).

Even with this accomplished, modeling is only an estimate of current, depth, and/or substrate preferences. Research strongly points to nutritional resources as an important limiting factor of aquatic macroinvertebrate densities (Richardson 1993; Diehl 1993) The dam has decreased the amount of nutrients coming into the system on many levels. The nutrient recycling from sockeye salmon (Onchorynchous nerka) runs shown to contribute to benthic macroinvertebrate abundance (Wipfli *et al*. 1998), has been cut off, as migration past the dam into the head waters is no longer possible. Release from the Coquitlam Reservoir truncates the natural flushing of primary products derived on the surface of the lake and furthermore woody debris that would of made its way naturally through the system and provided both food and pool habitat is now stopped at the dam. Pool habitat leads to complexity and forms sinks for both fine and coarse particulate matter.

The Coquitlam River is an oligotrophic system. Simply modeling and maximizing habitat will not be enough. Serious consideration of the lowest trophic levels needs to be undertaken. Structures, and flow and substrate interactions, which will increase complexity and act as sinks for coarse and fine organic matter should be pursued as well as depths and flows which encourage periphyton growth. Perrin and Richardson (1997) experienced significant increases in benthic invertebrate density and emergence numbers coinciding with the addition of nitrogen and phosphorous in the Nechako River. Ongoing studies on the Checkamus River, though still in the field stages, are finding nitrogen levels to be an important factor contributing to insect density (Chris Perrin pers. comm.). It is worth pointing out that nitrogen and phosphorous concentrations would be diluted by an increase of minimum flows unless somehow supplemented.

Aquatic invertebrates play a major role as integrators of environmental conditions and should be considered an essential component of any sound management strategy (Gore and Judy 1981; Ward 1984; Boon 1988; Gore 1989). Competing factors such as river amenity, recreation, and fisheries serve to play down the weight that should be afforded to macroinvertebrates (Ward 1984). It is important to remember that a healthy benthic macroivertebrate population is intrinsic to a healthy river.

List of Terms and Acronyms

References

Anderson, N.H., & J.R. Bourne. 1974. Bionomics of three species of glossosomatid caddisflies (Trichoptera: Glossosomatidae) in Oregon. Can. J. Zool. 52: 405-411

Anderson, N.H., & K.W. Cummins. 1979. Influences of Diet on the Life Histories of Aquatic Insects. Journal of the Fisheries Research Board of Canada 36: 335-342

Barton, B.A. 1977. Short-term effects of highway construction on the limnology of a small stream in southern Ontario. Freshwater Biology 7: 99-108

Beisel, J.N., P. Usseglio-Polatera, S. Thomas & J.C. Moreteau. 1998. Stream community structure in relation to spatial variation: the influence of mesohabitat characteristics. Hydrobiologia 389: 73-88

Boon, P.J. 1988. The Impact of River Regulation on Invertebrate Communities in the U.K. Regulated Rivers: Research and Management 2: 389-409

Borchardt, D. 1993. Effects of flow refugia on drift loss of benthic macroinvertebrates: implications for habitat restoration in lowland streams. Freshwater Biology 29: 221-227

Bouckaert, F.W., & J. Davis. 1998. Microflow regimes and the distribution of macroinvertebrates around stream boulders. Freshwater Biology 40(1): 77-86.

Britain J.E. 1990. Life history strategies in Ephemeroptera and Plecoptera, pp. 1-12. *In* I.C. Campbell (ed.). Mayflies and stoneflies: life histories and biology. Kluwer Aced. Publ., Dordrecht. The Netherlands 336pp.

Brusven, M.A., & K.V. Prather. 1974. Influence of stream sediments on distribution of macrobenthos. J. Of the Ent. Soc. Of B.C. 71: 25-32

Chutter, F.M. 1969. The effects of silt and sand on the invertebrate fauna of streams and rivers. Hydrobiologia 34: 57-76

Cobb, D.G., T.D. Galloway, & J.F. Flannagan. 1992. Effects of discharge and substrate stability on density and species composition of stream insects. Canadian Journal of Fisheries and Aquatic Sciences 49: 1788-1795

Collier, K.J. 1993. Flow Preferences of larval Chironomidae (Diptera) in Tongariro River, New Zealand. New Zealand Journal of Marine and Freshwater Research 27: 219-226

Culp, J.M., S.J. Walde, & R.W. Davies. 1983. Relative importance of substrate particle size and detritus to stream benthic macroinvertebrate microdistribution. Canadian Journal of Fisheries and Aquatic Sciences 40: 1568-1574

de March, B.G.E. 1976. Spatial and temporal patterns in macrobenthic stream diversity. Journal of the Fisheries Research Board of Canada 33: 1261-70

Death, R.G. 1995. Spatial patterns in benthic invertebrate community structure: products of habitat stability or are they habitat specific. Freshwater Biology 33: 455-467

Degani G., G.N. Herbst, R. Ortal, H.J. Bromley, D. Levanon, Y. Netzer, N. Harari & H. Glazman. 1993. Relationship between current velocity, depth and the invertebrate community in a stable river system. Hydrobiologia 263: 163-172

Diehl, S. 1993. Relative consumer sizes and the strengths of direct and indirect interactions in omnivorous feeding relationships. Oikos 68: 151-157

Gore, J.A. 1977. Reservoir manipulations and benthic macroinvertebrates in a prairie river. Hydrobiologia 55: 113

Gore, J.A. 1989. Models for predicting benthic macroinvertebrate habitat suitability under regulated flows, pp. 253-265. In Alternatives in Regulated River Management. Gores, J.A. and Petts, G.E. (eds.). CRC Press. Boca Raton, Florida, U.S.A.

Gore, J.A., D.J. Crawford, & D.S. Addison. 1998. An analysis of artificial riffles and enhancement of benthic community diversity by physical habitat simulation (PHABSIM) and direct observation. Regulated Rivers-Research & Management. 14(1): 69-77.

Gore, J.A., & R.D Judy. 1981. Predictive Models of benthic macroinvertebrate density for Use in instream flow studies and regulated flow management. Canadian Journal of Fisheries and Aquatic Sciences 38: 1363 – 1370

Hawkins, C.P., M.L. Murphy, & N.H. Anderson. 1982. Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams of Oregon. Ecology 63:1840-1856

Hynes, H.B.N. 1970. The Ecology of Running Waters. University of Toronto Press, Toronto, Ontario, Canada.

James, F.C., & C.E. McCulloch. 1990. Multivariate analysis in ecology and systematics: panacea or Pandora's box. Annu. Rev. Ecol. Syst. 21:129-166.

Jewett, S.G. 1959. The Stoneflies (Plecoptera) of the Pacific Northwest. Oregon State College Press, Corvallis, Oregon, U.S.A.

Korman, Josh. 2000. Personal Communication

Mackay, M.R. 1972. Larval sketches of some Microlipidoptera, chiefly North American. Mem. Ent. Soc. Can. 88: 1-83

Mathur, D., W.H., Bason, E.J., Purdy Jr., & C.A. Silver. 1985. A critique of the instream flow incremental methodology. Canadian Journal of Fisheries and Aquatic Sciences 42: 824

Merrit, R.K., & K.W. Cummins. 1996. An Introduction to the Aquatic Insects of North America. 3rd Edition. Kendall Hunt Publishing Company, Dubuque, Iowa, U.S.A.

Minshall, G. W. 1984. Aquatic insect-subtratum relationships, p. 358-400. *In* Resh, V.H., and Rosenberg, D.M. (ed.). The Ecology of Aquatic Insects. Praeger, New York, NY.

Orth, D.J., & O.E. Maughan. 1982. Evaluation of the Incremental Methodology for Recommending Instream Flows For Fishes. Trans. Am. Fish. Society. 11: 413-445

Orth, D.J., & O.E. Maughan. 1983. Microhabitat Preferences of Benthic Fauna in a Woodland Stream. Hydrobiologia 106: 157-168

Perrin, C.J., & J.S. Richardson. 1997. N and P limitation of benthos abundance in the Nechako River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 54: 2574-2583.

Perrin, Chris. 2000. Personal Communication.

Pritchard, G. 1983. Biology of Tipulidae. Ann. Rev. Ent. 28: 1-22

Quinn, J.M., & C.W. Hickey. 1994. Hydraulic parameters and benthic invertebrate distributions in two gravel-bed New Zealand rivers. Freshwater Biology 32: 489-500

Rabeni, C.F. & G. W. Minshall. 1977. Factors affecting microdistribution of stream benthic insects. Oikos 29: 33-43

Reece, P.F., & J.S. Richardson. 1998. Seasonal changes of benthic macroinvertebrate communities in Southwestern British Columbia. Environment Canada DOE-FRAP1998-33, 87pp.

Reece, P.F., & J.S. Richardson. In press. Benthic macroinvertebrate assemblages of coastal and continental streams and large rivers of Southwestern British Columbia, Canada. Hydrobiologia

Rempel, L.L., J.S. Richardson, & M.C. Healey. 2000. Macroinvertebrate community structure along gradients of hydraulic and sedimentary conditions in a large gravel-bed river. Freshwater Biology 45: 57-73

Rice, J.C. 1993. Forecasting abundance from habitat measures using nonparametric density estimation methods. Can. J. Fish. Aquat. Sci. 50: 1690-1698.

Richardson, J.S. 1993. Limits to productivity in streams: evidence from studies of macroinvertebrates. pp.9-15. *In* R.J. Gibson and R.E. Cutting [Eds.]. Production of Juvenile Atlantic Salmon, *Salmo salar*, in Natural Waters. Canadian Special Publication of Fisheries and Aquatic Sciences 118.

Richardson, John. 2000. Personal Communication

Statzner, B., J.A. Gore, & V.H. Resh. 1988. Hydraulic stream ecology: observed patterns and potential applications. Journal of the North American Benthological Society. 7: 307-360

Strand, R.M., & R.W. Merritt 1997. Effects of episodic sedimentation on the net-spinning caddisflies *Hydropsyche betteni* and *Ceratopsyche sparna* (Trichoptera: Hydropsychidae). Environmental Pollution 98(1): 129-134.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, & C.E. Cushing 1980. The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130-137

Wipfli, M.S., J. Hudson, & J. Caouette. 1998. Influence of salmon carcasses on stream productivity: response of biofilm and benthic macroinvertebrates in Southern Alaska, USA. Canadian Journal of Fisheries & Aquatic Sciences 55(6): 1503-1511.

Appendix A

List of genera from kick samples taken in the Coquitlam River between September 19th and October 2nd, 2000.

Sample ID			R2b Rif #1	R2b Rif #2	R2b Rif #3	R2b Rif #4	R2b Rif #5	R2b Rif #6	R2b Rif #7	R2b Rif #8	R2b Run #1	R2b Run #2	R2b Run #3	R2b Run #4	R2b Run #5
Depth			0.13	0.2	0.25	0.17	0.1	0.15	0.17	0.18	0.35	0.25	0.35	0.63	0.47
Velocity			0.56	0.9	0.89	0.43	0.6	0.66	1.47	0.48	0.37	0.47	0.41	0.50	0.79
Substrate*			g/c	g/c	b/g	c/g	c/g	c/c	c/c	c/g	c/g	c/g	c/g	c/g	g/g
Order	**Family**	**Subfamily/Genus**													
Hydracarina	Hydracarina	Hydracarina	0	0	0	0	1	0	0	0	1	0	0	0	1
Oligocheata	Oligocheata	Oligocheata	10	1	0	3	0	4	7	3	2	0	2	2	1
Arachnida	Arachnida	Arachnida	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Ceratopogonidae	*Probezzia*	0	1	0	0	0	0	0	0	0	0	0	0	0
	Chironomidae	*Chironominae*													
		Tanytarsini	38	10	0	2	10	3	1	0	1	1	6	0	2
		Orthocladiinae	34	13	9	5	36	5	0	3	6	4	14	3	2
	Dixidae	*Dixa sp.*	0	0	0	0	0	0	0	0	0	0	0	0	0
	Empididae	*Chelifera sp.*	5	0	0	0	0	0	0	0	4	0	0	0	0
		Oreogeton	0	0	0	0	0	0	0	0	0	0	0	1	0
	Simuliidae	*Simulium sp.*	3	0	1	4	6	0	0	0	0	0	0	0	0
	Tipulidae	*Antocha*	0	0	0	0	0	0	1	4	2	1	0	0	7
		Dicranota sp.	4	1	0	1	1	0	4	2	0	0	0	2	2
		Hexatoma sp.	0	0	0	0	1	0	1	0	0	0	0	0	0
	Adults	Adults	0	0	0	0	0	1	0	2	0	0	2	0	1
	Pupae	Pupae	5	1	0	0	1	0	0	1	1	0	2	1	1
Ephemeroptera	Baetidae	*Baetis sp.*	68	32	48	42	121	33	38	32	9	8	27	22	22
	Ephemerellidae	*Drunella sp.*	1	1	0	0	0	0	0	0	0	0	0	0	0
		Serratella sp.	9	3	0	0	12	4	0	2	0	1	1	0	0
	Heptageniidae	*Cinygma sp.*	0	0	0	0	0	3	0	0	0	0	0	0	0
		Cinygmula sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
		Rithrogena sp.	4	7	6	8	7	2	17	11	1	2	2	4	4
	Leptophlebiidae	*Paraleptophlebia*	0	0	0	0	0	0	0	0	0	0	0	0	0
Plecoptera	Capniidae	*Capnia sp.*	0	0	0	0	0	0	0	0	1	0	0	0	0
	Chloroperliidae	*Neaviperla sp.*	0	0	1	1	1	0	0	0	0	0	0	0	0
		Sweltsa sp.	12	5	5	5	2	2	9	4	1	0	1	0	2
		Utaperla sp.	1	1	0	0	0	0	0	0	0	0	0	0	0
	Nemouridae	*Zapada sp.*	8	5	1	5	10	4	1	2	0	0	2	2	2
	Perlodidae	*Skwala sp.*	14	3	1	9	3	2	1	4	1	0	0	4	4
Trichoptera	Glossosomatidae	*Glossosoma sp.*	0	1	2	0	0	0	0	0	0	0	0	1	0
	Hydropsychidae	*Hydropsyche sp.*	2	1	0	0	2	0	0	0	0	0	1	0	0
	Limnephilidae	*Chyranda sp.*	0	0	0	0	0	0	0	0	0	0	0	0	1
	Rhyacophilidae	*Rhyacophila sp*	6	1	0	0	3	1	0	1	1	0	1	0	4
Total			214	86	74	82	216	60	73	68	28	17	59	40	54

* (b;boulder, c;cobble, g;gravel, f; fines)

Sample ID			R2b Run #6	R2b Run #7	R2b Pool #1	R2b Pool #2	R2b Pool #3	R2b Pool #4	R2b Pool #5
Depth			0.41	0.55	0.48	0.53	0.69	0.46	0.8
Velocity			1.03	1.09	0.11	0.15	0.10	0.06	0.07
Substrate*			c/g	c/g	g/g	g/b	g/f	g/f	g/g

Order	Family	Subfamily/Genus							
Hydracarina	Hydracarina	Hydracarina	0	0	0	1	0	0	1
Oligocheata	Oligocheata	Oligocheata	1	7	1	1	0	2	0
Arachnida	Arachnida	Arachnida	0	1	0	0	0	0	0
Diptera	Ceratopogonidae	*Probezzia*	0	0	0	0	0	0	0
	Chironomidae	*Chironominae Tanytarsini*	3	1	2	0	0	1	0
		Orthocladiinae	3	3	1	2	0	2	0
	Dixidae	*Dixa sp.*	0	0	0	1	0	0	0
	Empididae	*Chelifera sp.*	0	0	0	0	0	0	0
		Oreogeton	0	0	0	0	0	0	0
	Simuliidae	*Simulium sp.*	0	0	0	0	0	0	0
	Tipulidae	*Antocha*	4	2	0	0	1	1	1
		Dicranota sp.	0	5	9	0	0	0	1
		Hexatoma sp.	0	0	0	1	0	0	0
	Adults	Adults	0	1	1	0	0	1	1
	Pupae	Pupae	2	2	0	0	0	1	0
Ephemeroptera	Baetidae	*Baetis sp.*	16	31	5	2	1	9	10
	Ephemerellidae	*Drunella sp.*	0	0	0	0	0	0	0
		Serratella sp.	1	1	4	0	1	1	0
	Heptageniidae	*Cinygma sp.*	0	0	0	0	0	0	0
		Cinygmula sp.	0	0	1	0	0	0	0
		Rithrogena sp.	12	12	1	0	0	2	4
	Leptophlebiidae	*Paraleptophlebia*	0	3	0	0	0	0	0
Plecoptera	Capniidae	*Capnia sp.*	0	0	0	2	0	0	0
	Chloroperliidae	*Neaviperla sp.*	0	0	0	0	0	0	0
		Sweltsa sp.	2	6	3	0	0	0	0
		Utaperla sp.	0	0	0	0	0	0	0
	Nemouridae	*Zapada sp.*	0	0	1	2	0	0	0
	Perlodidae	*Skwala sp.*	1	4	1	1	0	0	0
Trichoptera	Glossosomatidae	*Glossosoma sp.*	0	0	0	0	0	0	0
	Hydropsychidae	*Hydropsyche sp.*	0	0	0	0	0	0	0
	Limnephilidae	*Chyranda sp.*	1	0	0	0	0	0	0
	Rhyacophilidae	*Rhyacophila sp*	1	1	1	1	1	2	0
Total			46	73	30	12	4	20	17

* (b;boulder, c;cobble, g;gravel, f; fines)

Appendix B - **Still working on this**

Study	Orth and Maughan, 1983	Degani et al., 1993		Gore et al., 1998	Gislason, 1985	Gore, 1978	Horne et al., 1992	
Study Site	Glover Creek, Okalahoma	Dan River, northern Isreal		Holly Fork Creek, Tennessee	Skagit River, Washington		Laboratory, Australia	
Index	diversity	Abundance of taxa	Number of individuals	diversity	Density	Diversity	Austrosimulium furiosum	Simulium ornatipes
Optimum depth	34 cm	<30 cm		27 cm	Highest density found at 15 cms (density measured at 15, 25, 35, and 45 cm)	19 cm		
Optimum Velocity	60 cm/s	80-100 cm sec^{-1}	<60 cm sec^{-1}, > 90 cm sec^{-1}	65 cm sec^{-1}		72 cm sec^{-1}	20 –30 cm sec^{-1} final instar <25 cm sec^{-1}	90 –130 cm sec^{-1} final instar <25 cm sec^{-1}
Optimum Substrate	Rubble and boulder			Gravel and small cobble				
Min. / Max. Velocity		0-20 cm sec^{-1} / >140 cm sec^{-1}						