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Andrew Marr – GVRD
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Carrie Baron – City of Surrey
Richard Boase – District of North Vancouver
Tony Barber – City of North Vancouver
David Zabil – Kerr Wood Leidal Associates

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Summary

The purpose of this report is to identify and evaluate approaches for assessing and monitoring the health of urban streams in the GVRD. Assessment is the measurement of current condition while monitoring is the repeated collection of measurements to define trends over time. Stream health is a measure of the integrity of the ecological processes, chemical composition, habitats, and biological community that make up the stream ecosystem.

Monitoring contributes to the management of stream health by defining current condition, informing land use planning processes through forecasting, and measuring the success of stormwater management activities including low impact development practices in maintaining existing stream health.

Defining a question or questions is an essential component of the monitoring program. Three questions should form the basis of each monitoring plan: 1) What is the current health of the stream measured using a suite of indicators? 2) What is the predicted change in the stream's health in response to future urbanization and stormwater management activities? 3) What is the measured trend in a stream's health as urbanization and stormwater management activities occur? These questions should be modified to address specific management objectives and watershed conditions.

Five groups of approaches for monitoring stream health are described, assessed and compared: 1) watershed land cover; 2) hydrology; 3) environmental chemistry; 4) channel morphology and habitat; and, 5) aquatic biota. These groups represent different components of watershed processes or stream features. Ten criteria were used to assess and compare different monitoring approaches.

Approaches using watershed land cover or land use are generally highly rated because they are suitable for many areas of the GVRD, are strongly linked to other measures of stream health, are easily communicated and incorporated into land use planning, and do not exhibit temporal variability other than associated with land development. However, they may not be effective for all watersheds in the GVRD.

Hydrology monitoring requires an integrated program that combines the measurement of streamflow and precipitation with hydrologic modeling. It can use time-series analysis to compare measured streamflow or it can calculate a range of hydrologic metrics using computer models that are either based on streamflow parameters or water balance parameters. Metrics are useful because they can communicate complex hydrologic processes.

Traditional water quality approaches that measure field and lab parameters during summer baseflow are poor for monitoring trends or addressing variability, but they are generally lower cost and can be completed anywhere in the region.Automated water quality monitoring or storm event sampling address the inherent variability of water quality and are suitable for trend analysis, but they are also expensive to implement.

Channel morphology and instream habitat approaches received low ratings because they are difficult to measure consistently and are not necessarily associated with stream health. Visual estimates of substrate composition and other channel characteristics vary between observers.
As well, channel conditions change in response to natural stream processes unrelated to urbanization.

Of the approaches focusing on aquatic biota, the Lower Mainland B-IBI and RCA-CABIN approaches to benthic invertebrate monitoring received the higher ratings. The Lower Mainland B-IBI approach is more strongly linked to measures of stream health such as imperviousness and is more easily used to detect trends because of the statistical properties of the index. However, the RCA-CABIN approach can be used on a wider variety of stream types and is lower cost. Additional work is needed to refine or develop benthic invertebrate sampling methods that are appropriate for the range of stream types in the region, including intermittently flowing streams.

The report also suggests monitoring approaches for the GVRD based on the results of the review. It provides recommendations on using a suite of monitoring approaches, and provides preliminary direction on specific variables, methods, and monitoring frequency. It also discusses further work that is needed to develop, test, or refine monitoring approaches or methods.
Part 1 - Introduction

The purpose of this report is to identify and evaluate approaches for assessing and monitoring the health of urban streams in the GVRD. Watersheds and streams experience predictable changes in land cover, hydrology, channel morphology, water and sediment chemistry, and biological characteristics during urbanization (Booth and Reinelt, 1993; Schueler, 1994; Karr and Chu, 1999; Snyder et al., 2003). Forests are cut, wetlands and floodplains are drained, and roads, parking lots, and buildings replace natural vegetation and permeable soil. Stormwater systems are the primary driver of changes to stream health in urban areas because they control or influence the movement of water, sediment, and chemical constituents in the watershed. Increasing amounts of stormwater runoff result in systemic and cumulative changes to stream processes and physical characteristics that generally result in a decline in stream health. Many of these changes are associated with hydrologic disturbance, while others, particularly at higher levels of urban development, are associated with chemical or physical changes in water and sediment.

Monitoring contributes to the management of stream health by defining current condition, improving the understanding of ecological processes in streams, informing land use planning processes through forecasting, and measuring the success of low impact development (LID) and other stormwater management activities in maintaining stream health. Monitoring can also be used to track changes to stream health across the Greater Vancouver region as part of commitments under the Liquid Waste Management Plan (LWMP).

1.1 Assessment, Monitoring, and Forecasting of Stream Health

In urbanizing watersheds, the goal of assessment and monitoring is to measure the current health of the stream and track changes in health that are associated both with the broad effects of urbanization and the specific effects of stormwater management activities. Assessment is the measurement of current condition while monitoring is the repeated collection of measurements to define trends over time. Forecasting is a separate but related part of the process that links the results of assessment and monitoring to the decision-making process involved in land use planning. Forecasting uses relationships between stream- and watershed-scale variables that are defined by assessment and monitoring activities to predict future condition. An example of forecasting is the Watershed Health Tracking Tool that was developed for the current Integrated Stormwater Management Plan (IMSP) template (KWL, 2005). It uses Effective Impervious Area and riparian forest integrity to predict stream health based on changing urban land use.

Trends in stream health may be expressed in a variety of ways including changes to fish or benthic invertebrate community, increased concentrations of contaminants in water or sediment, increased magnitude or frequency of peak flows, or changes to stream channel morphology.

The spatial scope of environmental monitoring programs can range from the whole region, to a municipality, a stream or tributary, or a specific site. However, most environmental monitoring

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1 *Stream health* is a measure of the integrity of ecological processes, chemical composition, habitats, and biological community in a stream ecosystem. It incorporates processes at multiple scales including watershed hydrology, riparian-stream channel interactions, and instream (inwater, benthic, and hyporheic) components. Karr (1999) noted that healthy “is short-hand for good condition”. 

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for stormwater is undertaken on a single stream within a defined watershed. In the GVRD, most
stream health monitoring is undertaken as part of ISMP initiatives in watershed between 500
and 1,500 ha.

Effective Monitoring – An effective monitoring program for urbanizing streams has the
following traits:

1. It can quantify and simplify the complex biological and physical response of streams to
   urbanization and stormwater management;
2. It is stable (low variability) through time and space in response to sources of variance not
   associated with stormwater management or not addressed through the monitoring method;
3. It can be consistently measured over time by different users using standardized methods;
4. It is cost effective to measure and analyze;
5. It provides information that is useful for land use planning and other decision-making
   processes and for communicating with resource managers and the public; and
6. It can assist in the forecasting future conditions.

Most monitoring programs for urban streams use indicators as surrogates for complex
processes or responses that are more difficult to measure directly. Indicators may be associated
with the causes of environmental change (pressure indicators) in urbanizing watersheds (e.g.,
land cover measures of increasing imperviousness and loss of forest cover), with changes to
watershed-scale processes (e.g., process indicators such as measures of hydrologic
disturbance), or with effects to habitat or the biological community (e.g., response indicators
such as channel dimensions or the benthic invertebrate community). Indicators are often
compared to reference values obtained from streams in the region with very low levels of
urbanization or to regional or provincial standards. For example, both multimetric (e.g., B-IBI)
and multivariate (e.g., RCA) approaches to analyzing benthic invertebrate data compare the
sampled community to the structure and diversity found in undisturbed, reference streams.
Concentrations of metals or nutrients in urbanized streams are sometimes compared to levels
found in undisturbed streams with similar environmental characteristics, but more often to
standards such as the BC Water Quality Guidelines. Indicators are also selected for their ability
to communicate results; indicator trends for stormwater management are most useful if they can
clearly draw attention to underlying changes in stream health.

Defining Monitoring Questions – The range of options for monitoring stream health provides
many opportunities for municipalities and other organizations to develop innovative monitoring
programs suited to local conditions. However, the diversity of sampling methods and techniques
are also a distraction which reduces emphasis on monitoring program design. Scholz and Booth
(1999) commented that: “the major shortcoming is in choosing an approach that will provide
sufficient data to answer particular management questions and that is feasible for the
institutional context and available resources.” Too often most of the time and resources are
spent on equipment, field sampling, or lab analysis rather than on the development of clearly
defined monitoring questions and adequate time for analysis, reporting, and dissemination of
results. The development of new techniques such as automated water quality monitoring
(AWQM) and benthic invertebrate sampling has worsened this situation by vastly increasing the
amount of data collected without providing a clear approach for analyzing trends or linking
results to decision-making. Chapman (1996) restated this issue succinctly in the context of
water quality monitoring: “no assessment programme should be started without scrutinising
critically the real need for water quality information (i.e. the “need to know” as opposed to “it
would be nice to know”). It is unfortunate that much of the data collected on stream health is never analyzed. Even more rarely does information on stream health inform decision-making for land use planning and stormwater management.

**Core Monitoring Questions** – Defining a question or questions is the most important component of the monitoring program and relates to the scale of the program (regional, municipal, watershed, or subwatershed), the level of urbanization, the spatial patterns of urbanization, stormwater management activities, and the time and resources available. The majority of stream monitoring activities in the GVRD will be undertaken for individual streams as part of the ISMP process.

Three questions should form the basis of each monitoring plan, although these are expected to be modified to suit specific ISMP or municipal objectives and watershed conditions:

1. **What is the current health of the stream measured using a suite of indicators (e.g., land cover, hydrologic, biological, and chemical parameters)?** This is an assessment question that will begin to define the baseline from which predicted or measured change will be compared. Assessment occurs during or prior to the beginning of Phase 2 of the ISMP process.

2. **What is the predicted change in the stream's health in response to future urbanization and stormwater management activities?** This is a forecasting question that will use modelling and other methods to predict stream health from the distribution and intensity of future development. It uses the information collected during the assessment of current stream health to form the baseline from which future change is forecast. Forecasting occurs during the middle of Phase 2 of the ISMP process.

3. **What is the measured trend in a stream's health as urbanization and stormwater management activities occur?** This is a monitoring question. Its purpose is to measure changes to stream health, evaluate the success of land use planning and stormwater management, and guide future stormwater management activities as part of adaptive management. Monitoring occurs during implementation of the ISMP. A monitoring program from 5 to >20 years duration will be needed to detect changes in stream health.

**Other Monitoring Questions** – Other monitoring questions may be developed for more general or more specific projects. Examples include:

- What are the overall trends in stream health in the GVRD since 2001?
- Have recent stormwater management activities improved the health of Como Creek?
- Has instream habitat restoration resulted in an increase in B-IBI values in Beecher Creek from 2001 to 2004?
- Do concentrations of total and dissolved metals in Wagg Creek exceed BC Water Quality Guidelines during small (<20 mm/24hrs) storms?
- Does the Lost Lagoon biofiltration wetland reduce the total zinc concentration in effluent water in <6 month return-period storms based on EMC (event mean concentration)?
1.2 ISMP Monitoring Approaches

The Liquid Waste Management Plan (LWMP) guides stormwater management planning in the GVRD. It states that “the District and member municipalities will undertake monitoring, assessment and forecasting to evaluate effects of stormwater discharges to receiving environments”. As part of this commitment, the GVRD through the Stormwater Inter-agency Liaison Group (SILG) provides direction to member municipalities on approaches for assessing and monitoring the effects of urbanization and stormwater management on the health of streams and rivers. The LWMP requires the development of Integrated Stormwater Management Plans (ISMPs) for all regional watersheds by 2014.

The current ISMP template (KWL, 2005) provides guidelines for assessing and monitoring several aspects of stream health. The ISMP template is not prescriptive but is intended to provide municipalities with guidance for urban watershed management planning that is suitable for the environmental and regulatory conditions in Greater Vancouver. It includes tasks described as “minimum effort” (core tasks) and “maximum effort” (optional tasks). The minimum effort for environmental monitoring includes:

- Collection of hydrometric (precipitation and runoff) data from one site in the watershed for dry and wet seasons (+/-12 months);
- Assessment of Effective Impervious Area (%EIA) from flow monitoring and modeling;
- Measurement of riparian forest cover (%RFI) within 30 m of the stream channel;
- Collection of benthic invertebrate using the B-IBI methodology for riffle streams in Greater Vancouver (Lower Mainland B-IBI);
- Field sampling of water temperature, specific conductivity, dissolved oxygen, pH under baseflow conditions for all tributaries, storm outfalls, and stream reaches; and
- Baseflow water quality sampling at one site for total metals (ICP scan), total suspended solids, ammonia nitrogen, hardness (alkalinity), fecal coliforms, and total coliforms.

Under maximum effort, the ISMP template also suggests additional tasks for assessing land use, fish populations, and water quality such as increased baseflow sampling of water quality at major storm outfalls or conducting detailed fish population sampling in reference sites.

The ISMP template provides modest direction on the use of monitoring to track stream health in urban watersheds. It does not, for example, provide direction on the duration or frequency of various sampling approaches nor does recommend the development of a monitoring plan as a component of minimum level of effort. Instead the ISMP template provides general direction on the use of adaptive management principles and recommends as a minimum level of effort to use B-IBI scores, riparian forest cover, EIA, flow monitoring, and other performance measures for monitoring change in stream health over time. It also notes that municipalities can include additional parameters such as dry weather water quality in an expanded (maximum effort) monitoring program. A joint SILG/EMC subcommittee is working toward an environmental monitoring guide for the region that will expand the guidance for stream monitoring as part of ISMPs.
1.3 Examples of Stream Monitoring in the GVRD

Municipalities and other organizations in Greater Vancouver have undertaken stream assessment or monitoring within or outside of ISMP-related watershed planning. Examples of these activities are described below.

- The Ministry of Sustainable Resource Management (MSRM) measured land cover change in the GVRD between 1986, 1998, and 2002 using Landsat imagery (see Geospatial and Timberline, 2004). This was not combined with watershed and catchment boundary information, but it could be also used to examine land cover change in urbanizing watersheds.

- The GVRD measured land use (BC CLUCS codes), TIA, and riparian forest cover in most watersheds and catchments in 1999 using a GIS-based interpretation of 1996 orthophoto imagery. This used methods described in Page et al. (1999) and the results of the TIA and riparian forest cover assessments are summarized in GVS&DD (1999). This analysis was subsequently expanded to predict watershed health using projections of population change and the relationship between TIA and population density (Hicks and Woods, 2000).

- The GVRD will soon complete a 4-yr study that examines temporal and spatial variability of B-IBI in 13 streams in Greater Vancouver from 1999 to 2006 (Page et al., 2005). This study sampled benthic invertebrates using the B-IBI system developed for riffle streams in the GVRD (Lower Mainland B-IBI). It has shown the B-IBI is stable through time in watersheds with minor changes in land use, and is strongly correlated with watershed-scale measures of urbanization.

- The District of North Vancouver sampled benthic invertebrates in eleven streams and rivers in 2003 using the Lower Mainland B-IBI approach (Page, 2004). It is noteworthy that sampling program was undertaken in a range of streams that may be the focus of ISMP planning in the next decade, rather than individual streams at the time of ISMP development. The municipal-scale approach is effective at providing comparative information on stream health throughout the municipality, and may also be more cost effective than sampling individual streams.

- UBC Utilities monitors stormwater quality in three developed catchments on the UBC campus and one reference site (Cuthroat Creek) in Pacific Spirit Regional Park (Raincoast Applied Ecology, 2003). This program, started in 2001, collects water temperature, turbidity, specific conductivity, temperature, and water level data using automated probes at 15 minute intervals. Storm sampling for metals, hydrocarbons, fecal coliform bacteria, and total suspended solids was also undertaken for 11 storms in 2001–2003. Some benthic sampling was also completed in 2002. This is the longest running automated water quality monitoring program for stormwater in the GVRD.

- Environment Canada has sampled benthic invertebrates at 24 sites in the GVRD since 1998 as part of ongoing assessment work on freshwater ecosystems in the Georgia Basin (Sylvestre et al., 2005). This includes agricultural and urban watersheds. The approach combines kicknet sampling with a multivariate reference condition approach (RCA) that is termed RCA-CABIN. All sites in the GVRD are test sites (e.g., disturbed streams) rather
than reference sites. Results indicate that most streams in the region are stressed or possibly stressed. This monitoring program is part of a national initiative.

- The City of Surrey initiated a stream monitoring program in 1997. It currently includes six rain gauges, 11 hydrometric stations, one automated water quality station on the Little Campbell River, six water temperature probes, and 21 benthic invertebrate monitoring sites (see below).

- The City of Surrey also developed its own benthic invertebrate monitoring program to assess developing streams (Dillon Consulting, 2005). Twenty-one sample locations have been established since 1999. Because of the low summer flows and low gradient stream channels in Surrey, sampling as been completed spring (late-April) and fall (early-November). It uses a standard 10-metric B-IBI approach to analyze data collected from three replicate samples using a 250 micron Surber sampler from three adjacent riffles. No subsampling is undertaken and the level of taxonomic resolution is slightly higher than used in other B-IBI approaches in the GVRD (e.g., chrinomomids to subfamily). It has found that B-IBI values are quite variable in both disturbed and undisturbed sites.

- The City of North Vancouver incorporated forest cover mapping, benthic invertebrate sampling (Salmonweb B-IBI; 3 replicates at one site), and water quality sampling (seasonal baseflow sampling using non-flow partitioned composite samples of metals and other basic parameters) into a city-wide environmental monitoring program started in 2002 (KWL, 2005). Benthic invertebrates were resampled in 2006 to track changes to stream health using the Lower Mainland B-IBI method.

- The BC Ministry of Environment through the Environmental Quality Section of the Lower Mainland Region has assessed and analysed a wide variety of water quality data from urban streams. Examples include water quality analysis and risk assessment (Quilty and Fleming, 2005) and ongoing benthic benthic sampling in 14 streams in the region using B-IBI methods. Water quality data for streams in the GVRD is available on the web (see MOE, 2006).

- Students and faculty at the University of British Columbia have undertaken a broad range of research projects that provide a strong foundation for environmental monitoring in urban watersheds. Most of this work has been directed by Ken Hall and Hans Schreier in the Institute for Resources, Environment, and Sustainability. This includes work on the Salmon and Brunette river watersheds (Hall and Anderson, 1988; Berka et al., 2001; McCallum, 1995; McDonald et al., 1997; Zandbergen, 1998), as well as recent work on biofiltration wetlands using DGT technology by Brydon (2004). Other works include Smith (1994), Finkenbine et al. (2000), Richardson et al. (1998), and Cohen (2005).

- Stewardship groups such as local streamkeepers are also active in monitoring programs. This includes stream assessment using Streamkeepers methods, or more intensive water quality or habitat monitoring. Examples include water quality work by the Stoney Creek Environment Committee (Soukatchev, 2005), benthic invertebrate sampling by Markus Eymann with the Musqueam Creek Committee (MCC, 1998), water quality and benthic invertebrate work by the Shared Waters Alliance and A Rocha Canada. There are many other examples.
• The GVRD, Environment Canada, District of North Vancouver, and the Township of Langley jointly supported a study that compared the composition of benthic invertebrate samples collected using Lower Mainland B-IBI (Surber) and RCA-CABIN (kicknet) methods, as well as the results of the two analysis methods on characterizing stream health (Page and Sylvestre, 2006.). The study used data collected in North Vancouver in 2003 and more broadly in the GVRD in 2004. It found that both methods provided similar estimates of benthic community structure, and similar assessments of stream health.

• The City of Burnaby and the Beecher Creek Streamkeepers recently compared B-IBI values in a section of Beecher Creek that has been enhanced for fish populations to a section that was not enhanced. There was no statistical difference between the sampling sites and indicated equally degraded stream conditions.

• The Township of Langley implemented a benthic invertebrate sampling program on Yorkson Creek in 2004 and 2005 to collect baseline data with which to evaluate stormwater management performance (Page, 2005). This compliments the use of Yorkson Creek as one of the GVRD’s study streams for assessing variability in B-IBI.

• Water quality and benthic invertebrate sampling has been undertaken as part of ISMPs for Bertrand Creek (3 benthic sites; 12 wq sites) in Langley (2004), Hyde Creek (1 site; ongoing water quality monitoring) and Partington Creek (1 benthic site in 2005) in Coquitlam, South Schoolhouse Creek in Port Moody (1 benthic site in 2004 and 2006), and the lower Brunette River (1 benthic site in 2006). McDonald, Lawson, Marr, and Rodgers creeks in West Vancouver were sampled in 2003. Lawson and McDonald creeks were also sampled in 2001 and 2004 to assess B-IBI variability, and Marr and Rodgers creeks were resampled in 2006. Bertrand and Yorkson creeks were also sampled using RCA-CABIN methods in 2005 to provide complimentary information on stream health.

• Many municipalities have installed hydrometric stations and rain gauges in urban watershed that can be used for a variety of stormwater management activities. These include the District of North Vancouver (3 hydrometric stations; 3 rain gauges), District of West Vancouver (1 hydrometric station; 1 rain gauge), City of North Vancouver (2 hydrometric stations; 1 rain gauge). City of Burnaby (2 hydrometric station; 2 rain gauges). City of Whiterock (1 rain gauge), City of Surrey (2 hydrometric stations; 4 rain gauges), Port Coquitlam (1 rain gauge), and City of Coquitlam (2 hydrometric stations; 2 rain gauges).

• As part of the Hyde Creek integrated watershed management plan, the City of Coquitlam has undertaken a comprehensive monitoring program to determine baseline conditions prior to development and monitor changes development progresses. It consists of: 1) automated hydrometric stations at three sites (2004 to present); 2) automated continuous recording water quality stations (temperature, pH, sp. conductivity, diss. oxygen, turbidity) with depth sensors; 3) bimonthly sampling (June 2004–December 2005) of an expanded set of water quality parameters (inc. total metals, diss. metals, nutrients, and hydrocarbons) at 10 sites; and, 4) benthic invertebrate sampling at four sites using B-IBI methods, but during spring and fall flows. Benthic invertebrate sampling and the installation of a hydrometric station was also completed in Partington Creek in 2005 as part of an ISMP.
Environment Canada used Yorkson Creek for a comprehensive assessment of non-point pollution in a representative urban-rural watershed (see Fluegel et al., 2004). They exposed cutthroat trout and crayfish to stream-water in a managed system while at the same time monitoring a variety of water quality parameters. The biological effects of exposure were investigated by analysis of contaminants in tissue, organ histology, biochemical indicators, as well as fish growth and health.

1.4 Understanding Natural Variability in Stream Ecosystems

A critical challenge for monitoring programs in urban streams is to separate the effects of stormwater management from variability associated with natural fluctuations or anthropogenic factors that are unmanaged. It can be difficult to detect the effect of stormwater management activities given the seasonal or precipitation-related variability of many stream processes. While stream health declines predictably with urbanization, the response of each stream is unique (Figure 1). Patterns of development (headwaters or lowlands), soil or geomorphological conditions (steep vs. shallow; glacial till vs. porous gravels), watershed size, or the use of stormwater management source controls (e.g., infiltration features) influence the response of streams to urbanization. Schueler (2002) found that many indicators of stream health in small watersheds in which stormwater source controls were used were indistinguishable from those in watersheds that lacked treatment. He stated that: “the impact of watershed treatment would need to be extremely dramatic to be detected, given the inherent statistical variability seen in small watersheds”. Horner and May (2000) found that structural stormwater BMPs (employing only rate control and water quality treatment methods such as detention facilities) do not maintain ecological integrity and were indistinguishable from watersheds without BMPs (Figure 2). This issue is even more important in moderately or highly urbanized watersheds because the reduction in stormwater-related impacts on hydrology and water quality must be very large for there to be a measureable improvement in stream health.

Fig. 1. Nonlinear relationship of B-IBI to total impervious area in 32 streams and rivers in Greater Vancouver (unpublished data from 2003–2005). Note that the most rapid change occurs between 0–10% TIA. The site indicated in red is South Schoolhouse Creek in Port Moody which has a substantially higher B-IBI value than would be predicted by its level of urbanization. The three sites in the lower left (shown in blue and excluded from the regression line) are Capilano River, Seymour River, and Lynn Creek in North Vancouver. All three have different benthic communities than small streams despite their low imperviousness.
Many biological, hydrological, or chemical characteristics of streams change over time in response to daily, seasonal, or longer-term ecological or physical processes. Some of these changes are predictable such as diurnal and seasonal water temperature fluctuations and can be accounted for using consistent sampling methods (e.g., continuous recording or defined seasonal measurements). Other parameters such as water quality characteristics are more variable and may respond to short-term changes in precipitation or chemical inputs, particularly in moderately or highly urbanized streams. For example, total suspended solids, turbidity, and total metal concentrations increase in response to rainfall but their maximum concentrations are difficult to predict for individual storms because of differences in rainfall intensity, antecedent dry periods, and other factors (Figure 3). Figure 4 shows an example of water chemistry in three stormwater catchments and one reference site (Cutthroat Creek) at the University of British Columbia in response to two storms in January 2003. Streams in undeveloped watersheds have much more stable water chemistry characteristics than urbanized streams.

Environmental characteristics in streams in Greater Vancouver may also respond to long-term climate cycles such as El Nino Southern Oscillation (ENSO). A recent study using long-lived freshwater mussels (western pearlshell mussel \( \textit{Margaratifera falcata} \)) from Coghlan Creek in Langley found that mussel growth rates were highly correlated with summer precipitation.
Increased summer precipitation during weak El Nino periods may increase shell growth by increasing nutrient-rich runoff. The pattern between 1955–2003 showed peaks in growth coinciding with increased summer precipitation every 7.5–9.0 years (Figure 5). This suggests that regional scale climate patterns may influence ecosystem dynamics in small streams in Greater Vancouver. However, too little is known about how long-term regional climate patterns influence stream ecosystems to evaluate their effect on stream health trends at present.

Fig. 4. Variation in specific conductivity, water temperature, and turbidity in two stormwater catchments (red and blue lines) on the UBC campus and one reference site (Cutthroat Creek; green line) in response to two small storms (13.8 and 12.4 mm) in January 2003. Note the rapid decline of specific conductivity with increasing dilution from rainfall in the stormwater catchments, as well as the lack of a pronounced response in conductivity, temperature, or turbidity in Cutthroat Creek. Unpublished data from UBC Utilities.
The benthic invertebrate community also varies over time because of the lifecycles of organisms, as well as floods, chemical spills, or other events that disturb the invertebrate or algal community (see Figure 6 showing invertebrate taxa richness in Musqueam Creek). Seasonal differences can be minimized by collecting samples during a specified time period each year (typically August–September) and short-term fluctuations can be reduced by avoiding sampling during or soon after large storms. The benthic invertebrate community may also change in response to seasonal climate (e.g., precipitation or temperature), although the effects of climate are uncertain and likely subtle. Benthic invertebrate samples from Greater Vancouver streams indicate that B-IBI is stable over time (Page et al., 2005). B-IBI values for 1999, 2003, 2004 and 2005 were all highly correlated (r>0.90) indicating strong agreement between the different sampling years. For 1999 vs. 2003, the mean difference in B-IBI was 3.4 points lower in 1999. For 2003 vs. 2004 and for 2004 vs. 2005, the agreement was closer with an average difference of 0.4 points lower and 0.6 points lower respectively. However, individual streams can experience large annual differences: the mean B-IBI value of the Serpentine River was 8 points higher in 2003 than in 1999 (20.5 vs. 12.5) then declined 4 points (20.5 vs. 16.5) between 2003 and 2004 (Page et al., 2005).
Most other studies have found similar yearly differences for multimetric indexes (Hughes et al., 1998; Karr and Chu, 1999; Fore, 2002), however, a recent study in the City of Surrey and studies in other regions have found greater variability. Sampling in the City of Surrey mean B-IBI was 3.6 points higher in the spring of 2002 than at the same time in 2001 (-2 to +6 difference). Similarly, mean B-IBI from fall sampling in 2002 was 4.9 points higher in the fall of 2001 (0 to +12 difference) (Dillon Consulting, 2004). Increased variability in benthic invertebrate communities found in the City of Surrey results may be caused by higher hydrologic variability during the spring and fall.

1.5 Trend Monitoring vs. Screening-level Surveys

An essential objective of stream monitoring is to detect trends in stream health (Figure 7). Trends can be assessed qualitatively through the visual assessment of data, or more rigorously using statistical techniques such as linear regression (parametric) or a Seasonal Kendall test (nonparametric). Helsel and Hirsh (2002) provide a good introduction to trend monitoring for water resources. The data requirements for statistical trend analysis are large: 5 years of consistently measured monthly water quality data is recommended by Lettmeir et al. (1992) as a minimum for trend analysis. Many municipal monitoring programs do not have resources or expertise to commit to rigorous, long-term monitoring programs for more than 1 or 2 years. Another option, generally recommended by the ISMP template, is to conduct screening-level surveys that provide both baseline information on stream health, and data against which future change can be compared. A screening-level survey will generally be less rigorous than a trend monitoring study and therefore will tell you less about stream health and with less certainty.

Fig. 7. Example of water quality trend analysis using sulfate concentrations in the Palachicola River, Florida from 1972-89. Note that the overall trend masks the abrupt increase in sulfate concentration in 1981. The Seasonal Kendall test was used for trend detection (red line; p<0.001) (from Hirsch et al., 1991)

1.6 Consistency of Methods

Consistency of data collection and analysis is a critical component of all environmental monitoring programs, but particularly for those using statistical analysis to measure trends. Hirsch et al. (1991) noted that “there can be no exceptions to this requirement of constancy” for data used for trend analysis. Consistency includes following a standardized sampling plan that
specifies the frequency, location, field collection methods, sample storage or treatment, and laboratory-based analytical techniques that are used.

For field sampling this should include the location of the site that is sampled, equipment used, and sampling method (time of day, etc). Descriptions of data analysis should include details on data transformation, treatment of censored data, and referenced descriptions of statistical tests. For benthic invertebrate sampling, issues such as mesh size of the sampling net, time sampled (e.g., 2 minutes of substrate disturbance), lab-based subsampling procedures, the level of taxonomic resolution, and the accuracy of the identification through reference collection review are also critical. All methods should provide adequate information to guide repeat sampling in the future.
Part 2 - Potential Environmental Monitoring Approaches

Five groups of approaches for monitoring stream health are presented in this section:

1) watershed land cover;
2) hydrology;
3) environmental chemistry;
4) channel morphology and habitat; and
5) aquatic biota.

These groups represent different components of watershed or stream processes ranging from hydrologic changes associated with land cover, to changes in water quality or the benthic invertebrate community. Figure 8 shows a hierarchical summary of these components and their connections. Selected references are provided in Appendix 1.

Fig. 8. Relationships between different components of stream health. Arrows show the interactions between the components; the width the arrows indicates the strength of the interaction. Watershed land cover can be considered the primary driver of changes to hydrology, environmental chemistry, channel morphology and habitat, and aquatic biota.

2.1 Watershed Land Cover and Land Use

There is a strong link between watershed-scale land cover or land use patterns and the chemistry, physical structure, and biological community of streams and rivers. Considerable research, much of it in the Pacific Northwest, has shown predictable declines in a variety of measures of stream health with increasing urbanization (May et al., 1997; O’Neil et al., 1997; Snyder et al, 2003; Booth et al., 2004; Alberti et al. 2004). Most changes are linked to different aspects of urban development including impervious areas and their associated stormwater drainage systems, watershed forest cover, loss of riparian forest, and increasing road density. For example, research in the GVRD has shown that B-IBI declines with increasing imperviousness (Fig. 1), and that B-IBI is more strongly correlated with watershed land use than
with site-level factors such as substrate (Page et al., 2005). It is important to note that most of the research on watershed land cover and stream health has been undertaken at a watershed scale; the variables may be less effective for monitoring changes to small catchments. Recent work by King et al. (2005) has shown that analyses examining the relationships between land cover and water chemistry or biological condition should consider the interdependence of land cover types, autocorrelation, and indirect and direct linkages that result in environmental change.

Imperviousness is the broadest indicator of the effect of stormwater on stream health (Schueler, 1994; Arnold and Gibbons, 1996; May et al., 1997). Impervious areas are hard surfaces such as roads, parking areas, and roofs that collect precipitation and rapidly convey it to streams through ditches and pipes. Impervious areas also prevent the infiltration of precipitation into the ground, and increase the volume and rate of surface runoff. Impervious areas, particularly roads and parking areas, are also effective at capturing sediment-bound contaminants or spills from which they can be transported by surface runoff to streams.

Other parameters may be good predictors of stream health depending on specific watershed conditions. Roads are a ubiquitous component of watershed development and they directly and indirectly affect water quality and hydrology (Avolio, 2003). Roads account for a high proportion of impervious areas and are a precursor to further urbanization. Road density was strongly correlated with total imperviousness in a study of urbanization effects in Puget Sound (May et al., 1995; Wheeler et al., 2005). In a study of urban development patterns in Puget Sound using remote sensing data, road density and the number of road-stream crossings were a better predictor of biological condition in small streams than imperviousness (Alberti et al., in press in Avolio, 2003). However, this result needs further research. Watershed forest cover may be more useful in watersheds with a mix of urban, rural, and agricultural land use. Forests represent the proportion of the watershed where intact hydrologic and water quality processes occur (Booth et al., 2002). Septic field density is a useful indicator of bacteriological and nutrient pollution in some rural watersheds, but is only a concern in rural areas that are not fully serviced by municipal sanitary sewers. Stream channel density (km of stream channel/ km²) may also be an indicator of the effect of urbanization on streams. Stream density is often increased by urbanization as anthropogenic drainage features are developed (Graf, 1977; May et al., 1997). Population is a driver of many processes that affect stream health, and population density may also be a broad indicator of urbanization impacts. Hicks and Woods (2000) found a nonlinear relationship between TIA and population density in Greater Vancouver (at high population density, further increases in population do not result in major changes to imperviousness).

Land cover or land use is measured with GIS analyses using data from air photos, satellite imagery, or other mapped or model-based information. Land cover is defined as the mixture of natural and modified surface elements such as forest, field, and water. Land use is the economic activity that occurs on the land such as golf course, transportation, or park. Like many indicators, issues of consistency of spatial and temporal scales are important; land cover obtained from 30 m pixel Landsat data from 1998 cannot be compared to land cover obtained by detailed assessment of 2005 orthophotos. Interpretation of land use by different analysts may also produce inconsistent datasets. Similarly, the delineation of the stream channel network affects measures such as stream network density or road crossing per stream kilometer. The stream channel network shown on 1:20,000 TRIM mapping is much less precise than the field-based stream network mapping with a differential GPS.
Potential Approaches

- **Watershed Land Use - Orthophotos**: analysis of land use based on the Corporate Land Use Classification System (CLUCS) land use codes and recent (within 2 years of assessment date) orthophotos is a suitable approach for land use analysis in the GVRD. Existing land use data is available for the GVRD from 1996 orthophotos (see GVS&DD, 1999) and can be used for comparison.

- **Total and Effective Imperviousness (Land Use Derived)**: calculation of imperviousness from land use information based on standard TIA and EIA conversion factors adapted for CLUCS land use codes provided in Page et al. (1999). Imperviousness calculations using land use are not as accurate as those derived from hydrometric data, but they remain a useful assessment and monitoring tool for stream health that can clearly linked to land use planning.

- **Watershed Forest Cover**: GIS assessment of recent (<2 yr old) colour orthophotos; suggested definitions: forest is woody vegetation >5 m in height and >75% canopy closure; minimum patch size is 0.2 ha.

- **Riparian Forest Cover**: delineation of forest cover adjacent to open stream channels defined as 30 m wide zone adjacent to the centerline of the stream network. TRIM mapping is recommended for regional applications to improve consistency between different spatial datasets, but more detailed mapping is recommended for ISMPs. Existing data is available for most streams in the GVRD from 1996 orthophotos (see GVS&DD, 1999). It is important to note that this assessment method was not designed to be compatible with RAR standards, and is meant to encompass a range of stream channel-riparian interactions. Other factors such as the type, quality, and continuity of the plant community may also be important factors.

- **Watershed Land Cover – Satellite Imagery**: land cover estimates based on interpretation of satellite imagery (typically Landsat). Geospatial and Timberline (2004) provide a good description of their method which allows for comparison to existing 1986, 1998, and 2002 land cover data from the GVRD. Alberti et al. (2004) and Snyder et al. (2005) are also useful as examples of the use of satellite imagery for urban land cover mapping and watershed analysis.

- **Transportation Indicators**: many measures of transportation impacts are strongly associated with stream health such as road density (km/km²), road crossings (no/km² of stream), and transportation intensity (vehicle kilometers/day/km²).
2.2 Hydrology

Changes to hydrology (e.g., the rate, timing, and volume of water movement in different pathways) accompany many forms of watershed-level disturbance and are particularly pronounced in urban watersheds (Hall, 1984; Booth et al., 2004; Konrad et al., 2005). Because of flow variability in response to precipitation, hydrological monitoring approaches focus on the collection of continuous recorded streamflow and precipitation data followed by modeling and/or statistical analysis of trends or the calculation of numerical metrics. Monitoring in urban watersheds must address both elevated storm flows and decreased summer baseflows; both are related to changing runoff and infiltration patterns caused by increasing imperviousness. Precipitation monitoring is often completed to examine the hydrologic response to rainfall and allow for a water balance to be developed.

Hydrotechnical analysis is done through modeling software such as SWMM, MOUSE, and HSPF (see review of software packages in KWL, 2005). Hydrologic modeling focuses on hydrotechnical tasks such as the sizing of culverts and bridges but they can be used to derive a wide variety of metrics to assess current hydrologic condition and monitor changes over time. Examples of hydrologic or streamflow metrics include (from Konrad et al. (2005) and others): 1) estimates of % effective impervious area; 2) response time of flow increase following precipitation; 3) increase in 2-year discharge (m³/s or m³/s/km²); 4) % daily mean discharge exceeds mean annual discharge; 5) % exceedance of a specified flood quantile or mean streamflow (T exceed); 6) fraction of time that streamflow exceeds the 0.5-year flood (T0.5); 7) coefficient of variation of the annual max flood; and 8) 10-year predevelopment discharge to 2-yr current discharge; 9) coefficient of variation of annual maximum streamflow (CVAMPF); 10) summer low flow volume per hectare (L/s/ha); and 11) total annual runoff as a percentage of total annual precipitation. It is important to note that 12 months of hydrometric data may be insufficient for the calculation of some metrics. As well, correlations between flow monitoring data or hydrologic indices and biological or water quality variables are not defined and would require substantial resources to measure.

Annual water balances for development scenarios can be made using the Water Balance Model (Graham et al., 2004) or other methods; they can be used to monitor changes to interception, evapotranspiration, infiltration, and surface runoff over time. Bauer and Mastin (1997) provide a good example of a water balance in small, glacial till mantled catchments in Puget Sound. However, direct measurement of all water balance parameters is often difficult and costly.

Potential Approaches

- **Streamflow**: continuous monitoring of streamflow using pressure transducer probes, areal-velocity meters using Doppler profilers, weirs, or other techniques is the primary approach to hydrologic monitoring. This data is collected at a high frequency (1–15 min interval, typically 5 minutes). Flow volume calculation depends on the development of a stage-discharge relationship for the monitoring site. Statistical analysis to remove data scatter, fill data gaps, and calculate summary statistics are required.

- **Effective Impervious Area (EIA) Calculation**: modeling programs can use flow and precipitation data to calculate EIA for urbanizing watersheds. EIA values have the potential
to be used to monitor the effectiveness of stormwater management in maintaining or reducing EIA in urban areas. Information on soil and surficial geology may be important in some watershed. See the ISMP Template (KWL, 2005) for more information on standard methods for EIA calculation based on hydrometric and precipitation data.

- **Hydrologic Metrics**: to aid in regional comparisons of the hydrologic condition of different streams or to monitor changes to the stream discharge over time, a variety of statistical hydrologic metrics have been proposed. Examples include: (1) total annual runoff (m$^3$/yr + m$^3$/km$^2$/yr; 2) mean annual runoff (m$^3$/s); (3) runoff as a percentage of precipitation (m$^3$/m$^3$/yr or km$^3$/km$^3$/yr); (4) 2-yr discharge (m$^3$/s) + discharge per area (m$^3$/s/km$^2$); (5) 7-day September baseflow discharge and discharge (m$^3$/s + m$^3$/s/km$^2$); (6) 7-day January baseflow discharge (m$^3$/s + m$^3$/s/km$^2$); and 7) fraction of time that streamflow exceeds the 0.5-year flood ($T_{0.5}$).

- **Water Balance Model**: Water balance modeling is used to forecast changes the movement of water in urbanizing watersheds (see Graham et al., 2004 for a local example). Measurement or calculation of the key model parameters (e.g., infiltration, surface runoff) could be used to monitor hydrologic change over time and would be similar to the use of hydrologic metrics.

### 2.3 Environmental Chemistry

Urbanization is associated with a range of chemical and physical changes in water and sediment: elevated concentrations of metals, nutrients, hydrocarbons, organic chemicals, pesticides, elevated water temperature, increased fine sediment, and increased concentrations of fecal coliforms and other bacteriological indicators. Many chemical changes are associated with urban stormwater because impervious areas are efficient collectors of urban contaminants and drainage systems rapidly convey water and sediment to streams and rivers. Natural watershed features or processes such as wetlands or saturated soils contribute to the capture, transformation, or retain of chemical compounds or bacteria are destroyed or bypassed by stormwater systems. However, the preferred approach to water quality management is to minimize contaminant sources. Contaminants such as fecal coliform bacteria are associated with urban land uses due to septic fields in rural areas, cross-connections between sanitary and stormwater systems, and domestic animal waste. Water temperature is a physical property of water and typically increases in urban streams because of reduced riparian forest cover which leads to increased insolation.

A wide variety of methods have been developed to measure different components of environmental chemistry including chemical or physical properties of water, sediment, or biological tissue. Most approaches focus on determining a mean or maximum concentration of a particular parameter or group of parameters in water (e.g., 0.56 mg/L of total nitrate) at a specific time or over a define period of time such as a single storm. Other common approaches examine the loading (mass of a parameter over a defined time period (e.g., 1150 kg/yr of nitrogen) based on concentrations and flow. Overall, methods for environmental chemistry are extremely variable and range from very simple (e.g., a single temperature measurement in the
Water chemistry is the primary focus of stormwater monitoring. There are five approaches to water quality assessment and monitoring: 1) summer (or seasonal) baseflow sampling which measures contaminant concentrations and other parameters under low, stable water levels; 2) storm event sampling which measures contaminant concentrations during precipitation periods; 3) continuous automated sampling which records general water quality characteristics on a continuous basis; 4) in situ deployment of resin (DGT; diffusion gradient in thin films) devices that absorb contaminants over time; and 5) lab-based toxicity tests using fish or other organisms. Methods that may be suitable for more detailed studies or research projects include the use of tissue chemistry in sedentary aquatic organisms such as sculpins or mollusks, or the chemical signatures recorded in freshwater mollusk shells.

Potential Approaches

- **Baseflow Field Parameters**: August–September baseflow measurements of chemical and physical parameters (water temperature, specific conductivity, dissolved oxygen, pH, turbidity) are the most common water quality monitoring method. These parameters are general indicators of water quality in urban streams. This method uses a hand-held multi-probe at one or more sites over one or more time periods under baseflow conditions. This method can be expanded to examine seasonal or monthly concentrations. Multiple measurements are needed to provide an accurate value.

- **Baseflow Lab-based Measurements**: grab-samples with lab analysis for total metals (ICP or selected metals), nutrients (total nitrate, dissolved orthophosphate), total suspended solids, and fecal coliform bacteria from grab samples at one or more sites over one or more time periods; it is often combined with instream measurements described above.

- **Automated Monitoring**: continuous (e.g., 5–60 min interval) measurement of general parameters (water temperature, specific conductivity, dissolved oxygen, pH, turbidity) using automated probes with recording devices (data-loggers).

- **Storm Event Sampling**: Contaminant concentrations generally increase with precipitation and storm event sampling is often needed to adequately characterize water quality in industrial or highly urbanized watersheds. It can be undertaken as interval-based sampling (e.g., 1 sample every 30 min for the first 6 hrs of a storm) or through a flow-partitioned composite sample (e.g., 1 sample every 500 l of flow). Measurement of the Event Mean Concentration (EMC) is the most common method of examining stormflow concentrations of metals and other contaminants (see USEPA, 2002). EMC is a flow-partitioned composite sampling method using automated sampling devices to determine the average concentration of a contaminant. It is variable between storms and multiple storm samples are needed to characterize a stream. It is important to note that an EMC will not provide the maximum concentration of a contaminant during a storm and cannot be compared directly to BC Water Quality Guidelines.

- **Loading Studies**: loading can be calculated several ways but it is most commonly expressed as: contaminant load = average concentration x runoff volume. Loading incorporates information on contaminant concentrations during high and low flows. It is calculated from regular baseflow and storm flow grab samples of total metals, dissolved metals, nutrients, hydrocarbons, and/or bacteriological parameters (fecal coliforms, E. coli) combined with flow measurements (see Marselek (1991) for more info).
• **DGT Technique**: DGT (Diffusion Gradient in Thin Films) devices measure the time-averaged concentration of the bioavailable forms of trace metals in water or sediment over time by accumulating them through diffusion into resin material followed by lab-based analysis (DGT, 2002). Calibration studies may also be required and differing flow levels may increase variability of ion uptake. DGT devices are typically deployed between 1–3 wks in urban streams depending on site-specific conditions.

• **Sediment Chemistry**: because sediment accumulates contaminants over time, sediment analysis may provide a less variable matrix than water for assessing contaminant concentrations. Typical parameters include total metals, hydrocarbons, or organic contaminants such as PAHs in streambed substrates. This requires field-collection and lab-based analysis.

• **Tissue Chemistry**: concentrations of more complex contaminants such as PAHs, pharmaceuticals, pesticides, other organic compounds including endocrine disrupting compounds can be analyzed in fish or mollusk tissue. Sculpins (*Cottus* spp.) have been used in urban watersheds in King County as suitable for tissue analysis because they are resident fish that are common in many streams (MacCoy and Black, 1998).

• **Toxicology**: toxicity tests of field-collected water using fish, daphnia, or other organisms can be used to measure acute mortality or sublethal effects such as reproductive impairment, liver function, or genetic effects. Most stormwater is below acute toxicity and the use of toxicity studies is likely to cases where high loadings occur. Sublethal effects can be difficult to measure accurately.

### 2.4 Channel Morphology and Instream Habitat

The physical structure of stream channels respond to both changes to hydrologic patterns such as larger and more frequent high flows, as well as to direct disturbance to stream channels, floodplains, and riparian zones. Booth (1991) documented channel incision in response to increases in peak flows and flow duration in Puget Sound streams. Channel expansion (quasi-equilibrium increase in width and depth) may also occur to accommodate larger flows. Both types of changes are accompanied by loss of structural features such as pools, undercut banks, and large woody debris, which support high quality fish habitat. Large woody debris is particularly important for juvenile coho salmon and cutthroat trout, and losses from channel changes and lack of replenishment from young riparian forests, has a major effect on fish populations (Bisson et al., 1987).

There are a variety of parameters that can be monitored over time to detect patterns in the structure or processes (e.g., channel stability or sediment movement) of stream channels. Many are linked to fish habitat components or channel stability attributes that may affect property or drainage infrastructure. Most changes occur because of hydrologic changes, but also because of modification of stream channels or riparian vegetation. Scholz and Booth (1999) recommended that instream habitat monitoring focus on bank erosion, bank hardening, and in-stream large woody debris, with the inclusion of channel gradient, substrate composition, and pools in some situations. They commented that: “the other myriad physical parameters that have historically been measured on rivers and streams show little apparent value in these
watersheds and institutional settings”. Most habitat variables must be considered in relation to biological information to be of value.

**Potential Approaches**

- **Channel Dimensions**: measurement of basic channel dimensions including bankfull width, wetted width, maximum pool depth, mean riffle depth, and channel gradient within a stream reach.
- **Substrate Composition**: visual or quantitative (sieve-based) analysis of substrate composition at reference sites or within a stream reach. Visual estimates are often separated into particle size classes: bedrock, organic, boulder, cobble, large gravel, small gravel, sand, and fines. Quantitative analysis can also be presented by particle size class or by semi-log graphs.
- **Large Woody Debris**: large woody debris (LWD) represents the interaction of riparian forest and stream channels, as is closely tied with fish habitat value. Calculation of LWD density (no./km) or volume (m3/km) are standardized methods for analyzing data on LWD data collected during stream surveys (e.g., fixed reach). LWD density and volume can be assessed over time.
- **Channel Reference Sites**: channel cross-sections at fixed, reference points can be used to monitor changes to channel morphology over time. Harrelson et al. (1994) provide a detailed summary of methods for using reference sites for monitoring trends in fluvial and geomorphic condition.
- **Bank Instability and Hardening**: Scholz and Booth (1999) recommended that measures of bank stability such % eroding bank, % hardened bank and % natural bank are effective for monitoring the effect of urbanization on small streams.
- **Habitat Quality Index (HQI)**: there are a variety of methods for integrating data collected on instream habitat or channel morphology. They follow similar methods to the use of metrics for assessing benthic invertebrate community data. A method for Puget Sound lowland streams in described in May et al. (1997). The use of a HQI would require calibration for physical conditions in the GVRD.

### 2.5 Aquatic Biota

Many components of the biological community have been used to monitor stream health because they integrate changes to hydrology, water and sediment chemistry, and channel morphology. Resident fish, aquatic invertebrates, and periphyton (algae) experience the hydrologic, chemical, and physical conditions that occur over time in stream ecosystems. Changes to the biological community accompanying urbanization may include reduction in species richness, loss of sensitive species, increase in tolerant species, changes in dominance, genetic changes, and the introduction of non-native species. Benthic (streambed) invertebrates have been the focus of biological monitoring in the Pacific Northwest and other regions because they are diverse, abundant, and easy to sample in small streams (Rosenberg and Resh, 1993). In Greater Vancouver, benthic invertebrate sampling has been undertaken using several approaches but primarily using the multimetric index called the Benthic Index of Biological Integrity (B-IBI) approach that was modified for conditions in the GVRD, and a multivariate...
reference condition approach supported by Environment Canada’s Canadian Aquatic Biomonitoring Network (CABIN). Others include a separate B-IBI approach that the City of Surrey has used for seasonal streams (Dillon Consulting, 2004) and an older B-IBI approach that was developed for the Salmonweb Program in King County (Salmonweb, 2006). While all these approaches are effective at characterizing stream health, the most important factors to consider are the appropriateness of the method for local stream conditions and the study’s objectives.

Fish presence, juvenile fish abundance (density in g/m² of juvenile fish), fish community composition (e.g., coho salmon / cutthroat trout ratio) or spawning fish abundance have also been used as indicators of stream health. However, factors other than stormwater including ocean productivity and harvesting affect fish populations and reduce the effectiveness of fish for environmental monitoring. Furthermore, fish populations are not found in many small streams that may be the focus of monitoring programs which also reduces their usefulness as a regional approach. Finally, coho salmon and cutthroat trout are resilient to low to moderate levels of urbanization and major changes to the fish community occur only at higher levels of urban land use (e.g., 30–50% TIA).

Periphyton has not been use as a monitoring tool in urbanizing streams in Greater Vancouver but it has been successfully elsewhere (Fore and Grafe, 2001). Like benthic invertebrate monitoring, it uses changes to diversity and abundance of diatoms and other components of periphyton communities to assess change. Algae may respond more rapidly than benthic invertebrates to stressors in urban streams.

Potential Approaches

- **Benthic Invertebrates (Lower Mainland B-IBI):** this approach to benthic invertebrate sampling was developed specifically for riffle (gravel-cobble) streams in Greater Vancouver (see EVS, 2003). It uses 10 metrics to calculate a numerical value of stream health. It is based on four composite samples collected with a Surber sampler in August–September. Because of its summer sampling window, it is only suitable for permanently flowing streams with riffle habitats. However, the field sampling methods could be used for Spring or Fall sampling. See Appendix 2 for more detail.

- **Benthic Invertebrates (RCA-CABIN):** this approach uses a form of multivariate analysis to compare the benthic invertebrate community to reference communities defined by environmental characteristics (Reynoldson et al., 2003; Rosenberg et al., 1999). It uses a single sample collected with a kicknet and can be used in a variety of stream and river types including soft-bottomed streams. It is supported by a national research and database management program called CABIN. It is not calibrated for intermittent streams; new reference sites and model calibration are required. See Appendix 2.

- **Benthic Invertebrates (City of Surrey B-IBI):** the City of Surrey developed a B-IBI sampling method that uses a Surber sampler to collect invertebrates from small, gravel bed streams in the Spring and Fall to avoid low summer flows that are common in the Fraser Lowland (Dillon Consulting, 2003). It does not composite field samples and it also uses different subsampling and taxonomic identification standards than the Lower Mainland B-IBI approach (see Appendix 2). However, it uses the same 10-metric B-IBI scoring system as the Lower Mainland B-IBI method. Initial results indicate that B-IBI values are highly variable; this may be related to flow variability in the Spring and Fall.
• **Benthic Invertebrates (Rapid Bioassessment Protocol (RBP))**: the Rapid Bioassessment Protocol includes approaches for conducting biological assessments of streams and rivers using fish, invertebrates, and periphyton. It presents a variety of methods for benthic invertebrate sampling but a multihabitat method using a D-net is likely the most useful for GVRD streams. Barbour et al. (1999) note that: “the protocols presented are not necessarily intended to replace those already in use for bioassessment nor is it intended to be used as a rigid protocol without regional modifications. Instead, they provide options for agencies or groups that wish to implement rapid biological assessment and monitoring techniques”. See Barbour et al. (1999) for a more complete description of possible methods. More work is need to evaluate a RBP method that could address the range of stream types in the GVRD.

• **Fish Density**: the density of juvenile coho salmon and cutthroat trout (measured in g/m² or no. of fish/m² or m³ or as a ratio of coho to cutthroat (coho decline and cutthroat generally increase in response to urbanization (May et al., 1997)) may be effective as a long-term indicator of stream health because fish respond to changes in instream habitat and water quality. It may be particularly useful for integrating changes to channel conditions during urbanization (e.g., LWD and pool volume). However, fish density is affected by differences in spawning escapement (ocean survival) and can only be used in fish-bearing streams that can be effectively sampled with nets and electrofishing. Many urban streams in the GVRD do not support salmon or trout.

• **Periphyton**: periphyton is the microbiological film on streambed substrates consisting of algae (diatoms) and other microbes. The periphyton community responds rapidly to changing environmental conditions and components of the periphyton community such as species richness, mass (g/cm²), or chlorophyll content can be used like benthic invertebrates to determine stream health. Development of a multimetric assessment method would be required for the GVRD. See Barbour et al. (1999), Fore and Grafe (2001) or Rodgers et al. (1979) for descriptions of possible sampling and analysis methods.
Part 3 – Comparing Monitoring Approaches

3.1 Criteria

Ten criteria were used to assess and compare the monitoring approaches presented in the preceding sections. Table 1 summarizes information on many types of monitoring approaches using a five point scale (very poor=1, poor=2, fair=3, good=4, excellent=5), as well as a summary value. Appendix 3 provides more detail on each of the monitoring approaches.

1. **Suitability**: is the monitoring approach suitable for the range of stream types in Greater Vancouver?

2. **Link to stream health**: is the indicator clearly linked changes in stream health?

3. **Manages variability**: does the monitoring approach manage the temporal variability of the indicator?

4. **Trend analysis**: does the monitoring approach allow for the statistical or comparative assessment of trends in stream health?

5. **Consistency**: do the methods allow for consistent measurement by different users, over time through well-documented, publicly available descriptions?

6. **Regional capability**: is equipment and professional expertise available within Greater Vancouver to undertake the monitoring?

7. **Communication ability**: does the monitoring approach allow for effective communication with resource managers and the public?

8. **Scientific foundation**: is the monitoring approach supported by a foundation of published scientific analysis and testing?

9. **Environmental impact**: does the monitoring approach cause impacts to the stream through sample collection or other activities?

10. **Cost**: what is the approximate cost per stream (or site) per year for the monitoring approach?
Table 1. Summary of environmental monitoring methods for stream health in Greater Vancouver.

<table>
<thead>
<tr>
<th>Monitoring Approaches</th>
<th>Regional Suitability</th>
<th>Link to Stream Health</th>
<th>Manages Variability</th>
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<th>Consistent Methods</th>
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Scoring: very poor=1, poor=2, fair=3, good=4, excellent=5
3.2 Comparison Results

The analysis identified a number of monitoring approaches that are effective for monitoring stream health in Greater Vancouver. Key results include:

1. Approaches using watershed land cover or land use are generally highly rated (average score of 39.6) because they are suitable for many areas of the GVRD, are strongly linked to other measures of stream health, are easily communicated and incorporated into land use planning, and do not exhibit temporal variability other than associated with land development. They are also generally cost effective. It is also important to note that they are most useful in a typical watershed in the GVRD with a mix of land use, some remaining forest cover, and a relatively intact stream network; small watersheds, watersheds with split development patterns (e.g., forested headwaters and developed lowlands; or urban upslope areas and agricultural lowlands), and watersheds such as those found in Richmond or Delta that lack forest cover and have highly modified stream networks may be more difficult to assess using land cover and land use approaches.

2. Hydrology monitoring requires an integrated program that combines measured stream flow and precipitation, with hydrologic modeling. In general, hydrologic monitoring can use time-series analysis (a group of sophisticated statistical techniques) to compare measured streamflow or it can calculate a range of hydrologic metrics through models that are either based on streamflow parameters (e.g., 2-yr discharge) or water balance parameters (e.g., effective impervious area, % infiltration, etc). The use of the hydrometric station was rated the lowest of the four approaches because of its high cost and relatively poor communication ability, however, it is the only suitable method for collecting hydrologic data from streams. Only %EIA was strongly linked to stream health.

3. The comparison of environmental chemistry monitoring approaches provided contradictory results; the most highly rated approaches (water quality measurement of baseflow field and lab parameters) are generally poor for monitoring trends or addressing variability, but they are low cost and can be completed anywhere in the region. Approaches such as automated water quality monitoring or storm event sampling address the inherent variability of water quality and are more suitable for monitoring trends, but they are also expensive to implement.

4. Approaches for monitoring channel morphology and instream habitat received the lowest ratings (average of 31.5) because they are difficult to measure consistently. For example, visual estimates of substrate composition vary between observers. In addition, channel characteristics change in response to natural stream processes unrelated to urbanization (e.g., natural bank erosion, channel movement, etc). The measurement of channel dimensions (e.g., bankfull width) and large woody debris (LWD) frequency received the highest overall rating for the group.

5. Of the approaches focusing on aquatic biota, the Lower Mainland B-IBI and RCA-CABIN approaches to benthic invertebrate monitoring were rated equally (36) but for different reasons. The B-IBI approach is more strongly linked to measures of stream health such as imperviousness and is more easily used to detect trends because of the statistical properties of the index. However, the RCA-CABIN approach can be used on a wider variety of stream
types and is cheaper to undertake. The City of Surrey's B-IBI approach is similar to the Lower Mainland B-IBI approach but it appears to increase temporal variability because of the spring and fall sampling window which reduces its ability to detect trends; it also has minor gaps in the description of the methods, and there is a weaker scientific foundation for the response of urbanization on benthic invertebrate communities in intermittent streams. Approaches using fish as indicators (e.g., fish density; coho:cutthroat ratio) are not recommended because of their high spatial and temporal variability and lack of a strong link to stream health.
Part 4 – Suggested Monitoring Approaches

The purpose of this report has been to describe and evaluate monitoring approaches for urban streams. However, during the course of this project it has become apparent that municipalities and other organizations require more specific guidance for the development of monitoring programs. In this section, we identify suggested monitoring approaches and methods that are suitable for most streams in the region.

4.1 Monitoring Watershed Land Cover and Land Use

Watershed land cover or land use has a number of desirable qualities including low variability, clear link to stream health, and link to land use planning and stormwater decision making. However, variables such as forest cover may not be suitable for watersheds in Delta, Richmond, and the lowlands of Surrey.

The following monitoring approach is not a conclusion or a necessarily 'correct' approach; it is offered as a starting point for discussion purposes only.

**Suggested approach:** Measurement of key land cover and use variables using GIS-based interpretation of recent (<2 yr old) orthophotos (see ISMP Template Clauses 6, 7, and 10).

**Suggested variables and methods:**

1. Total impervious area (%TIA; land use derived with CLUCS codes).
2. Riparian forest cover (ha and %RFI using 30 m assessment area).
3. Watershed forest cover (ha and % of watershed area).
4. Natural wetlands (ha and % of watershed area).
5. Road density (km/km²).

**Suggested measurement frequency:** Years 0, 6, and 12 in the ISMP schedule; plus Years 3 and 9 in rapidly developing watersheds.

**Further work:**

1. Develop regional standards for land cover / land use measurement.
2. Review the application of regional land cover assessment using satellite imagery (Landsat) for watershed-scale applications.
3. Review similarity between RFI and SPR (Simple RAR) assessments.

4.2 Monitoring Hydrology

Hydrologic monitoring requires an integrated program of stream discharge (hydrometric station), precipitation (automated rain gauge), and computer modeling. Some direct field measurement (for stage-discharge relationship) and confirmation of summer and winter baseflow is also required.
The following monitoring approach is not a conclusion or a necessarily 'correct' approach; it is offered as a starting point for discussion purposes only.

**Suggested approach:** Combined use of hydrometric and precipitation data collection followed by development of a hydrologic model and calculation of standardized hydrologic metrics (see ISMP Clauses 3 and 16).

**Suggested variables and methods:**
1. Effective impervious area (%EIA; streamflow, precipitation and modelling derived; see ISMP Clause 3).
2. Total annual runoff (m$^3$/yr or km$^3$/yr) + m$^3$/km$^2$/yr) + total annual runoff as a percentage of total annual precipitation.
3. 2-yr discharge (m$^3$/s) + 2-yr discharge per watershed area (m$^3$/s/km$^2$).
4. September baseflow (7-day) discharge (m$^3$/s + m$^3$/s/km$^2$).
5. January baseflow (7-day) discharge (m$^3$/s + m$^3$/s/km$^2$).
6. 0.5-year flood exceedance (T$_{0.5}$) (measured as cumulative fraction of time; see Konrad et al., 2005 for more information).

**Suggested measurement frequency:** Years 0, 6, and 12 in the ISMP schedule; continuous hydrometric and precipitation data collection is desirable with ongoing calibration of hydrologic model with new data to increase accuracy.

**Further work:**
1. Develop of regional standards for calculation of hydrologic metrics.
2. Conduct additional analysis of relationships between hydrologic metrics and other stream health measures.

### 4.3 Monitoring Environmental Chemistry (Water Quality)

Water quality is difficult to incorporate into stream health monitoring programs. While it is clearly an essential component of stream health, it is often highly variable in urbanizing streams and is expensive to measure intensively. We recommend a screening-level assessment for all streams using summer baseflow sampling, supplemented with more intensive water quality assessment in streams draining rapidly developing, highly urbanized, industrial, and agricultural watersheds\(^2\) or in watershed in which specific water quality problems have been identified (e.g., history of fish kills, spill records, etc).

The following monitoring approaches are not a conclusion or necessarily 'correct' approaches; they are offered as a starting point for discussion purposes only.

**Suggested approaches:** (1) summer baseflow sampling of key physical and chemical parameters with more rigorous sampling methods to better measure variability; (2) increased

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\(^2\) Preliminary definitions: agricultural watersheds = >40% agricultural or rural land use; industrial watersheds = >5% industrial (heavy or moderate) land use and/or permitted discharges; rapidly developing watersheds = >5% change in %TIA in 10 yrs; heavily urbanized watersheds = >40% total impervious area.
use of automated monitoring systems in streams draining rapidly developing, highly urbanized, or industrial watersheds; and (3) use of storm event sampling in streams draining highly urbanized and industrial watersheds.

Suggested variables and methods:

1. Field-based measurement of key physical and chemical properties during summer baseflow (water temperature, specific conductivity, dissolved oxygen, pH, turbidity); min. 3 measurements between Aug 15–Sept 30 at least 1 wk apart; min. of 5 days after >5 mm precipitation (expanded ISMP Template Clause 13).
2. Lab-based measurement of additional chemical variables during summer baseflow: total metals (ICP metals or copper, iron, manganese, lead, arsenic, aluminum, and zinc), nutrients (total nitrate, dissolved orthophosphate, ammonia-nitrogen), and fecal coliform bacteria; min. 3 measurements between Aug 15–Sept 30 at least 1 wk apart; min. of 5 days after >5 mm precipitation (expanded ISMP Template Clause 13).
3. Automated monitoring (5–30 min interval) of water temperature, specific conductivity, pH, and turbidity in rapidly developing, highly urbanized, or industrial watersheds.
4. Automated monitoring (5–30 min interval) of water temperature and turbidity in agricultural watersheds.
5. Storm event sampling (flow partitioned EMC or interval-based) of total metals, dissolved metals, total suspended solids, turbidity, total hardness, and pH in highly urbanized, industrial, or in watersheds with historical water quality impairment (e.g., fish kills, spills, contaminated sites, landfills, etc); min. of 3 normal storms (>10 mm over 12 hrs) per year.
6. Higher frequency (seasonal or monthly) sampling of fecal coliform bacteria and nutrients (total nitrate, dissolved orthophosphate, ammonia-nitrogen) in agricultural and rural watersheds.

Suggested measurement frequency: Years 0, 3, 6, 9, and 12 in the ISMP schedule; more frequent sampling is recommended if water quality impairment is pronounced.

Further work:
1. Review the potential use of DGT techniques for urban stream monitoring.
2. Review the use of tissue analysis using sculpins and other resident fish for assessing the concentrations of organic compounds.
3. Conduct additional analyses of relationships between water quality parameters and other stream health measures.
5. Review the link between BC Water Quality Guidelines and the results of IMSP-related water quality monitoring.

4.4 Monitoring Channel Morphology and Instream Habitat

Habitat or channel approaches are not recommended for most stream health monitoring programs. The inherent variability of habitat variables, the difficulty in standardizing their measurement, and the variable relationship between stormwater and instream habitat characteristics precludes their inclusion. They are generally unsuitable for trend analysis. They should be considered for specific monitoring plans in streams where changing channel
conditions (e.g., sediment erosion or accretion, loss of LWD, channel instability, etc) are pronounced or fish habitat value is very high.

4.5 Monitoring Aquatic Biota (Benthic Invertebrates)

Benthic invertebrates are recommended as the focus for biological monitoring in streams in Greater Vancouver. Fish populations are too variable to be used reliably to assess stream health.

The following monitoring approaches are not a conclusion or necessarily 'correct' approaches; they are offered as a starting point for discussion purposes only.

Suggested approaches:
1. Lower Mainland B-IBI or RCA-CABIN (with B-IBI calculation added) for permanent, coarse substrate streams (see Clause 2).
2. RCA-CABIN for permanent, soft substrate streams (with refinement of methods including B-IBI calculation added; min. of 400 organisms subsampled, enumerated and identified).
3. City of Surrey B-IBI for intermittent (seasonal), coarse substrate streams (with refinement of methods).

Suggested variables and methods:
1. B-IBI value (Puget Sound 10-metric using lowest practical taxonomic level (LPTL)); min. of 400 organisms.
2. If measured, CABIN stress assessment and reference group.
3. Total invertebrate taxa richness based on LPTL taxonomy; min. of 400 organisms.
4. Total EPT (mayfly, stonefly, caddisfly) taxa richness based on LPTL taxonomy; min. of 400 organisms.

Suggested measurement frequency: Years 0, 3, 6, 9, and 12 in the ISMP schedule.

Further work:
1. Review options for an amalgamated CABIN-BIBI method using CABIN-based field sampling methods (kicknet) and both B-IBI and CABIN stress assessment output.
2. Review of the use of periphyton monitoring in the other jurisdictions in the Pacific Northwest.
3. Refine the Surrey B-IBI method to clarify sample timing, mesh size, taxonomic standard, subsampling, taxonomy review, and other procedures.
4. Conduct a calibration study of benthic invertebrate methods in intermittent streams using both the Surrey B-IBI and CABIN methods (combined study).
Part 5 – Recommendations

The following summary points are made to guide environmental monitoring of urbanizing streams in the GVRD:

1. **Develop Monitoring Plans for ISMPs** – Monitoring plans focusing on stream health should be considered an essential component of ISMPs. We recommend that a separate clause be included in the ISMP template to guide their development. All monitoring plans should define a specific question or questions that will be its focus. All monitoring plans should also describe sampling and data analysis methods (e.g., qualitative or statistical), measurement frequency and schedule, as well as reporting and data management requirements.

2. **Use a Suite of Indicators** – There is no single monitoring approach that will measure the response of streams to urbanization in the GVRD. A suite of monitoring variables is recommended that encompass different components of the stream ecosystem including watershed land cover, hydrology, water quality, and aquatic biota.

3. **Use Consistent Techniques** – Consistent data collection and analysis is critical for all environmental monitoring programs. Field collection, lab analysis, quality control, and data assessment methods should be clearly defined for all monitoring activities. Standardized reporting formats may be useful for improving consistency in ISMP development.

4. **Link to Land Use Planning and Decision-Making** – Monitoring programs should be clearly linked to the decision-making processes involved in stormwater management and land use and development planning (e.g., OCPs, neighbourhood plans). Stream health monitoring should be viewed as an indicator of the success of both stormwater management and land use planning.

5. **Balance Regional Consistency with Local Conditions** – There is a balance between the objective of regional consistency and the need to recognize differences in environmental characteristics in the region. Regional consistency will aid in assessing regional trends in stream health and improve our overall understanding of the effects of urbanization on stream health. We recommend that regionally consistent methods be followed where possible. However, we recognize that topographic, land use, and climate differences between the Fraser Lowland and Coast Mountains reduce our ability to use consistent monitoring approaches for all streams in Greater Vancouver. Municipalities and other organizations should select monitoring approaches that are suitable for their stream and watershed conditions.

6. **Promote Intramunicipal Collaboration** – Many watersheds span municipal boundaries and joint monitoring programs may be cost efficient and increase the success stormwater management activities. Municipalities that share responsibility for the management of watersheds include District of North Vancouver and City of North Vancouver, City of Coquitlam and City of Port Coquitlam, and City of Surrey and Township of Langley. Many of these shared watersheds are already jointly managed.

7. **Balance Intensity with Long-term Monitoring** – There is a balance between the financial resources needed to monitor a suite of variables intensively and the number of streams that
can be monitored over time. With limited municipal resources, it is generally more effective to examine more streams over a longer time period using lower intensity monitoring approaches. A rotating panel design is an effective monitoring strategy because changes to stream health occur slowly.

8. **Use Alternative Monitoring Schedules** – Stream health monitoring does not necessarily have to be guided by schedules for ISMP development in individual watersheds. There are advantages, both in terms of cost and data consistency, for collecting data from groups of streams at the same time. For example, the District of North Vancouver sampled benthic invertebrates from 11 streams and rivers in 2003 to assist in developing ISMP priorities and provide baseline data for future monitoring.

9. **Partner with Academic Researchers** – Municipalities and other organizations can form partnerships with academic researchers or graduate students that can improve monitoring programs and aid in the development of new monitoring approaches. Similarly, some stream health monitoring can be undertaken by stewardship groups such as water quality sample collection if adequate training, financial resources, and supervision are provided. Where appropriate, data from stream health monitoring programs should be made accessible for students, researchers, or consultants for analysis.

10. **Monitor Regional Changes in Land Cover** – The GVRD should monitor land cover and land use variables on a regional basis that are clearly linked to stream health. This includes monitoring changes to land use, imperviousness, watershed forest cover, and riparian forest cover. This approach would build on the 1999 assessment of TIA and riparian forest cover for all watersheds and catchments in the GVRD. The GVRD should also examine the potential for using remote sensing techniques for monitoring land cover in urban watersheds in the GVRD.

11. **Undertake Additional Research or Testing** – There are a variety of monitoring approaches that require the development or refinement of standard methods (e.g., benthic invertebrate sampling) or further research into their effectiveness and suitability for conditions in Greater Vancouver. These include the use of DGT techniques for water and sediment quality assessment and periphyton for monitoring the biological condition of urban streams. More work is also needed to expand the ISMP Watershed Health Tracking Tool to incorporate other measures of stream health.
References


Greater Vancouver Sewerage and Drainage District (GVS&DD).1999. Assessment of current and future GVS&DD area watershed and catchment conditions. GVRD, Burnaby, BC.


British Columbia, Vancouver, B.C.


Appendix 1. Selected References

Selected References for Land Cover and Land Use Assessment


**Selected Hydrology References**


**Selected Environmental Chemistry Resources**


Selected References for Monitoring Habitat and Stream Channels


Selected References for Monitoring Aquatic Biota


Appendix 2. Summary of benthic invertebrate sampling and data analysis approaches for streams in the GVRD.

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<td>Area: 0.09 m² Surber sampler frame and time: 3 minutes travelling kick</td>
<td>Area: 0.09 m² Surber sampler frame and time: 2 minutes of substrate disturbance</td>
<td>Area: 0.09 m² Surber sampler frame and time: 2 minutes of substrate disturbance</td>
<td>Area: 0.09 m² Surber sampler frame and time: 2 minutes of substrate disturbance</td>
<td>Area: 0.09 m² Surber sampler frame and time: 2 minutes of substrate disturbance</td>
<td></td>
</tr>
<tr>
<td># samples collected to represent site:</td>
<td>3 Surber samples at 1 riffle in each 125 m stream segment; 3 Surber samples amalgamated to form 1 composite sample</td>
<td>1 composite sample from 3 Surber samplers in 1 riffle</td>
<td>3 Surber samples at 3 adjacent riffles</td>
<td>3 Surber samples at 3 adjacent riffles</td>
<td>1 composite sample from all habitats within a 100 m reach</td>
<td></td>
</tr>
</tbody>
</table>

Sample Summary

| # samples analysed per stream: | 4 composite samples consisting of 12 Surber subsamples | 1 sample per stream | 3 samples per stream | 3 samples per stream | 1 sample per stream consisting of 3 Surber subsamples | 1 sample |

Lab Processing

| Subsampling | 400 organisms | 300 organisms | No subsampling | No subsampling | 500 organisms | 200 organisms |
| Taxonomic resolution | Lowest practical taxonomic level | Family-level | Lowest practical taxonomic level (chironomids to subfamily) | Lowest practical taxonomic level | Lowest practical taxonomic level* | Lowest practical taxonomic level including midges |

Data Analysis

| Biological data: | 10 metric summary of key taxa groups | Multivariate summary of all taxa | 10 metric summary of key taxa groups | 5 or 10 metric summary of key taxa groups | 10 metric summary of key taxa groups | Metrics (variable) |
| Environment variables used: | No – not integrated into assessment, but used for interpretation | Yes – required for model | No – not integrated into assessment, but used for interpretation | No – not integrated into assessment, but used for interpretation | No – not integrated into assessment, but used for interpretation | No |
| Biological condition assessment: | Scaled on defined gradient of stress related to urbanization – 5 defined categories of biological condition | Predictive models – comparison of observed vs. expected; 4 defined categories based on probability ellipses | Scaled on defined gradient of stress related to urbanization – 5 defined categories of biological condition | Numerical score indicating relative biological condition | Numerical score indicating relative biological condition | Variable |
| Output: | Probabilities of membership with reference groups; visual and statistical assessment of biologic condition using reference sites and probability ellipses; expected and observed taxa. | Multivariate score indicating relative biological condition; 10 metric values that can be interpreted; range from 0-50 | Multivariate score indicating relative biological condition; 10 metric values that can be interpreted; not calibrated for intermittent streams (e.g., highest condition may not be B-IBI 50) | Numerical score indicating relative biological condition; 10 metric values that can be interpreted. | Numerical score indicating relative biological condition; 10 metric values that can be interpreted. | |

Estimated Cost

| | $2400 per stream | $800 per stream | $1400 per stream | $1500 per stream | $800 per stream | $600 per stream |
Appendix 3. Summary expanded of monitoring approaches to stream health monitoring in the GVRD

<table>
<thead>
<tr>
<th>Watershed Land Cover</th>
<th>Regional Suitability</th>
<th>Link to Stream Health</th>
<th>Manages Variability</th>
<th>Stream Health Trends</th>
<th>Consistent Method</th>
<th>Regional Capability</th>
<th>Communication Ability</th>
<th>Scientific Foundation</th>
<th>Environmental Impact</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orthophtos</td>
<td>All watersheds</td>
<td>High</td>
<td>Temporal Variability: very low; no management required Spatial variability: very high; managed through analysis method</td>
<td>Comparative (too few data points for statistical analysis over 2-10 yr)</td>
<td>Yes; GIS analysis (see Page et al. 1999; based on CLUCS codes)</td>
<td>Yes; resources and technical skills available</td>
<td>Yes; mapped change easily communicated</td>
<td>Strong</td>
<td>No impact</td>
<td>$1000-$5000 per watershed</td>
</tr>
<tr>
<td>TIA / EIA: Land Use Assessment</td>
<td>Urban watersheds</td>
<td>Very high</td>
<td>Temporal Variability: very low; no management required Spatial variability: very high; managed through analysis method</td>
<td>Comparative (too few data points for statistical analysis over 2-10 yr)</td>
<td>Yes; GIS analysis (see Page et al. 1999; based on CLUCS codes and standard conversion factors)</td>
<td>Yes; resources and technical skills available</td>
<td>Yes; mapped change easily communicated</td>
<td>Very strong</td>
<td>No impact</td>
<td>$500-$1000 per watershed with land use information available</td>
</tr>
<tr>
<td>Watershed Forest Cover</td>
<td>All watersheds</td>
<td>High</td>
<td>Temporal Variability: very low; no management required Spatial variability: very high; managed through analysis method</td>
<td>Comparative (too few data points for statistical analysis over 2-10 yr)</td>
<td>Yes; GIS analysis; riparian forest cover</td>
<td>Yes; resources and technical skills available</td>
<td>Yes; mapped change easily communicated</td>
<td>Strong</td>
<td>No impact</td>
<td>$500-$2000 per watershed</td>
</tr>
<tr>
<td>Riparian Forest Cover</td>
<td>All watersheds</td>
<td>Very High</td>
<td>Temporal Variability: very low; no management required Spatial variability: very high; managed through analysis method</td>
<td>Comparative (too few data points for statistical analysis over 2-10 yr)</td>
<td>Yes; GIS analysis; riparian forest cover</td>
<td>Yes; resources and technical skills available</td>
<td>Yes; mapped change easily communicated</td>
<td>Very strong</td>
<td>No impact</td>
<td>$500-$2000 per watershed</td>
</tr>
<tr>
<td>Natural Wetland Distribution</td>
<td>Lowland watersheds</td>
<td>Moderate; good for agricultural watersheds</td>
<td>Temporal Variability: very low; no management required Spatial variability: very high; managed through analysis method</td>
<td>Comparative</td>
<td>No; wetland delineation open to interpretation</td>
<td>Yes; some skills available</td>
<td>Yes; mapped change easily communicated</td>
<td>Moderate</td>
<td>No impact</td>
<td>$500-$5000 per watershed</td>
</tr>
<tr>
<td>Watershed Land Cover: Satellite Imagery</td>
<td>All watersheds</td>
<td>Moderate; more research needed</td>
<td>Temporal Variability: very low; no management required Spatial variability: very high; managed through analysis method</td>
<td>Comparative (too few data points for statistical analysis over 2-10 yr)</td>
<td>Yes; see Hill et al. 2003; Alberti et al., 2004; Geospatial and Timberline 2004</td>
<td>Yes; resources and technical skills available</td>
<td>Yes; mapped change easily communicated</td>
<td>Moderate</td>
<td>No impact</td>
<td>$20,000-$50,000 for entire region</td>
</tr>
<tr>
<td>Transportation Indicators</td>
<td>Urban watersheds</td>
<td>High; more research needed</td>
<td>Temporal Variability: very low; no management required Spatial variability: high; managed through method</td>
<td>Comparative (too few data points for statistical analysis over 2-10 yr)</td>
<td>Yes; Alberti et al., 2004; Geospatial and Timberline 2004</td>
<td>Yes; resources and technical skills available</td>
<td>Yes; mapped change easily communicated</td>
<td>Moderate</td>
<td>No impact</td>
<td>$500-$2000 per watershed</td>
</tr>
</tbody>
</table>

Hydrology

<p>| Streamflow (Hydrometric Station) | All watersheds | Moderate | Temporal variability: very high; continuous recording (5-15 min) captures variability. Spatial variability: moderate; not addressed | Statistical | Yes; see ISMP Template | Yes; resources and technical skills available | Moderate; technical issues difficult to communicate | High | Minor channel impact if weir required + equipment installation | $15,000-$20,000 per stream for one year including equipment |
| EIA (Hydrologic Model) | All watersheds | High; additional work needed | More work needed | Statistical? | Yes; see ISMP Template | Yes; resources and technical skills available but training needed | Moderate; technical issues difficult to communicate | Moderate | No impact; but hydrometric data needed (direct impact) | $1500 for analysis if data available |
| Hydrologic Metrics (model-derived) | All watershed | Moderate | Temporal variability: very high; metrics can partially address variability Spatial variability: moderate; not addressed; metrics can partially address variability | Statistical | Yes; see ISMP Template; Konrad et al. (2005); others | Yes; resources and technical skills available but training needed | Moderate-low; technical issues difficult to communicate | Moderate | No impact; but hydrometric data needed (indirect impact) | $1500-$2500 for analysis if data available |
| Water Balance Model | All watersheds | Unknown | Addresses variability by creating an annual water balance | Statistical | Yes; see WBM website or Graham et al. (2004) | Yes; resources and technical skills available | Good; some technical issues difficult to communicate | High | No impact; but hydrometric data needed (ind. impact) | $1500-$2500 for analysis if data available |</p>
<table>
<thead>
<tr>
<th>Environmental Chemistry</th>
<th>All streams</th>
<th>Good (esp. temp. and sp. conductivity)</th>
<th>Temporal variability: high; short-term and seasonal variability not addressed Spatial variability: moderate; partially addressed through site selection</th>
<th>Comparative</th>
<th>Yes, RISC method or local methods</th>
<th>Yes, resources and technical skills available</th>
<th>Good</th>
<th>Moderate (lots of data, not always clearly linked to stream health)</th>
<th>No impact</th>
<th>$350-$600 per stream (6-12 sites) ($75 in equipment costs per day) per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Quality: Baseline Field Parameters</td>
<td>All streams</td>
<td>Good</td>
<td>Temporal variability: high; short-term and seasonal variability not addressed Spatial variability: moderate; partially addressed through site selection</td>
<td>Comparative</td>
<td>Yes, RISC method</td>
<td>Yes, resources and technical skills available</td>
<td>Moderate (some technical aspects)</td>
<td>Moderate</td>
<td>No impact</td>
<td>$175-$350 per sample (inc. $170 in lab costs)</td>
</tr>
<tr>
<td>Water Quality: Automated Continuous Monitoring</td>
<td>All permanent streams</td>
<td>Moderate</td>
<td>Temporal variability: high; addressed for standard parameters Spatial variability: moderate; partially addressed through site selection or with additional sites</td>
<td>Statistical</td>
<td>EPA; RISC; Wagner et al. (2006); others</td>
<td>Yes, resources and technical skills available; analysis skills limited</td>
<td>Moderate (graphical depiction of change; but technical)</td>
<td>Moderate</td>
<td>Minor impact from probe installation</td>
<td>$10,000-$12,000 per site per year (not inc. data analysis; inc. $8500 in equipment)</td>
</tr>
<tr>
<td>Water Quality: Storm Event Sampling</td>
<td>All streams</td>
<td>Moderate</td>
<td>Temporal variability: high; short-term variability addressed; but multiple samples required Spatial variability: moderate; partially addressed through site selection or with additional sites</td>
<td>Statistical (in some cases using EMC)</td>
<td>US EPA guide</td>
<td>Yes, resources and technical skills available; equipment limited</td>
<td>Poor (technical and difficult to grasp)</td>
<td>Moderate-High (extensive US literature)</td>
<td>No impact</td>
<td>$500-$800 per site (for one sample inc. $200-$400 in lab costs) per storm</td>
</tr>
<tr>
<td>Water Quality: Loading</td>
<td>All streams</td>
<td>Moderate</td>
<td>Temporal variability: high; but uses data from both low and high flows Spatial variability: moderate; partially addressed through site selection or with additional sites</td>
<td>Comparative or Statistical</td>
<td>Marsalek (1991)</td>
<td>Yes, resources and technical skills available</td>
<td>Poor (technical but summary value good for comparison to other streams)</td>
<td>Moderate-High</td>
<td>No impact</td>
<td>$5000-$25,000 per stream (highly variable depending on parameters and flow information)</td>
</tr>
<tr>
<td>Water Quality: DGT Techniques</td>
<td>All streams</td>
<td>Moderate-Low</td>
<td>Temporal variability: high; addressed through deployment period Spatial variability: moderate; partially addressed through site selection or with additional sites</td>
<td>Comparative or Statistical</td>
<td>DGT (2002); Brydoff (2003); others</td>
<td>Yes; but may require specialists from outside region?</td>
<td>Poor (technical but summary value good for comparison to other streams)</td>
<td>Moderate-High</td>
<td>Very minor impact from probe installation</td>
<td>$3000-$4000 per year for 4 – 2 wk deployments at 10 sites (inc. $120 for lab costs (ICP metals) but not including calibration)</td>
</tr>
<tr>
<td>Sediment Quality: Standard Lab Parameters</td>
<td>All streams</td>
<td>Moderate</td>
<td>Temporal variability: moderate; partially addressed through use of sediment Spatial variability: moderate; partially addressed through multiple sites</td>
<td>Comparative (some statistical with large enough sample size)</td>
<td>RISC standards</td>
<td>Yes, resources and technical skills available</td>
<td>Poor</td>
<td>Moderate (studied but not linked to stream health)</td>
<td>Minor impact from localized sediment disturbance</td>
<td>$200-$300 per sample for total metals and extractable petroleum hydrocarbons ($155 in lab costs)</td>
</tr>
<tr>
<td>Tissue Chemistry</td>
<td>Streams with fish or mollusks</td>
<td>Moderate</td>
<td>Temporal variability: high; partially addressed through use of resident organisms Spatial variability: moderate; partially addressed through multiple sites</td>
<td>Comparative (too few data for statistical)</td>
<td>Variable; see ___</td>
<td>Yes; analyses may require specialists from outside region?</td>
<td>Poor (technical but understandable as fish health)</td>
<td>Strong (well studied)</td>
<td>Moderate impact; Mortality of fish or mollusks retained for analysis</td>
<td>$400 per sample (inc. $275 in lab costs and prep + $200 in sample collection)</td>
</tr>
<tr>
<td>Toxicology</td>
<td>All Streams</td>
<td>Moderate</td>
<td>Temporal variability: high; temporal variability not addressed without multiple samples Spatial variability: moderate; partially addressed through multiple sites</td>
<td>Comparative</td>
<td>Variable; see EPA or check Musqueam reference</td>
<td>Yes, resources and technical skills available</td>
<td>Poor (sublethal effects difficult to grasp and communicate)</td>
<td>Strong</td>
<td>Minor impact to stream; mortality or injury to test organisms</td>
<td>High (&gt;$1000 per sample?)</td>
</tr>
</tbody>
</table>
## Channel Morphology and Fish Habitat

### Channel Dimensions (by reach)
- **Wadeable streams**
  - Moderate: Temporal variability: low (except for flow related parameter); Spatial variability: high; addressed through frequent sampling
  - Comparative: Channel Assessment Guidebook (MOF, 1999); USHP assessment procedures (Michalski and Stewart, 1995)
  - Yes; resources and technical skills available
  - Moderate: Minor disturbance during field survey
  - $200-$400 per stream kilometer (5-10 sites)

### Substrate Composition
- **Wadeable streams**
  - Poor (highly variable): Temporal variability: low; Spatial variability: high; addressed through frequent sampling
  - Comparative: Channel Assessment Guidebook (MOF, 1999); USHP assessment procedures (Michalski and Stewart, 1995); Bunte and Abt (2001)
  - Yes; resources and technical skills available
  - Moderate: Minor disturbance during field survey
  - $50-$30 per site ($300 for quantitative analysis inc. lab costs)

### Large Woody Debris
- **Wadeable streams**
  - Moderate: Temporal variability: low; Spatial variability: high; addressed through frequent sampling
  - Comparative: USHP assessment procedures (Michalski and Stewart, 1995)
  - Yes; resources and technical skills available
  - Poor (subtle change hard to explaining): Poor: Minor disturbance during field survey
  - $300-$600 per site

### Channel Reference Sites
- **Wadeable streams**
  - Poor: Temporal variability: low; Spatial variability: high; addressed through frequent sampling
  - Comparative: Hazleton et al. (1994)
  - Yes; resources and technical skills available
  - Poor: Minor disturbance during field survey
  - $300-$600 per site

### Bank Instability and Hardening
- **Wadeable streams**
  - Moderate: Temporal variability: low; Spatial variability: moderate
  - Comparative: Unknown
  - Yes; resources and technical skills available
  - Moderate-poor: Poor
  - $200-$400 per stream kilometer

### Habitat Quality Index (by reach)
- **Wadeable streams**
  - Moderate: Temporal variability: low; Spatial variability: high; addressed through frequent sampling
  - Comparative: Variable, see May et al., 1997
  - Yes; resources and technical skills available
  - Moderate (summary value easy to compare): Poor
  - Minor disturbance during field survey
  - $200-$400 per stream kilometer

### Aquatic Biota

#### Benthic Community: Lower Mainland BIBI
- Wadeable, permanent gravel streams
  - Very good
  - Temporal variability: moderate; partially managed through consistent sampling period
  - Spatial variability: low-moderate; addressed through sampling
  - Comparative or Statistical: EVS (2003)
  - Yes; resources and technical skills available; taxonomists are limited in region
  - Moderate (summary value easy to compare): Strong
  - Minor substrate disturbance during sampling; mortality of captured invertebrates
  - $2200-$2600 per site (4 samples in a 500 m sampling reach)

#### Benthic Community: RCA-CABIN
- Wadeable, permanent streams
  - Good
  - Temporal variability: moderate; partially managed through consistent sampling period
  - Spatial variability: low-moderate; addressed through area sampled
  - Comparative or Statistical: Reynoldson et al. (2003)
  - Yes; resources and technical skills available; taxonomists are limited in region
  - Moderate (visual depiction): Strong
  - Minor substrate disturbance during sampling; mortality of captured invertebrates
  - $600-$900 per site

#### Benthic Invertebrates: Surrey B-IBI
- Wadeable, permanent and intermittent streams
  - Good-Moderate
  - Temporal variability: high; partially managed through consistent sampling period
  - Spatial variability: low-moderate; addressed through area sampled
  - Comparative or Statistical: Dillon Consulting (2003)
  - Yes; resources and technical skills available; taxonomists are limited in region
  - Moderate (summary value easy to compare): Good (intermittent streams poorly studied but uses B-IBI)
  - Minor substrate disturbance during sampling; mortality of captured invertebrates
  - $600-$900 per site

#### Benthic Invertebrates: RBP
- Wadeable, permanent and intermittent streams
  - Good
  - Temporal variability: high; partially managed through consistent sampling period
  - Spatial variability: low-moderate; addressed through area sampled
  - Comparative or Statistical: Ballou et al. (1999)
  - Yes; but funding needed; taxonomists limiting
  - Moderate (summary value easy to compare): Good (used in the US)
  - Minor substrate disturbance during sampling; mortality of captured invertebrates
  - $600-$900 per site

#### Fish Density
- Wadeable, salmonid-bearing streams
  - Poor
  - Temporal variability: high; addressed through consistent
  - Comparative or Statistical: DFO South Coast Reference Stream
  - Yes; resources and technical skills
  - Moderate (fish numbers/density): Moderate (some published work)
  - Minor disturbance to fish
  - $800-$2,500 per stream (one site)
<table>
<thead>
<tr>
<th>Entity</th>
<th>Type</th>
<th>Temporal variability:</th>
<th>Approach</th>
<th>Available</th>
<th>Community from electrofishing and handling: some mortality and injury</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periphyton</td>
<td>Wadeable gravel streams</td>
<td>Moderate; partially managed through consistent sampling period</td>
<td>Comparative</td>
<td>Yes; but very limited ability; training needed</td>
<td>Poor (hard to grasp what it means)</td>
<td>Minor substrate disturbance during sampling</td>
</tr>
</tbody>
</table>

- **Temporal variability:** Moderate; partially managed through consistent sampling period.
- **Spatial variability:** Low-moderate; addressed through multiple samples.