Greater Vancouver Sewerage and Drainage District
Liquid Waste Management Plan
Environmental Monitoring and Assessments Task Group

Proposed Watershed Classification System for Stormwater Management in the GVS&DD Area

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PROLOGUE

The Greater Vancouver Sewerage and Drainage District (GVS&DD) and its member municipalities are committed to the principle of managing liquid wastes (including urban stormwater runoff) in a manner which protects the receiving environment using cost effective approaches. This commitment is detailed in the 1996 Liquid Waste Management Plan (LWMP) submission for the GVS&DD area and is the basis for development of the Stage 2 LWMP scheduled for completion in 1999. The LWMP process is mandated by the provincial government and is designed to facilitate an integrated and local approach to making liquid waste management decisions.

Ideally stormwater should be managed on a watershed basis within a broad framework of land management, and ecosystem planning. Within the GVS&DD area, responsibilities for stormwater management rest primarily with municipalities. The stormwater component of the Stage 2 LWMP is intended to help municipalities address stormwater management in a regional context while recognizing the uniqueness of each municipality, their needs, priorities, and objectives. However, the entire watershed community (senior and local governments, developers, industry, farmers, public, etc.) needs to work together for effective stormwater management and environmental protection to be achieved. To this end, advisory groups comprised of municipal, GVS&DD, senior government, and independent members, were established to help develop various components of the Stage 2 LWMP. Advisory groups involved with stormwater management include the Environmental Assessments, the Stormwater Management, and the Brunette Basin task groups.

The purpose of this report is to provide a proposed approach to health assessment of watersheds in the GVS&DD. Watershed assessment information is a precursor to planning, and is needed to identify appropriate protection, restoration and enhancement opportunities.

The watershed classification approaches in this report are intended to enable comparisons between watersheds with reference to natural and introduced conditions to help select appropriate stormwater management planning approaches. This report is not intended, nor does it provide sufficient information to enable direct specification of management prescriptions and related capital and operating programs. Such detailed matters can only reasonably be addressed through detailed attention to drainage systems (natural and introduced) with reference to ecosystem considerations such as hydrological regimes, water quality, stream channel and associated riparian conditions.

This report presents two watershed classification systems. These classification systems both use the same watershed health indicators but differ in the manner in which fish and fish habitat are considered. The first system was proposed by the consulting team after reviewing other classification systems. The Fisheries agencies (DFO and MELP) have indicated that the first method is not consistent with the legislation and policies of the Fisheries agencies. The second system was recommended by the Fisheries agencies as being the only system that is consistent with Provincial and Federal legislation, policy and mandates.

The proposed classification system is not intended to be used other than within a framework for the purposes of stormwater management planning.

Studies initiated in August 1998 to further evaluate and assess the ecological effects of stormwater discharges in the GVS&DD area may help to validate or refine some aspects of the proposed classification system. For more information on Liquid Waste Management Plan programs, please contact:

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SYNOPSIS BY ENVIRONMENTAL ASSESSMENTS TASK GROUP

This synopsis addresses the Environmental Assessments Task Group's reasons for requesting the development of the watershed classification system, how the system may be used, and potential future uses. The report findings and two classification systems are summarised in the executive summary that follows.

This report and its proposed classification system are intended to assist municipalities in the GVS&DD area with identifying and targeting appropriate stormwater management initiatives for cost effective drainage and environmental protection needs in watersheds in the GVS&DD area. While this report has been examined by a number of participants in the GVS&DD LWMP process, it is not intended to contain formal or informal statements of policy or direction.

At their December 17, 1998 meeting, the EATG acknowledged the DFO/MELP system of characterizing fisheries resources is consistent with the legislation and policies of Fisheries agencies.

Given the scope of this report and the limited number of criteria used to classify watersheds and recognizing the unique goals, needs, and priorities of each municipality, this report does not and cannot recommend any specific stormwater management initiatives that would be appropriate for the various classes of watersheds. Next steps in the testing and development of the proposed watershed classification system, and related work, may include:

- Determining how all of the watersheds in the GVS&DD area could be classified using the system proposed here. Testing the system on more watersheds may help to validate or refine some aspects of the classification system. In addition this may provide a general perspective on the environmental status of watersheds within the GVS&DD area;
- Reviewing information collected in studies initiated in August 1998 to further evaluate and understand the ecological effects of stormwater discharges in the GVS&DD area. Information collected in these studies may help to validate or refine some aspects of the proposed classification system;
- Developing general guidelines on appropriate municipal stormwater management programs for each class of watershed;
- Forecasting how the classification of watersheds in the GVS&DD area might change in the future under existing management policies, growth, and development patterns. This information could be considered by stakeholders in determining what policies, practices, and stormwater management controls are appropriate for a particular watershed.

As the LWMP process evolves some aspects of this report and the proposed classification system may be incorporated into the Stage 2 LWMP.

EXECUTIVE SUMMARY

This report presents a procedure for classifying watersheds within the Greater Vancouver Sewerage and Drainage District (GVS&DD) using indicators of watershed health and fisheries resources. Total impervious area and riparian forest integrity are the primary indicators of watershed health. Agricultural land use was also considered as an indicator, but was ultimately rejected because of the lack of empirical relationships between the extent of agricultural activity and watershed health. The two watershed health indicators are integrated graphically to form a classification system with four classes: excellent, good, fair, and poor.

Two options are presented that differ only in their approaches to considering fisheries resources and fish habitat potential. The first method differentiates watersheds using an evaluation of native fish species diversity in combination with a scoring system that assesses the conservation significance of the fish community. The Fisheries agencies have indicated that the first method is not consistent with existing legislation and policies. The second method was proposed by the Department of Fisheries and Oceans (DFO) and Ministry of Environment, Lands and Parks (MELP) staff and classifies watersheds based on fish presence and habitat value. Using this system, watersheds are separated into three categories based on the presence or potential presence of salmonids and/or rare and endangered fish species, or the importance of the watershed in sustaining downstream fish populations through food and nutrient contributions. The Fisheries agencies have stated that this second method is the only system that is consistent with Provincial and Federal legislation, policy and mandates. Both methods for evaluating fisheries resources were incorporated into the classification system by subdividing the four watershed health classes into four or three subclasses, depending on the method.

Nineteen subwatersheds within seven watersheds were used to test the practicality and sensitivity of the classification system. Test watersheds were chosen because of the availability of watershed-level information, including fish presence and distribution, as well as their representativeness of physiography and land development patterns in the GVS&DD area. Watersheds included the Brunette River, Salmon River, Serpentine River, Mosquito Creek, Mossom Creek, Como Creek, and Musqueam Creek. Watersheds were defined as drainage basins of streams that flow into the tidal waters of Burrard Inlet, Boundary Bay, or the Pitt, Fraser or Nooksack rivers. Subwatersheds are tributaries of larger watersheds whose drainage boundaries are defined by municipal drainage or topographic mapping. Residual watershed areas were not treated as subwatersheds for the purpose of this study.

Watershed health indicators were divided into primary and secondary indicators. Primary indicators were total impervious area, riparian forest integrity, and agricultural land use. Watershed forest cover, agricultural use in riparian areas, surficial geology, and water license information were included as secondary indicators because they may modify the response of a watershed to land-use change. However, they were not integrated into the classification process at this time. Both sets of indicators were chosen from a number of previous assessment or classification studies including work by May *et al*., 1997; Zandbergen, 1998; Steedman, 1989; and Rood and Hamilton, 1993.

Two general approaches for defining watershed classes were compared. The first approach integrated riparian forest integrity and total impervious area to separate subwatersheds into four

classes: excellent, good, fair, and poor. The second approach was similar but it also incorporated agricultural land use into a three-dimensional representation of watershed classes. The results were relatively similar using these two methods, and for reasons of practicality and scientific defensibility, only riparian forest integrity and total impervious area were used for the final classification procedure. Figure A shows the watershed health classes using the total impervious area and riparian forest integrity relationship used for this project, and identifies the watershed class designation for the nineteen subwatersheds.

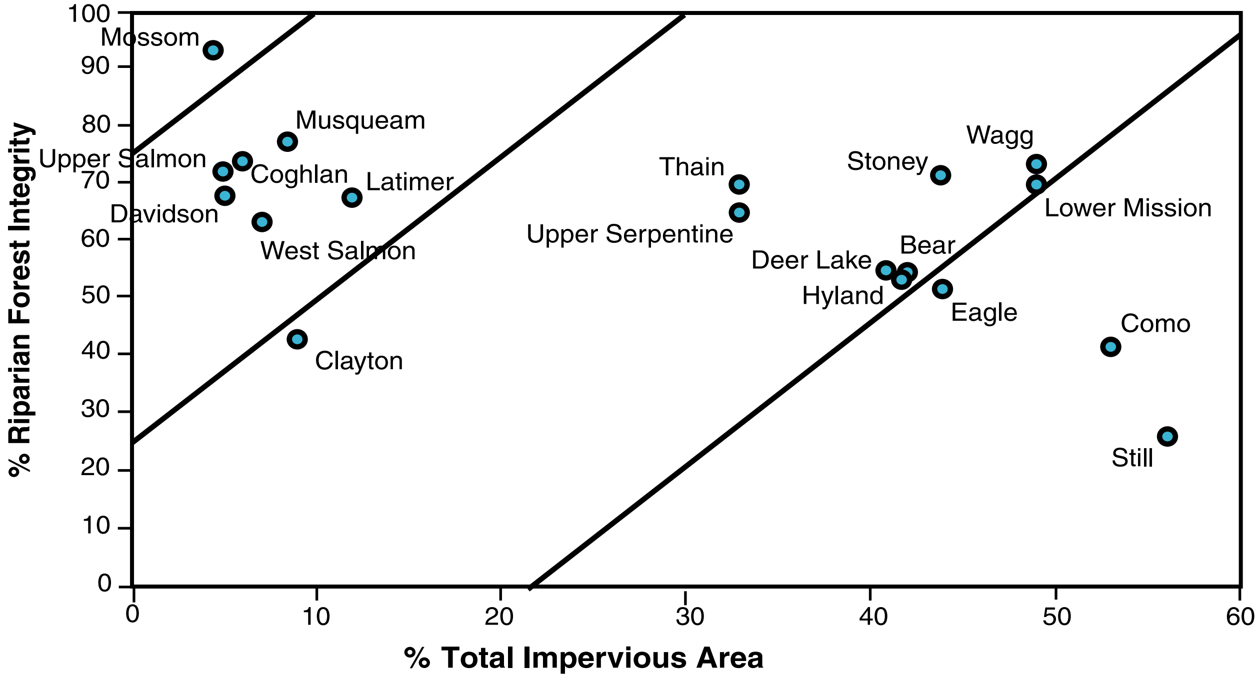

Figure A. Watershed health of the nineteen test subwatersheds.

Fisheries resource indicators from both assessment options were incorporated as subclasses in the classification system. In the first assessment option, the proposed measures of native fish diversity and conservation significance were used to separate the classes into high, moderate, and low categories. Using these divisions, subwatersheds that contain or flow into watersheds with fish populations of high conservation value were separated from other subwatersheds. Similarly, subwatersheds that contain or flow into subwatersheds with high diversity fish populations were treated separately. Finally, subwatersheds that contain or flow into subwatersheds with moderate conservation significance or moderate fish diversity are separated from subwatersheds that contain or flow into subwatersheds with low conservation significance and low fish diversity. A general assumption of this process is that, in terms of management importance based on fisheries resources, subwatersheds are inseparable from the downstream portions of watersheds into which they drain.

In the second assessment option, subwatersheds were separated into subclasses based on the three categories of fish presence and fish habitat value proposed by the Department of Fisheries and Oceans and Ministry of Environment, Lands and Parks staff. The categories are broad and all nineteen subwatersheds were designated as Category 1 systems (watersheds inhabited by salmonids and/or rare or endangered fish species, or potentially inhabited with access enhancement).

The proposed classification of the nineteen test subwatersheds is presented in Tables A and B on the following pages. Table A integrates fish diversity and conservation significance as subclasses, while Table B designates subclasses using the watershed categories proposed by DFO and MELP staff. At their December 17, 1998 meeting, the EATG acknowledged the DFO/MELP system of characterizing fisheries resources is the only system that is consistent with the policies of Fisheries agencies.

Table A. Classification of test subwatersheds using fish diversity and conservation significance to define subclasses.

Watershed Class	Subclass Based on Fisheries Resource Characteristics	Subwatersheds in Test Group
A. Excellent	**A1** *-Contain or flow into watersheds or subwatersheds with fish populations of high conservation significance*	-
	A2 *- Contain or flow into watersheds or subwatersheds with high fish diversity*	-
	A3 *- Contain or flow into watersheds or subwatersheds with fish populations of mod. conservation significance or mod. fish diversity*	**Mossom Creek**
	A4 *- Contain or flow into watersheds or subwatersheds with fish populations of low conservation significance and low fish diversity*	-
B. Good	**B1** *- Contain or flow into watersheds or subwatersheds with fish populations of high conservation significance*	**Upper Salmon River**
	B2 *- Contain or flow into watersheds or subwatersheds with high fish diversity*	**Coghlan Creek** **Latimer Creek** **Davidson Creek** **West Salmon River**
	B3 *- Contain or flow into watersheds or subwatersheds with fish populations of mod. conservation significance or mod. fish diversity*	**Musqueam Creek**
	B4 *- Contain or flow into watersheds or subwatersheds with fish populations of low conservation significance and low fish diversity*	-
C. Fair	**C1** *- Contain or flow into watersheds or subwatersheds with fish populations of high conservation significance*	-
	C2 *- Contain or flow into watersheds or subwatersheds with high fish diversity*	**Upper Serpentine River** **Stoney Creek** **Thain Creek** **Hyland Creek** **Bear Creek** **Deer Lake Brook** **Wagg Creek** **Lower Mission Creek**
	C3 *- Contain or flow into watersheds or subwatersheds with fish populations of mod. conservation significance or mod. fish diversity*	**Clayton Creek**
	C4 *- Contain or flow into watersheds or subwatersheds with fish populations of low conservation significance and low fish diversity*	-
D. Poor	**D1** *- Contain or flow into watersheds or subwatersheds with fish populations of high conservation significance*	-
	D2 *- Contain or flow into watersheds or subwatersheds with high fish diversity*	**Eagle Creek** **Still Creek**
	D3 *- Contain or flow into watersheds or subwatersheds with fish populations of mod. conservation significance or mod. fish diversity*	**Como Creek**
	D4 *- Contain or flow into watersheds or subwatersheds with fish populations of low conservation significance and low fish diversity*	-

Table B. Classification of test subwatersheds using DFO / MELP method of assessing fish presence and fish habitat value.

Watershed Class	Category Based on Fisheries Resource Characteristics		
	Category 1	**Category 2**	**Category 3**
A - Excellent	Mossom Creek	None	None
B - Good	Musqueam Creek Coghlan Creek Latimer Creek Upper Salmon River Davidson Creek West Salmon River	None	None
C - Fair	Clayton Creek Thain Creek Upper Serpentine River Stoney Creek Lower Mission Creek Wagg Creek Bear Creek Hyland Creek Deer Lake Creek	None	None
D - Poor	Eagle Creek Como Creek Still Creek	None	None

PROJECT PROCESS

This project was initiated in May 1998 following the development of a detailed Request for Proposal. Considerable input went into the Request for Proposal to ensure the concerns, issues, and ideas of a broad number of LWMP stakeholders were incorporated.

After project initiation, the project team presented a preliminary work program to the Environmental Assessments Task Group (EATG) on May 28, 1998. This provided an opportunity for the project team to refine the scope of work, as well as allowing EATG members to identify any outstanding concerns.

A workshop was held on July 30, 1998 to present a framework for the proposed classification system to the EATG. The workshop was well attended by Federal, Provincial, and municipal staff. A discussion paper, outlining a possible classification framework and indicators that were identified as important to include in the classification process, was presented. The project team also distributed copies of a document summarizing the fifteen classification systems that were reviewed as the first stage in this project.

Between July 30, 1998 and early September, the classification procedures were tested and refined. Considerable GIS-based analysis was undertaken to determine riparian forest integrity and other factors. A draft report was submitted on September 11, 1998 to the EATG. More than sixty copies of the draft report were distributed to members of the LWMP technical task groups (Environmental Assessments, Brunette Basin, Stormwater), provincial and federal officials, and other interested municipal and GVS&DD staff for their review. As well, the project team made a presentation to the EATG describing the methods, results, and rationale for the proposed classification system. Reviewers were given approximately one month to provide comments on the draft report.

The final report incorporates comments received from a number of people on the draft report. In particular, a number of Department of Fisheries and Oceans and Ministry of Environment, Lands and Parks staff provided detailed comments on the proposed measures of fisheries resources. A second measure of fisheries resources was proposed by DFO and MELP staff which has been incorporated into the final report. A number of substantive changes were made to the report to address issues regarding total impervious area calculation, riparian forest integrity assessment methods, and the definition of subwatersheds.

The final report was presented to the EATG on December 17, 1998. At this meeting, the EATG acknowledged the DFO/MELP system of characterizing fisheries resources is the method that is most consistent with the policies of Fisheries agencies. During January through April, 1999 LWMP stakeholders conferred on the wording of the introductory sections of the report before settling on the final text.

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1. INTRODUCTION

Despite a long history of stream classification based on physical and biological characteristics in British Columbia, relatively little work has been undertaken on classifying urban watersheds to guide environmental management activities. Recent research on the impacts of urbanization on watershed functions and health has provided a strong case for focusing protection efforts on those watersheds where natural ecological and hydrological processes are most intact, and directing restoration efforts on others where such efforts will be feasible and viable.

Urbanization, and to a lesser degree agricultural activities, cause profound changes to hydrology, riparian-stream channel interactions, instream habitat, and water quality that lead to a reduced ability of streams to support healthy fish populations, as well as to increased maintenance costs to address flooding and channel instability. Several recent publications have argued that in those watersheds where intense urbanization has occurred, it may be difficult or impossible to meet resource protection goals such as sustaining diverse and abundant fish populations (Booth and Jackson, 1997; Fresh and Lucchetti, in press.). However, to date, there has not been an analysis of how differences in the physical, biological, and land use characteristics of urban watersheds should be used to determine appropriate stormwater management strategies in watersheds of the GVS&DD. This project was meant to address this need by developing a watershed classification system that provides a comparison between watersheds, and can assist in targeting stormwater management and related resource protection strategies where they will be most effective. The priority watersheds for increased stormwater management emphasis may range from moderately, or even heavily degraded, watersheds with a high potential for improvement, to healthy watersheds that require additional protection to avoid future urbanization related impacts.

As described in the Prologue, the primary focus of this project is to contribute to the development of a Liquid Waste Management Plan (LWMP) for the GVS&DD. The LWMP will provide direction to municipal governments on regional objectives for stormwater management and methods to address the environmental effects of stormwater. The GVRD is currently developing a BMP manual that addresses operational and maintenance BMPs, capital and structural BMPs, and non-structural BMPs (e.g., land use planning) for the GVRD.

The classification system could also be used for a number of additional resource management objectives including:

- Targeting restoration planning;
- Guiding appropriate stewardship activities for each class of watershed;
- Providing a framework to implement the Streamside Directive under the *Fish Protection Act*. For example, riparian protection requirements could be higher in streams with good or excellent ecological health.
- Providing input to growth management.

This report is divided into six sections. Section 1 provides an introduction to the project and a general description of physical characteristics of watersheds in the GVS&DD study area. Section 2 summarizes the range of impacts to watersheds and streams caused by urban and agriculture land use.

An important aspect of this report is to provide an introduction to the components of watershed health. Section 3 discusses the range of indicators, the justification for their selection, and methods, while Section 4 presents the integration of the indicators to describe watershed health classes. An introduction to the test watersheds in presented in Section 5. Finally, Section 6 summarizes the results of the testing phase of the project, compares the assessment findings for the nineteen subwatersheds, and presents the classification of the watersheds and subwatersheds.

As the initial step in this project, we reviewed fifteen classification systems that were pertinent to this study because of environmental similarities to the GVS&DD, useful or well organized classification framework or process, applicable criteria, or representativeness of a range of classification systems. Classification systems were identified from academic databases, Internet searches, and discussions with resource management professionals in other jurisdictions. Several were not explicitly classification systems, but rather presented methods of characterizing ecological health. A summary of classification systems reviewed is provided in Appendix 1. Maps of the test watersheds are presented in Appendix 2.

1.1 Environmental Setting of the GVS&DD Area

The GVS&DD encompasses portions of eighteen municipalities in the Lower Mainland[1] and is the most heavily urbanized region in western Canada. Despite the dense population and rapid urban growth over the last fifteen years, this area also supports some unique environmental values and features. The forested hillsides of West and North Vancouver, large urban parks such as Green Timbers Urban Forest, Central Park, and Stanley Park, the marshes of Boundary Bay and the Fraser Delta, and productive salmon rivers such as the Capilano, Seymour, Salmon and Kanaka Creek are examples of environmental features of regional significance. The network of small streams and their riparian corridors also contribute to the cultural and economic well being, as well as the environmental quality of the region by sustaining fish and wildlife populations and providing linear parks and greenways.

The following sections provide a brief description of the physiographic, climatic, and land use characteristics of the GVS&DD study area.

1.1.1 Climate

The lower Fraser Valley climate is characterized by a modified maritime climate with a wet, cool winter and a pronounced summer dry period. Annual precipitation averages about 1,000 mm at Vancouver Airport, increasing to the north and, to a lesser extent, to the east, prior to uplift of air masses over the Coast and Cascade Mountains. Annual precipitation reaches about 1,600 mm at the eastern edge of the lowlands and increases rapidly into the higher elevations of the Coast Mountains. The headwaters of Mosquito Creek receive over 2,700 mm of precipitation annually.

[1] The GVS&DD encompasses all, or portions of, Vancouver, Surrey, Delta, Township of Langley, City of Langley, Burnaby, New Westminster, District of North Vancouver, City of North Vancouver, West Vancouver, Port Moody, Port Coquitlam, Coquitlam, Maple Ridge, Pitt Meadows, Richmond, White Rock, University Endowment Lands.

Along the Pacific Coast, winter extends from late September or October until March and consists of a continual procession of Pacific westerlies onto the coast, occasionally broken by the formation of high pressure ridges. Roughly three-quarters of the annual precipitation falls in these months. During summer a high-pressure zone dominates off the coast and little rain falls. Drought, or periods without rain, which usually occur in July, August or September can extend from a few weeks to 50 days or more. Summer storms are usually brief and intense; however, large storms occasionally disrupt the high-pressure zone and can produce extreme flooding (Ward and Skermer, 1992; Evans and Lister, 1984).

1.1.2 Physiography

The GVS&DD region encompasses two distinct physiographic regions: i) the Fraser Lowland; and, ii) the southern slopes of the Coast Mountains. The Fraser Lowland is a triangular-shaped depositional feature that extends east from Point Grey to Laidlaw and south to Bellingham, lying between the Coast and Cascade Mountains. The Fraser River bisects the Lowland, flowing in a valley that is up to 5 km wide and up to 200 m below the surrounding terrain.

The lowland on the south side of the Fraser River is characterized by broad, flat-topped or gently rolling uplands or hills (reaching up to 200 m above sea level) that are separated by wide, flat-bottomed valleys (Armstrong, 1957). The largest valleys are the Serpentine-Nicomekl lowland, the Matsqui Prairie, and the Sumas Valley (which lies entirely outside of the GVS&DD). Elevations in the lowlands are typically less than 15 m.

On the north side of the Fraser River, the terrain consists of gently rolling uplands or hills, up to about 200 m elevation, separated by the broad valleys of the Pitt, Alouette and Stave rivers. The upland surfaces range from flat-topped outwash or deltas to hummocky till and glaciomarine sediments.

The Coast Mountains are dominated by erosional landforms from the last glaciation. Peaks are craggy and are separated by deep saddles and narrow, steep-walled valleys. The main valleys through the Coast Mountains are glacial troughs with steep upper slopes and gentle lower slopes. Tributary streams often originate in a cirque (now often filled by a lake) and often hang with respect to the main valley.

1.1.3 Surficial Geology

Armstrong (1956; 1957; 1960a; 1960b) mapped the exposed surficial materials of the Fraser Lowland in detail and later summarized his work in Armstrong (1983; 1984). The Lowland has experienced repeated glaciations, separated by non-glacial intervals, and deposits from all these periods are partly preserved in the 300 m of sediment that fill the Fraser Valley.

Atwater (1994), Halstead (1986; 1957; 1953), and Armstrong and Brown (1953) describe the hydrologic and hydrogeologic character of the various units. The marine and glaciomarine sediments that are near the surface throughout most of the study area are commonly less than 30 m thick and are of moderate to low permeability. The deltaic sands and gravels are highly permeable, up to 40 m thick and generally have a flat or gently sloping surface. Most rain that falls on these sediments percolates to groundwater rather than leaving as surface runoff. The glacial tills are of varying grain size and compactness and consequently have varying permeabilities. At higher elevations ablation tills, that are not compact, often overlie lodgement tills.

The steep upper slopes of the Coast Mountains are covered by thin layers of colluvium or glacial deposits; the granodioritic bedrock is often exposed. Less steep slopes, which occur at low and middle elevations, are often covered by glacial drift, principally till. Glaciofluvial and glaciolacustrine deposits are found at low elevations in the major valleys and may be exposed by erosion in the lowest reaches of some tributaries.

1.1.4 Hydrology

The stream hydrograph of most streams in the GVS&DD closely follows the precipitation cycle. The greatest monthly discharges occur in November, December and January and maximum daily discharges are also usually recorded in these months. Flows generally decrease during the spring and summer until they reach a minimum in July, August, or September. Seven-day low flows almost always occur in July, August or September, typically at the end of a long period without rain. Flows vary greatly throughout the year and, in small watersheds, the maximum daily flow is often 500 times greater than the minimum daily flow.

Annual maximum flows and seven-day low flows vary from watershed to watershed, partly in response to surficial materials. Soils in glaciomarine and till deposits are often underlain by compacted, consolidated strata with very low infiltration rates. Water infiltrating the surface soil commonly moves laterally down slopes as interflow, along impervious horizons at the base of the soil, often re-emerging at the base of slopes, and rapidly reaching streams. Only a part of the annual precipitation is stored as groundwater; as a result, flow declines rapidly during the dry, hot summer months, and low flows may be zero, or close to zero, in small watersheds.

Soils developed on gravel and sand deposits have high infiltration rates and a large portion of annual precipitation is stored as groundwater. Streams draining these deposits often intercept the groundwater table and much of their flow derives from groundwater discharge. As a result, these creeks have a slower response to rainstorms, lower peak flows, a less steep recession curve and higher base flows - in effect these streams exhibit a much smaller range, and a more even distribution, of flows. Groundwater discharge often maintains summer base flows that are well in excess of those in watersheds with moderately impermeable surface materials.

Some of the streams in the GVS&DD, or some reaches of these streams, go dry during very low flows. These streams may either be groundwater effluent (that is, water is discharged from the stream channel through its bed to a groundwater reservoir) or, at low flows, the discharge flows sub-surface through the alluvial gravel in the bed of the channel. In the latter case, pools may remain full of water and receive some inflow from the upstream riffle. Streams that are reported to have dry reaches include the Campbell River (Armstrong 1957), Anderson Creek and the small upper tributaries of many of the GVRD streams.

1.1.5 Stream Channels

The streams in the GVS&DD typically originate in an upland where they are moderately steep, have gravel and cobble bed materials and flow in a narrow creek valley incised into glacial deposits. The mid- and lower reaches of the salmon streams generally lie in one of the major lowlands or cross the floodplain of the Fraser River. These reaches are low-gradient, the channel bed is often sand, and, for flood protection, the channel has often been diked, enlarged or artificially straightened.

On the north side of the Fraser River, the typical stream begins in the Coast Mountains where thin deposits of colluvium or glacial material overly bedrock. The channel is steep and often contained in a gully or narrow valley, where coarse sediment is contributed by landslides, debris flows and snow avalanches. Further downstream, in the Fraser Lowland, many of these streams flow across a fan or debris cone, before crossing thick accumulations of glacial or recent sediments. Streams are often unstable on their fans, or wander on the low-gradient recent or glacial deposits, and bank erosion is a major source of coarse sediment to the stream.

1.1.6 Development History and Land Use

First Nations historically occupied what is now the GVRD for at least 10,000 years prior to the arrival of European settlers in the 1820s. Settlers arrived in greater numbers during the gold rush of the 1850s, and the Vancouver area was logged until the 1880s, when the focus of the logging industry shifted to the east and north. Dyking of the river banks, initiated in the 1860s, reduced flooding and allowed for agricultural development of the lowland areas, although it was not until the railway was completed in 1885, that settlement increased dramatically in the area (Boyle *et al*., 1997).

Since the turn of the century strong population growth in the GVS&DD region has continued, with a commensurate increase in land clearing for agriculture and urban development. A study which examined the changes in land cover in the Lower Fraser basin from 1827 to 1990 determined that the area of coniferous forest cover changed from 71% prior to 1827 to 50% in 1930 to 54% in 1990. However, prior to 1827, only 27% of the forest was immature (<120 years old), while 40% was immature in 1930 and 73% of the forest was immature in 1990. The amount of wetland decreased from 10% to 1% while urban and agricultural area increased to 26% of the study area in 1990 (Boyle *et al*., 1997). Because these changes were calculated for the entire Fraser Valley from Hope to the mouth of the Fraser River, the deterioration in forest cover and increase in land conversion can be expected to be greater in the more populous GVRD than the Valley-wide averages presented above.

Today, over one-half of British Columbia's population lives in the GVRD or the communities immediately adjacent to it, and it is Canada's third largest urban region. The majority of the GVRD's land base has been cleared for agriculture and urban development, or altered by industrial forestry activities. The trend in population growth is expected to continue - between 1991 and 2021 the GVRD's population is expected to increase from 1.6 million to almost 2.7 million, an increase of almost two-thirds (GVRD, 1996).

1.2 The Basis for Classification - Watershed Differences

Watershed classification provides a means for generalizing or grouping watersheds by characteristics such as fish use, ecological health, or land use patterns, so that they can be managed, treated, or compared efficiently. Classification can be based on a number of attributes related to natural or anthropogenic differences in watersheds or streams. Natural features include climate, physiography, soils, nutrient productivity, watershed size and connectivity to other aquatic ecosystems. Anthropogenic features are primarily related to land use and include land-use types (urban, agriculture, forest), the degree of hydrologic disturbance and imperviousness, water withdrawals, water quality, instream habitat conditions, and riparian integrity. Finally, classification can be driven by biological indicators such as fish or macroinverterbrate diversity, abundance, or presence of pollution- tolerant or intolerant aquatic species.

As described in a previous section, watersheds in the GVS&DD can be divided most broadly into two units based on physiography: i) watersheds draining from the Coast Mountains into Burrard Inlet; and, ii) watersheds draining from the Fraser Lowlands into the Fraser River, Nooksack River (Washington State), and Boundary Bay (Figure 1.1). A brief description of the differences in physiography, climate, land use and fish diversity between these two areas is described below to provide a context for later sections of this report.

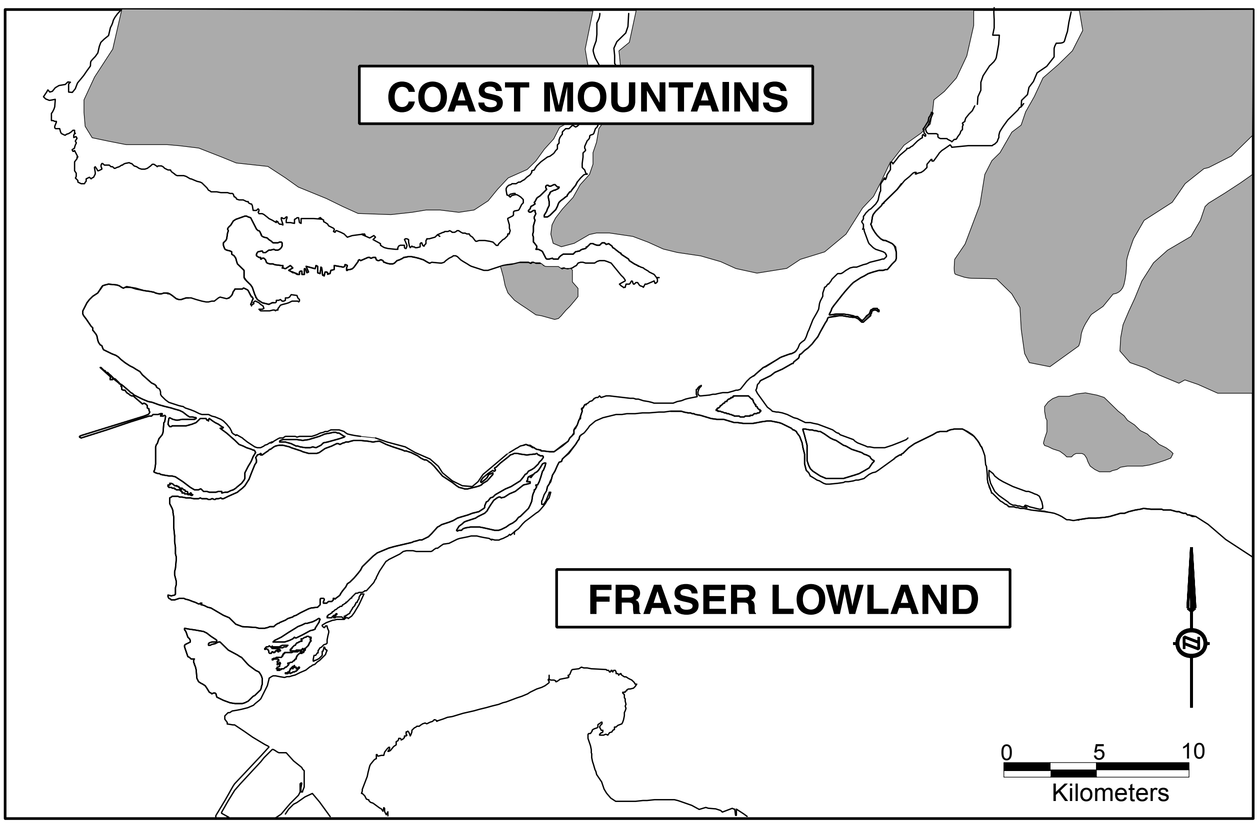


Figure 1.1 Overview of physiographic division of the GVS&DD study area.

1.2.1 Mountain Watersheds

The streams and rivers originating in the Coast Mountains are found within the municipalities of North and West Vancouver, Port Moody, Port Coquitlam, and Maple Ridge. Of the test watersheds, Mosquito and Mossom creeks are most representative of mountain watersheds. Streams in these watersheds are high or moderate gradient (e.g., >5%) that originate above 1000 m of elevation along the crest of the North Shore Mountains (see Figure 1.2 for longitudinal channel profile). The upper tributaries of some of these streams are prone to debris flows and other natural disturbance because of unstable slopes.

The mountain watersheds have a different climate than the Fraser Lowlands. Precipitation is substantially greater; for example, the headwaters of Mosquito Creek receive over 2700 mm annually compared to just 1250 mm for Musqueam Creek on the western side of the Fraser Lowland. Snowfall and subsequent snowmelt alters the annual hydrograph of these systems by sustaining higher late spring and early summer flows; snowmelt during fall rainstorms increases peak flows Soils are primarily developed on glacial till, colluvium, and bedrock.

The fish community also reflects the physiographic characteristics of the mountain watersheds. In general, mountain streams of the GVS&DD support fewer fish species than streams in the Fraser Lowlands. Salmonids and sculpins that prefer or tolerate higher flow velocities predominate, while minnow species including chub and dace are absent. Cutthroat trout, coho salmon, and prickly and coastrange sculpin are the most common species in these watersheds. Cutthroat trout are ubiquitous and occur from sea level to above 500 m in elevation. The lower fish diversity of mountain streams also reflects the isolation of these systems from the Fraser River and Nooksack River which were source areas for colonization following deglaciation. Anadromous species likely dominate because of their ability to disperse through saltwater. Fish abundance may also be influenced by the low nutrient productivity of many of the mountain streams.

Land use is characterized by intense residential development along the lower slopes of the North Shore Mountains below approximately 300 m in elevation. Single family residential is the most common land use, although newer areas support some multi-family housing. Industrial use is concentrated on the foreshore of Burrard Inlet and commercial activity is confined largely to town centres or linear commercial districts. Above 300 m, the watersheds are largely forested with second growth Douglas-fir, western hemlock, and red alder forests that are bisected by occasional roads and powerline corridors.

1.2.2 Fraser Lowland Watersheds

Fraser Lowland watersheds are found primarily within Langley, Surrey, the southern portions of Coquitlam and Vancouver, and Delta. All of the Fraser Lowland streams flow into the tidal lower reaches of the Fraser River, Boundary Bay, or flow south into the Nooksack River in Washington State. The Salmon and Serpentine rivers, Como Creek, and Musqueam Creek are test watersheds that are representative of the physiography and land use in the Fraser Lowland.

Streams of the Fraser Lowland originate below 150 m of elevation and are characterized by low channel gradients (1 to 3%) (see Figure 1.2 for a representative longitudinal channel profile). Channels may be only partially confined, and floodplains and off-channel ponds and wetlands are common in less disturbed areas. Fish habitat, as a result of the low gradient, is complex and productive.

Soils range from sedimentary deposits created during the formation of the Fraser Delta to glacial till at higher elevations. Fine silts and clays support agriculture and are also characterized by low infiltration rates. Discharge is dominated by the effects of precipitation from November to March, and pronounced summer dry periods coinciding with the lack of summer rainfall. Annual runoff is about 1,000 mm or approximately 0.3 L/s per hectare.

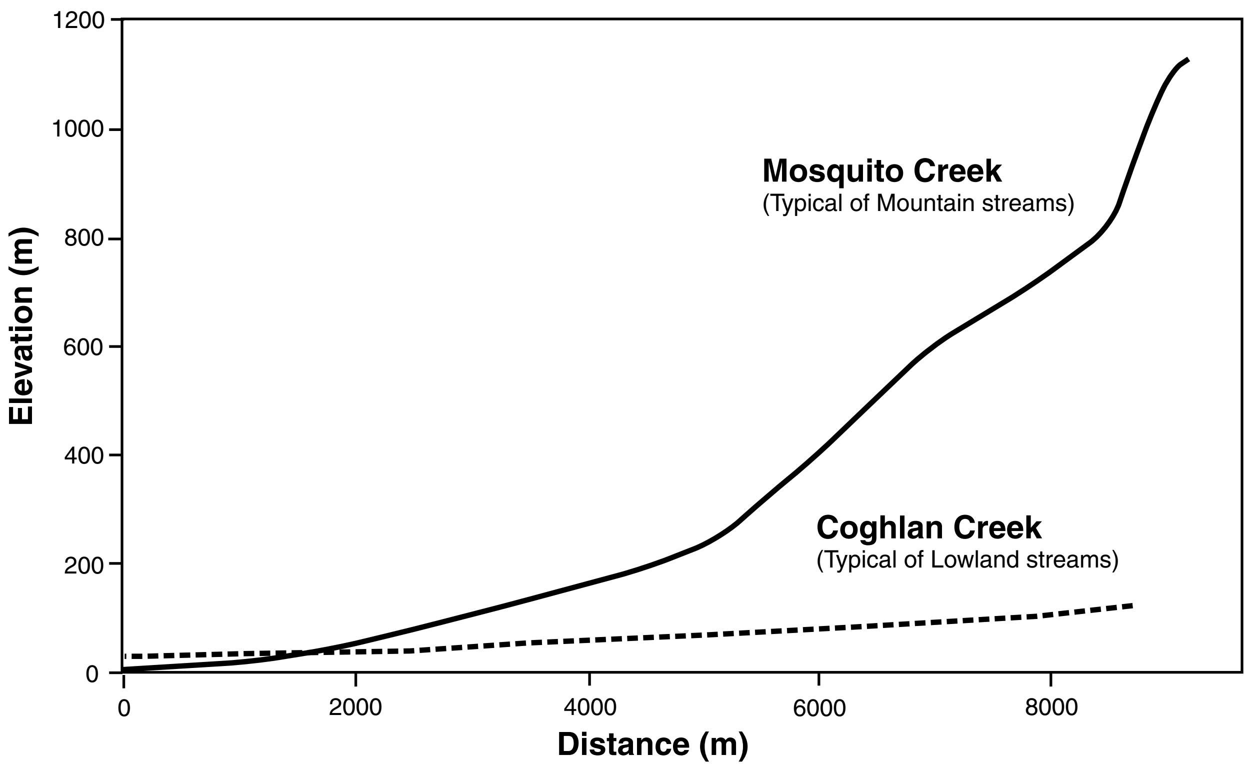


Figure 1.2. Comparison of longitudinal channel profiles for Mosquito and Coghlan creeks.

Biologically, the streams of the Fraser Lowland are unique in B.C. Not only are they connected to the largest freshwater river system in British Columbia, the Fraser River, but they occur at the convergence of marine and freshwater systems at the western end of the Fraser River delta. Following deglaciation of coastal B.C., fish colonization occurred along three major routes (McPhail and Carveth, 1993). Fish tolerant of saltwater (including anadromous salmonids) were able to migrate from glacial refugia south of the Fraser Delta. At the same time, several species that survived the last glaciation in the Chehalis Refuge south of Puget Sound were able to colonize the Nooksack River tributaries of south Langley (i.e., Bertrand and Pepin creeks) and the Salmon River. Lastly, a number of fish species from the Columbia and Great Lakes refuges used the Fraser River to colonize the Lower Fraser by dispersing downstream. Up to fifteen freshwater species occur in Fraser Lowland streams including six salmonids: coho, chum, pink, chinook, cutthroat trout, and steelhead. Two endangered species, the

Nooksack dace and the Salish sucker are also found in the Fraser Lowland watersheds (McPhail and Carveth, 1993; Inglis *et al*., 1992; Inglis and Pollard, 1994).

Land use in the Fraser Lowland is a mosaic of agriculture, urban and suburban development. Agricultural is concentrated on the low-lying floodplain areas because of productive soil conditions. Urban development is a mix of concentrated developments within town centres and urban sprawl. More recently, urban growth has expanded from urban and suburban nodes into the surrounding rural area. Growth in the last 20 years has been extreme.

2. EFFECTS OF URBAN AND AGRICULTURAL DEVELOPMENT ON WATERSHED HEALTH

Urban watersheds are complex ecosystems in which land use, surficial geology, climate, and topography are interrelated with biological components such as vegetation and fish communities. Maintaining the health of urban streams depends on sustaining the complex ecological processes among stream channels, riparian corridors and their watersheds. Indeed, one of the most significant changes in water resource management in the past decade has been increased emphasis on the condition and hydrologic function of the watershed rather than the stream or river channel.

The following sections provide a summary of the effects of urbanization and agricultural development on watershed level processes, fish and other aquatic organisms, and other components of GVS&DD watersheds. An important impetus for this work is the increased understanding of the systemic changes caused by urbanization, and to a lesser extent agricultural development, on the ecological health of small watersheds. Recent work in the Lower Mainland, Washington State, and elsewhere in North America also provides the basis for this classification system by proposing and testing indicators, and analyzing the relationships between watershed-level variables, stream character, and the biological community.

Changes to hydrology, riparian-stream channel interactions, instream habitat, and water quality that result from urbanization reduce the ability of streams to support diverse and productive fish populations, as well as increase maintenance costs associated flooding and channel instability (May *et al*., 1997; Fresh and Lucchetti, in press; Booth and Reinelt, 1992). Stream channels are destabilized by more frequent floods as impervious surfaces increase the rate and volume of surface run-off. Summer base flows may also decline due to the reduced infiltration and lack of soil-water storage in urban areas. Instream changes include reduced habitat complexity as the loss of mature riparian forest leads to fewer and smaller sources of large wood inputs into the channel. And in areas of intense urban development, contaminants such as zinc and copper are introduced into the stream through stormwater systems and may accumulate in stream bed substrates. In response to intense urbanization, the fish community generally changes from one dominated by coho salmon, to one where cutthroat trout, threespine stickleback, or non-native species such as carp are the primary fish species.

Agricultural land use also affects stream health, although research indicates that the effects are not as drastic as those caused by urbanization (Wang *et al*., 1997; Allan *et al*., 1997; Steedman, 1988). Habitat degradation of rural streams is associated with loss of riparian forest, channelization and diking, sedimentation, and moderate nutrient enrichment (Steedman, 1988; Wernick *et al*.,1998; Zandbergen, 1998). In some regions, biotic integrity (one measure of ecological health using the fish community as an indicator) does not begin to decline until agricultural land use exceeds 50% land use of the watershed area (Wang *et al*., 1997; Allan *et al*., 1997). Water quality problems, including nutrient enrichment and riparian forest loss, rather than hydrologic disturbance, may be the most important concern in watersheds dominated by agricultural land use.

It is important to point out that our understanding of watershed-level processes is a complex and rapidly changing area of research. We recommend the reader consult the a number of documents in the references section for more thorough and rigourous descriptions of development related changes to the ecology of small watersheds.

2.1 What Characterizes Healthy Watersheds?

Recent research has used human health as an analogy of the health of streams, watersheds, and landscapes (see Schaeffer *et al*., 1998; Kaufmann *et al*., 1994). Many definitions exist for ecological health. The Clayoquot Scientific Panel (1995) stated that healthy watgrsheds are functioning, self sustaining systems undergoing no systematic changes as the result of unnatural (i.e., human-induced) manipulations. Kaufmann (1994) defined a healthy ecosystem as "one in which structure and functions allow the maintenance of the desired condition of biological diversity, biotic integrity, and ecological processes over time." Naiman *et al*., (1992) focused on the importance of natural disturbance in defining watershed health: "Ecologically healthy watersheds are maintained by an active disturbance regime operating over a range of spatial and temporal scales. This natural disturbance regime produces a dynamic equilibrium for riparian forests, habitat, water storage, and biodiversity resulting in resilient and productive ecological systems."

However defined, it is appropriate to focus on the components of ecological health that can be measured and compared. Naiman *et al*., (1992) opined that the ecological health of watersheds is dependent on the inter-relationships of five main structural and functional components:

- **Basin geomorphology** which influences hydrologic and disturbance processes such as sediment supply and channel movement;
- **Hydrologic pattern** including discharge rates, seasonal timing of flows, and peak flow frequency;
- **Water quality** referring to the chemical, physical, and biological conditions of water that are related to biogeochemical processes in the soil, riparian zones, and headwaters;
- **Riparian forest characteristics** including species composition, age, and disturbance frequency; and,
- **Instream habitat characteristics** such as pool frequency, bankfull width and depth, and large wood accumulations.

All these components are directly or indirectly affected by urban and agricultural land use. However, as we will discuss in more detail later, changes to watershed hydrology and riparian forest are the focus of this classification system for four reasons:

- They appear to be the primary stressors on the health of the watershed and, of the five components listed above, the most directly affected by land use change;
- There are well defined indicators to assess them at the watershed or subwatershed level;
- They are strongly linked to changes in the stream-level components of instream habitat, water quality, and fish populations; and,
- They are practical to measure in comparison to water and sediment chemistry and channel morphology (e.g., pool:riffle ratio, large woody debris frequency, etc.).

2.2 Urban Development and Hydrology

Urban development may alter the hydrologic regime in several ways. Water withdrawals, either from groundwater or surface water, often reduce mean annual flows and seasonal seven-day low flows in streams; they may also reduce flood discharges if storage is developed as part of the project.

Urban development is also accompanied by changes in the watershed – primarily creation of impervious areas – which greatly affect its hydrologic response. Roads and drains are constructed which collect and concentrate surface and shallow subsurface runoff; vegetation is cleared, soil is compacted and partly stripped, which reduces or eliminates soil storage and increases the potential for surface flow. Often, the ground surface is regraded and depressions are filled, eliminating surface water storage: subsurface utilities and drainage trenches intercept deeper subsurface flow and pipe it to surface drainage. Buildings add additional impervious area, reduce infiltration, and provide surface runoff to streams.

A common result of urban development is an increase in the overall mean annual runoff. The increase results from increased stormflow, as a result of reduced infiltration, as well as reduced evapotranspiration. Booth (1990) describes increases of mean annual runoff amounting to several hundred millimeters in King County, Washington. The same result might be expected in the Fraser Lowland where surficial geology and climate are similar.

Studies elsewhere have demonstrated increased storm volumes, increased peak flows, and more frequent small floods after urban development. In King County, Booth (1990) found a consistent increase in the ratio of post to pre-development storm peaks with increasing effective impervious area (EIA) in small watersheds. Based on simulation, the increase in the 100-year discharge averages about 2 times and that of the 1.5-year flood about 2.5 times for an EIA of 20%, increasing further with additional development. There is wide variation in the ratio of post to pre-development flood discharges in individual basins, partly as a result of terrain and surficial sediments. Also, detention or retention structures or other stormwater control measures may help reduce the post to pre-development flood magnitude ratios. Figure 2.1 depicts generic changes to a flood hydrograph in urban watersheds (from Zandbergen, 1998).

The altered flood hydrology in urban streams not only increases the velocities experienced by fish that use the stream during winter, but it is also associated with morphologic changes that affect habitat. Typically streams widen, bank erosion and channel shifting accelerate, and pool area decreases (see May *et al*., 1997; Finkenbine, 1998). Urban streams also have much less large woody debris, partly as a result of dislodgement and stranding during floods. Lack of new large wood additions, as a result of loss of riparian forest, and removal of wood debris as part of stream clearing programs are also important factors that contribute to lower quantities.

It is often assumed that reduced infiltration and increased storm runoff reduces soil and ground water recharge, ultimately leading to lower base flows during the late summer. However, removal of vegetation tends to counteract this effect and decreased transpiration raises base flows in late summer. It is generally accepted that the effect of urban development on low flows is likely to be site-specific

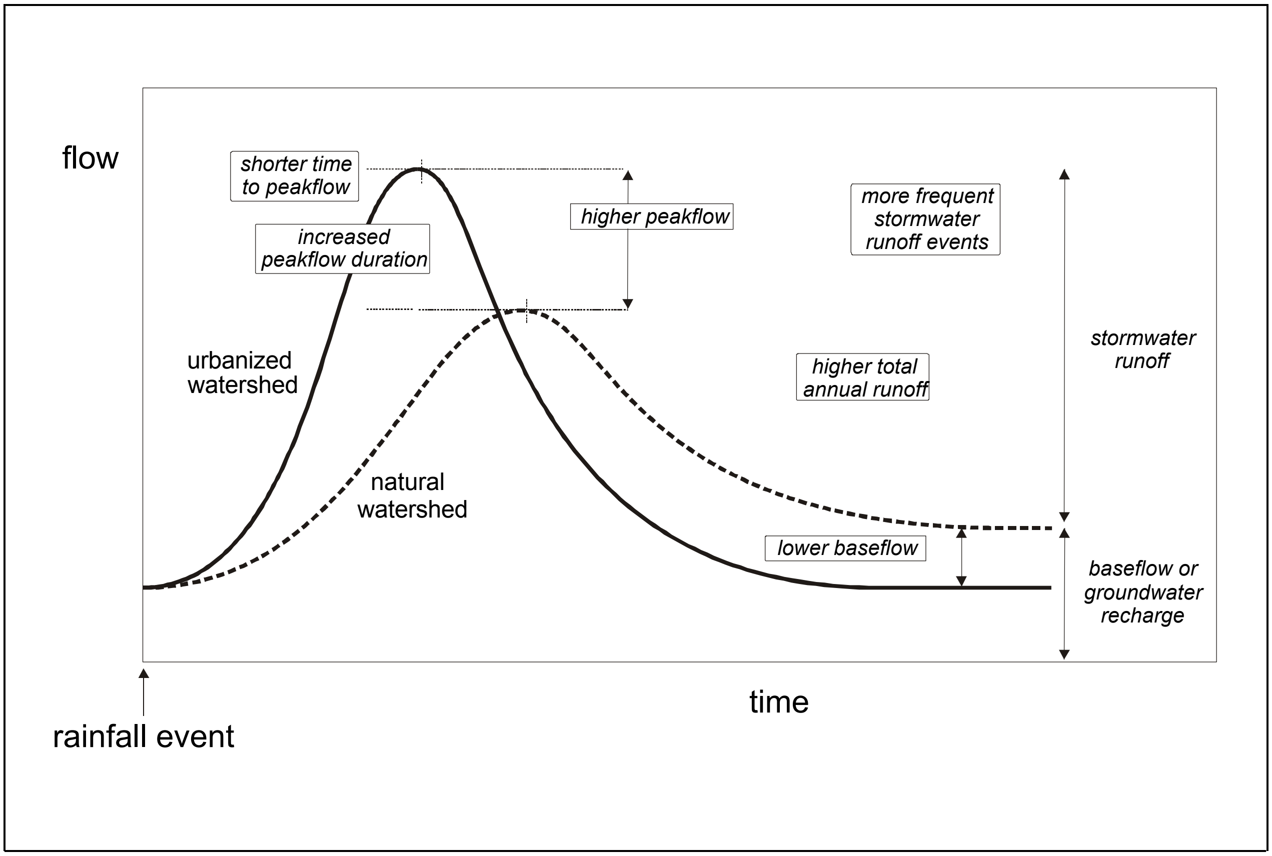


Figure 2.1. Generic changes to storm runoff hydrograph in urban watersheds (from Zandbergen, 1998).

and at least partly dependent on the surficial materials. In small basins in relatively impervious soils (tills, glaciomarine sediments), flows tend to be close to zero between rainstorms. In these circumstances on-site detention, which stores water and releases it gradually, may increase base flows. For low density developments on permeable sediments (i.e., glaciofluvial sands and gravels) sufficient recharge may reach the groundwater table to maintain the low flow regime experienced prior to development.

2.3 Agriculture and Hydrology

Agriculture affects both the quality and quantity of water in the GVS&DD streams. Clearing of forested lands at the turn of this century, and development for agriculture, are thought to have increased peak flows from less than 5 to as much as 50% (Northwest Hydraulic Consultants, 1995). Some stream channels may still be changing in response to this alteration of their hydrology, particularly those that have also had their riparian forest removed.

Agriculture is also a major user of surface and ground water. Surface water is extracted from streams for stock watering, domestic use and irrigation. Extractions for domestic use and stock watering occur all year long at very low volumes. It is irrigation that has the main effect on stream hydrology. The greatest extractions from surface water occur during July and August, when about 60% of the water for irrigation is typically required, which often corresponds with seven-day minimum low flows.

2.4 Groundwater Extractions and Surface Flows

Much of the GVS&DD area is underlain by a thick complex of glacial, glacio-marine and fluvial deposits of varying porosity and permeability and, as a result, has a complex hydrogeology (see Table 6.13). Aquifers, or deposits that contain or transmit significant quantities of water, occur both near the land surface - these are called water table or unconfined aquifers - and at depth. Aquifers at depth are often overlain and underlain by aquitards or aquicludes, deposits that transmit only small quantities of water such as clays, silts and tills. In these confined aquifers, water levels will rise above the top of the deposit and wells tapping them are referred to as "artesian".

Halstead (1986) estimated a total groundwater production in the Fraser Valley of 30 million cubic metres in 1981. The Groundwater Section of the Ministry of Environment has records for about 8,000 drilled wells. Groundwater is used for a variety of purposes, such as domestic supply, irrigation, industry, and fish hatcheries. A large, but unknown, part of the groundwater production is from relatively deep wells penetrating confined aquifers and its extraction has little or no impact on quantities of surface water in the Fraser Lowland.

However, extractions from unconfined, or water table, aquifers may reduce streamflows. Thick glaciofluvial sands and gravels, deposited as deltas by meltwater streams, provide water table aquifers with excellent water quality. The large raised delta south of Langley, the raised delta east and north of Langley, and the outwash plain south of Abbotsford that includes the Abbotsford Airport are all underlain by glaciomarine deposits; groundwater discharges from springs along the contact with the glaciomarine deposits. These springs are important in maintaining base flows in Anderson and Fishtrap creeks and the upper Salmon River.

Aquifers are also the source for many municipal and irrigation wells (Halstead 1986). Municipal, irrigation and industrial wells withdraw more than 600 L/s from the outwash deposits that lie south of Abbotsford during the summer irrigation season (Halstead 1986). A significant portion of the annual discharge from this groundwater reservoir is consumed rather than provided as base flow to streams.

2.5 Water Quality

The term water quality refers to the chemical, physical, and biological conditions of water and the degree to which it is impaired for human use or aquatic organisms by natural or anthropogenic factors. Urbanization typically results in higher levels of pollutants entering the streams including sediments, oxygen depleting substances, pathogens, metals, hydrocarbons, and various organic contaminants. Reasonably strong correlations have been found between imperviousness and various water quality parameters, including baseflow conductivity, fecal coliforms, hydrocarbons and various metals in the water column and metals in sediment (e.g., May *et al*., 1997; Zandbergen, 1998). Despite the evidence that water quality worsens, the exceedance of water quality guidelines or objectives for the protection of aquatic life does not occur very frequently at low and moderate levels of urbanization during baseflow. Exceptions to this are suspended sediments from land clearing and construction activities, and fecal coliforms that may exceed limits set for secondary contact recreation.

In the case of agriculture, the water quality impacts are somewhat different. The main concerns include increased sediment loading from erosion, nutrient inputs from manure and fertilizer, and agricultural chemicals. Concerns include both stream water conditions for the protection of aquatic life and drinking water supplies.

2.6 Riparian-Channel Processes

Riparian communities are found along stream margins, floodplain areas, wetlands, and seepage sites where high plant species diversity reflects higher light levels, varied soil moisture levels, and chronic disturbance such as windthrow and channel erosion. In the GVS&DD area, riparian communities are typically associated with the broad floodplain of the Fraser River or narrow and fragmented corridors surrounding small streams. The range of vegetation communities is diverse including mature coniferous forest, immature mixed or deciduous forest, shrub thickets, pasture, golf course, and unmaintained grassed areas. Red alder and black cottonwood are common on sites with recent disturbance or high water tables, while Douglas-fir, western hemlock, and big-leaf maple occur in stream ravines and dominate later-successional forests. Many urban riparian areas do not support forest. Reed canary grass dominated areas, active pasture, and shrub thickets are common riparian communities throughout the Lower Mainland and often indicate periodic human disturbance or livestock grazing.

Two general trends in riparian condition are observed throughout the GVS&DD area. First, almost all riparian areas were logged within the last 100 years resulting in loss of mature riparian forest and its replacement with non-forest communities or young forest stands. Many riparian areas in the urbanized portion of the study area do not support trees older than 80 years. However, the degree of riparian buffer encroachment in relation to impervious area coverage is variable. May *et al*., (1997) found riparian forest integrity at 20% total impervious area ranged from 73% to 35%.

Second, riparian areas are both narrow and fragmented. Encroachment into riparian areas for residential or agricultural land uses is common, and historically small ravines and headwater streams were filled to provide developable land. In heavily urbanized watersheds such as Como Creek, riparian forest is confined to steeply sloped stream ravines that resisted early land subdivision. Fragmentation of riparian corridors caused mainly by roads and utility corridors is an ubiquitous impact in urban areas. Zandbergen (1998) found 2 to 5 road crossings per kilometer of stream in the Brunette Watershed.

What makes riparian forest so critical in sustaining stream health? As Naiman *et al*. (1992) succinctly described: "*The heart of the ecologically healthy watershed is the riparian forest. The riparian forest is shaped by channel geomorphology, hydrologic pattern, spatial position of the channel in the drainage network, and the inherent disturbance regimes. Yet the riparian forest affects, and is affected by, habitat dynamics, water quality and the animal community*." This highlights the importance of riparian forest in sustaining the physical habitat of streams, and begins to describe the usefulness of riparian integrity as an indicator of watershed health.

Direct functional interactions between stream channels and the riparian zone include the following processes (after Gregory *et al*. 1993; Franklin 1992;):

- Recruitment of large woody debris (LWD) including fallen logs and snags into the stream channel;
- Addition of nutrients and organic matter (e.g., litter and insect fall);
- Stabilization of the banks of the channel and stream bed substrates;
- Modification of microclimate (e.g., light, temperature, and humidity); and,
- Control of the flow of water, sediments, and nutrients from upslope areas into the stream channel.

Previous work summarized the range of buffer widths that are needed to sustain riparian-channel processes in coastal British Columbia (Millar *et al*., 1997). In general, microclimate regulation and nutrient control require the largest buffer widths to maintain complete function (Chen *et al*., 1995). Large woody debris recruitment from the riparian forest into the channel and floodplain is also a key factor in sustaining coastal streams (Bisson *et al*., 1987). Indeed, there is probably no factor more critical in shaping the physical conditions of coastal stream channels than large instream wood. The loss of large woody debris in urban streams is likely to be partially responsible for the change from coho to cutthroat trout dominance. May *et al*. (1997) found both the volume and frequency of large wood declined as urbanization increased. Only stream segments with greater than 70% upstream cumulative buffer width over 30 m wide had high volumes and frequency of large wood. The rate of large woody debris recruitment is determined by the height and age of the riparian forest, as well as disturbance factors. In many coastal areas, a buffer of approximately one tree height, or 45 to 55 m, in width would be required to ensure 100% of predevelopment log recruitment into the channel (McDade *et al*., 1990). Decline in the frequency and volume of large woody debris in urban streams is also caused by washout from increased peak flows and removal of instream wood to prevent debris jams and obstructions.

Another important aspect of riparian ecology is the influence of disturbance processes including periodic flooding, wind throw, and stream channel changes on vegetation. Chronic and episodic disturbance increases structural forest features such as snags, downed logs, and a multi-layered, uneven aged canopy, as well as the range of successional stages from recently exposed gravel bars to mature western redcedar forest. Part of the loss of riparian integrity appears to stem from diking, bank armouring, floodplain loss, and other engineered approaches to river and stream control. Many floodplains in GVS&DD streams have been heavily developed and are no longer inundated except during infrequent and intense flows. Likewise, vegetation management in urban areas reduces the occurrence of windthrow or snag development because of danger-tree removal.

2.7 Stream Channel Conditions

As described previously, urban development leads to an increased magnitude and frequency of peak flows, as well as loss of riparian forest. These changes lead to a consistent set of disturbance in stream channels in urban watersheds. Typically, stream channels widen (by eroding their banks) and they often downcut, by eroding their beds, scouring gravel from the stream. The extent of widening is partly controlled by local bank materials and the presence of riparian vegetation. The material eroded from the bed and banks is then deposited along the stream, reducing it to a more stable slope, for the greater peak flows. Where the bed materials deposit, bank erosion is often aggravated and more frequent overbank flooding results, both from the more frequent floods and from the raised channel bed. Deposition may occur in the lowest reaches of the stream or at control points, such as inadequately sized bridges and culverts. Municipalities and landowners respond to sediment deposition and other problems with bank armouring, channel straightening, dredging or diversion.

The increased peak flows, and the channel adjustments, tend to reduce the extent and depth of pools along the stream. This becomes particularly evident when large woody debris is removed by increased peak flows or through clearing programs designed to improve the channel capacity (Finkenbine, 1998).

Changes in sediment supply, as a result of urban development, may also affect the stream channel. Initially, urban development is thought to result in an increase in the supply of fine sediment to streams, released from construction sites, that may degrade spawning gravels. Following development, the supply of sediment from the land surface is often reduced. However, stream bed and bank erosion may then begin to contribute large quantities of coarse and fine sediment that lead to profound changes in stream morphology.

2.8 Fish and Macroinvertebrates

An important attribute of healthy watersheds is that they support an assemblage of aquatic species including fish, macroinvertebrates, and amphibians, similar to, or indistinguishable from, that which occurred prior to anthropogenic disturbance. Watersheds with degraded ecological health typically support fewer sensitive fish species, such as salmonids, that are intolerant of urbanization-related impacts and more native or non-native species such as threespine stickleback and carp that tolerate changes in watershed health. Cutthroat trout often displace juvenile coho salmon as the dominant salmonid in degraded urban streams (Lucchetti and Fuerstenberg, 1993; Scott *et al*., 1986) and several biologists have also observed declines in sculpin abundance (K. Fresh pers. comm).

Fish and macroinvertebrates (aquatic insects and other organisms) also provide a useful indicator of the effects of urbanization or agricultural development on stream health (Karr, 1991; Claytor and Ohrel, 1995; May *et al*. 1997). Measures of abundance, diversity, and species presence have been used in many jurisdictions as a measure of the health of streams or watersheds. For example, the Index of Biotic Integrity (IBI) uses fish presence, diversity, abundance, condition, and local indicator species to evaluate human effects on a stream relative to regional standards. In the Pacific Northwest where fish diversity is relatively low, alternative biotic measures such as Benthic Index of Biotic Integrity (B-IBI) have been developed using macroinvertebrates rather than fish (Kleindl, 1995; Karr, 1998). Several classification systems we reviewed incorporated IBI or B-IBI into the classification process.

Fish diversity in GVS&DD streams is related to five primary factors: i) watershed size; ii) stream gradient; iii) watershed elevation; iv) historic connectivity to source or colonization areas; and, v) the effects of land use change. Low gradient, low elevation, higher order systems that are connected to the Fraser River support the most diverse and abundant fish populations in the GVS&DD area. For example, the Salmon River watershed supports approximately fourteen fish species excluding those associated with the tidal reaches near the Fraser River. Steep, first order basins support the fewest fish species and often at low abundance. Only six fish species occur in Mossom Creek despite its low level of urbanization and lack of riparian disturbance, although chum salmon spawning abundance is high. Heavily urbanized basins typically retain small populations of coho salmon, cutthroat trout, and increasing populations of pollution-tolerant native and non-native species such as carp and threespine stickleback.

Three main changes in the fish population accompany urbanization or intense agricultural land use. The most significant and documented change in the fish community of urban streams is from coho dominance to cutthroat trout dominance. Lucchetti and Fuerstenberg (1993) and Scott *et al*. (1986) documented reductions in the percentage of coho relative to cutthroat in a number of urban streams (Figure 2.2). In healthy streams, juvenile coho account for 2 to 10 times the number of cutthroat fry. As urbanization proceeds, juvenile and adult resident cutthroat become more dominant and eventually surpass coho both in total numbers and biomass. Scott *et al*. (1986) found that 85% of fish biomass was contributed by cutthroat trout in the heavily urbanized Kelsey Creek near Seattle, while only 4% was from juvenile coho. This change is likely due to the reliance of juvenile coho on stable channels with complex habitat created by large woody debris - habitat conditions that are less common in urban streams. In our own work on fish communities in GVS&DD streams these same generalizations hold true. Sampling in a small section of Musqueam Creek in 1994 showed that coho salmon were nearly twice as common as cutthroat trout. However, it is important to note that we have also observed coho to cutthroat ratios of 5:1 in fairly degraded streams in the GVS&DD.

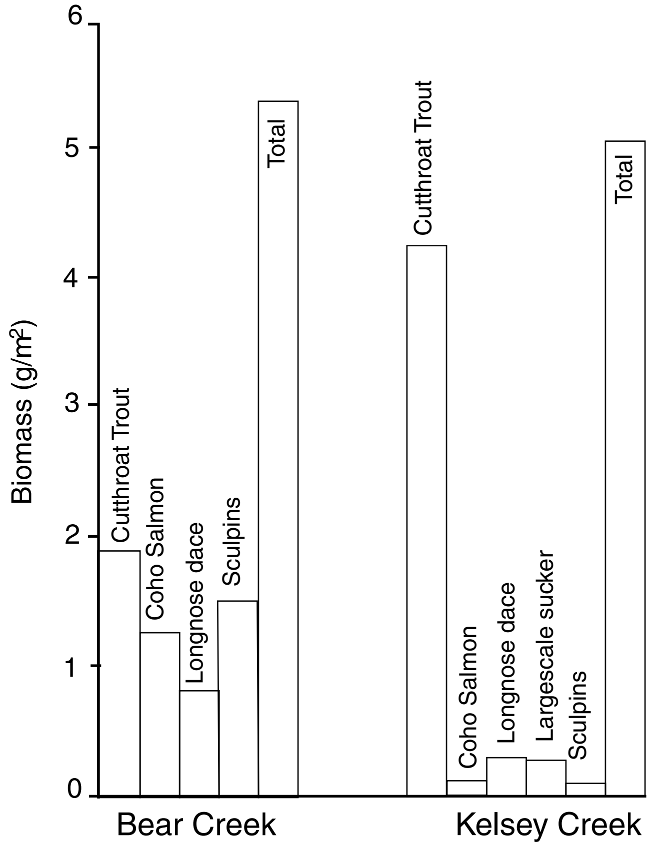


Figure 2.2. Comparison of fish biomass in a healthy stream (Bear Creek) to an urbanized stream (Kelsey Creek) (from Scott et al., 1986).

Urbanization is also associated with the local extinction of fish populations. Approximately twenty small streams in the Vancouver area were culverted during the initial phases of urban development resulting in the extirpation of their fish communities (Harris and Proctor, 1989). Other small stocks have or will likely become locally extinct because of the cumulative effects of urbanization including culverting and habitat loss. Chum populations appear to be particularly susceptible to urbanization. We have observed many small streams in the GVS&DD in which chum stocks are either chronically depressed, or extirpated. In many ways, the sensitivity of chum salmon to urbanization is counter-intuitive. Unlike coho salmon that spend over one year in the stream before migrating to sea, chum migrate soon after emergence from the gravel and are not exposed to the habitat or water quality impacts for a lengthy period of stream residency. However, two factors may make chum more susceptible to urbanization-related impacts: i) preference for low gradient stream channels in the lower reaches; and, ii) relatively uniform run timing. The lower reaches of most urban streams have undergone the most substantial development related changes. In Como Creek for example, less than 4% (205 m of 5335 m of stream channel) of the watershed within the floodplain of the Fraser River has not been channelized or culverted. Uniform run timing may also make chum more susceptible to changes in hydrology or intense fishing pressure as they congregate near the mouths of small streams until flows increase with the first fall storms.

Lastly, urban streams in the GVS&DD are often colonized by non-native fish species that are tolerant of degraded stream conditions such as high temperatures and low dissolved oxygen. Carp, goldfish, brown bullhead, black crappie, pumpkinseed, and bass have been introduced into many urban streams and lakes or have dispersed from larger, non-native populations in the Fraser River. The interaction of non-native and native fish populations is poorly understood, but in other ecosystems, susceptibility to invasive species colonization is a sign of ecosystem stress.

The benthic macroinvertebrate community also provides a measure of long-term water and sediment quality conditions. In many ways it is a more accurate measure of streams ecological health (or biotic integrity) than periodic water quality testing, which often fails to capture chronic toxic events, "first-flush" stormwater, and peaks of high temperature and low dissolved oxygen. The diversity and percentage of intolerant species such as mayflies, caddisflies, and stoneflies (i.e., EPT taxa) can be used to measure the health of the aquatic ecosystem relative to regional standards (Kleindl, 1995; Kerans and Karr, 1994).

3. WATERSHED CLASSIFICATION METHODS

The proposed classification system integrates physical indicators of watershed health, including imperviousness and riparian forest integrity, with an assessment of fisheries resources to determine watershed class and subclass. Watershed health indicators were divided into primary and secondary indicators. Primary indicators were incorporated or tested as part of the classification procedure, while secondary indicators were assessed for each subwatershed because they may modify watershed response to land use change. However, at this time, there is too little information on their effects on watershed health to include them in the classification system. Both sets of indicators were chosen from a number of previous assessment or classification studies including work by May *et al*., 1997; Zandbergen, 1998; Steedman, 1989; and Rood and Hamilton, 1993.

It was decided early on that, where possible, indicators would be based on empirical studies rather than qualitative comparisons or other methods. This limited the range of possible indicators but increased the scientific defensibility of the system. However, much of the research base we relied on was developed for other areas of North America. Even the recent work in Puget Sound may not be entirely comparable to the mountain streams of North and West Vancouver, given the differences in channel morphology, channel gradient, and soil conditions. In addition, agricultural land use may confound measures of watershed health. Several studies indicate loss of stream function is associated with relatively high agricultural use (e.g. > 50% agricultural land use).

The following sections provide a description and justification of the primary and secondary indicators used in the watershed testing, as well as assessment methods. Finally, we include a brief discussion of community value and watershed resiliency. While neither factor is included in the classification system at this time, we believe both have implications for urban watershed management in the GVS&DD.

3.1 Primary Indicators of Watershed Health

As outlined in Section 2.1, we have used the term *watershed health* to describe the functional integrity of ecological processes such as the hydrologic regime in the watershed. Three indicators of watershed health were evaluated: i) total impervious area; ii) riparian forest integrity; and, iii) percentage agricultural land (Table 3.1). In combination, these indicators provide a surrogate measure of four of the five components of ecologically healthy watersheds including hydrology, water quality, riparian forest characteristics, and, instream habitat characteristics.

3.2 Impervious Area Coverage

Imperviousness has evolved from a method of understanding drainage function and predicting run-off rates and volumes from urban watersheds to one of the most widely used measures of the effect of urbanization on watershed health (see Arnold and Gibbons, 1996; Schueler, 1994).

Impervious surfaces are those that prevent, or reduce, infiltration into the underlying soils and include roads, parking lots, and roofs, as well as vegetated areas such as lawns or golf courses that are partly compacted or have had their surface soil removed. Impervious area can be expressed as “total

Table 3.1. Summary of primary indicators of ecological health.

Proposed Indicators of Watershed Health	Measurement Description	Typical Range of Values
1. Percentage Total Impervious Area	Calculated from land use areas derived from the Corporate Land Use Classification System for B.C. (1993). Conversion factors for impervious area are adapted from May *et al*., 1997 (from Taylor, 1993). Watershed and subwatershed boundaries provided by the GVS&DD, from municipal mapping or interpretation of topographic mapping.	0 to 65%
2. Riparian Forest Integrity (% Riparian Forest)	GIS based measurement of total forest cover within 30 m wide corridor. Extent of stream network derived from Fish Inventory Atlas; stream location derived from GVRD drainage mapping.	0 to 100%
3. Percentage Total Agricultural Land	GIS based measurement using land use category from Corporate Land Use Classification System for B.C.. Agriculture included row crops, pasture/forage, and old-field areas.	0 to 60%

impervious area (TIA)", a measure of the area of the watershed that is covered by impervious surfaces; it is usually quoted as a percentage of total watershed area (%TIA). It may also be expressed as "effective impervious area (EIA)", which is a measure of the impervious area that is connected directly to the drainage network through stormwater systems or surface run-off. This parameter is usually also quoted as a percentage of total watershed area (%EIA). Effective impervious area is always less than total impervious areas because some areas drain to terrain where stormwater infiltrates – the usual example is a roof whose gutters discharges to a lawn rather than a drainage system.

The importance of imperviousness as an indicator of hydrologic function is supported by a broad range of biological, engineering, and hydrologic studies over the past fifteen years (see Schueler, 1994; Arnold and Gibbons, 1996 for summaries). Schueler (1994) reviewed nineteen urban stream studies that examined the relationship between imperviousness or urban land use and biological and physical conditions. Almost all found impoverished macroinvertebrate or fish communities associated with moderate (10 to 15%) to high levels (>25%) of imperviousness. May *et al*. (1997) confirmed imperviousness was an excellent watershed-level indicator of urban impacts and was strongly correlated with changes to the physical habitat, water quality, and the biological communities of Puget Sound streams. Research in various areas, however, is not entirely consistent: some have found no detectable change in stream health until 10 to 15% TIA, while others have found noticeable changes at 5% or less.

It should also be noted that the studies of imperviousness vary in several ways, including the methods of measurement, the indicators used to describe instream conditions, and the physiographic conditions of the watersheds studied. In addition, the existence and location of a threshold in imperviousness above which degradation occurs is dependent on a number of factors, including topography, climate, surficial materials, and spatial distribution of urban development within the watershed. For example, soils developed on permeable glaciofluvial sediment are expected to have less alteration of their pre-development hydrologic regime, in response to development, than soils developed on glaciomarine sediments or till.

3.2.1 Measurement of Total Impervious Area

Total impervious area can be measured in two ways: i) by direct measurement of rooftops, pavement, roads, parking lots, etc, from orthophotos or air photographs; or, ii) by applying typical percentages of total impervious area to various land use classes. The GVS&DD has compiled estimates of total impervious area from digital orthophotos for most of the sanitary catchments within the GVRD. Within these catchments, the area of any large pervious or impervious areas (e.g,, parks, shopping malls, or industrial areas) was delineated. Total impervious area in the remaining, primarily residential, portions of the catchment was estimated from measurements of roads, driveways, rooftops and other impervious areas. The total impervious area outside of the sanitary catchment, but within a watershed or subwatershed, was then estimated from land use classification and the typical conversion factors in Table 3.2, as described below. These two sets of measurements are then combined for an estimate of the total impervious area in the sub-watershed or watershed.

The second method relies on the land use categories defined by the Corporate Land Use Classification System (CLUCS) for B.C. (1993). Once the total area of each different land use in the subwatershed was determined, then the total impervious area within each type was estimated from typical percentages that are suitable for that land use. The key issue, for this approach, lies in selecting appropriate conversion factors.

Table 3.2 summarizes the land use conversion factors that have been used in studies in Washington State or the Lower Mainland, as adapted to the CLUCS. The factors compiled by the various authors are based on other studies, inspection of watersheds, or, for some residential and industrial developments, they were measured from large-scale air photos areas (e.g., McCallum 1995; Zandbergen, *et al*. 1998). The factors quoted by the various authors were adapted to the CLUCS categories based on descriptions in the original sources (Table 3.2).

Residential development is the dominant land use in most of the study basins, with agricultural land use and commercial and industrial development important in some of the watersheds. Consequently, the conversion factors that are applied to these three land use categories are likely to be most significant to the estimated total impervious area in the study watersheds.

Conversion factors for total impervious area in single family residential developments vary greatly, depending, in part, on housing density or typical lot sizes. This leads to one of the difficulties with the Corporate Land Use Classification System. It only has two categories for single family residential development (S110 and S120), which is restrictive, given the broad range of housing densities that occur within the GVRD. High-density single family residential developments typically have a conversion factor of about 50%, though some developments, particularly on small lots in Vancouver

Table 3.2. Comparison of various conversion factors for calculating Total Impervious Area.

Land Use	Notes	Land Use Code	*Dincola (1990) (1)*	*May et al. (1995) (2)*	*Finkenbine (1998) (3)*	*Zandbergen et al. (1998) (4)*	*McCallum 1995 (5)*	*GVRD (6)*
Low Density Rural Residential	Residential areas that are less dense than S110	S120	10%	10%	10%	-	-	10%
Med. Density Residential	Single family housing	S110	20%	35%	25%	25%	-	40%
High Density Residential	Single family housing	S110	35%	60%	50%	50%	50%	40%
Multi-Family Residential	Multi-family dwellings in structures up to 4 storeys high	S130	60%	60%	80%	-	-	80%
High Rise Residential	Multi-family dwellings in structures more than 4 storeys high	S135	-	-	-	-	-	90%
Commercial	Retail and personal services, offices, hotels and motels	S200	90%	90%	80-95%	80%	80%	90%
Industrial	Processing, manufacturing, warehouses	S300	90%	90%	75-90%	80%	80%	75%
Institutional	Schools, universities, community colleges, Hospitals, correctional facilities, cemeteries	S400	-	90%	30-95%	varies	-	90%
Transportation and Communication	Airports, ferry terminals, railyards, shipping, Transmission lines, sewage treatment, landfills	S500	-	100% (roads)	-	100% (roads)	-	90%
Extraction Industrial	Peat extraction, gravel pits, rock quarries	M300	-	-	-	-	-	0%
Open	No visible activity; trees, green space that is not parks; also highway cloverleafs	U100	-	5%	5%	0%	-	1%
Agricultural	Farming and greenhouses	A500	-	5%	5%	0%	-	5%
Watershed Areas		W400	-	0%	-	-	-	0%
Harvesting and Research		F100	-	0%	2%	-	-	0%
Parks and Protected Areas	Local, regional & Provincial parks; ecological reserves, golf courses; ski areas, etc	R100	-	10%	2%	-	-	1%
Lakes		R200	-	-	-	-	-	0%

Notes: (1) Low density refers to 1 to 2.5 ha lots (about 0.4 to 1 Lots/ha); medium density to 4,000 m² lots (2.5 lots/ha); high density to 1,000 m² lots (9 lots/ha). Multi-family refers to low rise townhouses. (2) Typical numbers of lots/ha not provided for single family residential classes. (3) Low density refers to less than 3 units/ha; medium density to 3 to 7 units/ha; high density to 7 to 15 units/ha Multi-family refers to more than 15 units/ha. (4) Medium density imperviousness measured for 2,000 to 6,000 m^2 lots (about 2 to 5 lots/ha) in Salmon River watershed; High density imperviousness from McCallum (1995). (5) High density residential measured in Brunette Watershed for 600 to 1,200 m² lots (about 8 to 16 lots/ha). Commercial/Industrial imperviousness measured in same watershed. (6) Provided by T. Wong and R. Hicks, GVS&DD. Used to calculate TIA in watershed areas outside of their sanitary catchments.

may be slightly higher. Rural residential developments typically have a conversion factor of about 10%. One weakness is that the total impervious area of those single family developments in the GVRD with intermediate housing densities, have conversion factors between these values, and their impervious area may be over-estimated or under-estimated, depending on how they are classified.

Conversion factors for agricultural area, which are either 0% or 5% in Table 3.2, also affect the estimated TIA in the GVRD watersheds. Applying the higher value increases estimated total impervious area in watersheds or subwatersheds such as Davidson Creek, Salmon River, Coghlan Creek, Clayton Creek and Serpentine River, which are dominated by agriculture. It certainly seems that the conversion factor should be greater than zero to account for roads and structures in agricultural areas, and factors much higher than 5% are appropriate where greenhouses are a major component of agricultural production. The variation in total impervious area between various types of agricultural production can not be easily incorporated in a regional conversion factors. To correctly model greenhouses, revised factors will need to be developed for these operations, and applied only to those subwatersheds where they are a major component of agricultural-classified lands. This requires measurements from the digital orthophotos.

There is reasonable agreement among the various authors regarding the conversion factor for industrial and commercial land use. Their values range from 80 to 95% for commercial and 75 to 90% for industrial uses. Note that conversion factors for institutional land uses are expected to be much more variable and a particular value should often be assigned based on inspection of the facilities in a particular subwatershed, where this is practical. Otherwise an intermediate value may be assigned for a regional conversion factor.

For each land use category, total impervious area was calculated its total area multiplied by the appropriate conversion factor, summed across all categories, and divided by the watershed or subwatershed area, to provide a %TIA value. We adopted the conversion factors used by May *et al*. (1997), primarily because we propose to apply their classification system to the GVRD. However, their factors are in general agreement with other studies in the GVRD, when modified slightly. Category S110 (single family residential) was assigned a conversion factor of 50%, intermediate between the medium and high residential categories of May *et al.* (1997). We also revised the conversion factor for S500 (Transportation and Communications) to 25% as most of these facilities in this category in the GVRD include substantial open area. Similarly, we revised the coversion factors for U100 (open) and R100 (park) used in the Mossom and Musqueam watersheds based on local conditions.

Improved estimates of total impervious area for individual subwatersheds can be prepared by inspecting land use, either on orthophotos or on the ground, and adjusting the conversion factors as appropriate. Total impervious area factors for agricultural, single family residential, institutional, and transportation and communication land uses are particularly important to adjust.

Effective impervious area was not estimated, however, its value for each land use type can also be estimated from regional values, as a percentage of the total impervious area for that type. For better estimates, a site visit to the watershed can help identify whether effective percentages should be increased or decreased, based on local stormwater management practices.

3.3 Riparian Forest Integrity

Riparian forest integrity is a measure of the area of forest cover surrounding the stream. It provides a direct indicator of the functionality of riparian-channel processes that are sustained by forested areas, and an indirect indicator of the condition of instream habitat. As described in Section 2.6, riparian forest is critical for maintaining stream channels through large wood debris and detritus additions, bank stabilization, shading, and other factors. Channelization and other direct impacts to instream habitat (e.g., dredging, bank armouring, etc.) are typically associated with loss of, or disturbance to, riparian vegetation. Therefore, riparian forest integrity may be used as a surrogate for direct impacts to the stream channel.

Riparian forest integrity is also an indicator of the ability of instream and riparian habitats to evolve because of disturbance processes such as channel movement and windthrow. Streams with low riparian forest integrity are generally constrained within a narrow corridor, and may require engineering solutions to prevent damage to adjacent property.

3.3.1 Riparian Forest Integrity Assessment Methods

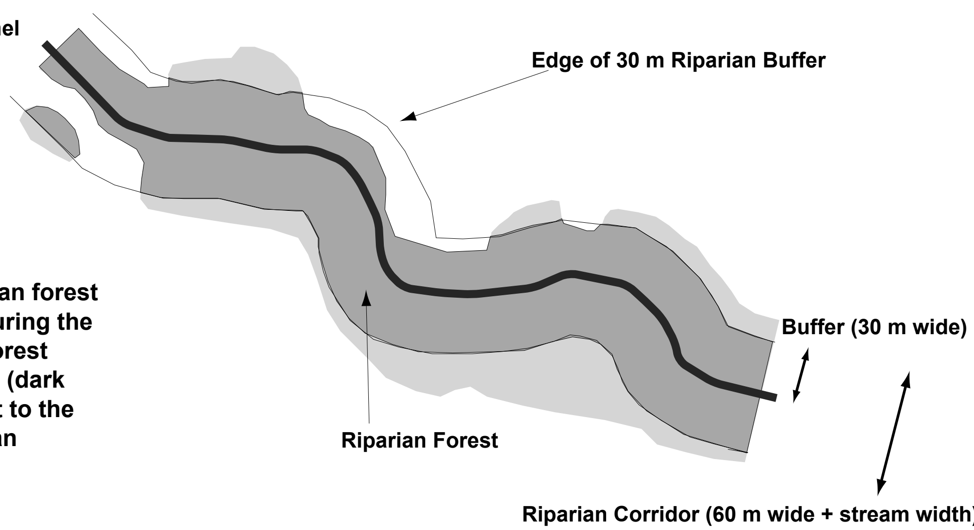
Riparian forest integrity was assessed using two measures that evaluate the area of forest cover within a riparian corridor surrounding the stream. The riparian corridor is equal to twice the buffer width plus the stream channel in larger systems[2]. While both measures assess the amount of riparian forest surrounding the stream, they capture important differences in the overall integrity of the riparian corridor. A graphical presentation of the two methods is presented in Figure 3.1.

The width of the buffer used to define the corridor was 30 m either from the centreline of the channel for small streams or from the banks of larger channels. May *et al*. (1997) found that of range of buffer widths they examined, 30 m was the most strongly correlated with other measures of stream health. In addition, Zandbergen *et al*. (in press) used a 30 m buffer width to evaluate differences in riparian forest cover in the Salmon and Brunette River watersheds. Using the same measure as these previous studies allowed us to compare our results more closely than if we had chosen a wider or narrower buffer. However, it is important to point out that this does not imply that 30 m is necessarily an adequate buffer for stream protection.

Given the complexity of surface drainage in urban environments, an important issue in assessing riparian forest integrity was to define a comparable stream network for each of the test watersheds. Zandbergen (1998) pointed out that in urban watersheds many of the headwater tributaries may have been culverted or relocated. This can reduce the comparability of measures of riparian forest integrity between predominantly natural and urbanized watersheds. In addition, we had some difficulty in defining the extent of the stream network in agricultural areas due to the large number of drainage ditches. We were concerned that measuring riparian forest from all surface drainage

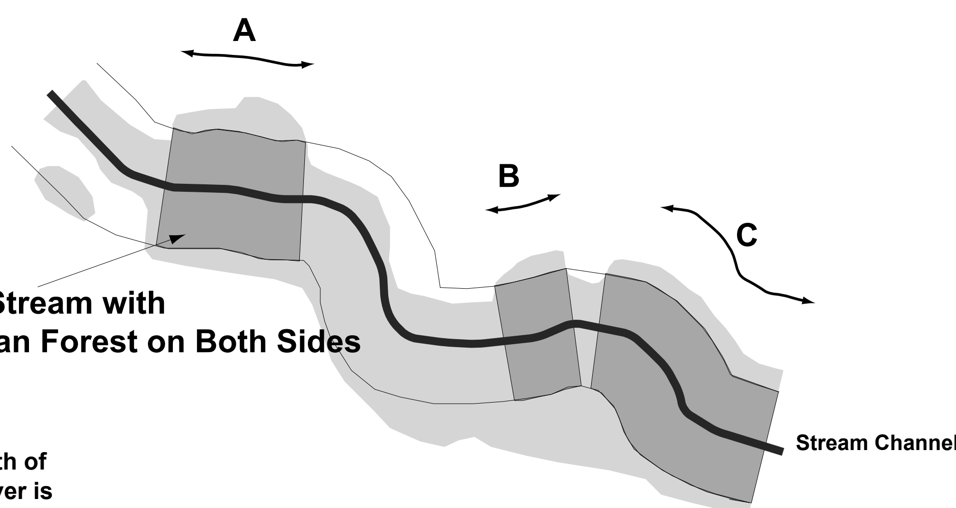
[2] We have used the term "buffer" to identify a linear zone on one side of the stream that is uniform in width (for example this assessment uses a 30 m buffer). "Riparian corridor" denotes the combined area of the buffers; 60 m in width for this assessment plus the stream channel in larger systems.

Method A
Percentage Total Riparian Forest



Note:
Percentage total riparian forest is calculated by measuring the total area of riparian forest within the buffer areas (dark grey) and comparing it to the total area of the riparian corridor.

Method B
Percentage Stream Length with Riparian Forest >30 m Wide



Note:
Percentage stream length of intact riparian forest cover is calculated by adding all the stream segments that support >30 m or greater of riparian forest (e.g. Segments A, B, and C in dark grey) and comparing them to the total stream length.

Figure 3.1. Graphical depiction of the two methods used to determine riparian forest integrity.

features would skew the results by indicating extreme forest loss even though the primary fish streams may be well forested. In addition, measuring riparian forest adjacent to all the drainage ditches would reduce the practicality of the system because of the increased time requirements for assessment.

Consequently, the Lower Fraser River Stream Inventory Atlas (Fraser River Action Plan, 1996) which incorporates the TRIM dataset of aquatic features was used to define the extent of streams for the assessment of riparian forest integrity. This provided a comparable level of mapping detail across the test watersheds and excluded some drainage ditches and small ephemeral streams from the assessment. If major tributary streams which were excluded erroneously from the atlas were found during the forest cover assessment, they were included in the calculations. Stream location was determined from recent GVRD watercourse mapping (ENKON dataset) at a scale of 1:5000.

The first measure (Method A in Figure 3.1) is an assessment of the percentage total riparian forest. It was measured by summing the total area of forest cover within the riparian corridor compared to the total corridor area. For example, Musqueam Creek has 42.3 ha of riparian forest within a total riparian corridor area of 54.4 ha (total riparian forest integrity is 77.8%). Forest was defined as vegetation with closed canopy tree cover and was interpreted from 1 m pixel digital orthophotos from 1995 using an Arcview GIS system.

The second measure assessed the percentage of total stream length with riparian forest at least 30 on both sides of the stream channel (Method B in Figure 3.1). This was measured by identifying those stream segments that have complete (i.e., > 30 m on either side) riparian forest cover. The lengths of the segments were then added, divided by the total stream length, and expressed as a percentage. It is important to point out that this measure is slightly different than that used by May *et al*. (1997). They compared the mean width of the forested portion of the riparian corridor and expressed as a percentage length within four classes (e.g., % stream length with a mean forested riparian corridor < 10 m wide). Mean width is likely proportional to the 30 m fixed width buffer, but this was not analyzed for this project.

3.4 Agricultural Land Use

Agricultural land use was the most difficult of the ecological health indicators to integrate, and we ultimately rejected it as part of the classification procedure. There are relatively few studies that have assessed the relative effect of agriculture compared to urban land use. Studies that have examined the effects of mixed land use on biotic integrity showed that effects of urbanization appeared to greatly exceed the effects of agriculture (Wang *et al*., 1997; Allan *et al*., 1997). Changes in IBI scores for varying levels of agricultural and urban land use from Wang *et al*., (1997) are presented in Figure 3.2.

The purpose of incorporating percentage agriculture land use was to capture the effects of agricultural land use on watershed health over and above those resulting from total impervious area and riparian forest integrity. Water quality contamination and water withdrawals for irrigation are examples of stream impacts specifically associated with agricultural use. For example, the Davidson Creek subwatershed of the Salmon River watershed has about 637 ha of agricultural land within a total drainage area of 998 ha. Percent impervious area is approximately 5.0% including a small area of rural residential. This is not much greater than the 4.1% TIA for the Mossom Creek watershed even though Mossom is almost entirely forested. Riparian forest integrity is also relatively similar given the overall differences in land use - Mossom Creek has 93.5% of its riparian forest intact, while Davidson Creek has 81.5%.

3.4.1 Agricultural Land Use Assessment Methods

Estimates of the area of agricultural land use were obtained during the assessment of imperviousness described in Section 3.2. It was measured in the GVRD land use database in Category A500, which includes the total agricultural area in each subwatershed and watershed. This category includes both farms and greenhouses, which have very different total impervious area. These two types of agricultural activity can be distinguished by inspection of 1:5,000 orthophotos if further detail is required.

3.5 Secondary Indicators of Watershed Health

The following secondary indicators were assessed during the testing phase of the project, but were not integrated into the classification system. Other factors such as percent stream channel modified by channelization or dyking and percent natural floodplain may also be useful for assessing the health of GVS&DD streams.

3.5.1 Watershed Forest Cover

Forested area is a measure of the "undeveloped" state of the watershed, when expressed as percentage of the total watershed area. It provides a useful measure of the portion of the watershed that retains the pre-development hydrologic characteristics.

It was estimated as the sum of parks and protected areas (Category R100), harvesting areas (Category W400) and open or undeveloped areas (Category U100), as the land use data base does not specifically include a measure of areas that are covered by trees. It is almost certain that the estimate of forested area, calculated above, is too high, and includes areas that have been altered or modified by urbanization. Category U100 includes all areas with no visible activity, as well as green space (forested and non-forested) that has not been identified as park.

3.5.2 Surficial Geology

As described previously, the hydrologic response, and the potential damage to streams, depends on soil type as well as the level of development. The GVRD database incorporates the surficial geology maps of the Geologic Survey of Canada (Armstrong 1956; 1957; 1960a; 1960b) and it was queried to provide the area of the following groups of surficial sediments:

Quadra Sands – *PVa and PVb*
Fraser and Salish Deposits – *SAa through SAk and Fa through Fe; SA-C*
Glaciofluvial – *Sa through Se; FLb and FLe; Vb*

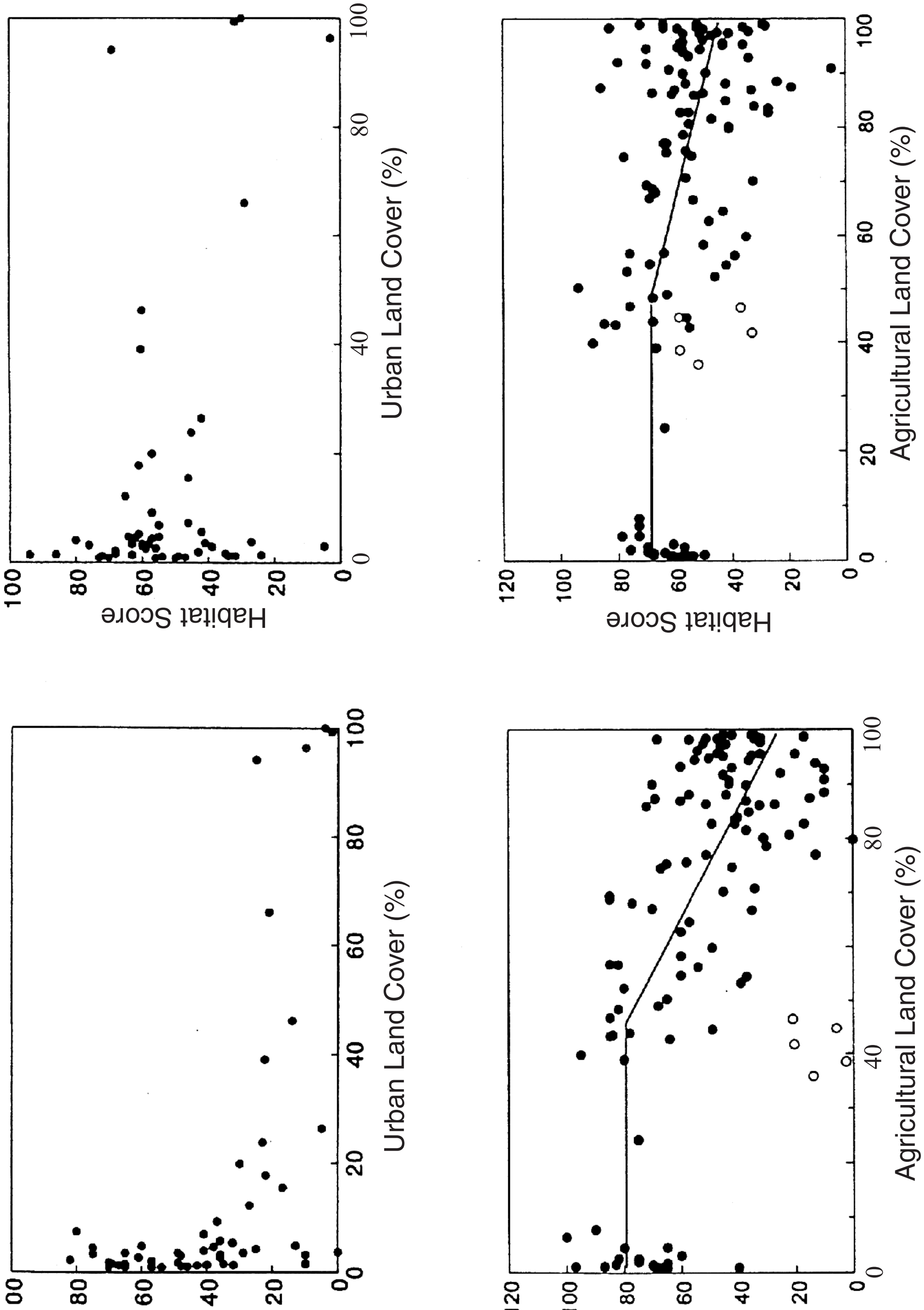


Figure 3.2. Relationship of Index of Biotic Integrity (IBI) and Habitat Quality scores to percent urban and agricultural land use in Wisconsin (from Wang et al., 1997).

Glaciomarine & tills – *Sf, Sg, Sh, FLa, FLc, FLd, Va, Pvc through Pvh; UPV*
Bedrock – *T and PT*
All others – *any classes not covered above.*

The above combinations of surficial deposits were selected from Armstrong (1984). These classes distinguish the area of recent (Fraser and Salish deposits) from the permeable glaciofluvial sediments and impermeable glaciomarine or till sediments in each sub-watershed.

3.5.3 Agricultural Land Use in Riparian Areas

The percentage of agricultural land use in the 30 m riparian buffer was measured for the Salmon and Serpentine watersheds (other watersheds did not have agricultural land use). This provided a secondary measure of the potential impact of agriculture on water quality and other factors. It was calculated using a GIS-based query of land use codes overlayed with 30 m buffers on either side of the centreline of the stream channel (or bankfull margin for large channels).

3.5.4 Water Licenses

The Water Rights Branch of the Ministry of Environment, Lands and Parks maintains a computerized database of water licenses in British Columbia. Summaries, by license type, were produced for all the test watersheds based on queries of their database.

The summary included consumptive licenses under the categories of domestic, waterworks, irrigation, land development, mining, and industrial, as well as non-consumptive licenses for conservation and storage. Calculation of potential demand associated with these licenses follows the procedures outlined in Rood and Hamilton (1994). A summary of non-consumptive licenses (power generation, storage and conservation) was also included although these licenses do not represent extractions from instream flows.

3.6 Measures of Fisheries Resources

How fish and fish habitat should be incorporated into the classification process was one of the most difficult aspects of this project to resolve. There was agreement that fish are of primary importance in stormwater management planning in the GVS&DD because of their ecological importance in aquatic ecosystems, and the emphasis on fish and fish habitat management in federal and provincial environmental protection policies and legislation. However, there were many concerns raised by the Department of Fisheries and Oceans (DFO) and Ministry of Environment, Lands and Parks (MELP) staff regarding the appropriateness of using measures of species presence, abundance, or other factors in a classification system, and more generally, the compatibility of a classification system with the *Fisheries Act* and the *National Policy for Management of Fish Habitat*.

At the heart of the matter was the conflict between four objectives of the classification system. First, it had to be practical and rely on existing fisheries information that was available from government databases, consultants reports, and from individuals knowledgeable about specific watersheds. Second, it had be useful as a classification tool by providing some separation between watersheds or subwatersheds based on their fish community. Third, the specific measures used in the classification process must be scientifically sound. Finally, to be accepted by DFO and MELP, the principle of a fisheries-based component of the classification system must be compatible with the *Fisheries Act* and the policies and management objectives of those agencies. In the end, there was no agreement on an acceptable method of incorporating fisheries resources into the classification system, and two approaches are presented in Section 3.7 and 3.8 as options. The discussion below provides a summary of the evolution of this issue during the project and the following section summarizes the disadvantages of using fish as classification tool.

3.6.1 Evolution of Fisheries Resource Assessment Methods

We examined and tested three methods for incorporating fisheries resource into the watershed classification system. Initially, we developed a scoring system that used nine questions to provide a relative value score of the fisheries resource. It was called "biological value" and it incorporated indicators of fish species presence, diversity, and abundance, as well as uniqueness factors such as the presence of rare, threatened and endangered fish species. For example, one of the measures of fish presence was "Are streams in the watershed or subwatershed used by coho salmon or other anadromous salmonids for spawning and/or rearing?". Similarly, we asked if the watershed or subwatershed supported any anadromous salmonid populations with escapement greater than 125 fish. This system met with considerable opposition from the environmental agencies who felt that measures of abundance and species presence were incompatible with the *Fisheries Act* and were not scientifically defensible in assigning resource value. Particular concern was raised regarding using fish abundance as a factor influencing the relative management importance of watersheds or subwatersheds. Abundance was considered to be unsuitable because it is affected by too many factors outside of the freshwater environment, in addition to being inaccurate because of data collection uncertainty.

A second method was developed that attempted to address some of the concerns regarding the initial system by using native fish species diversity, as well as a refined assessment of the conservation significance of the fish community, to determine relative management importance. Fish diversity was considered important because it could be used as a tool to focus stormwater management attention on watersheds or subwatersheds with higher diversity due to larger size, productivity, connection to multiple post-glacial source areas (e.g., glacial refuges), or other factors. Watersheds or subwatersheds with seven or more native fish species were separated from watersheds with three to six species, and those with only one or two. While this appears arbitrary, the basis was that most subwatersheds support four to six fish species - typically coho salmon, cutthroat trout, threespine stickleback, prickly sculpin and western brook lamprey, and that those with more species usually support salmonids such as steelhead and chinook that are associated with larger streams and rivers. Larger watersheds, like larger patches of forest or larger interconnected parks, may be a more suitable conservation focus than small, isolated watersheds because their size may impart greater resiliency to change. They may also sustain more diverse and abundant fish populations that will resist the genetic effects of small population size and act as source areas for recolonizing extirpated populations in the future. Furthermore, larger systems may also contain more fish stocks of economic and recreational importance (however, coho populations are a good example of the importance of many small stocks in sustaining commercial fisheries).

Conservation significance was also included as a component of the fisheries resource assessment during the development of the second classification method. It was also devised as a scoring system and incorporated a number of factors related to the importance of the fish community as a component of biological diversity such as does the watershed or subwatershed support rare, threatened or endangered species, does it have wild or hatchery fish stocks, and were stocks at extinction risk because of small population size. The use of a scoring system to evaluate conservation significance was modified from Allendorf *et al*., (1997).

This second method also met with many of the same questions and critical comments from environmental agency staff as did the first method. In addition, the proposed classification system was described as inappropriate in its use of fish diversity as an important factor in classification, and rudimentary in its assessment of conservation significance. Perhaps most importantly, a number of reviewers were concerned that it would reduce the resources allocated for protection and restoration in small watersheds with low diversity fish populations. We think it should be stated again that the intention is not to reduce the resources allocated for protection or restoration in watersheds that are small, degraded, or support few fish species. Rather that costly and difficult interventions such as riparian land acquisition, large scale BMP installation, and development restrictions should be used where they can be most effective in sustaining or restoring watershed health and protecting fish populations. The priority watersheds for increased stormwater management may range from moderately, or even heavily degraded, watersheds with a high potential for improvement, to healthy watersheds that require additional protection to avoid future urbanization related impacts.

A third method of incorporating fisheries resources into the classification system was proposed by DFO and MELP staff during the review of the draft report. They recommended watersheds and subwatersheds be separated into three categories based on fish and fish habitat value that have been developed for watercourse classification by MELP Region 2 Fisheries staff and the City of Surrey. Categories include:

- **Category 1**: Watersheds or subwatersheds inhabited by salmonids and/or rare or endangered fish species, or potentially inhabited with access enhancement;

- **Category 2**: Watersheds or subwatersheds that are a significant source or a potentially significant source of food and nutrients to downstream fish populations. These watersheds are characterized by no fish presence and no reasonable potential for fish presence through flow or access enhancement (lack of summer flow is the most common factor limiting fish presence in these systems);

- **Category 3**: Watersheds or subwatersheds with insignificant contribution of food or nutrients to downstream areas supporting or potentially supporting fish populations (these watercourses are generally manmade roadside ditches).

The main criticism for this system is that every subwatershed examined for this project would be classified as Category 1. In fact, except for the culverted watersheds in the City of Vancouver, all watersheds and subwatersheds in the GVS&DD we could evaluate based on previous experience would be designated as Category 1 systems. So while this is a simple and efficient classification process, and useful in affirming that all watersheds deserve a high level of protection to support their fish populations, its classes may be too broadly defined to be effective as a classification tool. Simply put, it provides no separation between the test watersheds, which is the primary goal of a classification system.

3.6.2 Are Fish Species A Good Indicator?

Despite the importance of fish in stormwater management in B.C., there are three major difficulties in using fish as part of a classification system for GVS&DD watersheds. First, all fish species are protected equally under the federal *Fisheries Act* and are managed in the same manner under the *National Policy for Management of Fish Habitat*. Consequently, the Department of Fisheries and Oceans and the Ministry of Environment, Lands and Parks has concerns with any classification system that discriminates between the resource “value” or management importance of different fish species. For example, coho and other anadromous salmonids are not afforded a higher level of protection under the *Fisheries Act* than resident cutthroat trout, non-native carp, or a broad range of other fish species. This being said the Department of Fisheries and Oceans generally exercises its mandate selectively by focusing on species of economic importance. The Classification System for Lower Mainland Region Watercourses (MELP, 1998) is an example of a system that discriminates between stream sections based on fish species presence. As described above, the presence or absence salmonids and/or rare and endangered fish species in the site or downstream of the site, is used as the primary classification tool.

The second difficulty is that most fish species in Pacific Northwest are resilient to changes to stream and watershed conditions. For example, all nineteen subwatersheds in the test group support salmonids and only three do not contain spawning populations of coho salmon (Still, Thain, and Wagg creeks). This reduces the usefulness of fish species as precise indicators of environmental conditions. The Benthic Index of Biotic Integrity (B-IBI) was developed by researchers in Washington State to provide a more sensitive and specific measure of biotic integrity in Pacific Northwest streams (Kleindl, 1995; Karr, 1998). In addition, the abundance of anadromous fish such as coho salmon are affected by a range of factors outside of freshwater areas. Changes in ocean productivity, overfishing, and predation have contributed to the recent decline of some salmonid stocks.

Lastly, fish are only part of the biological community in GVS&DD watersheds. Other species, including aquatic or riparian dependent wildlife such as the tailed frog and Pacific water shrew, are also important in considering stormwater management planning. However, there is much less information available on the occurrence of wildlife species in the GVS&DD compared to fish presence and distribution. Legislation and policies governing the management of wildlife habitat are also less rigourous than those for fish habitat protection.

3.7 Fish Diversity and Conservation Significance as a Classification Method

As described above, we developed a classification procedure that was divided into two components: i) fish diversity; and, ii) conservation significance.

3.7.1 Fish Diversity

The first step in assessing the fisheries resource was to determine the occurrence of native fish species in each test watershed or subwatershed, as well as catchments into which the subwatersheds drained (for determining downstream fish use). We collected and reviewed information from the Fisheries Information Summary System (FISS), the Salmon Escapement Data Base (SEDS), and municipal government reports such as environmentally sensitive area studies. In addition, we reviewed consultants reports, monitoring studies, and other unpublished materials we were able to obtain. Finally, we contacted fisheries biologists, knowledgeable local residents, and stewardship groups to obtain anecdotal information on fish presence and distribution.

In general, fish diversity and distribution, particularly of non-salmonid species, is relatively poorly known in many small stream systems in the GVS&DD. We found it difficult to rely on some consultants reports and other studies because of the lack of expertise in differentiating some species such as prickly and coastrange sculpins, and juvenile cutthroat trout and steelhead. Similarly, some older reports did not record the presence of non-salmonid fish captured during sampling. In some cases, we made assumptions about fish presence in the test watersheds based on more reliable information on adjacent systems. For example, both coastrange and prickly sculpin have been recorded from MacKay Creek in North Vancouver (Stoddard, 1996). This information was used to infer the presence of both species in the adjacent and environmentally similar Mosquito Creek watershed. For these reasons, fish presence information should be considered preliminary. Species that were associated with estuarine or the tidal portions of Fraser River (i.e., starry flounder) were excluded from the comparison.

Fish diversity was divided into three categories as shown in Table 3.3. Categories were based on a subjective interpretation of fish diversity in GVS&DD watersheds. As described previously, there appear to be several thresholds of fish diversity in the test watersheds. While these thresholds have not been evaluated with empirical studies, we have observed that the majority of streams in the GVS&DD contain between three and six fish species including coho salmon, cutthroat trout, prickly sculpin, western brook lamprey, and threespine stickleback. Some also contain chum salmon, rainbow trout, or coastrange sculpin. Larger watersheds typically support a range of other species such as steelhead, chinook or pink salmon, Pacific lamprey, or minnow species. On the other end of the spectrum are small, high gradient subwatersheds or heavily urbanized subwatersheds that support few fish species. Prickly sculpin and threespine stickleback are common in low gradient streams, while resident cutthroat trout are often the only species found in small, high gradient streams. Again, while these are broad generalizations, they appear to be reflected in many watersheds in the Lower Mainland.

Table 3.3. Fish diversity classes for GVS&DD streams and rivers.

Fish Diversity Class	Number of Native Fish Species
Low Diversity	0 to 2
Moderate Diversity (average)	3 to 6
High Diversity	7 or more

3.7.2 Relative Conservation Significance of Fish Populations

There is also a growing awareness of the importance of fish species as a component of biological diversity. The identification of Salish sucker and Nooksack dace in the upper Salmon River and the Nooksack River tributaries is a topical example, however, many small streams contain fish populations that are reproductivily isolated by natural or manmade barriers. Populations of resident cutthroat trout for example, may contain local adaptations that are expressed either morphologically, behaviourally, or genetically. Individual populations of anadromous salmonids within an area as small as the GVS&DD are not likely reproductively isolated from other populations because of natural rates of straying (see Wehrhahn and Powell (1987) for example of coho salmon in southern B.C.). However, the overall productivity and population persistence of larger stock groups depend on sustaining the smaller populations of which they are composed. McPhail and Carveth (1993) highlight the importance of freshwater fish populations as examples of "made-in-B.C." biodiversity.

A number of attributes may make a fish community or species of conservation significance. Rarity, genetic or behavioral uniqueness, high species diversity, or extinction risk have been put forward as indicators of conservation significance. We recommend the reader review Allendorf *et al*. (1997), Slaney *et al*. (1996), and McPhail and Carveth (1993) for more information on these issues.

Six indicators were used to provide the basis for a scoring system for assessing the conservation significance of fish populations in test watersheds and subwatersheds (Table 3.4). The indicators focus on attributes that may make particular fish populations of conservation concern because of unique local adaptations, small population size, or other factors. Indicators are scored and the total points summed to indicate relative conservation concern. Three classes of relative conservation significance were designated (Table 3.5). For each indicator other than the presence of rare, threatened, or endangered species, score one point for each "yes" answer. For subwatersheds with rare, threatened, or endangered species score four points. A "no" answer is assigned zero points. It is important to point out that all questions must be answered to provide a useful score.

Information on which to base the assessment was obtained from the same sources described in the previous section. Some of the questions required interpretation and inference and we stress that the scores are preliminary and some useful information sources were not available. Most of the questions however, can be answered using existing fisheries reports, discussions with DFO or MELP representatives, other municipal government sources such as ESA studies. In some cases, professional biologists or technicians would be required to conduct additional fish sampling.

3.8 DFO / MELP Assessment Method

As described in the introduction, DFO and MELP staff proposed a classification procedure which separated watersheds or subwatersheds into three categories based on fish presence and fish habitat value (Table 3.6). This procedure used the classes and definitions developed for the Classification System for Lower Mainland Region Watercourses (MELP, 1998). However, where the original classification system considered portions of watercourses in its classification process, it was expanded to encompass whole watersheds or subwatersheds for this project.

Table 3.4. Indicators of relative conservation significance of fish populations in GVS&DD watersheds.

Proposed Indicators of Relative Conservation Significance	Assumptions / Justification
1. *Do streams in the subwatershed contain any rare, threatened, or endangered fish species? (score 4 points)*	Uniqueness of the fish community because of presence of rare, threatened or endangered species confers additional management concern and biological value. Rare threatened, or endangered species in the GVS&DD include Salish sucker, Nooksack dace, and brassy minnow and are important enough to rate four points in the scoring system.
2. *Are streams in the subwatershed used by three or more species of salmonid for spawning and rearing? (1 point)*	Most GVS&DD streams support permanent populations of coho salmon and cutthroat trout. Streams that also contain chum salmon, steelhead, or chinook are typically larger systems which may have higher salmon habitat values.
3. *Do streams in the subwatershed contain any salmonid populations that may be considered unique because of life history traits, local adaptations, or genetically important attributes? Similarly, are there any unusual habitat factors in the subwatershed that may be associated with unique or uncommon life history traits in salmonid populations (e.g., presence of lakes, unusual flow regime)? (1 point)*	Genotypic and phenotypic variation in salmonid populations ensures long-term population persistence and productivity. While all populations contribute to the health of larger stock groups, individual populations with unique genetic or behavioral (life-history) traits are of particular concern. Unusual habitat features may be used as a surrogate for population uniqueness because of the response of salmonids to their environment.
4. *Does the subwatershed contain any stocks with a salmonid population less than 200 or less than 20% of the long-term mean? (1 point)*	Stocks are of greater management concern if they have small population size and are at risk of extinction. This attribute was used by Slaney *et al*. (1996) to identify high extinction risk.
5. *Are all anadromous salmonids in the subwatershed considered wild stocks? (1 point)*	Wild stocks express the long-term behavioral and genetic response to their environment and are more likely to contain local adaptations than hatchery stocks. Wild stocks are of conservation concern in the GVS&DD area because of the widespread introduction of hatchery stocks.
6. *Have any fish species been extirpated from the subwatershed? (1 point)*	Extirpation of a fish species from the watershed indicates stress on the aquatic ecosystem and greater vulnerability of extirpation for remaining species.
Score	**Score out of a maximum of nine points**

Table 3.5. Classes of relative conservation significance of fish populations for GVS&DD streams and rivers.

Relative Conservation Significance	Conservation Significance Score
Low	0 to 1[1]
Moderate (average)	2 to 3
High	4 or more

[1] A score of 1 is often because of extirpation of a fish stock or the presence of stock of low population size.

Table 3.6. Proposed fisheries resource categories in DFO /MELP classification method.

Category	Description of Fish Use / Fish Habitat Importance by Category
Category 1	Watersheds or subwatersheds inhabited by salmonids and/or rare or endangered fish species or potentially inhabited with access enhancement.
Category 2	Watersheds or subwatersheds that are a significant source or a potentially significant source of food and nutrient value to downstream fish populations. These watersheds are characterized by no fish presence and no reasonable potential for fish presence through flow or access enhancement (lack of summer flow is the most common factor limiting fish presence in these systems).
Category 3	Watersheds or subwatersheds with insignificant contribution of food or nutrients to downstream areas supporting or potentially supporting fish populations (these watercourses are generally manmade roadside ditches).

Fisheries information that had been collected on fish diversity and conservation significance was used to determine the category of the subwatersheds. Results are discussed in Section 5.6.3.

3.9 Community Interests

During the first phase of this project, community interests were identified as potentially important for classifying and managing urban watersheds. The following section provides a preliminary discussion of how these factors might be evaluated. At this point, we have not incorporated them into the classification system.

Urban watersheds provide a range of resources, attributes and interests that are valued by the public and communities. For some people, clean water is important, for others having fish in a local stream is an important feature. Some people may never visit a stream or watershed, but just knowing it is there and in relatively good condition is important to them. Others may value the open or green space and recreational attributes that a stream or watershed offers. Property owners may be concerned about flooding. Some watersheds may contain water licenses for irrigation, community water supply or other purposes. There may be permitted discharges from point sources within a watershed. Watersheds can also hold spiritual, cultural or sustenance values, particularly for First Nation groups.

While community interests are not included here as part of the classification system for determining overall watershed priorities in the same manner as watershed health or fisheries resources, it is recognized that community interests play an important role in establishing priorities. There should be an effort made, in any watershed classification to include and understand the community interests associated with watersheds. They could be included as modifiers or considerations when prioritizing watersheds for stormwater management purposes. It is also important to remember that there are both real and perceived values associated with urban watersheds. For example, a watershed that might be considered degraded based on ecological or biological criteria may still possess value from a community perspective (e.g., open space, green space, etc.).

The following is a preliminary checklist of indicators that could be used to determine the presence of community interests in a watershed (Table 3.7). Some interests can be derived relatively easily from existing information such as knowledgeable individuals, reports or direct observation, some can be derived from case studies in other areas, while the determination of others will require further effort or research. In some cases, sophisticated survey tools would be rgquired.

Table 3.7. Preliminary checklist of community interests indicators for urban watersheds.

Proposed Indicator	Measure	Comments
1. Stewardship activities in the watershed	No. of groups Volunteer hours Stewardship funds allocated	Information available through municipalities, USHP, DFO Community Advisors
2. First Nations interests in the watershed, such as traditional hunting or fishing and spiritual or cultural values		Contact with First Nation representatives Land claim documents
3. Protected areas within the watershed	No. of parks Conservation covenants ESAs Specific local govt. policies/regulations WMAs Ecological Reserves	Information available through municipalities
4. Public awareness/activism in the watershed	Letters to the editor Content analysis of news articles Written briefs Public information available (brochures, pamphlets) Surveys Calls to politicians Issues raised in council meetings	Information can range from that relatively easy to collect to more sophisticated (surveys, interviews, etc.)
5. Educational and research activities in the watershed	School projects Outdoor/field classroom, case studies for universities, colleges Curriculum No. of research projects and expenditures Interpretation Tours	Contact with local schools, colleges and universities DFO Community Advisors USHP
6. Recreational activities in the watershed	Types of activities (hiking, bird watching, fishing, boating, swimming, etc.) Participation rates Expenditures by recreationists User surveys	Information available from local governments Results of surveys in other areas Surveys required for more sophisticated measures (i.e., participation rates and expenditures)

Table 3.7. Preliminary checklist of community interests indicators for urban watersheds (cont).

Proposed Indicator	Measure	Comments
7. Open space/green space amenities of watershed	Local government policies Attitudinal surveys Derived values of importance through willingness to pay or to be compensated surveys	Contact with local governments Review of local policies (OCPs, Park/Recreation Master Plans, ESAs)
8. Community water supply/water withdrawal licenses/waste discharge permits	Licenses and permits	Ministry of Environment, Lands and Parks
9. Does the watershed have broad regional community value or significance?	Regional/Prov. Policies Regional reports or surveys	Some watersheds may play a broad regional role because of the relative scarcity of certain values it contains within a regional setting

3.10 Resiliency or Sensitivity to Urban Development

Watershed resiliency was also examined as a possible attribute to incorporate into the classification system. However, at this stage, it is only included for discussion.

Resiliency expresses the ability of some watersheds to resist the effects of urban development. Those systems that have little resiliency – either because of their existing level of development or their watershed characteristics – are "sensitive". In effect, these watersheds are expected to have a more severe response to urban development than is typical. On the other hand, resilient watersheds are expected to have much less severe response than is typical and are anticipated to maintain higher fisheries resource values compared to less resilient watersheds.

3.10.1 Resiliency and Watershed Characteristics

The portion of the watershed that is covered by glaciofluvial sediments controls the degree of modification of the hydrologic regime, particularly at low levels of development, and is a major component of resiliency. Rood and Hamilton (1994), for the watersheds that they examined in the Fraser Delta Habitat Management Area, found that the coverage by glaciofluvial deposits ranged from 0 to about 48% of watershed area. The coverage by impermeable deposits (called "glacial till") ranged from 8 to 86%. Those watersheds that have relatively high coverage of glaciofluvial deposits will have a less severe alteration of their hydrologic regime by residential development and will typically have much higher summer and winter base flows. Those that are mostly covered by "till-like" deposits are expected to have a more severe alteration than typical watersheds.

The characteristics of the individual streams also affect the extent to which they are altered by increased peak flows. Streams in narrow valleys, or with relatively inerodible bank and bed material, or with plentiful large organic debris may change their morphology very little in response to urban development. Unfortunately, there is no database that describes stream characteristics and these characteristics can not easily be incorporated into a measure of resiliency.

3.10.2 Sensitivity and Watershed Development

Existing development in watersheds, as well as watershed characteristics, may result in an unexpectedly severe response of the watershed, and its fish populations, to urban development. Sensitive watersheds are expected to have the following characteristics:

- High potential licensed demand on summer base flows through waterworks, irrigation, or groundwater extractions. Rood and Hamilton (1994) showed that potential demand from licensed extractions, at the mouths of salmon streams, ranged from 0 to about 90% of mean discharges in August and September.
- Watershed characteristics that result in unusually low summer discharges, primarily impermeable surficial materials, are expected to cause the watershed, and its fish populations, to be more sensitive to development.
- Easily erodible stream bed and banks, low quantities of large woody debris, or stream modifications such as channelization, dyking or loss of off-channel areas, all result in lower quality habitat that exposes fish populations to a greater risk from increases in peak flows.

3.10.3 Possible Methods of Incorporating Resiliency and Sensitivity in the Watershed Classification

At this point, we have not incorporated resiliency and sensitivity into the watershed classification. However, these factors could be incorporated by either raising or lowering the rating for the watershed, as assigned by its total impervious area and riparian integrity.

Resiliency could be expressed by the degree of coverage by glaciofluvial materials in the watershed. For instance, those watersheds with greater than 25% of their area in these materials could have their rating raised by one category; those that classify as “fair” are raised to “good”, etc. The rating would not be changed for those watersheds already classified as “excellent”.

Sensitivity could be expressed by the potential demand on summer base flows by licensed extractions and by the extent of modification of the stream channel by human activity. Those subwatersheds that potentially have more than 25% of their estimated mean August and September flows used for irrigation, industrial, waterworks or domestic demand, could have their rating reduced by one category. For instance, those that are classified as “good”, based on their impervious area and riparian integrity, would be reduced to “fair”, if they have high summer water demand.

The extent to which streams have been modified also expresses sensitivity, and is used to adjust the classification based on impervious area and riparian integrity. The most highly-modified streams, based on information in Rood and Hamilton (1994) or Department of Fisheries and Ocean’s *Wild, Threatened, Endangered, and Lost Streams* publication (Precision Identification Consultants, 1998) could also have their rating reduced by one category. This would be in addition to the reduction that results from licensed demand on summer flows and may result in watershed declining from the “good” to “poor” categories.

4. DEFINING WATERSHED HEALTH CLASSES

We used two approaches to define watershed health classes. The first approach graphically integrated riparian forest integrity and total impervious area to separate subwatersheds into four classes: *excellent, good, fair,* and *poor*. This approach was first developed by Steedman (1988) for classifying streams in southern Ontario. Subsequently, other studies including May *et al*., (1997) and Zandbergen (1988) have used similar systems.

The second approach incorporated agricultural land use, in addition to riparian forest integrity and total impervious area, into a three-dimensional representation of watershed classes. The advantage of this approach is that it provides greater separation between watersheds with low imperviousness values, but substantially different proportions of agricultural land use. The disadvantage is that the lack of empirical relationships on the relative effect of agricultural and urban land uses creates difficulties in assigning the watershed health classes.

4.1 Integration of Riparian Forest Integrity and Total Impervious Area

Riparian forest integrity and total impervious area were integrated based on the findings of several studies that examined watershed conditions and stream health (see Steedman, 1988; May *et al*., 1997; Zandbergen *et al*., 1998). Each study defined a series of thresholds that separate watershed health classes along a gradation of imperviousness and riparian forest values. It should be clear that the delineation of thresholds and classes includes a combination of scientific and practical considerations: while watershed ecology may provide some insights into the existence of distinct conditions and/or thresholds between conditions, in many cases a gradient of conditions is observed without clearly identifiable categories.

Establishing classes using only biological conditions is also subjective. For example, the Benthic Index of Biological Integrity (B-IBI) developed by Karr (1998) used five classes (excellent, good, fair, poor and very poor) and defined the ranges for the B-IBI scores which corresponded to these classes. However, the Puget Sound Lowland Streams study which used the B-IBI as the key measure of biological integrity chose to use only four categories (May *et al*., 1997).

4.1.1 Imperviousness and Thresholds of Degradation

Several reviews have pointed out that scientific studies over a broad geographic area have yielded surprisingly similar conclusions on the impact of imperviousness on biological communities, channel morphology, and other factors (Schueler, 1994). Previous research suggests a clear direction: good stream health at low imperviousness; poor stream health at high imperviousness. In addition to this general trend, a number of observations have been made with respect to the changes that occur as a watershed urbanizes. In turn, these observations can be used to define thresholds between watershed health classes.

The most significant changes in stream health occur roughly between 10 and 25 or 30% imperviousness. While some watersheds with an overall imperviousness of around 30% still show good stream health conditions, most watersheds at this stage of urbanization have already degraded significantly. Further increases in imperviousness result in further degradation, although the rate of decline is much less than at moderate levels of imperviousness, mainly because the stream has already degraded substantially.

Studies using imperviousness to classify watershed conditions differ in the number of classes used, ranging from three to five. Schueler (1994), in his review of eighteen studies up until 1994, found that a three category classification was most appropriate as a starting point: stressed streams (1 to 10% imperviousness); impacted streams (11 to 25% imperviousness); and degraded streams (26-100%). The recent Puget Sound research has used four categories: natural streams (<10% imperviousness); impacted streams (10-30%); degraded streams (30-45%); and non-supporting streams (>45%). Zandbergen (1998) used five categories to classify the Brunette and Salmon River watershed, following the classification inherent in the IBI methodology: excellent (<10%), good (10 to 18%), fair (18 to 27%), poor (27 to 45%) and very poor (>45%). For this study, a choice has been made to use four categories, following the approach taken by May *et al*. (1997).

4.1.2 Riparian Forest Integrity and Thresholds of Degradation

While many studies have attempted to determine the width of the riparian forest cover required for specific buffer functions (e.g. see Castelle *et al*., 1994; Millar *et al*., 1997), less work has been done to relate riparian forest cover for a whole subwatershed to overall stream health indicators. Research in Puget Sound has indicated a strong positive correlation between a Benthic Index of Biotic Integrity and the percentage cumulative upstream riparian buffer zone of at least 30 meters, but no threshold was found (May, 1996). Similarly, Steedman (1988) found a fairly strong correlation between the Index of Biotic Integrity and the proportion of stream with riparian forest, but again no clear threshold.

Similar to the evaluation of imperviousness, establishing whether or not a threshold exists for riparian forest integrity is complex because:

- studies vary in the way they measure riparian forest or are not explicit about how it was measured;
- riparian forest integrity is a function of both of the buffer width and the extent of the forest cover along the length of the stream and few studies have attempted to distinguish between these two measures of riparian integrity;
- riparian forest integrity correlates fairly well with other measures of watershed disturbance, including imperviousness, making it difficult to use it as an independent variable (a very large sample size is required to test the influence of imperviousness and riparian integrity independently).

Despite the limitations, there is widespread recognition that a wide and continuous buffer can mitigate some of the impact of increased imperviousness on watershed health.

4.1.3 Integration of Imperviousness and Riparian Forest Cover

For the watershed classification system developed in this study, imperviousness and riparian integrity are integrated into a single system. Good riparian forest cover and low watershed imperviousness are both required for good or excellent stream health, although each condition in itself is insufficient. For example, a perfect buffer will not be able to mitigate the impacts of a high level of imperviousness. And conversely, a low level of imperviousness but a very poor buffer will likely also result in stream degradation. Therefore, subwatersheds are classified using the two variables in combination. Of the two variables, imperviousness is considered to be the most important one, with riparian forest cover as a modifying variable.

As noted above, riparian forest cover and imperviousness are not completely independent variables. A typical pattern of urbanization will result in an increase in imperviousness and a reduction in the riparian forest cover. However, for a given level of human activity in a watershed, the levels of both variables are not necessarily predictable, and a wide range of possible combinations is observed in urban watersheds. Different approaches to land use and site planning will result in different levels of imperviousness and riparian forest cover for the same overall level of human activity. This suggests a significant potential for management intervention.

One way to look at the two variables in combination would be to use some formula to average the two parameters and come up with a single "watershed health score". This could be defended since they are both required conditions and the positive and negative impacts may balance out. Imperviousness is likely a more important variable at the watershed level and a weighting factor could be added to this formula to increase the importance of imperviousness. However, each of the two variables is connected to very different types of management decisions and land use planning activities. As a result, a single combination score would lose its relevance to management. Instead, for this study a different integration procedure was used consisting of a graph, as illustrated in Figure 4.1. This integration relies on the relationships developed by Steedman (1988) which are described in detail below. Both May *et al*. (1997) and Zandbergen (1998) previously used Steedman's work to classify streams on the basis of their imperviousness and riparian integrity.

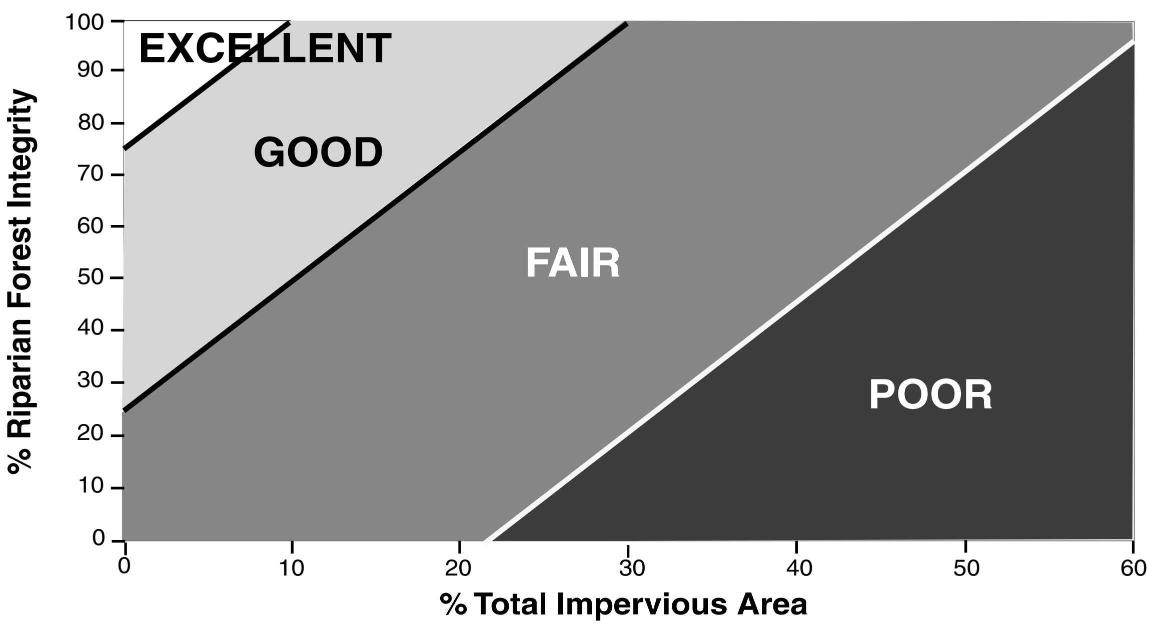


Figure 4.1 Graphical depiction of watershed health classes using total impervious area and riparian forest integrity.

The relative importance of imperviousness and riparian forest cover is reflected in the slope of the lines separating the four classes. A slope of 1 would imply they are equally important while a vertical line would mean forest cover is irrelevant to stream health and imperviousness is the only important variable. Conversely, a horizontal line would imply imperviousness is irrelevant. Intuitively, it is clear that neither of the two extreme situations is valid, since both low imperviousness and good riparian forest cover are considered necessary - but in themselves insufficient - conditions for good stream health. The slope and approximate location of the lines in Figure 4.1. are based on the relationships developed by Steedman (1988).

Steedman (1988) related the Index of Biotic Integrity (which uses fish communities) for 209 sampling location in 10 watersheds near Toronto, Ontario to riparian forest cover and degree of urbanization. A few observations with respect to Steedman's study:

- % urban land use was used as the measure of urbanization and not imperviousness; this can be translated to imperviousness by assuming 100% urban land use corresponds to approximately 60% imperviousness; and
- no clear description is provided of the manner in which riparian integrity was determined.

Despite these limitations, the findings on the relative importance of riparian forest integrity and imperviousness are thought to be valid, and have been used by May e*t al*. (1997) and Zandbergen (1998). The diagram developed by May *et al*. (1997) is similar to Steedman's (1988) for slope and location of the threshold lines; the diagram by Zandbergen (1998) is identical to Steedman's (1998) for the slope of the lines, and only differs in the number of categories (five instead of four).

The integration of impervious area and riparian forest integrity in assessing watershed health is successful for a number of reasons. As May *et al*. (1997) summarize: "Total impervious area and riparian buffer integrity (% corridor with buffer width > 30 m) alone were nearly as well related to physical habitat indices (r=0.63) as the full set of urban impact indices (r=0.77) and were fully as predictive of biological indices (r=0.70) as the full set of indices (r=0.77)." Zandbergen (1998) also substantiates the use of these two indicators: "Results show that the combination of the two physical indicators [TIA and % riparian > 30 m] presents an excellent opportunity for linking land use and land cover to indicators of non-point sources of pollution in an integrated manner."

4.1.4 Integrating Agricultural Land Use

To integrate agricultural land use, we used the same conceptual framework as for the two dimensional depiction of imperviousness and riparian forest integrity, but expanded the watershed classes into three dimensions. Watershed health classes become a volume rather than an area (Figure 4.2). However, as described previously, defining the threshold between classes based on agricultural land use was problematic. Unlike the relationship between total impervious area, riparian forest integrity, and stream health, there are few studies that describe similar relationships with agricultural land use. Part of this likely stems from the broad range of land use activities encompassed by the term "agriculture", including ranching, pasture crops, intensive vegetable and berry production, and greenhouses. In addition, the location of agricultural activity in the subwatershed is likely extremely important for understanding the degree of impact. Intuitively, a hay field several kilometers from a stream has far less an impact than a large feedlot built on a portion of the floodplain.

The threshold at which agricultural watersheds progress from "excellent" to "good" health was defined as 50% agricultural land use. This was largely drawn from the work of Wang *et al*. (1997) (see Figures 3.2). A hypothetical subwatershed with 5%TIA, 95% riparian forest integrity, and 60% agriculture, would be classed in the "good" watershed health, rather than "excellent" using only %TIA and riparian forest integrity. Similarly, a subwatershed like Davidson Creek with a relatively high proportion of agricultural land (63.8%) would be moved from good to fair using the incorporation of agricultural land use.

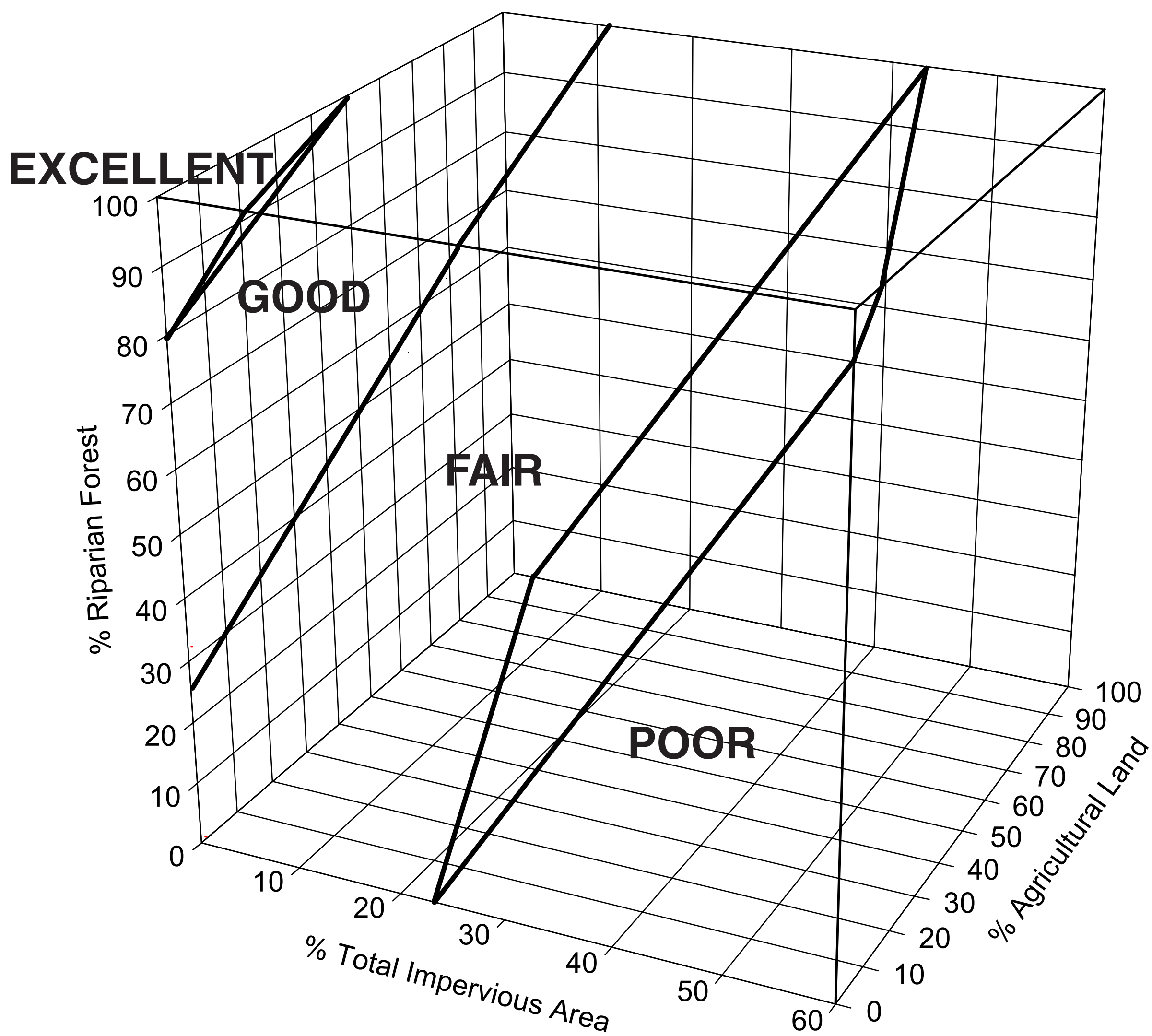


Figure 4.2 Graphical depiction of watershed health classes using total impervious area, riparian forest integrity, and percentage agricultural land use.

5. TEST WATERSHEDS

Nineteen subwatersheds within seven watersheds were used to test the practicality and sensitivity of the classification system. Test watersheds were chosen based on the availability of fish presence and distribution data, as well as their representativeness of physiographic and land development patterns in the GVS&DD area. Watersheds included the Brunette River, Salmon River, Serpentine River, Mosquito Creek, Mossom Creek, Como Creek, and Musqueam Creek. In total, they encompass 330 km^2 or roughly 20% of the GVS&DD area serviced by separate stormwater systems.

Watersheds were defined as drainage basins with streams that flow into the tidal waters of Burrard Inlet, the Fraser Delta, Boundary Bay, the Pitt River and the Fraser River. Subwatersheds are subunits of larger watersheds encompassing a single tributary stream with a defined point discharge into the main stream channel. Subwatersheds in the test group varied from 92 to 3,997 ha in size. Watershed and subwatershed boundaries were determined from municipal drainage mapping in developed areas, and from interpretation of topographic mapping in headwaters and other undeveloped areas.

5.1 Overview of Test Watersheds

The test watersheds span a broad gradation of urban and agricultural land use. Percent total impervious area range from 56% in Still Creek and 53% in the Como Creek drainage areas, to 4.1% in the Mossom Creek watershed. The Salmon and Serpentine River watershed encompass large agricultural areas. Roughly 47% of the Salmon River watershed and 28% of the Serpentine River watershed is used for agriculture, although several subwatersheds in these watersheds have over 55% agricultural land use. Two of the watersheds were selected from the high gradient mountain streams of Burrard Inlet – Mosquito and Mossom creeks, while the rest drain from the Fraser Lowlands into the Fraser River or Boundary Bay.

Another factor that contributed to the selection of these seven watersheds was the range of fisheries, drainage, water quality, and land use information that existed on them. The Salmon and the Brunette River watersheds in particular, have received considerable attention from researchers over the past decade. Students and faculty from the University of British Columbia's Institute for Resources and Environment have completed several projects on water quality, land use, and watershed conditions over the past decade (see McCallum,1995; Berka, 1996; Wernick, 1996; Zandbergen, 1998). Several of the other watersheds, including Como, Mossom, and Musqueam creeks are the focus of community assessment work and have been recently assessed by projects funded under the Urban Salmon Habitat Program or other initiatives.

A brief description of each of the test watersheds is included below to provide some context. Table 5.1 summarizes a range of watershed-level variables including drainage area, relief ratio, and stream length for each of the test watersheds.

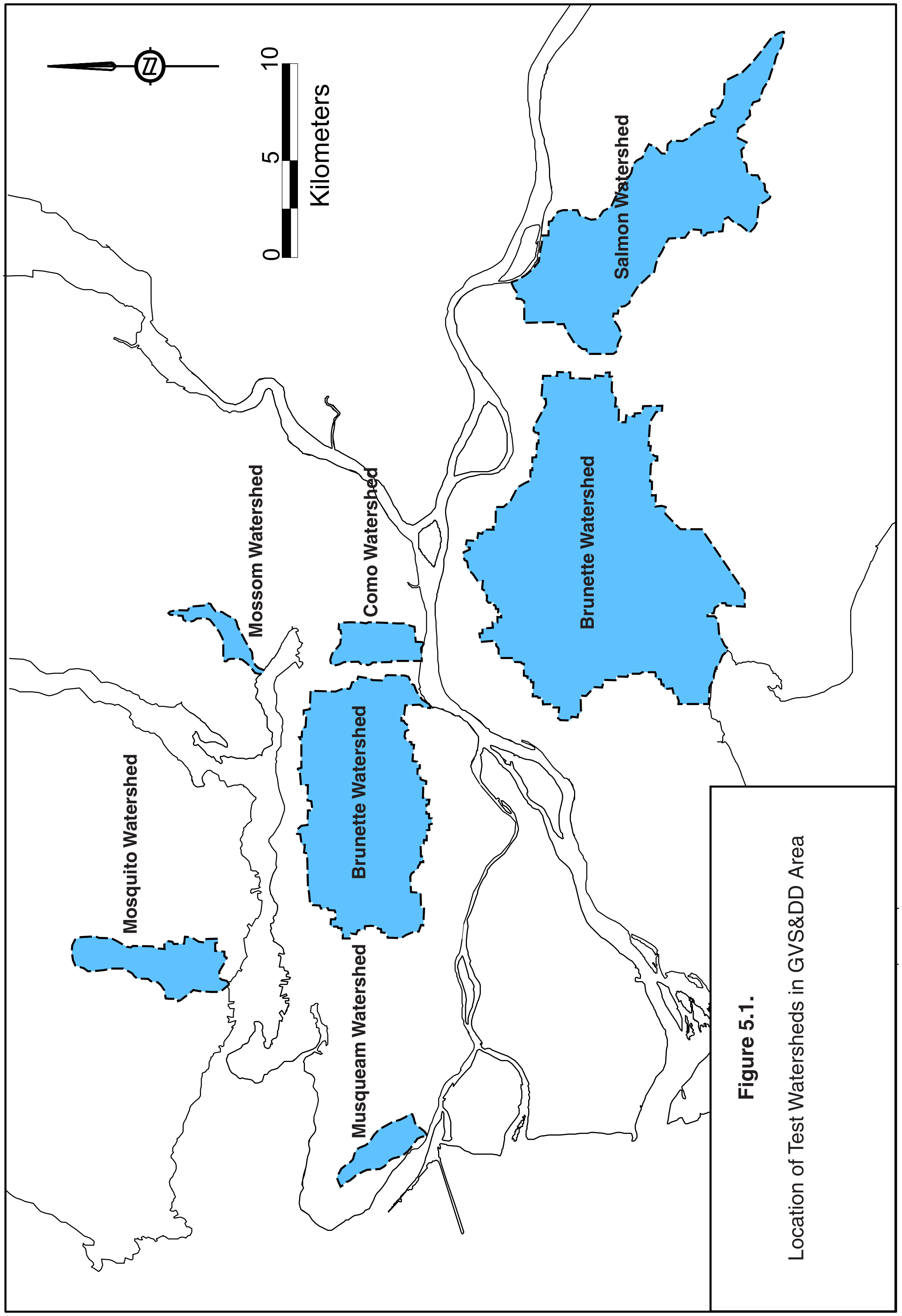


Figure 5.1.
Location of Test Watersheds in GVS&DD Area

Table 5.1. Summary of physical characteristics of GVS&DD test watersheds and subwatersheds.

Watersheds / Subwatersheds	Drainage Area	Elevation		Relief Ratio[1]	Stream Channels	
	km^2	Min (m)	Max (m)		Length	km / km^2
Isolated Small Watersheds	-	-	-	-	-	-
1. Como Creek	8.9	0	166	56	14.2	1.6
2. Mossom Creek	3.9	0	892	455	12.8	3.3
3. Musqueam Creek	6.5	0	104	41	9.2	1.4
Serpentine River Watershed	**149.0**	**0**	**106**	**9**	**157.5**	**1.1**
1. Hyland Creek	14.0	0	90	24	15.1	1.1
2. Bear Creek	33.9	0	105	18	44.8	1.3
3. Upper Serpentine River	19.2	12	73	14	23.3	1.2
4. Latimer Creek	92.9	6	96	9	16.5	0.2
5. Clayton Creek	11.9	4	81	22	5.9	0.5
Salmon River Watershed	**75.0**	**2**	**147**	**17**	**133.4**	**1.8**
1. West Salmon River	5.8	10	90	33	7.9	0.7
2. Davidson Creek	10.0	6	94	28	17.3	1.7
3. Coghlan Creek	13.8	25	75	13	19.5	2.0
4. Upper Salmon River	26.0	25	124	19	42.8	1.6
Mosquito Creek Watershed	**14.4**	**0**	**1120**	**294**	**25.9**	**1.8**
1. Thain Creek	3.1	95	685	334	7.0	2.3
2. Lower Mission Creek	0.9	35	115	83	1.7	1.9
3. Wagg Creek	3.6	0	300	159	2.8	0.8
Brunette River Watershed	**72.9**	**0**	**370**	**43**	**62.3**	**0.9**
1. Deer Lake Brook	9.4	14	111	32	8.7	0.9
2. Still Creek	28.2	14	94	15	20.1	0.7
3. Eagle Creek	5.5	14	306	125	6.3	1.1
4. Stoney Creek	7.3	14	356	126	6.2	0.8

[1] Relief ratio = relief/drainage$^{0.5}$. This provides a measure of average watershed slope.

5.1.1 Brunette River Watershed

The Brunette River watershed is the most highly urbanized large watershed (> 50 km^2) in the GVS&DD. The Brunette River drains a watershed area of approximately 72.9 km^2, and flows through several municipalities - 76% of the watershed falls within the City of Burnaby, while the remaining watershed area is divided between Vancouver (14%), Coquitlam (8%), New Westminster (2%), and Port Moody (<1%) (McCallum, 1995). The GVS&DD has jurisdiction over the main channel of the Brunette River to convey flood waters. The Brunette discharges to the Fraser River at New Westminster, and major tributaries include Deer Lake Brook, and Still, Eagle, Robert Burnaby and Stoney creeks. Mean annual flow at the mouth of the Brunette River is estimated to be 3.2 m^3/s (Rood and Hamilton, 1994).

Water quality monitoring programs for the Brunette River have shown that lead, copper, zinc, total phosphorus, dissolved oxygen and fecal coliforms have chronically or periodically failed to meet water quality objectives (MacDonald, Hall and Schreier, 1997; Zandbergen, 1998). High concentrations of suspended solids and certain organic contaminants have also been measured (Environment Canada, 1992). Studies on the lower Brunette River have demonstrated that commercial land uses are associated with the most toxic runoff, followed by industrial, residential and open space (Hall and Anderson, 1988). Automobile traffic in the Brunette River watershed also contributes significantly to the presence of toxic elements in the river's water column and sediment (Dawson *et al*., 1985; McCallum, 1995). In addition to the above noted water quality impacts, clearing of riparian vegetation along much of the length of the Brunette River in New Westminster for industrial development has affected the habitat values and physical stability of the watercourse (Foy, 1992).

The Brunette River is one of the most important fish streams in the Lower Mainland (Foy, 1992), and contains a high diversity of native and non-native fish species. Coho salmon and cutthroat trout are the widely distributed salmonids in the watershed. Of the large tributary streams, only Still Creek does not support remnant populations of coho salmon, although resident populations of cutthroat trout still occur. All reaches of the Brunette River are currently fish passable - a new fishway provides access past the Cariboo Dam year round. Burnaby Lake also supports several non-native species such as bass that are characteristic of lake ecosystems.

5.1.2 Salmon River Watershed

The Salmon River watershed is one of the most productive salmon streams in the GVS&DD area due largely to its low channel gradient. It is located primarily within the Township of Langley, and drains a watershed area of approximately 75.0 km^2. The mainstem discharges to the Fraser River just west of Fort Langley. Major tributaries to the Salmon River include Davidson, Coghlan, Tyre and Union creeks. Mean annual flow at the mouth of the Salmon River is estimated to be 2.2 m^3/s (Rood and Hamilton, 1994).

The Salmon River is approximately 33 km long and is a low gradient watercourse (0.5 - 2 %). The upper watershed is in a low lying, marshy agricultural area, where the mainstem and tributary channels flow through shallow valleys. The middle reaches of the river flow across gently sloping terrain in a protected meandering channel. The stream has excellent gravel deposits between kilometres 10 and 22. The gradient decreases in the lower 10 km where the deep channel cuts a series of tortuous meanders through meadowland.

Rearing potential is excellent in the Salmon River mainstem. Although the upper reaches of the Salmon River have no spawning gravel, good spawning and rearing is found in the middle reaches of the mainstem near 256th Street. Coghlan Creek accounts for a large percentage of the Salmon River escapement due to its abundant spawning and rearing habitat.

Anadromous salmonids and other fish species are present throughout most of the watershed. Anadromous fish have access as far as Highway 13 on the mainstem (although the culvert at 248th Street is impassable at low flows) and to the headwaters of Coghlan, Davidson and Union Creeks. DFO has designated the Salmon River as an Index Stream. It is considered indicative of general trends in status of coho stocks in the Lower Mainland that exhibit a similar marine distribution.

Irrigation licenses along the lower part of the Salmon River account for a significant portion of summer low flows (Rood and Hamilton, 1994). Summer water temperatures of 27°C near the mouth and 22°C in the headwaters of the river have been recorded. Furthermore, overwintering habitat may be limiting. Entrances to some side channels are well above the main channel, causing them to be dry most of the year. This probably results from downcutting of the main channel.

5.1.3 Serpentine River Watershed

The Serpentine River drains a watershed area of 149.8 km^2, and is one of the largest urban watersheds in the GVS&DD area. The Serpentine discharges to Boundary Bay, and its major tributaries include Hyland, Bear, and Latimer creeks. The main river is approximately 27 km long. It develops in marshy terrain in north Surrey and then flows across a moderately sloping plateau. The lower 22 km of the river flows in ditches and diked channels through a lowland agricultural area and a wetland complex in the Serpentine Fen Wildlife Management Area. The stream discharges to Mud Bay through an estuarine marsh. The mean annual flow of the Serpentine River is 6.23 m^3/s (Rood and Hamilton, 1994).

The headwaters of the Serpentine River provide the only suitable spawning habitat on the mainstem, although rearing habitat exists throughout. Fish access is limited by the floodgates on the Serpentine River which are impassable at high tide. Anadromous access is restricted by several impassable culverts on the Serpentine mainstem, and on Hyland, Quibble, and Latimer creeks. Anadromous fish have access to the headwaters of Bear, Enver, Lay and Damsite creeks.

The upper reach of the Serpentine River is the most urbanized of the large streams in the Fraser Delta Habitat Management Area (Rood and Hamilton, 1994). In the lowlands, dyking for primarily agricultural purposes has resulted in complete riparian clearing and some channel instability. Irrigation in the lower reaches imposes a considerable demand on summer low flows and there are a number of outstanding water license applications. Furthermore, water quality problems (low dissolved oxygen) associated with corn silage leachate have been noted. Water velocities are very low in the lower reaches in the summer and water temperatures often exceed 23°C (Rood and Hamilton, 1994).

5.1.4 Mossom Creek Watershed

Mossom Creek Watershed is the smallest of the test watersheds and drains a watershed of approximately 3.6 km^2. It is also the least disturbed by urbanization primarily because of its location on the urban fringe of Port Moody. Mossom Creek originates above 800 m in elevation on Eagle Mountain and discharges to Burrard Inlet near Dockrill Point. Average discharge of Mossom Creek is approximately 0.32 m^3/s (Poirier, 1998). The lower watershed is located within the City of Port Moody, while the central area is encompassed within the Village of Anmore. Two B.C. Hydro transmission lines bisect the centre of the watershed.

Although the headwater areas of Mossom Creek were logged in the late 1800s and again in the early 1970s, the majority of the watershed remains forested. There is some urban development in the lower reaches of the watercourse at the Village of Anmore and the City of Port Moody. Presently, the total impervious area for the Mossom Creek watershed is approximately 4.1%. The lower reaches of the stream are located in a forested stream ravine.

Anadromous salmonids including chum, coho, and occasional pink salmon (strays) use the lower gradient lower reaches of the system from its mouth to approximately 1.4 km upstream of Ioco Road (Poirier, 1998). Resident cutthroat trout are found in the higher gradient upper reaches where the stream is characterized by steplike sequences of cascades, riffles and small pools. No known barriers to fish migration exist in the watershed, although a culvert located approximately 0.5 m upstream from the mouth is impassable at low flows. The high gradient, confined stream channel with little floodplain or off-channel habitat development in combination with low nutrient productivity limit salmonid spawning and rearing values.

5.1.5 Musqueam Creek Watershed

The Musqueam Creek watershed is a small, low gradient watershed draining the southwest portion of Point Grey. Its watershed is approximately 6.5 km^2 in area with total stream channel length of 8.0 km. Run-off from approximately an 1.1 km^2 on the east side of the watershed is diverted to a combined sewer which reduces the effective drainage area to 5.4 km^2. The Musqueam Creek watershed is unique because it is the only intact watershed in the City of Vancouver that support populations of coho salmon and cutthroat trout (Page, 1993; Musqueam Creek Committee, 1997).

Approximately 65% of the watershed lies within Pacific Spirit Regional Park while the remainder is within the City of Vancouver (i.e., Musqueam Park and residential areas) and the Musqueam Indian Reserve (i.e., village site, leased residential areas, and golf courses). The most heavily urbanized part of the Musqueam watershed (located in the Dunbar Area) is diverted to a combined sewer so that its flow does not enter the stream.

Two streams – Musqueam and Cutthroat creeks, arise near the crest of the Point Grey uplands and flow parallel with one another before joining in Musqueam Park. Musqueam Creek is located on the eastern side of the watershed and originates south of 16th Avenue near the Sasamat Reservoir. Cutthroat Creek originates in a series of small forested wetlands on the west side of the watershed and flows generally southeast through an ecological reserve, the Shaughnessy Golf Course, and Musqueam Park. The confluence of the two streams is located in Musqueam Park immediately upstream from the boundary of the Musqueam Indian Reserve. Downstream, Musqueam Creek flows through the Musqueam Indian Reserve and the Musqueam Golf Course before discharging into the Fraser River.

Populations of coho salmon, chum salmon, cutthroat trout, prickly sculpin, western brook lamprey, and threespine stickleback are found in Musqueam Creek below Marine Drive and in Cutthroat Creek below the Shaughnessy Golf Course. An unique population of resident cutthroat trout occurs in Cutthroat Creek in Pacific Spirit Regional Park (Northcote and Hartman, 1988). Chum salmon were recently reintroduced into the watershed by the Musqueam Indian Band using Kanaka Creek stock.

5.1.6 Como Creek Watershed

The Como Creek (aka Schoolhouse Creek) watershed is approximately 8.9 km^2 hectares in area with a total stream channel length, including tributaries, of 14.2 km. It is located entirely within the City of

Coquitlam. The primary stream, Como Creek, originates in Como Lake and flows south, down the Maillardville slopes, and into the Fraser River immediately east of Fraser Mills. Two tributaries, Booth and Popeye creeks, also originate near the crest of the Maillardville slopes and join Como Creek immediately upstream of Lougheed Highway. Two smaller tributaries, Mill Creek and McDonald Creek are located in the lower watershed.

The watershed can be divided into two units, the upper and the lower watershed, based on significant differences in topography, fish distribution, and land use (Page and Millar, 1997). Anadromous fish, including coho salmon and cutthroat trout, occur in the lower watershed, while only resident cutthroat trout and stocked rainbow trout (from Como Lake) have been documented in the upper watershed. Stream channel gradient is typically less than 1% in the lower watershed, and greater than 5% in the upper watershed which is a significant factor influencing instream habitat conditions. The upper watershed is primarily developed for residential housing, while the lower watershed is characterized by commercial, industrial, and high density residential land use.

Even compared to other urban streams in the Lower Fraser Valley, the Como Creek watershed has been extensively impacted by urban and industrial development. Apart from the stream ravines which remain largely forested, only a very small portion of the watershed has not been developed for residential housing, or commercial and industrial land use. A study that reviewed the effects of urbanization and water use on streams in the Pitt/Stave Habitat Management Area documented higher than average peak flows and lower summer flows for Popeye and Booth (Laurentian) creeks (Rood and Hamilton, 1994). Como Creek (Schoolhouse Creek) was identified as a “sensitive” stream due to urbanization in a similar study of streams in the Fraser Delta Habitat Management Area (Rood and Hamilton, 1994).

5.1.7 Mosquito Creek Watershed

The Mosquito Creek watershed is located on the North Shore of Burrard Inlet in the District of North Vancouver and the City of North Vancouver. The watershed is approximately 14.4 km^2 with total stream channel length of 25.9 km. Three subwatersheds were identified by municipal drainage systems: Thain, Wagg, and Lower Mission subwatersheds. All occur in predominantly residential areas in the lower portion of the watershed.

Like most of the mountain watersheds, land use and topography divide the watershed into two distinct units. The upper watershed is steep and forested with little urban development. Grouse Mountain ski runs and facilities are the only substantial land use other than intact second growth forest. Stream channels are steep and partially incised with substrates dominated by cobble, boulder, and bedrock. Channel instability is common. Debris flows in the early 1980s caused damage to houses, bridges, and culverts and necessitated extensive channel engineering and bank protection.

The lower watershed is generally less steep and is heavily developed for residential, commercial, and industrial land use. Culvert barriers preclude access by anadromous salmonids into much of the watershed (Queens Road is the upper limit of coho use on the mainstem). In addition, extensive channel armouring in the 1980s has reduced habitat values, even for resident cutthroat trout.

Riparian forest cover is only beginning to mature following extensive construction disturbance in the middle third of the watershed. Industrial activities along the foreshore caused the loss of the estuary at the mouth of Mosquito Creek early in the century. Redevelopment of residential and commercial areas, rather than new development, is the predominant land use changes in the lower watershed. Two types of redevelopment are occurring: i) replacement of smaller houses with large houses; and, ii) expansion of commercial and high density residential along the Lonsdale Corridor (Barber *et al*., 1996).

Fish use includes coho salmon, cutthroat trout, and steelhead in the mainstem. The occurrence of both coastrange and prickly sculpin, as well threespine stickleback and western brook lamprey are inferred from extensive fish sampling on adjacent MacKay Creek. Chum salmon appear to have been extirpated from Mosquito Creek. Currently, the North Shore Fish and Game Club, DFO, and the City of North Vancouver are developing a series of off-channel ponds and channels to enhance coho populations.

6. ASSESSMENT RESULTS

The following sections present the results and key findings of the subwatershed and watershed assessment and classification process.

6.1 Total Impervious Area

The area covered by the various land use categories, the estimated total impervious area, and percentage total impervious area are summarized in Table 6.1. In calculating the total impervious area, we assumed that the single family residential development category (S110) has a conversion factor of 50%. This factor is thought to overestimate TIA in low-density developments and underestimate it in the most densely developed areas. We assigned a factor of 70% to the high rise residential category (S135) and a factor of 0% to lakes (R200). May *et al*. (1997) did not include either category in their tables. May *et al.* (1997) assign high values of 90% to commercial, industrial and institutional land uses. These values are at the high end of the range for commercial and industrial and likely over-estimate some institutional land use conversion factors. We also adjusted May *et al.* (1997) factor for transportation and communications from 100% to 25%. In order to complete the calculations for the Salmon River watershed, we assigned a conversion factor of 0% to the unclassified lands in the upper watershed. This area, which lies in Abbotsford, is primarily agricultural and open so this assumption will not greatly affect the overall %TIA for the Upper Salmon River or the Salmon Watershed. We also assigned a conversion factor of 0% to the U100 (Open) category in the Mossom Watershed and the R100 (Park) category in the Musqueam Watershed. In both cases, the areas designated were densely forested, rather than open or urban park.

Table 6.2 compares the %TIA values calculated by land use conversion to those measured from digital orthophotos using a GIS. The two sets of values are very similar, particularly for the overall watershed, though those for the individual subwatersheds are more variable. This occurs because residential areas may only be assigned one of two conversion factors, leading to over-estimation or under-estimation for medium density developments. Also, as discussed previously, conversion factors may vary from watershed to watershed for agriculture and institutional land uses.

For the individual subwatersheds, %TIA values ranged from a minimum of 4.1% in Mossom Creek to a maximum of 55.6% in Still Creek. The subwatersheds are broadly divided into agricultural watersheds that typically have about 10% or less total impervious area and urban watersheds that typically have 25% of more total impervious area. Musqueam Creek, which includes part of Pacific Spirit Regional Park, is the only urban study watershed with low %TIA.

6.2 Riparian Forest Integrity

The results of the assessment of riparian forest integrity are presented in Table 6.3. Percentage total riparian forest ranged from 26.0% to 93.5% with an average of 62.6% for the nineteen subwatersheds. Percentage stream length with riparian forest greater with 30 m varied from 4.6% to 81.3% (average, 36.8%). Not surprisingly, this second measure is lower than the measure of total riparian forest. The

Table 6.1. Total impervious area calculated from CLUCS land use conversion factors.

Study Watershed	Basin Area	Total Impervious Area		Area by Land Use Category (1)												
		% TIA of Basin Area	Total	Unclass. 0%	A500 5%	S110 50%	S120 10%	S130 60%	S135 70%	S200 90%	S300 90%	S400 90%	S500 100%	R100 10%	R200 0%	U100 5%
	(ha)	(%)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)
Brunette River	5046.4	**47.3%**	3446.0	0.0	0.0	2309.5	0.0	246.6	45.9	272.3	486.9	446.9	65.7	910.3	30.4	231.7
Still Creek	2821.9	**55.6%**	1569.6	0.0	0.0	1521.0	0.0	98.3	29.0	200.8	336.4	226.9	51.0	229.6	0.0	129.0
Deer Lake	942.4	**42.4%**	399.7	0.0	0.0	440.6	0.0	42.3	13.2	60.3	0.0	67.9	14.7	239.5	30.4	33.3
Eagle Creek	548.3	**43.5%**	238.4	0.0	0.0	160.6	0.0	20.2	1.7	0.0	122.5	15.0	0.0	191.9	0.0	36.3
Stoney Creek	733.8	**45.2%**	331.8	0.0	0.0	187.3	0.0	85.9	2.0	11.2	28.1	137.1	0.0	249.4	0.0	33.1
Como Creek	894.3	**52.8%**	472.4	0.0	0.0	539.0	0.0	38.5	0.0	37.6	84.7	62.9	19.3	59.3	4.6	48.5
Mosquito Creek	759.2	**30.5%**	116.4	0.0	0.0	470.7	0.0	52.2	1.7	16.2	0.2	31.7	0.0	62.8	0.0	485.4
Thain Creek	312.3	**33.4%**	104.4	0.0	0.0	173.6	0.0	2.2	0.0	1.5	0.0	9.4	0.0	5.7	0.0	120.0
Lower Mission Ck.	92.1	**48.8%**	44.9	0.0	0.0	66.8	0.0	6.3	0.0	0.0	0.0	7.3	0.0	11.6	0.0	0.1
Wagg Creek	354.7	**49.1%**	174.3	0.0	0.0	230.3	0.0	43.7	1.7	14.7	0.2	15.0	0.0	45.5	0.0	3.6
Mossom Creek	384.7	**4.1%**	15.75	0.0	0.0	19.8	54.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	309.7 (2)
Musqueam Creek	535.1	**7.4%**	39.6	0.0	0.0	55.6	0.0	2.8	0.0	0.9	0.0	11.2	0.0	466.9 (3)	0.0	1.7
Salmon River	5566.3	**7.0%**	526.8	501.8	2604.2	24.4	439.8	0.0	0.0	11.8	0.0	2.6	22.2	88.8	0.8	1869.9
West Salmon River	580.9	**6.8%**	39.4	0.0	260.9	10.4	112.9	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	195.3
Davidson Creek	998.6	**5.0%**	50.1	0.0	636.7	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	359.3
Coghlan Creek	1382.2	**5.7%**	79.2	0.0	721.7	0.0	108.7	0.0	0.0	0.0	0.0	0.0	22.2	3.5	0.0	526.1
Upper Salmon River	2598.2	**5.3%**	138.6	495.4	984.8	14.0	215.6	0.0	0.0	11.8	0.0	2.6	0.0	84.0	0.8	789.2
Serpentine River	9434.0	**25.3%**	3763.8	0.0	976.8	3257.4	878.4	268.1	3.5	328.4	454.9	261.7	59.5	924.5	0.0	2020.7
Upper Serpentine	1915.2	**32.5%**	623.1	0.0	104.9	721.9	136.4	102.9	2.7	76.4	0.0	55.2	38.5	355.2	0.0	321.1
Bear Creek	3997.7	**41.5%**	1659.7	0.0	237.2	1753.2	139.7	107.6	0.8	190.3	356.0	134.2	0.2	514.3	0.0	564.3
Hyland Creek	1400.5	**41.3%**	577.7	0.0	64.0	673.1	50.8	57.3	0.0	50.8	83.0	64.5	0.0	44.1	0.0	312.9
Clayton Creek	1191.6	**8.7%**	103.1	0.0	392.2	35.5	355.5	0.4	0.0	3.5	4.2	2.9	0.0	10.9	0.0	386.6
Latimer Creek	928.9	**12.3%**	114.0	0.0	178.5	73.8	195.9	0.0	0.0	7.5	11.6	4.9	20.8	0.0	0.0	435.9

Notes: (1) Total impervious area for the watersheds and sub-watersheds calculated from the area by land use category and the regional conversion factors in the column headings, categories F100, M300, and W400 were excluded because of inapplicability to the test watersheds; (2) U100 category in Mossom Creek was converted to 0%; (3) R100 for Musqueam Creek was converted to 0%.

Table 6.2. Comparison of percentage Total Impervious Area by different methods for test watersheds and subwatersheds.

Watersheds / Subwatersheds	**Percent Total Impervious Area**	
	GIS Measured (1)	**Land Use Conversion (2)**
Isolated Small Watersheds	-	-
1. Como Creek	**53%**	**52.8%**
2. Mossom Creek	**5%**	**4.1%**
3. Musqueam Creek	**4%**	**7.4%**
Serpentine River Watershed	**24%**	**25.3%**
1. Hyland Creek	39%	41.3%
2. Bear Creek	39%	41.5%
3. Upper Serpentine Basin	31%	32.5%
4. Latimer Creek	8%	12.3%
5. Clayton Creek	7%	8.7%
Salmon River Watershed	**6%**	**7.0%**
1. West Salmon River	4%	6.8%
2. Davidson Creek	5%	5.0%
3. Coghlan Creek	7%	5.7%
4. Upper Salmon River	5%	5.3%
Mosquito Creek Watershed	n/a (3)	**30.5%**
1. Thain Creek	n/a	33.4%
2. Lower Mission Creek	n/a	48.8%
3. Wagg Creek	n/a	49.1%
Brunette River Watershed	**50%**	**47.3%**
1. Deer Lake Brook	42%	42.4%
2. Still Creek	61%	55.6%
3. Eagle Creek	37%	43.5%
4. Stoney Creek	35%	45.2%

Notes: (1) Provided by the GVS&DD from their GIS measurements. Not available for the North Shore or for Vancouver. (2) Calculated from the conversion factors of May *et al* (1997) revised as described in the text. (3) n/a is not available

stream length measure may underestimate the extent of riparian forest because areas of riparian forest < 30 m wide were excluded from this calculation. At the same time, the percentage of riparian corridor with forest cover may overestimate riparian forest integrity by including isolated patches that were not contiguous with the channel. Overall, the results of the estimate of total riparian forest were used as the primary indicator of riparian forest integrity. We believe they provide a more accurate assessment of the amount of functioning riparian forest than that derived from the evaluation of total stream length with 30 m or greater of riparian forest. Too many small patches of forest that contribute to shading, bank stability, and other functions, are disregarded using the latter measure.

During the data analysis phase of the project, we compared the results of the percent total riparian forest cover assessment to the work done by Zandbergen (1998) in the Brunette and Salmon River watersheds. Differences were substantial and were both greater and less than the values measured for this study. However, further analysis indicated these differences were largely caused by different subwatershed boundaries, as well as the extent and location of the stream network used.

As expected, riparian forest integrity decreased with increasing urbanization and agricultural land use (see Figures 6.1 and 6.2). However, differences were broad from one subwatershed to the next. For example, Davidson Creek has 63.8% agricultural land use and 68.1% riparian forest integrity, while the Upper Salmon River has approximately 37.9% agriculture and 72.7% riparian forest integrity. Three urbanized subwatersheds (> 30% TIA) also had higher than average riparian forest integrity values (Lower Mission, Wagg, and Stoney creeks).

Table 6.3. Results of the assessment of riparian forest integrity for test watersheds and subwatersheds.

Watersheds / Subwatersheds	% Total Riparian Forest[1]	% Stream Length with Riparian Forest > 30 m Wide
Isolated Small Watersheds	-	-
1. Como Creek	**41.5%**	**13.1%**
2. Mossom Creek	**93.5%**	**81.3%**
3. Musqueam Creek	**77.8%**	**69.6%**
Serpentine River Watershed	**44.4%**	**21.3%**
1. Hyland Creek	55.0%	14.2%
2. Bear Creek	53.5%	27.6%
3. Upper Serpentine Basin	64.9%	36.8%
4. Latimer Creek	68.2%	41.6%
5. Clayton Creek	43.2%	29.6%
Salmon River Watershed	**60.4%**	**35.1%**
1. West Salmon River	63.3%	31.3%
2. Davidson Creek	68.1%	44.2%
3. Coghlan Creek	74.2%	45.9%
4. Upper Salmon River	72.7%	49.0%
Mosquito Creek Watershed	**76.6%**	**56.6%**
1. Thain Creek	69.9%	41.4%
2. Lower Mission Creek	69.6%	60.0%
3. Wagg Creek	72.3%	31.8%
Brunette River Watershed	**43.9%**	**14.1%**
1. Deer Lake Brook	53.6%	31.0%
2. Still Creek	26.0%	4.6%
3. Eagle Creek	51.8%	19.4%
4. Stoney Creek	71.2%	26.3%
Subwatershed Average[2]	**62.6%**	**36.8%**

[1] Results for the whole watersheds were obtained by summing the values, by area, for the subwatersheds and dividing them by the total area of the riparian corridor.
[2] Subwatershed average includes all subwatersheds plus Mossom, Musqueam, and Como watersheds.

6.3 Agricultural Land Use and Agricultural Land Use within Riparian Buffer

The results of the agricultural land use assessment and the evaluation of agricultural land use within the 30 m buffer are combined and presented in Table 6.4.

Agriculture occurs in only two of the seven watersheds - the Salmon and Serpentine rivers. In the Salmon River watershed, agriculture is spread relatively evenly among several of the subwatershed (values ranged from 38 to 64%). Agriculture in the Serpentine River is concentrated in the lower portion of the watershed (Central Serpentine catchment) which was not assessed as part of this study. However, Clayton and Latimer subwatersheds also have substantial agricultural activity (19% and 33% respectively). Only two subwatersheds (Davidson and Coghlan creeks) have greater than 50% agricultural land use by watershed area.

Percentage agricultural land within the 30 m riparian buffer ranged from 6.8% in the Bear Creek subwatershed to 48.3% in the West Salmon River subwatershed. Interestingly, this factor did not appear to be closely associated with the percentage total agricultural land in the subwatershed. For example, despite relatively similar values for agricultural land use in the riparian buffer of the Salmon and Serpentine watersheds (35% and 32% respectively), total agricultural use is substantially different (28.4% in the Serpentine; 46.9% in the Salmon). More work will be needed to be able to incorporate agricultural land use in the riparian buffer into the classification system.

Table 6.4. Total agricultural land and agricultural land within 30 m buffer for the test watershed and subwatersheds.

Watersheds / Subwatersheds	Percentage Total Agricultural Land	Percentage Agricultural Land within 30 m Buffer
Serpentine River Watershed	**28.4%**	**32.0%**
1. Hyland Creek	4.5%	8.5%
2. Bear Creek	7.0%	6.8%
3. Upper Serpentine River	5.4%	21.2%
4. Latimer Creek	19.2%	14.2%
5. Clayton Creek	32.9%	33.2%
Salmon River Watershed	**46.9%**	**35.0%**
1. West Salmon River	44.9%	48.3%
2. Davidson Creek	63.8%	37.7%
3. Coghlan Creek	52.2%	14.7%
4. Upper Salmon River	37.9%	21.1%

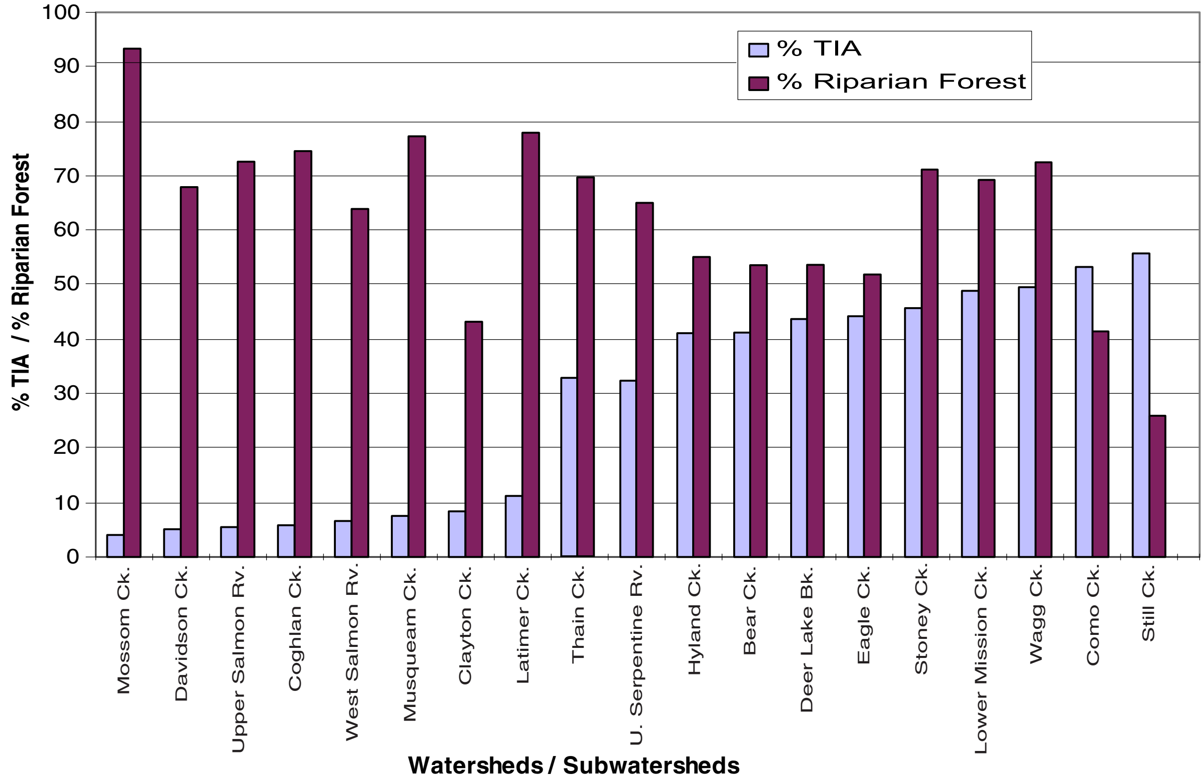


Figure 6.1. Comparison of %TIA and % riparian forest integrity for test watersheds and subwatersheds.

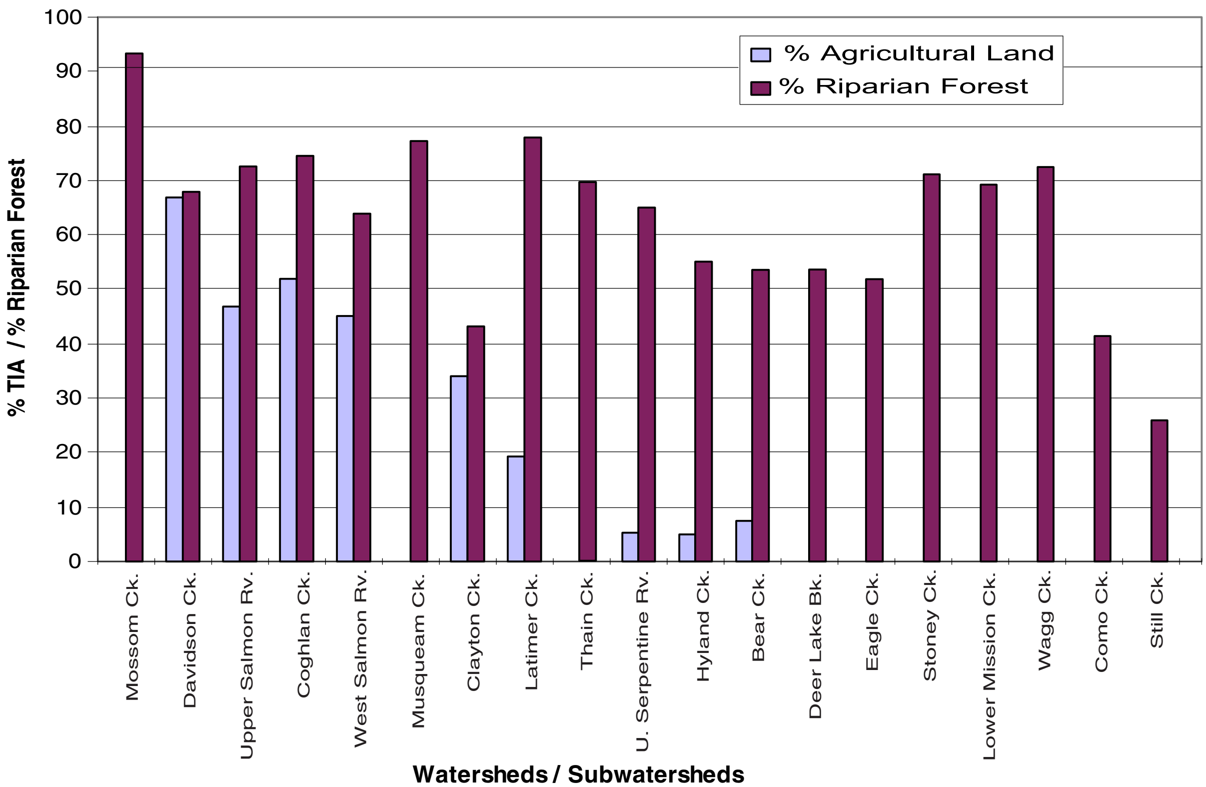


Figure 6.2. Comparison of % agricultural land use and % riparian forest integrity for test watersheds and subwatersheds.

6.4 Classification Results

Table 6.5 provides a summary of total impervious area, riparian forest integrity, and agricultural land use values by subwatershed that were used for the classification process. Subwatershed order is arranged from least urban (low %TIA) to most urban (high %TIA). Table 6.9 summarizes the same parameters for the seven watersheds. Figures 6.3 and 6.4 graphically present the position of the test subwatershed and watersheds in the two-dimensional depiction of watershed health classes. Figure 6.5 presents the results using the three-dimensional depiction of watershed health classes.

The results of the classification of the nineteen subwatersheds using the two different approaches are summarized in Table 6.7. Similarly, the classification of the seven watersheds is shown in Table 6.8.

Table 6.5. Summary of imperviousness, riparian integrity, and percentage agricultural land values for test subwatersheds and isolated watersheds.

Subwatershed / Watershed	% TIA	% Riparian Forest	% Agriculture
Mossom Creek	4.1%	93.5%	0.0%
Davidson Creek	5.0%	68.1%	63.8%
Upper Salmon River	5.3%	72.7%	37.9%
Coghlan Creek	5.7%	74.2%	52.2%
West Salmon River	6.8%	63.3%	44.9%
Musqueam Creek	7.4%	77.8%	0.0%
Clayton Creek	8.7%	43.2%	32.9%
Latimer Creek	12.3%	68.2%	19.2%
Thain Creek	33.4%	69.9%	0.0%
Upper Serpentine River	32.5%	64.9%	5.4%
Hyland Creek	41.3%	55.0%	4.5%
Bear Creek	41.5%	53.5%	7.0%
Deer Lake Creek	42.4%	53.6%	0.0%
Eagle Creek	43.5%	51.8%	0.0%
Stoney Creek	45.2%	71.2%	0.0%
Lower Mission Creek	48.8%	69.6%	0.0%
Wagg Creek	49.1%	72.3%	0.0%
Como Creek	52.8%	41.5%	0.0%
Still Creek	55.6%	26.0%	0.0%

Table 6.6. Imperviousness, riparian integrity, and agricultural land values for test watersheds.

Watershed	% TIA	% Riparian Forest	% Agriculture
Mossom Creek	4.1%	93.5%	0.0%
Mosquito Creek	30.5%	76.7%	0.0%
Musqueam Creek	7.4%	77.8%	0.0%
Salmon River	7.0%	60.4%	46.9%
Serpentine River	25.3%	44.4%	28.4%
Brunette River	47.3%	43.9%	0.0%
Como Creek	52.8%	41.5%	0.0%

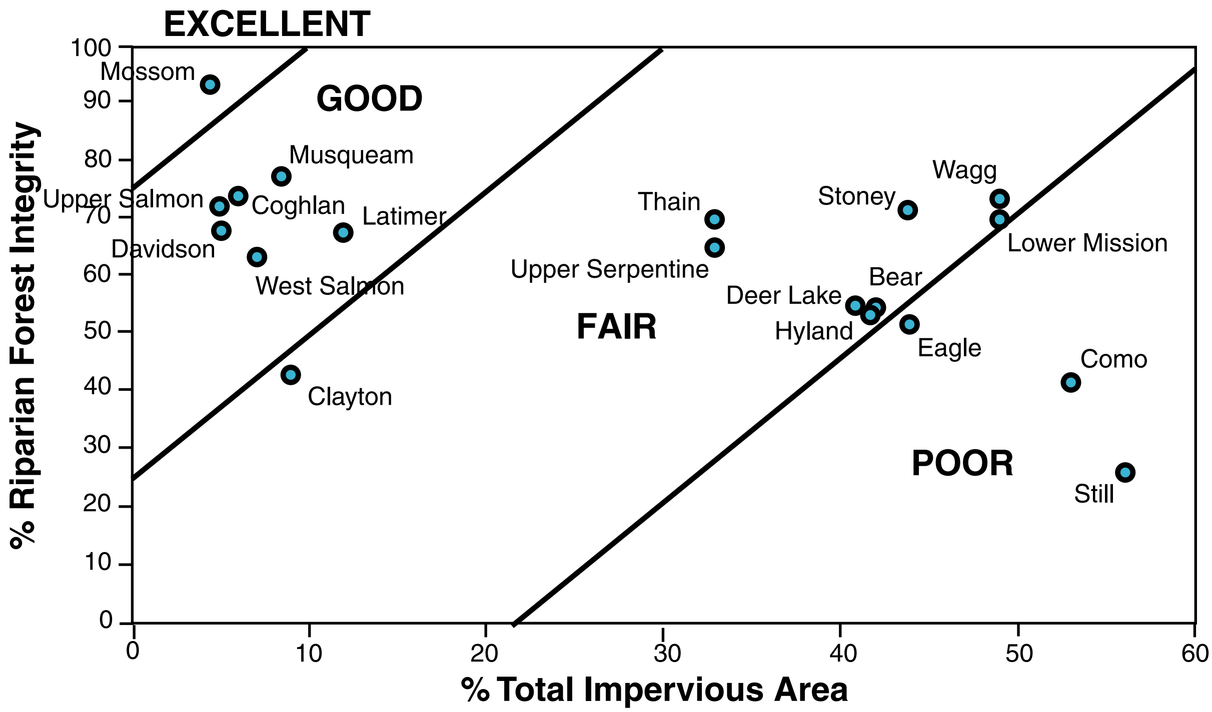


Figure 6.3. Comparison of % TIA and % riparian forest integrity for test subwatersheds.

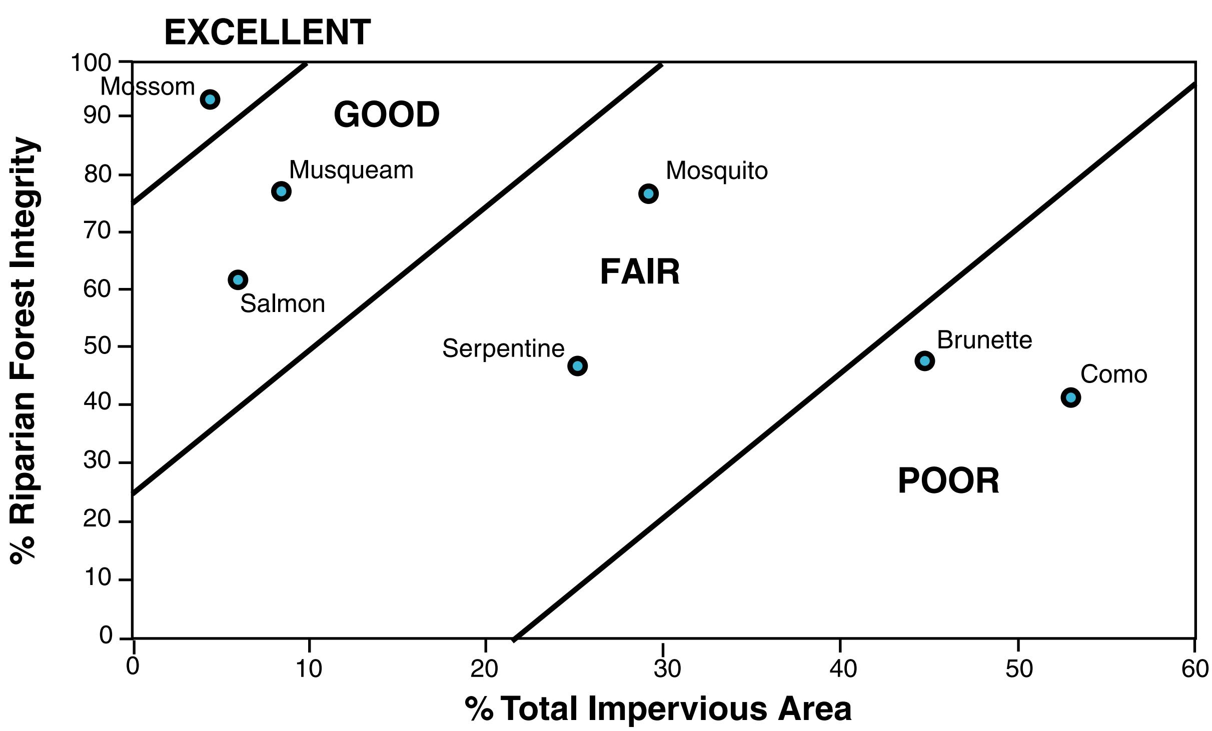


Figure 6.4. Comparison of % TIA and % riparian forest integrity for test watersheds.

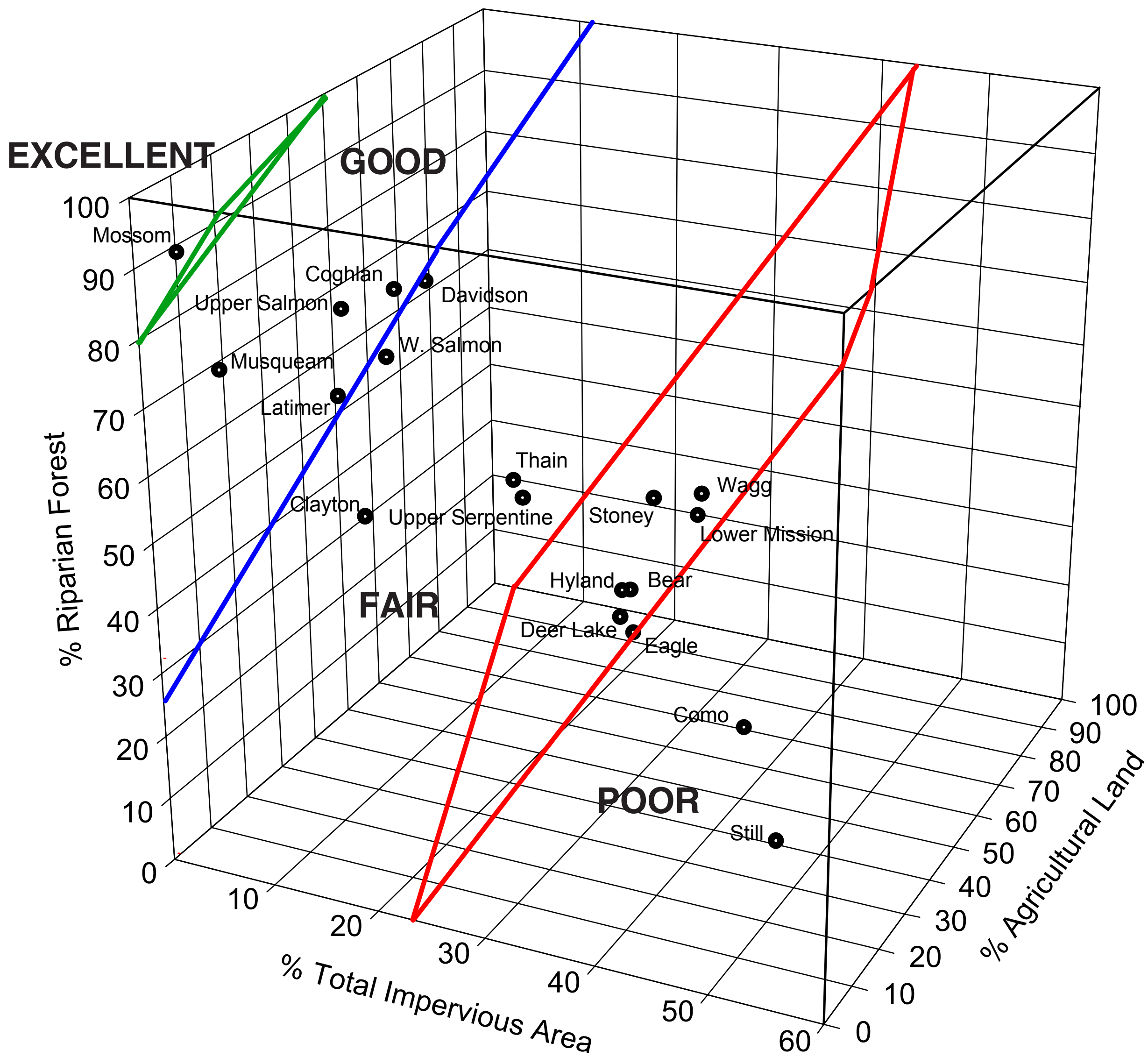


Figure 6.5. Location of test subwatersheds in three-dimensional depiction of watershed classes.

The differences between the classification of the study watersheds by the two approaches are relatively minor. The incorporation of agricultural land use resulted in only two subwatersheds - Davidson and West Salmon, being moved from “good” into “fair”. Both had extensive agriculture (44.9% in West Salmon and 63.8% in Davidson). No subwatersheds moved from “fair” to “poor”. For the seven watersheds, only the Salmon River watershed moved from “good” to “fair” after the incorporation of agricultural land use.

The advantage of incorporating agriculture is that it provides a more sensitive of subwatersheds with moderate agricultural land use (e.g., > 50%). However, it may also create a broader class of subwatersheds classified as “fair”. Overall, this may reduce the usefulness of the three parameter system for the GVS&DD, as it is expected that many watersheds with moderate to high urban and agricultural land uses will be classified as “fair”.

There are two key advantages to only using riparian forest integrity and total impervious area to define watershed class. First, the use of two indicators instead of three is generally more practical and requires a little less assessment work. Second and more importantly, the use of riparian forest integrity and imperviousness as indicators is based on empirical relationships that have been the focus of a range of research studies. While the effects of agriculture have also been examined, the relationship is much more poorly defined.

6.5 Secondary Indicators

6.5.1 Watershed Forest Cover

Watershed forest cover ranged from a minimum of 12.0% in the Como Creek watershed to 80.5% in Mossom Creek watershed (Table 6.9). Subwatersheds that were dominantly urban or agricultural did not differ substantially.

It is important to point out that the method used for assessing watershed forest cover is expected to overestimate the true value. This occurs because the land use category U100 includes all undeveloped areas, including non-forested sites.

Table 6.7. Subdivision of test subwatersheds based on two approaches to the integration of watershed health indicators.

Watershed Class	%TIA and Riparian Integrity only (2-d)	%TIA, Riparian Integrity, and Agricultural Land Use (3-d)
Excellent	Mossom Creek	Mossom Creek
Good	Musqueam Creek Coghlan Creek Latimer Creek Upper Salmon River Davidson Creek West Salmon River	Musqueam Creek Coghlan Creek Latimer Creek Upper Salmon River
Fair	Clayton Creek Thain Creek Upper Serpentine River Stoney Creek Lower Mission Creek Wagg Creek Bear Creek Hyland Creek Deer Lake Creek	Davidson Creek West Salmon River Clayton Creek Thain Creek Upper Serpentine River Stoney Creek Lower Mission Creek Wagg Creek Bear Creek Hyland Creek Deer Lake Creek
Poor	Eagle Creek Como Creek Still Creek	Eagle Creek Como Creek Still Creek

Table 6.8. Subdivision of test watersheds based on two approaches to the integration of watershed health indicators.

Watershed Class	%TIA and Riparian Integrity only (2-d)	%TIA, Riparian Integrity, and Agricultural Land Use (3-d)
Excellent	Mossom Creek	Mossom Creek
Good	Musqueam Creek Salmon River	Musqueam Creek
Fair	Mosquito Creek Serpentine River	Mosquito Creek Salmon River Serpentine River
Poor	Brunette River Como Creek	Brunette River Como Creek

Table 6.9. Results of the assessment of watershed forest cover for test watersheds and subwatersheds.

Watersheds / Subwatersheds	% Watershed Forest Cover[1]
Isolated Small Watersheds	**-**
1. Como Creek	**12.0%**
2. Mossom Creek	**80.5%**
3. Musqueam Creek	**72.3%**
Serpentine River Watershed	**26.3%**
1. Hyland Creek	25.5%
2. Bear Creek	26.9%
3. Upper Serpentine River	35.3%
4. Latimer Creek	46.9%
5. Clayton Creek	33.4%
Salmon River Watershed	**35.6%**
1. West Salmon River	33.9%
2. Davidson Creek	36.0%
3. Coghlan Creek	38.3%
4. Upper Salmon River	33.6%
Mosquito Creek Watershed	**50.2%**
1. Thain Creek	40.2%
2. Lower Mission Creek	12.7%
3. Wagg Creek	13.8%
Brunette River Watershed	**28.0%**
1. Deer Lake Brook	29.0%
2. Still Creek	12.7%
3. Eagle Creek	41.6%
4. Stoney Creek	38.5%

[1] Includes parks and protected areas (Category R100), harvesting areas (Category W400) and open or undeveloped areas (Category U100).

6.5.2 Surficial Geology

Table 6.10 presents a summary of the surficial geology of the watersheds and subwatersheds by class (Quadra sands, Fraser and Salish Deposits, Glaciofluvial, Glaciomarine and Tills, Bedrock, and All Others).

Thick deposits of glaciofluvial sediments that will help mitigate the increased peak flows that are associated with urban development and provide higher than typical summer base flows are only found in the Salmon River watershed. The other watersheds, with the exception of Mosquito, which has some glaciofluvial deposits in its upper watershed, are mostly underlain by till or glaciomarine sediments. The lower reaches of the south shore watersheds often cross Holocene (recent) sediments deposited along the Fraser River or along shorelines.

The glaciofluvial sediments in the Salmon River are associated with the Huntington Aquifer in the middle of the watershed. Over 40% of the surficial sediments in Coghlan Creek are glaciofluvial; the Lower Salmon subwatershed also has a very high percentage of its surface area covered by glaciofluvial deposits. The Upper Salmon River subwatershed is primarily underlain by glaciomarine sediment and till. Coghlan Creek and the Lower Salmon River subwatershed have sufficient coverage by permeable deposits to affect the hydrologic response to land use change. Effectively, the glaciofluvial deposits in these watersheds help compensate for the surface water extractions and concentration of agriculture.

6.5.3 Water Licenses

No consumptive licenses are currently active for Como or Musqueam watersheds and flows in their main creeks or tributaries are not reduced by surface water extractions (Table 6.11). Most other watersheds and subwatersheds have some potential demand, though it may often be a minor portion of stream flow. Several streams are licensed for unspecified quantities of water that may be diverted to maintain water levels in ponds. These diversions are expected to occur during the warmest weather, which often corresponds with the lowest flows in the streams.

Irrigation demand occurs on the lower Brunette River, in all the sub-watersheds and in the central Serpentine basin, and, to a lesser extent, in Mahood and Latimer Creeks. These extractions, which may not all be actively used, reduce summer base flows (Table 6.11).

Water is extracted for domestic and industrial purposes from the Lower Brunette basin, Mossom Creek, and all the Salmon and Serpentine subwatersheds. Domestic and industrial demands, are extracted year round, if licenses are active, providing a continuous removal of small quantities of water.

At its mouth, the demand on the Salmon is moderate, accounting for about 20% of the total August flow. The demand is much higher in Coghlan Creek where it amounts to 1/3 of the August flow. The demand is also high at the mouth of the Serpentine River, where it accounts for about 40% of the August flow (Rood and Hamilton, 1994). The distribution of demand varies in the two watersheds. In the Serpentine, most of the water is extracted from the agricultural lower watershed; very little is removed from the upper tributaries which are urbanized. The extractions from the Salmon are in the middle and upper part of the watershed, particularly on Coghlan Creek, and from the lower watershed closer to the mouth.

The subwatersheds with the greatest percentage of their summer flows used by irrigation extractions are Coghlan, Lower Salmon, upper Salmon and Central Serpentine. The domestic license on Mossom Creek may also remove a large portion of summer low flows, if it is active.

Table 6.10. Summary of surficial geology of the study watersheds.

Stream Name	Drainage *Area (ha)*	*Area and Percentage by Surficial Geology Class*											
		Unclassified		*Quadra Sands 1*		*Fraser and Salish 2*		*Glaciofluvial 3*		*Glaciomarine + Tills 4*		*Bedrock 5*	
		(ha)	*(%)*	*(ha)*	*(%)*	*(ha)*	*(%)*	*(ha)*	*(%)*	*(ha)*	*(%)*	*(ha)*	*(%)*
Brunette River	7287	166	2	0	0	1475	20	226	3	5123	70	298	4
Still Creek	2822	0	0	0	0	662	23	8	0	2130	75	22	1
Deer Lake	942	31	3	0	0	105	11	0	0	807	86	0	0
Eagle Creek	548	14	3	0	0	9	2	90	16	361	66	75	14
Stoney Creek	734	8	1	0	0	121	17	25	3	408	56	171	23
Como Creek	894	4	0	0	0	196	22	58	6	636	71	0	0
Mosquito Creek	1443	225	16	0	0	2	0	235	16	573	40	409	28
Thain Creek	312	0	0	0	0	0	0	41	13	130	41	142	45
Lower Mission Creek	92	0	0	0	0	0	0	4	4	88	96	0	0
Wagg Creek	355	0	0	0	0	1	0	14	4	331	93	9	2
Mossom Creek	385	27	7	0	0	0	0	15	4	157	41	186	48
Musqueam Creek	535	0	0	0	0	43	8	80	15	412	77	0	0
Salmon River	7475	258	3	0	0	529	7	3963	53	2725	36	0	0
West Salmon Rr.	581	0	0	0	0	0	0	529	91	52	9	0	0
Davidson Creek	999	51	5	0	0	126	13	388	39	433	43	0	0
Coglan Creek	1382	0	0	0	0	57	4	674	49	651	47	0	0
Upper Salmon River	2598	0	0	0	0	18	1	1258	48	1322	51	0	0
Serpentine River	14896	181	1	0	0	3730	25	9855	66	1130	8	0	0
Upper Serpentine Rv.	1915	187	10	0	0	51	3	1622	85	54	3	0	0
Bear Creek	3998	120	3	0	0	167	4	3367	84	343	9	0	0
Hyland Creek	1401	84	6	0	0	23	2	1075	77	218	16	0	0
Clayton Creek	1192	0	0	0	0	296	25	789	66	107	9	0	0
Latimer Creek	929	14	2	0	0	61	7	821	88	33	4	0	0

NOTES: 1 - Quadra Sands - Pva and PVb; 2 - Fraser and Salish Deposits - Saa through Sak and Fa through Fe, Sa-C; 3 - Glaciofluvial - Sa through Se; FLb and Fle; Vb; Ca through Ce; 4 - Glaciomarine and Tills - Sf, Sg, Sh, Fla, FLc, FLd, Va, Pvc through Pvh; UPV; Vca and VCb; 5 - Bedrock - T and PT

Table 6.11. Summary of water license information on study watersheds.

Stream Name	Total Drainage Area (ha)	Total Water Licenses: Domestic (g/day)	Irrigation (ac-ft)	Waterworks (g/day)	Industrial (g/day)	Conservation (cfs)	Licensed Demand (L/s): August	September	February	Storage: Total Non-Power	Total Conservation	Total Irrigation
Brunette River	7287	1000.00	40.00	0.00	500 + 0.00TF*	0.00	5.61	2.94	0.08	0.74	0.00	0.00
Still Creek	2822	0	0	0	0.00 TF*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deer Lake	942	0	0	0	500 + 0.00TF*	0.00	0.03	0.03	0.03	0.00	0.00	0.00
Eagle Creek	548	0	0	0	0.00 TF*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stoney Creek	734	0	0	0	0.00 TF*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Como Creek	894	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mosquito Creek	1443	0	0	0	1500 + 0.00TF	0.00	0.08	0.08	0.08	0.00	0.00	0.00
Thain Creek	312	0	0	0	1500 + 0.00TF	0.00	0.08	0.08	0.08	0.00	0.00	0.00
Lower Mission Creek	92	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wagg Creek	355	0	0	0	0.00 TF	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mossom Creek	385	6500	0	0	0.00	0.27	0.34	0.34	0.34	0.00	0.00	0.00
Musqueam Creek	535	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salmon River	7475	6000.00	454.50	0.00	222861.4TF	0.00	74.88	44.50	12.03	57.70	193.40	89.70
West Salmon Rr.	581	0	13.5	0	8000	0.00	2.29	1.39	0.42	0.00	0.00	0.00
Davidson Creek	999	2000	38.8	0	3000	0.00	5.63	3.03	0.26	0.00	193.40	0.00
Coghlan Creek	1382	2100	146.25	0	15000+0.00TF	0.00	21.12	11.35	0.90	50.00	0.00	82.00
Upper Salmon River	2598	1500	102.4	0	0.00 TF	0.00	14.24	7.39	0.08	7.70	0.00	7.70
Serpentine River	14896	3850	1008.935	0	831437 + 0.00TF	0.16	183.42	115.99	43.90	0.00	1000.00	0.00
Upper Serpentine Rv.	1915	1650	0.25	0	0.00	0.16	0.12	0.10	0.09	0.00	0.00	0.00
Bear Creek	3998	0	39.875	0	47377.6	0.00	8.00	5.34	2.49	0.00	0.00	0.00
Hyland Creek	1401	0	1	0	0.00 TF	0.00	0.14	0.07	0.00	0.00	0.00	0.00
Clayton Creek	1192	200	0	0	500	0.00	0.04	0.04	0.04	0.00	0.00	0.00
Latimer Creek	929	0	35	0	0.00 TF	0.00	4.84	2.50	0.00	0.00	0.00	0.00

NOTES:

1 - Mahood Creek totals include Quibble Creek
2 - 0.00 TF are unspecified amounts of demand, often to maintain pond or lake levels
3 - 0.00 TF* in Brunette River basin are multiple intakes for the same license

6.6 Fisheries Resources

As discussed in the methods section, assessment of fish diversity and conservation significance was made difficult by the lack of reliable information on some of the subwatersheds and watersheds. Results presented in the following sections should be considered preliminary and may change substantially with more recent or reliable information.

6.6.1 Fish Diversity

Fish species diversity by watershed and subwatershed is presented in Table 6.12 and a graphical summary is shown in Figure 6.6. Fish diversity was also assessed in downstream catchments because of the incorporation of downstream fish presence or habitat values in the final classification.

Native fish diversity ranged from only one fish species (resident cutthroat trout) in Thain and Wagg creeks, to twelve fish species in the Lower Salmon River catchment. As expected, diversity was highest in subwatersheds flowing into larger watersheds that are connected to the Fraser River. Watersheds or subwatersheds larger than 10 km^2 appear to support seven or more species of native fish (high diversity class), however, it is important to point out that this is a generalization based on a relatively small number of watersheds.

All subwatersheds contained native species of fish and only Still, Thain, and Lower Mission subwatersheds supported two or fewer species. Diversity in both Thain and Lower Mission is limited by impassable culvert barriers, steep channel gradient, and low summer flows. Still Creek is heavily impacted by urbanization.

These results substantiate the assumption that fish diversity is useful for examining the broad differences in watersheds or subwatersheds, but not specific enough on which to base a classification system without incorporating other factors.

Table 6.12. Native fish occurrence by watershed and subwatershed.

Watersheds / Subwatersheds[1]	Fish Species Recorded [2,3]	Total No. of Native Fish Species
Isolated Small Watersheds		
1. Como Creek	CO, CT, TSB, BL, CAS, RB	6
2. Mossom Creek	CO, CM, CT, TSB, *BL*, CAS	6
3. Musqueam Creek	CO, CM, CT, TSB, BL, CAS	6
Serpentine River Watershed	**CO, CH, CM, CT, ST, BL, CAS, TSB, RSC**	**9**
1. Hyland Creek	CO, CH, CM, CT, *BL, TSB, RSC, CAS*	8
2. Bear Creek	CO, CH, CM, ST, CT, BL, TSB, CAS	8
3. Upper Serpentine	CO, CH, CM, CT, ST, BL, CAS, TSB, RSC	9
4. Latimer Creek	CO, CH, CM, CT, *ST, BL, TSB, RSC, CAS*	9
5. Clayton Creek	*CO, CT, BL, TSB, RSC, CAS*	6
Central Serpentine River	CO, CT, TSB, RSC, BL	5
Salmon River Watershed	**CO, CM, CT, ST, TSB, PCC, BMC[4,5], CAS, BL, PL, NSC, CSU, SSU[4], RSC**	**14**
1. West Salmon River	*CO, CT, ST, CSU, BL, TSB, CAS*	7
2. Davidson Creek	*CO, CT, ST, CSU, BL, TSB, CAS*	7
3. Coghlan Creek	CO, CM, CT, ST, CAS, PL, BL, TSB, CSU	9
4. Upper Salmon River	CO, CM, CT, ST, SSU[4], CSU, TSB, *CAS, PL, BL*	10
Lower Salmon River	CO, CM, CT, ST, TSB, PCC, BMC[4,5], CAS, BL, NSC, CSU, RSC	12
Middle Salmon River	CO, CM, CT, ST, *PL*, BL, CAS, CSU, TSB	9
Mosquito Creek Watershed	**CO, CT, ST, *CAL,* CAS*,* TSB*, BL***	**7**
1. Thain Creek	CT	1
2. Lower Mission Creek	CT	1
3. Wagg Creek	CO, CT, *CAS, BL, TSB*	5
Central Mosquito Creek	CO, CT, ST, *CAL,* CAS*,* TSB*, BL*	7
Brunette River Watershed	**CO, CM, CT, ST, NSC, PCC, CAS, TSB, BL, RL**	**10**
1. Deer Lake	CO, CT, ST, TSB, CAS, BL	6
2. Still Creek	TSB, CT	2
3. Eagle Creek	CO, CT, ST, CAS, TSB, BL	6
4. Stoney Creek	CO, CT, ST, CAS, TSB, BL	6
Lower Brunette	CO, CM, CT, ST, NSC, CAS, TSB, BL	8
Central Brunette	CO, CT, NSC, PCC, CAS, TSB, RL, *BL*	8

[1] Catchments shown in italics are not true subwatersheds but were included to provide information on downstream fish populations.
[2] CO = coho salmon, CH = chinook salmon, CM = chum salmon, CT = resident or anadromous cutthroat trout, ST = steelhead or rainbow trout, TSB = threespine stickleback, PCC = peamouth chub, NSC = northern squawfish, BMC = brassy minnow, CAS = prickly sculpin, CAL = coastrange sculpin, PL = Pacific lamprey, BL = western brook lamprey; RL = river lamprey; CSU = largescale sucker, SSU = Salish sucker, RSC = redside shiner
[3] The presence of fish species listed in italics is unconfirmed but is based on species occurrence in adjacent watersheds.
[4] Rare, threatened or endangered fish species.
[5] Regionally significant fish species.

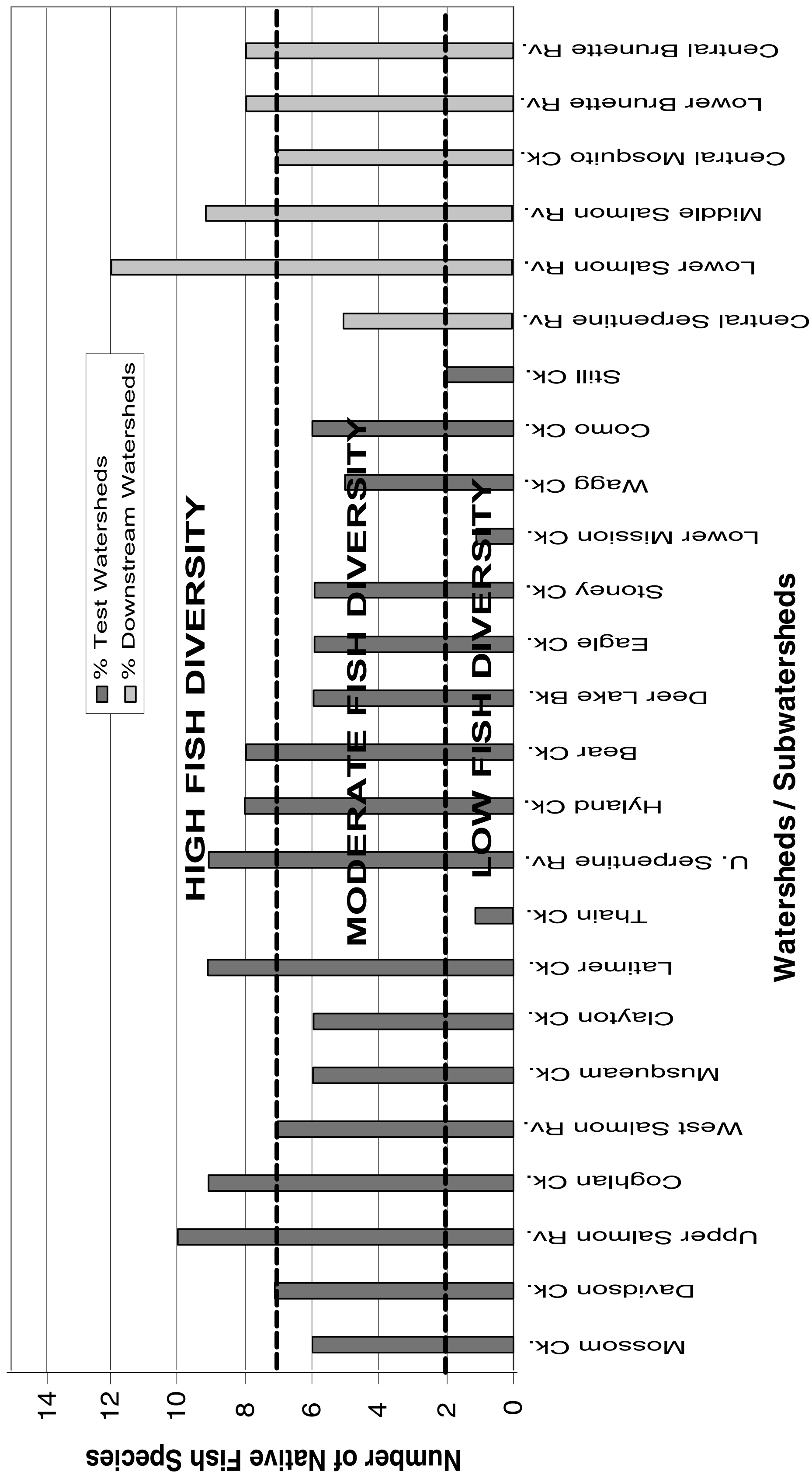


Figure 6.6. Estimated number of native fish species for study watersheds.

6.6.2 Relative Conservation Significance of Fish Populations

The results of the assessment of conservation significance are presented in Table 6.13 and are similar to the comparison of fish diversity. All of the subwatersheds rated at least one point on the scoring system, typically because of the extirpation of a specific fish species (commonly chum salmon), or low population size for coho salmon. Only two subwatersheds contained rare, threatened, or endangered species (Salish sucker in the Upper Salmon; brassy minnow in the Lower Salmon). Similarly, only one system contained a population that is deemed to be unique; an isolated population of resident cutthroat trout was identified in the headwaters of the Musqueam Creek watershed (Northcote and Hartman, 1988). This is likely related to the lack of sampling and genetic analysis of fish populations in the GVS&DD rather than lack of biological diversity within and between populations.

Similarly, no genetically or behaviorally unique anadromous salmonid populations were identified, however, this was also not surprising given our poor understanding of stock diversity in this area. Likewise, unusual habitat conditions that may be associated with unique fish populations were not identified in the test watersheds. A regional example of this type of diversity may include early spawning of coho salmon in the Capilano River.

No subwatersheds or small watersheds were identified as likely supporting only wild stocks of anadromous salmonids. Determination of wild stock status was based on a general understanding of previous stocking activities and more reliable information may be available.

6.6.3 Summary of Fish Resource Classification

Table 6.14 presents a summary of the fish diversity and conservation significance measures by subwatershed. The results indicate that high fish diversity is much more common (13 of 25 subwatersheds or catchments) than high conservation significance (2 of 25). Again, both subwatersheds with high conservation significance supported rare or endangered fish species (Salish sucker and brassy minnow).

Only three subwatersheds --Thain, Lower Mission, and Still creeks, have both low fish diversity and low conservation significance. However, as Section 5.7 describes in more detail, all three flow into larger systems that are classified as having high fish diversity. This effectively moves them up into the high diversity class in order to ensure stormwater management measures protect downstream fish populations.

Table 6.13. Summary of conservation significance scores for test subwatersheds.

Watersheds / Subwatersheds[1]	Score	Comments
Isolated Small Watersheds		
1. Como Creek	2	Chum extirpated; coho very low population size
2. Mossom Creek	2	Small coho population size; 3 salmonid species
3. Musqueam Creek	3	Genetically distinct cutthroat trout population; low coho population size; chum extirpated
Serpentine River Watershed		
1. Hyland Creek	2	3 salmonid species; low coho population size
2. Bear Creek	2	3 salmonid species; low coho population size
3. Upper Serpentine	2	3 salmonid species; low coho population size
4. Latimer Creek	2	3 salmonid species; low coho population size
5. Clayton Creek	2	3 salmonid species; low coho population size
Central Serpentine River	2	extirpation of chum or chinook; low coho population size
Salmon River Watershed		
1. West Salmon River	2	3 salmonid species; low coho population size
2. Davidson Creek	2	3 salmonid species; low coho population size
3. Coghlan Creek	2	3 salmonid species; low coho population size (?)
4. Upper Salmon River	6	Presence of Salish sucker (endangered); 3 salmonid species; low coho population size
Lower Salmon River	6	Presence of brassy minnow (threatened); 3 salmonid species; low coho population size
Middle Salmon River	2	3 salmonid species; low coho population size
Mosquito Creek Watershed		
1. Thain Creek	1	Chum and coho extirpated
2. Lower Mission Creek	1	Chum and coho extirpated
3. Wagg Creek	1	Chum and coho extirpated
Central Mosquito Creek	3	3 salmonid species; low coho population size; chum salmon extirpated
Brunette River Watershed		
1. Deer Lake	3	3 salmonid species; low coho population size; chum salmon extirpated
2. Still Creek	1	Chum and coho extirpated
3. Eagle Creek	3	3 salmonid species; low coho population size; chum salmon extirpated
4. Stoney Creek	3	3 salmonid species; low coho population size; chum salmon extirpated
Lower Brunette	3	3 salmonid species; low coho population size; chinook likely occurred historically and extirpated
Central Brunette	2	low coho population size; chum salmon extirpated

[1] Catchments shown in italics are not true subwatersheds but were included to provide information on downstream fish populations.

Table 6.14. Summary of fisheries resources (conservation rating and diversity rating).

Watersheds / Subwatersheds	Conservation Rating	Diversity Rating
Isolated Small Watersheds		
1. Como Creek	Moderate	Moderate
2. Mossom Creek	Moderate	Moderate
3. Musqueam Creek	Moderate	Moderate
Serpentine River Watershed		
1. Hyland Creek	Moderate	High
2. Bear Creek	Moderate	High
3. Upper Serpentine	Moderate	High
4. Latimer Creek	Moderate	High
5. Clayton Creek	Moderate	Moderate
Central Serpentine River	Moderate	Moderate
Salmon River Watershed		
1. West Salmon River	Moderate	High
2. Davidson Creek	Moderate	High
3. Coghlan Creek	Moderate	High
4. Upper Salmon River	High	High
Lower Salmon River	High	High
Middle Salmon River	Moderate	High
Mosquito Creek Watershed		
1. Thain Creek	Low	Low
2. Lower Mission Creek	Low	Low
3. Wagg Creek	Low	Moderate
Central Mosquito Creek	Moderate	High
Brunette River Watershed		
1. Deer Lake	Moderate	Moderate
2. Still Creek	Low	Low
3. Eagle Creek	Moderate	Moderate
4. Stoney Creek	Moderate	Moderate
Lower Brunette	Moderate	High
Central Brunette	Moderate	High

6.6.4 DFO / MELP Fish Presence and Habitat Classification Results

Information on fish diversity and distribution was used to determine habitat category. Results are presented in Table 6.15 below.

Table 6.15. Subwatersheds and watersheds by fish habitat category.

Watersheds / Subwatersheds	Category 1	Category 2	Category 3
Isolated Small Watersheds	-	-	-
1. Como Creek	Year-round salmonids	-	-
2. Mossom Creek	Year-round salmonids	-	-
3. Musqueam Creek	Year-round salmonids	-	-
Serpentine River Watershed	Year-round salmonids	**-**	**-**
1. Hyland Creek	Year-round salmonids	-	-
2. Bear Creek	Year-round salmonids	-	-
3. Upper Serpentine	Year-round salmonids	-	-
4. Latimer Creek	Year-round salmonids	-	-
5. Clayton Creek	Year-round salmonids	-	-
Central Serpentine River	Year-round salmonids	-	-
Salmon River Watershed	Year-round salmonids; rare or endangered fish species	**-**	**-**
1. West Salmon River	Year-round salmonids	-	-
2. Davidson Creek	Year-round salmonids	-	-
3. Coghlan Creek	Year-round salmonids	-	-
4. Upper Salmon River	Year-round salmonids; rare or endangered fish species	-	-
Lower Salmon River	Year-round salmonids; rare or endangered fish species	-	-
Middle Salmon River	Year-round salmonids	-	-
Mosquito Creek Watershed	Year-round salmonids	**-**	**-**
1. Thain Creek	Year-round salmonids	-	-
2. Lower Mission Creek	Year-round salmonids	-	-
3. Wagg Creek	Year-round salmonids	-	-
Central Mosquito Creek	Year-round salmonids	-	-
Brunette River Watershed	Year-round salmonids	**-**	**-**
1. Deer Lake	Year-round salmonids	-	-
2. Still Creek	Year-round salmonids	-	-
3. Eagle Creek	Year-round salmonids	-	-
4. Stoney Creek	Year-round salmonids	-	-
Lower Brunette	Year-round salmonids	-	-
Central Brunette	Year-round salmonids	-	-

6.7 Summary of Final Classification

The final step in the classification system was the integration of the watershed health measures and fisheries resources indicators. First, subwatersheds were classified according to the results of the total impervious area and riparian forest integrity integration presented in Table 6.7. Second, each watershed class (excellent, good, fair, and poor) was subdivided into three or four subclasses based on the results of the fisheries resource assessment.

There were several assumptions that drove the subclassification process including:

1. Subwatersheds cannot be treated separately from the watersheds into which they drain. Stormwater management planning must address issues of chemical contamination and hydrologic disturbance that occur at the subwatershed level, but the assessment and understanding of impacts must extend into downstream areas.

2. Subwatersheds that contain or flow into subwatersheds with fish populations of high conservation value should be treated separately from other watersheds based on their importance in protecting biological diversity. The likely enactment of federal endangered species legislation in the next year may increase the importance of rare and endangered fish species in conservation planning.

3. Subwatersheds that contain or flow into subwatersheds with high diversity fish populations are also of high management importance. This attribute partially addresses the issue of scale and interconnectedness of subwatersheds by focusing higher management emphasis on subwatersheds that flow into larger order systems. The four large watersheds (Salmon, Serpentine, Brunette, and Mosquito) contained seven to twelve native fish species.

4. Subwatersheds that contain or flow into subwatersheds with moderate conservation significance or moderate fish diversity are separated from subwatersheds that contain or flow into subwatersheds with low conservation significance and low fish diversity.

Results are presented in Tables 6.16 (watershed health with fish diversity and conservation significance) and 6.17 (watershed health with DFO / MELP fish presence and habitat value categories.)

Table 6.16. Final classification of test subwatersheds using fish diversity and conservation significance to define subclasses.

Watershed Class	Subclass Based on Fisheries Resource Characteristics	Subwatersheds in Test Group
A. Excellent	**A1** -*Contain or flow into watersheds or subwatersheds with fish populations of high conservation significance*	-
	A2 - *Contain or flow into watersheds or subwatersheds with high fish diversity*	-
	A3 - *Contain or flow into watersheds or subwatersheds with fish populations of mod. conservation significance or mod. fish diversity*	**Mossom Creek**
	A4 - *Contain or flow into watersheds or subwatersheds with fish populations of low conservation significance and low fish diversity*	-
B. Good	**B1** - *Contain or flow into watersheds or subwatersheds with fish populations of high conservation significance*	**Upper Salmon River**
	B2 - *Contain or flow into watersheds or subwatersheds with high fish diversity*	**Coghlan Creek** **Latimer Creek** **Davidson Creek** **West Salmon River**
	B3 - *Contain or flow into watersheds or subwatersheds with fish populations of mod. conservation significance or mod. fish diversity*	**Musqueam Creek**
	B4 - *Contain or flow into watersheds or subwatersheds with fish populations of low conservation significance and low fish diversity*	-
C. Fair	**C1** - *Contain or flow into watersheds or subwatersheds with fish populations of high conservation significance*	-
	C2 - *Contain or flow into watersheds or subwatersheds with high fish diversity*	**Upper Serpentine River** **Stoney Creek** **Thain Creek** **Hyland Creek** **Bear Creek** **Deer Lake Brook** **Wagg Creek** **Lower Mission Creek**
	C3 - *Contain or flow into watersheds or subwatersheds with fish populations of mod. conservation significance or mod. fish diversity*	**Clayton Creek**
	C4 - *Contain or flow into watersheds or subwatersheds with fish populations of low conservation significance and low fish diversity*	-
D. Poor	**D1** - *Contain or flow into watersheds or subwatersheds with fish populations of high conservation significance*	-
	D2 - *Contain or flow into watersheds or subwatersheds with high fish diversity*	**Eagle Creek** **Still Creek**
	D3 - *Contain or flow into watersheds or subwatersheds with fish populations of mod. conservation significance or mod. fish diversity*	**Como Creek**
	D4 - *Contain or flow into watersheds or subwatersheds with fish populations of low conservation significance and low fish diversity*	-

Table 6.17. Final classification of test subwatersheds using DFO / MELP method of assessing fish presence and fish habitat value.

Watershed Class	Category Based on Fisheries Resource Characteristics		
	Category 1	Category 2	Category 3
A - Excellent	Mossom Creek	None	None
B - Good	Musqueam Creek Coghlan Creek Latimer Creek Upper Salmon River Davidson Creek West Salmon River	None	None
C - Fair	Clayton Creek Thain Creek Upper Serpentine River Stoney Creek Lower Mission Creek Wagg Creek Bear Creek Hyland Creek Deer Lake Creek	None	None
D - Poor	Eagle Creek Como Creek Still Creek	None	None

6.8 Classification Costs

The time requirements of the classification process were estimated for several of the test watersheds. As expected, the two most time-consuming steps in the process were: i) GIS-based assessment of watershed-level indicators; and, ii) collection and review of information on fisheries resources. One factor that should be considered is that the test watersheds were not necessarily representative of the typical level of information that exists for GVS&DD watersheds. Several of the watersheds were selected because of the broad range of fisheries and land use information that existed.

GIS (Arcview) assessment included definition of the watershed and subwatershed boundaries (municipal mapping or topographic interpretation); stream selection; confirmation of land use types; assessment of riparian length; assessment of riparian forest cover; and GIS based overlays for secondary indicators. This relied on available land use information and current drainage mapping that was obtained from municipal governments. Assessment time was roughly proportional to the size of the watershed and ranged from 0.25 to 0.7 hours / km^2 (average of 0.4 hours / km^2). GIS technician costs were estimated a $55 per hour and workstation costs are approximately $25 per hour.

Assessment of fisheries resources required identifying, obtaining, and reviewing previous fisheries related work. No field assessment was undertaken. On average, each of the test watersheds took between 4 and 16 hours to obtain information on which to base the assessment. This included repeated requests to individuals or groups for information, on-site report review at municipal offices, and discussions with key individuals. Several sources of information were available to the consultants through in-house libraries. Estimated time requirements are from 0.1 to 0.4 hours / km^2. Costs for a biologist or fisheries technician to undertake this work range from $45 to $75 per hour.

6.9 Recommendations for Refinement of the Classification System

We recommend the following:

1. There should be further discussion and testing of methods for incorporating fisheries resource indicators into the classification system. GVRD staff should continue to work with DFO and MELP representatives to develop an efficient and appropriate system of identifying the highest priority watersheds and subwatersheds based on fisheries resources.

2. Further testing of the classification system should be undertaken to identify watersheds or fisheries resource conditions that are not encompassed using the current system. In particular, situations where the stream is culverted (e.g., many streams in the City of Vancouver) or where poorly defined and extensively modified drainage systems occur (e.g., Corporation of Delta) should be examined. In addition, fish diversity may not be a suitable measure if culverts are the primary factor affecting the distribution of native fish species.

3. The feasibility of validating the Benthic Index of Biotic Integrity (B-IBI) for the GVS&DD should be explored. Macroinvertebrate-based measures of stream health have been used extensively as accurate and cost-effective stream assessment tools. Many classification systems that were reviewed, and most of the assessment studies, relied on some form of biological sampling. The biological sampling program currently being undertaken for a number of GVS&DD streams (including many of the test subwatersheds) may provide more information on the usefulness and efficacy of the B-IBI in the study area.

4. More work should be undertaken to evaluate the role of resiliency in affecting the response of watersheds to urbanization. Comparative studies of flow response or hydrologic modeling could provide more accurate methods for incorporating resiliency into the classification system.

5. The role of community value in modifying management emphasis in urban watersheds should be discussed. At this point, it will be difficult to combine relatively objective based classification methods with value driven criteria. However, other methods may be available that would combine these types of measures.

6. Measures for assessing restoration potential in urban watersheds should be evaluated. While this factor was not discussed in this report, restoration potential may be important for identifying management importance in urban watersheds.

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Appendix 1

SUMMARY OF REVIEWED CLASSIFICATION SYSTEMS

Title 1:	**Handbook for Prioritizing Watershed Protection and Restoration to Aid Recovery of Native Salmon (Bradbury Framework).** W. Bradbury, W. Nehlsen, T.E. Nickelson, K.M.S. Moore, R.M. Hughes, D. Heller, J. Nicholas, D.L. Bottom, W.E. Weaver, R.L. Beschta. 1995. *Handbook for Prioritizing Watershed Protection and Restoration to Aid Recovery of Native Salmon* (Bradbury Framework). Prepared for the Pacific Rivers Council, Eugene, Oregon.
Purpose / Summary:	The Bradbury Framework proposed a three step process to systematically identify those areas and activities that can best protect and restore salmon and their watersheds. It is explicitly a watershed prioritization process and had two specific objectives: I) identify restoration activities for immediate implementation where limited public funds are available; and, ii) provide the basis for protection and restoration strategies that might be implemented over longer time periods. The system was developed by a committee of state, federal, tribal, and regional resource managers; scientists; and fishing and environmental organizations. The first step is to identify the geographic units to be prioritized such as a state, ecoregion, or landscape unit. The second step is to designate the priority of river basins (i.e., Columbia River) in the geographic unit using criteria in three areas: i) biological and ecological resources; ii) integrity and risks to these resources; and, iii) optimism and potential for protection and restoration. The third step, is to identify priority watersheds in each river basin. A weighting system is used to aggregate values and identify relative priority.
Criteria / Indicators:	Criteria by group include: **A. Biological and ecological resources** • number of anadromous salmonid species / races • relative abundance of anadromous salmonids • native aquatic assemblage diversity • number of key watersheds, source areas or aquatic diversity areas • ecoregions represented • other ecological benefits **B. Integrity and risks to these resources** • relative integrity • relative risk • risk of extinction **C. Optimism and potential for protection and restoration** • degree of optimism • potential increase
Classes:	**First Priority** - Watersheds that comprise aquatic diversity areas, key watersheds, and salmon source areas. **Second Priority** - Watersheds that comprise aquatic diversity areas and salmon source areas or key watersheds and salmon sources.

	Third Priority - Those source areas not identified as aquatic diversity areas or key watersheds and other areas that provide other ecological benefits.
Advantages:	• Biologically driven and incorporates uniqueness of biological resources well. • Meets the objective of providing a framework for rapid prioritization to guide restoration planning. • Incorporates multiple scales by prioritizing by ecoregion or state, basin, and watershed.
Disadvantages:	• Lacks specificity in criteria ranking - often only high, medium, or low. • Relative integrity may not be as important as it should be given the effects of forest harvesting or urbanization. • “Salmo-centric” classification. • Uses weighting system to incorporate disparate range of variables; arbitrary values? • Does not capture the effect of fish diversity based on spatial scale or basin / watershed size. Natural variation should be considered otherwise largest watersheds with highest fish diversity will always be highest priority. • Includes several value driven criteria such as optimism that are difficult to weigh besides more objective criteria. • More suitable for large areas than to regions with small watersheds.

Title 2:	**The Importance of Imperviousness** (A Possible Scheme for Classifying and Managing Headwater Urban Streams Based on Ultimate Imperviousness). Schueler, T.R. 1994. The Importance of Imperviousness. *Watershed Protection Techniques* 1(3). pp. 100-111.
Organization:	Center for Watershed Protection
Purpose / Summary:	Schueler summarizes the results of a number of studies that have examined the relationship between impervious area and stream quality or health. The results indicate that stream degradation occurs at relatively low levels imperviousness (10-20%) and that there are thresholds of impact that can be used guide watershed classification and management. Much of the paper is spent discussing the implications of imperviousness on hydrology, water quality, stream warming, and biodiversity. A useful review of studies examining the relationship between urbanization and stream quality is included. The paper also presents a proposed scheme for classifying urban stream quality potential based on imperviousness. Thresholds of imperviousness are described and resource, land use, and water quality objectives are outlined. The paper cautions that the relationship between imperviousness and stream quality needs to be regionally validated and that a monitoring and/or assessment program should be undertaken. The regional usefulness of BMPs should also be determined as a modifier of impervious area impacts on stream health.
Criteria / Indicators:	Percentage Total Impervious Area (TIA) is the sole criteria for classification.
Classes:	1. **Stressed** (0-10% TIA); 2. **Impacted** (11-25% TIA);

	3. **Degraded** (26-100% TIA)
Advantages:	• Simple and easily applied; requires only assessment of total impervious area to classify. • Relationship between impervious area and watershed health substantiated by a wealth of literature (see May et al., 1997; Zandbergen et al., in press). • Linked to strong management prescriptions encompassing water quality objectives, BMP selection factors, land use controls, riparian buffers, and enforcement activities.
Disadvantages:	• One indicator may not capture complexity of urban watersheds. • Threshold of degradation slightly different than both May *et al*., 1997 and Zandbergen *et al*., in press and may need to be validated for GVRD area. • Riparian integrity not captured and its ability to maintain stream quality in urban watersheds. • Modifiers of TIA such as headwater vs. mainstem, EIA, and diversion issues not included. • Resiliency of watersheds not captured (i.e., differences in soil types) • Classification lacks specificity; all sub-basins in the Brunette, Serpentine, Scott watersheds would likely be characterized as degraded and would have similar management priority.

Title 3:	**Coastal Watershed Assessment Procedure Guidebook - Level 1 (CWAP). 1995.** Forest Practices Code of B.C. (MELP and MOF). 1995. *Coastal Watershed Assessment Procedure Guidebook - Level 1* (CWAP).
Purpose / Summary:	CWAP is intended to help forest managers identify the type and extent of current water-related problems (i.e., stream channel changes, peak flow, water quality) that exist in forested watersheds and to recognize the possible hydrologic implications of proposed forestry-related development. It is also used as a tool to prioritize between watersheds for programs such as the Watershed Restoration Program.
Criteria / Indicators:	15 Impact indicators are assessed including: 1. Peak flow index (based on Equivalent Clearcut Area determination) 2. Road density (for assessing peak flow changes) 3. Road density (for assessing surface erosion) 4. Density of roads on erodible soils 5. Density of roads less than 100 m from a stream 6. Density of stream crossings 7. Portion of stream logged 8. Portion of fish stream logged 9. Portion of mainstem logged 10. Density of landslides in the watershed 11. Number of large landslides hitting the mainstem stream 12. Density of roads on potentially unstable terrain 13. Percentage of logged, potentially unstable terrain 14. Density of streams logged in slopes > 60%

	15. Density of stream crossings on slopes > 60% Indicators are normalized using a scoring system that makes the data easier to interpret. Data is scored from 0 to 1.0 with 1.0 representing the most severe impact.
Classes:	Classes are not established for CWAP. A watershed report card with a summary of hazard indices for five impact categories (peak flow, surface erosion, riparian buffer, mass wasting, headwaters) is constructed by incorporating the fifteen indicators. Impact categories are rated high (>0.7), medium 0.5 to 0.7), or low (<0.5).
Advantages:	• Encompasses a broad range of impact classes related to hydrology and riparian issues. • Provides a useful template for presenting information on watershed health using a watershed report card approach. • Office-based procedure is efficient and practical. CWAP results are used to refine assessment and restoration priorities, as well as guide forest planning.
Disadvantages:	• Indicators not applicable to GVRD conditions. • Hazard indices are weighted to allow comparison between different indicators. Weighting may compound data errors. • Type 1 and 2 errors have been identified for the CWAP (i.e., watershed rated as insensitive when it is sensitive is a Type 2 error).

Title 4:	**Protecting and Restoring the Habitats of Anadromous Salmonids in the Lake Washington Watershed** Fresh, Kurt (Washington Department of Fish and Wildlife) and Lucchetti, Gino, (King County, Department of Natural Resources). (1998. *in press*). Protecting and Restoring the Habitats of Anadromous Salmonids in the Lake Washington Watershed
Purpose:	Fresh and Lucchetti provide an ecosystem basis to protecting and restoring freshwater habitats in the heavily urbanized Lake Washington Watershed (LWW) in Washington State. The paper uses a range of indicators of fish use and diversity, in combination with watershed health, to classify watersheds. An ecosystem approach relies on large spatial scales rather than basins.
Criteria / Indicators:	Seven key indicators: 1. Amount of development 2. Imperviousness 3. Abundance of anadromous fish populations 4. Diversity of anadromous populations 5. Overall ecological integrity 6. Condition of headwaters 7. Overall condition of wetlands
Classes:	Basins (subwatersheds) were grouped into three categories (from report): *“Category I* represents the salmon conservation basins: they are the least

	developed basins and in general have the highest overall ecological integrity, the highest quality habitat, the lowest amounts of impervious surface, and healthiest and most diverse naturally spawning anadromous populations. Aquatic habitat protection would be the management priority in these basins and employ a variety of approaches such as acquisition of property and development rights, lower zoning, wide buffer strips, retention of the maximum amount of forest cover, better incentives for land owners, use of a wide variety of techniques to reduce impervious surfaces, BMP's and on-site infiltration of stormwater. Restoration efforts would target improving condition of surrounding forests, and increasing habitat complexity. "*Category II* basins are those that are moderately developed and still maintain more than remnant populations of naturally reproducing salmon and steelhead. To a large degree, we regard these basins as *potential* salmon conservation areas where management priorities would focus on preventing further degradation than restoring and rehabilitating degraded ecological processes. "*Category III* basins would consist of the most urbanized basins. Management priorities in these basins should focus on maintaining healthy populations of cutthroat trout which appear to be sustainable in urban settings. There should also be an emphasis on improving quality of stream waters in these heavily degraded basins to help maintain high quality water in Lake Washington and Lake Sammamish."
Advantages:	• Unlike many of the classification systems, the LWW system is biologically driven - it relies on fish presence and diversity (species and life history strategy) as an important attribute to guide management focus. • The LWW system goes beyond indices of watershed health to include management objectives. • Captures complexity of urban watersheds compared to use of general watershed indices. • Uses all available data. • Incorporates office and field based parameters
Disadvantages:	• Does not include agricultural development in watershed (different environment from GVS&DD). • Fish diversity generally higher than in many GVRD watershed (Lake Washington supports steelhead, coho, chinook, sockeye, and cutthroat trout). • Data quality may not be comparable (i.e., old or different field methods) • Does not capture sensitivity / resiliency to future change. • Three categories may not capture variation sufficiently. • Lack of clearly defined thresholds.

Title 5:	**Development of a Fish Habitat Sensitivity Indexing Scheme for Application in the Fraser River Basin.** Webb, T.M., Daniel, C.J., Korman, J., and J.D. Meisner. 1994. *Development of a Fish Habitat Sensitivity Indexing Scheme for Application in the Fraser River Basin*. Can. Manuscr. Rep. Fish. Aquat. Sci. 2234: 134 p.

Purpose / Summary:	The purpose of the study was to provide a structured method for evaluating the relative sensitivity of fish habitats within the Fraser River basin to a variety human activities. It uses a broad range of sub-indices to compare watersheds, as well as evaluate potential changes to watersheds from proposed development activities. An important use of the classification system was to identify "relative concern" based on five watershed characteristics: **1. Levels of human activity (i.e., > 20% of the watershed logged)** **2. Levels of important environmental variables (i.e., low DO, high temp.)** **3. Ability of the watershed to resist change (i.e., slope, soils, average flows)** **4. Characteristics of particular habitat types (i.e., spawning areas)** **5. Characteristics of fish stocks** The system was tested on nine sub-watersheds in the Horsefly, Bessette, and Coldwater watersheds in central B.C.
Criteria / Indicators:	Broad range including: forestry (%logged), riparian removal (% vegetation removed, linear developments (km / km^2), urban/rural (pop. / km^2), grazing (AUM/km^2), agriculture (% watershed in farm land), point sources (dilution at 7 day low flow), water withdrawals (licensed demand), foreshore work, instreamwork (# / mainstem km), mining (# mines / watershed), high temperature (max monthly ave.), flashiness (mean flood / mean annual flow), fine sediment (% fines), large debris (m^3/m^2), oxygen (mg/L), nutrient status (mg/L) + others
Classes:	No classes prescribed. Level of relative concern for each of the nine sub-watersheds was determined through a variety of aggregation methods. Sub-index values can also be used for direct comparison between watersheds.
Advantages:	• System examined sensitivity to changes as well as current condition - provides predictive tool to evaluate future watershed changes. • Incorporates biological, as well as physical criteria. • Framework for incorporating five watershed level characteristics useful as a model. • Useful as a comparative tool between watersheds. • Tested process makes it more relevant. • Discussion of classification theory and semantics useful, but academic.
Disadvantages:	• Very complex system that suffers from both high data requirements and difficult to understand weighting system - never used. • Data requirements are high, although the authors state that much of the data is already available. • Scale of watersheds relatively large - 154 km^2 to > 1000 km^2 • Many of the sub-indices are inapplicable to small, urbanized watersheds. Not suitable for GVRD given its complexity and weighting system.

Title 6:	**Quality Indices for Urbanization Effects in Puget Sound Lowland**

	Streams. 1997. May, C.W., E.B. Welch, R.R. Horner, J.R. Karr, and B.W. Mar. 1997. *Quality Indices for urbanization effects in Puget Sound Lowland streams*. Washington Department of Ecology. Water Resource Series Technical Report No. 154. 229 pp.
Purpose / Summary:	The Puget Sound Lowland Stream Study (PSLSS) examined the effects of urbanization on instream habitat characteristics, riparian condition, physio-chemical water quality, and biological attributes of 22 streams in the Puget Sound area. Streams were selected to span a gradient of development levels. The purpose of the project was to determine relationships between urbanization and stream quality and suggest target conditions for management and protection. In general, the study confirmed the relationship between increased urbanization and reduced biotic integrity: "The cumulative effects of a modified hydrologic regime (disturbance), the loss of instream structural complexity, and the alteration of channel morphological characteristics accompanying urbanization have resulted in substantial degradation of instream habitat during the initial phases of development. As the level of basin development increased above 5% total impervious area, results indicated a precipitous initial decline in biological integrity as well as the physical habitat conditions necessary to support natural biological diversity and complexity". Biotic integrity was measured using a Benthic Index of Biotic Integrity (B-IBI) that relies on macroinvertebrate presence, abundance, and diversity as an integrator of stream health. Coho to cutthroat ratio was also used as a indicator of biotic integrity.
Criteria / Indicators:	Quality indices included: i) urbanization, instream physical habitat, physio-chemical, and biological (B-IBI). As the report points out "Total impervious area and riparian buffer integrity (% corridor with buffer width > 30 m) alone were nearly as well as related to physical habitat indices (r=0.63) as the full set of urban impact indices (r=0.77) and were fully predictive of biological indices (r=0.70) as the full set of indices (r=0.77)."
Classes:	Four classes of stream quality were identified based on percentage watershed imperviousness and riparian integrity: excellent, good, fair, and poor.
Advantages:	• Puget Sound is biophysically comparable to GVRD. Levels and type of urbanization are also comparable. • Relative value of a broad range of indices are compared. Use of TIA and riparian integrity substantiated as useful indicators of stream health. • Results were accepted by scientific community.
Disadvantages:	• Study did not identify why some watersheds are more resilient to change than other watersheds. • B-IBI may need to be regionally calibrated for GVRD. • B-IBI influenced by factors other than urbanization. • Variation in B-IBI between watersheds with similar TIA indicate other factors must be considered. • Is it applicable to higher gradient streams like Mosquito Creek.

Title 7:	**US EPA National Watershed Characterization / Index of Watershed Indicators (1998).** Information available at: (http://www.epa.gov/surf/iwi) and (www.epa.gov/OW/indic)
Organization:	U.S. Environmental Protection Agency
Purpose / Summary:	The Index of Watershed Indicators (IWI) characterizes the condition and vulnerability of aquatic systems in each of the 2,111 watersheds in the Continental U.S. This involves an assessment of condition, vulnerability, and data sufficiency. Most watershed indicators used were a measurement of the response of the watershed to stressors (health indicators). Few factors affecting response were used including urban runoff potential, hydrologic modification from dams. Some inputs were used such as population change. As described in the EPA's introduction to the system: "The IWI approach is simple. First, indicators of the condition of the watershed are scored and assigned to one of three categories: better water quality, water quality with less serious problems, and water quality with more serious problems. Second, indicators of vulnerability are scored to create two characterizations of vulnerability: high and low." These two sets of indicators are then combined to create a seven class spectrum (see below). Water quality and the requirements under the Clean Water Act drive the IWI watershed characterization process. However, the process also recognizes the biological values of watersheds. Current documents state that additional indicators such as biological integrity, terrestrial condition, ground water, and air deposition will be added at a future date.

Criteria / Indicators:	Watershed indicators used by the IWI include:
	
	• fish and wildlife consumption advisories
	• indicators of source water condition for drinking water systems
	    • rivers and lakes supporting drinking water uses
	    • surrogates of source water condition
	    • occurrence of chemicals in surface and ground waters that are regulated in drinking water
	• contaminated sediments
	• ambient water quality data
	• wetland loss index
	• aquatic / wetland species at risk
	• pollutant loads discharged above permitted limits
	• urban runoff potential
	• index of agricultural runoff potential
	• population change
	• hydrologic modification caused by dams
	• estuarine pollution susceptibility index.

Classes:	Seven categories of watersheds are recognized by combining indicators of condition:

	1. better water quality – low vulnerability **2. better water quality – high vulnerability** **3. less serious water quality – low vulnerability** **4. less serious water quality – high vulnerability** **5. more serious water quality – low vulnerability** **6. more serious water quality – high vulnerability** **7. insufficient data**
Advantages:	• Good assimilation of a broad range of data on complicated issues into two variables and seven categories. • Most useful as a comparative tool between watersheds. • Incorporates vulnerability to stressors.
Disadvantages:	• Model of watershed valuation based only on information available. It is therefore limited in its scope and applicability. • Too large scale for GVS&DD application. • Level of sophistication to deal with sub-watershed is unavailable; specificity would have to be increased for GVS&DD application. • Water quality focus.

Title 8:	**Illinois EPA Targeted Watershed Approach (TWA)** Illinois EPA, 1997. Targeted Watershed Approach, A Data Driven Prioritization. Illinois Environmental Protection Agency, Division of Water Pollution Control.
Purpose / Summary:	The objectives of the Targeted Watershed Approach (TWA) were to: • Identify watersheds with the most critical water quality problems and direct programs and resources to the solution of those problems. • Direct programs and resources to those watersheds considered to have the highest potential for improvement. • Protect existing high quality water resources through a preventative approach to water quality management. • Identify watersheds where there is a need to coordinate multiple program priorities. Like many of the watershed management issues in the US, the TWA is driven by requirements under the Clean Water Act and water quality protection is paramount. The TWA has for program areas: streams (point source concerns), streams (nonpoint source concerns), inland lakes, and groundwater. Targeted watersheds (streams) were identified by a two tiered classification process. Selection criteria for streams and their watersheds were divided into preventative and restoration criteria. Following selection of watersheds into these two categories, streams were prioritized based on criteria in four areas.

	The system is relatively complex and the jargon and objectives under the Clean Water Act were confusing. In particular, the designation of preventative or restorative criteria prior to the prioritization process was unclear.
Criteria / Indicators:	Preventative based criteria: • Biological Stream Characterization (uses IBI) • High Quality Streams (designated as threatened or state protected) • Public Water Supplies Restorative based criteria: • Potential Index of Biotic Integrity (PIBI) • Water Quality Limited Waters Identified by Section 303(d) • Public Water Supplies • Illinois River Waterway from Lake Michigan to Mississippi River
Classes:	Designation of Priority 1 through 4.
Advantages:	• Integrates biotic integrity as a component of relative priority. • Framework applicable to GVRD project (i.e., designation of priority watersheds). • Semantics (“targeted watershed approach” and “priority watersheds”) work well to describe the process and management philosophy.
Disadvantages:	• Does not use watershed based indicators. • IBI not useful for GVRD watersheds due to lack of fish diversity. • Water quality is principle focus.

Title 9:	**Classification System for Lower Mainland Region Watercourses**. Ministry of Environment, Lands and Parks (E.M. Stoddard). 1998. Classification System for Lower Mainland Region Watercourses. (adapted from work done by City of Surrey and ECL Envirowest Consultants Ltd.)
Organization:	Ministry of Environment, Lands and Parks Region 2
Purpose / Summary:	The stated purpose of the classification system is to accurate identify salmonid, rare and endangered resources in regional districts and municipalities in Region 2 and to provide a more streamlined approach to undertaking regular and emergency drainage system maintenance works. Its primary focus is to map salmonid presence and distribution in watercourses including stream, ditches, and wetlands. The City of Surrey was the first municipality to develop and implement this approach and it has been subsequently been promoted by MELP and DFO as a important resource management tool. Approval requirements such as timing windows, BMPs, and emergency works requirements are specified for each watercourse class.
Criteria / Indicators:	Permanent or seasonal salmonid presence and / or value to downstream fish habitat values. Presence of rare or endangered fish species.
Classes:	Four classes are identified:

	• <u>Class A (red codes streams):</u> Inhabited by salmonids and /or rare or endangered species year round or potentially inhabited year-round with access improvement. • <u>Class A(O) (red dashed streams):</u> Inhabited by salmonids only during the overwintering period or potentially inhabited by salmonids during the overwintering period with access improvement. • <u>Class B (yellow coded streams):</u> Significant sources of potentially significant sources of food and nutrient value to downstream fish populations. No documented fish presence and no reasonable potential for fish presence through flow or access enhancement due to insignificant low flows or significant natural or man-made barriers. • <u>Class C (green coded streams):</u> Insignificant food and nutrient value to downstream fish populations. No documented fish presence and no reasonable potential for fish presence.
Advantages:	• Clear and well defined criteria and classes. • Biologically driven; fish use is the primary requirement for determining value / importance of streams under DFO / MELP management structure.
Disadvantages:	• No differentiation based on watershed health, fish diversity, fish abundance, or biotic integrity. Salmonid use is not a reliable indicator of stream or watershed health. • Does not use a watershed based approach; specifically confined to watercourses (streams, ditches, wetlands, etc.). • Requires intensive field work to determine fish presence or absence. Overwintering use may be difficult to determine accurately. • Headwater areas have least fish use, but potentially highest value for hydrology protection.

Title 10:	**Hydrology and Water Use for Salmon Streams in the Fraser Delta Habitat Management Area, British Columbia**. Rood, K.M., and R.E. Hamilton. 1994. *Hydrology and water use for salmon streams in the Fraser Delta Habitat Management Area, British Columbia*. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2038.
Purpose / Summary:	"The main objective of the report is to express the habitat sensitivity of the salmon streams in the Fraser Delta Habitat Management Area through various indices that were calculated from the hydrologic, water use, and land use data collected for the streams." The indices were used to rank streams based on sensitivity to different stressors. Sensitivity was used to refer to the state of the hydrologic regime that affect habitat values and are altered by human activities. While the report does not classify watersheds explicitly, it groups them by

	sensitivity in four main areas: 1. Water demand; 2. Summer low flows; 3. Winter low flows; and, 4. Urbanization. Sensitivity was characterized by higher than average sensitivity in relation to other streams in the area. It is important to point out that this differs substantially from comparisons to undisturbed reference streams or undisturbed conditions.
Criteria / Indicators:	Eight indices in four main groups were used: 1. August water use as a proportion of 7 day low flow 2. September water use as a proportion of 7 day low flow 3. August water use as a proportion of the mean monthly flow for the same month 4. August water use as a proportion of the mean monthly flow for the same month 5. Summer Low Flow 6. Winter Low Flow 7. Peak Flows 8. Urban Development
Classes:	Each index was rated as High, Average, or Low in relation to other streams in the region. Indices rated as High identified the stream as sensitive. The first four indices were aggregated to form “water demand”.
Advantages:	• Hydrology is central to stream health. • Information is comparative between watersheds. • Regional focus and extremely pertinent to the GVRD area. • Clear justification for indices that are included. • Well used and respected document. Data incorporated into several other classification systems (particularly EIA calculations).
Disadvantages:	• Lack of biological criteria. • Streams rated against the <u>average</u> for others in the Habitat Management Area. More useful to compare against reference or historical values. • Hydrologic data lacking for many systems. • Low flow sensitivity may be underestimated. • EIA calculations may be inaccurate.

Title 11:	**Maryland Department of Natural Resource - Draft Unified Watershed Assessment (1998).** Information available at: http://www.dnr.state.md.us//cwap/summary.html
Organization:	Maryland Department of Natural Resource
Purpose / Summary:	The stated purpose is to assess the physical, biological and chemical condition of Maryland watersheds and classify them into categories. This process is driven by the requirement of states under provisions of the Clean Water Act to complete a Unified Watershed Assessment (UWA). The UWA provides the foundation for setting watershed restoration, protection and preservation priorities by USGS designated watersheds. The UWA is intended to help

	Maryland meet two overall goals: I) **clean water goals** - Maryland watersheds should meet water quality standards, including numerical criteria and designated uses; and, ii) **other natural resource goals** - watersheds should achieve levels of natural resource indicators related to the condition of aquatic living resources, water chemistry, and physical habitat, as well as watershed lands.
Criteria / Indicators:	Assessment criteria are divided into clean water goals and other natural resource goals. **A. Clean Water Goals**: Assessment methods examine water quality parameters related to provision under the Clean Water Act using 305(b) report, 303(d) list and tributary strategies information. **B. Other Natural Resource Goals**: Assessment methods include: 1. Living Resources: • IBI, B-IBI, tidal and non-tidal fish • submerged aquatic vegetation coverage • rare, threatened and endangered aquatic species • wetlands of special state concern 2. Water Chemistry • Nutrients and suspended sediments • over-enrichment impact • submerged aquatic vegetation requirements • acidification potential 3. Physical Habitat • instream physical habitat • fish blockages 4. Watershed Lands • Soils and soil conservation • hydrologic disturbance • stream drainage density • nutrient loadings • wetland resource base • forest resource base • riparian forest • forest fragmentation • interior forest • large undisturbed wetlands • non-tidal wetlands of high habitat value • intact headwater systems • designated wildlands • major point source discharges 5. Drinking water source protection watersheds
Classes:	**Category 1** - Watersheds not meeting clean water and other natural resource protection goals and needing restoration.

	Category 2 - Watersheds currently meeting goals that need preventative actions to sustain water quality and aquatic resources. **Category 3** - Pristine or sensitive watersheds that need and extra level of protection.
Advantages:	• Large research focus of project allows for incorporation of complexity, as well as testing of indicators. • Long-term project with opportunity to incorporate other indicators as needed. • Field and office-based procedures incorporated. • Regional focus allows for better comparison of the range of watershed conditions and scales (GVRD is conversely almost all affected by urban development and / or agriculture.)
Disadvantages:	• Data requirements are large (for example Landsat imagery, seasonal IBI information). • Unfeasible for an agency like GVRD to implement. • Analysis paralysis may prevent actions being taken based on conservative management principles. • Water quality focus as part of requirements of the Clean Water Act. • Counter intuitive classification system. Restoration given priority over protection.

Title 12:	**Fraser River Basin Strategic Water Quality Plan - Lower Fraser River: Fraser Delta, Pitt-Stave, Chilliwack and Harrison-Lillooet Habitat Management Area.** Nener, J.C. and B.G. Wernick. 1997. *Fraser River Basin Strategic Water Quality Plan, Lower Fraser River: Fraser Delta, Pitt-Stave, Chilliwack and Harrison-Lillooet Habitat Management Areas.* Fisheries and Oceans Canada - Fraser River Action Plan Water Quality Series. Vancouver, BC.
Organization:	Fraser River Action Plan, Department of Fisheries and Oceans
Purpose / Summary:	The objectives of the Strategic Water Quality Plan were to: 1. Document and assess water quality conditions throughout the Fraser River Basin [Lower Fraser Valley only for this report] 2. Identify areas where degradation of water quality may impact aquatic life with a focus on salmon bearing streams; and, 3. Identify specific actions necessary to address the identified impacts to water quality, and where possible, implement programs to address these impacts. While the plan is not explicitly a classification system, the assessment results are used to generalize the condition of the stream, and could be used as a classification tool. Criteria and classes used for the plan could be adapted for either assessment or classification systems. The plan is comprehensive. Water quality information including surface water, contaminants in fish tissue, and sediment contaminants are presented

	graphically using a four tiered gradation depicting level of concern (red, yellow, green, blue - see below). In addition, information on impacts from land uses and hydrology including urban development, agriculture, forestry, low flows, and water demand is presented for each stream where information was available.
Criteria / Indicators:	The report provides criteria to designate the level of concern for four groups of indicators: • **Surface Water** quality criteria included dissolved oxygen, phosphorous, ammonia, fecal coliform, metals. • **Sediment Quality** was compared to existing MELP standards. • **Contaminants of Fish Tissue** included assessment of organic contaminants (i.e., total dioxins and furans) where available. • **Land Use and Hydrology** evaluation included urban development, agriculture, forestry, low flows, and water demand. Urban development criteria were Red - > 9% EIA, Yellow - 2 to 9% EIA, Green - < 2% EIA, Blue - no EIA or land use information available.
Classes:	For each group of indicators, four levels of concern are presented: **Red:** Available information indicates that water quality conditions limiting to fish production are likely to occur in the watercourse. **Yellow**: Available information indicates that there may be some impairment of water quality, with potential implications for fish. **Green**: Information indicates that water quality is unimpaired and should not be limiting to fish production. **Blue**: There is not enough information available to assess water quality conditions
Advantages:	• Extremely comprehensive. • Incorporates key land uses that impact hydrology and water quality. • Provides justification for designating classes by specifying explicit thresholds.
Disadvantages:	• Explicitly water quality issues, does not integrate habitat concerns. • Does not encompass all watersheds in the GVRD, only Fraser River tributaries. • Relies on existing information rather than standardized methodology and new data collection. Some data may be old, erroneous, or primarily qualitative. • Lack of comparable information (different sources, age of data, etc.) makes it more difficult to use as a classification tool to identify relative level of concern. • Smaller systems often lack information such as fish contaminants and sediment quality compared to larger systems.

	• No fisheries information other than tissue contamination.

Title 13:	**Surface Freshwater Classifications Used in North Carolina (1998)** Information available at: http://h2o.ehnr.state.nc.us/wswp/index.html
Organization:	North Carolina Department of Environment, Health, and Natural Resources.
Purpose / Summary:	North Carolina classifies surface water resources to guide management emphasis and protection. Like may classifications in the US, water quality (Clean Water Act) is a primary focus. Watershed / waterbody classification is undertaken by the N.C. Division of Water Quality. Primary classification is Class A (swimmable / fishable), Class B (primary water contact) and Water Supply (drinking water). Supplemental classifications are intended to incorporate biological or other values within this system. The classification system is used to guide watershed protection activities. The accompanying table provides a summary of development restrictions by watershed class. In general, water supply watersheds for domestic use are afforded the highest level of protection. While biological value may be overlayed on this designation, water quality protection is the primary focus.
Criteria / Indicators:	**A. Water Quality** **Water Supply Watersheds** WS-I: Waters used as sources of water supply for drinking, culinary, or food processing. WS-I are those waters within natural and undeveloped watersheds in public ownership with no permitted point source discharges. WS-II: Waters used as sources of water supply for drinking, culinary, or food processing but not meeting WS-I classification. WS-II waters are generally in predominantly undeveloped watersheds. WS-III: Waters used as sources of water supply for drinking, culinary, or food processing but not meeting WS-I or WS-II classification. WS-III waters are generally in low to moderately developed watersheds. WS-IV: Waters used as sources of water supply for drinking, culinary, or food processing but not meeting WS-I, WS-II, or WS-III classification. WS-IV waters are generally in moderately to highly developed watersheds. WS-V: Waters protected as water supplies which are generally upstream and draining to Class WS-IV waters. No development restrictions. **Class B Waters** Waters used for primary recreation including swimming, skin diving, and water skiing. There are no restrictions on watershed development

	activities. **Class C Waters** Waters protected for secondary recreation, fishing, wildlife and fish propagation or for human body contact on an infrequent basis. **B. Supplemental Classifications** Future Water Supply: Is applied to WS-I through IV waters that are intended for future drinking water source. Nutrient Sensitive Waters: Is applied to waters needing additional nutrient management due to their growth being subject to excessive growth of vegetation. Outstanding Resource Waters: Supplemental classification intended to protect unique and special waters having excellent water quality and being of exceptional state or national ecological or recreational significance.
Classes:	see above
Advantages:	• Linked to explicit management rules or objectives. • Surface water protection for drinking water and other health factors may confer protection for ecological values as well.
Disadvantages:	• Primarily focus is water quality protection and management. • Some aspects are clearly watershed scale while other aspects are directed at streams or other surface waters. • Biologically weak; does not incorporate biological integrity / ecological health, • Classification system overlays primary classes with supplemental designations which create confusion.

Title 14:	**Wild, Threatened, Endangered and Lost Streams of the Lower Fraser Valley - Summary Report.** Precision Identification Biological Consultants. 1997. *Wild, Threatened, Endangered, and Lost Streams of the Lower Fraser Valley: Summary Report.* June 1997. Prepared for the Fraser River Action Plan, Habitat and Enhancement Branch, Fisheries and Oceans Canada, Vancouver, B.C.
Organization:	Fraser River Action Plan, Department of Fisheries and Oceans
Purpose / Summary:	The objectives of the project were to i) identify lost streams; and, ii) evaluate the condition of streams that remain in the entire Lower Fraser Valley (LFV). This project is an expansion of an information poster entitled Lost Streams of the Lower Fraser Valley that was developed for the western portion of the valley in 1995. Streams were identified using historical maps, NTS maps, and existing databases. Classification was accomplished through reviews of reports, interviews, and orthophoto examination. Workshops were held with

	knowledgeable local residents and MELP and DFO staff to confirm and / or modify classifications. Results are presented in a database that specifies impact by criterion. A status designation of wild, threatened, endangered and lost is also described based the number of designated impacts (see classes section). A total of 779 streams were classified in the entire Lower Fraser Valley. 15% were designated lost, 48% endangered, 23% threatened, and 14% wild. Only 8 streams were designated as wild in the GVRD area.
Criteria / Indicators:	Criteria using in classification include: • **Riparian Removal** - Significant loss of riparian vegetation along more than 50% of the fish frequented length of the stream • **Channelization / Dyking** - channelization, armourization, or dyking of over 50% of the fish frequented length of the stream • **EIA** - Effective impermeable area covering over 15% of the stream's watershed • **Water Diversion** - Greater than 50% diversion of stream flow (i.e. diversion out of the system) • **Water Quality** - Documentation of severe water quality problems. • **Logging** - Permanent deforestation of over 50% of the stream basin • **Urbanization** - Settlement has significantly affected the stream basin. • **Other** - Other impacts include linear development and cumulative effects urban / agricultural impacts.
Classes:	**Lost** - A stream was considered lost if over ¾ of its length was covered (e.g. in an underground sewer). **Threatened** - A stream was considered threatened if it was affected by one of the impact criteria **Endangered** - If two or more of the above criteria applied, it was considered endangered. **Wild** - Streams with no significant impacts were considered wild (although often not in a pristine state).
Advantages:	• Successful as a educational / public awareness tool. • Covers key issues of concern in urban watersheds. • Useful to identify regional differences in stream or watershed quality. • Database structure provides status as well as information on impacts. • Highlights overall extent of stream protection issue.
Disadvantages:	• Criteria lack specificity; impacts were either present or not (does not

	capture gradation). • Classes too broad; 78% of streams in the settlement areas of the LFV were designated as endangered (need more specificity to be useful for management) • Lacks biological criteria (biotic integrity, fish use, fish abundance). • Some criteria appear to be subjectively determined.

Title 15:	**Contrasting Urban and Rural Watersheds: A GIS-based Analysis Linking Imperviousness, Riparian Forest Cover, Land use, and Pollution Indicators.** Zandbergen, P and H.S. Schreier, and A. Radecki-Pawlik. 1998 (in press). Contrasting urban and rural watersheds: A GIS-based analysis linking imperviousness, riparian forest cover, land use and pollution indicators. Draft submitted for publication.
Organization:	Institute for Resources and Environment, University of British Columbia and Hydraulics and Civil Engineering Dept., Agricultural University of Krakow.
Purpose / Summary:	As stated in the abstract: “the objectives of this study were to compare watershed imperviousness and riparian forest cover to other land use and pollution indicators and to develop a classification framework to assess the risk to watershed health from various types of non-point sources of pollution.” GIS analysis was undertaken for the Salmon and Brunette River basins in the GVRD relating watershed imperviousness, riparian forest cover, land use, and pollution for the entire watersheds, as well as within the riparian corridors. An important aspect of the paper is it incorporation of variables such as swimming pool density, gas stations and other industrial discharges that have not been examined in other studies. In addition, water and sediment quality were examined. The results indicated that an integration of imperviousness and riparian forest cover was useful as an indicator of non-point sources of pollution. The paper also presents a classification system for developed watersheds using imperviousness and riparian forest cover. Additional indicators such as water quality were tied to imperviousness and riparian integrity and were useful, but extraneous for classification.
Criteria / Indicators:	Classification criteria included % watershed imperviousness (TIA) and % riparian forest cover within a 30 m buffer. Other parameters were examined but these two were integrated for the classification system.
Classes:	Five classes: **Excellent, good, fair, poor,** and **very poor.**
Advantages:	• Regional validation of the relationship of land use to watershed health. • Strengthening of the relationship of land use to water and sediment quality variables. • Greater differentiation of gradation of watershed health (five classes rather than the typical three). In particular, subdivision of degraded watersheds into poor and very poor provides useful specificity.
Disadvantages:	• Parameters not linked to biological monitoring, fish populations, biotic integrity, etc. (this is addressed in thesis work by P. Zandbergen • Does not explain resiliency of some watersheds compared to others. • Thresholds between classes defined by linear integration of imperviousness and riparian forest cover. • Thresholds not explicitly discussed (taken from other studies?). • Directed at water quality; does not address hydrology.