Impervious Surfaces in French Creek

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1.0 Impervious Surfaces

Impervious surfaces (IS) are those that resist the absorption of water into the ground. While impervious surfaces exist in nature in the form of exposed competent bedrock, their exposure on the surface is generally restricted. More commonly, imperviousness is associated with human growth and expansion. The footprint of human growth includes the mass of pavement in transportation corridors and parking lots, the buildings, from urban sprawls to garden sheds, and the many other landuses; commercial, industrial, residential and recreational that compact the soil and impede its ability to absorb water.

Recently, amount of imperviousness has been linked to the overall condition of urban watersheds (Zanderbergen and Schrier, 2000, Finkenbine et al., 2000, Zanderbergen et al., 1999, Arnold and Gibbons, 1996, Schueler, 1994 and others). Work done particularly in the past decade suggests that impervious surface coverage may be used as a key indicator to watershed health (Finkenbine et al., 2000, Arnold and Gibbons, 1996). Schueler (1994) identified several effects of changes to imperviousness. Those include subsequent changes to; runoff, stream morphology, water quality, stream warming, stream biodiversity and fish health. Schueler (1994) also proposed a relationship between impervious cover and overall stream quality (Figure 1). In this proposal, streams were considered impacted when impervious cover exceeded 10%, and degraded when impervious cover exceeded 25%. In degraded streams the pre-development status of the stream could not be maintained even with the implementation of various best management practices (BMP). Despite this, BMPs may have significant positive impacts in reducing imperviousness by as much as 50% in some cases (Schueler, 1994).

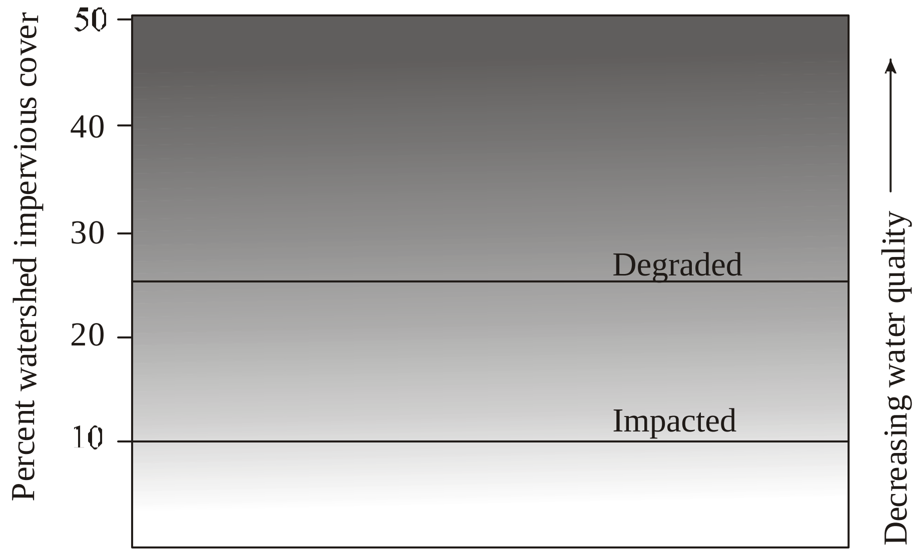

Figure 1. Relationship between impervious cover and overall stream quality (modified from Prisloe et al., 2000).

Runoff

Hydrologists and geologists have generally understood changes in runoff due to increased imperviousness for decades (Reid, 1981, Dunne and Leopold, 1978, Leopold, 1968). Generally speaking the effects are to lower groundwater levels and to increase the timing, frequency and magnitude of flood events. Roads, ditch lines and sewer drains all serve to effectively increase the drainage network, and eventually to divert water away from old stream beds to a new man made conduits. Reduced infiltration means an almost instantaneous response routing precipitation to streams as runoff. Schueler (1994) compared by way of example, an undeveloped meadow and a parking lot of the same size (0.4 ha): the parking lot produced a runoff volume 16 times greater than the meadow.

Stream morphology

It follows that with increased runoff the stream channels will undergo changes in shape and design. Increased cross sectional areas are necessary to accommodate higher flows. The stream widens, deepens or both. Increased sediment loads triggered by greater transport capability and by bank erosion further compound the changing dynamics of a stream. This cycle of changes lasts until the stream finds a balance at the new hydrological regime.

Impervious surfaces also become a proxy indicator in the context of stream morphology. Where people live near a stream, they develop, landscape, protect and construct on their properties in such a manner that may restrict, redirect or otherwise change the shape of the stream. This may have more effects than the runoff, as the change in stream morphology is immediate, focussed and generally not suited to, or designed for the natural characteristics of the stream.

Water quality

In the natural environment, rain and snow melt run over land into surface waters or seep through the soil to become groundwater. As the water seeps down it is absorbed and purified by soils, bacteria and plants. Surface water runs over the land and paved surfaces and accumulates pollutants including; suspended solids, nutrients, heavy metals, pathogenic bacteria, and organic contaminants. During storms, these pollutants are rapidly delivered to the adjacent streams and lakes. General sources of pollutants in urban runoff include motor vehicles (fuel and oil leakage; antifreeze; particles from tire, clutch and brake wear; exhaust emissions; etc.), atmospheric fallout, litter, spills (sand, dust, cement, agricultural and petroleum products), deliberate dumping, erosion, and excessive use of fertilizers and pesticides.

It has been shown that as watershed imperviousness and urbanization increase, the overall water quality of a given stream will degrade (Schueler, 1994). Fortunately, studies have also shown that overall chemical water quality of urban streams is not normally significantly impacted at relatively low impervious levels (May et al., 1997).

Stream warming

Stream temperature is affected in two ways: water runoff from a parking lot is typically several degrees warmer than runoff from a forest. The increased temperature of water entering a stream is further compounded by the increased volume (as discussed previously) of higher temperature water entering the stream (Galli, 1991).

Urbanization and land clearing activities result in riparian corridor encroachment, which exacerbates the effects of warmer water entering streams from paved surfaces. The streamside shading provided by riparian vegetation is critical in maintaining lower temperatures necessary to support the fisheries resource in coastal streams (Galli, 1991).

Biodiversity and Fish Health

Salmonid fish species (trout and salmon) are negatively impacted by increased imperviousness. Sensitive species, defined as those with a strong dependence on the substrate for feeding or spawning decline rapidly as IS increases. For example, research by Luchetti and Feurstenburg (1993) indicate that sensitive coho salmon were seldom found in watersheds beyond 10 to 15% imperviousness. Booth (1993) found that most urban stream reaches had poor fish habitat when IS exceeded 8 to 12%.

Coastal streams such as French Creek have evolved over thousands of years to form a rich, diverse, interactive biological community that can withstand or recover rapidly from natural disturbance. However, the scale, frequency, and complexity of human disturbance is often well in excess of natural variability. Our actions tend to put stream health at risk by affecting one or more of five factors: physical habitat, seasonal water flow, food base of the system, biotic interactions and chemical contamination (Karr, 1991).

Coho salmon rely heavily on smaller lowland streams and associated off channel wetlands during their rearing phase. They are the only species of anadromous salmon that overwinter in our coastal streams. They rear in pools with high habitat complexity, abundant cover, and large woody debris (LWD) as a basic structural component. They rely on an abundant diverse food source including benthic invertebrates such as mayflies, caddisflies, and stoneflies. Benthic invertebrates similarly rely on diverse habitat, leaf litter from riparian vegetation, water quality, algal growth, and suitable substrates. Algal communities rely on suitable nutrient levels, water quality, light, habitat, and substrate. Impacts on any of these will affect the entire biological integrity of the stream. Furthermore, the effects are cumulative, both temporally and spatially. Klein (1979) was one of the first to note that benthic invertebrates diversity declines sharply in urban streams. He found that diversity consistently became poor when watershed imperviousness exceeded 10 to 15%. The same essential threshold has been consistently found by all other research studies examining benthic invertebrate density in urban streams. In these studies, sensitive aquatic insect species were replaced by those more tolerant of pollutants and hydrologic stress. Stoneflies, mayflies, and caddisflies virtually disappear and are replaced by chironomids, tubificid worms, amphipods and snails. Moreover, species that employ specialized feeding strategies such as shredding leaf litter, grazing rock surfaces, filtering organic matter and preying on other species were lost.

According to Bisson et al (1988), LWD may be the most important structural component of salmonid habitat. LWD is critical in forested lowland streams in dissipating flow energy, protecting stream banks, storing sediment, stabilizing streambeds while providing instream cover for juvenile salmonids and habitat diversity, which in turn supports the underlying productivity of the stream. As development, urbanization and imperviousness increase in a watershed, the amount of LWD typically decreases.

Sedimentation of the streambed can have ramifications throughout the biological stream community. The deposition of fine sediment can dramatically affect the abundance and diversity of the benthic invertebrate. Sedimentation of spawning beds can clog gravels, which decreases salmonid egg survival. Sediment can also affect algal growth through physical abrasion and smothering as well as increasing turbidity which lowers light availability. Urban sediments transported often contain increased quantities of contaminants such as heavy metals that may further affect the benthic invertebrate community.

Other studies

Impervious surface (IS) studies are being implemented across North America. Much of the work in the United States is co-ordinated by the University of Connecticut via the NEMO (nonpoint education for municipal officials) project and involves several municipalities on across the country (Prisloe et al., 2000, Arnold and Gibbons, 1996).

Coastal British Columbia also has several examples. Impervious surface data has been generated for various watersheds in the Greater Vancouver Regional District (Zandbergen and Schreier, 2000, Greater Vancouver Regional District, 1999), selected watersheds in the Lower Mainland by the University of British Columbia (Zandbergen and Schreier, 2000) and the Millard-Piercy watershed on Vancouver Island (Zandbergen and Schreier, 2000). Several municipalities are currently interested in the application of IS as indicators of watershed health and the impacts of development.

How the information is gathered

Impervious surface data may be gathered directly through ground surveys and stereo-photogrammetry where roads, roofs, sidewalks and all other impervious surfaces are actually outlined. Alternatively IS data may be gathered indirectly by determining land use through satellite interpretation, air photograph interpretation and zoning analysis. Land use classes are then given average imperviousness values. This allows for larger areas to be dealt with more efficiently, however, requires some calibration for several of the land use classes. A more thorough discussion on direct and indirect measures of imperviousness is in Zandbergen and Schreier (2000).

Total vs. Effective

Total impervious surface is the common use of IS and it measures all areas that impede water infiltration. However, it is important to recognize that this method likely overestimates the amount of imperviousness. Effective imperviousness is the term used to more accurately describe imperviousness and incorporates the concept that some landuses are not a total barrier to water. For example, roofs may drip water onto the lawn rather than into a stormdrain system, therefore reducing the effects of imperviousness. This particular measurement, however, is not currently practical as it is to difficult to determine at a watershed scale. Similarly, if municipalities or individuals use BMPs, these practices are not resolvable at the data gathering level (at least for indirect methods) and also reduce imperviousness. This is expected to be more of an issue in the future than now, as the best management practices are still relatively new. Alley and Veenhuis (1983) worked on a relationship between total impervious area, and effective impervious area that calibrates IS to impervious areas that have direct hydrologic connection to the drainage network. That been said, however, the measures of impact have been calibrated against total imperviousness due to the relative ease with which that data is gathered.

2.0 Methods

Landuse/landcover maps

Landuse and landcover maps refer to a spatial product that shows the existing land condition in terms of an interpreted activity (commercial use, residential use and forested for example) and in ground cover (shrub, bedrock, pavement, mature timber) respectively. These interpretations are distinct from 'designated landuse' as a planning term. Landuse/landcover mapping was completed for four map sheets (92F028, 92F029, 92F038, 92F039), three by the winter of 1999, and the last in January 2001. Accuracy was confirmed by overlaying landuse polygons onto 1m resolution digital orthophotographs. Output maps are considered accurate at 1:20,000 scale.

Landuse mapping followed the classificatio n scheme determined by Geographic Data BC and the Aboriginal Affairs Group outlining 75 possible landuse classes of which 30 were identified within the French Creek boundaries. Table 1 describes the landuse classes identified and their requirements.

Landuse classes were visually interpreted using color air photographs at 1:15,000 (1998) and 1:40,000 black and white air photographs (1987), Landsat 5 TM (1998) and Landsat 7 TM (1999) imagery with 30m resolution. Field checks and ancillary data supplemented image interpretation.

Landcover classes were interpreted according to the BC Land Classification Scheme and were digitally interpreted using the multispectral (Landsat) satellite imagery combined with high-resolution (5m) IRS satellite data. Interpretations were supplemented by field checks and ancillary data.

GIS component

The landuse and landcover maps were transferred to ArcView. The maps were clipped to determine data that remained within the French Creek boundary. The remaining landuse polygons were given IS values based on typical values for similar studies in coastal British Columbia (Zandbergen and Schreier, 2000). Table 2 shows the IS values for each landuse class. Several landuse polygons were determined directly by digitizing IS onto 1m orthophotographs (1999) for calibration of the values. This was particularly important for rural residential values and single family dwellings.

Zoning bylaws and planned property divisions supplied by the Regional District of Nanaimo (Figure 2) for the areas to which they applied (Electoral Area 'G') were incorporated into the GIS to determine future landuse-by-zoning. An Official

Community Plan and proposed landuse designations for the remaining area (Electoral Area 'F') was also supplied by the Regional District of Nanaimo (RDN) and incorporated into the GIS. We assumed the RDN guidelines would be followed in area 'F' and determined the potential landuse-by-zoning map based on a conservative estimate of what was possible within those guidelines. The data for both areas within the watershed were merged to produce a final landuse-by-zoning map.

The map was assigned IS values based on the landuse lookup table. Complex sites such as Coombs market, were assigned IS values in a weighted fashion depending on the percent of a particular use designated in the Official Community Plan.

The landuse by zoning map was merged with the current landuse map to produce a potential IS-buildout map.

Sub-basins were delineated and ordered within the watershed and merged with the IS-by-landuse and IS-buildout maps. This produced IS-by-basin and IS-buildout-by-basin maps and related data.

3.0 Results

A detailed landuse map is shown in Figure 3. Approximately three-quarters of the French Creek watershed is forested land and about one quarter of the watershed has been logged in the last 20 years (Figure 4). Approximately 15 % of the watershed is used for agriculture and rural residential areas and only a small percentage of the watershed is actually urban residential (2.5%). Other uses include commercial, industrial and roads, and comprise another 5% of the watershed.

Urban and commercial landuse is distributed near the watershed mouth and along highway 4 in concentrations around Hilliers and Coombs. Farms and rural residences tend to be distributed fairly evenly through the middle of the watershed, while the upper third of the watershed, to the headwaters remains forested land.

Impervious surfaces range by landuse from 1% for forests up to 90% for roads and large areas of pavement such as the airport (Table 2). The percent impervious surface for the entire French Creek watershed is 4.6%. Impervious surfaces are concentrated in the developed and developing areas in the urban core leading into Parksville, and around the highway, particularly at Hilliers and Coombs (Figure 5).

French Creek is hydrologically divided into several long narrow sub-basins resulting in a forth order stream (for a discussion about stream ordering see the Coastal Watershed Assessment Procedure Guidebook (BC Ministry of Forests and Ministry of Environment, Lands and Parks, 1999)). When impervious surfaces are analyzed by watershed sub-basins, they all fall well below the 10% threshold for impacts (Figure 6). Table 3 shows impervious surface values for all the basins in the watershed.

Impervious surfaces were projected by both landuse and watershed sub-basin for the build out analysis and are shown in Figures 7 and 8. Imperviousness remains concentrated around Parksville, Hilliers and Coombs, but also in the agricultural and rural residential areas in the middle portion of the watershed. The area between Parksville and the highway changed very little in the projection due to zoning by-laws.

4.0 Discussion

The French Creek watershed is characteristically similar to many of the developing watersheds on eastern Vancouver Island. Sub-basins of French Creek are long and linear and begin in the forested headwaters. In terms of impervious surfaces, development has occurred lower in the system, primarily near the mouth of the river where it meets the sea, and along the old highway at Coombs and Hilliers. This means that the system currently has a significant buffering capacity built into it reducing potential effects of increased run-off, changes in channel morphology, water quality, stream warming, biodiversity and fish habitat due to impervious surfaces.

Overall French Creek was determined to be 4.6% impervious. This result was similar to previous results on Vancouver Island in the smaller Millard/Piercy watersheds where the results in the Millard subwatershed were 4.5% and in Piercy were 9.3% (Zandbergen and Schreier, 2000). Clearly a reflection of intensity of landuse, the results were substantially less than for urbanized areas such as Vancouver. Results from a study in the Brunette watershed of Vancouver indicated average impervious surfaces of about 50% (GVRD, 1999).

Residents of the French Creek watershed may take comfort in the fact that the overall current levels of imperviousness fall well below the 10% threshold of a degraded system. However, comfort need not give way to complacency. There are several areas in French Creek that are or may be substantially affected by impervious surfaces. The hydrologic configuration of French Creek tends to smooth out the effects of IS in the GIS analysis. The lower third of the watershed for example is identified as a forth order stream; it contains most of the development from the areas around Coombs/Hilliers to the lower urban zone. Impervious surfaces range in areas to 90%, however, owing to the nature of the watersheds there are no sub-basins to highlight as being affected by this development. For this reason, IS are best displayed in French Creek by landuse (Figure 5). Small streams draining directly into French Creek and passing through zones of imperviousness will have effects, and some will be substantially altered. In addition, despite the significant buffering capacity of French Creek itself, some effects on the mainstem are likely to be noticed at the current levels. This is due to the fact the IS act as both a direct indicator of changes, and a proxy indicator of changes due to development. For example, while local changes in runoff are expected in the lower reaches, channel morphology changes are a certainty. These changes are not, however, simply attributable to increased runoff, but instead to the influence of human habitation. Individual landowners alter the characteristics of the stream by shoring up their property, installing gabian rip-rap and cement walls to protect against natural erosion, change the bank level to afford access to the stream or protect against flood and other such measures. These constitute massive changes in the morphology of the stream, and consequently change its behaviour as well. In this case, the proxy changes are likely to overshadow the direct effects. The overall IS numbers are low enough for this stream that the expected changes in runoff would be hard to differentiate from changes in runoff due to changing climate patterns, or changes due to the hydrologic consequences of forest harvesting and land clearing higher up in the watershed. This is also likely true for other effects. The amount of large woody debris in areas with high percentages of impervious surfaces may be due to increased flows, however, it is more likely due to direct and indirect effects of development.

In either case, it is important to note that the land covered by IS will result in impacts to the system, and that IS remains an excellent indicator of the potential location and severity of those impacts.

The build out model estimates where growth may occur in the watershed and how that in turn may affect impervious surfaces (Figure 7). It is based on zoning by-laws (for area G) and the official community plan (for area F). Conservative estimates of buildout were used to try and achieve a realistic picture of the sort of development that may occur in the next decade. This is a coarse but reasonable predictor, and errors, particularly in the distribution of impervious surfaces will occur.

Multifamily and other residential development in lower French Creek will cause significant increases in impervious surfaces there. According to the Regional District of Nanaimo, much of the forested land between Parksville and the Coombs/Hilliers will not be subdivided in the near future. If this property remains intact, it will provide something of a buffer to the effects of impervious surfaces on the urban development downstream.

Industrial, commercial and residential development is expected to grow around the Hilliers and Coombs business centres, with consequent increases in impervious surfaces. Despite potential increases, French Creek is expected to remain resilient in the foreseeable future due to relatively low development to date (compared with major urban areas) and a strong headwater component that will remain relatively pervious for the foreseeable future. This headwater component is notable in Figures 6 and 8 that show the IS level for the entire watershed (4th order basin) compared to the individual inputs. The headwaters will help dampen extremes in runoff, during storm events and summer low flow, diluting contaminated water and supplying wood and organic material to the stream.

Effects of increased imperviousness will be evident locally as well as downstream of the development. Both direct and indirect (proxy) effects are expected on the French Creek mainstem with the overall imperviousness potentially increasing beyond 10% for the watershed. Zoning laws in area G currently restrict development between the airport and the highway. This zone of land will probably act as a buffer to the effects of development. Development in area F is based on the OCP bylaw and guidelines that are currently assumed agreed to by the community at large. If that assumption is wrong, or if members of the community should disagree, substantial land changes not predicted here are possible. A proposed zoning bylaw is currently being drafted for area F. Through the latter portion of the 20th century, the relative size of the transport component of imperviousness has steadily increased due to the ascendancy of the automobile in our culture. To be effective, restrictions on development must be accompanied by limitations on the transport component of imperviousness.

Another forgiving aspect of the French Creek watershed is the attention that has been given to leaving riparian corridors intact. Despite minor encroachments to the stream, and past logging practices, 92% of the riparian zone is relatively intact to 30m along the fish bearing portions of French Creek and its tributaries. This riparian strip acts as an additional buffer between human activity and the stream, reducing deleterious effects of IS on temperature change, biodiversity and fish health.

One of the key questions associated with imperviousness is how to plan future development. In many watersheds a choice is made to concentrate development in one sub-basin and let others provide the buffering effect of relatively clean water. The morphology, character and history of French Creek, however, make this kind of proposal difficult. The headwaters are likely to remain relatively untouched in the future (in terms of IS) and due to the long linear nature of the sub-basins, this will in turn provide regulating flows. Site-specific issues that may be observed in the French Creek watershed could be dealt with using various best management practices such as stormwater ponds, wetlands, filters, and infiltration basins, to minimize impacts where development is occurring. Several resources discussing ways to minimize impacts and amounts of impervious surfaces in urban settings are available (Marsh, 1998**,** NEMO, no date). BMP's are more effective as a preventative measure rather than a mitigative tool. Once a stream has "degraded", fully applied BMP's and retrofits will not be enough to return or maintain the stream's biodiversity and channel stability.

As development within the watershed continues it is critical that the existing relatively intact riparian corridor be maintained. Loss of riparian vegetation will serve to exacerbate the effects of impervious surfaces. Localized high imperviousness and loss of riparian cover can not only have significant immediate near field impacts but can also be seen for a considerable distance downstream. Each new impacted zone can exacerbate other existing downstream impacts, resulting in an ecological domino effect.

While recent research has linked impervious cover to overall stream quality, it should not be used in isolation. Simply looking at imperviousness cannot and should not replace the collection of good consistent data examining stream health. However, it is a useful tool for both resource managers and community planners in protecting urban streams, which are under development pressures.

5.0 References

Alley, W.M., and J.E. Veenhuis, 1983. Effective impervious area in urban runoff modeling. Journal of Hydraulic Engineering, 109 (2), pp. 313-319.

Arnold, C.L. and C.J. Gibbons, 1996. Impervious surface coverage: the emergence of a key environmental indicator. Journal of the American Planning Association 62(2), pp. 243-258.

BC Ministry of Forests and Ministry of Environment, Lands and Parks, 1999. Coastal Watershed Assessment Procedure Guidebook (CWAP), Second Edition. Ministry of Forests and Ministry of Environment, Lands and Parks, Victoria, British Columbia, 41 pp.

Bisson, P.A., K. Sullivan and J.L. Nielsen, 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout in streams. Transactions of the American Fisheries Society 117: 262-273.

Booth, D. and L. Reinelt, 1993. Consequences of Urbanization on Aquatic Systems. – measured effects, degradation thresholds, and corrective strategies. Pp. 545-550 in Proceedings Watershed '93 A National conference on Watershed Management. March 21-24, 1993. Alexandria, Virginia.

Dunne, T. and L.B. Leopold, 1978. Water in environmental planning. W.H. Freeman and Co., San Francisco, 818pp.

Finkenbine, J.K., J.W. Atwater and D.S. Mavinic, 2000. Stream health after urbanization. Journal of the American Water Resources Association, 36 (5), pp. 1149-1160.

Galli, J., 1991. Thermal impacts associated with urbanization and stormwater management best practices. Metropolitan Washington Council of Governments. Maryland Department of Environment, Washington DC, 188 pp.

Greater Vancouver Regional District, 1999. Assessment of Current and Future GVS&DD Area Watershed and Catchment Conditions. Greater Vancouver Sewerage and Drainage District, Liquid Waste Management Plan, Stormwater Management Technical Advisory Task Group, Vancouver BC.

Karr, J.R., 1991. Biological Integrity: A long-Neglected Aspect of Water Resources Management. Ecological Applications 1(1): 66-84.

Leopold, L.B., 1968. Hydrology for urban land planning: a guide book on the hydrologic effects of urban land use. U.S. Geological Survey, Circular 554, 18pp.

Luchetti, G. and R. Fuersteburg, 1993. Relative fish use in urban and non-urban streams. Proceedings Conference on Wild Salmon. Vancouver, B.C.

May, C.W., R.R. Horner, J.R. Karr, B.W. Mar and E.B. Welch, 1997. Effects of urbanization on small streams in the Puget Sound Ecoregion. Watershed Protection Techniques 2 (4): 483-494.

Marsh, W., 1997. Landscape Planning, Environmental Applications, Third Edition. John Wiley and Sons, Inc., New York.

NEMO, no date. Non point Education for Municipal Officials. On the Web at: http://www.canr.uconn.edu/ces/nemo/ University of Connecticut, college of Agriculture and Natural Resources.

Prisloe, S.M., L. Giannotti and W.Sleavin 2000. Determining Impervious Surfaces for Watershed Modeling Applications. Nonpoint Education for Municipal Officials, University of Connecticut, College of Agriculture and Natural Resources, 17pp.

Reid, L.M. 1981. Sediment production from gravel-surfaced forest roads, Clearwater basin, Washington. Final report to Washington State Department of Natural Resources, University of Washington College of Fisheries, Fisheries Research Institute, Seattle Washington, 247pp.

Schueler, T., 1994. The Importance of Imperviousness. Watershed Protection Techniques 1(3): 100-111.

Zandbergen, P. and H. Schreier, 2000. Comparative analysis of methodologies for measuring watershed imperviousness. Watershed Management 2000 Conference, Water Environment Federation, Institute for Resources and Environment. University of British Columbia, Vancouver BC.

Zandbergen, P., J. Houston and H. Schreier, 1999. Summary of report on methods of measuring imperviousness in the Georgia Basin 1999.

List of Tables

Table 1. Landuse classes and definitions.

Code	Landuse	Definition
A	Agriculture	Land and site based agricultural activities undifferentiated as to crops
Ad	Sod production	The production of turf (improved grass)
Af	Forage/Grazing	Agricultural land that is used for hay and other forage crops or grazing (ie. Pasture)
Am	Market Gardening	Agricultural land used for market gardening (ie. Vegetables, flowers and tree nurseries) activities, excluding forestry tree nurseries
Ao	Fruit, Berry, Hop and Nut production	Agricultural land used for cultivating fruit and nut trees (orchards), grapes (vineyards), berries (rasberries, strawberries, blueberries) and Hops
As	Site Based Agricultural Activities	Agricultural activities that use land as a site and not as a producing medium (ie. Housing or feeding livestock or poultry, greenhouses, crop storage, mushroom growing, bee keeping)
At	Annual Tillage Crops	Agricultural land that is tilled annually
Ax	Residiential/Agricultural Mixtures	Areas where agriculture activities are intermixed with residential and other buildings with a building density of between 0.5 to 2 per ha
Fc	Recently Logged	Timber harvesting within the past 20 years or older if tree cover is less than 40% and under 6 metres in height.
Fe	Raising Seedlings	
Fo	Old Forest	Forest greater than or equal to 140 years old and greater than 6 metres in height.
Fs	Selectively Logged	Areas where the practice of selective logging can be clearly identified
Fu	Tall or Low shrubs	naturally occurring shrub cover with at least 50% coverage. Not wetlands, shrub covered logged areas (or other man made disturbance)
Fy	Young Forest	Undifferentiated forest less than 140 years old and greater than 6 metres in height
G	Grasslands	Unimproved pasture and grasslands based on cover rather than use. Cover includes drought tolerant grasses, sedges, and scattered shrubs to 6 metres in height and less than 25% forest cover. Sparse forest stands are included with their understory of drought tolerant shrubs and herbs.
Mg	Extractive Industrial	Land used for the surface extraction of rock, sand, gravel or peat
Rc	Campgrounds and/or seasonal cottages	
Rg	Golfing	
S	Human settlement or Urban	All compact settlements including built up areas of cities, towns and villages as well as isolated unites away from settlements such as manufacturing and military plants. Generally residential use. Includes some open space.
Sc	Urban Commercial	Retail, office and personal service including hotels and motels. May include a mix of residential and commercial uses.
Sd	Urban Residential Detached	Land used for residential activities that includes high-rise apartments greater than 5 stories

Table 1 continued. Landuse classes and definitions.

Sm	Urban Manufacturing or Industrial	Includes all processing and manufacturing activities, warehousing, tank farms and log storage. May include minor commercial activities
Sr	Rural residential	Single detached dwellings on large lots (>0.5ha)
St	Trailer Parks	
Ta	Airports	
Tr	Roads	
Ue	Electrical generation	Power transmission line corridors
Uh	Waste handling facilities	landfills, dumps, junkyards, wreckers, recycling activities
Wt	Wetlands	

Table 2. IS values by landuse type.

Code	Landuse	Percent Impervious Surface
A	Agriculture	3
Ad	Sod production	3
Af	Forage/Grazing	3
Am	Market Gardening	3
Ao	Fruit, Berry, Hop and Nut production	3
As	Site Based Agricultural Activities	3
At	Annual Tillage Crops	3
Ax	Residiential/Agricultural Mixtures	6
Fc	Recently Logged	3
Fe	Raising Seedlings	3
Fo	Old Forest	1
Fs	Selectively Logged	2
Fu	Tall or Low shrubs	3
Fy	Young Forest	1
G	Grasslands	3
Mg	Extractive Industrial	5
Rc	Campgrounds and/or seasonal cottages	3
Rg	Golfing	3
S	Human settlement or Urban	80
Sc	Urban Commercial	80
Sd	Urban Residential Detached	25
Sm	Urban Manufacturing or Industrial	80
Sr	Rural residential	8
St	Trailer Parks	23
Ta	Airports	90
Tr	Roads	90
Ue	Electrical generation	3
Uh	Waste handling facilities	80
Wt	Wetlands	0

Table 3. Summary of IS values by stream order.

Stream order	% Impervious surface	
	Current	Buildout
1*	3.7	9.2
2a	1.5	5.5
2b	2.3	5.3
2c	1.6	2.3
2d	1.8	4.5
2e	1.7	4.5
3a	2.6	6.5
3b	2.1	6.1
4	4.6	12.3
Below junction of 4th order	9.4	24.2

*Combined first order streams (29 of them)

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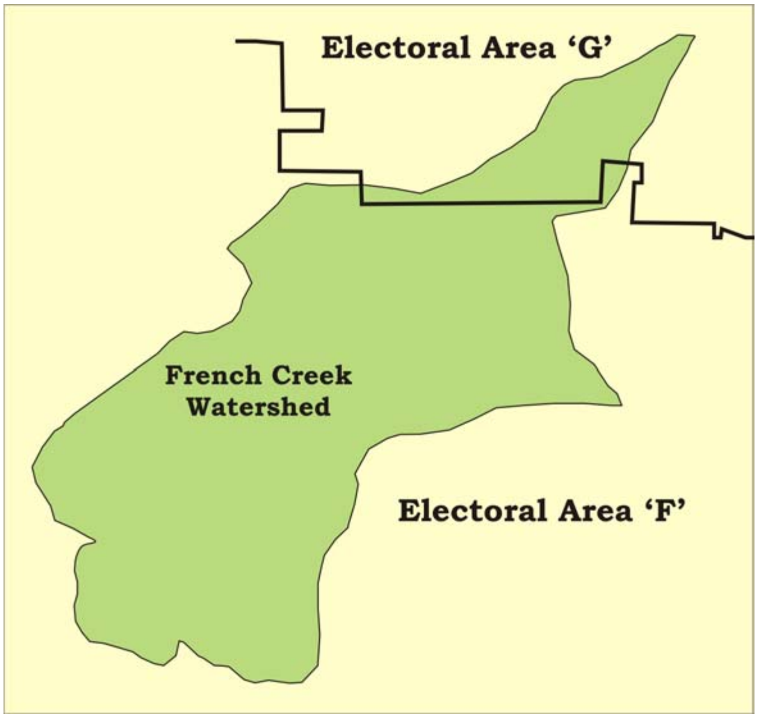
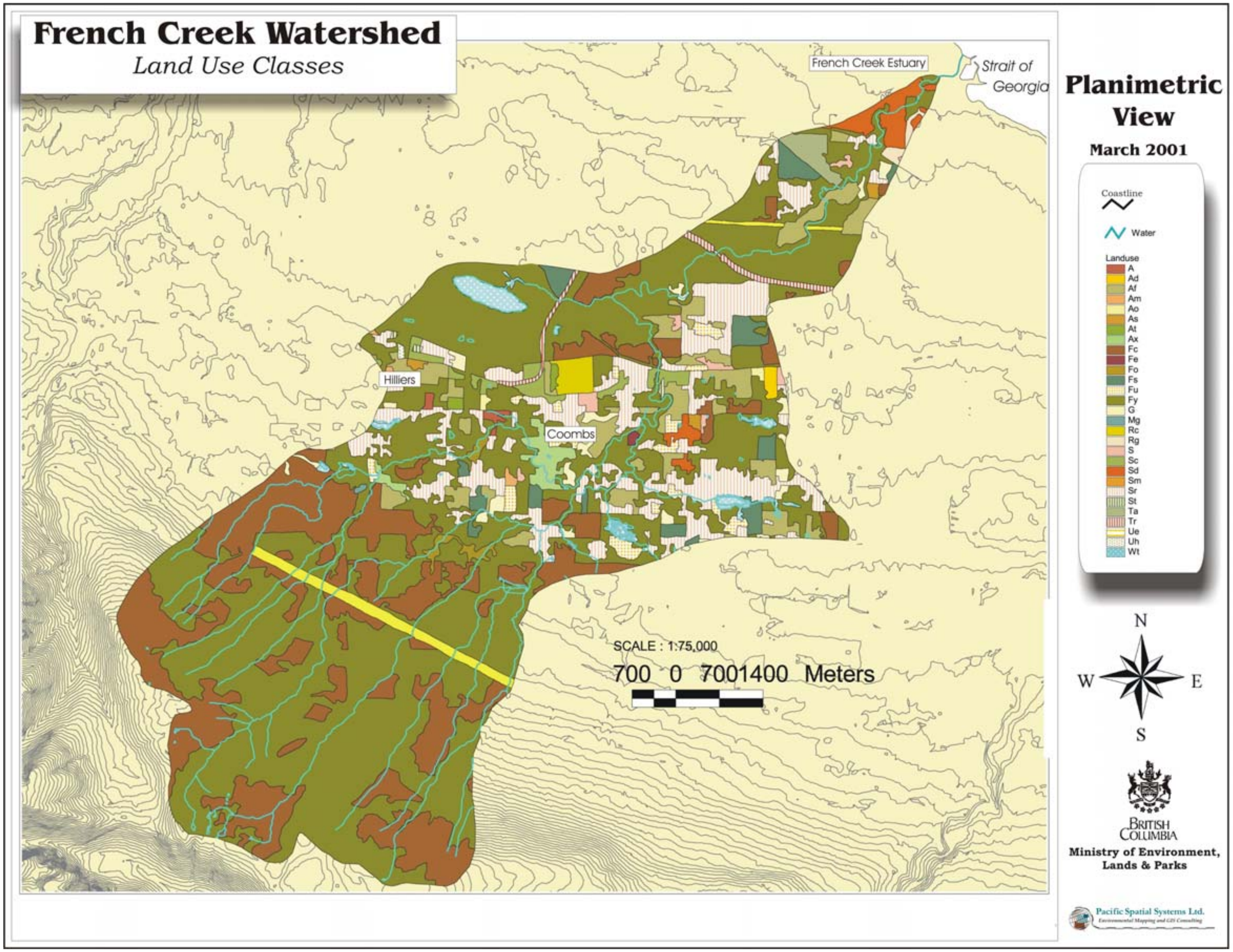
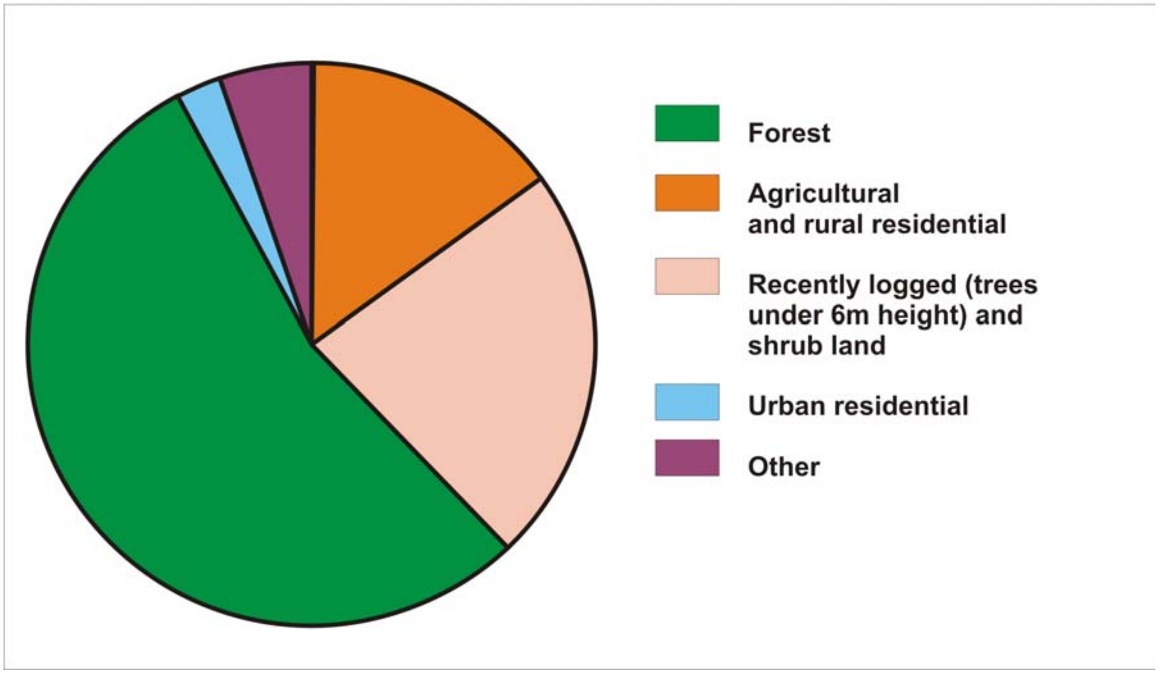
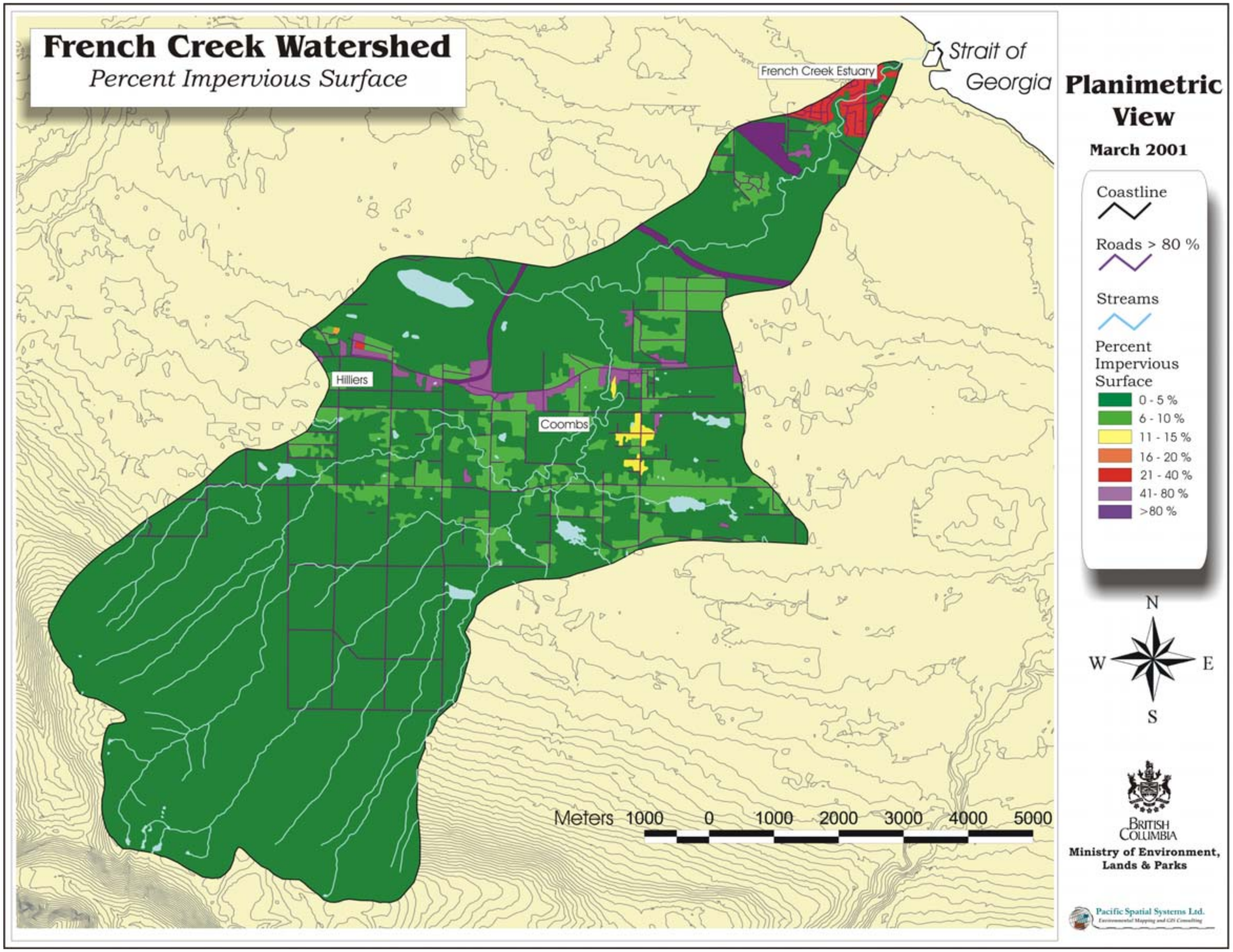

Electoral Area 'G'
French Creek
Watershed
Electoral Area 'F'

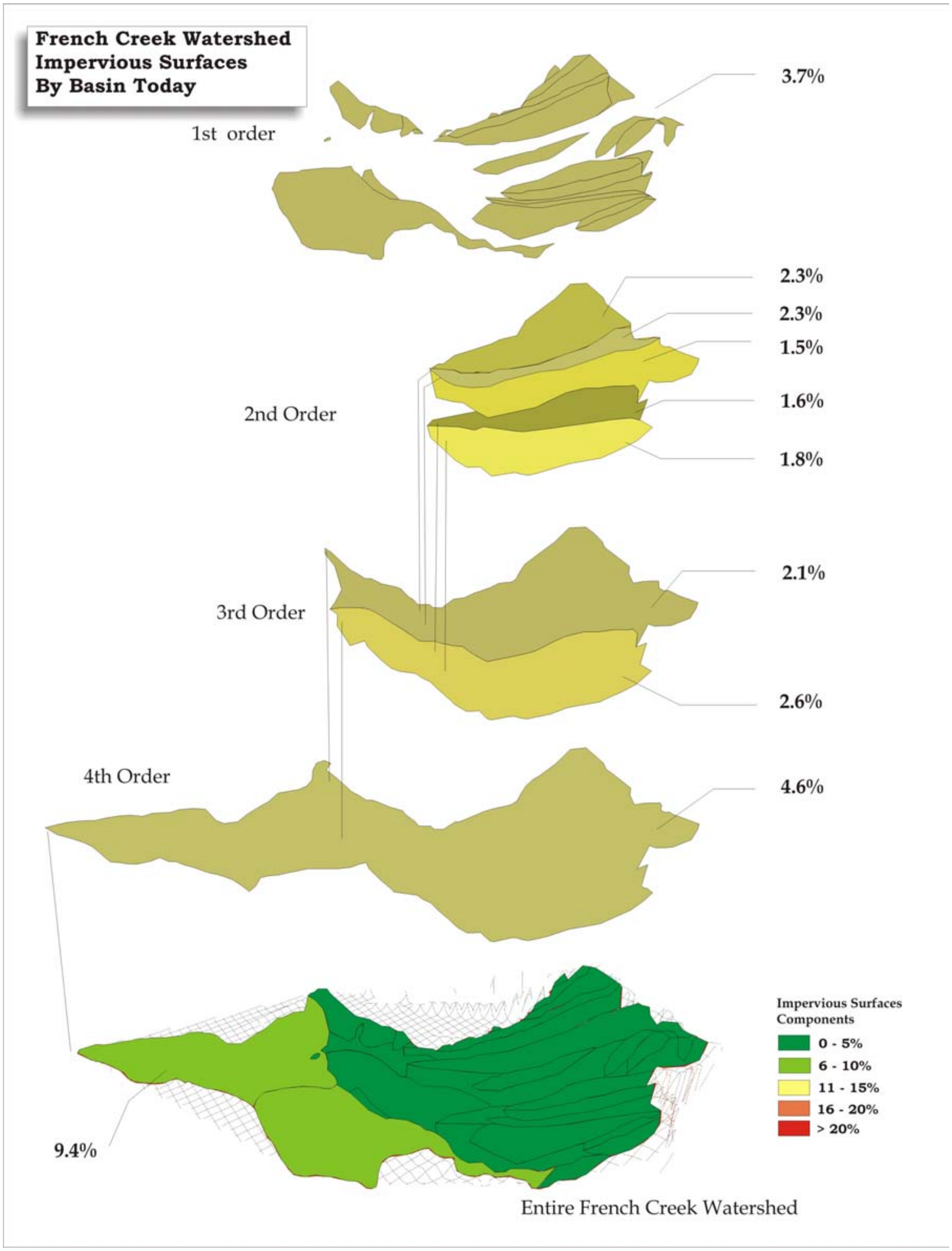

French Creek Watershed
Land Use Classes
French Creek Estuary
Strait of Georgia
Hilliers
Coombs
SCALE : 1:75,000
700 0 7001400 Meters
Planimetric View
March 2001
Coastline
Water
Landuse
A
Ad
Af
Am
Ao
As
At
Ax
Fc
Fe
Fo
Fs
Fu
Fy
G
Mg
Rc
Rg
S
Sc
Sd
Sm
Sr
St
Ta
Tr
Ue
Uh
Wt
N
W
E
S
British Columbia
Ministry of Environment, Lands & Parks
Pacific Spatial Systems Ltd.

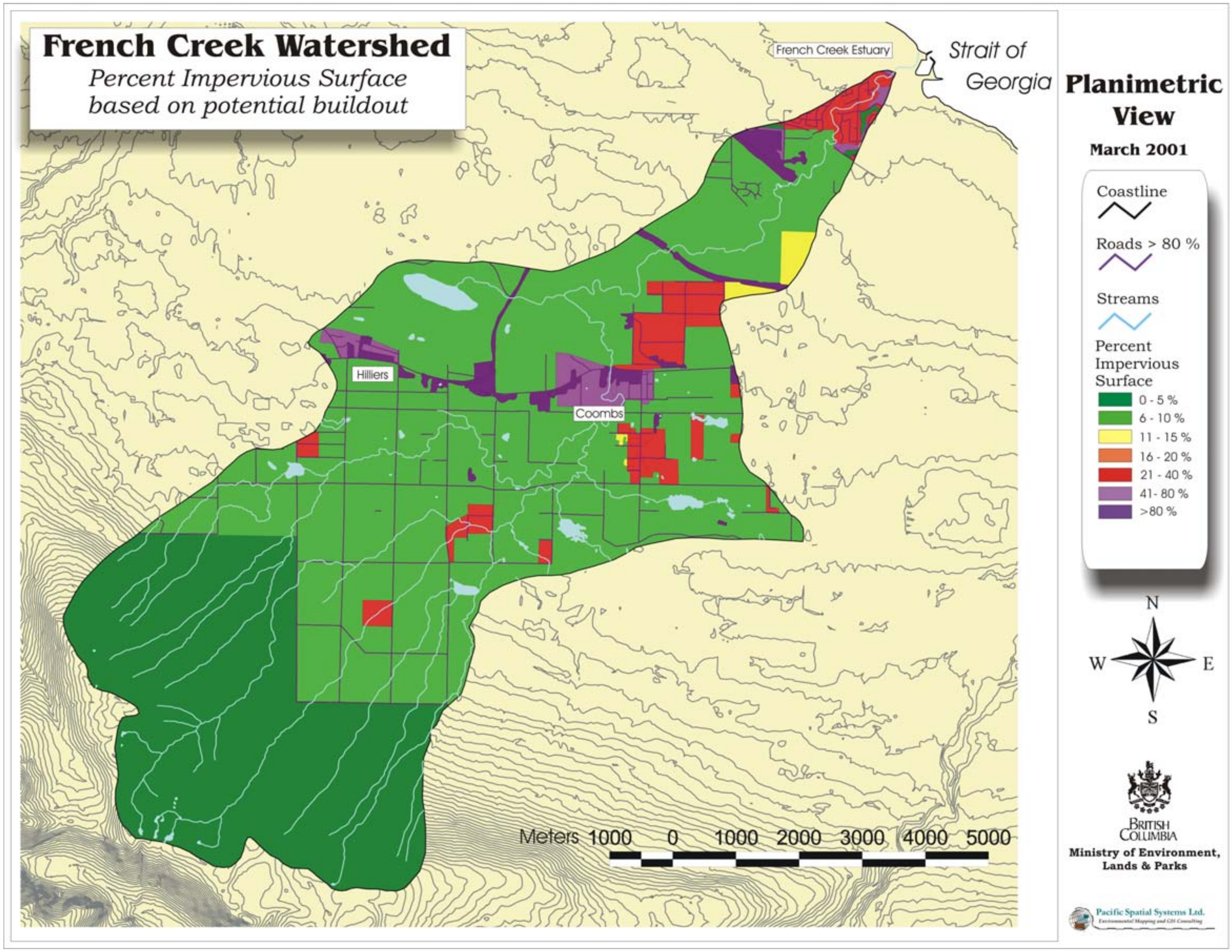
Distribution of (general) landuse in French Creek.

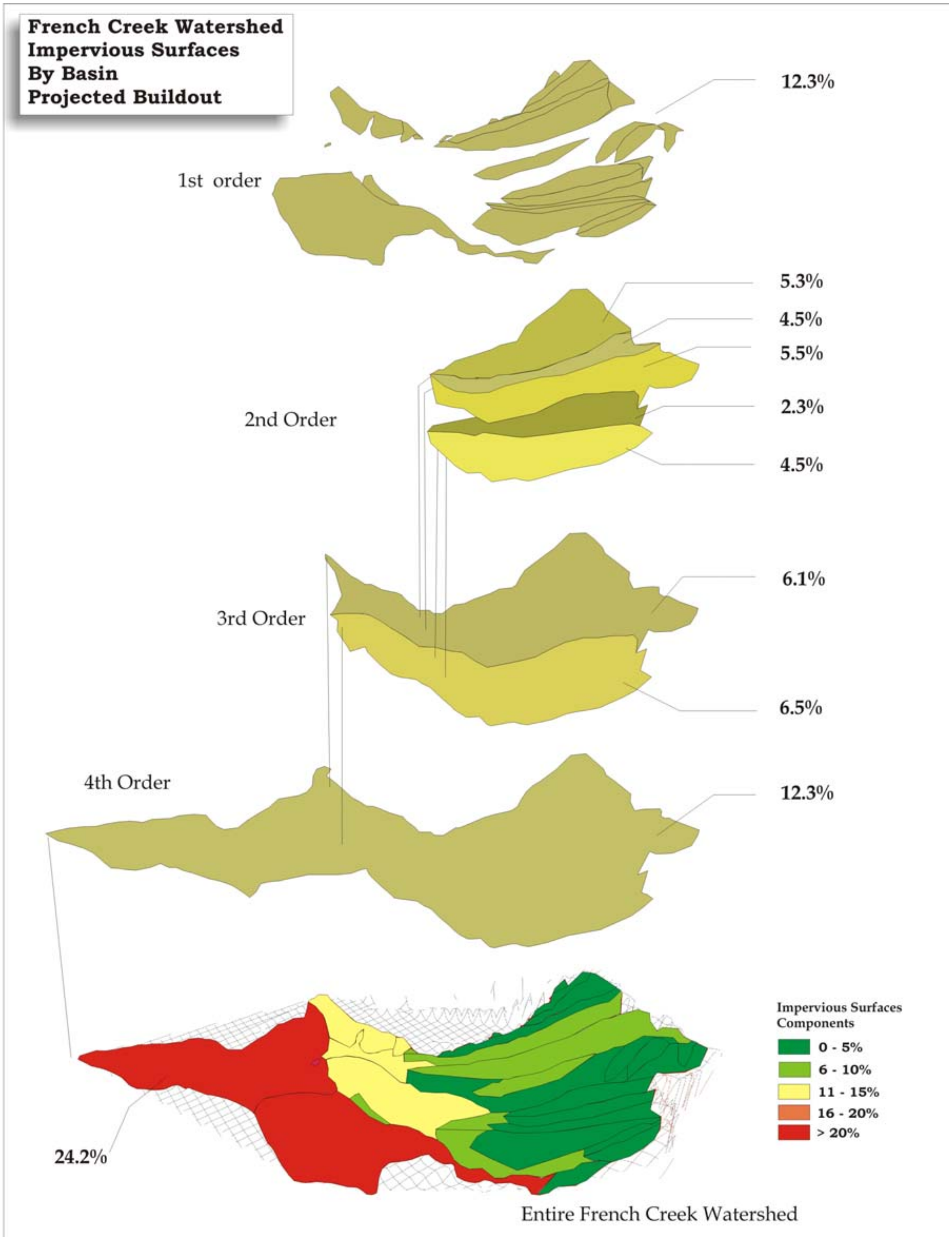




French Creek Watershed
Percent Impervious Surface
French Creek Estuary
Strait of Georgia
Hilliers
Coombs
Planimetric View
March 2001
Coastline
Roads > 80 %
Streams
Percent Impervious Surface
0 - 5 %
6 - 10 %
11 - 15 %
16 - 20 %
21 - 40 %
41 - 80 %
>80 %
N
W
E
S
Meters 1000 0 1000 2000 3000 4000 5000
British Columbia
Ministry of Environment, Lands & Parks
Pacific Spatial Systems Ltd.


French Creek Watershed
Impervious Surfaces
By Basin Today
1st order
3.7%
2nd Order
2.3%
2.3%
1.5%
1.6%
1.8%
3rd Order
2.1%
2.6%
4th Order
4.6%
9.4%
Impervious Surfaces Components
0 - 5%
6 - 10%
11 - 15%
16 - 20%
> 20%
Entire French Creek Watershed


French Creek Watershed
Percent Impervious Surface
based on potential buildout
French Creek Estuary
Strait of Georgia
Hilliers
Coombs
Meters 1000 0 1000 2000 3000 4000 5000
Planimetric View
March 2001
Coastline
Roads > 80 %
Streams
Percent Impervious Surface
0 - 5 %
6 - 10 %
11 - 15 %
16 - 20 %
21 - 40 %
41- 80 %
>80 %
N
W
E
S
British Columbia
Ministry of Environment, Lands & Parks
Pacific Spatial Systems Ltd.


French Creek Watershed
Impervious Surfaces
By Basin
Projected Buildout
12.3%
1st order
5.3%
4.5%
5.5%
2nd Order
2.3%
4.5%
6.1%
3rd Order
6.5%
4th Order
12.3%
Impervious Surfaces
Components
0 - 5%
6 - 10%
11 - 15%
16 - 20%
> 20%
24.2%
Entire French Creek Watershed