LAND USE, RIPARIAN BUFFERS AND THE EFFECTS OF URBANIZATION ON STORMWATER RUNOFF IN THE HOY CREEK WATERSHED, COQUITLAM, B.C.

By

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Abstract

The Lower Fraser Valley in British Columbia is undergoing rapid urbanization and due to the agricultural land reserve much of this urbanization is occurring on sloping land. Concerns have been expressed that the increased climatic variability and the generation of impervious surfaces as a result of urbanization will have serious impacts and consequences on stormwater management in the region.

The objectives of this research were to determine how the land use has changed in the Hoy Creek Watershed in Coquitlam and document how this change impacts the stormwater hydrology.

Land use and land cover GIS maps were produced for 1979 and 1999 and the emphasis was placed on determining differences in impervious surfaces in the urban areas and different land cover in all the non-urban areas. The results showed that the urban area expanded by 29% over the 20-year period mostly at the expense of forest cover, which declined by 38%. The total impervious area for the watershed increased from 7% to 25% and considering the new areas slated for development in 1999 this is expected to increase to 36% by mid 2000. The stream buffer zone integrity was examined for a 10, 30, 50, and 100 m wide zone and the results showed that the vegetated portion of the buffer zone declined from a very effective vegetation cover of 94% within the 10 m zone to a mere 58% within the 100 m buffer zone, and at the same time the total impervious surface area within the buffer zone increased from 4.5% in the 10 m buffer to 18% in the 100 m buffer zone. In terms of buffer zone integrity it was found that the Lower Hoy Creek and part of West Hoy had the lowest riparian zone integrity and these areas were identified as key areas for rehabilitation of the riparian buffer.

Soil penetrometer resistance was measured in the main combined soil and vegetation categories and the results were then converted into percolation rates using regression analysis. The watershed was then divided into three percolation categories with 35% of the watershed falling into the high percolation class (0.89 cm/min) and 45% into the moderate percolation rate (0.4 cm/min). The impact of the impervious surfaces and the partially pervious areas on stormwater runoff was then estimated for the watershed using an average storm (2 year return period-33 mm) and the maximum storm (112 mm). The results showed that the average storm produced 6.2 mm of runoff in 1999 and this is expected to reach 7.9 mm once development of forest that is currently designated as urban area is completed. For the maximum storm this resulted in 64.4 mm runoff reaching 74.6 mm once the forest development is completed. This represents a 16% increase in maximum storm runoff based on the past climatic record. Given the growing evidence of increasing climatic extremes it is possible that these values may increase even further. To verify these calculations the Soil Conservation Service curve number method was used to determine runoff values for the same watershed. Using this approach it was possible to show that the average storm runoff increased by more than 100% between 1979 and 1999 and the maximum storm runoff increased by 36% over the same time period. The results between the two methods were comparable but the SCS curve method produced somewhat lower values than the regression approach using percolation rates inferred from cone penetrometer readings.

The results showed that more attention needs to be given to designing urban development with low impact design that minimizes imperviousness. At the same time larger buffer zones are needed in the more urban areas to facilitate the development of stormwater detention systems within the buffer zone.

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1 Introduction and Objectives

The growth of population in the Pacific Northwest has lead to an increase in urbanization, the rate of which has seldom, if ever, been seen before in history. Humans have been moving from the countryside and into urban centers for centuries, but now we see this occurring at an ever increasing rate. In recent decades there has been a large increase in development in the Lower Mainland of British Columbia. This development has largely occurred in the form of an increase in urbanization (British Columbia Nearshore Habitat Loss Work Group 2001). Urbanization in the Pacific Northwest and the Lower Mainland of British Columbia has brought about increasing degradation of stream ecosystems and fish habitat which has lead to a decline of local salmon stocks (BC Nearshore Habitat Loss Work Group 2001; Northcote and Burwash, 1991; Horner and May, 1999; State of Washington Governor's Salmon Recovery Office 2002).

In the Pacific Northwest the degradation of stream ecosystems has had far reaching implications. A substantial part of our economies and culture are dependant on many of the goods provided by these ecosystems and the fish populations they support (State of Washington Governor's Salmon Recovery Office 2002). Local streams, and the fish they supply, provide us with an economic, aesthetic and recreational value.

The preservation of local fish populations depend on proper management of the broad ecosystem that contributes to their health. Two factors that play a role in the quality of stream ecosystems and fish habitat are the riparian buffer zones and impervious surfaces within the stream's watershed (Arnold and Gibbons 1996, Booth and Jackson 1997, Horner and May 1999, Lowrance et. al. 1985, Schueler 1994, 2000, Zandbergen 1999).

1.1 The Importance of Riparian Buffers

A riparian buffer zone is the important interface between terrestrial and aquatic ecosystems. The riparian zone is considered to be the strip of vegetated land that runs alongside the banks of a stream. It is an integral part of the stream (Schueler 2000a) and controls the stream environment (Horner and May 1999). Urbanization within a watershed is often coupled with the loss of riparian areas yet if maintained the riparian zone can help to mitigate adverse effects of development (Horner and May 1999).

A riparian zone buffers a stream ecosystem via many physical properties and processes. Some of the important natural functions of a vegetated riparian buffer include sediment trapping, filtering of nutrients or contaminants from surface runoff and subsurface flow, stabilization of stream banks, moderation of stream temperature, input of large woody debris and small organic debris to the stream ecosystem, a decrease in surface and subsurface flow rates, and the provision of aquatic and terrestrial ecosystem diversity. Through these functions the riparian zone can serve to buffer the aquatic ecosystem from upslope land use practices.

1.1.1 The Role of Riparian Buffers

Sediment Trapping

Sediment, which can originate from overland flow or instream actions resulting in bank erosion or resuspension of bed sediments, can be beneficial to a stream ecosystem in that it provides a degree of ecosystem diversity, but too much sediment in a stream can cause a decrease in diversity as the sediment covers over much of the habitat needed by many of the aquatic species. For example, vital spawning gravels may be covered over which may not only lead to the loss of these gravels but also decreased oxygen levels within the gravel which is essential for developing fish eggs (Castelle et. al. 1994, Horner and May 1999). The vegetation, as well as the local topography that is influenced by the vegetation, can serve to trap sediment that may be suspended in surface runoff. The stems or trunks of the vegetation can act as barriers to the surface runoff. The runoff hits the vegetation and looses some of its energy thereby decreasing the flow rate which then enables suspended sediment to fall out before it reaches the stream (Lowrance et. al. 1985). The forest litter that falls to the floor can also serve the same function as it provides surface roughness that decreases runoff rates

(Castelle et. al. 1994). Roots can shape local topography, creating small ridges and gullies that can slow runoff rates and trap suspended sediment. The degree to which a riparian can trap sediment is also dependent upon the particle size of the sediment as well as the slope of the topography within and above the riparian (Osborne and Kovacic 1993).

Filtering of nutrients/contaminants from surface runoff and subsurface flow

While a certain degree of nutrient loading is required for a stream ecosystem to remain healthy, high concentrations of nutrients can be detrimental (Arnold and Gibbons 1997). An over abundance of nutrients can lead to eutrophication of a stream ecosystem thereby drastically diminishing the diversity of the aquatic biota within the ecosystem. Contaminant loading can lead to fish kills or even complete destruction of aquatic populations. The roots of the riparian vegetation, as well as the soil itself, can adsorb, and thereby trap, some or all of the nutrients or contaminants that might otherwise make their way to the stream via subsurface flow (Castelle et. al. 1994, Gregory et. al. 1991, Lowrance et. al. 1985). Nutrients or contaminants that are associated with the sediments suspended in surface runoff are also filtered out by the same means that the sediment itself is trapped before reaching the stream ecosystem (Osborne and Kovacic 1993).

Decreased surface and subsurface flow rates

Stems, trunks and leaf litter serve to decrease surface flow rates just as they diminish sediment loading by breaking up the energy of the surface runoff (Castelle et. al. 1994, Lowrance et. al. 1985). This loss of energy means that the runoff reaches the stream with less power, and therefore the stream itself flows with less power thereby leading to a diminished ability to erode stream banks. Plant litter that accumulates on the surface of the riparian zone serves to break up the energy of individual raindrops as they hit the ground. This then also leads to a decrease in erosion and suspended sediment in surface runoff. The roots of riparian vegetation, and the soil itself, absorb some of the subsurface flow as it seeps toward the stream, thereby diminishing the rate at which the flow reaches the stream. This means that peak flows, after a rainfall event, are reached more gradually, which in turn leads to a decrease in stream flow power and a diminished likelihood of erosion.

Stabilization of stream banks

Stream bank erosion can lead to increased sediment loading and a permanent or temporary loss of habitat diversity. The roots of the riparian vegetation can serve to stabilize stream banks and decrease the likelihood of erosion that may occur from increased flow rates during storm events (Castelle et. al. 1994, Ferguson 1991, Lowrance et. al. 1985).

Moderation of stream temperature

Riparian vegetation can provide the stream ecosystem with cover. The cover can serve to shade a stream during hot summer months thereby protecting the stream from the sun's radiation and moderating stream temperatures (Castelle et. al. 1994, Lowrance et. al. 1985). Cool stream temperatures are preferred by many aquatic species. Warmer stream temperatures can serve to increase the metabolic rate of many aquatic species thereby increasing the productivity to a certain point. Excessively warm temperature can increase metabolic rates to the degree where the oxygen carrying capacity of the water is diminished (Nener and Wernick, 1997). In fact, some fish cannot tolerate high temperature. In addition, high temperatures serve to increase evaporation rate which can decrease flows during the summer months when flows are already at their lowest. In these ways shade can be vital for maintenance of healthy aquatic ecosystems. Vegetation cover can also serve to protect a stream from harsh winter climates by providing a windbreak that may keep a stream from freezing over.

Input of large woody debris

Large woody debris (LWD) such as logs and branches can add to the habitat diversity of a stream ecosystem. The LWD can be introduced to the stream during windstorms or natural undercutting of the stream bank. The debris can change the flow patterns of a stream and dissipate the energy of the flow. LWD can also serve to protect stream banks from erosion and stabilize the streambed (Horner and May 1999). Fallen logs can create small in-stream dams which can lead to the development of pools and riffles. A healthy aquatic ecosystem contains a variety of habitat, particularly pools and riffles (Ferguson 1991). The debris can also provide shade for aquatic species as well as cover for protection from predators (Bjornn and Reiser 1991).

Input of small organic debris

Organic matter is of vital importance to a healthy aquatic ecosystem. The small organic matter, provided by fresh and partially decomposed leaf litter and plant debris, is an important food source for aquatic invertebrates (Gregory et. al. 1991, Murphy and Meehan 1991, Oikos Ecological Services and T. Johnson and Associates 1996). In fact, small organic matter can be considered to be the base of the aquatic food web.

Terrestrial habitat diversity

Vegetated riparian zones can provide habitat diversity for terrestrial species such as, birds, rodents, mammals, etc (Castelle et. al. 1994). Riparian zones can also provide humans with a diversity of recreational settings.

1.1.2 Factors That Influence the Effectiveness of a Riparian Buffer

A vegetated riparian zone can be quite effective at buffering the stream ecosystem from upslope land use practices. It has been shown that a forested riparian buffer can be most effective at buffering a stream ecosystem from watershed land use abuses (Horner and May 1999, Osborne and Kovacic 1993, Schueler 2000a). In the Pacific Northwest, the most important components of an effective riparian are wide, continuous buffer zones (Schueler 2000a, Horner and May 1999) that are predominantly composed of a mixed forest (Horner and May 1999).

The type and density of the vegetation plays a key role in the buffering capacity, as does the continuity of the vegetation. Generally, the more dense and continuous the vegetation, the greater the buffering capacity. Breaks in the vegetation allow runoff to reach a stream somewhat unimpeded and less filtered. Patchy or discontinuous vegetation within the buffer can lead to higher levels of sediment and pollutants reaching the stream via surface runoff or subsurface flow. As well, runoff reaches the stream with more power; therefore, the erosion potential is increased. The effectiveness of a buffer zone is also limited by patchy vegetation in that a certain degree of cover is lost. Also, the source of large woody debris and organic matter is diminished by patchy vegetation.

A very important factor in the effectiveness of a riparian buffer is the soil type within the buffer zone. Stable soil types, such as those with relatively high clay content, can decrease the likelihood of erosion. As well, soils with high clay or organic matter content have a greater capacity to adsorb pollutants in subsurface flow compared to more sandy soils (Brady 1996). However, soils with high clay content tend to produce more surface runoff if the rainfall intensity exceeds the soil's infiltration capacity. In wet climates, like those of coastal British Columbia, soils with a good balance of a coarse fraction (for good drainage) and a fine fraction (for greater stability from erosion) can be advantageous.

One factor that has the potential to greatly limit the buffering capacity of a riparian zone is land use practices within the rest of the watershed. A buffer zone can only buffer surface runoff and subsurface flow from upslope. That is, land use practices upstream can have severe consequences downstream regardless of the quality of the riparian buffer along the lower reaches. Lack of Best Management Practices upslope can drastically limit the effectiveness of an otherwise adequate riparian buffer zone. For example, excessive use of fertilizers in the surrounding region can diminish, or even eliminate, the adsorption capacity of the riparian vegetation and soil. As well, impervious surfaces in the surrounding region can serve to limit the effectiveness of a riparian buffer. It should also be noted that the buffering capacity of a riparian is optimized when sheet flow is maintained. Any road breaks, stormdrain outfalls, channelized flow or rilling that may occur within the riparian can serve to short-circuit the buffering capacity of the riparian (Schueler 2000a).

1.1.3 Riparian Buffer Size Requirements

The optimum width for a riparian buffer depends on many factors. Some of these factors include the intensity of upslope land use, characteristics of the riparian buffer, specific requirements for the buffer, the value of the resource for which the riparian is intended to protect, and the size of the stream (Castelle et. al. 1994, Schreier et al. 1997). Many studies have shown that minimum riparian width requirements vary depending upon the specific functions required of the riparian. For instance, it has been found that a buffer width of about 15-30 m is appropriate if moderation of stream temperature is to be obtained from a riparian buffer. Likewise, buffer widths of 10-60 m are required for adequate sediment removal, 5-90 m for nutrient removal and 5-100 m for species diversity (Castelle et. al. 1994). It has been found that smaller buffers suffice if watershed land use practices have low impact potential, the riparian is in good condition and the resource for which the buffer serves to protect is of relatively low value (Castelle et. al. 1994). It has also been found that the more fragmented and asymmetrical the buffer the wider it needs to be (Horner and May 1999, Schueler 2000a).

Policy makers generally serve the public for whom the loss of land to riparian buffers could have a large economic impact while resource managers often have to answer to the policy makers. Thus, riparian buffer widths are often determined based on political acceptability rather that scientific knowledge (Castelle et. al. 1994). Therefore, it is important to accurately assess the width requirements needed for the riparian so as to minimize loss to landowners of otherwise valuable land while maximizing the buffering ability of the riparian.

Some land use practices may be allowable within the riparian provided they are of sufficiently low impact to the riparian and aquatic ecosystem. For instance, hiking trails within the riparian may have little impact if the trails are constructed so as to minimize erosion. The impact of the trail can also be diminished if use is restricted and stream crossings are minimized. In a forested catchment limited and selective logging can be acceptable within the riparian provided that impacts are minimized, by employing appropriate logging techniques. In fact, under some circumstances, selective logging within the riparian can benefit the aquatic ecosystem by providing light, thereby increasing productivity within the stream. Private landownership of the riparian within an urban watershed can be an acceptable land use provided that Best Management Practices are required and practiced.

In general terms a buffer of 5-10 m can be considered too small, 15-30 m is a minimum size, and a 30-100 m buffer can be considered to be a realistic compromise (Schreier, et. al., 1997).

1.2 Impervious Surfaces

Another factor that plays a role in the quality of stream ecosystems is impervious surfaces. Certainly, this is one of the key issues in urban watersheds. An impervious surface is any surface that does not allow surface water to infiltrate the soil such as: roadways, rooftops, sidewalks, buildings, etc. The presence of impervious surfaces within a watershed has far reaching implications. Urbanization and the consequent increase in impervious surface cover can have a significant impact on the physical, chemical and biological characteristics of a stream (Horner and May 1999). Impervious surfaces can lead to dramatic differences in stream flow regime, sediment loading, pollutant loading and stream temperatures compared to pre-development conditions (Booth and Jackson 1997, Horner and May 1999, Nener and Wernick 1997). These changes can, in turn, adversely effect the ecosystem of the entire watershed, particularly that of the aquatic ecosystems. In fact, research has shown a strong correlation between imperviousness and stream health (Arnold and Gibbons 1996).

Impervious surfaces have been shown to be directly related to stormwater runoff (Schueler 1994). They serve to concentrate the flow of water. Pavement and rooftops collect rainfall and roads and ditches then concentrate and direct the runoff. In fact, the flow can be concentrated to the point where channels are formed and runoff can cut through the riparian zone by-passing the buffering capacity of the riparian (Schueler 2000a). In these ways, impervious surfaces alter the drainage network within a watershed. The changes in drainage lead to changes in the flow regime and geometry of the stream. The evidence shows that strong correlations exist between imperviousness and physical degradation of the stream network (Booth and Jackson 1997).

For each watershed there exists a threshold of impervious surface area after which stream habitat begins to show signs of degradation (Booth and Jackson 1997). Some of the factors that bring about this degradation in habitat include a decrease in; runoff filtration, groundwater storage, stream low flows and habitat diversity. Impervious surfaces can also lead to an increase in sediment and pollutant levels in the waterway as well as an increase in the power of stream flow.

1.2.1 The Effects of Impervious Surfaces

Increase in stream flow and power

Because of the decrease in infiltration and the loss of vegetation for breaking up the energy of runoff, increases in stream flow are often associated with impervious surfaces within a watershed (Arnold and Gibbons 1996, Booth and Jackson 1997, Horner and May). Since less water is soaking into the ground more of it reaches the stream, and the runoff reaches the stream more rapidly. Therefore, peak flows can be greater and they can occur more rapidly. This means that stream flow can have more power and a greater capacity for eroding of stream banks. Also, since stream flows can be greater, there is an increased likelihood for flooding as well as streambed scour that can wash away vital spawning gravels. What might otherwise have been a mild flood could cause fish habitat to be obliterated (Booth and Jackson 1997, Horner and May 1999).

Decrease in runoff filtration

By diminishing the degree to which runoff can be filtered through the soil, impervious surfaces cause runoff to arrive at the stream with much higher levels of sediments and pollutants (Arnold and Gibbons 1996, Booth and Jackson 1997). The rain that falls on an impervious surface is not able to soak into soil; therefore, runoff reaches a waterway fully unfiltered. That is, there is a decreased opportunity for sediments to fall out and contaminants are not filtered out by adsorption via roots and soil.

Increase in stream pollutant levels

Impervious surfaces also act as efficient collectors and conveyors of pollutants commonly associated with the urban environment (Arnold and Gibbons 1996). The pollutants are concentrated on these surfaces and are readily dissolved into surface runoff and can then be washed into the waterways at elevated levels during a rainfall event (Arnold and Gibbons 1996, Hall 1988, Schreier et. al 1991, Schueler 1994,). This can lead to severe spikes in stream water pollutant concentrations. Decreased filtration of runoff can lead to higher concentrations of nutrients or contaminants in the aquatic ecosystem. It is not uncommon to find levels of herbicides, insecticides and nutrients associated with fertilizers in runoff from residential areas. Stream levels of some nutrients have been found to be high enough to trigger eutrophication (Schueler 2000g).

Increases in imperviousness have also been found to be associated with increased stream temperatures, particularly in the summer. This is partially due to the fact that impervious surfaces absorb and reflect heat thereby contributing to increases in local air and ground temperatures (Schueler 1994). Imperviousness is also associated with increases in temperature fluctuations (Arnold and Gibbons 1996).

Decrease in groundwater storage and stream low flows

Another way in which impervious surfaces have an effect on a watershed is through the loss of groundwater recharge and storage. Rainfall spends less time on the ground thereby diminishing the potential for infiltration to groundwater reservoirs (Arnold and Gibbons 1996, Ferguson 1990). The riparian vegetation and soil are effective at capturing and holding water for long periods of time. In fact, rainfall infiltration is a key process for groundwater recharge (Arnold and Gibbons 1996). The decreased capacity for groundwater storage effects stream low flows. In many watersheds, groundwater provides a large portion of stream flow during the dry summer months (Arnold and Gibbons 1996). With less available groundwater a stream can have critically low summertime flows. In fact, flows may be so low, or even non-existent, that aquatic species cannot survive throughout the summer months. With increased urbanization, and the subsequent additions of impervious surfaces, year-round streams can become ephemeral and lose the capacity to sustain an aquatic ecosystem.

Decreased habitat and species diversity

An increase in impervious surfaces within a watershed likely leads to a decrease in terrestrial habitat and habitat diversity. Because of the detrimental effects that impervious surfaces can have on a riparian zone, an increase in impervious surfaces can also lead to a decrease in aquatic habitat (Arnold and Gibbons 19966, Booth and Jackson 1997). In addition to the loss of habitat diversity, a decrease in macroinvertabrate diversity and abundance and diversity of fish populations has been found to be related to increases in imperviousness (Schueler 1994). Macroinvertabrates are an important food source for salmonids (Murphy and Meehan 1991).

A wide array of evidence points to a level of imperviousness around 10% as the threshold at which the aquatic environment is adversely effected by the impervious cover. Evidence indicates that 30% impervious cover is the point at which aquatic ecosystems can be severely degraded (Arnold and Gibbons 1996, Booth and Jackson 1997, Nener and Wernick 1997, Scheuler 1994).

These far-reaching implications of impervious surface cover within a watershed make it a valuable indicator of urban watershed health. As an indicator of the impact of development on the watershed, impervious surface cover is both reliable and integrative (Arnold and Gibbons 1996). In fact, the measure of imperviousness is used as an indicator of watershed health by both The U.S. Environmental Protection Agency (US EPA) and The Fraser River Action Plan (FRAP) of The Department of Fisheries and Oceans in Canada (Nener and Wernick 1997, USEPA website).

1.3 Objectives

The objectives for this thesis were:

1. To produce a digital map of the land use and land cover in the Hoy Creek Watershed in Coquitlam and to determine the total impervious area in the watershed for 1979 and 1999 and determine the changes that have occurred over this 20-year period.

2. To evaluate the 10-100 m riparian buffer zones within the watershed in terms of land use, crown cover and riparian integrity and identify where improvement in the buffer zones would be beneficial for protecting the ecosystem health.

3. To measure penetrometer resistance in the different soils and land use/cover categories in the watershed and relate penetrometer resistance measurements to percolation rates.

4. To estimate the effect of increased imperviousness on stormwater runoff for an average rainstorm event and the maximum daily storm event.

5. To compare how the land use changes between 1979 and 1999 have influenced the stormwater runoff conditions and project further increases in stormwater runoff due to continuing urbanization.

2 The Hoy Creek Watershed Study Area

The objectives, as stated in Chapter 1, were met using a combination of fieldwork and land use mapping utilizing Geographical Information System (GIS) analysis of orthophotos, airphotos and digital maps of the study area. This project was carried out in the Hoy Creek Watershed which lies entirely within the boundaries of the city of Coquitlam, a suburb 35 kilometers east of Vancouver, British Columbia (Figure 2-1).

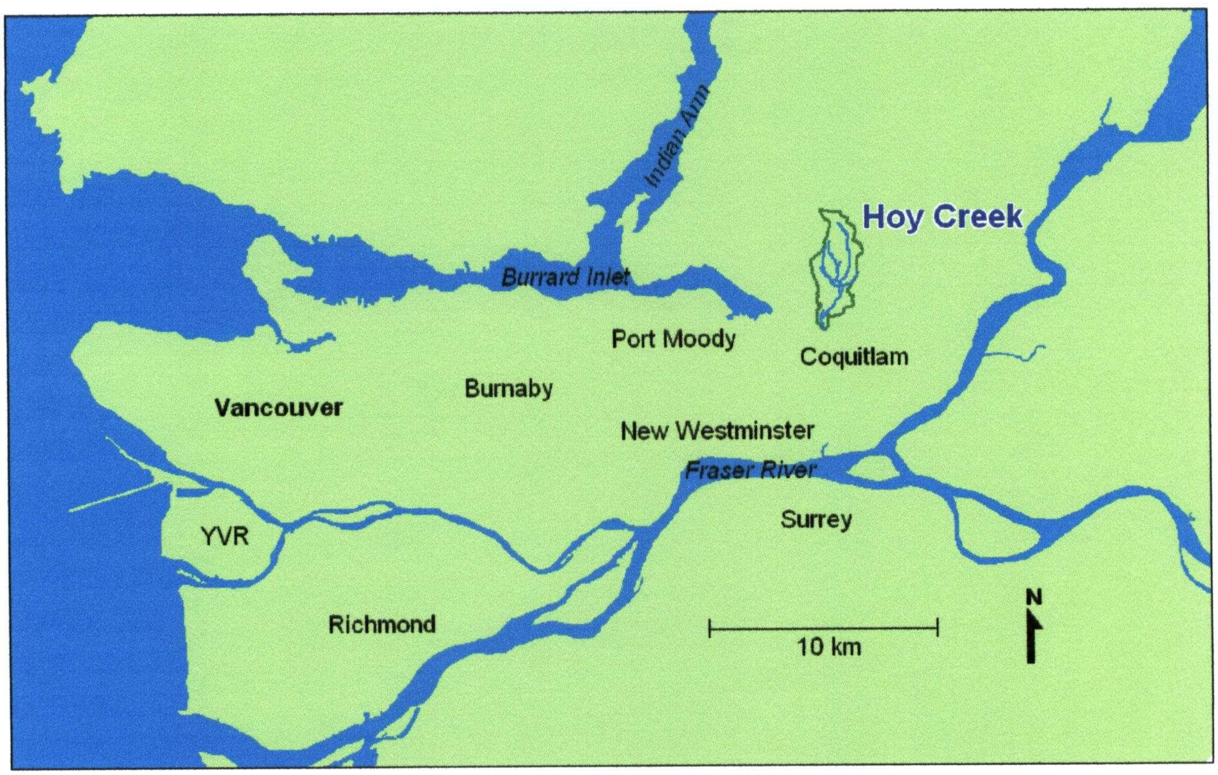

Figure 2-1 The location of Hoy Creek watershed within the Lower Mainland of British Columbia

Population within the city of Coquitlam over the past twenty years has grown considerably. In 1986 the population was approximately 70,000. This number had grown to nearly 113,000 in 2001.

The Hoy Creek watershed covers approximately 700 ha and is a sub-watershed of the Coquitlam River watershed that drains into the Fraser River, one of British Columbia's most important waterways. The Coquitlam River is one of the important salmon producing waterways of the Fraser Basin. In the past, the Coquitlam River has been classified as one of the worst managed rivers in British Columbia with indices of salmon habitat sensitivity indicating severe problems (Rood and Hamilton 1994).

Hoy Creek also provides vital habitat for valuable fish stocks in British Columbia. The species of salmonid fish that have been found in the creek are steelhead, cutthroat, coho, chum and pink. In fact, the creek supports a fish hatchery that rears chum and coho which are present in the creek throughout the year. The hatchery has been in operation since 1999 and is run by volunteers for the Hoy/Scott Watershed Society with assistance from the Federal Department of Fisheries and Oceans as part of the Salmonid Enhancement Program.

Hoy Creek watershed is largely urbanized with development continuing at a rapid rate and with many undeveloped areas slated for future development. In fact, the upper reaches of Hoy Creek lie within Westwood Plateau, one of Canada's largest planned developments. Construction in Westwood Plateau has been blamed for elevated sedimentation in Hoy Creek and the Coquitlam River (Nener and Wernick 1997, Rood and Hamilton 1994). Urbanization and the subsequent increase in impervious surfaces, throughout the entire watershed is one of the key issues of concern for salmonid preservation. Chemical and concrete spills have been reported to lead to fish kills and a golf course in the upper watershed could cause leachate from hog fuel and grounds maintenance that may adversely affect fish habitat (Anderson 1998, Nener and Wernick 1997).

Water quality monitoring performed by Douglas College Habitat Restoration Program indicates problems with turbidity, particularly during the rainy season. They have also reported peaks in phosphates and nitrates. Benthic macroinvertebrate surveys indicate declining stream health. Summertime low flows are a concern in Hoy Creek. Mean annual flow is approximately 0.2 m^3/s with average low flows around 0.01 m^3/s (Anderson 1998). Low flows cause a stream to be relatively sensitive to inputs of pollutants due to the possibility of increased concentrations.

The municipal government is sensitive to the effects of inappropriate land use practices and is currently taking steps to improve management of the watershed in order to restore a healthier aquatic ecosystem.

The lower watershed lies at an elevation of 30 meters and rises up to more than 600 meters at the top of the watershed. The lower watershed is relatively flat with average streambed gradients of less that 2% (Anderson 1998). Development in the lower portion of the watershed took place in the 1950's and is largely in the form of commercial and industrial use. The vegetated riparian is narrow and patchy in the lower watershed and composed mainly of broadleaf trees and shrubs such as blackberries, alder, birch, cottonwood and maple.

Intensive residential development within the middle and upper region of the watershed began in the 1980's and continues today. As one moves up in the watershed slopes become steeper, the riparian width increases and conifer trees are more abundant. At the top of the watershed the riparian is at it's widest and is composed predominantly of conifers such as fir, hemlock and cedar. Logging within the watershed took place in the 1920's. Throughout the entire watershed the vegetated riparian zone rarely extends beyond the top-of-bank.

The creek bed material is coarse gravel and is relatively steep with mean gradients reaching 11% (Anderson 1998). Soils within the watershed are largely coarse textured glacial till and marine deposits.

The climate in the watershed is typical of that for the Lower Fraser Valley and Coast Mountains dominated by the interaction of westerly atmospheric circulation and the Coast Mountains. This leads to wet winters that can have arctic outbreaks bringing cold air and strong winds. Precipitation decreases in the summer and temperatures become warm (Moore 1991).

Figure 2-2 illustrates the typical temperature and rainfall for the Hoy Creek watershed. The data was collected in Port Moody which is located just a few miles west of the Hoy Creek watershed at the same latitude as Hoy Creek and only 6" of longitude west. The elevation of the climate station is 130 meters which lies at the same elevation as points within the Hoy Creek watershed. Total annual precipitation for points within Hoy Creek watershed has been recorded to be near 2500 mm.

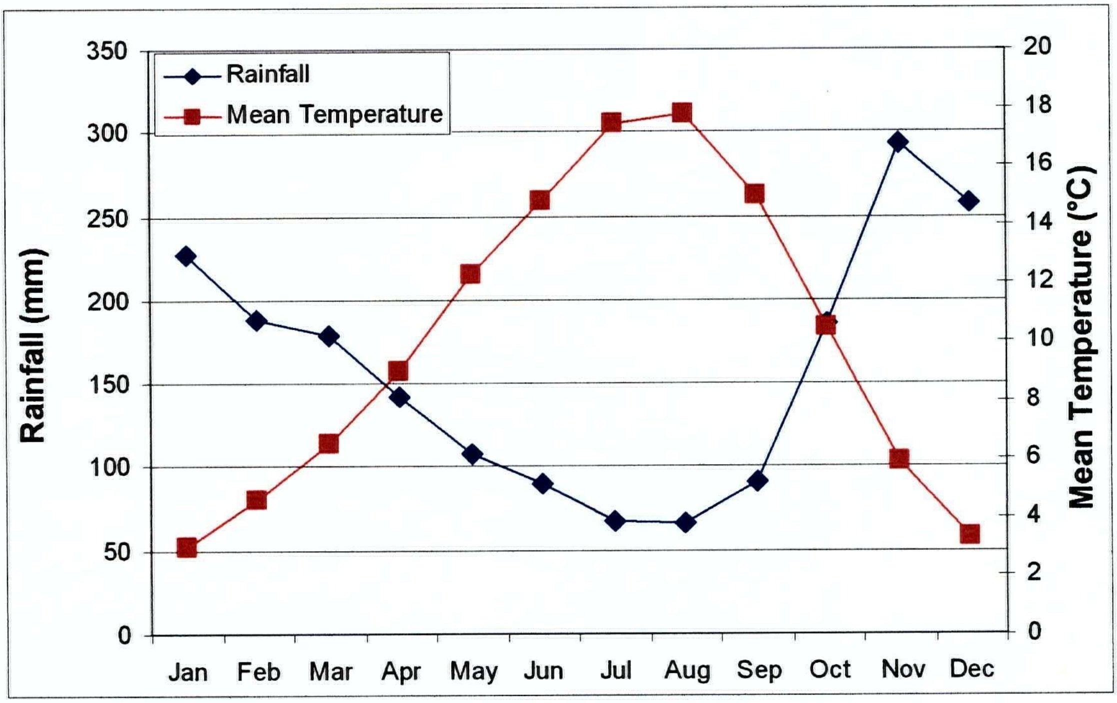

Figure 2-2 Average annual precipitation and temperature for Port Moody Glenayre

3 Methodology

3.1 1999 Land Use

Source Maps

In order to map land use and land cover for the watershed, a number of information sources was utilized. The Municipality of Coquitlam provided base maps in both hard copy and digital formats. The hard copy maps included storm drainage, legal boundaries, zoning and topography. The digital maps included the same information but in some cases the digital files were uncompleted versions of the hard copy maps, while in other cases the digital maps were partially updated versions of the hard copy maps. Digital 1-meter pixel color orhtophotos of the area for 1995 were also utilized to map land cover and land use for the watershed. Table 3.1-1 summarizes sources and details of the maps and orthophotos.

	Source	Year of Production	Map Projection and Datum	Scale
Storm drainage maps	Municipality of Coquitlam	1998	UTM, Zone 10, NAD 27	1:4000
Legal boundary maps	Municipality of Coquitlam	1997	UTM, Zone 10, NAD 27	1:3000
Topography maps	Municipality of Coquitlam	1994	UTM, Zone 10, NAD 27 and NAD 83	2m contour intervals
Zoning maps	Municipality of Coquitlam	1998	UTM, Zone 10, NAD 27	1:4500
Orthophotos	Triathalon Mapping Corporation, Burnaby, B.C.	1995	UTM, NAD 83	1-meter pixel

Table 3.1-1 Source map summary for the Hoy Creek watershed

The land use and land cover for the watershed was mapped in detail through a combination of the hard copy maps, digital maps, orthophotos, and ground-truthing in an attempt to make the land use and land cover mapping as accurate as possible.

GIS

The digital files were imported using to the GIS package, MapInfo. The files were transformed and geo-referenced to the North American Datum 1983 (NAD83) Zone 10 using road intersections and key features as control points. This was done in order to overlay the mapping information (drainage, topography, legal and zoning) onto each other as well as the orthophotos.

3.2 1979 Land Use

Air photos of the Hoy Creek area were obtained for land use mapping. The photos used were taken in 1979 and produced at an approximate scale of 1:10,000. The air photos were referenced to the Hoy Creek area using the GIS package. Land use was then digitized directly from the photos. Due to the limitation of air photo analysis, the land use categories mapped for 1979 were simplified to forest, shrub, grass, bare, development and water bodies.

3.3 Soils

Source Maps and GIS

The soils within the Hoy Creek watershed were mapped in the GIS using soil maps and ground-truthing.

The base map used to digitize the soils was the Soil Map of Maple Ridge, Pitt Meadows, Coquitlam Area, 1972. This map was produced by the Soils Division of the British Columbia Department of Agriculture, Kelowna, B.C., according to "The System of Soil Classification for Canada", Canada Department of Agriculture, 1970 and based on the National Topographic System, 1:25000 scale base maps, from map sheets 92G/1e; 92G/2f, g, h; 92G/7a, b, c; 92G/8d. The soil classifications associated with this map were subsequently updated and published by the BC Ministry of the Environment (Luttmerding 1981) which is the source of the soil descriptions for this study.

The soil map for the area was referenced to the Hoy Creek watershed using the GIS package. The soil polypedons were then digitized and added as another layer of information for the watershed. Locations within the watershed were chosen for calibration of the map for the five major soil series which were mapped.

Field and Laboratory Analysis

In-field Soil Classification

Soil pits were dug to maximum depth of 1 meter where possible. The depth of each horizon was recorded and the horizon designation was determined using the Canadian System of Soil Classification.

Bulk Density

The soils within the watershed are relatively coarse. Therefore, a soil sampler could not be used to collect bulk density samples. To collect a sample for bulk density the top organic layer was removed. A hole was then dug to a depth of 10 cm with a diameter of approximately 7 cm. All material was collected and sealed in a moisture tin. The hole was lined with thick plastic (5 mm) and a graduated cylinder was used to fill the plastic lined hole with water. The volume of added water was recorded. The samples were then weighed and oven dried at 110°C overnight. The samples were then reweighed and bulk density was calculated.

$$\text{Bulk density} = \frac{\text{oven-dried weight of sample (g)}}{\text{volume of water filling the hole (cm}^3\text{)}}$$

Organic Matter and Coarse Fragment Content

A soil sample of approximately 1 liter was collected from within the top 10 cm of mineral soil. The sample was oven dried overnight at 110°C and then passed through a 2 mm sieve. The mass of the sample remaining on the sieve was weighed. The mass of the sample passing through the sieve was weighed. The values were recorded and coarse fragment content was calculated.

$$\text{Coarse fragment content (\%)} = 100 * \frac{\text{mass of sample remaining on sieve (g)}}{\text{(mass of sample remaining on sieve (g) + mass of sample passing through sieve (g))}}$$

The sample passing through the sieve was reserved for determination of organic matter content.

The weight of a 600 ml beaker was recorded. 40.00 g of soil was added. Distilled water was added up to the 300 ml mark and the sample was stirred. 30% H_2O_2 was added to the beaker in 10-20 ml increments until the reaction slowed. The solution was allowed to sit at room temperature for two days. The beaker was heated on a hot plate to about 80°C until excess H_2O_2 was removed. The sample was removed from the heat and oven dried at 105°C for 24 hours. The sample was cooled and the final weight of the beaker and sample was recorded. The organic matter content was then calculated.

$$\text{Organic matter content (\%)} = 100 * \frac{\text{(mass of dried soil before O.M. digestion (g)- mass of dried soil after O.M. digestion (g))}}{\text{(mass of dried soil before O.M. digestion (g))}}$$

3.4 Permeability

Site Selection

Representative locations were chosen for measuring penetration resistance within the Hoy Creek watershed. The locations were chosen to maximize representation of land use, land cover and soil combinations and to cover as much of the watershed as possible.

Sampling Scheme

A minimum of ten penetration resistance measurements were taken at each location whenever possible. The measurements were collected at random sites dispersed throughout each location, within a maximum of approximately 1000 m^2 to a minimum of approximately 100 m^2.

Meter Description and Field Technique

A hand-pushed 13-mm diameter cone (30°) penetrometer with data logger (Agridry Rimik PTY Ltd., Toowoomba, QLD, Australia), was used to measure penetration resistance. Measurements were taken after a period of rain so that the soils would be near saturation. The surface organic matter was removed and the penetrometer probe was inserted into the ground. The probe was inserted at a relatively uniform speed of less than 2 meters per minute as per ASAE standards. The penetration resistance was measured to a maximum depth of 40 cm at intervals of 1.4 cm.

Statistics

The penetrometer readings were averaged by depth. The depth measurements were averaged from 0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm for each site. A statistical package was used to perform Mann-Whitney analyses on the penetrometer data using a significance level of 0.05. A penetration resistance map was created in the GIS package. The mapping categories were determined by statistical analysis to be significantly different.

3.5 Percolation

Percolation tests were performed in conjunction with penetration resistance at eleven locations within the watershed after a period of rain. To perform the percolation tests the organic matter was removed from the surface. A 10 cm hole was dug with a diameter of approximately 25 cm. A graduated cylinder was used to fill the hole with water and the volume of water added was recorded. A stop watch was used to measure the time required for all water to drain from the hole.

The penetration resistance values corresponding to the locations for which percolation test were performed were averaged over 0-10 cm and over location. A statistical package, SPSS 6.0, was used to determine the correlation between percolation rate and average penetration resistance.

4 Results and Discussion

4.1 Land Use within the Hoy Creek Watershed

Hoy Creek is one of British Columbia's many salmon spawning creeks located in an urban setting. Land use practices within the watershed can have an enormous impact on stormwater runoff which in turn effects the creek environment.

Land use managers can benefit from an improved inventory of land use and land cover within a watershed. This improves the knowledge-based decision making process; one in which areas of potential risk can be pinpointed and decisions focused on the relevant issues. This can hopefully lead to more satisfying compromises between stake-holders.

In order to determine land use and land cover within the Hoy Creek watershed the extent of the creek and the watershed boundaries were first determined. The first step in the process was to determine the extent of the creek system. The topographic and digital creek data obtained from the Municipality of Coquitlam were modified and incorporated into the GIS.

As with most natural creek systems, there are numerous small tributaries. As development increases in the watershed the smaller tributaries are lost to construction. As well, some small tributaries may be ephemeral. Ground-truthing was utilized to determine the tributaries in these two categories. These small and lost tributaries were not included in the analysis. The mapped extent of Hoy Creek for this project is illustrated in Figure 4.1-1.

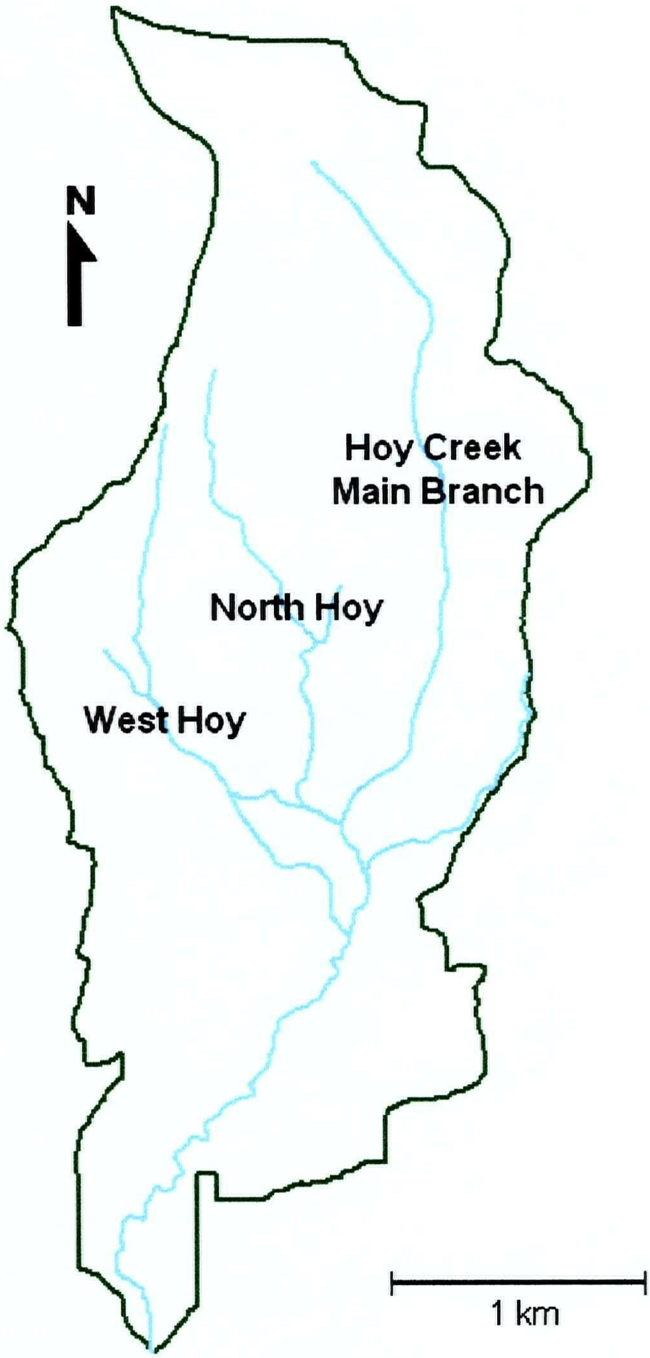

Figure 4.1-1 Hoy Creek watershed

The Hoy Creek watershed is largely developed and a considerable portion of the drainage no longer follows natural pathways, therefore, drainage maps were vital for determining the boundary of the watershed. Regardless of development, topography plays an important role in drainage. Based on the GIS analysis the Hoy Creek watershed covers approximately 700ha.

Land cover (i.e. vegetation) was also mapped for the Hoy Creek watershed. The categories that were used are conifer forest, broadleaf forest, mixed forest, shrub and grass. Shrub was considered as young trees, generally broadleaf trees under roughly 3 meters tall often with a grass or vegetated under story. Grass consists of land covered by grass that is allowed to grow wild with the exception of grass within the golf course.

In addition to vegetation, land use and roadways were also mapped for the entire watershed. Land use was mapped using the following categories; single-family residential (sfr), multi-family low density (mfLd), multi-family high density (mfHd), institutional (institu), commercial (comm), industrial (indust) and bare. These categories were mapped based on land use rather than zoning boundaries and were derived from aggregations of existing municipal zones. A list of the Coquitlam zones and the land use categories mapped can be found in Appendix I.

Land Use/Cover Differences between the Upper and Lower Watershed

Land use and land cover maps (Figure 4.1-2) indicate distinct differences between the upper and lower portions of the Hoy Creek watershed.

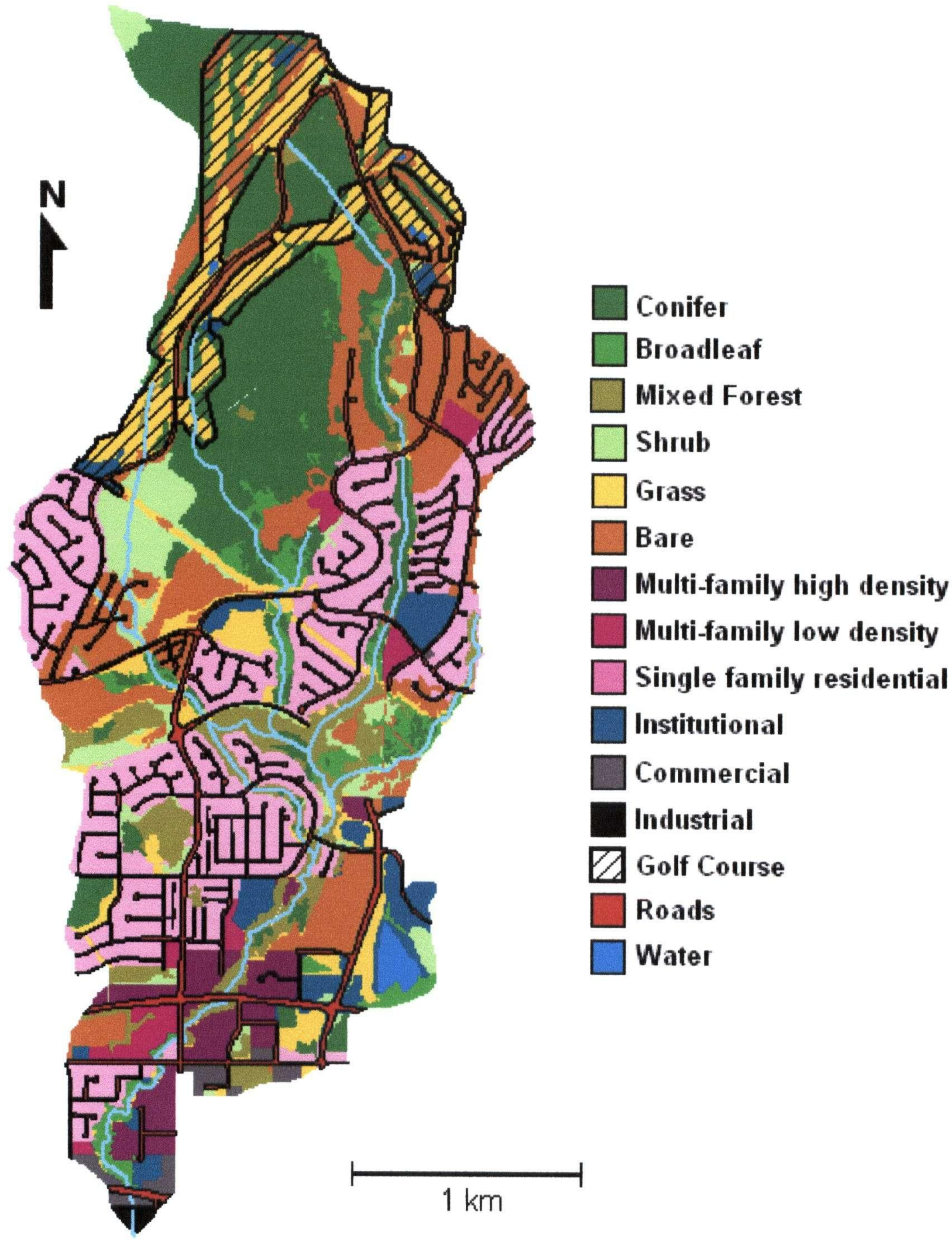

Figure 4.1-2 Land Use and Land Cover within Hoy Creek Watershed

The upper areas of the watershed are generally characterized by relatively large areas of vegetation, particularly conifer forest consisting mainly of western hemlock, red cedar and Douglas fir. Approximately 90% of the conifer forest in the watershed exists in the upper portion. In fact, the conifer forest in the upper watershed covers about 18% of the entire watershed. The other primary land use in the upper watershed is a golf course. The golf course comprises more than 11% of the entire watershed. As well, there are fewer residential areas in the upper watershed. The residential area that does exist in the upper watershed is mainly single-family residential with a few areas of multi-family low density housing and even fewer areas of multi-family high density. And there are virtually no commercial or industrial zones. It can also be noted that the road density is much lower in the upper watershed.

In the lower watershed one sees many more broadleaf trees including red alder, big leaf maple, black cottonwood and birch; as opposed to the predominance of conifer in the upper watershed. The relative area covered by forest is much less in the lower watershed where virtually all commercial, industrial and multi-family low density zones are located. Another feature that characterizes differences between the upper and lower watershed is the topography. A large portion of the lower watershed is fairly flat. As one moves up into the watershed slopes become much steeper.

For the watershed as a whole, 45.3% is covered by vegetation (conifer, broadleaf, and mixed forests, shrub and grass). And nearly 45% of the vegetation is conifer forest. 54.1% of the watershed is developed. This includes single-family residential (sfr), multi-family low density (mfLd), multi-family high density (mfHd), institutional, commercial and industrial. But the majority of this is comprised of sfr which covers 54% of the developed land. 8% of the watershed is covered by roadways with the highest density occurring in land mapped as single-family residential. The watershed holds a lake and several small ponds that cover a total of 0.6% of the watershed. This water is not included in the total percentage of developed or vegetated lands.

The land use category that covers the largest area of the watershed is single-family residential which covers 24.3% of the watershed. Conifer forest is the second largest land use in the watershed covering 19.9%. This data has been summarized in Figure 4.1-3.

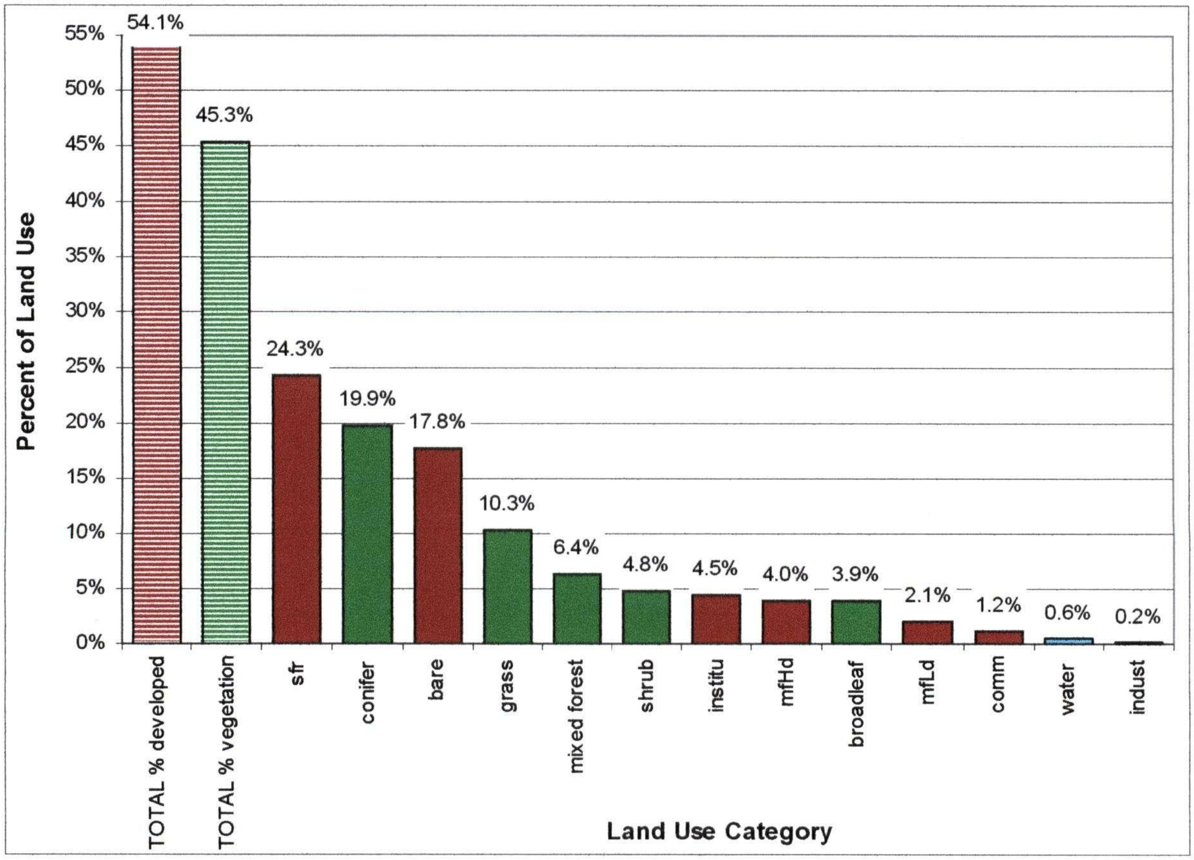

Figure 4.1-3 Land use and land cover for the Hoy Creek watershed

4.1.1 Test Areas

To get a better indication of land use characteristics within each of the land use categories, it was necessary to map land use in greater detail. Because of the size of the watershed it was unrealistic to map characteristics for the entire watershed. Therefore, several representative test areas were chosen for each land use category (sfr, mfLd, mfHd, institu, comm) with boundaries based on land use rather than zoning. These were then mapped in greater detail and represent the developed area only. The test areas were located throughout the watershed with the intention of including as great a variety of characteristics as possible. Test area locations within the watershed are illustrated in Figure 4.1-4.

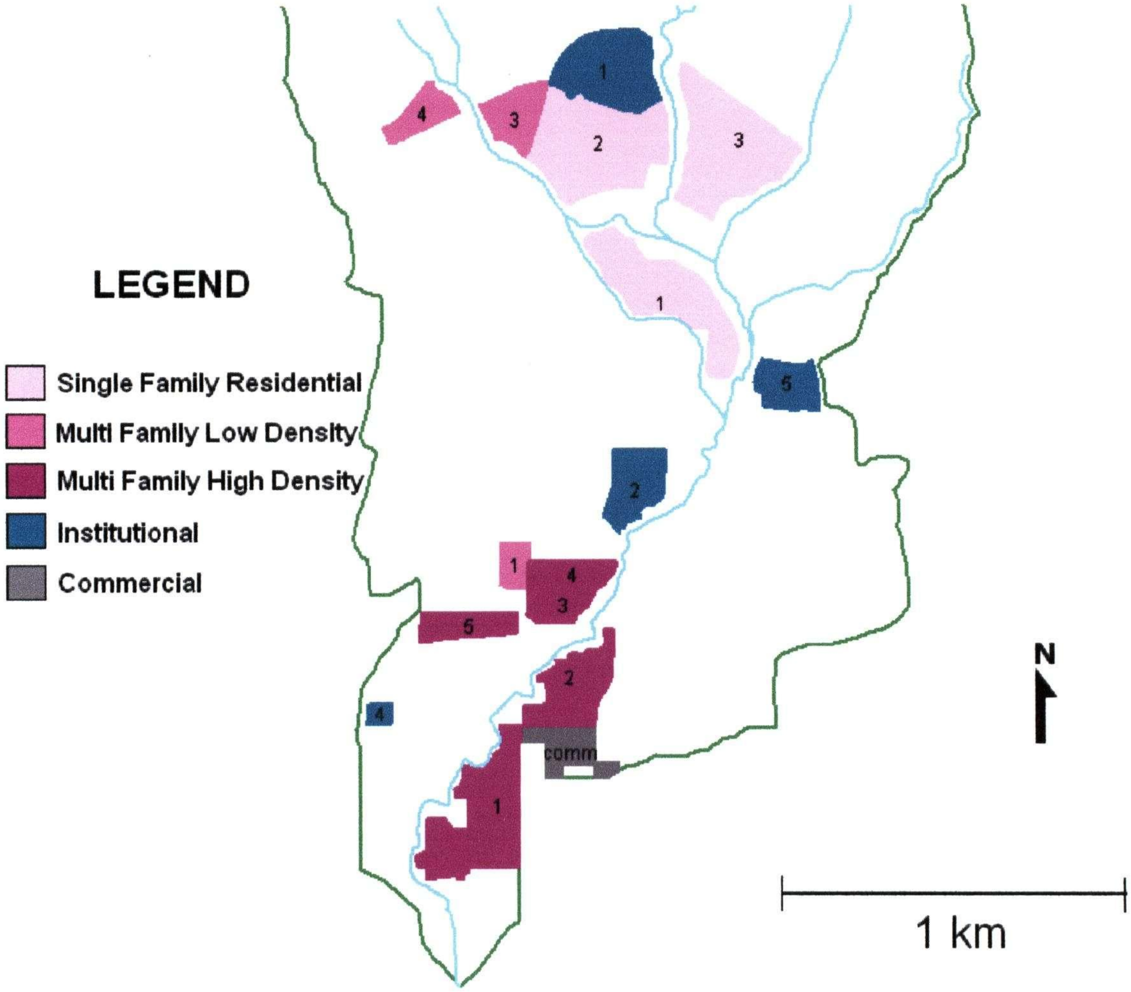

Figure 4.1-4 Location of all test areas in the Hoy Creek watershed corresponding to detailed GIS mapping and collection of penetration resistance

The test areas chosen for the institutional land use category included a school, a fire hall, a church and a park. Test areas for multi-family residential represent zones in which land use characteristics such as layout and parking differed. Single-family residential test areas represented average lot size for the watershed and were chosen to be of sufficient size (6.9 – 9.2 ha) and number of lots (85 – 124) so as to obtain a fair average estimate of land use characteristics. Land use for typical test areas can be seen in detail in Figure 4.1-5 and Figure 4.1-6 in which brown represents buildings, yellow is driveways, black is parking lots, roads are red and sidewalk is orange.

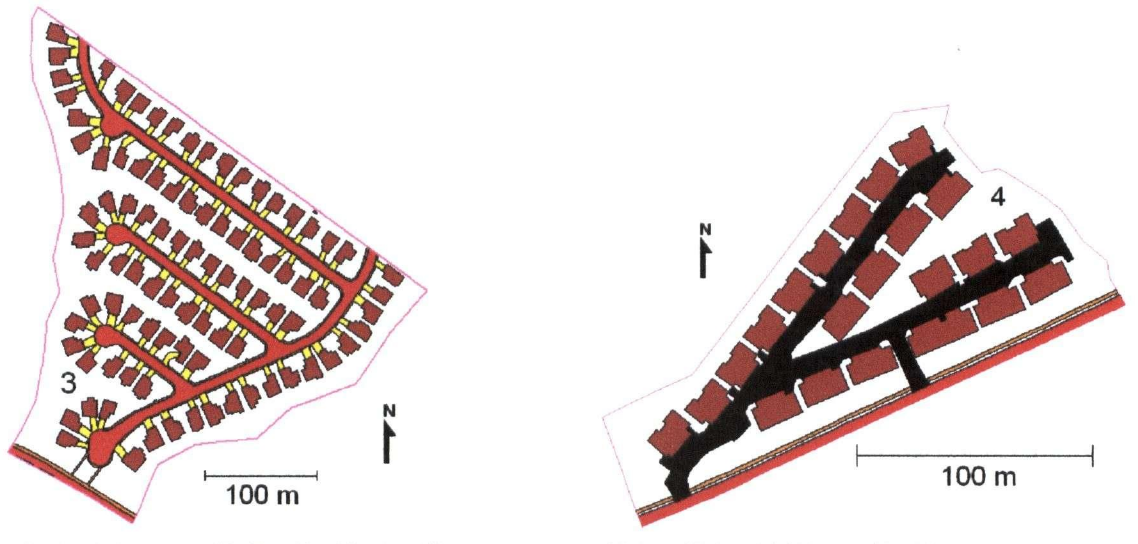

Figure 4.1-5 Typical test area for single-family residential and multi-family low density

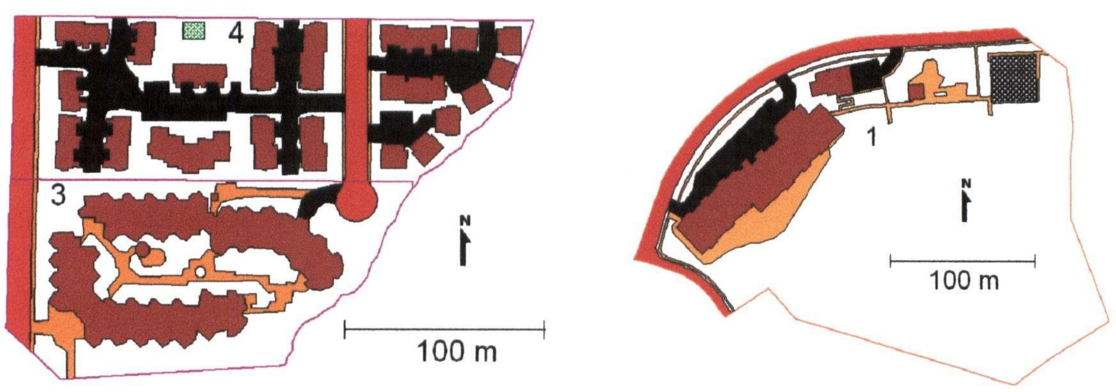

Figure 4.1-6 Typical test area for multi-family high density and institutional

One test area was chosen for mapping commercial land use (Figure 4.1-7). This is because commercial land use within the watershed was very similar; therefore, one test area was sufficient. Industrial land covers a very small portion of the watershed and it occurs in only one area; therefore, no test areas were needed.

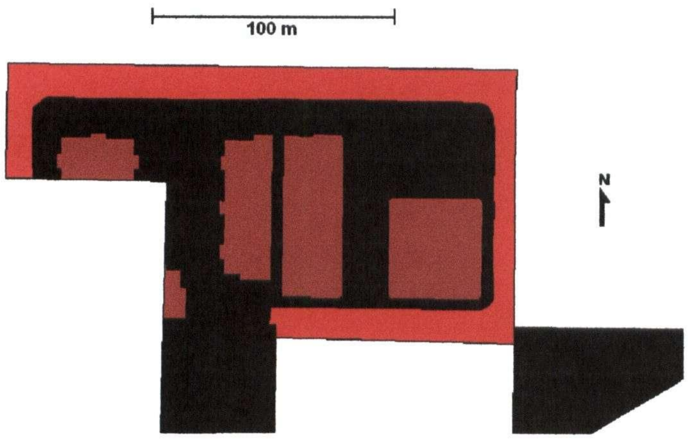

Figure 4.1-7 Commercial test area (black is parking lot, brown is buildings, red is roads)

The following land use characteristics were then fully mapped for all test areas: roads, driveways, parking lots, sidewalks, buildings and tennis courts.

Ground-truthing was utilized to increase the mapping accuracy and to clarify drainage pathways. In all cases roads, driveways, parking lots and sidewalks drained directly into the storm drains. Rooftop drainage was to underground, presumably directly into creeks as well. Based on the ground-truthing these characteristics were then assumed to be 100% impervious.

Land Use within Test Areas

The land use data for the test areas was tabulated and graphed, along with the standard deviation, in order to get a clearer indication of land use within each land use category. This can be seen in Figure 4.1-8.

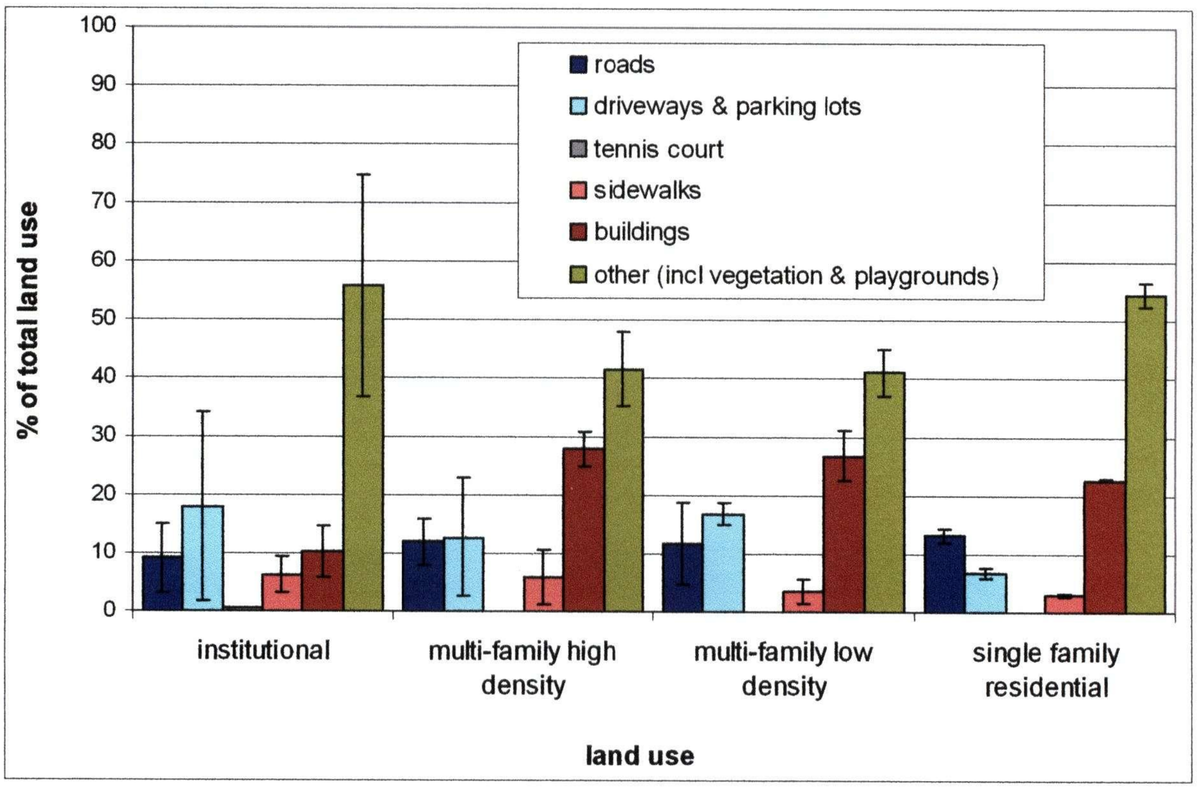

Figure 4.1-8 Land use characteristics within test areas

All test areas were covered by more vegetation than impervious surfaces. The variability of land use characteristics was highest for institutional test areas. This is because each of the lots is used for different purposes. This category was investigated in further detail which can be found in Appendix II. Test areas for single-family residential use have low variability with respect to land use characteristics. The land use variability is slightly higher for multi-family low density test areas and higher still for multi-family high density areas.

Impervious Surfaces

Given this data, impervious area was calculated for each of the test area categories. Institutional and sfr test areas have more vegetated land than impervious surface areas, whereas multi-family residential areas have more impervious surfaces than vegetated land. Multi-family residential has nearly 20% more impervious area than vegetated areas. This is summarized in Figure 4.1-9 with error bars showing the standard deviation of the data.

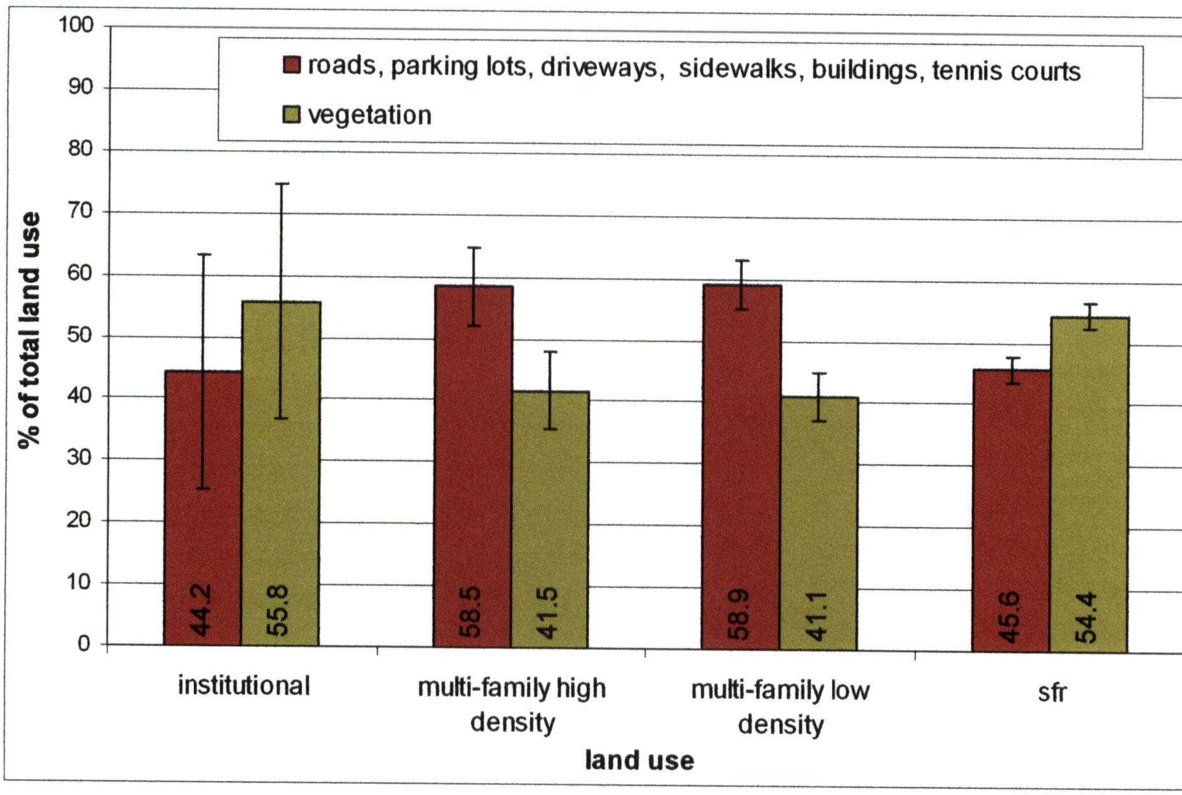

Figure 4.1-9 Impervious vs. semi-pervious land use within Hoy Creek test areas

The total impervious area (TIA) was calculated for each test area. These values were then averaged in order to determine TIA for each of the land use categories. Data were summarized in Table 4.1-1.

Land Use Category	Test area ID	TIA for individual test areas (%)	Average TIA for each land use category (%)	Standard Deviation	Coefficient of Variation
Institutional	1	27.45	**44.2**	19.0	43%
	2	31.85			
	4	69.24			
	5	48.34			
Multi-family high density	1	52.46	**58.5**	6.3	11%
	2	59.27			
	3	51.48			
	4	64.51			
	5	64.55			
Multi-family low density	1	62.30	**58.9**	3.9	7%
	3	59.81			
	4	54.65			
Single-family residential	1	45.10	**45.6**	2.0	4%
	2	47.82			
	3	43.87			

Table 4.1-1 Total impervious area for test areas and land use categories

Multi-family high density TIA was found to be 58.5% with multi-family low density TIA nearly the same at 58.9%. These TIA values are the same as those determined from other land use in the Lower Mainland of British Columbia and the Puget Sound (Zandbergen, 1999). Developed institutional land was found to have a TIA of 44.2%. Single-family residential areas were found to have a TIA of 45.6%. The TIA values for sfr are similar to those determined from other land use in the Lower Mainland of British Columbia and the Puget Sound for high density residential (Zandbergen, 1999). The TIA value for sfr is nearly the same as that of institutional area but the variability is considerably lower for sfr. Impervious surface cover for institutional test areas ranged from 27.5% to 69.2%

Total Impervious Area

Once the impervious surface cover was determined for each of the test area categories these numbers could then be scaled up to the entire watershed. Total impervious area values for all vegetation categories and for bare land were chosen from literature. Forest TIA is generally estimated at 1% while grass is generally considered to have a TIA of 10%. Bare land is commonly estimated at 10% TIA while shrub is typically estimated to be 5% (Zandbergen 1999). Roads are generally considered to be 100% impervious and water bodies 0% impervious. Total impervious area for all other land use categories came from the test area study. The TIA data have been summarized in Table 4.1-2.

land use	**area (ha)**	**Land use within watershed (%)**	**Average TIA (%)**	**Average TIA (ha)**
conifer	139.3	19.9%	1.0%	1.39
broadleaf	27.38	3.9%	1.0%	0.27
mixed forest	44.98	6.4%	1.0%	0.45
shrub	33.78	4.8%	5.0%	1.69
grass	72.29	10.3%	10.0%	7.23
sfr	170.44	24.3%	45.6%	77.72
mfLd	14.83	2.1%	58.9%	8.74
mfHd	27.81	4.0%	58.5%	16.25
institu	31.41	4.5%	44.2%	13.89
indust	1.65	0.2%	100.0%	1.65
comm	8.48	1.2%	100.0%	8.48
bare	124.6	17.8%	10.0%	12.46
roads (other than TA)	25.8	8.0%	100.0%	55.92
water	4.12	0.6%	0.0%	0.00
total watershed	701.4	100%	**25%**	206.15

Table 4.1-2 Total impervious area for all land use/cover categories

These numbers were then applied to the whole watershed. Total impervious area for the Hoy Creek watershed was calculated to be 25%

4.1.2 Future Development

It is of interest to note that a considerable area in the watershed consists of bare land. In fact, 17.8% of the watershed is bare. This represents nearly 125 hectares. This is land that has been cleared for development. The land is predominantly zoned single-family residential, multi-family low density, multi-family high density and institutional (including the golf course and schools) with the bulk of the land zoned for sfr and mfLd. It was determined that of the bare land 48.7 ha were zoned as sfr, 34.4 ha were zoned as mfld, 2.8 ha were zoned for mfhd and 12.4 ha were zoned for institutional. This represents 90% of the land mapped as bare. The breakdown of zoning for bare land is summarized in Table 4.1-3.

Zoning for Bare land	Area of bare land zoned for future development (ha)	Area of new land use after development of bare (ha)
sfr	48.1	218.5
mfLd	34.4	49.3
mfHd	2.8	60.6
institu	12.4	43.8
other	12.4	

Table 4.1-3 Expected land use changes in Hoy Creek watershed for land mapped as Bare

The maps representing these changes can be seen in Figure 4.1-10 and Figure 4.1-11.

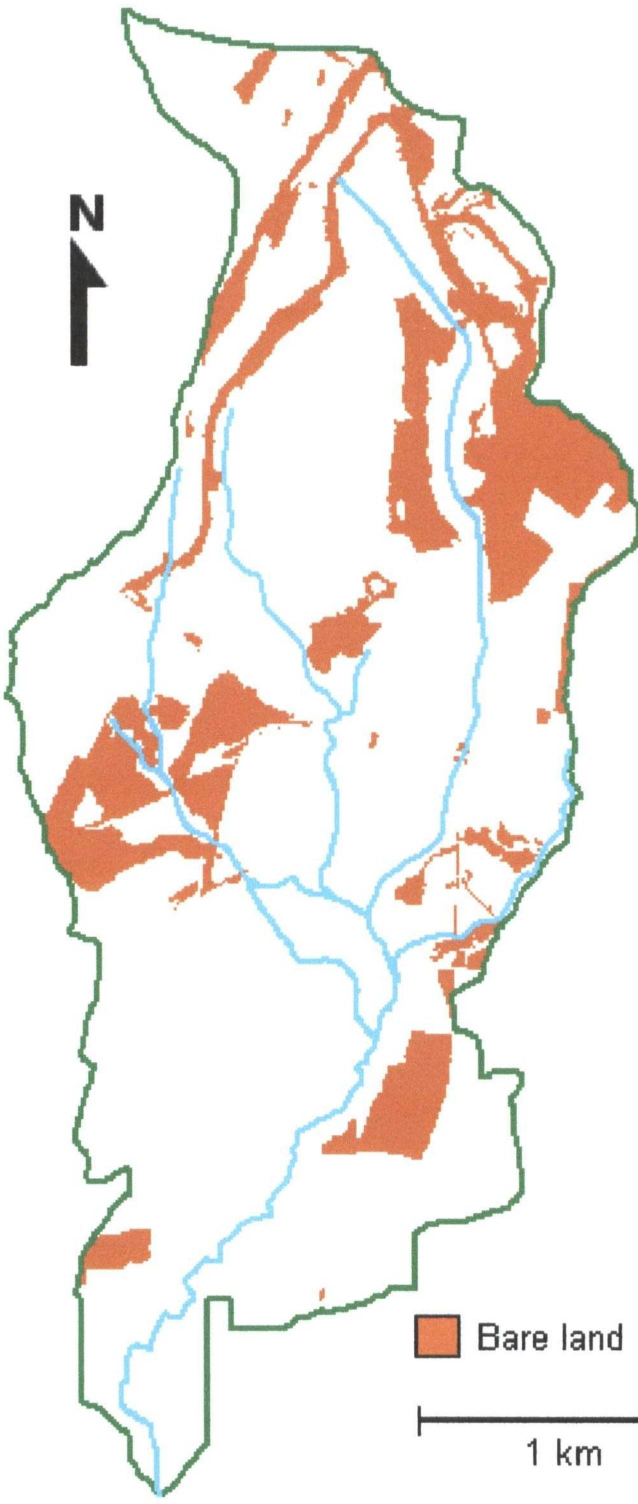

Figure 4.1-10 Bare land in Hoy Creek watershed in 1999

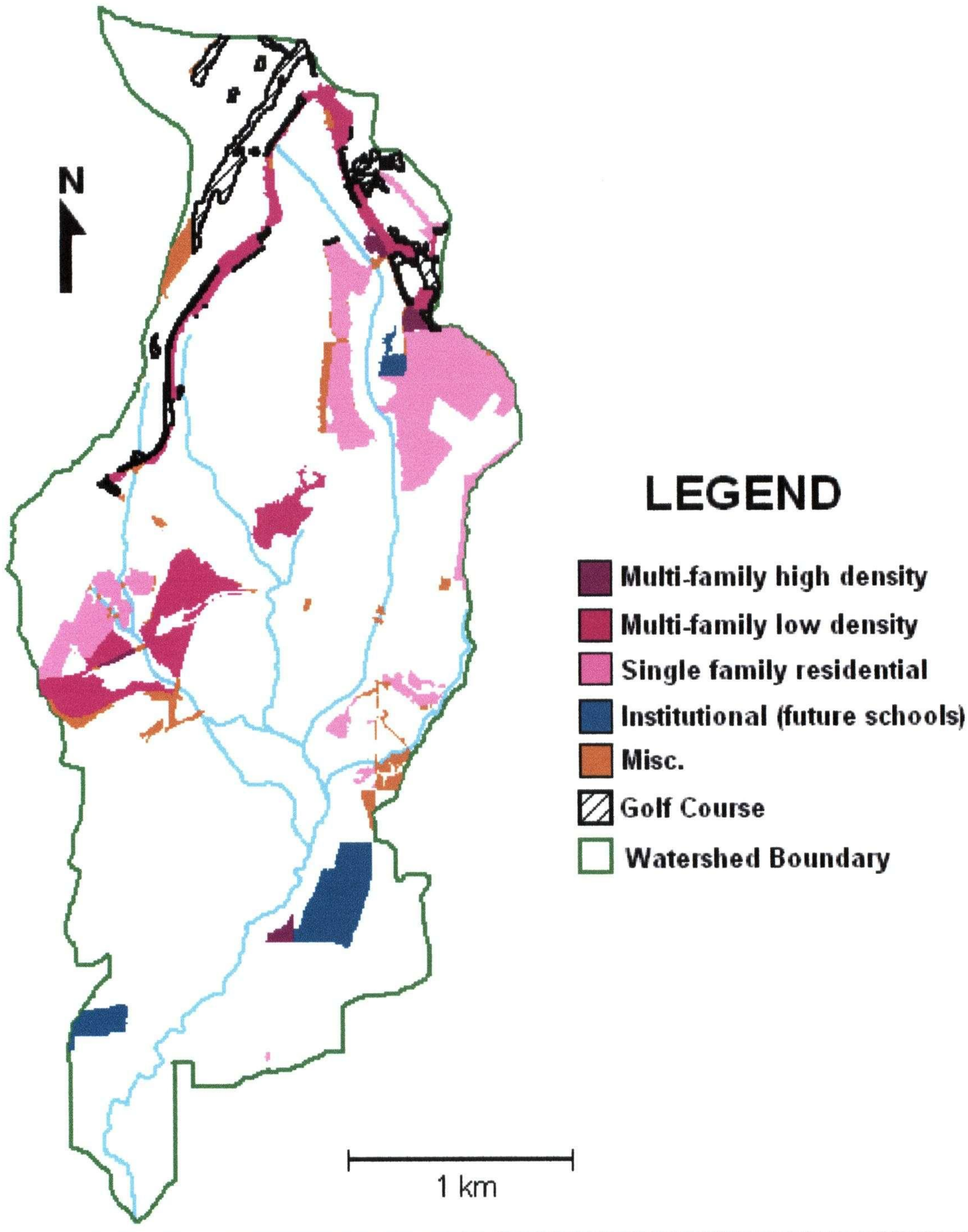

Figure 4.1-11 Probable land use after development based on Coquitlam zoning of Bare land

Once development occurs the imperviousness of this land will change. Therefore, applying these values to the TIA determined for the other land use categories should give an indication of how TIA may change in the future.

Based on the Test Area study it was determined that the bare land had a TIA of approx 12.6 ha. Assuming development continues based on the zoning and given calculated TIA values for these specific land use categories one can expect future TIA to be 55.4 ha for this land. This represents a change from 10% TIA (for bare land as chosen from literature) to approximately 42% TIA for the land mapped as bare once development occurs.

In addition to the bare land slated for development there are approximately 26 ha of forest that is zoned for single-family residential and 22 ha zoned for multi-family residential. Development of the forest will lead to a change in the TIA of this land; shifting it from a low TIA of 1% to 45% and 60% for the residential uses. This change will have a significant impact on the runoff characteristics of this land which could impact other areas of the watershed.

The changes in TIA values were then applied to the entire watershed to reflect increases in area covered by the newly developed land. A new TIA for the watershed was then calculated. Once this development occurs (which is now the case) the TIA for Hoy Creek watershed will be 36%. This represents an increase of 11% for the total impervious area within the watershed.

4.2 Hoy Creek Riparian Buffer Zones

The riparian zone of a creek is important in protecting the creek from upslope and upstream land use practices. As stated earlier, the optimum width for a good riparian buffer varies depending on many factors. The riparian area of Hoy Creek was examined at four different widths in order to get an indication of land use near the creek and the possible buffering capacity of the land surrounding the creek. Buffers of 10 m, 30 m, 50 m and 100 m radius were created using the GIS package. The buffers can be seen in Figure 4.2-1.

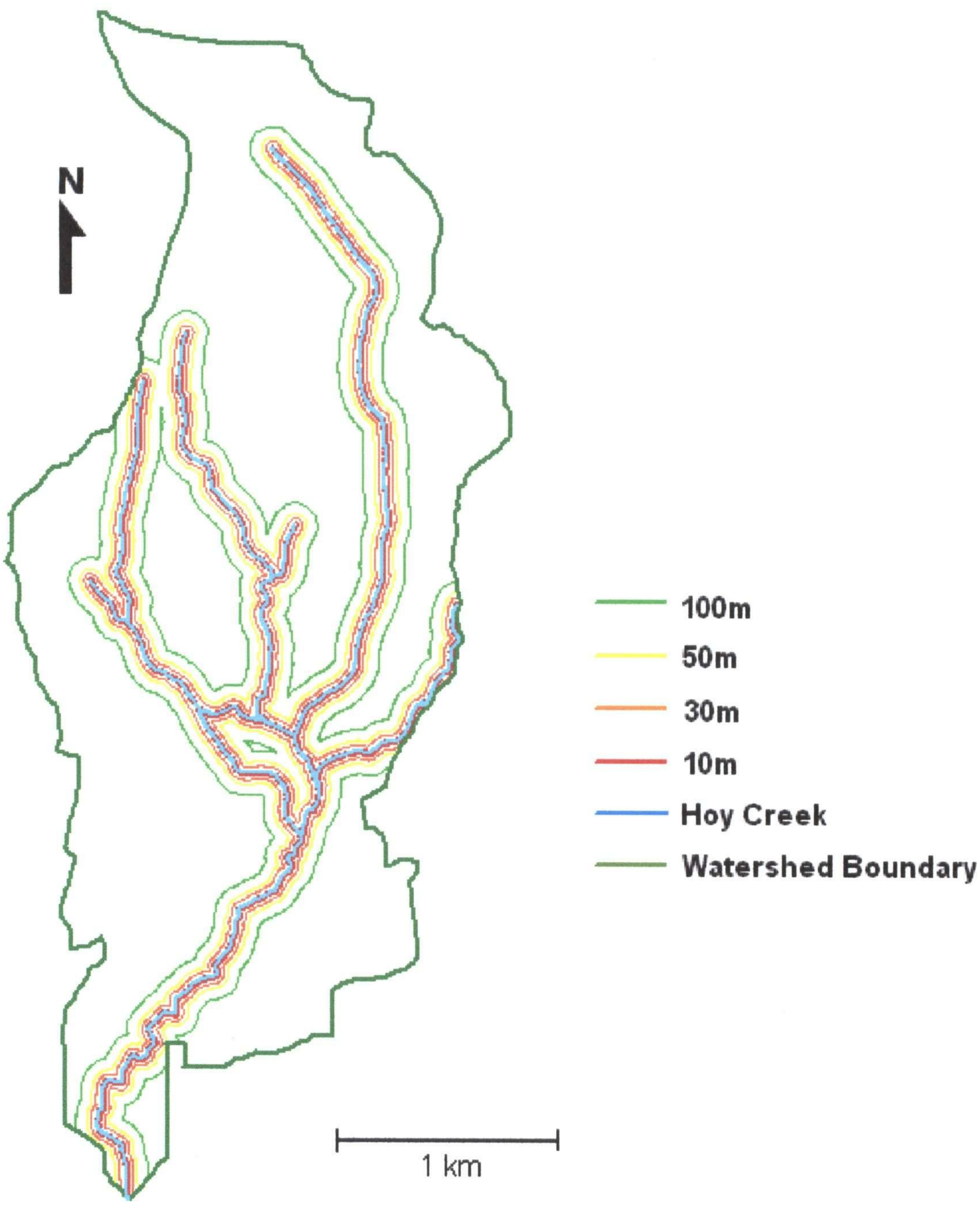

Figure 4.2-1 Hoy Creek buffer zones

4.2.1 Buffer Zone Land Use

The land use and land cover was then mapped within each of the buffers using the existing land use/cover maps. This can be seen in Figure 4.2-2 and in closer detail in Figure 4.2-3.

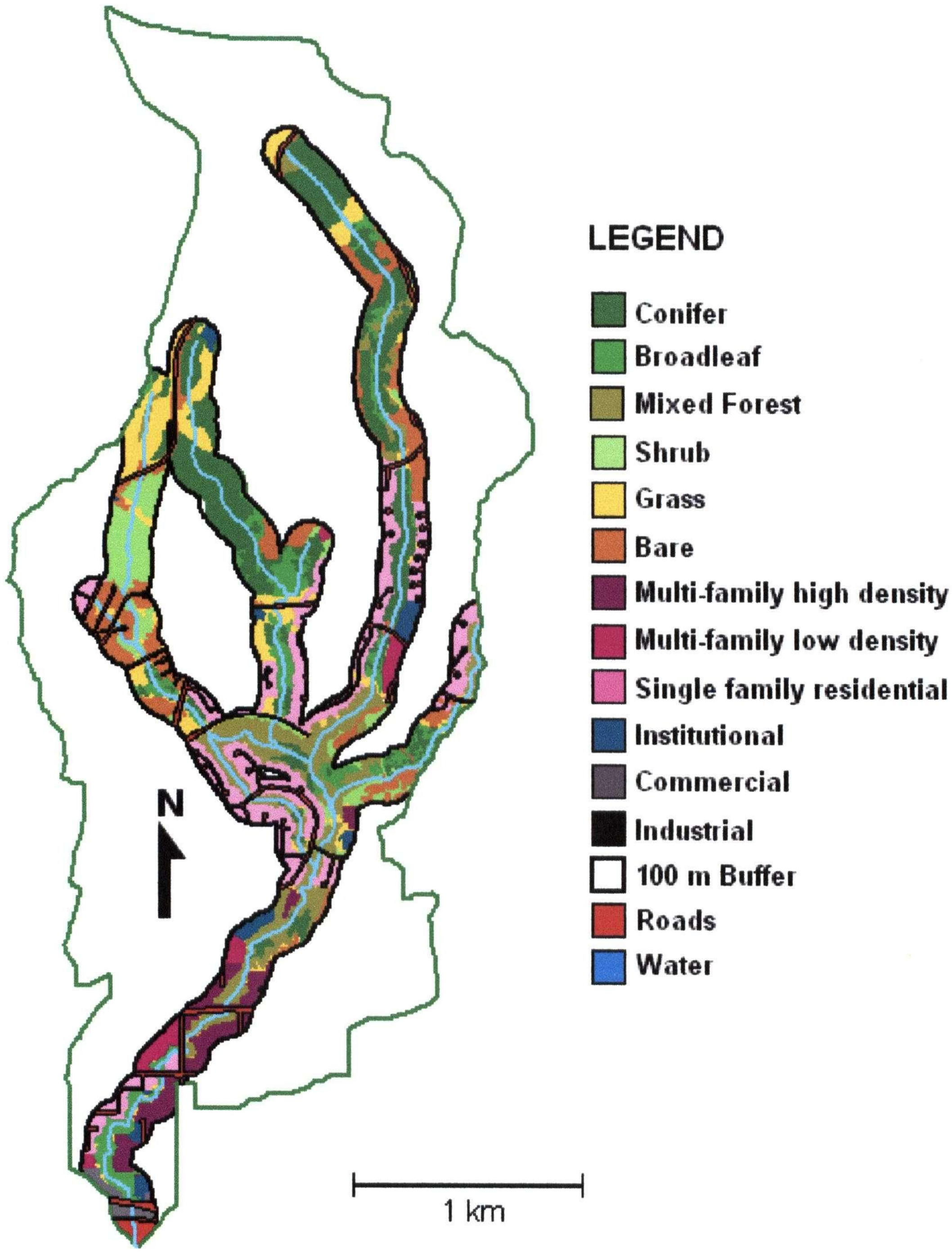

Figure 4.2-2 Land Use and Land Cover within 100 m of Hoy Creek

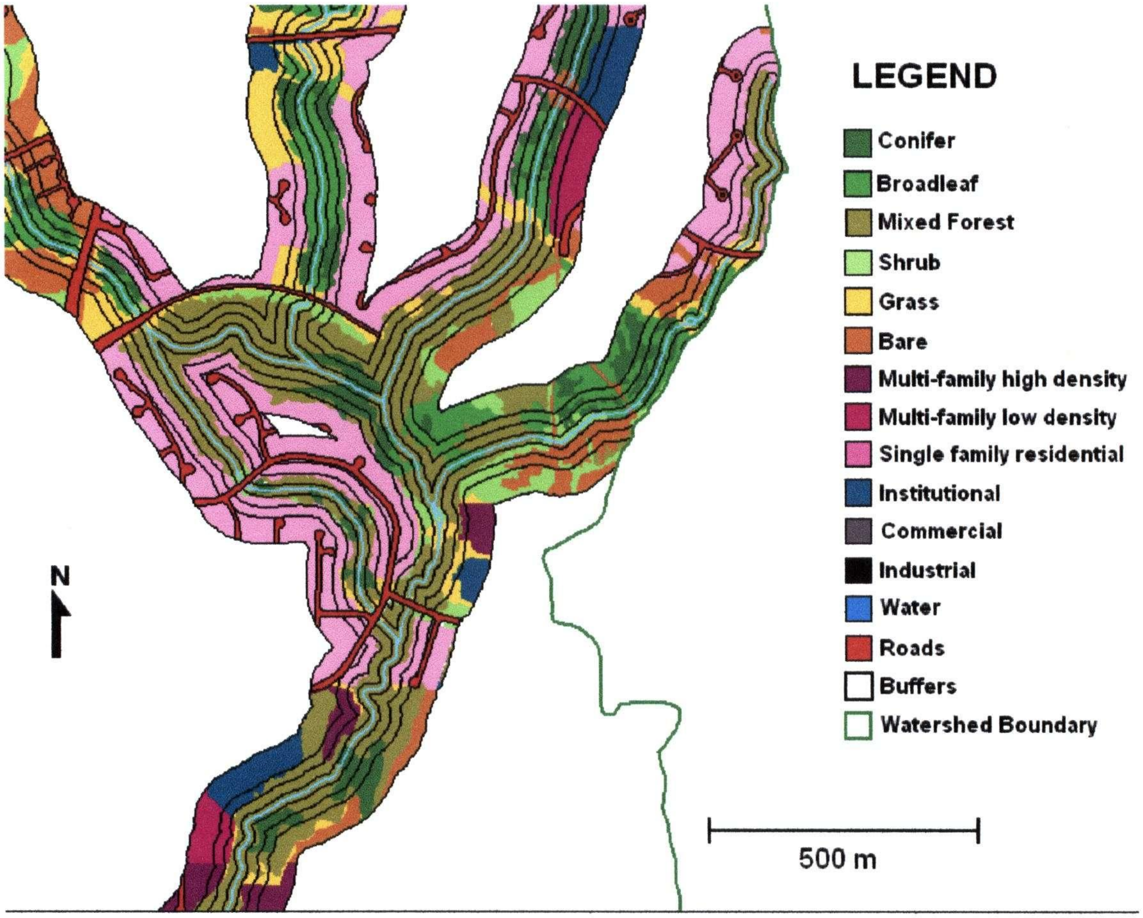

Figure 4.2-3 Land Use and Land Cover within 100 m of Hoy Creek in closer detail

Land Use differences between buffers

From the buffer zone land use maps one can see that land use/cover varies with buffer width. As buffer width increases the proportion of land covered by vegetation decreases and the proportion of developed land increases.

Vegetated land has a much greater buffering capacity than developed land; the more vegetation in the buffer zone the better the land is likely to be at buffering the creek. Forest is generally considered to have the greatest buffering capacity of all land use practices.

The Hoy Creek watershed has 76.3% of its land within 10 m of the creek covered by forest. This value falls to 41% covered by forest within 100 m of the creek. Shrub and grass in the riparian can also provide a great deal of protection for a stream. The 10 m buffer is composed of a large proportion of vegetated land relative to developed land. The ratio drops as buffer width increases. This can be seen in Figure 4.2-4.

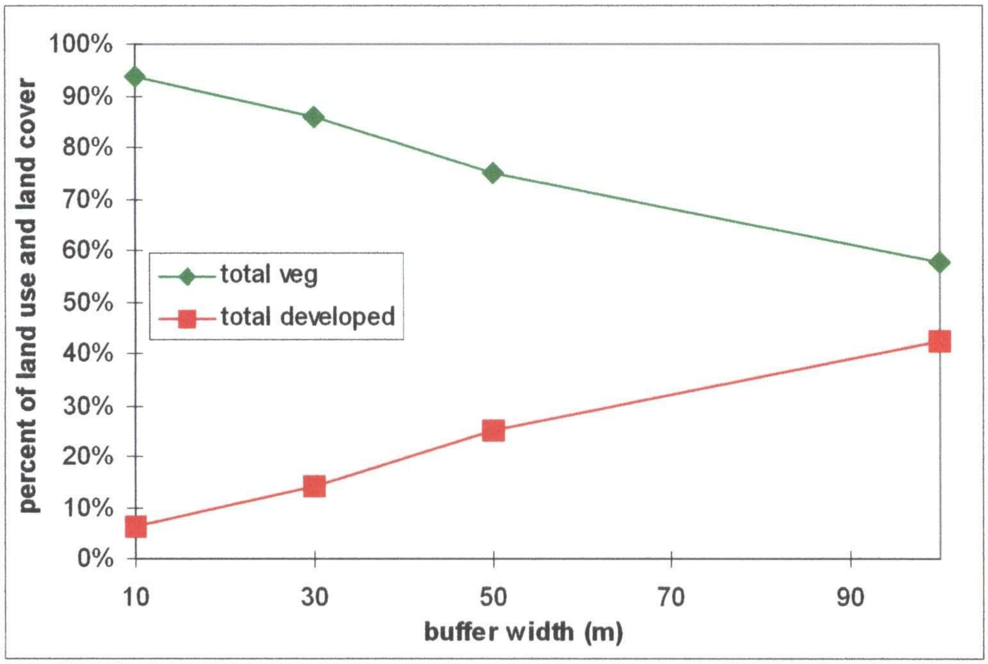

Figure 4.2-4 Changes in vegetation and development across Hoy Creek buffer zones

Vegetation

The percentage of area covered by grass and shrub remains fairly constant as buffer width increases. This is because land covered by these two categories generally covers fairly broad expanses that span the creek and extend beyond 100 m from the creek. The changes in vegetation across buffers have been summarized in Figure 4.2-5.

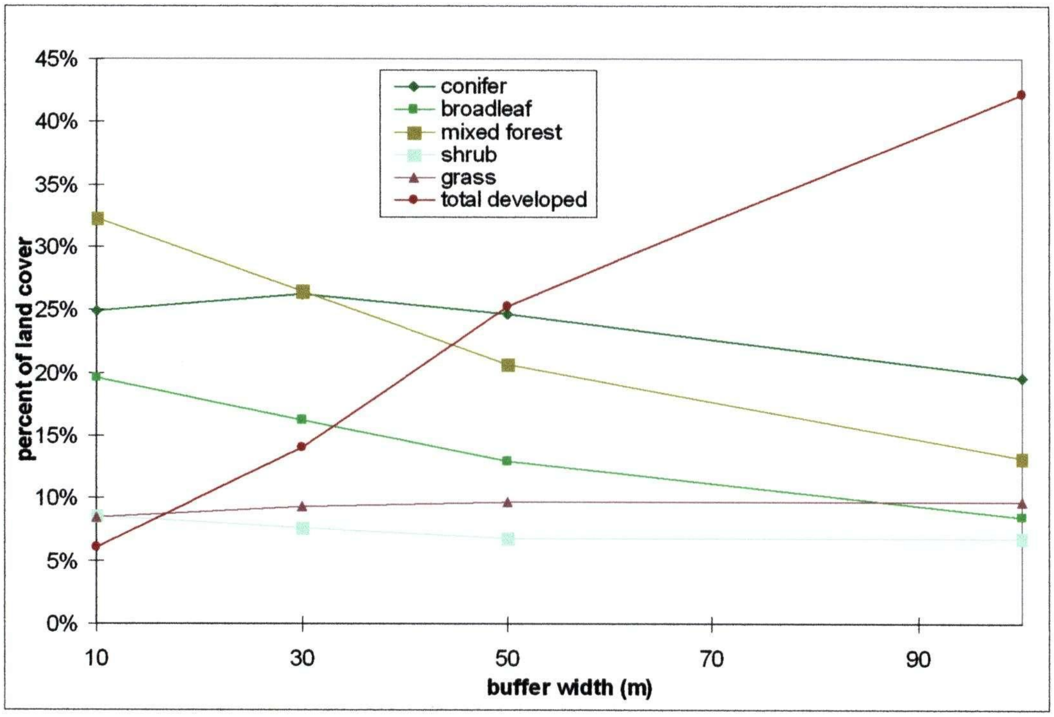

Figure 4.2-5 Land cover changes across Hoy Creek buffers

The percentage of land covered by mixed and broadleaf forest decreases with increasing buffer width. This decrease occurs at nearly the same rate for both forest types with mixed forest percentages falling off to a slightly greater degree. The percent of buffer covered by conifer forest in each of the buffer zones remains relatively constant compared to broadleaf and mixed forest. The differences in vegetation cover as buffer width increases are largely due to the location and topography. The majority of the conifer forest that exists in the watershed is in the upper watershed. The land on which the forest grows is fairly steep and rocky. This has limited development and hence encroachment into the riparian. Therefore, conifer forest can be seen to cover fairly broad expanses that span the creek and extend beyond 100 m from the creek. Broadleaf and mixed forests are more abundant in the lower watershed where the land is much flatter and development was not as limited. Therefore, development has encroached into the riparian and the area covered by these trees decreases away from the creek.

Development

The percent of multi-family low density, institutional, commercial and industrial land use remains fairly constant and low regardless of buffer width. The area covered by mfHd increases slightly with increasing buffer width, from 0.4% to 5.1%. It is sfr and bare land that increases the most with increasing buffer width. Bare land increases from 3.1% of the total 10m buffer area to 12.7% of the total 100m buffer. Single-family residential increases at the greatest rate climbing from 0.7% of the 10m buffer to 18% in the 100m buffer. The changes in development with changing buffer width have been summarized in Figure 4.2-6.

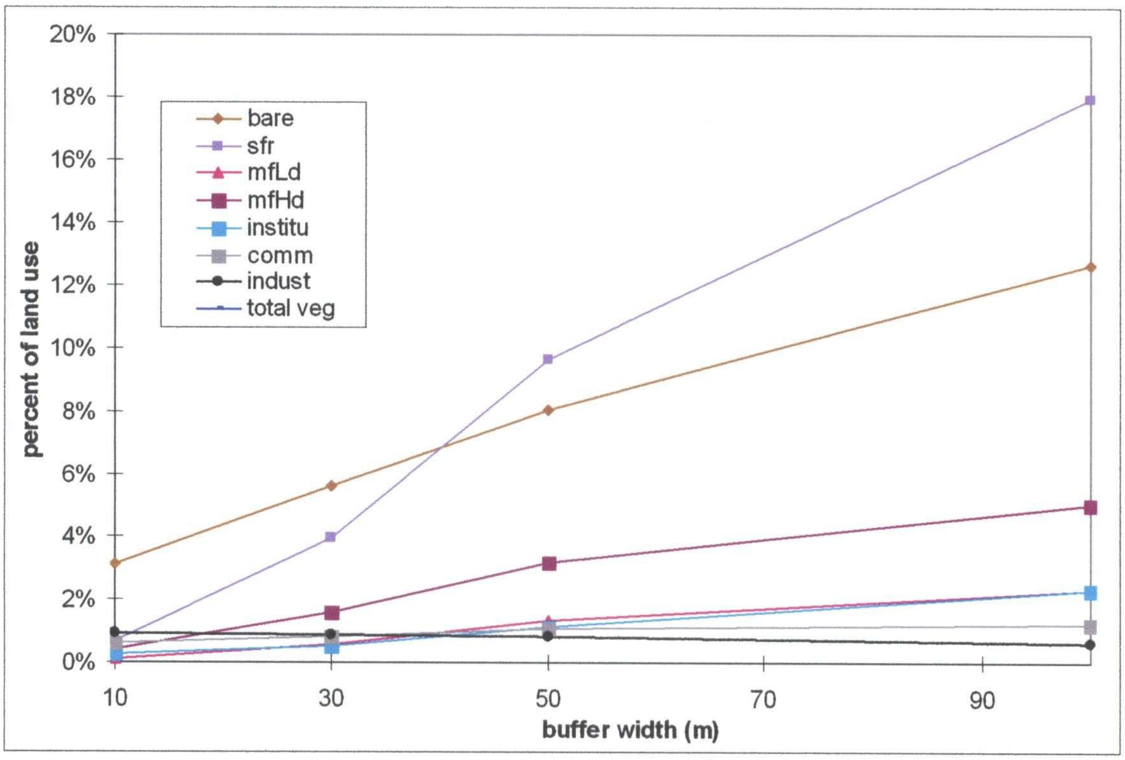

Figure 4.2-6 Land use changes across buffer zones

The more pronounced increase in sfr compared to that of mfLd and mfHd as you move away from the creek is due, in part, to topography and location. In the lower watershed, where multi-family housing predominates, the topography is fairly flat and development is older. Because of this it was easier to develop closer to the creek. In the upper watershed, where single family dwellings predominate, the creeks generally run through ravines that are quite steep. The terrain would have limited development. Also, development in the upper watershed is newer and building restrictions would have helped to protect the riparian from encroachment.

Land Use within each buffer

The land immediately adjacent to a creek is more likely to play a role in buffering the creek from upslope land use practices. Because of this the land use within the 10 m buffer is of vital importance.

The 10 m Buffer

The land within the 10 m buffer, summarized in Figure 4.2-7 is largely vegetated. 93.8% of the 10 m buffer is covered by vegetation, most of which is forest. 76.8% of the buffer is covered by conifer, broadleaf and mixed forest, 3% is developed and 3.1% is bare and slated for development. All other developed land use categories cover less than 1% each of the total buffer area. Total impervious area within the 10 m buffer is 4.3%. This value is relatively low and indicates the land immediately adjacent to the creek may provide a buffering capacity that approximates more natural conditions.

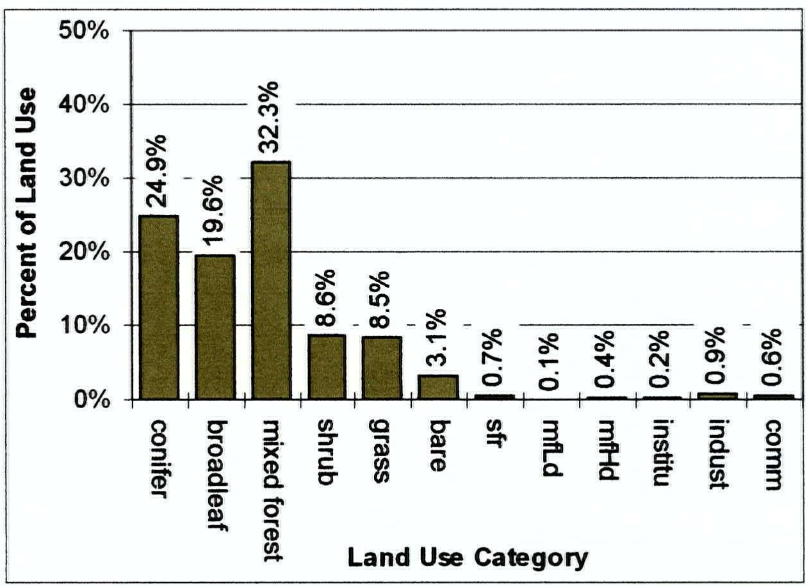

Figure 4.2-7 Land use within the 10 m buffer

The land beyond 10 m from the creek also plays a role in buffering the creek ecosystem. In fact, the buffering capabilities of the land within 10m of the creek may be inadequate for buffering the creek from the effects of some land use practices such as increased erosion from cleared land or over fertilization of lawns . Therefore, land use within each of the buffer zones is of interest.

The 30 m buffer

The 30 m buffer has more developed land and, therefore, less vegetation than the 10 m buffer. 86% of the 30 m buffer is covered by vegetation. Again, most of this is forest which covers 69% of the buffer. Developed land covers 14% of the buffer. This increase in developed land is due to a greater extent of bare and single-family residential within this buffer compared to the 10 m buffer. Bare land covers 5.6% and sfr covers 4% of the buffer. All other developed land use categories cover less than 1% each of the total buffer area and residential covers 6.2%. TIA for the 30 m buffer is 7.3% which is still below the commonly accepted threshold of 10%. The land use/cover data have been summarized in Figure 4.2-8.

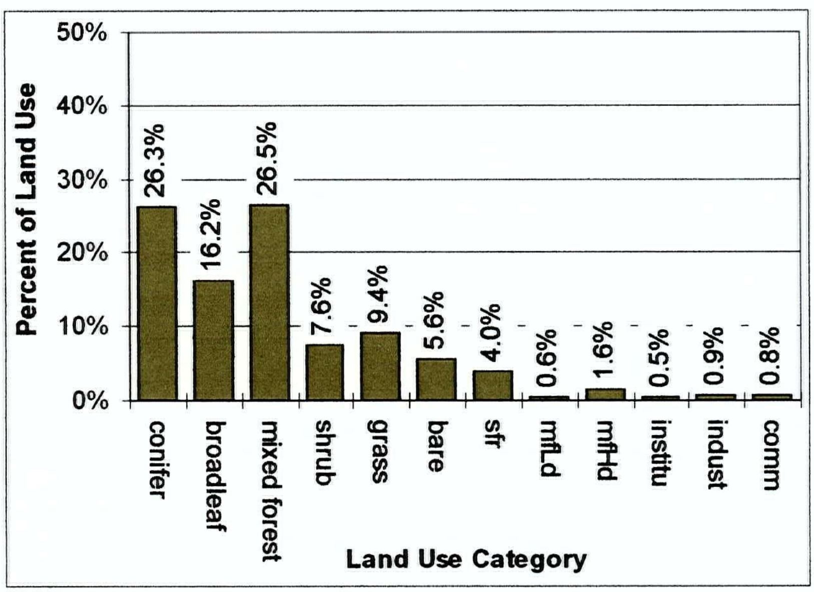

Figure 4.2-8 Land use within the 30 m buffer

The 50 m buffer

In the 50 m buffer the degree of development continues to increase. Only 74.8% of the 50 m buffer is covered by vegetation. The majority of vegetation remains as forest at 58.3% of the total buffer area. Again, bare and sfr cover the majority of the developed land within the 50 m buffer. Here we see 25.2% of the buffer is developed with 8.1% of that covered by bare land, 9.6% covered by sfr and 14.1% covered by the residential land use categories. The TIA within the 50 m buffer is 11.8% which exceeds threshold levels. This data have been summarized in Figure 4.2-9.

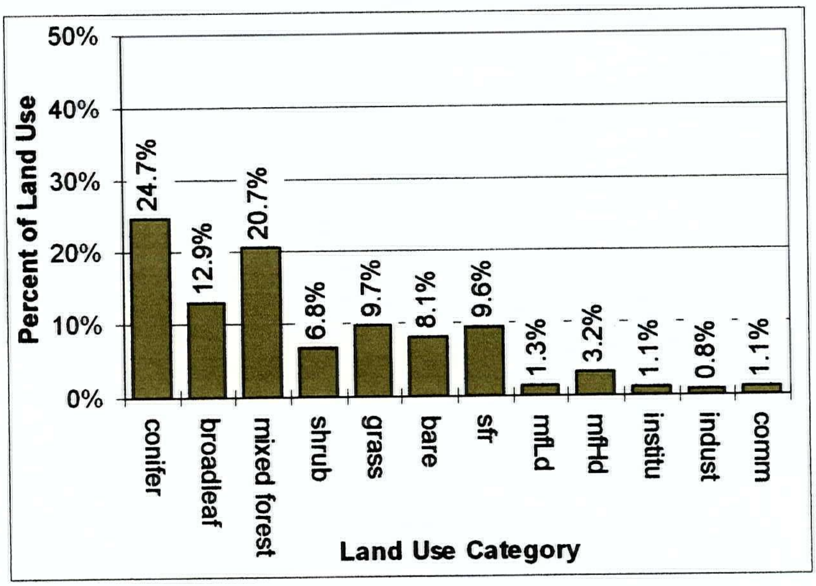

Figure 4.2-9 Land use within the 50 m buffer

The 100 m buffer

Land use within the 100 m buffer is 57.7% vegetation, again with most of the vegetation being forest. Nearly 20% of the 100 m buffer is covered by conifer forest and another 21.7% is covered by broadleaf or mixed forest. Developed land covers 42.3% of the 100 m buffer. This is comprised largely of single-family residential and bare land at 18% and 12.7% respectively. In the 100 m buffer, summarized in Figure 4.2-10, there is 25.4% of the total buffer area covered by residential land use and TIA is 18% which considerably exceeds threshold levels.

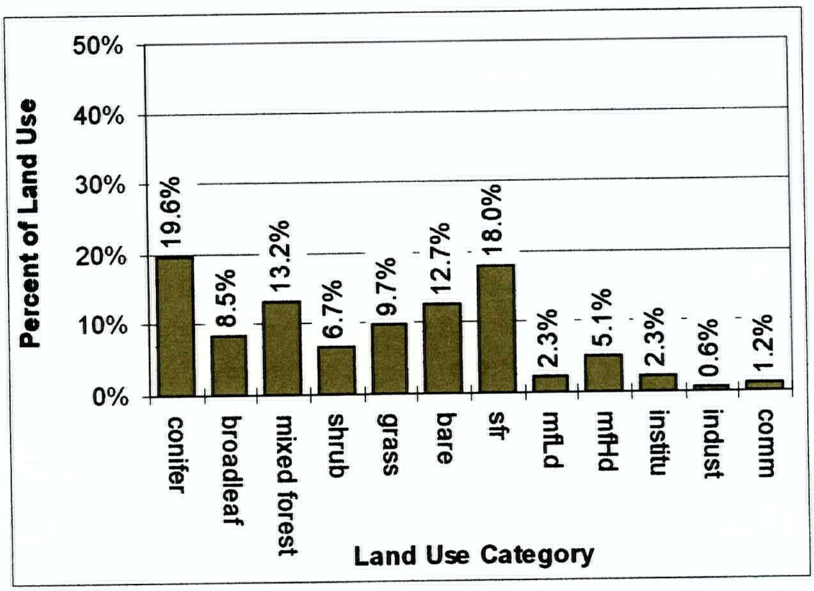

Figure 4.2-10 Land use within the 100 m buffer

4.2.2 Riparian Integrity

Continuity of the riparian is important for maintaining effective buffering capacity. Breaks in the riparian area can provide direct pathways for contaminants to enter the creek. In this way downstream reaches are affected by land use practices upstream. An adequate buffer in the lower reaches of a stream can be compromised by breaks in the riparian upstream.

Crown closure is also considered to be a good indicator of riparian effectiveness. The canopy of the riparian vegetation serves to shade the creek from the heat of the sun thereby allowing stream temperatures to remain low (Lowrance, et. al., 1985). A high degree of crown closure also represents a source for large woody debris, organic matter and habitat diversity. The crown closure and tree height were determined for most of the creek during fieldwork between July and September. Crown closure for the portions that were not accessible for walking was determined from nearby roadways and orthophotos.

The combination of vegetation cover within the buffer zones and crown closure can be more informative than either separately. When crown cover is high and vegetation cover is high one can expect buffering capacity to be relatively high. With high crown closure and high vegetation cover out to the 100 m buffer buffering capacity should tend toward a maximum. Minimum protection to the creek can be expected where there are low proportions of vegetation cover, especially within 10 m of the creek, combined with low crown closure and a road crossing. It is in these areas that land use practices can have the greatest impact. Roadways are very efficient carriers of runoff and pollution. Road crossings represent a break in the riparian and a more direct pathway for contaminants and surface runoff to enter the creek (Arnold and Gibbons 1996, Horner and May 1999). Also, the presence of a road means the absence of riparian vegetation. In these ways the buffering capacity of the land from upslope and upstream practices is diminished. Hoy creek has 21 road crossings.

In order to pinpoint areas of the riparian with low crown closure or breaks in continuity the Hoy Creek network was simplified into its three main branches, Hoy Creek main branch (upper and lower reaches), North Hoy and West Hoy. The simplification was based on a combination of Coquitlam base maps and ground-truthing to determine the first order creeks which were ephemeral or too small to consider for the study. The simplified creek system is illustrated in Figure 4.2-11.

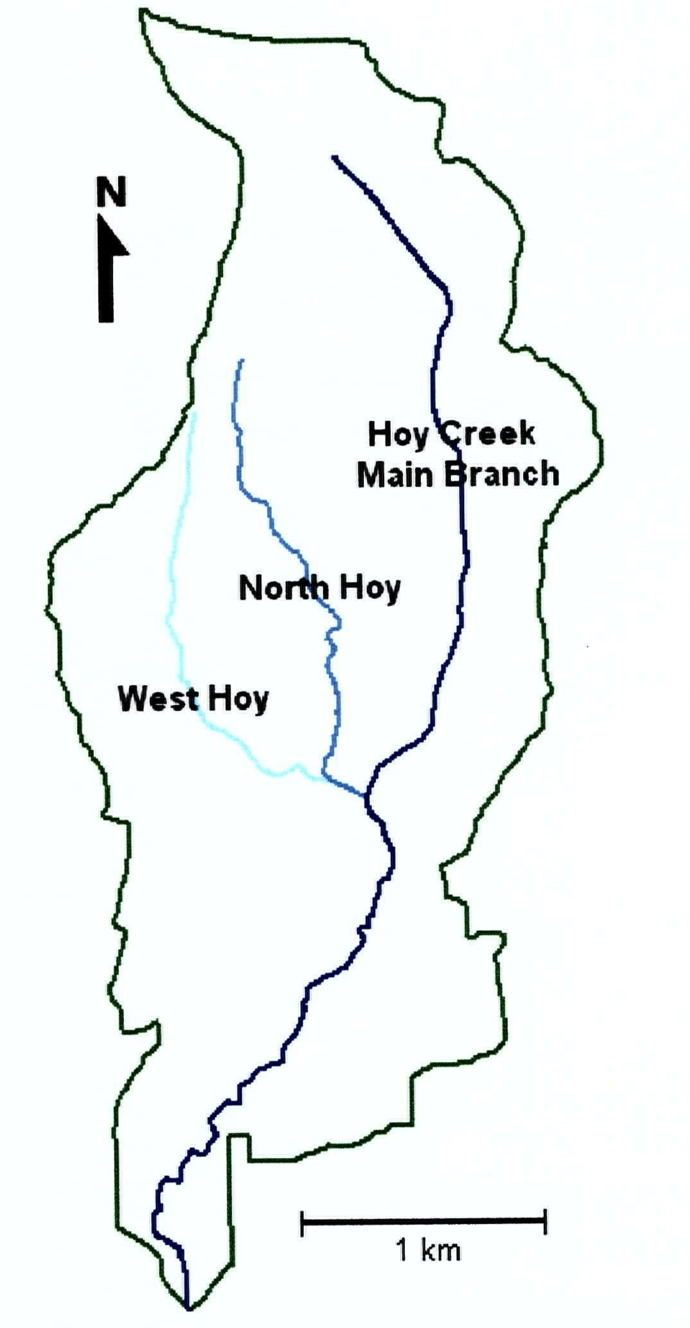

Figure 4.2-11 Hoy creek branches

Using the GIS, the 10 m 30 m, 50 m and 100 m buffers were divided into reaches of 200 m in length starting at the top of the watershed and the percent of vegetation within the buffers for each reach was mapped from the watershed vegetation maps already produced. Roadway and developed land was also mapped for each segment. Land use for each of the tributaries is illustrated in Figure 4.2-12 and Figure 4.2-13.

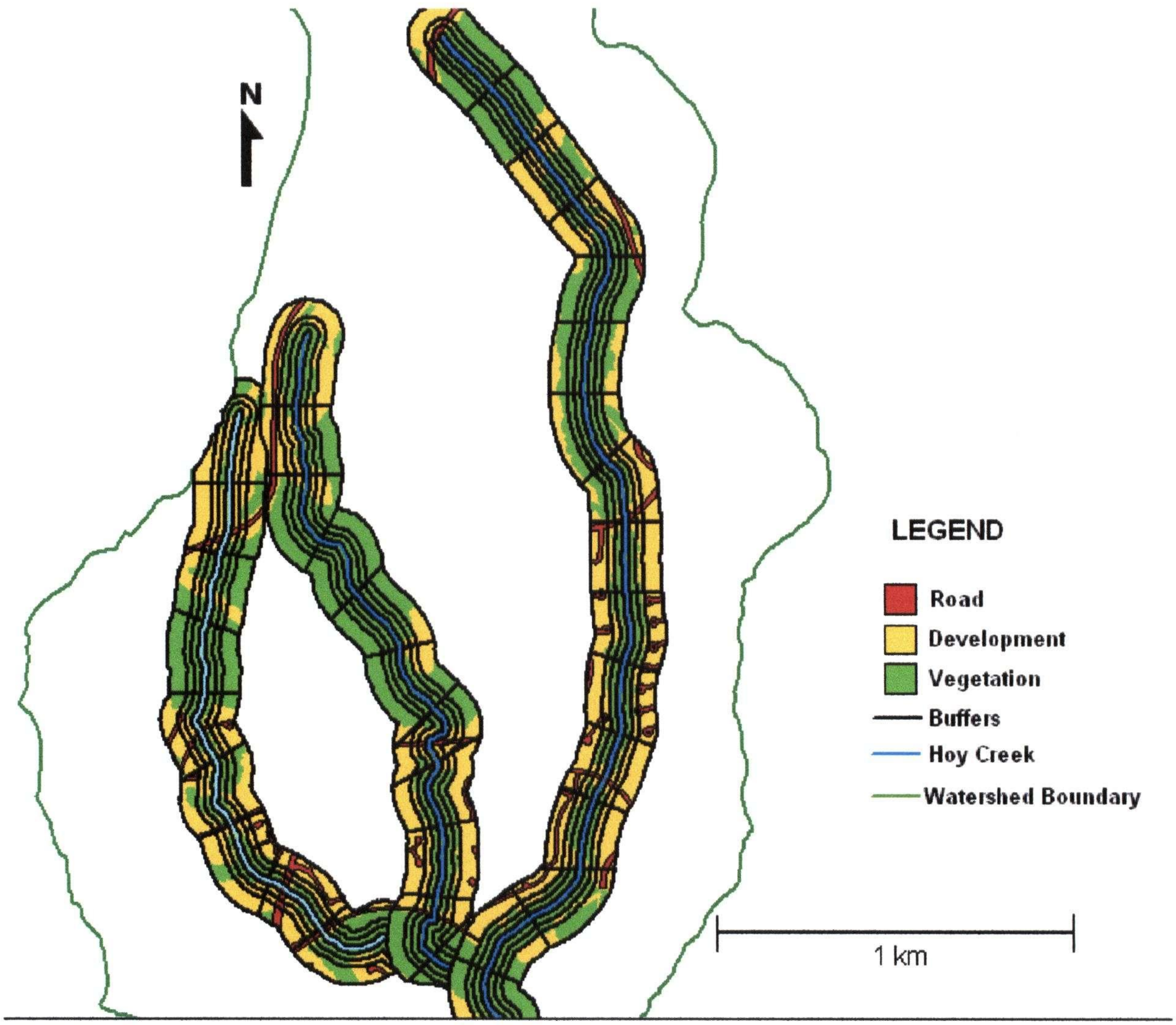

Figure 4.2-12 Land use within the buffers of the upper branches of Hoy Creek

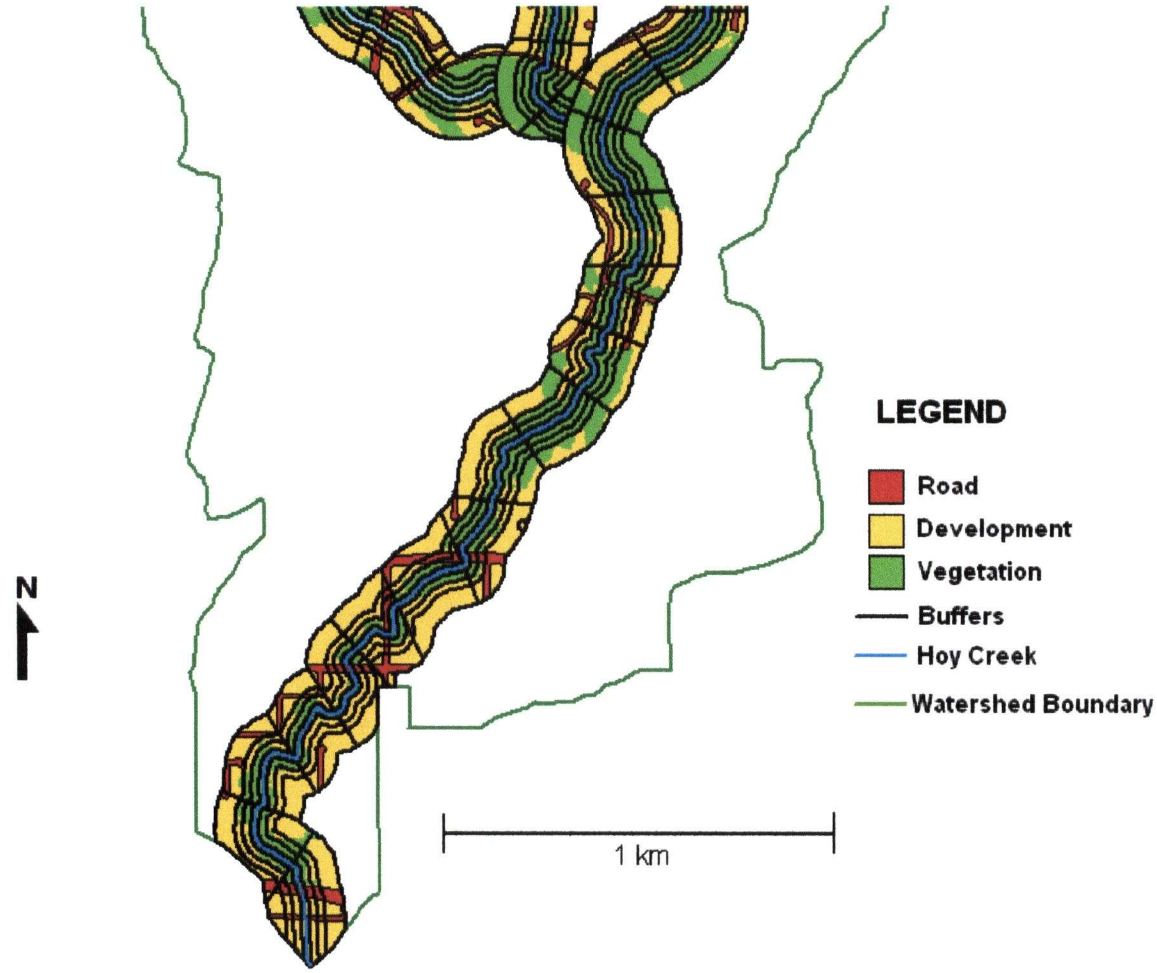

Figure 4.2-13 Land use within the buffers of the lower branches of Hoy Creek

The three main branches of Hoy creek converge near the middle of the watershed. Therefore, the cumulative effects of land use within each of the upper branches impacts the lower reaches of the main branch of Hoy Creek. The land use data was tabulated and graphed and reaches in which road crossings occur were identified.

Differences Between Branches

Comparison of each of the branches of Hoy Creek indicates differences between the branches. These differences have been graphed in Figure 4.2-14.

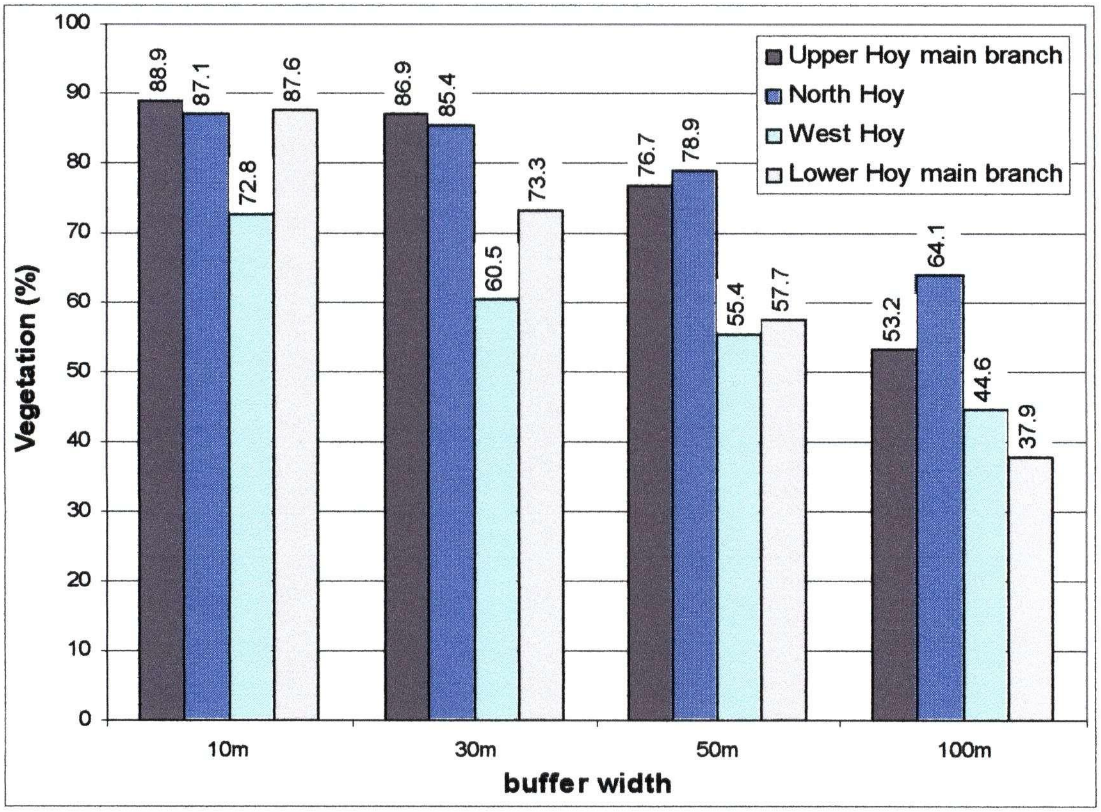

Figure 4.2-14 Average vegetation for all reaches of Hoy Creek branches above the confluence

Of the upper branches of Hoy Creek; upper Hoy main branch, North Hoy and West Hoy, it can be seen that West Hoy has the lowest average vegetation cover for all buffer widths. In fact, vegetation cover along West Hoy is even lower than that of the lower reaches of Hoy main branch except within the 100 m buffer. Within 100 m from the creek there is only 37.9% vegetation along the lower Hoy and 44.6% along West Hoy. Recall that the lower reaches of Hoy main branch run through relatively dense development. The diminished vegetation cover along West Hoy indicates a high level of development. In fact, West Hoy runs through a golf course and new development. The combination of these two land use practices contributes to the low proportion of vegetation along West Hoy Creek.

Upper Hoy

The upper reaches of the main branch of Hoy Creek runs through remnants of the watershed's conifer forest. Because of this crown closure is relatively high for the upper

2200 m of creek length. Buffer zone vegetation cover is diminished in the area where the creek runs through the golf course and new development (400-800 m reaches). Vegetation cover is also low in the 1400-1800 m reaches where the creek passes near new development. Vegetation cover is low in the 10 m and 30 m buffer from 1400 m down to the confluence. This is where residential development encroaches on the riparian zone. Crown closure is also seen to diminish in the area from 2000 m. Two road crossings occur on the upper reaches of the main branch; on the 1400-1600 m reach and on the 2200-2400 m reach, both of which have diminished vegetation cover. These are important locations where land use impact can have the greatest effect on the creek ecosystem. These locations occur where Plateau Blvd and Robson Dr each cross Hoy creek and represent areas at which stormwater BMP such as infiltration ponds would aid in diminishing the effects of land use practices.

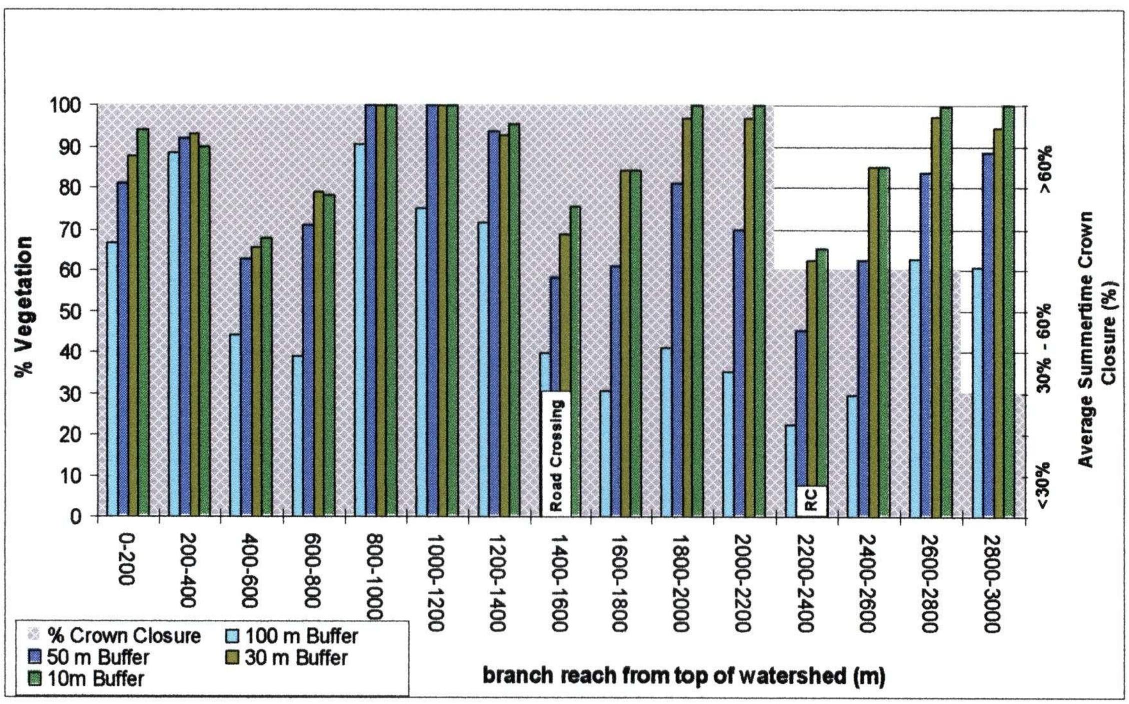

Figure 4.2-15 Vegetation cover, crown closure and road crossings for the upper reaches of the main branch of Hoy Creek

North Hoy

The north branch of Hoy Creek has a large proportion of reaches covered by greater than 60% vegetation. In fact, all but two reaches within the 10 m, 30 m and 50 m buffer have vegetation greater than 60%. The reaches where crown closure is low coincides with areas of low vegetation cover. One of these reaches (200-400 m) runs through the golf course and the 1200-1400 m has a road crossing. These are key locations where land use practices can have a large impact on the creek. The potential impact from the location, where Plateau Boulevard crosses North Hoy Creek, could be lessened by implementing stormwater mitigation measures, such as infiltration ponds, which impede runoff from reaching the creek directly. This data has been combined and summarized in Figure 4.2-16.

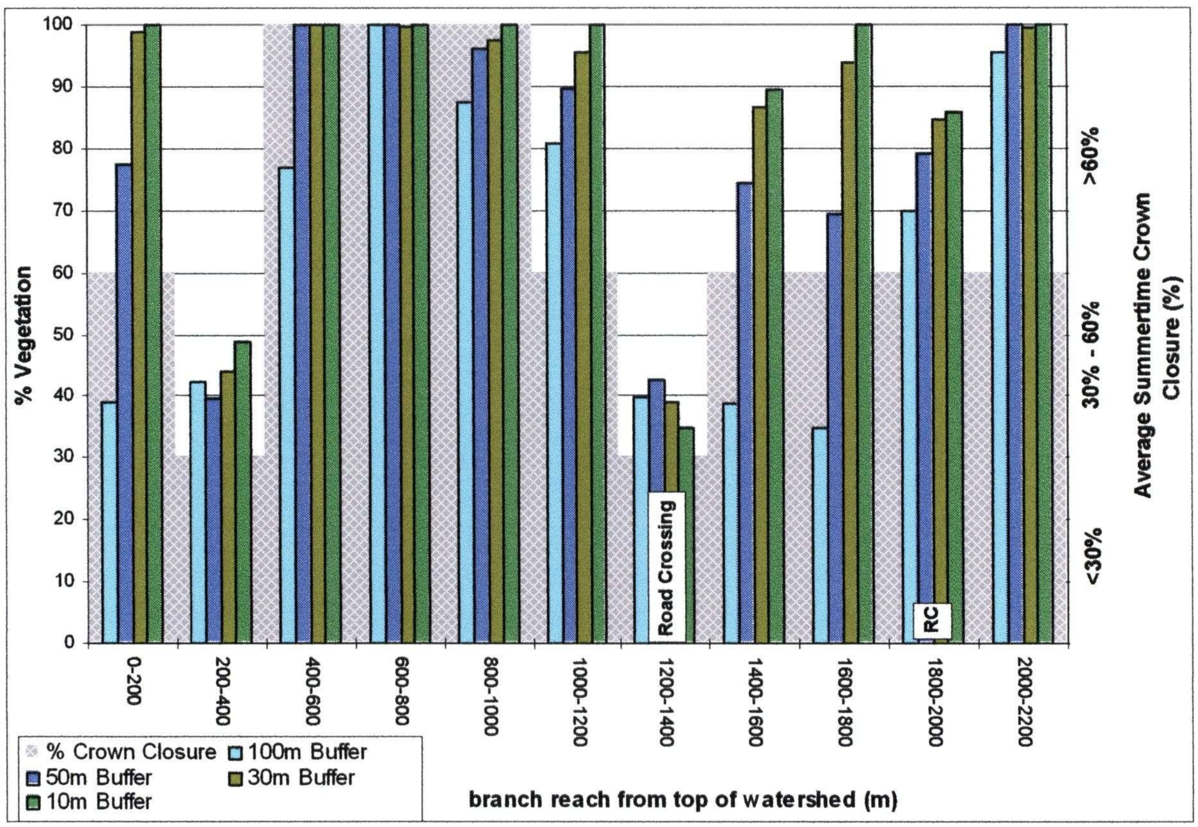

Figure 4.2-16 Vegetation cover, crown closure and road crossings for North Hoy Creek

West Hoy

West Hoy creek has considerably less vegetation cover relative to the other braches of Hoy Creek. Vegetation cover rises to near 100% for only one reach. Nearly all reaches within the 50 m and 100 m buffer have less than 60% vegetation. The 0-400 m reaches have a very low proportion of vegetation cover for all buffer widths. This area lies largely within a golf course and is where Parkway Boulevard crosses West Hoy Creek. Vegetation cover and crown closure are higher for the reaches from 400 m to 1200 m but two roads cross the creek in this area. Although the 1200-1400 m reach has a vegetation cover of 80% within the 10 m buffer, there is a road crossing (Rockcress Place) and low crown closure along this reach. This then is another area in which land use practices could have a large impact. The reach from 1400-1600 m also has diminished vegetation cover with crown closure at 30-60% combined with a road crossing. This is where Panorama Drive crosses over West Hoy Creek and could also be a key location to watch for impact from land use practices. It is also of interest to note that the West Branch of Hoy Creek has a large number of road crossings with six crossings in 1800 m of creek. This data has been combined and summarized in Figure 4.2-17.

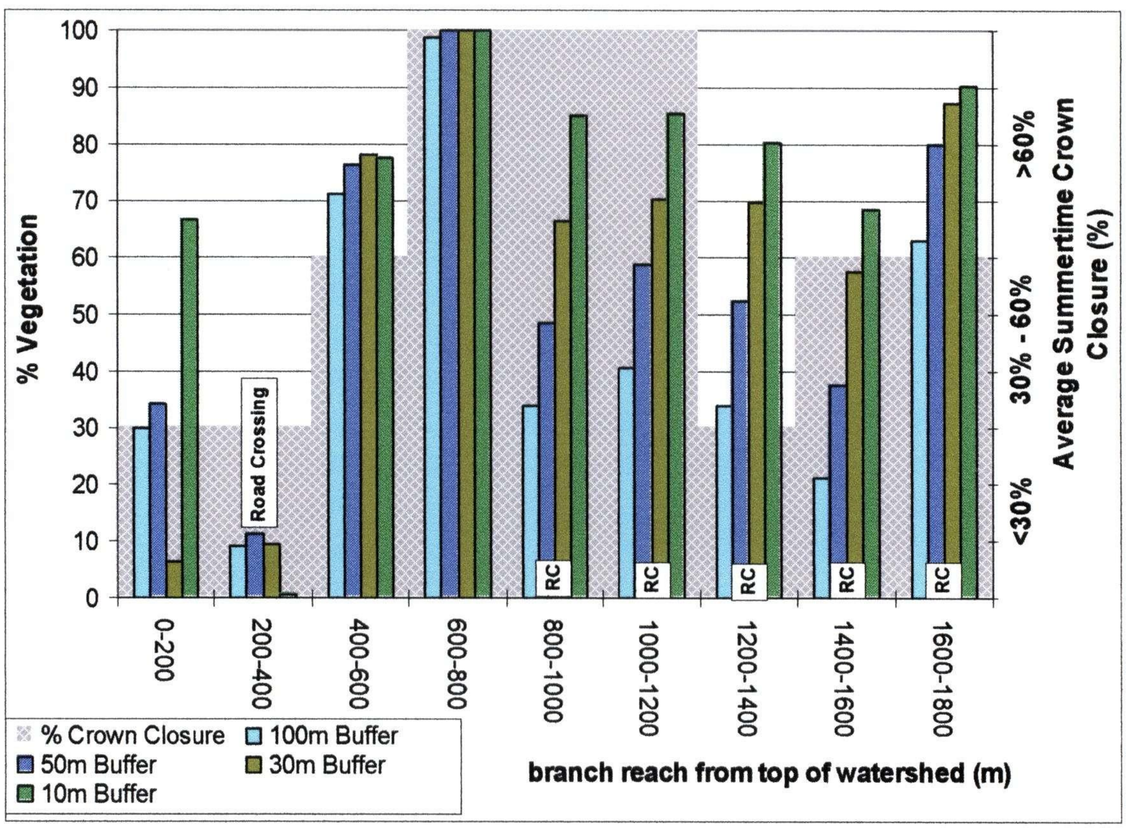

Figure 4.2-17 Vegetation cover, crown closure and road crossings for West Hoy Creek

The high proportion of road crossings combined with low vegetation cover and diminished crown closure within this branch of Hoy creek could cause this branch to be a major contributor to downstream impact of the entire lower creek system; therefore, implementation of stormwater BMP would be vital on this branch.

Lower Hoy

There is a decline in vegetation cover in the lower reaches of Hoy main branch. This decline is particularly evident within the 50 m and 100 m buffers and the lower reaches of the 30 m buffer. As well, nearly all of the lower reaches of the main branch of Hoy Creek have a crown closure less than 30%. The lower reaches of Hoy Creek flow through the area of the watershed that is the most densely developed. Therefore, this drop in vegetation cover is as expected. There are five reaches within the 10m buffer that have almost 100% vegetation cover but this can be seen in only one reach within the 30 m buffer. Three reaches have particularly low vegetation cover as well as road crossings (Glen Drive, Johnson Street and Guildford Way). The lowest reach, 5600-5800 m, has extremely low vegetation cover, less than 30% crown closure and two road crossings (Barnet Highway and Aberdeen Avenue). This data has been combined and summarized in Figure 4.2-18.

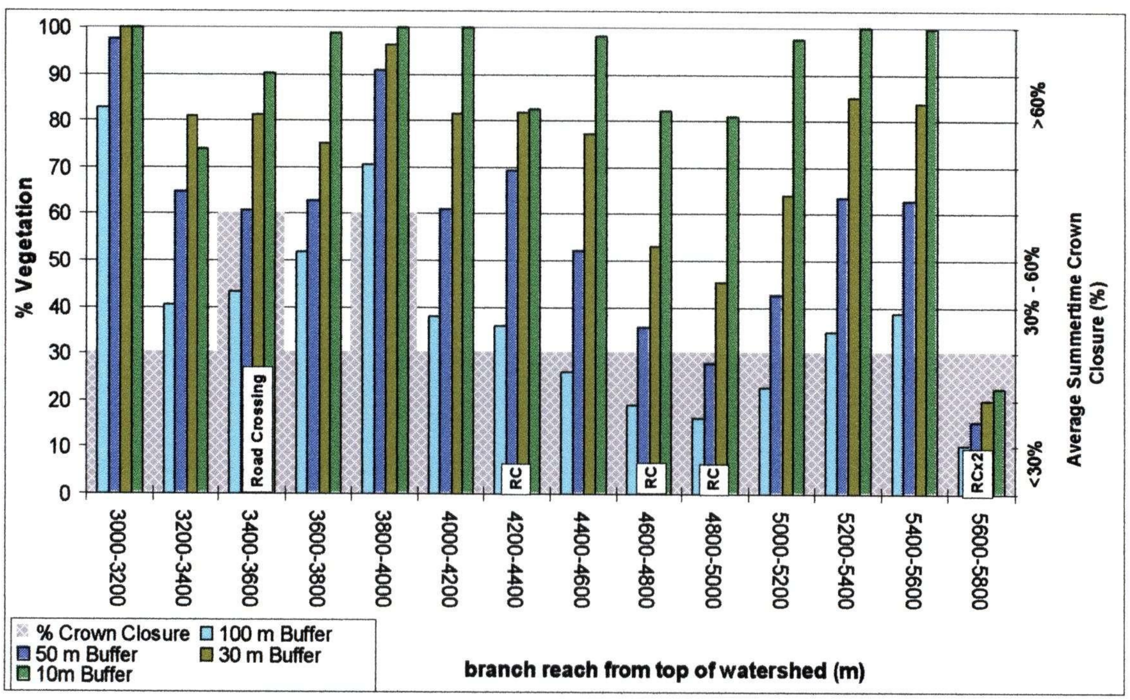

Figure 4.2-18 Vegetation cover, crown closure and road crossings for the lower reaches of Hoy Creek

It is within the Lower Hoy where the fish hatchery is located, approximately 4200 m from the top of Hoy Creek. Crown closure is quite low here (<30%) but the percent of vegetation within the 10 m and 30 m buffer is above 80%, while the nearest road crossing is approximately 700 m upstream. Risk of impact from land use practices is quite high in the lower watershed where development is highest and riparian protection is lowest; therefore, stormwater BMPs are of vital importance in this portion of the watershed.

4.3 Soils within the Hoy Creek Watershed

Soil plays an important role in buffering capacities and runoff characteristics. A very compact soil will have low permeability which could lead to a greater degree of surface runoff. Coarse soils have relatively diminished buffering capacity and may provide less filtering protection for the creek. Soils within the Hoy Creek watershed were mapped using the GIS in order to gain an indication of the spatial variability of soil characteristics relative to the creek. Because soils play such an important role in runoff, the soil hydrological conditions were considered in conjunction with land use/cover. Soil penetration resistance data was determined as a surrogate of infiltration/percolation rates for the various soil/land cover combinations. Penetrometer measurements were made at sites with different combinations of soil and land cover types and the penetrometer was then calibrated against percolation rates at eleven sites. The digitized soil map is illustrated in Figure 4.3-1.

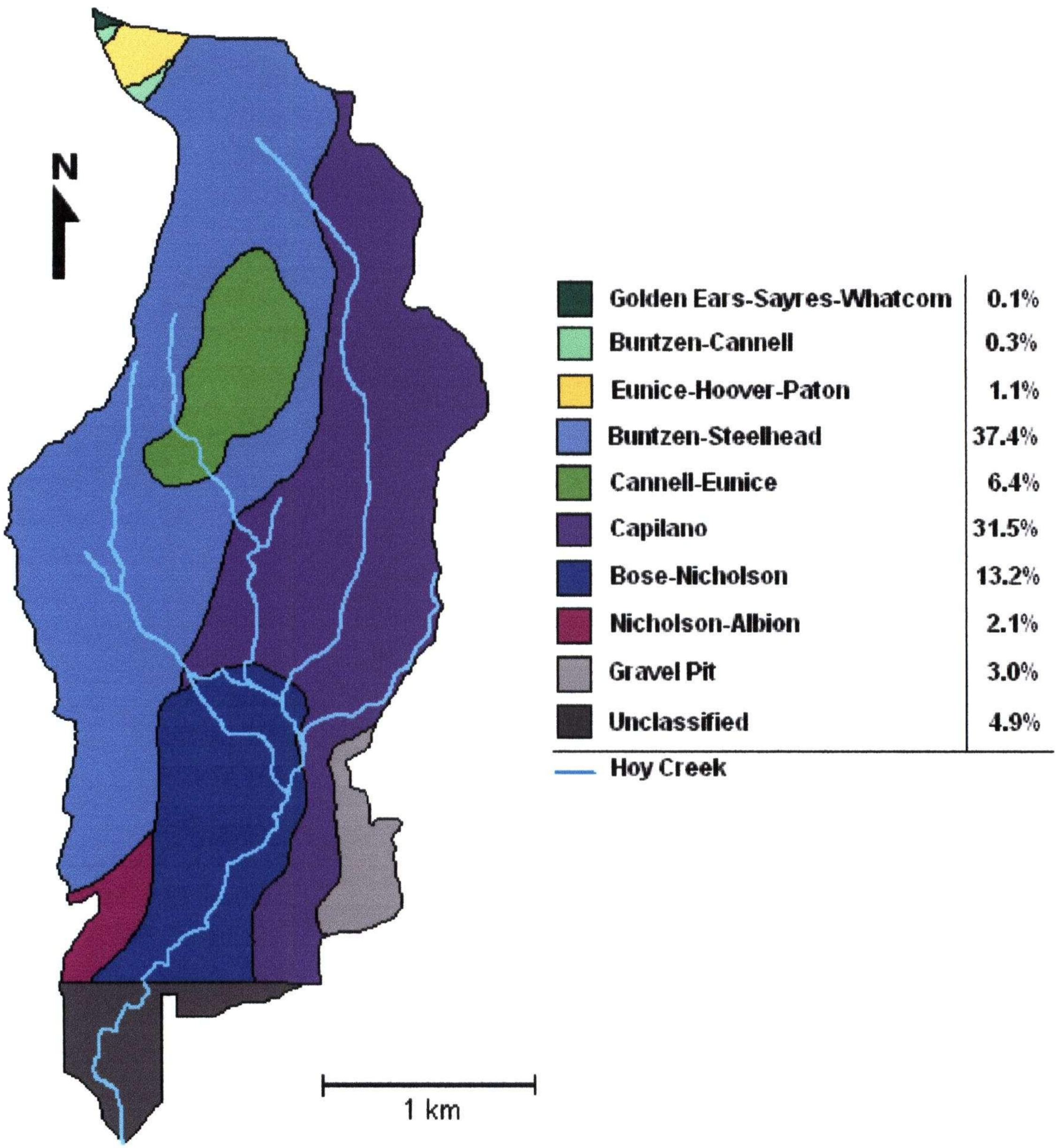

Figure 4.3-1 Soils within the Hoy Creek watershed (adapted from the Soil Map of Maple Ridge, Pitt Meadows, Coquitlam Area, 1972, Soils Division of the British Columbia Department of Agriculture)

4.3.1 Extent and Description of Soils in Hoy Creek Watershed

As shown in Table 4.3-1 nearly 40% of the soils were classified as well to rapidly draining, while only a small proportion of the soils fell into the poorly drained category.

Soil Name	Drainage	Area of watershed (%)
[1]Buntzen - [2]Steelhead (BZ-ST)	[1]moderately well, telluric seepage - [2]imperfect, perched water table, telluric seepage	37.4%
Capilano (CP)	well to rapid	31.5%
[1]Bose - [2]Nicholson (BO-N)	[1]well to moderately well, telluric seepage - [2]moderately well, telluric seepage	13.2%
[1]Cannell - [2]Eunice (CE-EU)	[1]well to rapid - [2]well to rapid	6.4%
Unclassified		4.9%
[1]Nicholson - [2]Albion (N-AB)	[1]moderately well, telluric seepage - [2]moderately poor to poor, perched water table	2.1%
previous gravel pit		3.0%
[1]Eunice - [2]Hoover - [3]Paton (EU-HV-PN)	[1]well to rapid - [2] moderately well, telluric seepage - [3]well	1.1%
[1]Buntzen - [2]Cannell (BZ-CE)	[1]moderately well, telluric seepage - [2]well to rapid	0.3%
[1]Golden Ears - [2]Sayres - [3]Whonnock (GE-S-WH)	[1]moderately well - [2]moderately well, telluric seepage - [3]imperfect, telluric seepage	0.1%

Table 4.3-1 Classification and extent of soils within the Hoy Creek watershed

(for soil complexes, the mapping units which consist of two or more classified soils, it is the first soil indicated which occupies the major portion of the map unit).

The British Columbia Department of Agriculture indicates that most of the soils within the Hoy Creek watershed are soils of the Podzolic order, with the exception of one Luvisol, one Folisol and one Gleysol, each of which occupy only a minor portion of the corresponding map unit. With the exception of Eunice (a Folisol) and Nicholson and Albion (Luvisols) all soils within the watershed are derived from parent material that is glacial in origin and gravelly, coarse and moderately coarse textured. The Luvisols are derived from parent material that is medium and moderately fine textured.

The drainage of the soils within the watershed is generally classified as moderately well to rapid. Two soils are classified as having poor or imperfect drainage with two exceptions of imperfect drainage (Steelhead and Whonnock) and one of moderately poor (Albion). Many of the soils have duric horizons or overlie bedrock, both of which can impede water flowing downward through the soil and may to experience telluric seepage during heavy rains. The compact, cemented or fine textured subsoil layers can also give rise to surface runoff once the upper layers become saturated. In addition, surface layers have been removed in much of the watershed as development has occurred thereby exposing the compact subsoil and increasing the likelihood for surface runoff.

The BC Department of Agriculture also quantifies slopes within the watershed. The Nicholson-Albion soil complex lies over land that has a slope from 5% to 15%. This is as expected as this complex occurs in the lower watershed. Three soils lie on land that has a slope from 9% to 30% (Buntzen-Steelhead, Capilano, Bose-Nicholson). All other soils occur on land that has a slope greater than 15%. Steep slopes can exacerbate surface runoff which can lead to increased erosion since the water has a diminished opportunity for infiltration or retention in surface depressions.

It is important to note that nearly all soils within the watershed are coarse textured. Soils of this nature are not only considered to be well draining but they also tend to have lower cation exchange capacity (Brady, 1996). This is partly because coarse particles have a lower specific surface area relative to fine textured particles. The low specific surface means the particles have fewer bonding sites which would otherwise be available for adsorbing cations. In this way these bonding sites play an important role in the buffering capacity of a soil. The presumably low cation exchange capacity of these soils should cause them to have a diminished buffering capacity relative to finer-textured soils.

A full description of soil classification, parent material, drainage, topography and slope can be found in Appendix III along with field and laboratory analysis performed in order to verify soil characteristics within the watershed.

4.4 Permeability

The Hoy Creek watershed, like all urbanized watersheds, is composed of impervious surfaces as well as those that are permeable. When water hits a surface it has only two paths. The water can infiltrate the soil or it can run off (Clothier, 2001). The amount that becomes runoff is dependent upon the permeability of the soil. When infiltration capacity is exceeded surface runoff can occur (Clothier, 2001). The runoff potential of the soils within the watershed was estimated by utilizing measures of penetration resistance and percolation rates.

Penetration resistance can be used to assess compaction (Bradford, 1986) and compaction plays a role in permeability. Compaction often leads to a reduced volume of large pores (Bengough 1991) which are good conductors of water (Brady 1996). In this way infiltration is related to pore size as well (Clothier 2001).

Penetration resistance is a measure of the force required to push a cone penetrometer into the soil and then dividing the reading by the cross-sectional area of the cone (Bengough, et.al, 2001). A cone penetrometer is quick and easy to use. In this way, large amounts of useful data can be collected all over the watershed in a relatively short time. Penetration resistance is a useful and rapid method for collection of compaction data (Campbell and Sullivan 1991). Infiltration can be estimated by using percolation tests, but these are much more time consuming to perform than measuring penetration resistance.

In order to obtain an assessment of the relative permeability of those surfaces that were not impervious, a large number of penetration resistance data was collected throughout the entire watershed. These measures were then calibrated using percolation tests at key locations within the study area. The calibration was then used to find a relationship between penetration resistance and percolation rate in order to create runoff potential maps for the Hoy Creek watershed. In order to choose appropriate locations for collecting penetration resistance measurements all possible combinations of land use, land cover and soil for the watershed were considered. The locations were chosen to maximize representation of the land use/land cover/soil combinations. The location of sampling sites is illustrated in Figure 4.4-1.

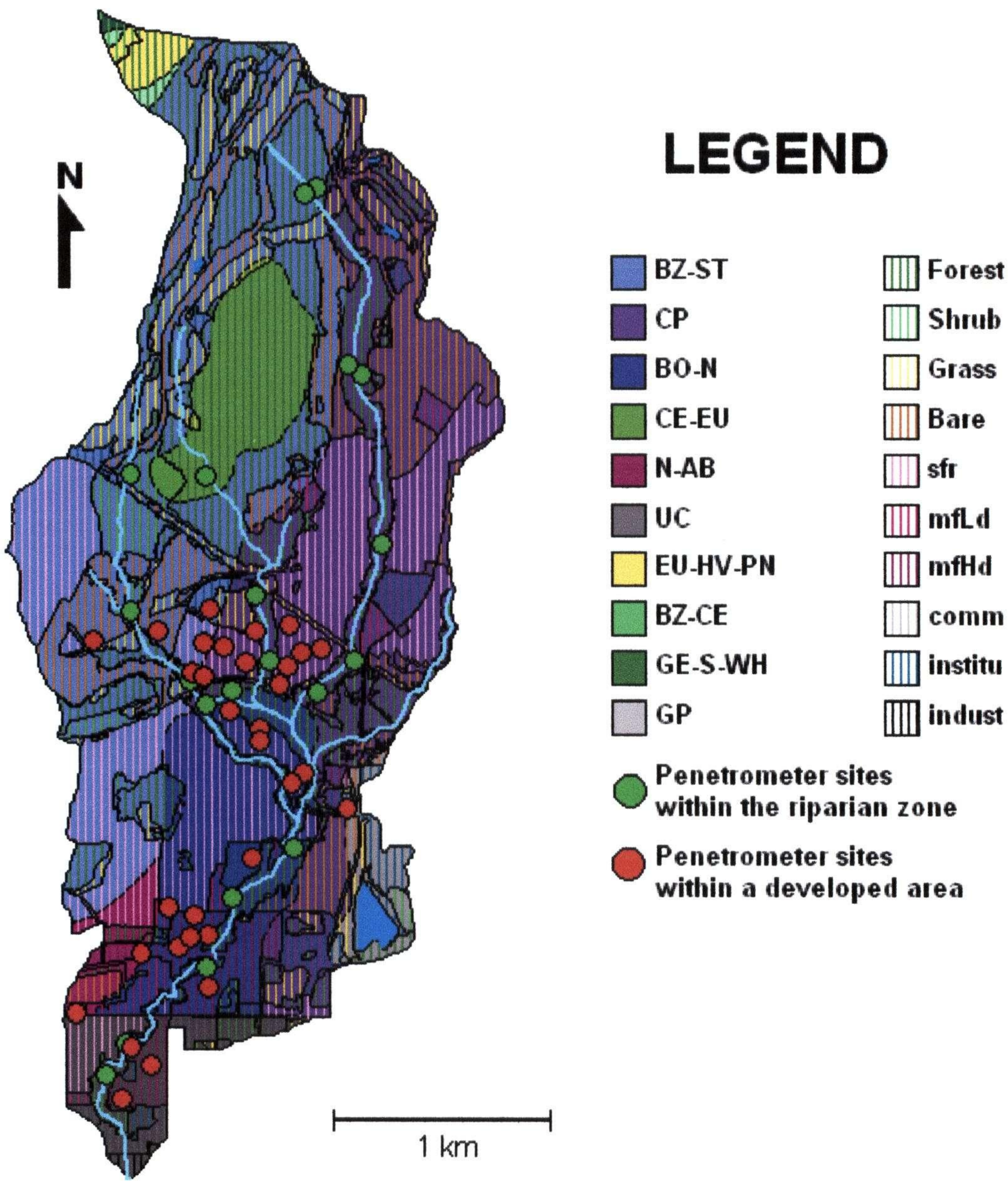

Figure 4.4-1 Soils, land use, land cover and sampling locations

Sampling locations included sites within the riparian as well as those within developed areas. The locations were also spread throughout a large portion of the watershed.

4.4.1 Penetration Resistance

Penetration Resistance Statistics

Although penetration resistance data were collected to a depth of 40 cm only the data from the top 10 cm was analyzed. This was done in order to make data analysis more manageable. But for the scope of this project, analysis of the top 10 cm was adequate. This is because penetration resistance was to be used as an indicator of permeability. In order for soil to be permeable water must be able to penetrate the surface; therefore, the physical state of the surface layer is critical (Clothier, 2001).

The Mann-Whitney non-parametric test was used to test the hypothesis that two independent samples come from populations having the same distribution. The Mann-Whitney test was chosen for analysis of the penetration resistance data because the data did not follow a normal distribution or show an equal variance of the populations to be compared. Also, since Mann-Whitney (MW) does not rely on the underlying distribution of the data, it is suitable to be used when population size is less than 30 (Zar 1984, Norusis 1993). A small population size was all that was available for some of the land cover/soil comparisons to be made. Also, a high degree of variability within the penetration resistance data was expected (Campbell and O'Sullivan, 1991) and the full data set was found to have a non-normal distribution as seen in Figure 4.4-2.

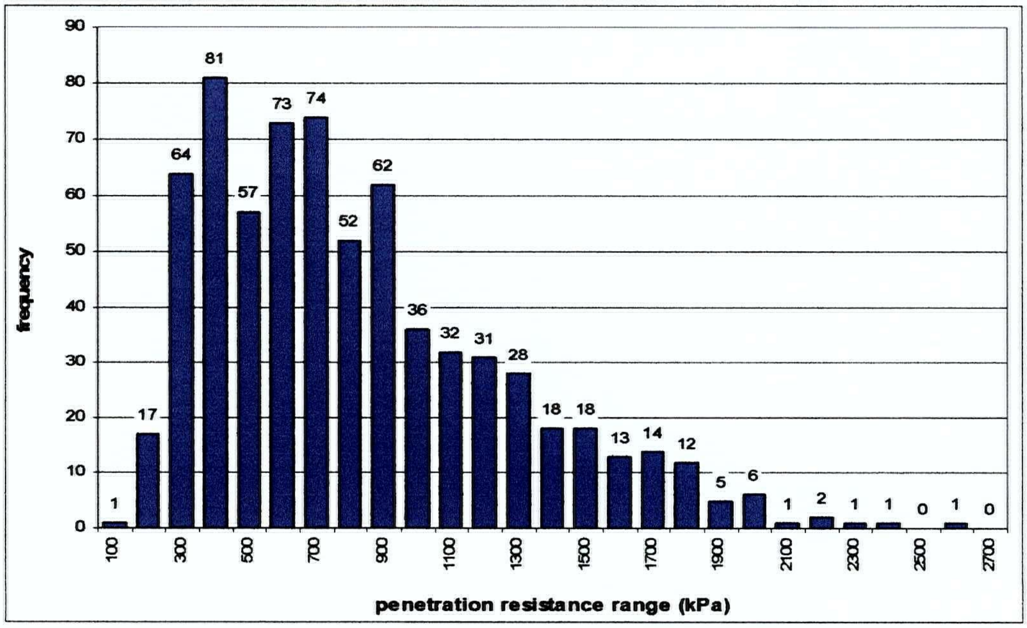

Figure 4.4-2 Frequency distribution for all penetration resistance data

The penetration resistance data were collected for seven different vegetation categories (lawns and planter beds, grass, shrub, conifer forest, broadleaf forest, mixed forest and bare), six different soils (BO-N, CP, BZ-ST, CE-EU, N-AB and UC), and four land use categories (sfr, mfLd, mfHd, institu). This leads to a 7 X 6 and a 4 X 6 matrix of possible combinations for comparison. This number was much too high and the matrices were simplified by combining all land use categories into one category labeled developed. The data collected from lawns and planter beds was used for analysis of developed areas in general. It was determined that penetration resistance data collected from lawns and planter beds be grouped into one category. This is due in part to the limitations of mapping such small objects. This grouping was also based on the knowledge that the soils under lawns and planter beds have often been highly modified by compaction or additions of soil from other locations. And since lawns and planter beds make up the largest portion of pervious land within developed areas the grouping was a logical one to be considered for estimating impervious cover in developed areas.

The vegetation matrix simplification began with a comparison of the forest vegetation categories. Initial MW analysis was performed on all forest vegetation (shrub, conifer, broadleaf and mixed) and soil. The soil category was held constant while vegetation varied and a Mann-Whitney comparison was performed on all possible combinations. The penetration resistance data for conifer forest were found to be statistically equivalent to those of broadleaf forest regardless of soil. Likewise for broadleaf verses mixed forest over all possible soil types. In fact, the data for all combinations were found to be statistically equivalent with the exception of shrub and broadleaf over unclassified soil. The average penetration resistance for shrub was within the same range as those of all forest categories, therefore, it was concluded that all forest types could be grouped together with shrub included. Penetration resistance data collected on bare and grass covered land was found to be statistically equivalent given constant soil, therefore these two data sets were grouped together. It was also concluded that soil is a key factor in penetrability.

The Mann-Whitney U test was used to compare the chosen groups (forest/shrub, lawn/planter beds and grass/bare). All forest/shrub penetration resistance data was compared with all grass/bare data and all lawn/planter bed data. Likewise for grass/bare with lawn/planter bed data. All forest/shrub data was found to be statistically different from grass/bare and lawn/planter bed data; whereas, grass/bare and lawn/planter bed data were found to be statistically different. These two remaining groups were each subdivided by soil and all possible combinations within lawn/planter bed and grass/bare were compared. It was determined that penetration resistance for grass and bare over CP and BZ-ST soil was statistically equivalent and that penetration resistance for lawn and planter beds over BO-N, BZ-ST, CP and UC was statistically equivalent.

Penetrability Categories for the Hoy Creek Watershed

The average penetration resistance for each possible land cover/soil combination was then calculated and the data were grouped into three categories summarized in Table 4.4-1.

Land Cover	Soil	Average Penetration Resistance (kPa)	Number of Observations	Penetration Resistance Range
Forest and shrub	CE-EU	291	5	Low
Forest and shrub	BZ-ST	381	70	Low
Forest and shrub	CP	531	83	Low
Forest and shrub	BO-N	548	53	Low
Forest and shrub	UC	558	41	Low
Grass and bare	CP	823	25	Medium
Grass and bare	BZ-ST	861	15	Medium
Lawn and planter bed	UC	866	56	Medium
Lawn and planter bed	CP	890	94	Medium
Lawn and planter bed	BO-N	933	154	Medium
Lawn and planter bed	BZ-ST	972	70	Medium
Lawn and planter bed	N-AB	1078	27	High
Grass and bare	BO-N	1484	7	High

Table 4.4-1 Average penetration resistance for all land cover and soil combinations

The categories of penetration resistance were based on the ranges, as determined from the statistical analysis, of 0-600 kPa, 600-1000 kPa and >1000 kPa, defined as low, medium and high respectively. The penetration resistance data were compared again using these new grouping categories and all were found to be significantly different (α=0.05) with P-values as summarized in

Table 4.4-2.

Penetration Resistance Comparison	P-value
Low vs. Med	0.0000
Low vs. High	0.0000
Med vs. High	0.0013

Table 4.4-2 P-values for from the Mann-Whitney comparisons for the three ranges of penetration resistance.

The average penetration resistance was then calculated for each of the final groupings. This is summarized in Table 4.4-3.

Penetrometer Resistance Category	Land cover /Soil	Average Penetration Resistance (kPa)	St Dev	COV	Maximum Penetration Resistance (kPa)	Minimum Penetration Resistance (kPa)	number of observations
low	forest and shrub over BO-N, CE-EU, BZ-ST, CP & UC	492.6	275	56%	2021	90	252
medium	grass and bare over BZ-ST & CP AND lawn and planter bed over BO-N, BZ-ST, CP & UC	911.4	431	47%	2303	155	414
high	grass and bare over BO-N AND lawn and planter bed over N-AB	1161.4	454	39%	2532	289	34

Table 4.4-3 Average penetration resistance for all penetration resistance categories

The average penetration resistance for the low category was calculated to be 493 kPa with a coefficient of variation (COV) of 56%. The average for the medium category was found to be 911 kPa with a COV of 47% and 1161 kPa was calculated to be the average for the high penetration resistance category with a COV of 39%.

The data were graphed with bars showing the extent of the range of values that occurred in each category. Samples within the low penetration resistance category exhibited values ranging from 90 kPa to 2021 kPa. Those within the medium penetration resistance category had values ranging from 155 kPa to 2303 kPa and the range of the samples within the high category was 289 kPa to 2532 kPa. This can be seen in Figure 4.4-3.

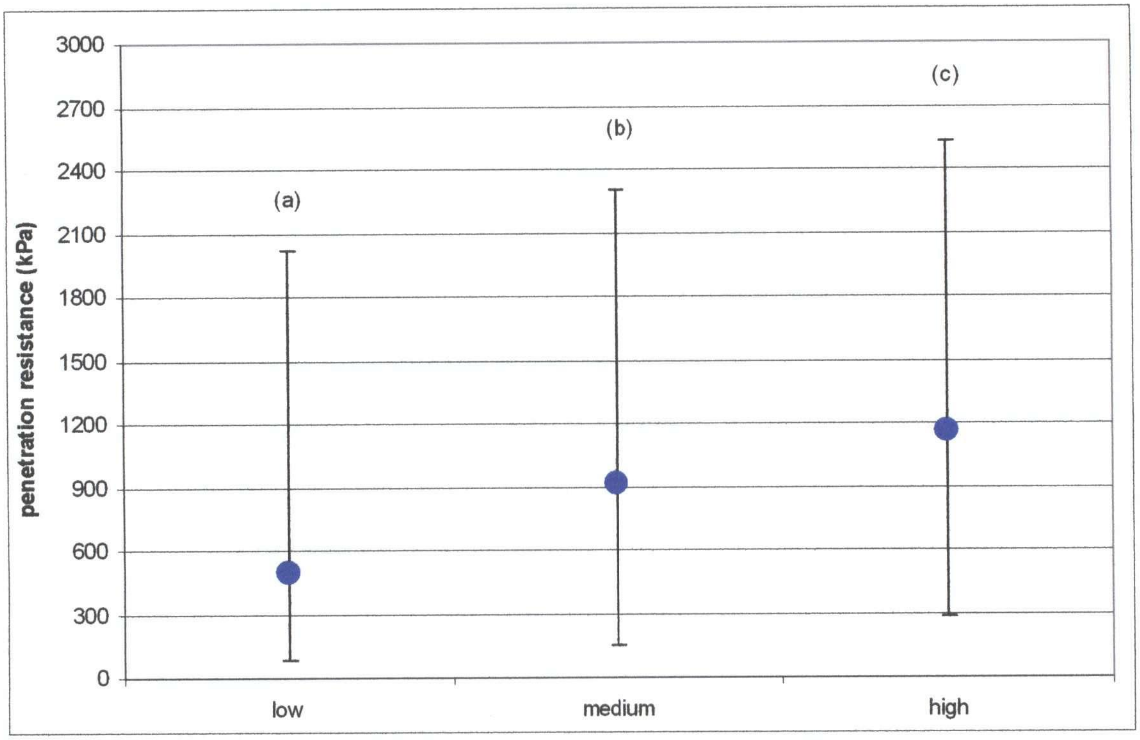

Figure 4.4-3 Average and range of three categories of penetration resistance

It can be seen that penetration resistance can be highly variable. All minimum values fell within the low penetration resistance range and all maximum values fell within the high range. But, the Mann-Whitney analysis showed that the populations had different distributions.

4.4.2 Percolation

In order to relate penetration resistance to runoff potential, infiltration must be considered. As stated earlier, when the infiltration capacity of a soil is exceeded surface runoff can occur. Infiltration is generally measured using a ring infiltrometer. These devices consist of a ring which is inserted into the soil. The infiltrometer is filled with water and the cumulative amount of water required to maintain the ponding at a constant shallow depth is measured over successively longer times (Marshall, et. al. 1996). One weakness of these devices is that they are difficult to insert in rocky soils. Since the soils in the watershed were known to be coarse, percolation tests were used as an estimator of infiltration rate.

Eleven locations were chosen for percolation tests. These locations were chosen to cover a variety of land cover and soil combinations. The sites were also chosen to include each of the three penetration resistance ranges. The rate at which water infiltrates a soil is dependent upon the water content of the soil (Clothier, 2001); therefore, the percolation tests were performed shortly after periods of rain so that the soils would be close to saturation. The data collected from the tests are summarized in Table 4.4-4.

Land Cover	Soil	Penetration resistance category	Average penetration resistance (kPa)	Percolation rate (cm/sec)
Forest	CE-EU	Low	291.3	0.017
Shrub	UC	Low	321.4	0.025
Forest	BZ-ST	Low	332.8	0.025
Forest	BO-N	Low	361.4	0.014
Forest	CP	Low	405.3	0.022
Grass	CP	Medium	834.8	0.005
Lawn	UC	High	1021.0	0.009
Grass	BZ-ST	High	1060.7	0.008
Lawn	N-AB	High	1144.1	0.006
Grass	BO-N	High	1483.7	0.010
Lawn	UC	High	1560.0	0.023

Table 4.4-4 Percolation rate and penetration resistance for each of the selected locations

Percolation Rate Statistics

A regression analysis was performed on the data using SPSS 6.0 (Figure 4.4-4). The analysis was performed in order to find a relationship between percolation rate and penetration resistance. It was determined that there was a significant quadratic relationship.

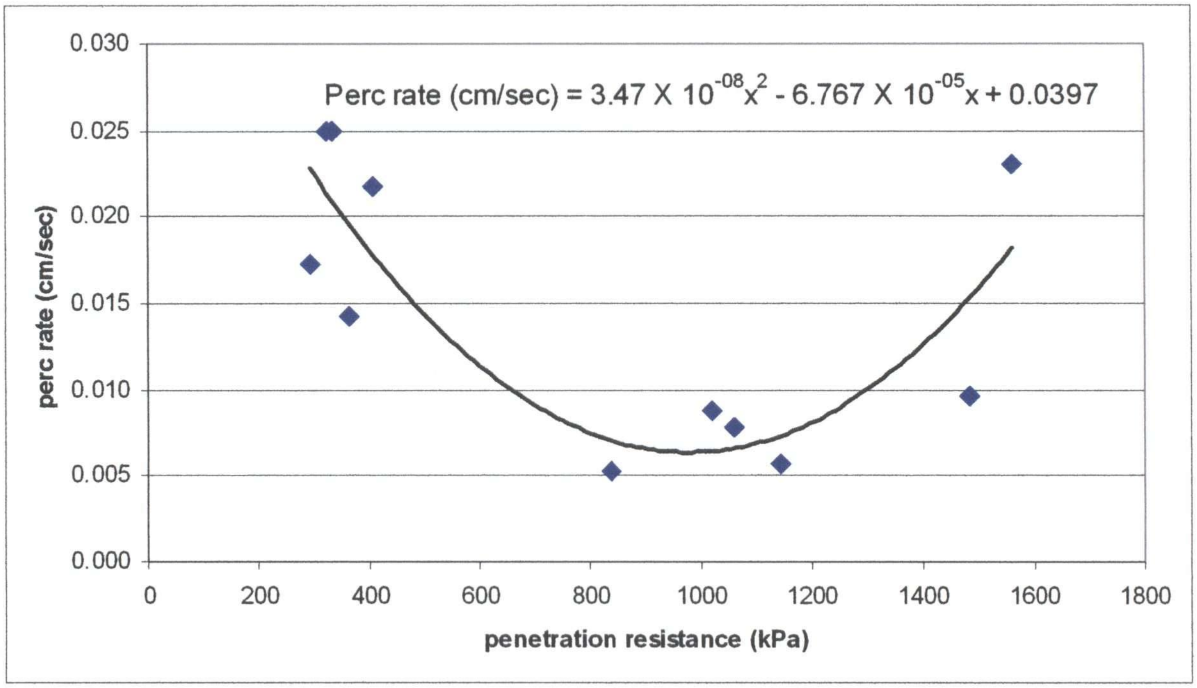

Figure 4.4-4 Percolation rate as a function of penetration resistance at 0-10 cm depth for locations in the Hoy Creek watershed

The linear regression lead to the following relationship:

Perc rate (cm/sec) = $3.47 \times 10^{-08} PR^2 - 6.767 \times 10^{-05} PR + 0.0397$ (Equation 4-1)

where PR is penetration resistance in kPa.

The standard error was determined to be 0.005 and the coefficient of determination, R^2, for this relationship was determined to be 0.71. The coefficient of determination is the proportion of the total variation in percolation rate that is accounted for by penetrometer resistance. That is, the regression accounts for 71% of the variation in the data. This value is high and implies the relationship is significant. At first consideration a quadratic relationship seems unlikely, but the soils in the watershed are coarse and often stony. Under these conditions it can be difficult to get a penetrometer reading without grinding past the larger particle and hence obtaining a higher penetration resistance. At the same time, coarse or stony soils allow for greater permeability. It stands to reason that while percolation rates initially decrease with increasing penetration resistance they may increase with increasing penetration resistance as soils texture becomes more coarse or stony.

Theoretically one would expect a decreasing curvilinear relationship between percolation rate and penetration resistance. The increase in percolation rate seen in the data is due to a different cause and, therefore, a different function. Two relationships may better describe the data. The regression was recalculated leaving out the anomalous data point with high penetration resistance and high percolation rate and a relationship that more closely resembles what would be expected was determined. The curve estimated by the regression can be seen in Figure 4.4-5. The anomalous data point could then be a separate category by itself.

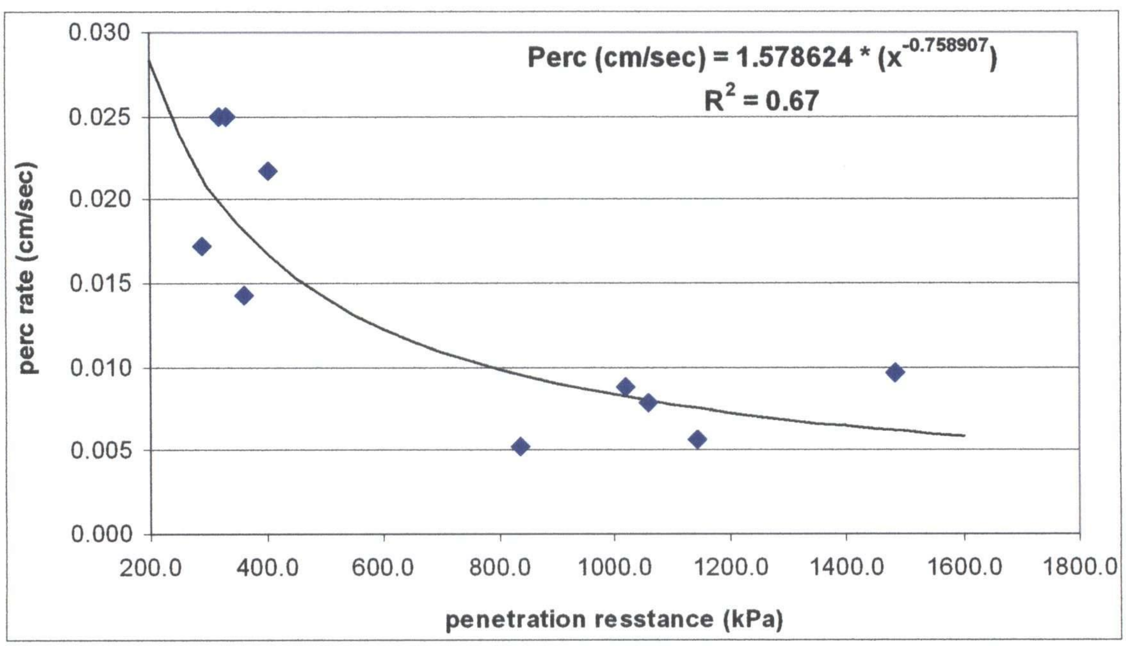

Figure 4.4-5 The regression of percolation rate on penetration resistance with the anomalous data point excluded

Although the quadratic relationship is not what would be expected from theory it significantly describes the data set; therefore this relationship was used to determine three categories of percolation rates from the three penetration resistance categories. Low penetration resistance was found to have an average value of 493 kPa which is equivalent to a high percolation rate of 0.89 cm/min. Medium penetration resistance was determined to have an average value of 911 kPa which is equivalent to a percolation rate of 0.41 cm/min. High penetration resistance values were averaged at 1161 kPa leading to a percolation rate of 0.47 cm/min.

The land use, land cover and soil overlay map was modified in the GIS to reflect the newly defined penetration resistance/percolation rate categories. The penetration resistance map (Figure 4.4-6) is equivalent to a percolation rate map.

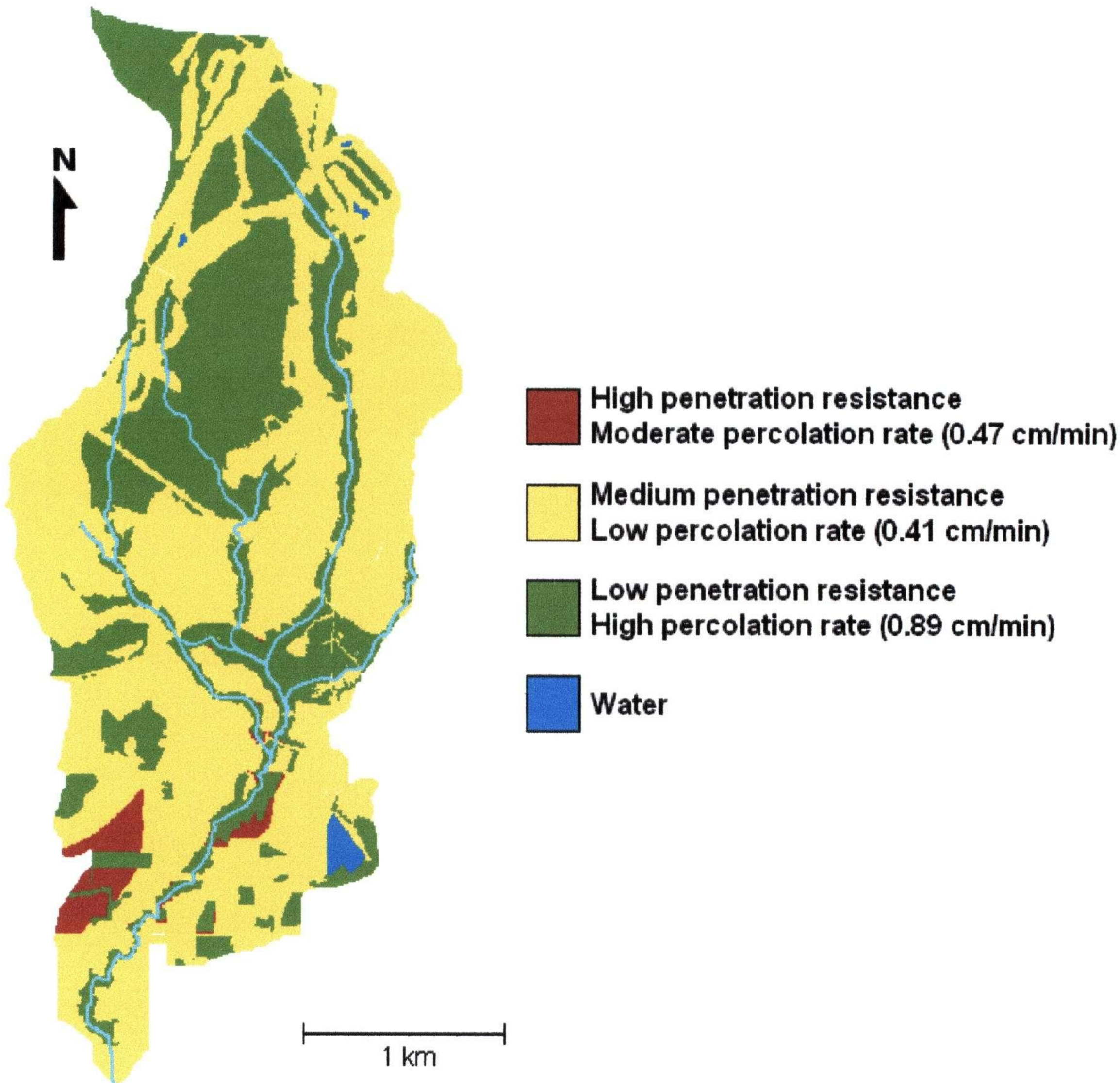

Figure 4.4-6 Penetration resistance and percolation rate categories within the Hoy Creek watershed

The data from the penetration resistance map was tabulated. The area of Hoy Creek watershed with low penetration resistance covers 35% of the watershed. Areas of medium penetration resistance cover 62.5% of the watershed while areas of high penetration resistance cover 2.1%. Those areas of high to medium penetration resistance and low to moderate percolation rate can be considered to have high runoff potential while those with low penetration resistance/ high percolation rate can be considered to have a relatively low runoff potential.

All land with low penetration resistance is covered by forest or shrub. A portion of the land with medium and high penetration resistance is covered with impervious surfaces. The area of the watershed covered by land with medium and high penetration resistance includes areas of different land use. This can be used to determine the amount of pervious land within the watershed and the percolation rates of that land.

Land with medium penetration resistance includes vegetated land (forest and shrub), as well as comm, indust, mfLd, mfHd sfr and institu. Land with high penetration resistance includes grass, bare, mfLd, mfHd, sfr and institu. The previous analysis of impervious surface cover for these land use categories can be used to estimate the semi-pervious area within the watershed based on the three penetration resistance/percolation rate categories.

Commercial and industrial land was determined to be 100% impervious. Single-family residential and institutional lands were found to have nearly equal areas of impervious surface cover (45.6% and 44.2% respectively). Therefore these two were combined into one category with TIA equal to 45%. Both multi-family land use categories were found to have similar TIA values (58.5% for mfHd and 58.9% for mfLd). Therefore, they too were grouped together and a TIA of 60% was applied. These TIA values were then used to calculate total permeable area within each of the penetration resistance/percolation categories (Table 4.4-5).

penetration resistance category	Land Use / Soil Combinations	percent permeable	total area (ha)	permeable area (ha)
low	all forest and shrub / all soils	100	245.5	245.5
medium with vegetation	grass or bare on CI-ST & CP	100	192.2	192.2
medium - 100% developed	industrial & commercial on BO-W, CI-ST, CP & UC	0	10.1	0.0
medium - 60% developed	multi family - high & low on BO-W, CI-ST, CP & UC	40	39.3	15.7
medium - 45% developed	institutional & single family residential on BO-W, CI-ST, CP & UC	55	196.5	108.1
high with vegetation	grass or bare on BO-W	100	5.7	5.7
high - 60% developed	multi family - high & low on WB	40	3.4	1.4
high - 45% developed	institutional & single family residential on WB	55	5.7	3.1

Table 4.4-5 Total permeable area for each of the three penetration resistance categories

The total area of the watershed that is covered by land with low penetration resistance was found to be 35%. The total area of the watershed covered by land with medium penetration resistance was found to be 62.5% and that of high penetration resistance is 2.1%. After accounting for pavement and buildings and applying the values for impervious surface cover of the developed land it was determined that the area of the watershed actually covered by land with medium penetration resistance was 45.1%. The actual amount of the watershed covered by land with high penetration resistance was found to be 1.5% while that of low penetration resistance remains unchanged. This is summarized in Table 4.4-6. Note that rocky soils have high penetration resistance but higher percolation rates than those with medium penetration resistance.

penetration resistance category	Proportion if the watershed covered by the penetration resistance category	Proportion if the watershed covered by the pervious area of the penetration resistance category	Average penetration resistance (kPa)	Percolation Rate (cm/min)
Low	35%	35%	493	0.89
Medium	62.5%	45.1%	911	0.41
High	2.1%	1.5%	1161	0.47

Table 4.4-6 Area of the watershed covered by the pervious area of each penetration resistance category

This data will be utilized in a subsequent chapter to estimate stormwater runoff in the Hoy Creek watershed.

4.5 Historical Land Use Comparison

The changes in land use and land cover from 1979 to 1999 were examined in order to demonstrate how land use has changed and how this is affecting runoff characteristics.

Air photos of the Hoy Creek area were used to map land use for 1979. Due to the limitations of air photo analysis the land use categories were not as detailed as those mapped for 1999 land use. The land use categories that were mapped for 1979 include, forest, shrub, grass, bare, development and water bodies. The land development category includes residential, institutional, commercial and industrial land use that was cleared or paved. Using the GIS the 1979 land use was mapped within the boundaries that were defined as Hoy Creek watershed boundaries for 1999. The land use for 1979 can be seen in the map illustrated in Figure 4.5-1.

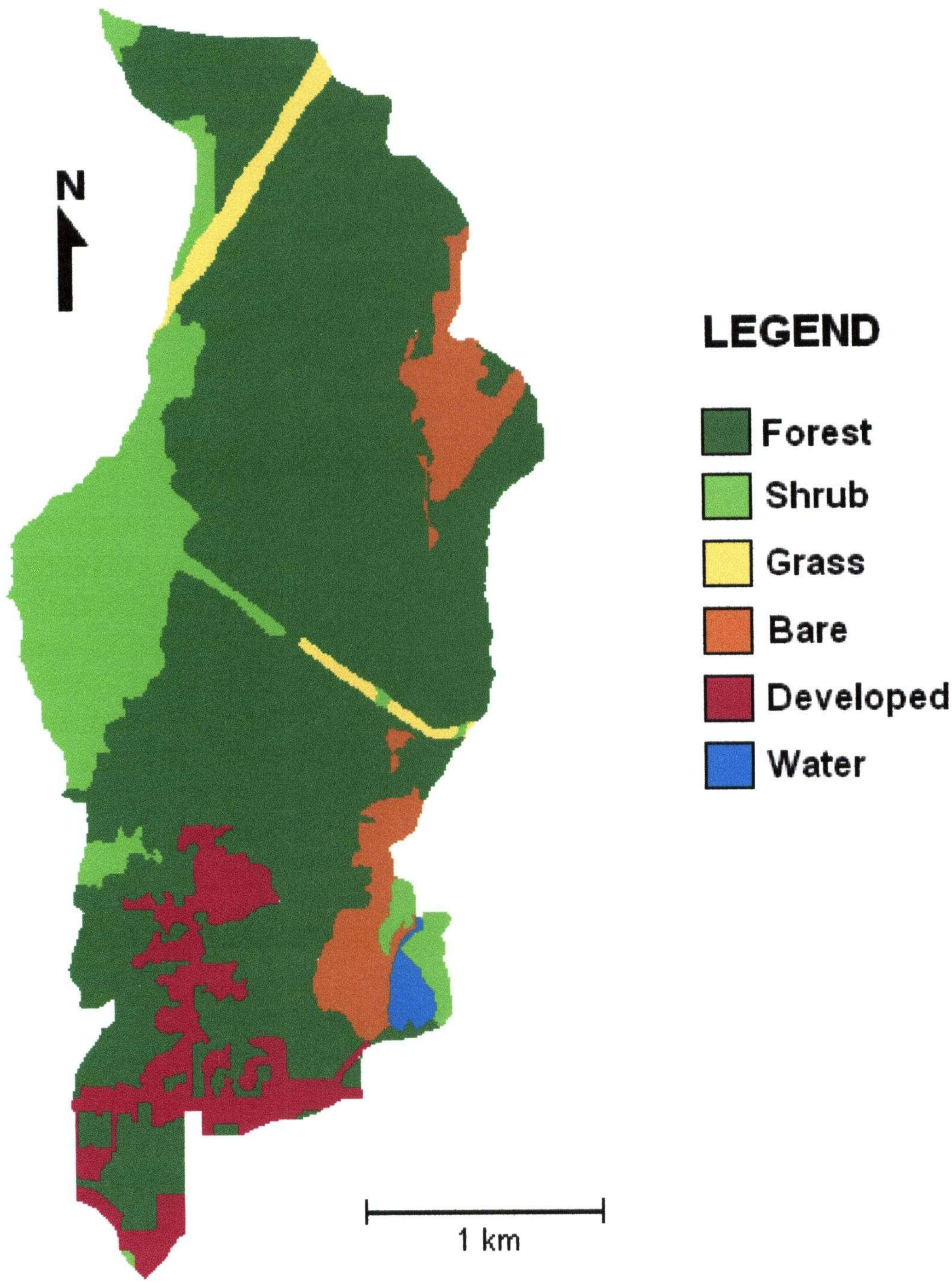

Figure 4.5-1 Land use and land cover within the Hoy Creek watershed in 1979

The land use maps for 1999 were simplified in order to make comparisons with 1979 land use. The 1999 land use categories, sfr, mfLd, mfHd, institu, comm, and indust were combined into one category labeled developed. Conifer, broadleaf and mixed forest were combined into one category, forest. Shrub grass and bare were left unchanged. The simplified land use map for 1999 is illustrated in Figure 4.5-2.

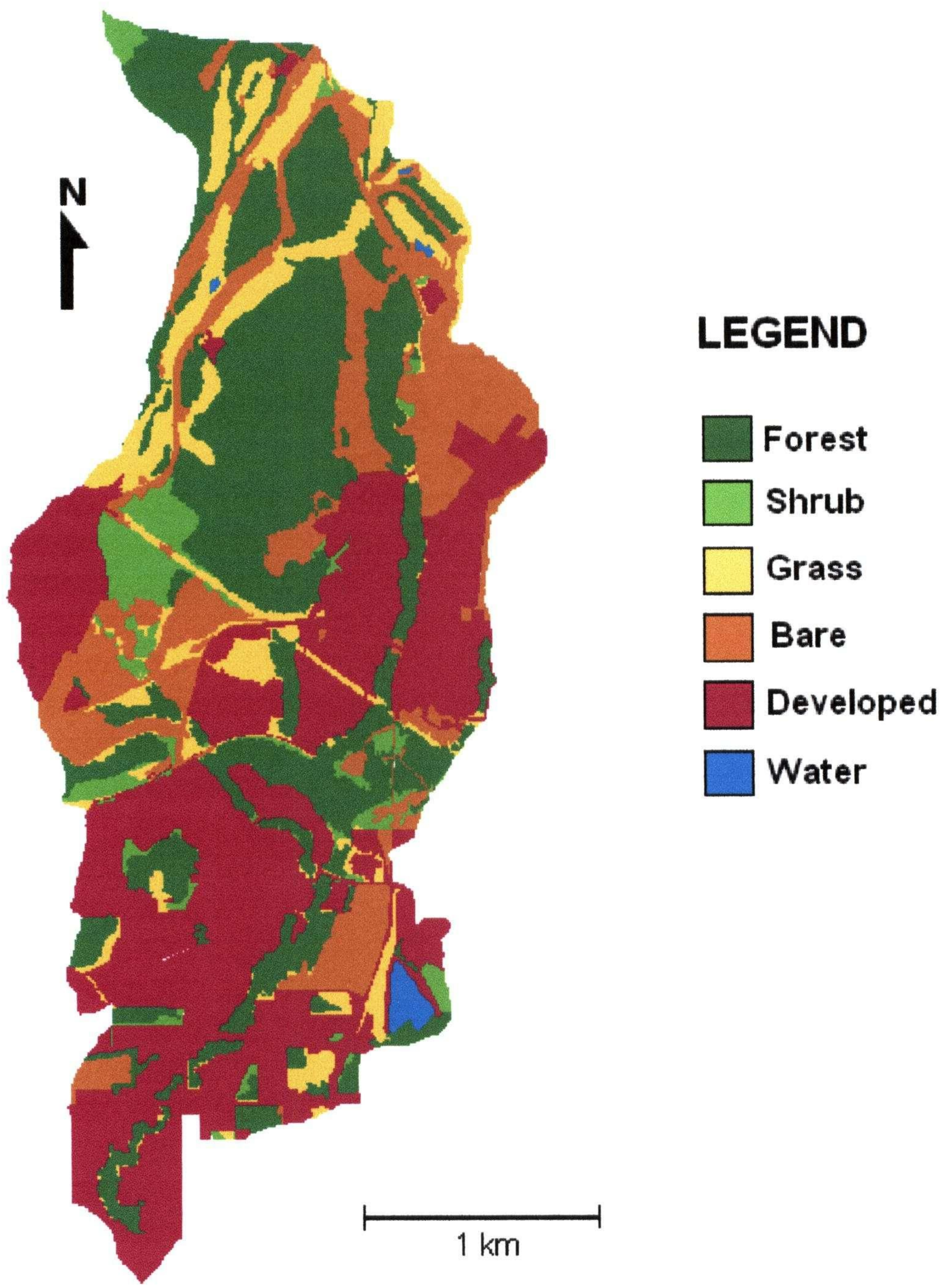

Figure 4.5-2 Land use and land cover within the Hoy Creek watershed in 1999

Land Use Comparison

It is clear to see that land use in the Hoy creek area changed dramatically from 1979 to 1999. The most significant change was the loss of a large area of forest coupled with an increase in development.

The area covered by forest dropped from 478.3 ha in 1979 to 211.7 ha in 1999. This represents a change from 68.2% to 30.2% of the watershed covered by forest. The area covered by shrub also decreased from 1979 to 1999 but not to the same extent as that of forest. Shrub diminished from 102.6 ha (14.6%) in 1979 to 33.8 ha (4.8%) in 1999. The data is summarized in Figure 4.5-3.

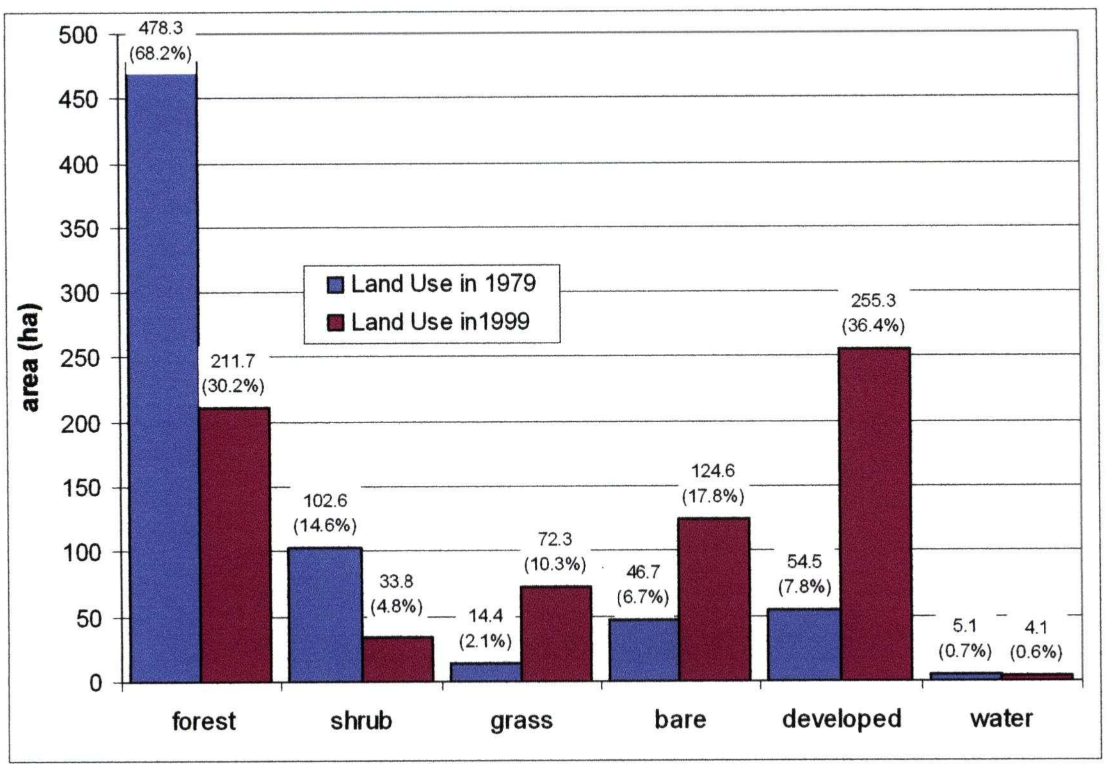

Figure 4.5-3 Comparison of land use and land cover in the Hoy Creek watershed in 1979 and 1999

Grass, bare and developed land use all increased from 1979 to 1999. The area of the watershed covered by grass increased from 14.4 ha (2.1%) in 1979 to 72.3 ha (10.3%) in 1999 while bare land increased from 46.7 ha (6.7%) to 124.6 ha (17.8%). These increases are likely due to early stages of development and portions of this increase could be expected to have become developed by now. Developed land increased nearly as dramatically as the decrease in forest cover. The area of the watershed covered by developed land increased from 54.5 ha (7.8%) in 1979 to 255.3 ha (36.4%) in 1999.

Total Impervious Area in 1979

The TIA was calculated for the Hoy Creek watershed for 1979. These calculations were based on new TIA values for developed land. In order to determine the TIA for 1979 TIA values for 1999 were modified. The TIA for all 1999 vegetation categories remained the same; likewise for bare land. Multi-family residential TIA for 1999 was nearly equivalent, therefore the two categories can be combined into one with TIA averaged. Assuming land use remains relatively constant from 1979 to 1999 the TIA for comm, indust, mfHd, mfLd, sfr and institu were averaged (Table 4.5-1) in order to estimate TIA for developed land in 1979.

TIA (%)	Land use
100	Comm. & indust
58.7	mfLd & mfHd
45.6	Sfr
44.2	institu
66.2	Average of all developed land use categories

Table 4.5-1 Average TIA for all developed land use categories

The average TIA for 1979 developed land was estimated at 66.2%. These values can then be applied to the entire watershed (Table 4.5-2) in order to determine Total Impervious Area in 1979.

	Land use in 1979 (ha)	Land use in 1979 (%)	Average TIA (%)	Total TIA (ha)
Forest	478.3	68.2	1%	4.78
Shrub	102.6	14.6	5%	5.13
Grass	14.4	2.1	10%	1.44
Bare	46.7	6.7	10%	4.67
Developed	54.5	7.8	62.2%	33.89
Water	5.1	0.7	0%	0.00
Total Watershed			**7.1%**	**49.9**

Table 4.5-2 Estimated total impervious area for the Hoy Creek watershed in 1979

Based on these estimations, the total impervious area for 1979 within the Hoy Creek watershed was determined to be 7.1%. As seen in Table 4.5-3 this compares to a TIA of 25% in 1999. This translates to an increase in TIA of nearly 20% over the twenty years from 1979 to 1999.

	Average TIA (%)	Total TIA (ha)
1979	**7.1%**	49.9
1999	**25%**	206.15

Table 4.5-3 Total impervious area in the Hoy Creek watershed for 1979 and 1999

4.6 Stormwater Runoff

The partitioning of rainfall incident on a watershed can be generally divided into two components, surface runoff and initial abstractions (evaporation, transpiration, interception, infiltration). These components represent the major processes of the hydrologic cycle. Urbanization changes the hydrologic cycle of a watershed. The greatest effect that urbanization has on the hydrologic cycle is an increase in surface runoff. This increase is brought about by changes in the watershed that lead to a decrease of initial abstraction.

The partitioning of rainfall can be used to form a generalized water balance equation by which one can estimate surface runoff.

$$R = P - Int - ET - Inf - \Delta S \qquad \text{(Equation 4-2)}$$

Where R is surface runoff, P is precipitation, Int is interception by vegetation, ET is evapotranspiration, Inf is infiltration into the soil and ΔS is the change in storage (Dunne and Leopold 1978, Grimmond et. al. 1986, Sorrell 2003, Viessman and Lewis 2003).

This equation was used to estimate the surface runoff in the Hoy Creek watershed for an average 2-year winter storm event and for a maximum winter storm event. The 2-year return period was chosen because storms of this magnitude occur on a relatively regular basis and could therefore be considered to represent typical storm conditions. The same 2-year average and maximum rainfall events were used to estimate surface runoff in 1979 when the watershed was much less developed. Surface runoff was also estimated based on predictions for future development based on zoning. In order to estimate surface runoff each component of the water balance equation must be considered.

Interception

Interception is that portion of rainfall that is captured by the leaves of vegetation. Rainfall interception by vegetation can be an important component of the water balance of a watershed. When rain begins, many of the first drops land on leaves and almost all are retained by the vegetation. As the rain continues water builds up on the vegetation and the water droplets coalesce until they grow big enough that gravity overcomes surface tension and the drop falls off the leaf and to the ground. Often the leaf is disturbed by wind causing the droplet to fall before gravity takes over (Linsley 1949). Never-the-less a certain amount of water is retained on the surface of vegetation and evaporates or is utilized by the plant before it reaches the ground. Therefore, it can be seen that vegetation and climatic conditions play a role in interception.

The most important vegetation factor that effects interception is canopy storage capacity which is a function of the type, density, form and age of the vegetation. Forest provides a greater degree of interception relative to shrub or grass. The leaf and branch geometry and surface area effect interception capacity as well. Upward-pointing or dish-shaped leaves are better collectors of water than conifer needles. Climatic conditions also play a key role in interception. The amount, intensity and duration of a rainfall event are important factors. Intense rain can serve to dislodge a large portion of the intercepted rain. Wind, air temperature and humidity also effect interception. Wind can serve to dislodge droplets from leaves and it can also increase the evaporation rate. Temperature and humidity also play a role in evaporation. Time of year is also an important factor in interception. The canopy density of a deciduous forest decreases dramatically in the winter thereby decreasing interception capacity (Black 1996, Lee 1980, Linsley 1949, Ward 1975).

All of these factors are highly variable and difficult to measure. Estimates published in literature show a great deal of variability even for similar forest stands (Lee 1980). Utilization of the total amount of rainfall is the most common and successful method to predict interception (Dunne and Leopold 1978). The relationship of interception to precipitation is generally considered to be curvilinear. At the outset of rainfall, when the vegetation is dry, a large portion of precipitation is intercepted. As rain continues to fall interception levels off; capacity is reached and interception in driven by evaporation and absorption by the plant. Because there is so much variability in the data and accurate collection methods are difficult, linear relationships are useful for first order estimations (Lee 1980).

There are many models for specific climates and vegetation types presented in literature. Many of the models are functions of vegetation geometry such as leaf area index, or height of trees. Simple linear model are not uncommon. These models are generally of the same linear form with empirical constants determined from individual studies. The models are all similar in form to the Horton models which were chosen for estimation of interception for this project.

Forest Interception, $I = a + bP^n$ (Equation 4-3)

This equation gives interception in inches for precipitation, P, in inches and a, b and n are empirical constants (Linsley 1949). This equation was chosen because it was intended to be used to estimate interception for an individual storm rather than for monthly or seasonal averages. In addition to this, the equation is simple and straightforward and has been shown to hold true for other studies (Dunne and Leopold 1978). Interception values are then adjusted for forest density by applying a simple projection factor to adjust for the proportion that is not covered by forest (Linsley 1949).

Rainfall can be intercepted by any object. In an urban watershed interception by buildings can be significant relative to a rural watershed. For purposes of this estimation interception by buildings was considered negligible. This is a valid assumption since a large portion of the buildings in the watershed are directly connected to storm sewers. Interception by grass is also considered negligible since the estimations are based on winter conditions.

Evapotranspiration

Evaporation is the process by which liquid water is converted to vapor. It represents a loss of water from the land to the atmosphere. Transpiration is the diffusion of water vapor from plants through the stomatal openings in the leaf and is part of the process of photosynthesis and temperature control (Lee, 1980). In practice it is difficult to separate evaporation and transpiration and so the two are generally considered together as evapotranspiration (Black 1996, Dunne and Leopold 1978, Viessman and Lewis 2003).

Potential evapotranspiration (PET) is defined as evapotranspiration that occurs at a rate that is not limited by deficiencies of soil water that is available for plant use (Viessman and Lewis 2003) which is the case for the winter storms considered for this study. In addition, transpiration is negligible when air temperatures are cool and leaves are wet. Evapotranspiration rates are affected by climate, location, vegetation and soil moisture. Climatic factors can have the greatest effect on PET. The major climatic factors that drive PET are atmospheric vapor pressure, air temperature, wind, and incident radiation. PET is also affected by location and time in that latitude, elevation, aspect, season and time of day all play a role in climatic variables such as wind and radiation. Vegetation type, geometry, reflectivity and stomatal resistance also play a role in PET rates (Black 1996, Dunne and Leopold 1978, Viessman and Lewis 2003, Ward 1975).

There are many ways to estimate PET, varying in complexity and required climatic variables. Commonly used methods for estimation of PET fall into three broad categories; those requiring temperature, those requiring radiation, and the more complex methods requiring a combination of climatic variables. For this study temperature is the only known climatic variable; therefore temperature based methods for estimating PET were considered. Two of the most commonly used temperature based methods are the methods derived by Thornthwaite and Hargreaves. The Thornthwaite method uses air temperature and an annual heat index which is an estimate of the energy available for evapotranspiration. The heat index is function of mean annual temperature which means that this method is best suited for estimates of annual or monthly PET (Black 1996, Dunne 1978, Xu 2001). The Hargreaves method is based on an estimation of solar radiation from extraterrestrial radiation which is a function of latitude and day of the year. The Hargreaves equation is also a function of the difference between the mean monthly maximum and minimum temperature making this method best suited for estimates of monthly PET (Amataya et. al 1995, Hargreaves and Samani 1982, Xu and Singh 2001).

The Hamon method for estimating PET from temperature data alone (Xu and Singh 2001) was chosen for purposes of this study. The Hamon equation is a function of hours of daylight and the saturation vapor density. The vapor density term is a measure of the amount of water vapor required to saturate the air and is almost exclusively a function of air temperature (Ahrens 1994, Linsley 1949, Wallace and Hobbs 1977). The Hamon equation is expressed as

$$\text{PET (in/day)} = 0.55D^2Pt \qquad \text{(Equation 4-4)}$$

where D is the hours of daylight for a given day (in units of 12 hours) and Pt is a saturated vapor density term calculated by

$$Pt = 4.95\ e^{(0.062Ta)} / 100 \qquad \text{(Equation 4-5)}$$

where Ta is the mean daily air temperature (°C).

While this method has been shown to underestimate PET (Xu and Singh 2001) it is a simple and straightforward method for estimating PET from daily temperature alone. For purposes of this study it was felt that an underestimate of PET was a conservative approach and therefore appropriate.

Infiltration

Infiltration is process by which rainfall penetrates into the surface of the soil. When water soaks into the ground its path to the creek is slowed. In this way the creek is buffered from rapid spikes in power and volume. The creek is also buffered by filtering processes that occur as the water flows through the soil.

Soil, vegetation and climate effect infiltration. The structure, texture and moisture of soil all have an effect on infiltration as does the surface and subsurface characteristics of the soil profile. For example, compaction can decrease infiltration. Vegetation density and type also play a role in infiltration through two factors. Vegetation serves to protect the soil surface from physical degradation and the presence of roots allows for water to infiltrate more readily. Climate also plays a role in infiltration. Rainfall amount, intensity and duration all have an effect. Heavy rainfall events can lead to surface sealing and physical degradation of soil structure (Black 1996, Dunne and Leopold 1978).

For this study infiltration is estimated from percolation which is similar to infiltration in that it is a measure of the rate at which water moves downward through the soil (Black 1996).

Infiltration will be estimated using the relationship determined from the regression of percolation rate on penetration resistance.

Infiltration = Percolation * proportion of watershed covered by percolation category,

where,

Percolation (cm/sec) = $(-6.767 \times 10^{-5})PR + (3.47 \times 10^{-8})PR^2 + 0.0394$ (Equation 4-1)

and PR = Average Penetration Resistance (kPa)

Storage

A portion of the rainfall that infiltrates the soil will be held within the pores of the soil as soil water and groundwater storage. The change in storage can be an important component of the water balance equation. This term can be difficult to measure and estimates are generally inferred by subtraction. For purposes of this study the change in storage is assumed to be negligible. This can be considered to be a valid assumption since the runoff estimation is for winter rainfall events. Given the climate in the region and the precipitation data it can be assumed that the soils were close to saturation.

Soil Conservation Service Method for Estimating Surface Runoff

As a check for the estimation of runoff determined from the water balance equation an independent method of runoff estimation was used. The U.S. Soil Conservation Service developed a method for estimating runoff that is widely used throughout North America. The method uses a runoff Curve Number (CN) that is based on land use, cover type and condition and general hydrologic properties of the soil.

The SCS runoff equation is

$$R = \frac{(P - I_a)^2}{(P - I_a) + S}$$

where R is runoff, P is precipitation, S is potential maximum retention after runoff begins and I_a is initial abstractions. All units are in inches (Soil Conservation Service, 1986).

Initial abstractions are the losses in precipitation before runoff occurs and include interception by vegetation, evaporation, infiltration and surface depression storage and S was found to be related to the CN through soil and cover conditions.

$I_a = 0.2S$

where;

$$S = \frac{1000}{CN} - 10$$

then by substitution

$$R = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

The method was empirically developed in small agricultural watersheds which is one of the limitations of this method. None-the-less its use is widespread. This is partly due to the straightforward procedures for estimating runoff and because it can be applied to a wide range of watershed conditions. Curve numbers are determined from tables and composite curve numbers can be calculated for watersheds with a variety of land use/cover conditions by weighting each curve number according to its area. Runoff can then be manually calculated or determined directly from charts but SCS provides a computer model (TR 55) that can be easily used to perform calculations based on the input of watershed conditions (Dunne and Leopold 1978, SCS 1986, Sorrell 2003, Trommer et. al 1996, Viessman and Lewis 2003).

Estimation of Surface Runoff for Hoy Creek watershed

In order to estimate surface runoff in the Hoy Creek watershed rainfall and temperature data were needed. There is only one climate station in the watershed and the data set is small and incomplete; therefore, rainfall and temperature data had to be estimated from nearby stations.

There can be a large degree of spatial variability in rainfall distribution for any given storm. The variability can be especially pronounced with changes in elevation. For this reason three stations in Port Moody, at three different elevations (23 m, 129.5 m, 325.5 m), were considered before choosing the more representative station. This range of elevations is similar to that within the Hoy Creek watershed which lies from approximately 30 meters and rises to just nearly 600 meters. On most days no differences in rainfall were seen but occasionally slight increases in rainfall were seen with increasing elevation. These differences were considered small enough to accept for purposes of this estimation. In order to determine the degree of spatial variability of rainfall within the region, rainfall data from a Port Moody station (Port Moody Centre) was compared to that of the same time for a station just east of Hoy Creek watershed (Port Coquitlam City Yard). To minimize the variation that might be due to differences in elevation these stations were chosen because they are located at similar heights (23 m in Port Moody and 6.7 m in Port Coquitlam). In almost all instances rainfall was nearly identical at each station. Based on these comparisons it was determined that the data from the station located in Port Moody (Port Moody Glenayre), just a few miles west of Hoy Creek, and at an elevation of 129.5 meters was an appropriate data set for the estimation of runoff in the Hoy Creek watershed for an average 2-year storm and a maximum storm.

Five years of rainfall and temperature data were analyzed using running averages in order to determine the amount of an average 2-year storm. There is no clear definition of a storm other than that it is a rainfall event that follows some period of less intense rainfall. For this estimation it was decided that a storm is a rainfall event with greater than average rainfall.

The running averages were determined for all rainfall events over the five years. The average winter rainfall was determined to be 14.5 mm. All days with rainfall events less than this were then eliminated from the analysis and 2-year running averages were then recalculated. The average 2-year winter storm was determined to be 30.4 mm and average temperatures were determined to be 5.8 °C. A characteristic storm was then chosen for estimation of runoff. This storm occurred on December 10, 1991 with 33.0 mm of rain and a mean daily temperature of 4.3 °C after 1 day of no rain preceded by several days with an average rainfall of approximately 15 mm.

The maximum winter storm event was determined from Environment Canada data. The maximum rainfall recorded at this station from 1971 to 1994 occurred on December 25, 1972. The rainfall recorded on this day was 112.3 mm with a mean daily temperature of 6.1 °C. This storm was preceded by 15 days of rainfall averaging nearly 30 mm. Two other rainfall events similar in magnitude (97 mm and 103.2 mm) have occurred during the same period.

Surface runoff generated by these two storms can be estimated by the following equation,

Runoff = Runoff from pervious surfaces + Runoff from impervious surfaces

then by substitution,

$$R = (P - E - Int - Inf) + (P*\%TIA) \qquad \text{(Equation 4-6)}$$

Runoff was calculated for the average and maximum storm events based on land use in 1979, land use in 1999 and expected land use in the future after development of forest that is slated for residential land use and assuming that infiltration characteristics of the pervious area remains unchanged from 1999. The TIA for 1979, 1999 and the future are summarized in Table 4.6-1.

	TIA (%)	**Pervious area (%)**
1979	7	93
1999	25	75
Future	29	71

Table 4.6-1 Impervious and pervious area in the Hoy Creek watershed for 1979, 1999 and after residential development of forested lands in the future

Recall,

$E = PET = 0.55*D^2*Pt$ (in/day); (Equation 4-4)

where $Pt = 4.95*e^{0.062Ta}/100$,

and D = hours of daylight in a given day (in units of 12 hours).

Date of storm	Precipitation (mm)	Mean daily temperature (°C)	Maximum possible hours of sun per month (Dunne 1978)	D (hours of sun per 12 hours)	Pt	PET (in/day)	PET (mm/day)
Dec 10, 1991	33.0	4.3	252	0.68	0.0646	0.016	**0.414**
Dec 25, 1972	112.3	6.1	252	0.68	0.0723	0.018	**0.463**

Table 4.6-2 Potential evapotranspiration for an average storm and the maximum storm

Average maximum possible hours of sun were used to determine PET since hours of sunshine for the given storm days was not available. The estimated evaporation values are on the same order of magnitude as those reported in literature for nearby regions (Grimmond 1986).

Interception, Int (forest) = (a + bP^n (inches)) * winter density of vegetation type * proportion of watershed covered by vegetation type

Vegetation type	a	b	n	P (mm)	P (in)	Potential Interception (in)	Winter density of veg cover	Proportion of watershed covered by veg type	Maximum Interception (in)	Maximum Interception (mm)	Total Interception, Int (mm)
Average storm (December 10, 1991)											
Conifer (hemlock/pine woods)	0.05	0.2	1	33.0	1.3	0.31	0.8	0.2	0.05	1.259	
Broadleaf (maple woods)	0.04	0.18	1	33.0	1.3	0.274	0.3	0.04	0.003	0.083	
Mixed (average of hemlock/pine & maple)				33.0	1.3	0.292	0.5	0.065	0.009	0.241	
Shrub (maple, hedges & open)	0.03	0.23	1	33.0	1.3	0.329	0.2	0.05	0.003	0.084	
TOTAL											**1.67**
Maximum storm (December 25, 1972)											
Conifer (hemlock/pine woods)	0.05	0.2	1	112.3	4.42	0.934	0.8	0.2	0.149	3.797	
Broadleaf (maple woods)	0.04	0.18	1	112.3	4.42	0.836	0.3	0.04	0.01	0.255	
Mixed (average of hemlock/pine & maple)				112.3	4.42	0.885	0.5	0.065	0.029	0.731	
Shrub (maple, hedges & open)	0.03	0.23	1	112.3	4.42	1.047	0.2	0.05	0.01	0.266	
TOTAL											**5.05**

Table 4.6-3 Interception of rainfall by forest vegetation for an average storm and the maximum storm

Interception by conifer forest was 24% and 21% of gross precipitation for the average and maximum storm event respectively. Interception by broadleaf forest was 21% and 19% for average and maximum storms. These interception values are close to expected as cited in literature for similar trees and for forests in this region (Dunne 1978, Linsley 1949, Rothacher 1963, Voigt 1960). It was assumed that interception by vegetation other than trees was negligible since the storms are winter events and density of other vegetation types would be at a minimum.

Infiltration, Inf = Perc rate * proportion of watershed covered by the pervious area of the percolation category; where,

Perc rate (cm/sec) = $(-6.767 \times 10^{-5})*PR + (3.47 \times 10^{-8})*PR^2 + 0.0394$ (Equation 4-1)

and PR = Penetration resistance (kPa).

Penetration resistance category	Average penetration (kPa)	Percolation rate (cm/sec)	Potential Percolation (mm/day)	Proportion of watershed covered by the pervious area of perc category	Infiltration (mm/day)	Total Infiltration, Inf (mm/day)
High	1161	0.0076	65.733	0.015	0.986	**70.27**
Medium	911	0.0065	56.584	0.451	25.52	
Low	493	0.0145	125.04	0.35	43.765	

Table 4.6-4 Total infiltration on high, medium and low penetration resistance lands

It can be seen in Table 4.6-4 that total infiltration exceeds rainfall for an average storm event; therefore, runoff will occur from impervious surfaces only and losses will be from interception and evaporation. Recall, in 1999 TIA was determined to be 25%.

Estimation of stormwater runoff was determined by inserting the values for PET, Int and Inf into the runoff equation. These calculations were applied using the same storm data and land use/cover data for the future based on expected land use/cover data after development of forest occurs (TIA = 29%) leading to a loss of approximately 50 ha of forest with corresponding gains in residential land use. The penetration resistance categories are based on soil/landuse/land cover combinations that cannot be estimated from the airphotos for

1979; therefore, this method cannot be used to estimate past runoff. However; runoff for 1979 can be estimated using the SCS method. The estimations are summarized in the table below.

	E from average storm (mm/day)	**E from maximum storm (mm/day)**	**Total Interception for average storm (mm)**	**Total Interception for maximum storm (mm)**	**Total Infiltration, (mm/day)**	**Runoff from Average storm (mm)**	**Runoff from Maximum storm (mm)**
1999	0.414	0.463	1.67	5.05	70.27	**6.2**	**64.6**
Future	0.414	0.463	1.30	3.93	65.91	**7.9**	**74.6**

Table 4.6-5 Runoff from an average storm and the maximum storm in 1999 and after development of forest

It is clear that after development occurs and forested land is converted to residential land use runoff will increase. In fact, these estimations predict that stormwater runoff will increase by 16% after development of the forested land. The increase in runoff is due to the loss of interception by vegetation and a decrease in lands with the capacity for infiltration (i.e. increased pavement and buildings). This is typical of the hydrologic changes brought about by urbanization.

This same storm and land use/cover data can be used to estimate runoff using the SCS curve number method. This method is based on simple land use/cover categories; therefore, this method can be used to estimate runoff for 1979 land use/cover data. The curve number calculation tables can be found in Appendix IV and the curve numbers and estimated runoff are summarized in the table below.

	Curve Number	**Runoff from Average storm (mm)**	**Runoff from Maximum storm (mm)**
1979	70.4	1.2	41.9
1999	77.0	3.4	54.6
Future	78.1	3.9	56.8

Table 4.6-6 SCS runoff estimations from an average storm and the maximum storm in 1979, 1999 and post-development of forest

Again, it is clear that runoff will increase as urbanization increases. These changes represent a 4% increase in runoff after development of forested lands and a 13% increase from 1979 to future development stage.

The runoff values estimated using the method derived for this project can be compared to those determined using the SCS method in order to verify the estimations of the derived method. These comparisons are summarized in the table below.

	Runoff (mm)			
	Average storm		**Maximum storm**	
	Derived method	**SCS method**	**Derived method**	**SCS method**
1979	—	1.2	—	41.9
1999	6.2	3.4	64.6	54.6
Future	7.9	3.9	74.6	56.8

Table 4.6-7 Comparison of Derived and SCS runoff estimations

The SCS method for estimating runoff predicts lower levels of runoff compared to the derived method. This is likely due to three factors. First of all, the SCS method does not differentiate between forest type and density, so that interception may be overestimated for Hoy Creek watershed. Secondly, SCS includes an initial abstraction of rainfall in surface depressions for which the derived method does not account. SCS calibrated the initial abstraction in an agricultural watershed which can be expected to be relatively flat and hence better capable of retaining water in depressions. A large portion of Hoy Creek watershed is steeply sloping and surface depression storage can be expected to be minimal. This effect is particularly evident in the smaller storm for which the SCS method may estimate that surface depression storage is not at full capacity. And lastly, the SCS method is based on average antecedent soil moisture. Both of the storms occurred during the wet winter season and after periods of rain. Soils in the watershed would likely be wetter than average; therefore, CN values would be higher and runoff would be greater (Dunne and Leopold 1978). With these factors considered it can be said that the derived method for estimation of surface runoff closely approximates that determined by the SCS method and both methods predict an increase in surface runoff as urbanization increases.

5 Summary, Conclusions and Recommendations

5.1 Land Use in the Hoy Creek Watershed

In 1999 Hoy Creek watershed, which covers 700 ha of land, had 45% vegetation cover and 55% was developed. It was determined that land used for residential purposes covers 30.4% of the watershed and land used for commercial and industrial purposes cover approximately 1.4% of the total watershed area. Forest covered 35% of the watershed while grass covered 10.3%. Developed institutional lands comprise 4.5% of the watershed and bare land covers 17.8%. The land use which covered the largest area is single-family residential, at 24.3% of the total watershed area. Conifer forest is the second largest use of lands, covering 19.9% and bare land slated for future development covered 17.8% of the watershed.

Representative test areas were chosen for each land use category and land use was mapped in greater detail in order to determine Total Impervious Area for each of the land use categories as well as the entire watershed. Developed institutional lands were found to have an average TIA of 44.2%. Single-family residential test areas had an average TIA of 45.6% while multi-family high density and multi-family low density had TIA values of 58.5% and 58.9% respectively. These values were then used to determine the TIA of the entire Hoy Creek watershed which was determined to be 25%

The high proportion of bare land within the watershed is indicative of the on-going development, particularly in Westwood Plateau. Most of the bare land mapped in 1999 has since been developed. Future land use can be estimated based on the zoning boundaries for bare land. Approximately 39% of the bare land was zoned for single-family, about 30% was zoned for multi-family residential and 11% was zoned for civic institutional (future schools). A portion of the forested land within the watershed is also zoned for other land use. 26ha of forested land is zoned for single-family residential and 22 ha are zoned for multi-family residential. Applying the previously determine TIA factors for each of these land use categories leads to an estimate of post-development TIA for the watershed. This was determined to be 36%.

The 1979 land use was compared to that of 1999 and the results showed that the forest cover had declined by 267 ha (a 38% loss), shrub declined by 69 ha (a 10% loss) and the land converted to urban use increased by 200 ha (a 29% increase). The total impervious area in the watershed was estimated at 7.1% in 1979 and increased to 25% by 1999. This considerable increase in TIA is indicative of the increased development that has occurred, and continues to occur, in the Lower Mainland of B.C.

5.2 Hoy Creek Riparian Buffer Zones

Land Use within Buffers

The GIS buffer analysis of Hoy Creek showed that 93.8% of the land within 10 m of the creek is covered by forest, grass or shrub and the TIA of the 10m buffer is 4.3%. The vegetation cover drops to 86% of the land and TIA is 7.3% within 30 m of the creek. 75% of the land within 50 m is covered by vegetation and the TIA is 11.8%. The 100 m buffer has 58% vegetation cover and a TIA of 18%. At 100 m from the creek the area covered by developed land (42.3%) is nearly equal to that of vegetated land. The TIA values for land within 50 and 100 meters from the creek exceed commonly accepted threshold values for which degradation of the stream ecosystem begins.

Riparian Integrity

Vegetation crown closure in the buffer zone of Hoy Creek was lowest in the lower reaches of Hoy Creek, while the upper branches generally had better crown closure. The buffers around West Hoy and Lower Hoy were determined to have the lowest levels of vegetation cover and West Hoy contained the highest concentration of road crossings.

One of the key areas of potential impact from land use practices occurs in the region where Plateau Boulevard crosses North Hoy Creek. The west branch of Hoy creek was also determined to be a key area for potential impact to downstream reaches. The Lower Hoy was determined to be an area with high potential for land use practices to have negative impact on the creek. In this area commercial land use is more dominant. The roads that cross the creek are the widest and the most heavily trafficked. Also of note is the fish hatchery housed upstream of the commercial development.

5.3 Soils

Soils play an important role in buffering capacities and runoff characteristics of a watershed and the riparian zone. The soils within the Hoy Creek watershed are predominantly glacial in origin and coarse textured or gravelly with moderately well drainage. The soils with medium to fine texture and poor or imperfect drainage make up a small portion of the watershed.

Because the soils in this watershed are generally well draining one could expect rainfall and contaminants to be flushed through the system at a relatively rapid rate. This could lead to high spikes in the hydrograph and, although these spikes may be short lived their impact can still be great. Large and rapid spikes in a hydrograph can cause damage to spawning gravels as well as bank erosion.

5.4 Permeability and Stormwater Runoff

Penetration resistance and percolation rates were used to examine permeability of the non-impervious surfaces within the Hoy Creek watershed. The penetration resistance was measured at a large number of locations throughout the watershed. This data was analyzed statistically and combined into three percolation categories based on high, medium and low penetration resistance.

Low penetration resistance is found on land covered by forest or shrub for all of the predominant soils in the watershed. The average value for low penetration resistance was determined to be 493 kPa. Medium penetration resistance occurs on land covered by lawn or planter beds on unclassified, Capilano, Bose-Nicholson or Buntzen-Steelhead soil as well as grass covered or bare land on Capilano or Buntzen -Steelhead soil. The average value for medium penetration resistance was determined to be 911 kPa. High penetration resistance occurs on land covered by grass or bare land on Bose- Nicholson soil as well as lawns and planter beds on Nicholson -Albion soil. The average value for high penetration resistance was determined to be 1161 kPa.

Penetration resistance was then calibrated with measured percolation rates. The regression analysis of percolation rate on penetration resistance was determined to be

$$\text{Perc rate (cm/sec)} = 3.47 \text{ X } 10^{-08}\, PR^2 - 6.767 \text{ X } 10^{-05} PR + 0.0397$$

where PR is penetration resistance in kPa.

Three percolation rate categories were calculated corresponding to the three penetration resistance categories. Percolation maps were created and it was determined that 35% of the watershed has a high percolation rate (0.89 cm/min). 45% had a low percolation rate (0.41 cm/min) and high penetration resistance which covers 1.5% of the watershed had a percolation rate of 0.47 cm/min. The reason why the higher penetration resistance resulted in relatively high percolation rates is that these soils and sites were very stony which affects the cone penetrometer readings. This data was used to create runoff potential maps for the Hoy Creek watershed.

Cone penetrometer readings are affected by many factors and the interpretation should be carried out with caution. Regardless of these limitations, the combination of cone penetrometer and percolation tests proved to be a relatively fast and easy method for estimating locations of higher runoff potential relative to the rest of the watershed.

The percolation maps were utilized to estimate stormwater runoff for an average 2 year return period storm and a maximum storm event (mm/day). The water balance equation was used to estimate runoff based on land use for 1999 and post-development of forest as per zoning. The runoff for an average storm was estimated to be 6.2 mm in 1999, and 7.9 mm after urban development of the forest. The runoff for the maximum storm was estimated to be 64.6 mm in 1999, and 74.6 mm after urban development of forest. The calculations indicate that stormwater runoff will increase as urbanization increases.

The Soil Conservation Service runoff curve number method was used as an independent method for estimating stormwater runoff in the watershed for the same storms based on land use in 1979, 1999 and after urban development of forested lands. The runoff for an average storm was estimated to be 1.2 mm in 1979, 3.4 mm in 1999, and 3.9 mm after development of forest. The runoff for the maximum storm was estimated to be 41.9 mm in 1979, 54.6 mm in 1999, and 56.8 mm after development of forest. This method verifies that stormwater runoff increases with increasing urbanization.

Neither of these methods considers infiltration capacity or rainfall intensity both of which are key factors in runoff potential. Once the soil becomes saturated or rainfall intensity exceeds infiltration rate runoff will occur. Either of these example storms may have had relatively high rainfall intensity and would, therefore, have produced greater surface runoff. The available rainfall data does not include intensity and therefore it was not possible to estimate the effect of rainfall intensity on runoff. Infiltration capacity can be estimated by measuring infiltration verses time and the accuracy could then be improved by increasing the number of observations.

5.5 Conclusions

The riparian zone of Hoy Creek varies for each of the major branches. The upper reaches of Hoy main branch and North Hoy run through relatively dense conifer forest that extends beyond the 100 m buffer. In this area the riparian zone is likely sufficiently effective at buffering the stream from surface runoff and contaminant loading. For most of the remaining reaches the riparian zone is largely vegetated up to the 30 m buffer with TIA less than 10%. Where development encroaches on the 30 m riparian zone and where TIA exceeds the 10% threshold degradation and flooding risk increases.

Given the intensiveness of land use and sparse vegetation in the lower watershed, 30m is likely insufficient for protecting the creek from increased surface runoff and contaminant loading. It is in this area where stormwater mitigation measures, such as infiltration basins, settling ponds or artificial wetlands, would have the greatest impact. In particular, stormwater runoff from road crossings should be diverted away from the creek and into some type of infiltration system. In this way runoff will reach the creek after a greater opportunity for filtering and on a time scale that is closer to natural.

If we, as a society, desire to preserve a healthy urban stream environment we must come to terms with the role development plays in terms of stormwater impacts. The stream ecosystem should be considered in the entire watershed. We can minimize our impact on the creek by minimizing the amount of impervious surfaces within watersheds slated for future development and by maintaining a healthy riparian zone. Orhtophotos and GIS can be useful tools to aid in an examination of the interplay between riparian buffer zones and impervious surfaces. This examination can possibly shed some light on better ways in which we can manage our watersheds for healthy ecosystems.

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7 Appendices

Appendix I
Coquitlam zone classifications

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Appendix I

Municipal Zones Corresponding to Land Use Categories

Zone Occurs within Hoy Creek Watershed	Municipal Zone ID	Municipal Zone	Land Use ID	Land Use
√	A-3	AGRICULTURAL AND RESOURCE		
√	RS-1	ONE-FAMILY RESIDENTIAL	sfr	Single Family Residential
√	RS-2	ONE-FAMILY SUBURBAN RESIDENTIAL	sfr	Single Family Residential
√	RS-3	ONE-FAMILY RESIDENTIAL	sfr	Single Family Residential
√	RS-4	ONE-FAMILY COMPACT RESIDENTIAL	sfr	Single Family Residential
√	RS-5	ONE-FAMILY COMPACT (STRATA LOT) RESIDENTIAL	sfr	Single Family Residential
	RS-6	ONE-FAMILY (STRATA LOT) RESIDENTIAL		
	RT-1	TWO-FAMILY RESIDENTIAL		
√	RT-2	TOWNHOUSE APARTMENT RESIDENTIAL	mfLd	Multi-Family Low Density
√	RM-1	TWO-STOREY LOW-DENSITY APARTMENT	mfHd	Multi-Family High Density
√	RM-2	THREE-STOREY MEDIUM-DENSITY APARTMENT	mfHd	Multi-Family High Density
√	RM-3	MULTI-STOREY MEDIUM-DENSITY APARTMENT	mfHd	Multi-Family High Density
√	RM-4	MULTI-STOREY HIGH-DENSITY APARTMENT	mfHd	Multi-Family High Density
√	RM-5	MULTI-STOREY HIGH-DENSITY APARTMENT	mfHd	Multi-Family High Density
√	RM-6	MULTI-STOREY HIGH-DENSITY APARTMENT	mfHd	Multi-Family High Density
	RMH-1	MOBILE HOME PARK		
√	P-1	CIVIC INSTITUTIONAL	institu	Institutional
√	P-2	SPECIAL INSTITUTIONAL	institu	Institutional
√	P-3	SPECIAL RECREATION	institu	Institutional (golf course)
√	P-4	SPECIAL CARE INSTITUTIONAL	institu	Institutional
√	P-5	SPECIAL PARK	institu	Institutional

√	C-1	LOCAL COMMERCIAL	comm	commercial
√	C-2	GENERAL COMMERCIAL	comm	commercial
	C-3	MEDICAL COMMERCIAL		
√	C-4	TOWN CENTRE COMMERCIAL	comm	commercial
	C-5	COMMUNITY COMMERCIAL		
√	CS-1	SERVICE COMMERCIAL	comm	commercial
	CS-2	LIMITED COMMERCIAL		
	CS-3	TOURIST COMMERCIAL		
	CS-4	CABARET COMMERCIAL		
	SS-1	SERVICE STATION RESIDENTIAL		
	SS-2	SERVICE STATION COMMERCIAL		
	SS-3	SERVICE STATION REPAIR		
	M-1	GENERAL INDUSTRIAL		
	M-2	SERVICE INDUSTRIAL		
	M-3	SPECIAL INDUSTRIAL		
	M-4	ASPHALT AND CONCRETE PLANT INDUSTRIAL		
√	M-5	RECYCLING AND SALVAGE INDUSTRIAL	indust	industrial
√	M-6	RETAIL INDUSTRIAL	indust	industrial
	M-7	RESTAURANT INDUSTRIAL		
	M-8	RETAIL AND LIGHT INDUSTRIAL		
	M-9	LIGHT INDUSTRIAL		

Appendix II

Detailed analysis of institutional land uses

Land use on institutional lands differs greatly. This was evident by the high degree of variability that was seen in the initial analysis. Land use analysis based on zoning boundaries served to isolate the variability. Two categories of institutional zoning (special and special care) include land use such as churches, daycares and seniors care. Civic institutional zones are used for schools, city hall, courthouse, fire hall and power line right-of-ways as well as a large park consisting mainly of conifer forest. One institutional zone (special recreation) covers the golf course while the remaining zone (special park) is composed largely of the riparian corridor. The land use/cover data for institutional lands has been summarized in Figure 7-1.

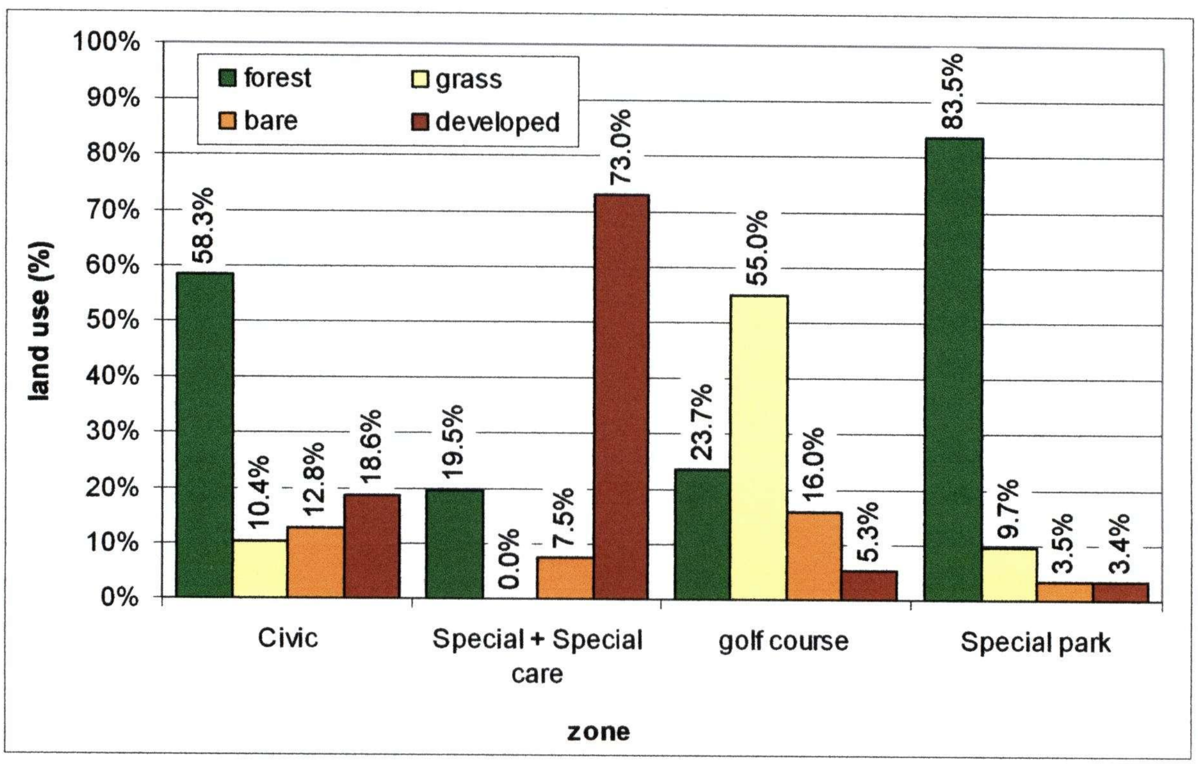

Figure 7-1 Land use within municipal institutional lands

The institutional land use differences are clear to see. Land zoned as special park has a high degree of vegetation cover (93.2%) with only 3.4% of the land developed. Civic institutional zones are 18.6% developed with 68.7% of the civic land covered by vegetation. Special and special care institutional lands are largely developed. These categories are covered by a combined 73% developed land and only 19.5% is covered by vegetation. The largest land use within the land zoned for golf course is bare land at 55% of the area. This is indicative of the fact that the golf course was still under development.

The test areas for institutional land include three areas zoned as civic and one zoned special institutional. The land use characteristics of the institutional test areas have been summarized in Figure 7-2.

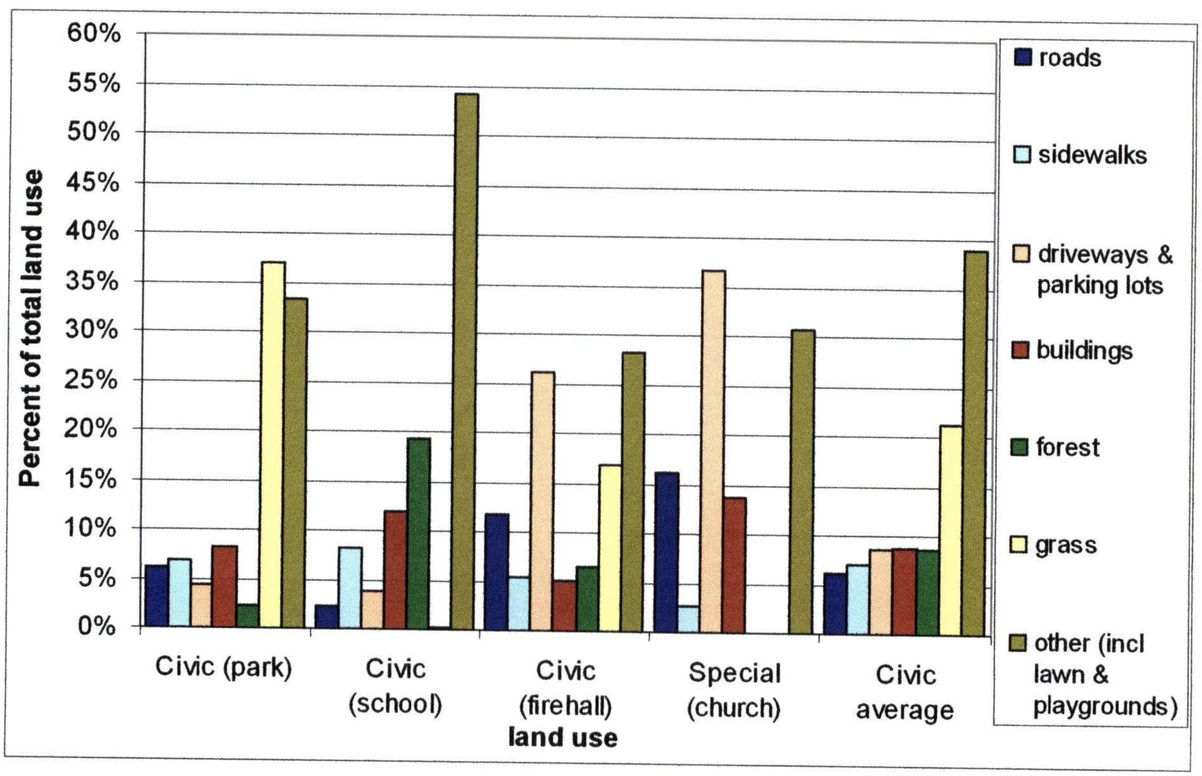

Figure 7-2 Land use characteristics for all municipal institutional test areas

Based on the land use characteristics mapped for each of the institutional test areas total impervious area can then be recalculated for civic land and special institutional lands separately. Recall that developed institutional lands were found to have a TIA value of 44.2%. The refined TIA values are summarized in Table 7-1.

Land Use	TIA (%)	Standard Deviation	Coefficient of Variation
Average of all Civic test areas	34%	12%	36%
Special Institutional	69.2%		

Table 7-1 Total Impervious Area for Institutional Test Areas based on zoning boundaries

This range of TIA values is indicative of the range of land uses for institutional land.

Appendix III

Soil Descriptions

BC Ministry of the Environment, Soils of the Langley-Vancouver Map Area, Vol. 3, RAB Bulletin 18, BC Soil Survey Report No. 15, 1981.

Soil Description	Soil Name (Series)	Soil Classification	Parent Material	Drainage	Simple Topography	Complex Topography	Slope %
BZ-ST/ef	[1]Buntzen - [2]Steelhead	[1]Duric Ferro-Humic Podzol - [2]Duric Ferro-Humic Podzol	[1]Moderately coarse to medium textured glacial till - [2]Moderately coarse textured glacial till	[1]moderately well, telluric seepage - [2]imperfect, perched water table, telluric seepage		moderately rolling to strongly rolling	9+ to 30
CP/E-f	Capilano	Orthic Humo-Ferric Podzol	Gravelly glaciofluvial and deltaic deposits	well to rapid	strongly sloping	strongly rolling	9+ to 30
BO-N/ef	[1]Bose - [2]Nicholson	[1]Duric Humo-Ferric Podzol - [2]Podzolic Grey Luvisol	[1]gravelly lag or glaciofluvial over moderately coarse glacial till and mod fine glaciomarine - [2] Moderately fine textured glaciomarine deposits	[1]well to moderately well, telluric seepage - [2]moderately well, telluric seepage		moderately rolling to strongly rolling	9+ to 30
CE-EU/fg	[1]Cannell - [2]Eunice	[1]Orthic Humo-Ferric Podzol - [2]Typic Folisol	[1]10-100 cm of moderately coarse glacial till over colluvium or bedrock - [2] More than 10cm of organic matter over bedrock	[1]well to rapid - [2]well to rapid		strongly rolling to hilly	15+ to 60

N-AB/D-e	[1]Nicholson - [2]Albion	[1]Podzolic Grey Luvisol - [2]Humic Luvic Gleysol	[1]Moderately fine textured glaciomarine deposits - [2]Moderately fine to fine textured glaciomarine deposits	[1]moderately well, telluric seepage - [2]moderately poor to poor, perched water table	moderately sloping	moderately rolling	5+ to 15
EU-HV-PN/H	[1]Eunice - [2]Hoover - [3]Paton	[1]Typic Folisol - [2]Orthic Humo-Ferric Podzol - [3]Orthic Ferro-Humic Podzol	[1]More than 10cm of organic material over bedrock - [2]Moderately coarse textured colluvium - [3]Coarse textured alluvial-colluviul fan deposits	[1]well to rapid - [2] moderatley well, telluric seepage - [3]well	extremely sloping		over 60
BZ-CE/G-gf	[1]Buntzen - [2]Cannell	[1]Duric Ferro-Humic Podzol - [2]Orthic Humo-Ferric Podzol	[1]Moderately coarse to medium textured glacial till - [2] 10-100 cm of moderately coarse glacial till over colluvium or bedrock	[1]moderately well, telluric seepage - [2]well to rapid	very steeply sloping		30+ to 60
GE-S-WH/fg	[1]Golden Ears - [2]Sayres - [3]Whonnock	[1]Duric Ferro-Humic Podzol - [2] Orthic Ferro-Humic Podzol - [3]Duric Ferro-Humic Podzol	[1]Moderately coarse textured glacial till - [2]10-100cm of moderately coarse to coarse colluvium or glacial till over bedrock - [3]Moderately coarse textured glacial till	[1]moderately well - [2]moderately well, telluric seepage - [3]imperfect, telluric seepage		strongly rolling to hilly	15+ to 60

For all but one soil complex in the watershed the major component of the map unit is a Podzolic soil. These are characterized by B horizons dominated by accumulation of amorphous material composed of humified organic matter combined with iron and aluminum. Podzols are soils that typically occur in coarse to medium textured parent material which is acidic. They generally form under forest vegetation in cool and humid environments. These conditions are typical of the natural conditions within the Hoy Creek watershed. Gleysols, Luvisols and Folisols are also reported to be present in the mapping area. Gleysolic soils are soils which have undergone periodic or sustained reducing conditions during their genesis. Luvisols have eluvial horizons overlying illuvial B horizons thereby leading to the accumulation of clay. These soils generally develop in humid climates under forest vegetation, which is typical of the study area. Folisols are organic soils that develop in the uplands and are generally forest in origin. (Agriculture and Agri-Food Canada, 1998)

Laboratory and Field Analysis

Laboratory Analysis

Five locations within the vegetated riparian zone of the watershed were chosen for collection of soil samples. The samples were obtained from the five predominant soil series within the watershed. The samples were analyzed for organic matter content, coarse fragment content and bulk density in order to validate, in part, the digitized map.

BZ-ST was found to have an organic matter content of 7%, a coarse fragment content of 19.9% with a bulk density of 0.75 g/cm^3. CP was found to have an organic matter content of 8.9%, a coarse fragment content of 38.5% with a bulk density of 1.1 g/cm^3. BO-N was found to have an organic matter content of 16.7%, with 0% coarse fragment and a bulk density of 0.28 g/cm^3. CE-EU was found to have an organic matter content of 16.2%, a coarse fragment content of 20.7% with a bulk density of 0.84 g/cm^3. The sample collected within the unclassified soil area was found to have an organic matter content of 6%, a coarse fragment of 2.2% with a bulk density of 0.86 g/cm^3. This data has been tabulated in Table 7-2.

Soil Description	Area of Watershed Covered by Soil (ha)	Area of Watershed Covered by Soil (%)	Organic Matter Content (from field samples)	Coarse Fragment (from field samples)	Bulk Density (g/cm^3)
BZ-ST	262.1	37.4%	7.0%	19.9%	0.75
CP	220.9	31.5%	8.9%	38.5%	1.1
BO-N	92.9	13.2%	16.7%	0.0%	0.28
CE-EU	44.9	6.4%	16.2%	20.7%	0.84
Unclassified	34.6	4.9%	6.0%	2.2%	0.86
N-AB	14.7	2.1%			
Gravel Pit	21.2	3.0%			
EU-HV-PN	7.4	1.1%			
BZ-CE	2.1	0.3%			
GE-S-WH	0.6	0.1%			

Table 7-2 Area, organic matter, coarse fragment and bulk density of soils within the Hoy Creek watershed

A relatively high level of coarse fragment content was found for the Capilano sample. This is consistent with the parent material of CP, gravelly textured glaciofluvial deposits.

Buntzen-Steelhead has a slightly lower coarse fragment content compared to CP which is consistent with the moderately coarse parent material of BZ-ST. The organic matter content of BZ -ST is lower than expected. BZ -ST is classified as a Ferro-Humic Podzol which should have a higher organic matter content relative to the Humo-Ferric Podzols (CP, BO-N, CE-EU).

The high organic matter and coarse fragment of Cannell-Eunice is also consistent with the parent material which is coarse till or colluvium with an organic accumulation.

The Bose-Nicholson sample exhibited a relatively high degree of organic matter with an unexpectedly low coarse fragment. BO-N soil is derived from gravelly lag or glaciofluvial with moderately fine textured glaciomarine deposits. These deposits are known to be relatively non-homogeneous due to the somewhat unpredictable nature of the glaciomarine environment. It is likely that the sample was collected from a pocket of the fine textured deposits.

BZ-ST, CE-EU and CP were found to have similar bulk density values at 0.75, 0.84 and 1.1, respectively. These values are consistent with uncultivated forest soils (Brady). The bulk density for the Bose-Nicholson sample was determined to be 0.28. This value is quite low and is perhaps a result of the high organic matter content relative to coarse fragment.

Field Analysis

In addition to sample collection, soil pits were dug and the profiles were classified to Great Group which classifies the soil with respect to the nature of the soil environment as well as the strength of the effect of the dominant soil forming processes (Agriculture and Agri-Food Canada, 1998).

The soil pit dug within the area of the watershed mapped as BZ-ST exhibited a Podzolic B horizon with a thick Bhf. This soil was therefore classified as a Ferro-Humic Podzol. The soil profile description is summarized in Table 7-3.

Depth (cm)	Horizon
3-0	LFH
0-10	Ah
10-13	Ae
13-33	Bhf
33-50+	Bfg

Table 7-3 Horizon description for soil pit dug within area mapped as BZ-ST soil

The soil pits dug within the areas of the watershed mapped as CP, BO-N and CE-EU exhibited Podzolic B horizons with thin Bhf layers. These soils were therefore classified as a Humo-Ferric Podzols. The soil profile descriptions are summarized in Table 7-4.

CP		BO-N		CE-EU	
Depth (cm)	**Horizon**	**Depth (cm)**	**Horizon**	**Depth (cm)**	**Horizon**
10-0	LFH	2-0	LFH	5-0	LFH
0-2	Ae	0-1	Ae	0-2	Ae
2-5	Bhf	1-7	Bhf	2-5	Bhf
5-30+	Bf	7-30+	Bf	5+	Bf

Table 7-4 Horizon descriptions for soil pits dug within CP, BO-N and CE-EU soils

In all cases, the field work was in agreement with the digitized soil map for the watershed.

Appendix IV

Tables for determination of SCS Curve Number

Runoff Curve Number for 1979				CN		
Estimated Hydrologic Soil Group	cover description	pervious CN (assume same as good grass)	area (acres)	SCS table 2-2	SCS figure 2-3 (or .exe)	Product of CN*area
B	forest (good woods)		569.9	60		34194
C	forest (good woods)		865.6	73		63188.8
B	grass (good open spaces)		9.055	61		552.355
C	grass (good open spaces)		26.44	74		1956.56
B	bare (newly graded)		96.34	86		8285.24
C	bare (newly graded)		18.99	91		1728.09
B	developed 66% TIA (user defined res)	61	7.011		85	595.935
C	developed 66% TIA (user defined res)	74	127.6		90	11484
CN = (sum of CN*area)/total area = 121984.98/1732 = **70.4**						

Runoff Curve Number for 1999				CN		
Estimated Hydrologic Soil Group	cover description	pervious CN (assume same as good grass)	area (acres)	SCS table 2-2	SCS figure 2-3 (or .exe)	Product of CN*area
B	forest (fair woods)		273.3	60		16398
C	forest (fair woods)		333.3	73		24330.9
B	grass (good open spaces)		56.8	61		3464.8
C	grass (good open spaces)		121.8	74		9013.2
B	bare (newly graded)		136.4	86		11730.4
C	bare (newly graded)		173.6	91		15797.6

B	sfr with 45.6% TIA (1/4 acre residential)	61	165.6		78	12916.8
C	sfr with 45.6% TIA (1/4 acre residential)	74	255.5		85	21717.5
B	mf with 60% TIA (1/8 acre multi-fam)	61	18.8		83	1560.4
C	mf with 60% TIA (1/8 acre multi-fam)	74	86.8		88	7638.4
B	institu with 44.2% TIA (1/8 acre res)	61	31.9		77	2456.3
C	institu with 44.2% TIA (1/8 acre res)	74	46.7		85	3969.5
B	comm (imp sfc)		0.5		98	49
C	comm (imp sfc)		20.5		98	2009
C	indust (imp sfc)		4		98	392
CN = (sum of CN*area)/total area = 133443.8/1732 = **77.0**						

Runoff Curve Number based on Future development of forest				CN		
Estimated Hydrologic Soil Group	**cover description**	**pervious CN (assume same as good grass)**	**area (acres)**	**SCS table 2-2**	**SCS figure 2-3 (or .exe)**	**Product of CN*area**
B	forest (fair woods)		244.62	60		14677.2
C	forest (fair woods)		240.99	73		17592.27
B	grass (good open spaces)		56.8	61		3464.8
C	grass (good open spaces)		121.8	74		9013.2
B	bare (newly graded)		136.4	86		11730.4
C	bare (newly graded)		173.6	91		15797.6
B	sfr with 45.6% TIA (1/4 acre residential)	61	187.61		78	14633.58
C	sfr with 45.6% TIA (1/4 acre residential)	74	297.75		85	25308.75
B	mf with 60% TIA (1/8 acre multi-fam)	61	25.47		83	2114.01
C	mf with 60% TIA (1/8 acre multi-fam)	74	136.86		88	12043.68
B	institu with 44.2% TIA (1/8 acre res)	61	31.9		77	2456.3
C	institu with 44.2% TIA (1/8 acre res)	74	46.7		85	3969.5
B	comm (imp sfc)		0.5		98	49
C	comm (imp sfc)		20.5		98	2009

C	indust (imp sfc)		4		98	392
CN = (sum of CN*area)/total area = 135251.3/1732 = **78.1**						

Runoff Curve Number based on Future development of forest and bare lands				**CN**		
Estimated Hydrologic Soil Group	**cover description**	**pervious CN (assume same as good grass)**	**area (acres)**	**SCS table 2-2**	**SCS figure 2-3 (or .exe)**	**Product of CN*area**
B	forest (fair woods)		244.6	60		14676.96
C	forest (fair woods)		241.0	73		17592.27
B	grass (good open spaces)		65.7	61		4004.869
C	grass (good open spaces)		143.6	74		10623.41
B	bare (newly graded)		8.8	86		759.5652
C	bare (newly graded)		24.4	91		2219.144
B	sfr with 45.6% TIA (1/4 acre residential)	61	266.3		78	20768.43
C	sfr with 45.6% TIA (1/4 acre residential)	74	337.9		85	28719.72
B	mf with 60% TIA (1/8 acre multi-fam)	61	43.0		83	3566.4
C	mf with 60% TIA (1/8 acre multi-fam)	74	212.1		88	18667.15
B	institu with 44.2% TIA (1/8 acre res)	61	54.5		77	4194.009
C	institu with 44.2% TIA (1/8 acre res)	74	58.8		85	4994.471
B	comm (imp sfc)		0.5		98	49
C	comm (imp sfc)		20.5		98	2009
C	indust (imp sfc)		4.0		98	392
CN = (sum of CN*area)/total area = 133236.4/1732 = **76.9**						