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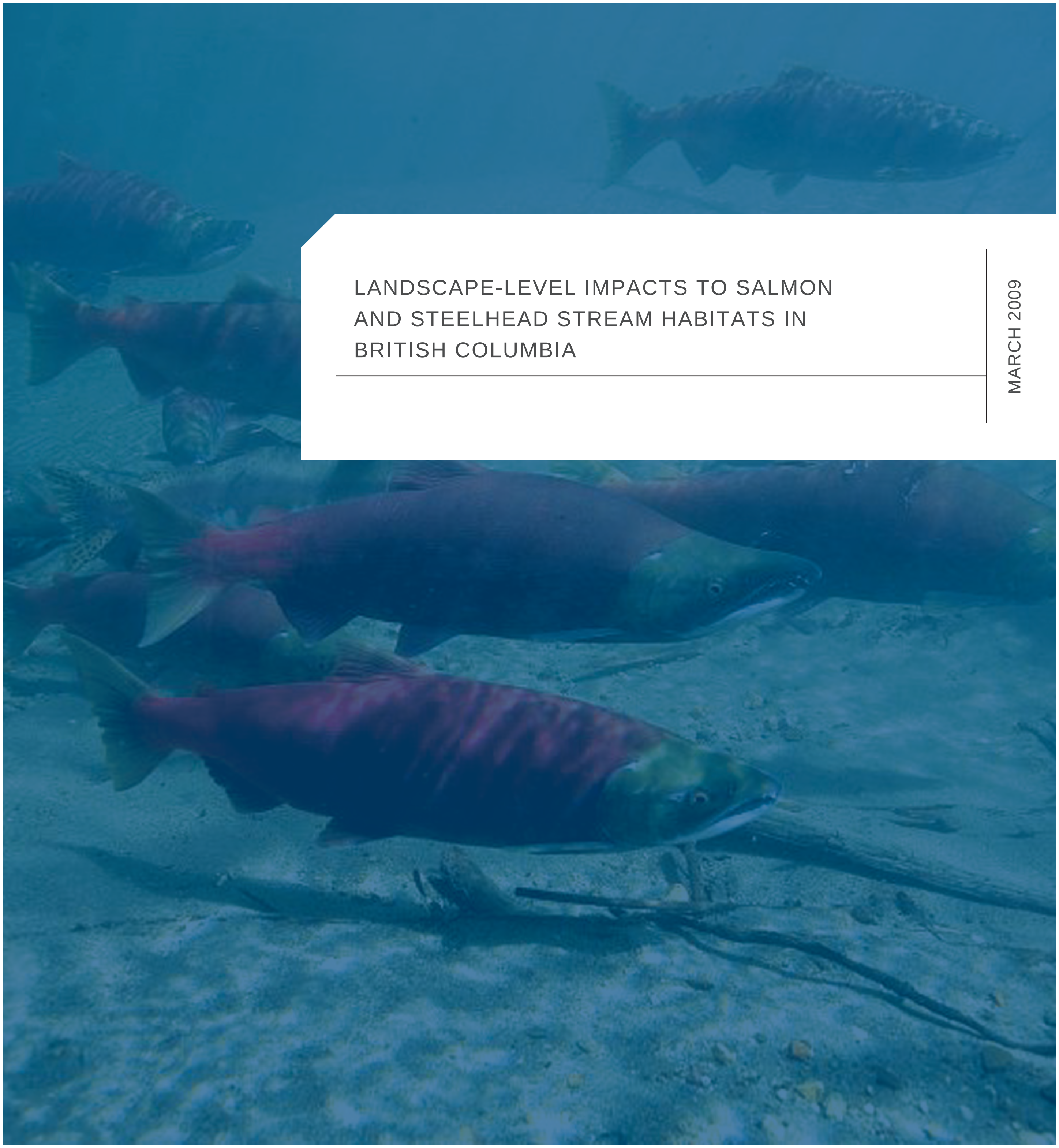

LANDSCAPE-LEVEL IMPACTS TO SALMON AND STEELHEAD STREAM HABITATS IN BRITISH COLUMBIA

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EXECUTIVE SUMMARY

The extent to which fish habitats are impacted by human activities at the landscape level is now being assessed and studied by fisheries scientists around the world. While there have been extensive efforts to protect and restore fish habitats in recent decades, traditional approaches have focused almost exclusively on in-stream and riparian areas. More recent work has begun to incorporate a broader, landscape perspective when developing strategies and policies aimed at protecting fisheries values.

In British Columbia some of the most important salmon and steelhead freshwater environments are physically, chemically and biologically diverse as a result of water flowing through a wide variety of landscapes. The geologies, hydrological regimes and ecological conditions vary significantly across the watersheds, creating a diversity of ecosystems and habitats. However, human activities, at the landscape scale have profoundly changed many of these features along many waterways, often to the detriment of the fish populations that exist within these broad geographic areas. This report examines the influences of landscape-level human activities on fish and fish habitat with a particular focus on activities relating to forestry, agriculture and urbanization.

FORESTRY

Significant changes to landscapes as a result of wood-harvesting practices have been taking place in BC for well over a century. Until recently, forest-harvest legislation, policy and government initiatives to protect fish and fish habitat have largely concentrated on dealing with instream and, more recently, nearby riparian areas. With the implementation of the *British Columbia Forest Practices Code Act*, consideration of activities in upslope areas relating to slope stability, drainage maintenance and road deactivation were clear indications that forestry managers were starting to address greater landscape issues.

While the implementation of the *Code* in the 1990’s started off in a somewhat cumbersome way, large gains were made in protection of salmon and steelhead habitat at the landscape level. This did change somewhat with the shift from the *British Columbia Forest Practices Code Act* to the *Forest and Range Practices Act* in 2002. Under this new approach, the harvesting of trees in British Columbia’s forests moved from a more regulatory “rules” approach where agencies provided oversight in the development of harvesting plans and their implementation to a “results-based” process whereby the industry largely regulated itself through “professional oversight”. Concern has been expressed by the public, and the authors of this report, that the latter is insufficient to protect fish and aquatic resources at the landscape level. The fact that compliance inspections by the Ministry of Forests and Range have also dropped off significantly since the implementation of the *Forest and Range Practices Act* is additional cause for concern. Efforts to remedy this situation will, in all likelihood, require a mix of legislative amendments, additional agency oversight and more frequent compliance inspections.

Another major influence on British Columbia’s forest landscape has been the recent pine beetle infestations that are manifestly changing the plant cover of widespread areas of the north and central part of the landscape in ways that may not have likely been seen for thousands of years. This phenomenon has influence on key aspects of salmon and steelhead habitat through the effects on stream hydrology, woody-debris (instream and riparian habitat) recruitment and slope stability. In response, the provincial government has opted to harvest the dead and dying wood as quickly as possible and as extensively as possible.

However, the results of some timely research undertaken by scientists and engineers, involved in the fields of hydrology, biology and fluvial (river) geomorphology (geography), within the Ministry of Forests and Range and associated institutions, has demonstrated that the Ministry's policies of extreme forest harvest are, to a degree, misguided.

As an example, changes to the hydrology of a watershed once the forest has died can increase both the volume and the intensity of spring-freshet flows while also reducing late-summer low flows, thus making conditions for fish more severe. Recent research results also indicate that, while dead standing timber does not have the snowmelt-mitigating capacities of a live forest, it does have hydrology-modifying benefits that can be beneficial to stream habitats when compared to the wholesale removal of beetle-affected pine over vast areas that is now taking place. Forest-harvesting policies should be revised to be more precautionary and less intrusive.

AGRICULTURE

Farming is a key economic driver in some areas of British Columbia. Many agricultural activities at the landscape level profoundly affect watershed ecosystems due to removal of native vegetation, physical re-arrangement of the natural drainage system, changes to hydrology, and inputs of high levels of nutrients and pesticides into watercourses. While many agrarian landscapes, such as those on the Fraser Valley, were largely modified between 50 and 100 years ago, current farming landscape practices continue to erode the viability of watersheds for various fish species through agricultural intensification. Increased efficiency in removing standing water in crop fields, through modernization of drainage systems, means that the natural hydrograph is even more disrupted, and low and high flows are exacerbated, significantly affecting fish communities. With the exception of outright purchase of such landscapes and restoration of hydrograph attributes through physical re-arrangement of the land, this particular conflict may be difficult to resolve.

However, one aspect that can be more easily addressed is the regulation of fertilizer applications (including manure and inorganic material) as well as pesticides. These materials often end up in aquatic ecosystems and can have adverse impacts. While this is laudable, many believe that compliance monitoring should be strengthened so that these regulations are more broadly adhered to.

Another farm-related issue that has arisen in British Columbia in recent years and that has had major impacts on aquatic values is the significant number of farming landscapes that have been removed from the British Columbia Agricultural Land Reserve. Many of these were considered to be "marginal" areas for cultivation, but had exceptional fisheries and aquatic-ecosystem values. This reassignment from farming to developed land has been almost universally damaging to fish habitats. The farming landscape-level-reassignment of Agricultural Land Reserve designations, and the subsequent commercial, industrial or urban development needs to be re-assessed and, in large part, curtailed. The Agricultural Land Commission, the regulatory agency for the Agricultural Land Reserve, has the prerogative to maintain farmland for other values, including ecosystems, but has rarely enacted this option.

URBANIZATION

British Columbia is experiencing unprecedented growth in its human population and, as a result, many new urban environments, which have been developed as a result of this expansion, are in close proximity to salmon and steelhead populations. Unchecked urbanization alters hydrographs and water quality in freshwater ecosystems and many salmon populations have been undermined by it. To address this, the environmental agencies and local governments are starting to re-think how they allow development to occur at the landscape level. This includes communities such as Metchosin that are restricting new development to less than 10% of impervious cover (e.g., concrete, blacktop, rooftops). Other communities, such as Surrey, are looking at "softer" infrastructure approaches to developing drainage and stormwater management, including green roofs and sophisticated computer models which assist in routing flows and infiltration areas, and this will help address some of the incremental effects on fish. Many urban communities have also developed rainwater management strategies as part of their Liquid Waste Management Plans and these should be strongly supported.

While local governments chiefly determine how development occurs within their borders and how these activities will affect aquatic resources, other government agencies such as the Ministry of Environment and Fisheries and Oceans Canada can strongly influence the behaviour of communities along these lines. In addition, other groups such as the Urban Development Institute and Smart Growth BC are also in a good position to influence a more environmentally sustainable approach to development that can positively affect fisheries habitat.

RECOMMENDATIONS

GENERAL

Landscape-level disturbances are now recognized around the world as potentially having significant adverse impacts on sensitive ecosystems, including affects to salmon and steelhead habitats here in British Columbia. This report discusses landscape-level activities relating to urbanization, forestry and agriculture.

In an effort to address this issue, it is recommended that the four levels of government—federal, provincial, local and First Nations—formally recognize the importance of addressing impacts on a broader landscape basis and that the recognition of landscape-level impacts as a concern be embedded in appropriate legislation. A more regionally focused approach to land use planning is also required.

The compounding effects due to the synergies of intensive agriculture and growing urbanization can make the issue more difficult as seen in the eastern Fraser Valley, and eastern Surrey, where large housing projects are now being developed in areas adjacent to intensive agriculture or on lands formerly used for farming. To resolve some of these issues, for example, sophisticated storm-water management plans that consider both the agricultural and the urban landscape need to be developed and implemented.

In addition, protective mechanisms such as incorporation of ecological values into the Agricultural Land Reserve would benefit salmon and steelhead. This may be particularly appropriate for areas confronting rapid urbanization, or where there is the continuing intensification of agriculture. If such ecological amendments are accompanied by tax breaks or other innovative measures this would help to take the burden off farmers for environmental protection within the agricultural landscape. Regardless such a shift will be required if landscape level impacts to fish habitat are to be contained, or at least made more manageable.

In the near term critical ecosystems essential to the habitat needs of salmon and steelhead must be better protected from the onslaught of landscape-level changes that are now occurring in much of the province. In order to achieve this, a multi-faceted approach will be required including the possible purchase of key private lands that are considered crucial for conservation efforts. Private-public partnerships for purchase of key private lands could also prove essential in providing additional leverage and the Heart of the Fraser initiative, which is being facilitated by the Nature Trust in consultation with numerous partners, is a potential model for such efforts.

FORESTRY

In general, forestry in British Columbia is already managed at the landscape level and current planning meets many of the goals for protection of the environment. A more ecosystem-aware approach has been in place over the last several decades given the evolving legislation and regulations that have occurred since the early 1990's. Nevertheless, ecosystem losses still continue to occur for some values including salmon and steelhead. Furthermore, under the *Forest and Range Practices Act* compliance and meeting 'results based' objectives is largely self policing by the licence holders. Combined with the drop in government enforcement and compliance, and the new knowledge that is being accrued due to the rapidly changing field of forest science, we feel there is the need for the regulatory agencies to become more diligent in ensuring that objectives to protect the environment are being met.

There appear to be significant opportunities for outside-interested parties to participate in the preparation and review of Forest Stewardship Plans (FSPs) which are the keystone of many forest-harvesting activities in British Columbia. These plans enable the outside groups to inform forest licensees (including BC Timber

Sales) about their interests within specified areas of public lands before roads and cutblocks are located. By law, forest licensees must give First Nations, other resource users, and the public a chance to review and comment on FSPs. This is a positive aspect of the landscape level-management in the forest sector in British Columbia and might have utility in other landscape-level issues

With the radical change in the forest landscapes throughout the interior of British Columbia due to pine beetle infestations over the last decade, there is the need for an extra-ordinary scientific understanding in regards to the large-scale landscape-level salvage of trees that is now happening. In particular, the science surrounding the effects of watershed-level hydrological changes, now occurring for both natural changes and logging-related effects, is key to properly managing the impacts and protecting aquatic and other ecosystem values. We encourage continued monetary and program support in regards to the undertaking of the science of these issues.

AGRICULTURE

Many of the impacts to fish, including salmon and steelhead, surrounding agricultural activities in British Columbia are in areas of intense farming such as the eastern Fraser Valley, the southern Okanagan and parts of south-eastern Vancouver Island. These are also areas of historically high-value salmon and steelhead habitats and need to be protected from increasing landscape-level farming activities.

Developing and enforcing existing and better standards for pesticide and fertilizer use at the landscape level are one of the keys to the restoration and maintenance of fish populations co-existing in these areas of intensive farming in British Columbia.

Since agricultural drainages and fish hydrological needs are often incompatible (i.e., farmers want standing water to be quickly drained off of the landscape to maintain crop viability; fish need water-retention rates that are high and for the landscape to release flows into rearing areas slowly), having farmers adopt landscape-level management that will provide a fish-friendly hydrograph is very difficult. Landscape-level purchases of property in strategically key locations may be the only way of providing some of these flow features for fish. Because of the cost, senior levels of government will have to be engaged to attain the kinds of funds required to undertake such an endeavour.

Specifically directing, and embodying in legislation, the Agricultural Land Commission (ALC) to take into consideration habitat values, and, in particular, salmon and steelhead ecosystems, during its review of exclusion applications would be a fundamental aspect of landscape-level protection of aquatic and other ecosystem attributes. Currently, if an owner of farmland applies to the Agricultural Land Commission to have his/her land excluded from the Agricultural Land Reserve, the ALC is under no obligation to consider the environmental values of the property. As a result, in recent years large-scale losses of sensitive aquatic landscapes have occurred to development due to this oversight.

The joint federal-provincial Environmental Farm Plan program has aspects that may assist in protecting landscapes (Rosenau and Angelo 2005). While we view this program as not being comprehensive enough to protect key hydrological aspects and sensitive areas from being cleared for agriculture, for example, the Environmental Farm Plan initiative does have components that will provide protection to sensitive ecological areas and aquatic attributes. The Provincial and Federal governments should continue to support and encourage farmers to support this important initiative.

URBAN

The rapid urban growth in the southern parts of British Columbia is precluding protection of salmon and steelhead stocks in certain areas of our province due to large-scale landscape-level changes. We note that half of the historical runs of salmon in the Fraser River watershed are in habitats downstream of Hope, and this includes areas of some of the fastest urban growth rates in this province. While Metro Vancouver and the Fraser Valley Regional District have developed Regional Growth Strategies, we point out that these have been shown to be weak and largely ineffective to protect fish and other sensitive ecosystems. We suggest that a serious commitment to liveable growth strategies by local governments in these areas is imperative, the strategies needs to be embodied in legislation, and this must be undertaken at the earliest opportunity.

Public advocacy groups such as SmartGrowthBC provide positions that are largely protective of greenfield landscapes and encourage the utilization and re-development of historically developed brownfield or greyfield areas. We support these concepts and suggest that local communities focus on developing the latter brownfield and greyfield areas rather greenfield landscapes. This would be a shift in how local governments currently do business insofar as many of the developments are now occurring in green landscapes that are adjacent to, and influence, salmon and steelhead ecosystems.

We note that the current growth objectives and re-zoning by local governments will have to change significantly if sensitive ecosystems such as salmon and steelhead habitats in areas of high urbanization in British Columbia are not going to be lost to the effects of the rampant landscape-level development that is now occurring. We believe that there is support for this by the citizenry of local communities should someone take the initiative to tap into these wishes. For example, in a most recent and remarkable turn of events (October 2008), over a seven-day period of open hearings, citizen groups in Mission blocked (at least temporarily) the passing of the third reading of a large landscape-level development in the south-western portion of that community based largely on the environmental (including fish habitat) values of the landscape. With appropriate leadership in this regards, local citizens have the opportunity to take back their communities in respect to sustainability, environmental viability and the protection of aquatic values.

What makes the issue of protecting landscapes in the urban environment important, compared to forest-harvest locations and agricultural farmland, is that for the former it comprises little crown land and the costs of property purchase of these locations is very high. However problematic it may be, landscape-level legislation that has specific mandates to protect ecosystem values and securing land in urban settings, may be the only way of adequately protecting salmon and steelhead ecosystems in British Columbia in the face of high rates of land-development activity. To make progress in this direction we recommend that the Minister of Environment appoint an independent expert panel to review mechanisms to protect and preserve environmental values in urban environments. This is crucial as it is our view that current legislation such as the Canada Fisheries Act, the British Columbia Riparian Area Regulations, and the various habitat-protection provisions, through policy and regulation, currently do not meet the needs of salmon and steelhead in areas of intense urban development.

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1.0 INTRODUCTION

OVERVIEW

Across British Columbia many natural landscapes are undergoing dramatic changes at a rate unlike anything that has occurred since the last ice age more than 10,000 years ago. These broad-scale landscape alterations, many of which are directly the result of human activities, are radically affecting terrestrial, avian and aquatic ecosystems in unprecedented ways. Such changes to habitat are making it increasingly difficult for natural resource managers to mitigate perturbations and their resulting impacts, which often include significant damage to salmon and steelhead habitats.

While the current rate of landscape change in British Columbia is remarkable, the fact that humans are currently modifying their surrounding physical and ecological environments, for habitation or resource-extraction purposes, to the point of environmental and ecological detriment is not a new phenomenon. As far back as ancient history, anthropogenic changes to landscapes have ineffably altered ecosystems at both large and small scales and these changes have almost always been negative to the natural environment (Krech *et al.* 2004). Not surprisingly, in many instances throughout history the effects of these modifications have resulted in the eventual collapse of the societies that so radically re-arranged them, but were also intimately dependent upon those same landscapes and the resources therein (Diamond 2005).

Some may ask, why we should be concerned about alterations to landscapes as governments should have the issue well in hand given our modern-day scientific knowledge of natural-resource management along with numerous legislative and regulatory commitments to protect the environment? The response is that despite good intentions by governments and environmental agencies, resource extraction of the world's landscapes is now occurring at unprecedented rates; as an example it has recently been estimated that about 29 percent of the world's land area—almost 3.8 billion hectares—has now been modified for both agricultural and urban areas (WRI and Wagener 2000). For many areas on the planet, these changes have now accelerated natural-ecosystem losses to the point of "no recovery". Moreover, human populations are still dramatically increasing in number and continue to expand their per-capita-demand for goods, many of which are derived from natural resources. Furthermore, radical advances in technology have allowed greater per capita exploitation rates of the earth's resources at landscape levels, with concordant geometric losses to natural environments, including fish ecosystems. Finally, while broad-scale landscape impacts have resulted in many ecosystem losses, landscape fragmentation is superimposed in this scenario where pieces of original habitat are still intact but are now too small and too widely separated to maintain the genetic integrity of populations, species or organisms (Meffe *et al.* 1997).

Scientists are now wondering aloud if the many ecosystem collapses have become such a global phenomenon that these wide-scale alterations of our natural world would ultimately undermine the ability of humans to thrive, or perhaps even survive (Diamond 2005).

HABITAT IS THE KEY

There are many examples around the world where landscape alterations have caused large-scale habitat losses. In most, if not all of these cases, such changes have resulted in substantive declines in local biodiversity. This often includes the loss of organisms that are economically and socially important, as well as species that may have little monetary value but are keystone components to properly functioning ecosystems (Fig. 1.1). Not only have numerical declines in species occurred as a result of habitat loss, but outright extirpations and extinctions as well. For example, over the last four centuries, the rates of human-caused extinctions of various species have ranged from 100 to 1000 times that of natural background levels, with about one-half of these losses occurring over the last 100 years (IUCN undated, Krech *et al.* 2004).

Scientists are now forming a view that the greatest cause of species endangerment and extinction is habitat destruction through landscape alteration (Krech *et al.* 2004). For the United States it has been estimated that at least 85 percent of species declines can be attributed to this phenomenon of habitat loss (Krech *et al.* 2004). From this perspective, alteration of the world's surface at the landscape level represents a major global change that has significant future implications for the planet's flora and fauna (Sala *et al.* 2000).

Of special interest to this report, freshwater fish populations and aquatic ecosystems appear to be particularly vulnerable to human disturbances of the landscape. Such a link has been clearly demonstrated in several recent studies that quantify the large losses of aquatic biodiversity that are now occurring in freshwater environments around the world (Miller *et al.* 1989, Bogan 1993, Williams *et al.* 1993, Taylor *et al.* 1996, Ricciardi and Rasmussen 1999). For North American freshwater organisms, Ricciardi and Rasmussen (1999) showed that aquatic species are being extirpated at rates five times faster than for those animals that live on land. Since 1900, at least 123 freshwater fishes, amphibians, molluscs and crayfishes on our continent have become extinct, and hundreds more are now imperilled. Finally, to put this phenomenon in a global context, Ricciardi and Rasmussen (1999) estimated that the extinction of these aquatic organisms has been occurring at a rate of 4% per decade, which is similar to the higher-profile extinctions of tropical-forest species.

British Columbia is not immune to the phenomenon of species and stock extinctions, including its totemic salmon and steelhead populations. Those who choose to believe that continued extinctions cannot happen here in British Columbia are, in all likelihood, deluding themselves (Fig. 1.2).

One of the most poignant descriptions of how salmon and steelhead in western North America are rapidly disappearing is given by James Lichatowich (1999) in his seminal book entitled *Salmon Without Rivers: A History of the Pacific Salmon Crisis* in which he states that the first large-scale impact to salmonid habitat in western North America took place at the landscape level, occurring before Europeans started to settle in the area. This impact was not through logging, or land clearing for agriculture, but came about as a result of the early over-exploitation of the beaver (*Castor canadensis*) for its fur. These aquatic rodents are responsible for making dams which create enormous natural wetlands for the rearing of fishes, including salmon and steelhead, while attenuating the effects of floods and low flows. Once the beaver were trapped almost out of existence in western North America (and elsewhere across the continent), the salmon and steelhead aquatic habitat created and maintained by them was inexorably lost as the dams and water impoundments disappeared.

Following the collapse of the fur trade, the habitat-related declines in salmon and steelhead populations continued in the Pacific Northwest, British Columbia and Alaska (Nehlson *et al.* 1991) as other major landscape changes occurred through the settlement of the area by Europeans in the 19th and 20th centuries. During this period, the alterations were the result of logging, agriculture and urbanization. Nevertheless, as many salmon and steelhead populations began to collapse in western North America, the trend in fisheries management, by the late 1900s, moved towards habitat protection, particularly, for inland and coastal waters (Lackey 2005a). For the United States, widespread recognition that some salmon species (populations) were at risk of extinction led to public pressure on governments to reverse such trends which resulted in the United States Endangered Species Act being enacted. Subsequently, large amounts of money for restoration and protection was spent to counter these declines in western United States salmon stocks (Lackey 2005a) albeit with limited effect. What became clear was that the old ways of viewing salmon and steelhead habitat from simply instream or riparian perspectives in nature is incomplete; the whole landscape must be incorporated into fisheries management.

For the U.S. Pacific Northwest (which is expected to grow from the current population of 15 million to more than 50 million in the next century), British Columbia and Alaska, the expanding human population increasing competition for water and habitat are just two of the significant reasons for the unrelenting declines in salmonid populations. Even more unfortunately, many of these central issues have yet to be adequately addressed by fisheries managers and elected officials (Lackey *et al.* 2006).

On a more positive note, the plight of salmon in British Columbia gets a high level of media attention, although it tends to be hand-wringing articles about the demise of wild salmon and steelhead stocks and bereft of any concrete solutions. Nevertheless, these articles have been helpful as a wake-up call for both government officials and the public to reverse the downward trend in fisheries that continue even in the face of severe harvest restrictions. Just as importantly, a growing number of non-government organizations and local conservation groups are doing effective work at the local level while encouraging governments to address broader landscape level impacts. Yet a key question remains: why is this trend continuing in spite of advances in scientific knowledge and constitutional and legislated obligations of governments to protect fish and fish habitat, and what can we do about it? One obvious correlation in respect to the declines in fisheries is that, given the human-population growth trends in British Columbia, the salmon and steelhead runs continue to collapse in proportion with the increase in numbers of people (Fig. 1.3). What is also apparent is that at the heart of many of the salmon extinctions are the human-induced landscape-level changes that occur as the population spreads across the expanse of British Columbia, extracting increasing amounts of resources and inhabiting more of its geography.

For the province of British Columbia, the major post-European-settlement landscape changes have occurred through forest harvest, agriculture and, more recently, intensive urbanization. These activities are still the backbone of the economy and social history, and have supplanted the fishing industry, that was largely tied to salmon and was a predominant industry in much of the 20th century. While not the focus of this particular report, it is also clear that carbon emissions and related climate-induced changes to habitat associated with the use of fossil fuels are also influencing freshwater ecosystems and landscape changes in our province.

However, to date, many landscape-level activities in British Columbia have been, and continue to be, in conflict with the sustainability of anadromous fish in British Columbia. Also missing, so far, is a mechanism for public dialogue pertaining to conflicting issues of landscape usage and impacts to salmon and steelhead (Moerke and Lamberti 2006) with the objective of ultimately mitigating these impacts. With this report we hope to address aspects of these two issues.

FIGURE 1.1. Relative affect of major environmental factors, or drivers, of biodiversity.

Figure and explanation taken from Sala et al. (2000). For this figure, the expected biodiversity change for each ecosystem for the year 2100 was calculated as the product of the expected change in factor or driver and the impact of each driver on biodiversity for each ecosystem. Values are averages of the estimates for each ecosystem and they are made relative to the maximum change, which resulted from change in land use. Thin bars are standard errors and represent variability among ecosystems.

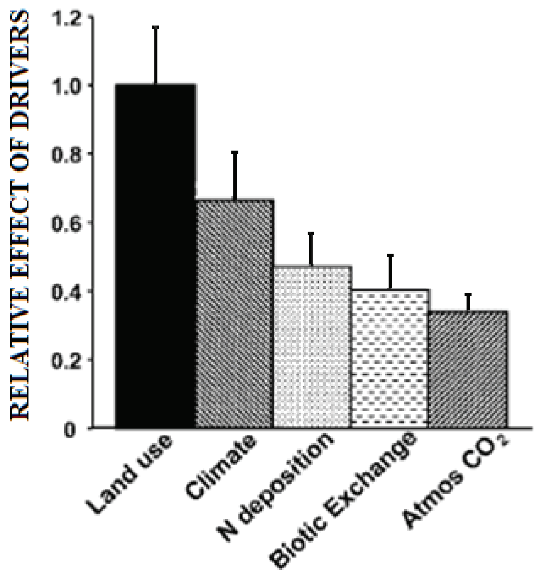


FIGURE 1.2. The collapse of Fraser Chinook salmon 2008 compared to its index escapement to the river, conducted by Albion test fishery near Mission.

These data represent the 1981–2006 average cumulative CPUE versus the 2008 cumulative CPUE an 8" gillnet (Fisheries and Oceans Canada 2008). Despite such low numbers, compared to historical averages, in 2008 commercial, First Nation and sport chinook fisheries continued to harvest these fish both within river and in marine areas in 2008.

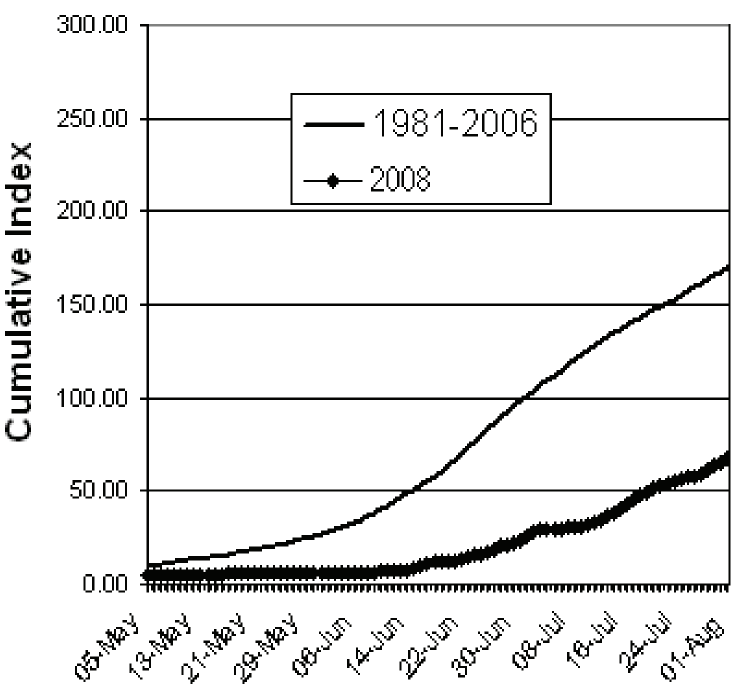
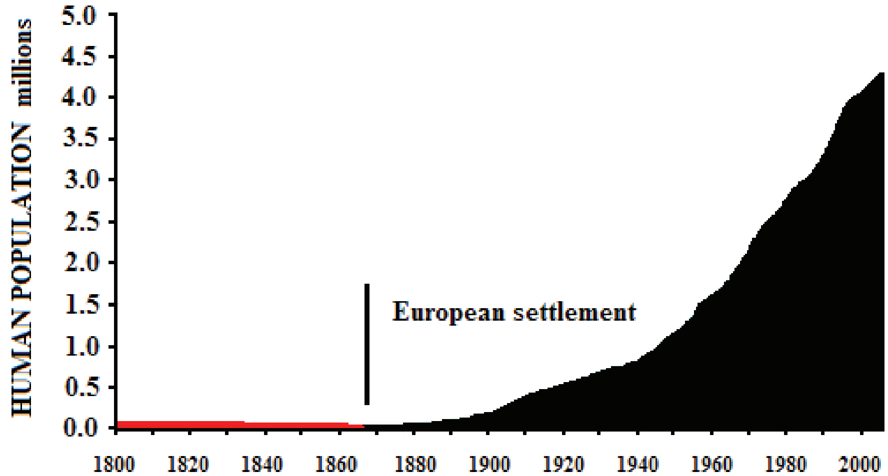


FIGURE 1.3. Change in human population in British Columbia from 1800 to the 21st century.
Data from: Ministry of Forests and Range (2006a).



WHAT IS A LANDSCAPE?

This report examines the effects of human activity on landscapes to salmon and steelhead habitats in British Columbia. However, the term "landscape" can mean many different things to many different people. For the purposes of this report a "landscape" is a geographic area that has roughly homogeneous and contiguous patterns of physical, biological and land-use characteristics. In other words: "…[a] landscape may be thought of as a heterogeneous assemblage or mosaic of internally uniform elements or patches, such as blocks of forest, agricultural fields, and housing subdivisions…"(Answers.com undated). A landscape can include natural features such as forests and lakes and streams, as well as areas altered by human activity such as farmlands, cities and towns (EPA 1998). The area of a landscape can be from a few thousand to several thousand square kilometres (EPA 1998). In defining a landscape, the U.S. Environmental Protection Agency also considers the predominant natural-vegetation community (e.g., prairie-type, forest-type, and wetland-type) or land-use-dominated activities (e.g., agriculture and urban) (EPA 1998).

An important large-scale geographic feature of a landscape is the "watershed". Within "landscapes" can flow a number of "watersheds" although a given watershed may be composed of, and be much larger than, a number of landscapes. The term watershed (sometimes also called a catchment) refers to an area of land that drains water, woody debris, sediments, and dissolved substances to a common outlet at some point along a stream channel and is topographically defined by the height of land, or a divide, and these materials drain in a collective general direction (Dunne and Leopold 1978). Thus, a watershed may be exceptional in size (such as the Fraser River watershed) and encompass many landscapes. Alternatively, a watershed may be very small (such as the Tincan Creek drainage in south-west Vancouver), and constitute only a small portion of a landscape (Metro Vancouver). To reiterate, a landscape can cross the boundaries of several watersheds insofar as it is defined by its broader geographic features, human use and/or vegetation characteristics while the watershed has a particular direction of water and sediment flow.

LANDSCAPE ECOLOGY AS A SCIENTIFIC DISCIPLINE

Determining the effects of altering a landscape on an ecosystem is part of the scientific study known as "landscape ecology," defined as: "*…the study of the distribution and abundance of elements within landscapes, the origins of these elements, and their impacts on organisms and processes…*" (Answers.com undated).

A variety of scientific disciplines are involved in the field of landscape ecology, including biogeographers, geomorphologists, land-use planners, hydrologists, and ecologists. Jointly and individually they study the distribution of organisms over broad geographic areas, the shape of the landscape, the human use of land, the flow patterns of water through watersheds, and the inte-relationships of organisms to each other. However, landscape ecologists integrate and bridge these various disciplines so that they can learn to understand the interconnections and relationships between the natural and human factors that influence the development of landscapes, the impacts of landscape patterns on humans (and vise versa) and other organisms, and the flow of water (Fig. 1.4), materials and energy among patches (discrete sub-units) within the landscape (Turner 1989, Answers.com undated).

Within the discipline of landscape ecology, scientists have also begun to study the influence of the greater area on particular sub-units, such as streams. There has been a major shift in how stream ecologists view running waters. Historically, instream-fisheries scientists tended to concentrate their assessments of human impacts on stream habitats looking at small, discrete physical units that were often not representative of the greater aquatic ecosystem. (For example, the fisheries habitat ecologist may have studied the effects of the removal of the riparian area, as a result of logging, on stream ecosystems, but now a landscape ecologist might assess the effects of tree harvest throughout the whole catchment on that same stream's biological community.) The shift in scientific scope has come about as stream ecologists have begun to understand the influence of the broader landscape on running waters (Hynes 1970), and fluvial scientists have now started to expand their scope of investigations increasingly and geographically outwards.

It is the opinion of Wang *et al.* (2006a) that the consideration of streams as a sub-set of landscape functions is a new science even though the connection between the greater landscape and associated physicochemical and biological characteristics of streams has already been recognized for some decades (Hynes 1970). While scientists have long had the impression that "the larger affects the smaller", the emerging science of landscape ecology in respect to flowing-water ecosystems has now been facilitated, in particular, by the growth of new disciplines and technologies. This includes the wider availability of regional data bases and the rapid development of geographic information systems (GIS) technologies, and these have now been combined with high-speed computers. These capabilities and tools have allowed scientists the ability to develop frameworks for measuring and modelling exceptionally complex linkages, from the greater landscape to what is happening within a particular stream (Hughes *et al.* 2006, Wang *et al.* 2006a).

WHY STUDY THE ECOLOGY AND HUMAN DISTURBANCE OF LANDSCAPES IN RELATION TO FISH?

Why might it be valuable to study how human activities, which are now profoundly changing the earth's surface at the landscape level, affect fish in streams in British Columbia? As stated above, a large proportion of the terrestrial areas of the world have now been directly or indirectly modified by human activities, and this can profoundly affect the proper functioning of streams and their aquatic ecologies (Hynes 1975, Gregory *et al.* 2003, Allan 2004, Hughes *et al.* 2006). British Columbia has experienced, in the past several decades, spectacular collapses of salmon and steelhead stocks that, for some populations, are explicable primarily in relation to landscape changes (e.g., lower Fraser coho, Strait of Georgia steelhead and coho). The equivocal cause-and-effect functional relationship between impact and collapse occurs because the degradation of streams through landscape change can be either highly obvious or slight; it is often difficult for the fisheries scientist to tease out the most prevalent reason for a decline in fish numbers amongst many causal factors.

Elosegi and Johnson (2003) also suggest that subtle changes in the physical nature of a watershed are likely to produce small shifts in the structure and function of a stream's ecosystems, but activities directly affecting the energetics of the aquatic community (such as sewage discharge, riparian clearing, or harvest) or the physical re-configuration of a stream (damming, channelization, water diversion) are likely to cause large changes. For the category of physical changes, the landscape-level impacts tend to be greatest to aquatic ecosystems where intensive soil use (for instance, agriculture, quarries, mining) and urban development dominate or coexist in complex landscape mosaics (Elosegi and Johnson 2003).

THE LANDSCAPE AND FISHES—ALL ARE CONNECTED

Landscapes are bio-geographical areas of infinitely connected parts. Merriam (1984) and Moilanen and Nieminen (2002) describe how the concept of connectivity is used by ecologists as one aspect explaining the distribution of species across landscapes. Connectivity is now also widely acknowledged by fisheries scientists as a fundamental property for the proper functioning of aquatic ecosystems (Kondolf *et al.* 2006). Nevertheless, the concept of considering the whole landscape from a habitat perspective when managing fisheries is still relatively new, and is not yet being applied in British Columbia.

Historically, the science of habitat management in stream ecosystems, and its understanding of the utilization by fishes therein, was concentrated in investigations specifically within active stream channels. However, in the latter part of the 20th century stream researchers began to expand their physical scope of study to encompass more than just site-specific locations within the normally wetted perimeter including, for example, the functioning of the riparian area. Other examples of some of the broader geographic scales that have been researched by stream scientists over the last several decades include the River Continuum Concept (Vannote *et al.* 1980; Fig. 1.5) and the Flood Pulse Concept (Junk *et al.* 1989; Fig. 1.6). The former links the physical and biotic interactions along the length of relatively homogeneous streams, all the while recognizing gradients down their lengths (Vannote *et al.* 1980), while the latter concept takes into consideration the idea that water in streams also moves laterally from the active channel, via natural hydrograph flooding, onto the floodplain and links these aspects, biologically and physically, into the proper functioning of an aquatic ecosystem (Junk *et al.* 1989). Amoros and Roux (1988) also showed that the linking of a stream's lateral components to the flowing water, was also important in maintaining a working fluvial ecosystem, with the riparian zone (Naiman and Décamps 1990) being a key aspect of this complex's ability to properly function.

Taking the concept one step further would be to consider that, for an aquatic ecosystem to function properly, it must link with lateral aspects of the greater landscape. Aquatic scientists have now started to demonstrate the importance of sub-surface-flowing water from the upslope and the floodplain/riparian areas of the landscape into, and from, the active stream channel. Thus, the groundwater and the hyporheic-zone (the hyporheic zone is the hydraulic interface between groundwater and the wetted bottom of a stream; Fig. 1.7) connections provide linkages from the stream to areas more distant from the flowing waters, and back again, ultimately influencing aquatic organisms in the stream (Gibert *et al.* 1990, Vervier *et al.* 1992).

Aquatic ecosystems and their organisms are affected not only by the immediate conditions found within the wetted perimeter of a stream or a lake, but also by the physical, chemical and hydrological complexity of the complete surrounding landscape, of which lakes and streams are part of. This is because the water volume, chemistry and temperature, and other physical conditions within the stream, at the local and micro-level, are extensively modified by the contiguous surrounding area. Indeed, Burnett *et al.* (2006) state that the condition of a stream ecosystem is largely a function of landscape characteristics of its watershed and cite Hynes (1975), Frissell *et al.* (1986), and Naiman *et al.* (2000) as evidence. Thus, properly functioning ecosystems, including their aquatic communities, operate over a variety of parameters including the biological, physical, chemical and temporal that make up, and pass through, a watershed (Vannote *et al.* 1980, Wiens 1989, Menge and Olson 1990, Poff 1997, Wang *et al.* 2006b). And, overarching this is the effect of the hydrological cycle linking the whole landscape through atmospheric, surface and sub-surface flows (Fig. 1.4).

SPATIAL DIVISIONS OF LANDSCAPES IN RELATION TO STREAMS

By 1970 Hynes (1970) began to discuss the idea that environmental variables, at multiple spatial scales and over large and different geographic areas, drive the physio-chemical and biological processes in streams (Weigel *et al.* 2006). Subsequently, Vanotte *et al.* (1980), Ward and Stanford (1989) and Junk *et al.* (1989) added to these ideas insofar as they viewed streams as open systems with interactive pathways that not only move water and other features along longitudinal, lateral, and vertical dimensions, but also have a temporal aspect with the hydrograph (Fig. 1.8) playing a key role in ecological organization over time. Thus, the organization of flowing water ecosystems is nested in a hierarchy, both spatially and temporally (Johnson *et al.* 1995).

For the purposes of further discussion with respect to streams, this report follows the landscape divisions of Wang *et al.* (2006a) who suggest that the landscape influences on flowing water can be divided into three spatial zones: the Active Stream Channel; the Floodplain/Riparian Area; and the Upslope Area (Fig. 1.9).

ACTIVE STREAM CHANNEL

The active stream channel is that part of the landscape having immediate contact with the water at, or below, bank-full conditions (e.g., Fig. 1.10). This zone is known for its dynamic transport of chemical and biological material (live and dead), and various size classes of sediments (Fig. 1.11). The active stream channel is either partially or completely wetted throughout the period of a normal year. It is characterized by the lack of terrestrial vegetation and, in some cases, has extensively exposed gravel and/or sand bars during the lowest of flows.

Historically, the protection and restoration of aquatic ecosystems and fish populations in freshwater stream environments have concentrated on understanding the various aspects of the functioning of the attributes found within the active stream channel and trying to manipulate them in order to increase fish production. Researchers have looked at parameters such as water temperature, physicochemical properties, channel hydraulics, pool-riffle complexity, substrate and instream-woody debris composition (Fig. 1.12), and how these factors affected fish production (e.g., Southwood 1977, Gorman and Karr 1978, Angermeier and Karr 1984, Colt and White 1991, Slaney and Zaldokas 1997, Roni and Quinn 2001). Throughout the 1970s and 1980s much research assessed minimum flow requirements in streams and an extensive amount of discussion followed from this scientific inquiry as to whether fisheries ecologists could actually use minimum flow criteria for maintaining a healthy aquatic ecosystem (e.g., Bartschi 1976, Tennant 1976, Bovee and Milhous 1978, Stalnaker 1979, Wesche and Rechard 1980, Newcombe 1981, Bovee 1982, Orth and Maughan 1982, Annear and Conder 1984, Loar *et al.* 1986, Reiser *et al.* 1987, Milhous *et al.* 1989).

To a degree, these kinds of scientific investigation helped inform fisheries managers on how to protect and restore fish habitat in the face of human activity in and around streams—but not always (c.f., Larson *et al.* 2001, Shields *et al.* 2003, Kondolf *et al.* 2001, Kondolf 2006). Thus, by the 1990s, it became apparent that to properly manage salmon and steelhead stream ecologies it was not simply enough to consider aspects of the aquatic ecosystem within the active stream channel. Processes outside of the regularly wetted perimeter of a stream were sometimes equally, or more significantly, defining the health of these fluvial ecosystems.

FLOODPLAIN/RIPARIAN AREA AND THE NATURAL-FLOW REGIME

The floodplain and/or riparian areas comprise those zones of the landscape sandwiched between the active stream channel and upslope areas and overlapping in their physical location in fluvial channels (Fig. 1.9). A riparian area is formally defined as an area of land adjacent to a pond, lake or stream, and is immediately influenced by the water; the floodplain is a zone adjacent to the active channel within the riparian area that is inundated regularly at a frequencies occurring well within a human lifetime (e.g., Fig. 1.13). The riparian area/floodplain comprises one of the some of the most bio-diverse habitats in the terrestrial part of the planet Earth (Naiman *et al.* 1993) and is the transition zone between terrestrial and aquatic ecosystems (Gregory *et al.* 1991).

The significance of the regular and natural flooding (e.g., Figs. 1.8, 1.13) in regards to the proper functioning of aquatic ecosystems has only been seriously investigated in recent decades. Poff *et al.* (1997) wrote a well regarded and seminal paper in which they describe the various functions that uninterrupted normal inundation has in maintaining floodplain ecosystems in natural streams. Their thoughts, however, followed from earlier work by Dunne and Leopold (1978), Junk *et al.* (1989), Poff and Ward (1989) which also put forward the thesis that the floodplain cannot be isolated from the active channel of the stream (i.e., the natural-hydrological flow) without negative consequences to the aquatic ecosystem. The development of the concept of the natural flow regime included the recognition that ecosystems in flowing waters were not simply bounded by the high-water mark of the active channel, but included spatial and temporal shifts in discharges over the whole hydrograph of the year and across the low-lying adjacent landscapes in the riparian areas.

The five critical components of the natural-flow regime include the magnitude, frequency, duration, timing, and rate of change in hydrologic (flow) conditions (Wang *et al.* 2006a); it is to these conditions that the aquatic organisms in streams, including salmon and steelhead, are evolutionarily adapted. Unlike the more simplistic earlier instream-flow-needs models of the 1980s, the natural-flow-regime concept recognized that minimum discharge was not the only, or necessarily even the most important, parameter of significance in the hydraulic range of normal flows. The whole scope of discharges had to be considered for ecosystems to function properly. These new ideas of natural hydrologic flows incorporated the principles that flow variability and floodplain inundation are also critical to maintain the ecological functions of stream systems; that is, the ebb and flows of water across the active channel and the floodplain, throughout the various seasons of a year, are key to stream ecosystems functioning properly (Poff *et al.* 1997). Obviously, the damming of streams, diking of floodplains, dredging of rivers and settlement in floodplains all disrupt and interfere with this natural flow regime.

What are some of the processes and attributes that fisheries managers and aquatic fluvial scientists should be aware of when considering the linkages between the active stream channel and the riparian and floodplain areas and the flood-flow patterns? Firstly, floodplain areas and riparian zones physically constrain the active stream channel's form, slope, and access to sedimentary materials (Wang *et al.* 2006a). Furthermore, floodplains store and slowly release water during a flood event, modify the movement of nutrients both away from, as well as to, the river channel, regulate the transfer of inorganic (e.g., sediments) and organic (e.g., large woody debris) materials from the more terrestrial areas, and provide spawning and nursery grounds for some species of aquatic organisms throughout certain times of the year (Junk *et al.* 1989, Welcomme 1995, Stanford *et al.* 1996, Pepin and Hauer 2002, Hauer and Lorang 2004, Stanford *et al.* 2005, Wang *et al.* 2006a).

The growth and density of vegetation in the riparian areas is also important to aquatic production in many streams. The amount of vegetation and species of plants can affect the quantity of solar radiation reaching smaller streams; this will regulate the amount of light that will be available for photosynthesis for within-stream aquatic macrophytes and algae. The amount of sunlight reaching a stream will modify water temperatures (i.e., the amount of the sun's energy to heat water) and profoundly affect the growth rates of plants, invertebrates and fish. Too much sunlight may heat water temperatures to lethal levels for some organisms, and too little can result in reduced algae, invertebrate and fish growth and production.

Plants growing along the edge of the stream in the riparian areas also consolidate the streambank and its sediments through their root networks and, thus, reduce erosion (Gregory *et al.* 1991). Vegetation in the riparian area also traps pollution, fine sediments from the upland areas and sequesters and releases nutrients (Gregory *et al.* 1991).

The riparian vegetation is also important for invertebrate production for fish species in the stream. This occurs either directly through insect drop from the vegetation itself or the production of leaves which, when they fall from deciduous trees, enter the wetted perimeter of the stream and provide both forage for aquatic invertebrates or nutrients for instream algae (as the leaves decompose); the algae in the stream, in turn, provide food for stream insects on which fish feed (Hynes 1975).

Another important aspect is the hyporheic zone which is often an integral part of most riparian areas. The hyporheic zone of a stream is the mixing area between surface water and groundwater and connects the stream in the active channel to groundwater and riparian areas (Fig. 1.7). The hyporheic zone is also an active ecotone (an ecotone is a transition zone between two ecological communities but which has characteristic species of each) between these layers of water (Boulton *et al.* 1998). Hyporheic zones are important to aquatic ecosystems in that water, nutrients, and organic matter are exchanged between the stream and the groundwater and the extent to which this happens varies according to flow, the shape of the stream bed, and the porosity of the endemic sediments (Boulton *et al.* 1998). There can be two directions of the hyporheic flow. For the first, groundwater can come to the surface through the hyporheic zone and provide nutrients to algal communities on the benthic substrates of flowing-water or within the water column. For the other, stream-water, containing dissolved oxygen and organic matter, can also move downward and which can then be used by microbes and invertebrates located in the hyporheic zone.

Throughout the hydrological year, and from location to location, there can be gradients throughout the hyporheic zone. Boulton *et al.* (1998) suggest that at the micro-scale there are gradients in redox potential that control chemical and microbiologically mediated nutrient transformations that take place on particle surfaces. Salmonid fishes often have their embryos and alevins buried in gravel nests, known as redds, and these incubating fishes are bathed by oxygenated hyporheic water from fertilization to the completion of their development. A hyporheic zone can extend for many kilometres from groundwater, thus providing the opportunity of streams to remain watered during low-flow periods.

UPSLOPE AREA

As scientific research and efforts towards ecological protection and restoration continued by stream ecologists throughout the latter decades of the 20th century, it became clear that something was still missing in regards to the understanding of the functional relationships of flowing waters and their constituent parts. That is, despite the fact that knowledge in respect to how processes in the active stream channel and the riparian/floodplain areas affect aquatic production had increased substantially, there was still a component that was absent in the understanding by scientists of how these ecosystems work. Empirically, numerous examples could be provided (particularly in urban and agricultural landscapes) where there was proper functioning of the active stream channel, and relatively intact riparian areas and floodplains, yet fish populations remained low relative to historical pre-landscape development levels.

Freshwater fisheries scientists began to realize that the "missing link" also included the role of the upslope areas (Fig. 1.9), or that part of the landscape that physically lay outside of both the active channel and the riparian/floodplain areas (Kaufman *et al.* 1997, Roper *et al.* 1997). In short, for a stream ecosystem to function properly it cannot have the active channel and the floodplain/riparian area isolated from the upslope areas; all three components must act in concert, retain a level of functionality and be connected in order to maintain an healthy aquatic ecosystem (Fig. 1.11). It is the integration of these three features—the active stream channel, the riparian/floodplain areas, and the upslope zones—that constitute the landscape and these must all be reasonably intact for aquatic ecosystems to flourish.

While most stream ecologists are only just beginning to understand the role of the complete landscape in the health of stream ecosystems, recognition of the broader geographic influences on the aquatic ecosystems in flowing waters is not completely new. As far back as 1975 the "father" of freshwater-stream biology, H.N.B. Hynes had already stated "*…in every respect the valley rules the stream*". His statement recognizes the fact that streams are a part of interconnected series of physical, biological and chemical gradients that make up the essential parts of flowing-water ecosystems, and from the highest elevations of a catchment down to the bottom of the valley (Ward 1998, Fausch *et al.* 2002, Wiens 2002).

This concept of the landscape-level influence on flowing waters is all the more important considering that human activities surrounding streams have largely re-constituted the surface and the shape of the upslope area in most countries around the world. Human actions at the landscape level extensively disrupt the connections and functionality of the active stream channel which are the focus of aquatic ecosystems in flowing waters (Townsend 1996, Ward *et al.* 2001, Poole 2002, Thorp *et al.* 2006) That is, landscape disturbances in upslope areas can be as influential as any, to aquatic ecosystems, and disrupt the linkages between water and land (Dunne and Leopold 1978); when these linkages are disconnected, stream degradation occurs (Wohl 2004).

Although upslope landscape areas are often some distance from the active river channel, they still have regular connections through either intermittent or constant groundwater flows in the direction of the stream, as well as sporadic contributions of surface discharges or Hortonian overland flows (via rainfall runoff dynamics) when it rains. Through surface and sub-surface flows these pathways convey water, fine sediment and chemical components to the stream from upslope areas.

Upslope connections can also be linked to the riparian/floodplain and the active stream channel through rare and episodic occurrences; such events can entrain large amounts of sediments, and/or woody debris, through forest fires, mass wasting of land and/or unusual floods. In other words, while the upslope area and the active stream channel are not normally directly attached by constant surface water, they are still inexorably linked through these more diffuse but occasionally direct connections (e.g., Fig. 1.14). Reeves *et al.* (1995) suggest that rare natural disturbances are a major influence on habitat and biota in Coast Range streams in western North America. Kaufman and Hughes (2006) suggest that episodic landslides, fire, and other natural disturbances importantly can contribute a wide range of sediment sizes, as well as large wood, to stream channels through erosion processes associated with these phenomena. The woody debris, when delivered along with sediment, stabilizes stream bed gravels and fine sediments, aiding the development of spatially and hydraulically complex habitat for stream biota (Kaufman and Hughes 2006).

Despite the extended distance from the flowing stream, the surrounding upslope landscape features can and will extensively affect a stream's chemical properties, channel hydraulics, morphology, benthic composition, and associated biological communities over a variety of spatial and temporal scales (Hynes 1975, Hughes and Hunsaker 2002, Wang *et al.* 2003, Allan 2004, Wang *et al.* 2006a). These upslope landscape features are modified by climate and include elevation, vegetative cover, land use, soil permeability, landscape slope, topography, and overall surface geology (Omernik 2004).

The area of the watershed is also a feature that is important in determining the local characteristics of a stream (Zorn *et al.* 1998). This is because the area of the watershed is a prime determinant in the discharge volume of a stream, and the quantity of flow affects stream power which, in turn, influences habitat abundance (Leopold *et al.* 1964). Thus, the larger a catchment is (i.e., the greater the surface area of the watershed to collect water), the greater the flows in the stream will be and, the greater the power of the stream to shape the landscape and create aquatic habitat.

WHY IS THERE AN INTEREST IN LANDSCAPE-LEVEL CONCEPT TO PROTECT AND RESTORE FISH HABITAT?

The protection and restoration of fish populations in freshwater habitats, can be more effectively achieved when the entire landscape is considered—from the active stream channel, to flood plain/riparian zones, to upslope areas along with all of the inherent physical, chemical and hydrological functions, processes and connections that make up the mosaic of these three areas. Having an understanding of the effects and interconnectedness enables aquatic scientists and fisheries managers to better maintain and influence these environments as functioning and productive ecosystems (Wang *et al.* 2006a). Changes to these aspects of fish habitat in British Columbia have been extensive and pervasive, and can be more readily perceived in terms of their cause from a landscape perspective.

FIGURE 1.4. The hydrological cycle operating over a variety of different landscapes and watersheds.
Figure adapted from (Trenberth et al. 2007).

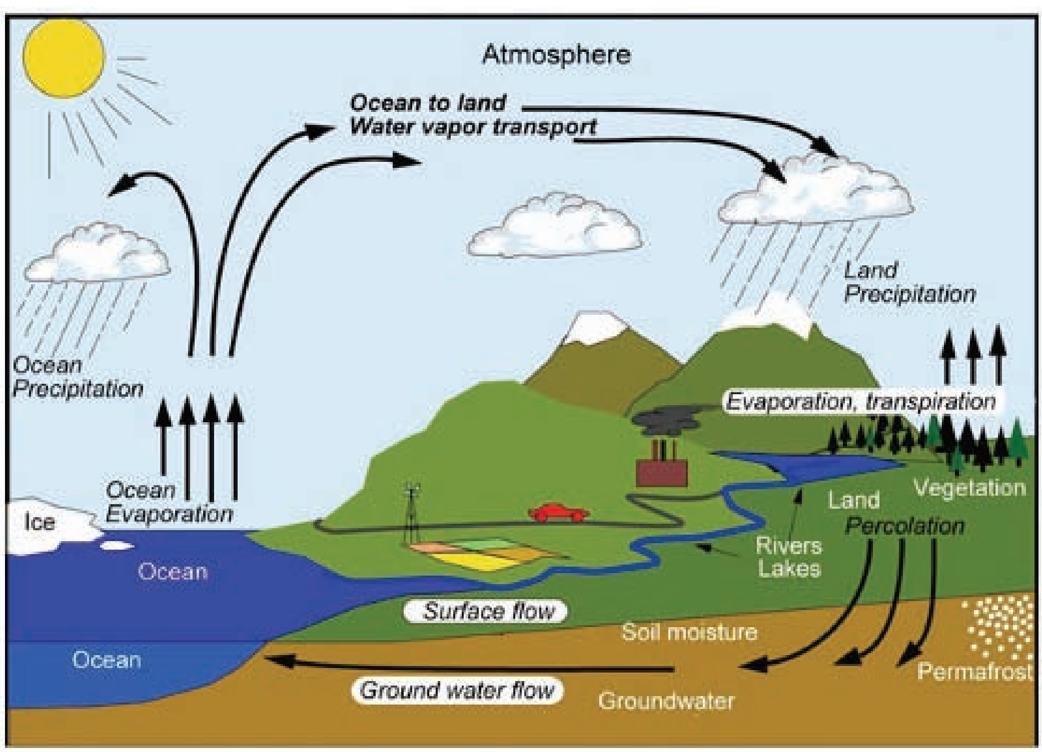


FIGURE 1.5. Diagrammatic representation of the conditions outlined by the River Continuum Concept of Vannote *et al.* (1980).

Figure adapted from Mussared (1997). Note that the organization of the various aspects of energy sources, insect groups, organic inputs and aquatic plants follows gradients along the length of the stream.

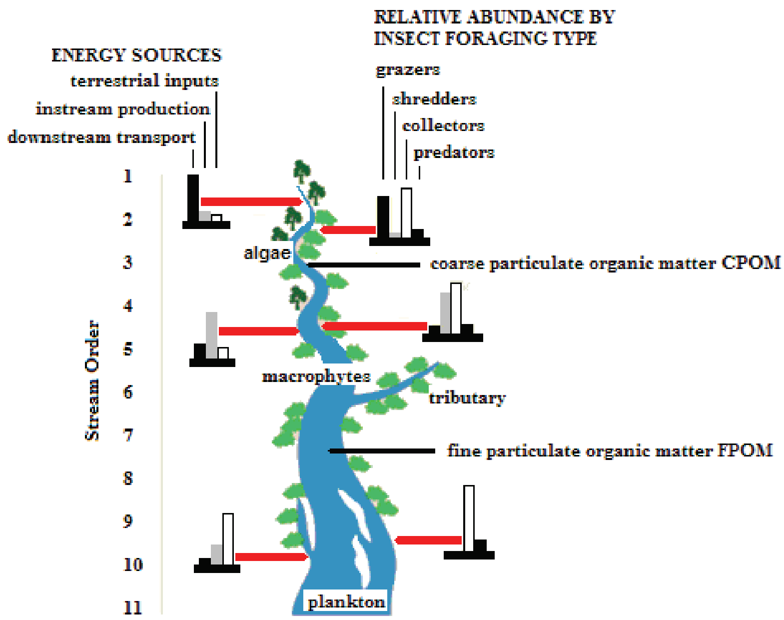


FIGURE 1.6. Diagrammatic representation of the Flood Pulse Concept following from Bayley (1995).

Figure adapted from EPA (undated a). For British Columbia this figure specifically describes interior snowmelt-driven spring-freshet hydrographs, although aspects of the above also apply to coastal streams. Coastal streams have the added feature of short-duration and large, rain-mediated flood events in the autumn/early winter for which the discharge volumes largely exceed their spring freshets.

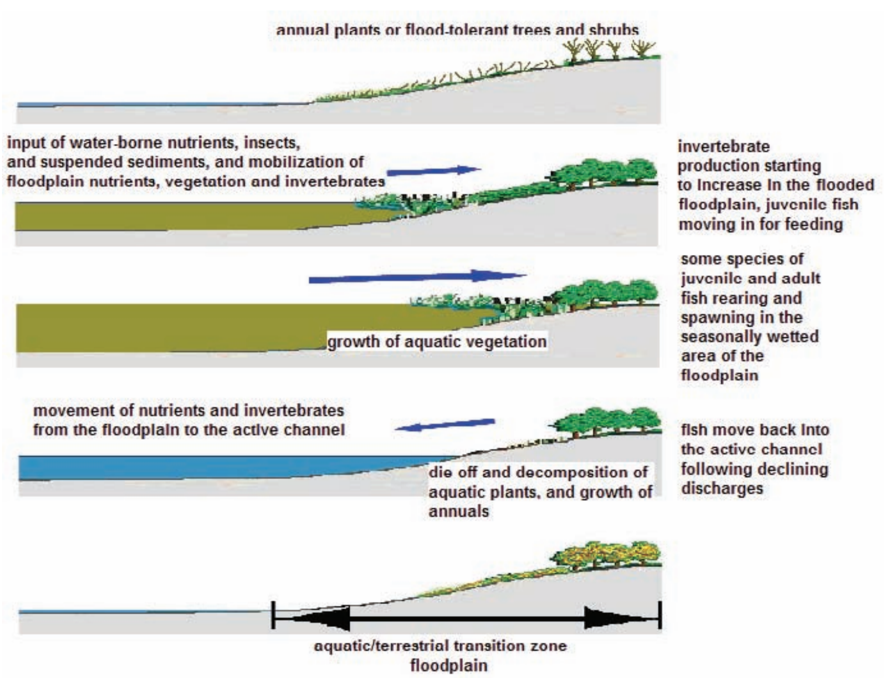


FIGURE 1.7. The hyporheic zone and its linkages to groundwater and the surface-flowing stream.
Figure adapted from Naiman et al. (2000). The hyporheic zone is that water under the ground's surface that is above the groundwater but in adjacent contact with surface water flowing along the stream bed. Hyporheic discharge can be found under the stream bed, in the adjacent non-inundated gravel bars, or out in the floodplain, and all of these are connected to varying degrees depending on sediment and hydraulic-head characteristics (Naiman et al. 2000).

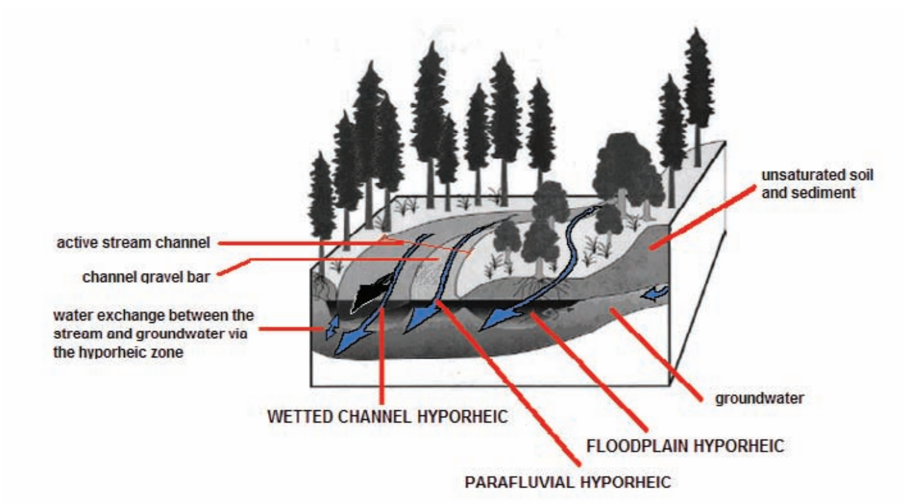


FIGURE 1.8. Example of a yearly hydrograph using the discharge and water-surface elevation measurements of the Fraser River hydrometric station at Hope, British Columbia.
The Fraser River at Hope represents an interior snow-melt-driven type of hydrograph. Note that for coastal British Columbia streams, the peak floods tend to be during the autumn when large rain events move off of the eastern Pacific Ocean and fall on fresh snow thus melting it; these autumn rain-on-snow-event floods tend to be of much shorter duration than spring-freshet flows. Figure adapted from Water Survey of Canada (undated) web site; data to construct the graphs are from 1912 to present.

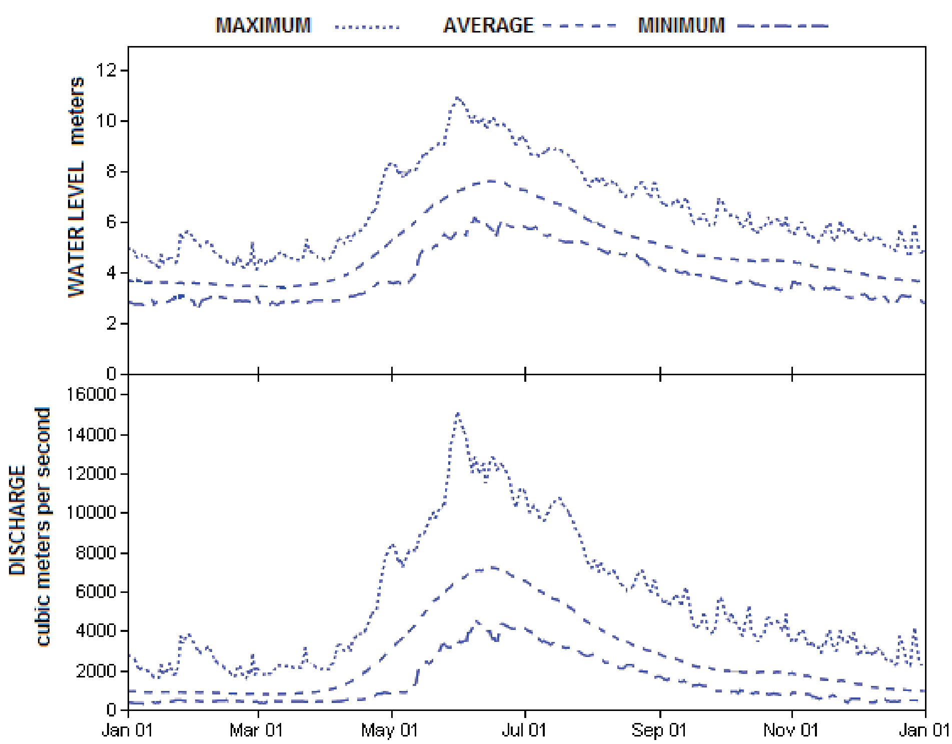


FIGURE 1.9. Cross-sectional representation of a landscape which includes a stream, and the divisions into its three component parts including: upslope, floodplain and riparian, and the active stream channel areas.
Figure based on Wang et al. (2006b).

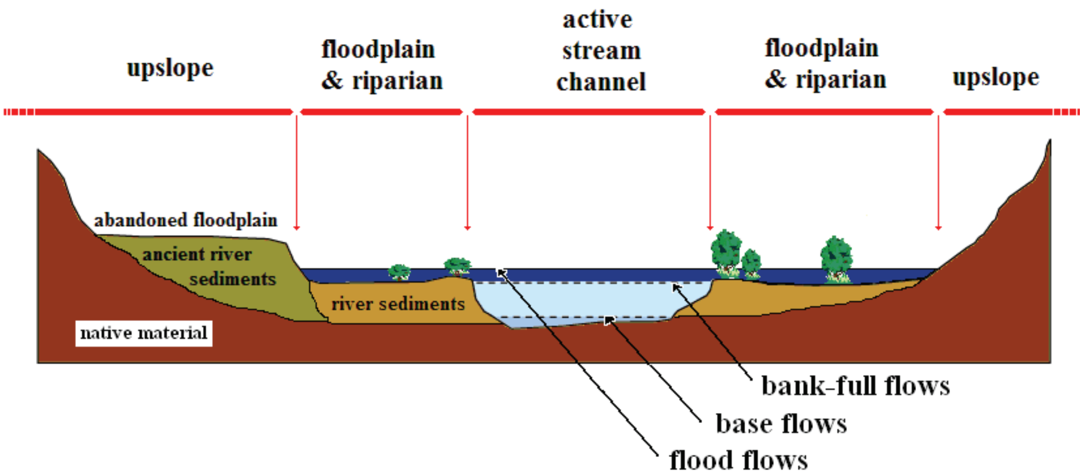


FIGURE 1.10. The Vedder River, British Columbia, is an example of an active stream channel.
Figure from: Natural Resources Canada (undated).

FIGURE 1.11. Origin, transport and deposition of materials in mountainous watersheds of the Pacific Coastal Ecoregion.
Figure and captions modified from Naiman et al. (2000). Note that the general trend of water, sediments and woody debris is in a downstream direction following from the effects of gravitational process on watersheds and landscapes.

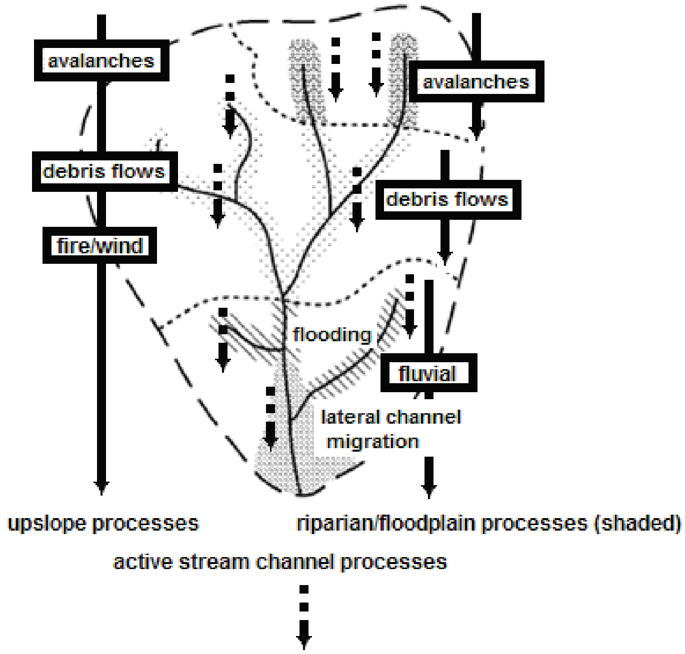


FIGURE 1.12. Instream and riparian large woody debris provide important aspects to fish habitats in flowing waters.
Photo: ASLO (undated).

FIGURE 1.13. Spring-freshet inundation of the intact portion of the floodplain of the Fraser River in the eastern Fraser Valley.
Note that before diking, dredging, ditching and channelization, much of the Fraser Valley would have looked like this during the spring snowmelt runoff of the Fraser River basin. The area in the photograph is now under threat by a proposed off-channel gravel mine.

FIGURE 1.14. Mass wasting of the upland portion at Chehalis Lake, December 2007.
Note the large volume of woody debris that was recruited into Chehalis Lake and will comprise important fish habitat within the wetted perimeter of the stream. While this is a previously logged area, there is no specific evidence that human activities were the cause of this large slide. Photos: Ministry of Forests and Range (2007).

2.0 INFLUENCE OF LANDSCAPE-LEVEL ACTIVITIES OF FORESTRY, URBAN DEVELOPMENT, AND AGRICULTURE ON STREAMS

OVERVIEW

As discussed in detail above, the productive capacity of flowing-water aquatic ecosystems, including salmon and steelhead habitats, is extensively affected by not only a stream's instream and riparian characteristics, but also by the functioning and influence of the broader landscape. Across British Columbia the landscape has often been extensively altered as a result of human activities in the upland areas, leading to significant ramifications for salmon and steelhead populations.

Two primary features of streams commonly perturbed through human activities on the greater landscape include changes to water quality (e.g., dissolved nutrients, dissolved gasses, pollutants and fine-sediment entrainment), and water quantity (the shape and magnitude of the hydrograph over time). Changes to the natural characteristics of the landscape within a watershed, through human activities, can alter these parameters (e.g., Table 2.1), and this occurs through changes in infiltration and surface runoff (Paul and Meyer 2001).

WATER QUANTITY CHANGES DUE TO LAND DEVELOPMENT

Changes to flow patterns can be particularly noticeable in landscapes and catchments that have been extensively developed. Stanfield and Kilgour (2006) point out that the transition from natural-forest cover to agricultural and urban landscapes normally results in an increase of Percent Impervious Cover (PIC) to the landscape (Fig. 2.1). PIC refers to the percentage of an area which has hardened surfaces preventing water, which falls as precipitation, from naturally entering the ground because of its imperviousness. PIC is a weighted-average metric that integrates various types of human development activities in catchments (Stanfield and Kilgour 2006). For natural landscapes, PIC is generally low but intermediate in agricultural landscapes, and high in urban landscapes (Stanfield and Kilgour 2006). Examples of development-related impervious cover include roof tops, asphalt, and concrete; these limit infiltration into the ground and subsequently result in high runoff rates across the landscape. Farm fields that have been tilled, and the soil compacted relative to forest cover also show increased PIC.

For landscapes with increased PIC during, and shortly after, a rain there is increased overland flow and this water discharges more quickly into the streams within the landscape (Fig. 2.2). The consequence of this is that during a storm event, streams in developed catchments often have unnaturally large peak discharges compared to pre-developed forested landscapes. The streams in developed landscapes have faster water velocities and more severe flood flows which, in turn, disrupt aquatic ecosystems.

For disturbed landscapes resulting from agriculture and urbanization activities, streams also tend to have smaller base flows during dry seasons as less water is stored subsurface due to the accelerated surface run-off and below-ground drainage systems that facilitate lowering of the natural water table (Fig. 2.2; Table 2.1) (Leopold 1968).

As a final note, the change in the pattern of a hydrograph can be opposite in regards to the low-flow period under an extensive forest-harvest scenario. The reduced transpiration through the removal of trees can actually increase base flows in streams in summer during low-flow periods (Table 2.1).

WATER QUALITY CHANGES DUE TO LAND DEVELOPMENT

Other factors affected by landscape-level disruption through development and forest harvest include increased nutrients, fine sediments and chemical-pollutant into streams (Paul and Meyer 2001). Generally, these changes to water quality cause negative impacts to aquatic ecosystems. Increases in the entrainment of nutrients and pollutants into stream flows are particularly prevalent when agriculture and urban development (including housing, commercial and industrial) cause large-scale landscape changes. Changes to sediment entrainment in stream flows are also a common result of forestry activities.

The substrate composition of a stream is an important determinant of the habitat capacity. As described earlier in this report, this feature may be defined by both local erosion/deposition actions as well as large-scale natural events occurring across the landscape (e.g., unusual floods, mass wasting, forest fires); these can influence the natural rates of recruitment of silt, sand, gravel and other sediment classes into flowing waters. However, human activities are known to augment and/or reduce natural rates of sediment to streams during large-scale landscape perturbations (Kaufman and Hughes 2006) including activities associated with agriculture, urbanization and forestry (e.g., Fig. 2.3). Fine sediments are often destructive to aquatic ecosystems in that they disrupt normal physical and biological processes (Wood and Armitage 1997) while coarse sediments are usually beneficial (i.e., spawning gravels, cobbles and boulders for juvenile-fish-rearing habitats).

DISRUPTION OF MACRO-HABITAT FEATURES DUE TO LANDSCAPE MODIFICATION

When landscape-events first begin to happen within a catchment area after development or forest harvest starts to occur, the result is often much more highly-mobile stream beds with excesses of fine sediments and simplified instream morphologies (Kaufman and Hughes 2006). This is because the fine materials are eroded from the upland areas, entrained from across the landscape through increased surface flows, and the increased velocities and erosive power of a stream disrupts the natural morphology of the stream bottom and banks, or unnatural mass wasting occurs due the destabilization of the area (Fig. 2.3).

Kaufman and Hughes (2006) also suggest that the beneficial effects of natural disturbances lessen over time if rates of sediment movements exceed their pre-perturbation rates of replacement from upland and riparian areas within stream catchments (i.e., eventually the streams become starved of sediments as natural sources are artificially “used up”).

In a similar vein to sediment transport, the distribution of large woody debris and its transport (or decay), recruitment and maintenance is affected by the greater landscape activities. Changes to the normal pattern can occur as a function of human intervention (Kaufman and Hughes 2006). In some instances, the natural rates of recruitment of large-woody debris can either be reduced close to zero (because the landscape was completely cleared to the banks of the stream), or accelerated temporarily (due to the riparian area becoming unstable as a result of land being cleared in the upland area) and then decline to low rates due to the eventual decay and/or flushing out of this excess material. Dikes and barriers to protect developed land can also sever the connectivity between the stream and the riparian and upland areas where wood would normally be recruited.

THREE TYPES OF HUMAN ACTIVITIES IN DEVELOPING LANDSCAPES

The magnitude of these landscape-impacts to streams varies with the type and intensity of land use (Arnold and Gibbons 1996, Moerke and Lamberti 2006). Various studies have found increasingly negative relationships between increasing amounts of human landscape use and stream-habitat quality (e.g., Roth *et al.* 1996, Allan *et al.* 1997, Wang *et al.* 1997, Meador and Goldstein 2003, Moerke and Lamberti 2006). In general, more intensive development degrades fish and benthos assemblages and instream habitats (Stanfield and Kilgour 2006). In North America, and around the world, human activities associated with agriculture and urbanization, for example, have radically changed many landscapes and, as a result, these activities have been important and widespread contributors to the loss of integrity of aquatic ecosystems (Allan 2004). Diana *et al.* (2006) has also cited a number of studies which have shown negative effects on fish assemblages in the face of activities associated with agriculture and urbanization (Walser *et al.* 1999, Brown 2000, Schleiger 2000, Wang *et al.* 2001).

The effects of forest harvesting on stream ecologies can be significantly negative to salmon and steelhead but somewhat different in mechanism from that of agriculture and urbanization. While forest harvesting can also substantially alter instream habitat and flow regimes, these may recover after a time if the vegetative cover is allowed to regenerate (Moore and Wondzell 2005). Sedimentation regimes can also be radically affected by forest harvesting with inputs of fine sediment from overland areas and disruption of bank and instream stability due to increased flow velocity (via increased discharges), mass wasting and the loss of stabilizing riparian areas.

Forestry, urban development and agriculture are all activities that are conducted extensively across British Columbia (Fig. 2.4). This report focuses, in more detail below, on their respective influences on landscapes and how this affects salmon and steelhead habitats.

FIGURE 2.1. Changes in flow patterns as a result of urbanization and changes to Percent Impervious Cover (PIC).
Figure adapted from EPA (2001).

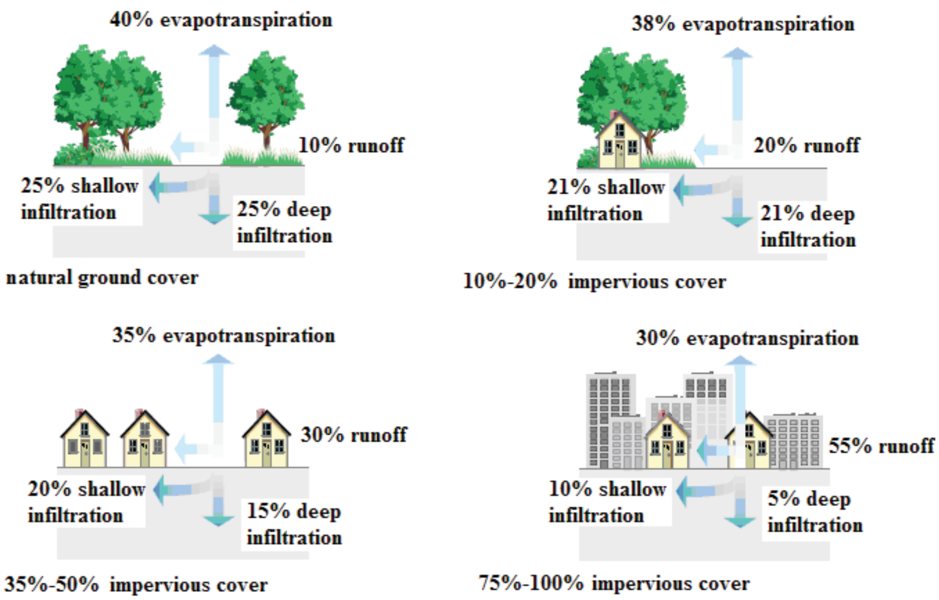


FIGURE 2.2. Change to flow patterns in a stream after an high rainfall event “before” and “after” gricultural- or urban-landscape disturbance.
Figure modified from EPA (2001).

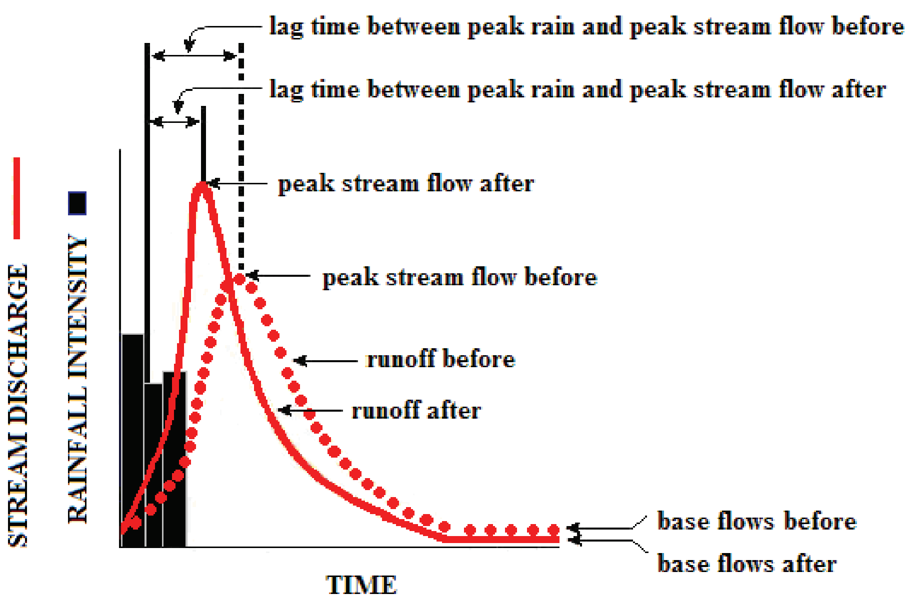


FIGURE 2.3. Mass-wasting of sediments due to improperly constructed logging roads.

Both the top and bottom slides were precipitated as pre-Forest Practices Code events. Top photo: Wahleach Reservoir near Hope; photo is c.a. 2001 but the slides had occurred already by November 1990. Photo: Mike Miles (Miles 2001). Middle and bottom photos: Donna Creek near Prince George; this slide occurred after a number of days of extremely heavy rain from May 25–June 2, 1992 and, due to the concentration of flows along logging road, saturated and precipitated the landslide of almost 0.5 million cubic meters of material. Photo and information: Schwab (2002).

FIGURE 2.4. Extent of forest, agriculture and urban landscapes in British Columbia.
Figure: Ministry of Forests and Range (2006a).

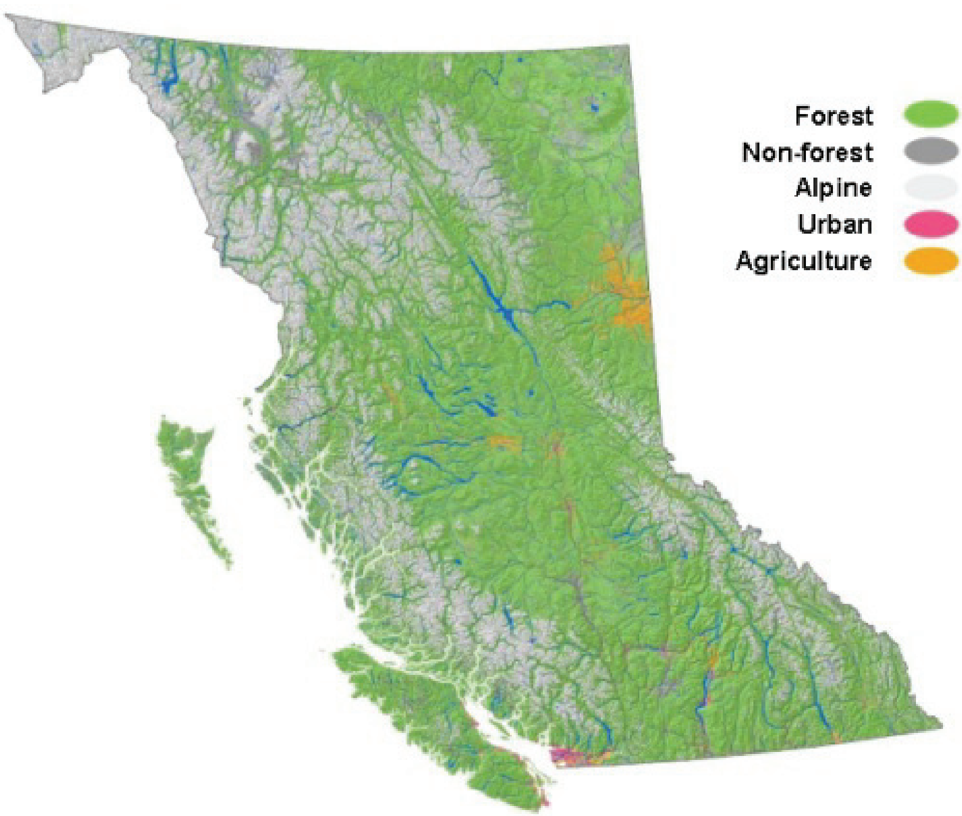


TABLE 2.1. Potential hydrological-related effects to fish habitat associated with human-induced upslope landscape disturbance.
Adapted from EPA (undated b).

Land Use	Land Use Practice	Hydrologic Component Affected	Potential Hydrologic Effects
Forestry	Timber harvest	Peak flow	Increased peak flows due to reduction in evapotranspiration and interception as well as more accumulation and melt of snow pack. Diminished impact as re-growth occurs even though damage to the stream channels may persist.
		Low flow	Increased low flows due to reduction in evapotranspiration and interception.
	Roads and harvest practices	Peak flow	Rerouted subsurface flows to surface runoff through roadside drainage ditches. Compaction of soil causes increased runoff and decreased infiltration. Logging practices such as skid trails contribute to the same effect.
		Annual yield	Increased water yield due to more accumulation of snowpack in open areas and reduction in evapotranspiration and interception. Most of increase occurs during wet part of the year.
Agriculture	Land drainage through ditching	Peak flow	Increased timing of storm runoff as surface flow moves more quickly to stream.
		Low flow	Lowered water table. Reduced groundwater recharge.
	Roads and harvest practices	Peak flow	Increased timing of storm runoff as surface flow moves more quickly to stream.
		Low flow	Lowered water table. Reduced groundwater recharge.
	Crop production	Low flow	Altered rates of transpiration affects runoff.
	Cattle grazing	Peak flow	Increased timing of storm runoff due to compaction of soils. Reduced infiltration.
	Dams and diversions for irrigation	Peak flow	Reduced magnitude and frequency of high flows. Can cause channel narrowing downstream of dam. Capture of sediment behind the dam can result in downstream channel erosion and bed armouring.
	Levees and channelization to protect fields	Peak flow routing	Reduced overbank flows. Isolation of the stream from its floodplain. Channel constriction can cause downcutting.
	Surface water diversions for irrigation	Low flow	Depleted streamflow by consumptive use. Streamflow depleted between point of withdrawal and point(s) of return.
	Groundwater pumping for stock watering and irrigation	Low flow	Lowered water table. If hydraulically connected, can cause streambank erosion and channel down cutting after loss of bank vegetation.
Urban	Increase in impervious surfaces	Peak flow	Reduced infiltration. Surface flow moves more quickly to stream, causing peak to occur earlier and to be larger. Increased magnitude and volume of peak. Can cause bank erosion, channel widening, downward incision, and disconnection from floodplain.
	Piping and drainage	Low flow	Reduced surface storage and groundwater recharge, resulting in reduced base flow.
	Use of stormwater facilities	Peak flow	Increased timing of runoff through increased velocity due to lower friction in pipes and ditches. Surface flow moves more quickly to stream via pipes and ditches, causing peak to occur earlier and to be larger. Increased total volume.

EFFECTS OF AGRICULTURAL ACTIVITY AT THE LANDSCAPE SCALE ON STREAMS

That agricultural activities will often affect stream ecosystems is well known by aquatic scientists and fisheries managers who deal with this subject. In general, streams that interface with farmlands that lack adequate riparian areas have the most degraded habitats when compared to the other landscape uses (e.g., Fig. 2.5; Moerke and Lamberti 2006). Studies by Judy *et al.* (1984), the US EPA (1996) and Diana *et al.* (2006) all suggest that agriculture is one of the primary factors responsible for stream degradation in the United States. The impacts of agriculture affect not only aquatic production *per se* but can often strongly alter the composition of fish assemblages as well (Trautman 1981, Harding *et al.* 1998, Wasler and Bart 1999, Brown 2000, Elosegi and Johnson 2003).

Farming and its effects on stream ecosystems arise in many forms, and the types of impacts and intensities of the habitat alterations differ with spatial scale and the sort of agricultural activities conducted on the landscape (Elosegi and Johnson 2003). For example, agriculture in the form of rangeland grazing, or field foraging of dairy cattle, is well recognized as often impacting watercourses through the physical effects of cattle defecating within or near streams (nutrient and bacterial pollution), mobilizing fine sediments through the physical act of churning up the landscape through hoof action, disrupting the integrity of stream banks and riparian areas through grazing and animal traffic through the watercourse (Fig. 2.5; Bewsell *et al.* 2007). For streams in dry, hot areas, the loss of the riparian vegetation and disruption of the stream width (often a widening of the channel as a result of animals walking within the wetted perimeter) can also increase water temperatures through loss of shade and stream depth (Maloney *et al.* 1999).

Many of the impacts associated with cattle foraging can be mediated through fencing and other methods excluding of animals from the stream and its riparian areas. An ancillary benefit of fencing off riparian areas from animal traffic is that by increasing the size of the protected zones through exclusion of cattle, the water-entrained sediments, pollutants, bacteria and nutrients (often the product of crop production and other activities) can be trapped by the intact vegetation before they enter a watercourse (Galeone *et al.* 2006, Bewsell *et al.* 2007). To reiterate earlier points, riparian zones are an important component of the proper functioning of stream ecosystems in rangeland landscapes. The quality, quantity and composition of plant life will affect a stream's water quality, temperature regimes, as well as vegetation inputs, including large woody debris and leaf matter (Elosegi and Johnson 2003).

Another form of agriculture that can affect streams is the intense farming of crops near a watercourse. Moerke and Lamberti (2006) suggest that it is not surprising that agriculture comprises one of the greatest impacts to fish stocks since the activities associated with intense farming often include the dredging and channelization of streams, concordant removal of stream-side riparian vegetation, and changes in upland vegetative cover. These are actions that directly, physically and severely alter stream habitat (Fig. 2.6).

The natural hydrograph in areas of intense crop agriculture is always disrupted due to changes in the flow patterns resulting from draining of water from the landscape. This results in higher peak floods and stream velocities, and lower base flows compared to the pre-farming discharge regimes, all of which affect stream aquatic ecosystems (Table 2.1, Fig. 2.2). These landscape-level increases in flood flows occur through the clearing of water-retaining natural vegetation in the upland areas, an increase in Percent Impervious Cover (the soils of tilled fields tend to be compacted), the levelling of the landscape (resulting in reduction in water-retaining low spots) and the installation of drainage structures such as tiles, dikes and ditches (Fig. 2.6; Rosenau and Angelo 2005, Diana *et al.* 2006). Stream flow velocities are also increased when farming overtakes a floodplain and constricts the natural movement of water as a result of diking and narrowing the naturally wetted range of the landscape (Fig. 2.7).

Shields *et al.* (1994) examined agricultural practices associated with incised, straightened stream channels (ditches) and these actions were seen to reduce the extent of wetlands and cause unnatural flooding (Elosegi and Johnson 2003). In another study, Richards *et al.* (1996) also identified row-crop agriculture as having a strong influence in disruptions to natural flooding regimes in east-central Michigan.

For low flows, Zorn and Wiley (2006) showed that drainage associated with agriculture normally reduces stream discharges in periods of low flows to significantly lesser levels (Table 2.1; Fig. 2.2). To reiterate some earlier observations, these disruptions of the hydrograph are important to consider as aquatic ecosystems are adapted to specific ranges and timings of flows. Substantial re-arrangement of these patterns normally causes ecological disturbances.

Another important aspect of intensive crop farming is that large woody debris recruitment (an important habitat feature for fishes in streams and riparian areas) is often disrupted. This phenomenon is especially prevalent when the growing of crops occurs right to the stream edge (Fig. 2.6). Large woody debris inputs to streams are almost always substantially reduced as a function of intense farming (Elosegi and Johnson 2003).

Pollution of streams also occurs as a result of landscape-level agriculture. The activities that cause pollution to streams through farming include grazing, ploughing, pesticide spraying, irrigation, fertilizing, planting, specific types of crops and methods of harvesting. The major impacts that result from these activities include sediment entrainment, nutrient inputs and eutrophication, pathogens, pesticides, and salts (EPA 2001, Moerke and Lamberti 2006).

The magnitude of the impacts to aquatic resources resulting from farming-activity pollutants depends on the type of agriculture and the intensity of the land use (Barton 1996). Judy *et al.* (1984) suggested that water-quality reductions which have been caused by agriculture have adversely affected fish assemblages in 29% of United States waters. Indeed, the vast “dead zone” of up to 20,000 square kilometres that is now found in the northern Gulf of Mexico has been directly attributed to the pollution from farming in the Mississippi River drainage. In Canada and British Columbia, governments have also acknowledged that there are such water impacts resulting from agriculture. They have introduced a number of initiatives, statutes, regulations and programs to discourage and control the impacts (Rosenau and Angelo 2005).

The removal of natural-vegetation cover via farming in upland and riparian areas, and then the repeated tilling of soils also increases fine-sediment transfer rates to local streams with resulting negative effects to aquatic ecosystems (Table 2.1; Fig. 2.8). Wind erosion of fields can also cause fine sediments to end up in watercourses when natural or cropped plants are stripped off the landscape.

Diana *et al.* (2006), and citations therein, all provide examples of how increases to sedimentation rates of fines into streams routinely occur as a result of intense agriculture. In the Diana *et al.* (2006) study the authors showed that, for their assessments, high levels of sedimentation and reduced flow stability in streams occurred in areas where intensive farming was practiced; this was in contrast to their control-observations in adjacent and unfarmed natural wetlands which had comparatively low rates of sedimentation and relatively stable flows. Fine sediments entrained into clear-water salmon and steelhead stream ecosystems are normally highly destructive (Rabeni and Smale 1995).

Farming-related non-point-source nutrient inputs are also commonly entrained into streams located near intensely farmed landscapes. For example, Moerke and Lamberti (2006) indicate that the over-application of fertilizers to agricultural fields (Fig. 2.9) in combination with rapid water removal through drainage systems often result in pulsed inputs of nutrients (nitrogen and phosphorus) to adjacent streams, and they cite Omernik (1977) and Cole *et al.* (1993) as providing examples of this happening. Salonius (2007) points out that, because most agriculture is a soil-nutrient-depleting practice, this carrying-capacity increase is unsustainable in the absence of exogenous nutrient supplies which are often over-applied to fields in the form of manure or inorganic fertilizers. The surplus ends up in adjacent watercourses or groundwater. Manure that is entrained into streams can have substantially negative impacts to the aquatic resources living within such watersheds in a number of ways including nutrient addition (algal and plant blooms), physical smothering of stream bottoms, and increases in the biological oxygen demand as the organic component of the livestock excrement decomposes.

The inappropriate use of pesticides can also affect aquatic ecosystems in adjacent streams where agriculture is being practiced (Fig. 2.10; Helfrich 1996). These chemicals have the ability to kill fish outright or result in significant sub-lethal effects (e.g., reduced growth, impacts on reproductive success) that can be significant in streams flowing through areas where pesticides are intensively used. British Columbia has recognized this and has instigated protocols and regulations guiding farmers in such use for agriculture (Rosenau and Angelo 2005).

It should additionally be noted that the effects of agricultural (as well as urban) activity in respect to pollution can also often extend considerably beyond the immediate farming area (Richards *et al.* 1996, May *et al.* 1997, Paul and Meyer 2001). These effects may be detected in areas far downstream of the farming activity in streams flowing through landscapes that are otherwise intact and properly functioning (Osborne and Kovacic 1993).

FIGURE 2.5. Cattle in streams cause substantial damage to their riparian areas and instream habitats if fences are not constructed to physically keep them out of these sensitive locations.
Photo: Fraser River Action Plan (1998).

FIGURE 2.6. A straightened, channelized and dredged salmon stream in the eastern Fraser Valley having lost most of its natural riparian vegetation.
Draining of fields using sub-surface tiles extensively disrupts the hydrograph and flow patterns of agricultural streams. This photo, with its lack of riparian buffer, typifies many agricultural streams in the Lower Mainland. Photo: Scott Barrett, British Columbia Ministry of Environment.

FIGURE 2.7. Changes to water-surface elevations and erosion of stream bottoms due to diking in the floodplain and constriction of the stream width.

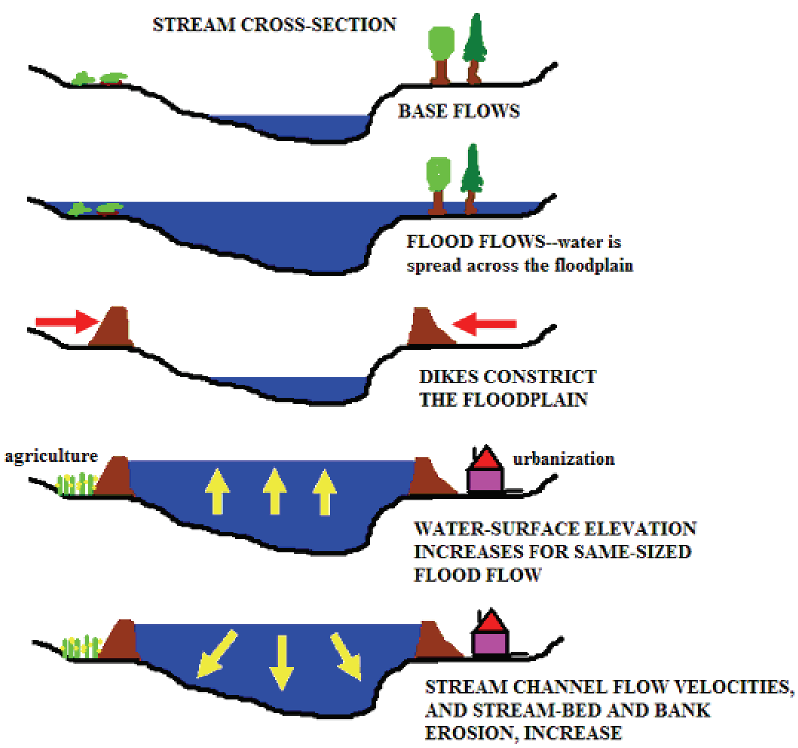


FIGURE 2.8. Silt is easily entrained from un-vegetated landscapes into watercourses during property development, and farmland clearing and cropping, causing impacts to aquatic ecosystems.
Photo: Friends of the Rouge Watershed (undated).

FIGURE 2.9. Application of animal manure across an agricultural landscape to increase nutrient availability to a crop field.
Over-application can result in excess nutrients ending up in groundwater and streams and affecting aquatic ecosystems. Large-enough riparian areas can mitigate this problem, to some degree, but often intensely farmed areas have insufficient buffers along stream perimeters to control this sort of pollution.
Photo: Utah State University (undated).

FIGURE 2.10. Pesticide application on an agricultural landscape can be particularly damaging to adjacent watercourses when appropriately-sized riparian zones are not present along streams.
Photo: United States Geological Survey (undated).

EFFECTS OF URBANIZATION AT THE LANDSCAPE SCALE ON STREAMS

Urbanization has visibly obvious impacts on landscape ecosystems (Table 2.1) and is an issue of significance for southern British Columbia (Fig. 2.11). Urban development can have adverse effects on stream structure, flow regimes and water quality as well as the composition and production of aquatic organisms for natural drainages flowing through the landscape being urbanized (Wang *et al.* 2001, Finkenbine *et al.* 2001, McBride and Booth 2005, Gurnell *et al.* 2007). Specific impacts associated with urban development include changes to the local hydrology (Booth 1990, May *et al.* 1997, Paul and Meyer 2001), morphological alterations of the stream bed and banks (Booth 1990), and increases in the concentrations of nutrients, contaminants and fine sediments entrained into the flows of the watershed (Paul and Meyer 2001). Urban-land development is particularly destructive to upland areas insofar as natural attributes (soil, vegetation, geographic heterogeneity) of the landscape are replaced with built-up structures such as buildings, roads, parking lots, and lawns.

Urban-land development commonly disturbs a comparatively low percentage of a geographic area when contrasted to landscape activities of agriculture and forestry, yet it exerts a disproportionately large influence on aquatic ecosystems therein (Paul and Meyer 2001). Furthermore, while agriculture is known, in total, to be the most damaging land-use activity to aquatic and terrestrial ecosystems across North America, urban land use may often be more destructive on a per-unit-area basis (Paul and Meyer 2001, Moerke and Lamberti 2006). Even greater still, the levels of intensity and extent of the urban development in a given area are key to the amount of impact this activity will cause; where the lots are residential and large (i.e., lots of intact vegetation), the effects can be significantly less to aquatic ecosystems than if the development is intensified. In intensively developed areas, there is a greater amount of Percent Impervious Cover and the infrastructure covers most of the landscape. Similarly, industrial or commercial development often builds on a high percentage of the land and/or has large amounts of concrete or asphalt covering the area (Yoder *et al.* 1999).

Like agriculture, urban development changes the flow patterns and hydrographs of the catchment area (Fig. 2.2; Paul and Meyer 2001, Moerke and Lamberti 2006). For streams draining urbanized landscapes, floods and runoff are often more frequent and larger (Klien 1979, Moscrip and Montgomery 1997) with reduced base flows (Diana *et al.* 2006). Higher discharges can lead to increased channel incision, sediment erosion and export of fines and gravel from both the landscape and within the stream channel (Figs. 2.7, 2.8; Booth 1990, Paul and Meyer 2001, Diana *et al.* 2006). With the disruption of the channel integrity (usually resulting in channel widening unless the stream is being constrained by bank armouring) and loss of shading riparian vegetation either through direct removal by the developer or increased lateral erosion of the stream banks due to the higher flow velocities, water temperatures can also increase and have negative effects on cool-water fish communities (Diana *et al.* 2006). In an Ontario study of landscape change at more than 10% Percent Impervious Cover (PIC), both fish and benthos consisted of mainly warmwater, or warmwater-tolerant, assemblages, compared to the cool-water ecosystem that was present prior to urban development (Stanfield and Kilgour 2006).

The severity of impacts to aquatic ecosystems though hydrograph disruption becomes greater as the amount of disturbed surface area increases, and the PIC becomes greater (Fig. 2.1). Studies by Klein (1979), Wang *et al.* (1997) and Yoder *et al.* (1999) have shown that streams exhibit a threshold response of extensive damage to aquatic ecosystems at 10–20% impervious surfaces for urban land use; in contrast, for agriculture, Roth *et al.* (1996), and Wang *et al.* (1997) showed that a similar response only started to occur when farming disturbed greater than 30–50% of the land base, even though crop-cultivation also increases the imperviousness of the soil. It should be noted, however, that other studies have shown that the impacts to aquatic ecosystems may occur at even lower levels of PIC; Dunne and Leopold's (1978) observations suggested a dramatic change in channel dimensions at only 4% PIC. In an eastern Canadian study in an area of southern Ontario which had a mixture of urban and agricultural development, brook and rainbow trout were sensitive to fairly low PIC and populations were found to be absent at percentages greater than 6.6 and 8.9, respectively (Stanfield and Kilgour 2006).

Studies of streams in urban areas have also found that after development the amounts of nutrients, pathogens, pesticides, organocarbons and metal concentrations generally increase in the runoff waters; these pollutants can lead to declines in algal and invertebrate communities, fish abundance and diversity, and general losses of biological integrity (Richards *et al.* 1996, Allan *et al.* 1997, Paul and Meyer 2001, Scott *et al.* 2002, Snyder *et al.* 2003, Moerke and Lamberti 2006). These pollutants usually end up in urban watersheds due to non-point-source releases and include lawn-fertilizers and pesticide applications, failing sewerage systems, small-business chemical releases, and vehicle-related contaminants (e.g., oil, gas, exhaust, rubber, road salts) (Omernik 1977, Paul and Meyer 2001).

As with agriculture, urban streams are often channelized and/or culverted (Fig. 2.12), and with the loss of the riparian area, large-woody debris recruitment and mobilization is interrupted from both instream and streamside locations. With the loss of the bank-stabilizing wood and the increase in flows, local governments resort to bank armouring with rip-rap or concrete to prevent the loss of property and infrastructure (Fig. 2.13; May *et al.* 1997). Once upland areas of a landscape have been cleared of their forests and developed, the increased risk of flooding is even more likely to lead to channelization and other control measures.

Furthermore, measures are then taken so that naturally unstable slopes are stabilized to protect life and property, and the recruitment of large woody debris to the stream is no longer possible from these areas.

Turbidity is also another issue that affects streams when natural areas are transformed into an urban landscape. However, Moerke and Lamberti (2006) found that turbidity measurements in urban and forested stream environments were considerably less at background (base) flows than for agricultural areas. This is probably due to the fact that exposed soil is either covered with concrete/asphalt or buildings, or grass/vegetation is planted on these terrains. Nevertheless, during the initial phase of development, and before the newly exposed ground is re-vegetated or covered by infrastructure, urban landscapes are notorious for causing elevated silt levels in streams, particularly if Best Management Practices to control sediment are not rigorously followed (Fig. 2.8).

FIGURE 2.11. In the last decade communities such as the City of Surrey, British Columbia, have rapidly urbanized and begun to encroach significantly onto agricultural lands and natural landscape features. *Natural vegetation is largely removed and replaced with roads, buildings, sidewalks and parking lots extensively increasing the Percent Impervious Cover. Photo: Google Earth (undated a).*

FIGURE 2.12. Urban drainage systems disrupt natural hydrographs and negatively affect aquatic ecosystems within a landscape's drainage.
Photo: Hanson (undated).

FIGURE 2.13. Armouring and loss of natural riparian vegetation in an urban stream.
Rip rapping (large angular rock) stabilizes banks but disrupts fluvial processes and biological integrity. Photo: International Erosion Control Association (undated).

EFFECTS OF FOREST HARVEST AT THE LANDSCAPE SCALE ON STREAMS

Overview

Many modern forest-harvesting operations around the world involve removing large volumes of wood over contiguous and substantial geographic areas. This technique is known as clear cutting and is the predominant mode of forest harvest in British Columbia (Fig. 2.14). Many effects of forest harvest practices, including clear cutting, on stream biotic communities are well documented (Campbell and Doeg 1989; Meehan 1991). The influences on aquatic communities in streams that flow through and downstream of logging landscapes can occur through both direct and indirect effects (Hemstad and Newman 2006). Clear cutting of forests results in extensive changes to the vegetation-cover characteristics of the landscape that is being logged. Depending on the criteria used in the logging practices, this activity can affect a forest-harvest landscape, instream, riparian and upslope parameters in a variety of ways including modifying the thermal regime, hydrology, flow pathways, sediment transfer, water temperatures, nutrient budgets, and wood recruitment (Rishel *et al.* 1982, Bowlby and Roff 1986, Bilby and Ward 1991, Gregory *et al.* 1991, Verry *et al.* 2000, Moerke and Lamberti 2006). Depending on the size of the landscape affected, changes to these parameters normally and extensively affect fish and fish habitats.

Does Logging Affect Aquatic Organisms?

Much scientific work has been undertaken to demonstrate cause-and-effect to fish populations and associated aquatic organisms, as a result of logging over large-scale landscape areas. As an example, Reeves *et al.* (1993) showed reduced diversity in juvenile anadromous salmonid assemblages in certain Oregon Coast Range drainages where there were high levels of logging and extensive road construction. In another paper, by Hemstad and Newman (2006), the cumulative effect of increasing forest harvest was associated with lower-quality fish assemblages and poorer instream habitat; this study showed that substantial forest harvests throughout a drainage (and even when the riparian zone is protected) can have negative effects on stream fish and habitat. Woodcock *et al.* (2006) demonstrated that invertebrate populations can be affected by a combination of broad-scale geomorphic and land-use factors.

Hydrology

At the landscape level, forest harvesting has the potential to negatively alter the hydrological regime, to which fish are adapted, and instream habitat quality and abundances are thusly regulated; this comprises one of the most important impacts to salmonid habitat relating to logging in British Columbia. Nevertheless, it is known that hydrological regimes vary naturally and significantly over the range of latitudes and longitudes where salmon and steelhead exist for British Columbia and the Pacific Northwest areas and the type of logging practices and subsequent impacts will vary amongst these. For western North American salmon and steelhead higher-order streams there are three primary hydrologic regimes. These are: the coastal (autumn or winter rain or rain on snow predominate, known as pluvial); interior (spring freshet snowmelts predominate, known as nivial, (Fig. 1.8)); and hybrid (having both pluvial and nivial)—each with its patterns and locations. Large-scale forest harvesting on landscapes having any one of these three characteristics can affect the hydrologic features of streams (Moore and Wondzell 2005).

The hydraulic patterns in a landscape which has been logged are generally similar from area to area and amongst primary hydraulic regimes (although there are some exceptions to the rule). Firstly, the total yield of water in a forested landscape is usually greater after logging. This is because, without the vegetation, water is now not lost to interception (Fig. 2.15) and/or evapotranspiration by trees once they have been removed (Moore and Wondzell 2005, Reid and Lewis 2007). Secondly, roads may also increase peak flows by concentrating discharges and then acting as conveyance channels (Nakamura and Swanson 2003). Thirdly, a proportionally greater amount of water that falls as precipitation more quickly enters streams. This is because the landscape's saturation of the sub-soil occurs sooner with more water, the ground is often compacted by equipment facilitating overland (Hortonian) flow, and the logging-constructed drainage systems can consolidate surface-discharges and route them into streams before they enter the ground (Moore and Wondzell 2005). Prepas *et al.* (2003) suggest that compaction of soil can be significant in forest-harvested areas, and this facilitates surface runoff. Tague and Band (2001) also suggest that logging roads can modify the concentration of soil moisture in a harvested forest by affecting drainage patterns; this is due to the fact that these roads often include drainage ditches or they, themselves, convey surface flow.

Finally, while it is often difficult to demonstrate, forest harvesting also can increase rates and timing of snowmelt, and the size of the peak of the hydrograph (Moore and Wondzell 2005). Moore and Wondzell (2005) reported that for several studies tree harvesting increased only the more frequent, geomorphically benign peak flows, but for other locations the effect continued to increase with return period. Where the logging is extensive, such as it is for some of the beetle-kill salvage areas in central British Columbia, the peak snowmelt water levels can be both earlier and greater (Forest Practices Board 2007).

It is not only the larger streams within logged landscapes that can be affected by forest harvesting. After forest harvesting, small-order headwater streams in western North America are particularly sensitive to flows and generally show increases in discharge due to a reduction of transpiration (Keppeler and Ziemer 1990, Moore and Wondzell 2005). Likewise, Moore and Wondzell (2005) also note that for small headwater catchments, logging generally increases annual runoff and peak flows, and it reduces the severity of low flows, although they point out that exceptions have been observed for each effect. Moore and Wondzell (2005) also indicate that, compared to the upslope areas, low flows are often more sensitive to transpiration in the riparian areas than they are in the upslope zones.

Not only can surface flows be affected by logging. Moore and Wondzell (2005) indicate that forest harvesting may potentially decrease the amount of hyporheic-exchange flow between below-ground water and the streams that they are connected to. This occurs when there are increases in fine sediment over the landscape which reduce the porosity of the soil, and clogging of stream-bed material also takes place. Recall that hyporheic flow is important for many biological processes including such phenomena as the interchange of flow through a salmon redd (nest).

Post-logging recovery of flows, to pre-harvest hydrological conditions, usually appears within about 10 to 20 years in some coastal catchments but may take many decades in mountainous, snow-dominated catchments (Moore and Wondzell 2005). Indeed, Troendle and King (1985) document hydrologic recovery taking in excess of 50 years after forest harvest under extreme circumstances. Supporting these observations, Mackay and Band (1997) suggest that, after the forest has been harvested and regrowth starts to occur, more trees will increase the evapotranspiration of soil water which, in turn, could cause an overall decrease of water volume in adjacent channels.

Large Woody Debris

Woody debris is an important aspect of fish habitat, in both streams and riparian areas. The recruitment of this material from outside of the active channel and from the riparian area is an important consideration with respect to forest harvesting. Natural and human-imposed disturbances in watersheds through logging can affect sources, rates of movement, transport processes, and accumulation sites of wood (Swanson 2003). Following from the previous topic, when forest harvest affects the peak streamflows, this change will potentially affect the size and distribution of wood pieces into a stream (Swanson 2003). Should the hydrology of the area change the propensity of the landscape to undergo mass movement (Figs. 1.14, 2.3), forest harvest may increase, or alternatively decrease, the amount of wood mobilized into a stream.

Several types of landslides can occur either naturally or due to logging including: rock falls, debris slides and debris flows and slumps. Sidle *et al.* (1985) showed that clearcutting can increase the chance of landslides by a factor of at least two times and this can carry both wood and sediment into the watercourse. Roads can also initiate landslides that mobilize wood to streams (Fig. 2.3); alternatively, the construction of roads can block passage of wood being transported by debris flows or floatation (Sidle *et al.* 1985, Wemple *et al.* 2001, Moerke and Lamberti 2006).

Wood can also be stored in sediments in the floodplain under anaerobic conditions for many thousands of years; it can then be recruited into a stream as it exposes this ancient material through erosion when normal flow-meandering takes place across the floodplain (Becker and Schirmer 1977, Nanson *et al.* 1995, Montgomery *et al.* 2003). Forest-harvesting practices can disrupt this process of recruitment of these old trees out of the sediments and into the stream, either through change in hydrology of the streams within the catchment, or due to road and bridge building. (Moerke and Lamberti 2006).

Nutrients

Important nutrients for both forest re-growth and aquatic ecosystems are re-arranged within the landscape and potentially lost from production as a result of logging (ius 2007). However, Prepas *et al.* (2003) suggest that, in the short term, nutrients (nitrogen and phosphorus) will be hydrologically exported into streams immediately subsequent to logging and this can lead to a (temporary) surge in aquatic production. Subsequently, Moerke and Lamberti (2006) suggest that for the medium term, in recently logged areas, nutrient retention and uptake by new vegetation will result in lower inputs of both nitrogen and phosphorus to streams within the immediate geographic area and cites (Likens *et al.*, 1970) as a study-example demonstrating this phenomenon. More insidious is that over the long term the continual export of wood in repeated harvests will eventually lead to the export of nutrients, causing a collapse in the nutrient-capital of a landscape including the streams therein (Salonious 2007).

While logging can disrupt the nutrient cycles and budgets of a landscape and its streams, at least temporarily, a potentially more menacing new aspect of forest harvest is on the horizon. This is the removal of both trees as well as high-nutrient slash (foliage, and fine branches with large bark/wood ratios) from forest harvesting operations as a source of biomass energy (i.e., all of the slash material is removed and burned to produce electricity). It has been suggested that the extensive use of this woody material to produce electric power will accelerate the depletion of the nutrient capital of forest soils and degrade their productive capacity (Dzwonko and Gawronski 2002, Jandl *et al.* 2002, Merganicova *et al.* 2005, Salonius 2007).

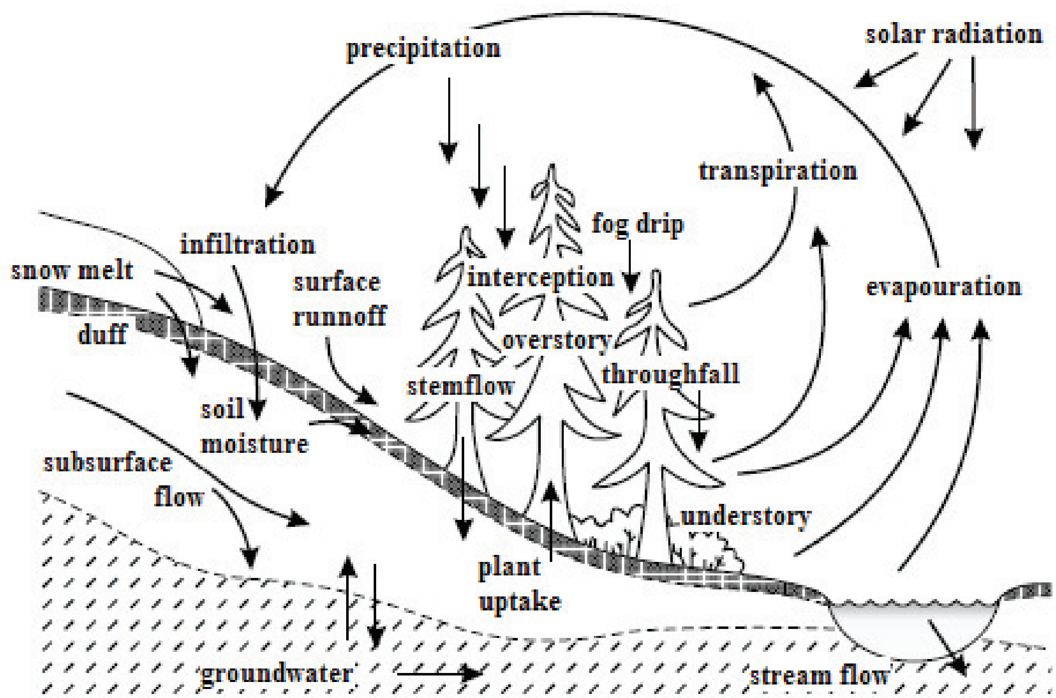
Sediments

Forest harvest generally affects sediments in streams in a number of ways. The removal of vegetation, exposure of soils through equipment activity, and further development of logging roads often facilitate the mobilization of fine sediments into streams after logging (Hemstad and Newman 2006). As an example at the catchment scale, Hemstad and Newman (2006) showed that landscapes that had been recently logged, as well as 5–8 years earlier, had an increase in unstable banks and more fine sediments within the watercourses. Heavy equipment working within the active stream channel also disrupts the benthic substrates (e.g., sand, gravel, cobbles) which are an integral component of the habitat of the stream, although modern legislation and regulation largely prohibits such activity.

Kaufman and Hughes (2006) suggest that for milder-sloping terrain, instream sediments tend to come from banks and riparian zones (Scott 2002), which argues for protection of these landscape features. However, for steep-sided slopes, another action that often occurs in forests and relates to sediment budgets in streams is mass wasting, or the wholesale mobilization of part of a hillside. Mass wasting can regularly occur on steep landscapes subject to considerable amounts of rain and is common in some parts of coastal British Columbia, with or without logging (Figs. 1.14, 2.3). However, logging often exacerbates this phenomenon and landscape disturbances can increase sediment delivery rates over that of natural processes in forest-harvest drainages (Waters 1995, Jones *et al.* 2001). Reid *et al.* (1981) and Furniss *et al.* (1991) found that mass-wasting from forest roads was the largest contributor of sediment to streams in steep-sided forest-harvest landscapes. Kaufman and Hughes (2006) found that fish and amphibian assemblages in Coast Range streams could be improved by reducing watershed activities that exacerbate erosion and mass-wasting of sediments. By ensuring that large-scale sediment entrainment is kept at natural rates, Kaufman and Hughes (2006) felt that this should also ensure adequate future instream supplies of appropriately-sized sediments for all biological processes.

FIGURE 2.14. Clearcut logging, which is the primary mode of wood harvest in British Columbia, normally affects substantial portions of the upland landscape.
Harvests greater than 20% have been shown to affect the hydrograph in a measurable way (Stednick 1996, Stednick and Troendle 2004). Photo: Greenpeace (undated).

FIGURE 2.15. The forest hydrologic cycle.
Adapted from Pike (1998).



3.0 INFLUENCE OF LANDSCAPE-LEVEL ACTIVITIES OF AGRICULTURE ON STREAMS IN BRITISH COLUMBIA

OVERVIEW

Agriculture historically has been, and still is, a vital component of the economy and culture of British Columbia, and there are almost 20,000 farms in this province. The designated land base for agriculture in British Columbia is the Agricultural Land Reserve, or ALR (Fig. 3.1), and comprises roughly 4.7 million hectares, or about 5% of the 89 million hectares that make up the province. Of this landscape area, about 2.6 million hectares of the ALR are regularly farmed with about 600,000 hectares routinely cultivated.

The bulk of the farmland in the province is privately owned and regulated under the British Columbia *Agricultural Land Reserve Act*, which is administrated by the Agricultural Land Commission. However, while about 60% of all farmland in this province is private, between a quarter and a third of the ALR is owned by the provincial government (Crown land) and leased to farmers. This makes the provincial government the single largest owner of agricultural land in British Columbia.

The types of agricultural production that occur vary considerably across British Columbia's diverse climatic and geographic landscapes. In the north-eastern part, grains are extensively grown while in the central area the grazing of cattle dominates. In the lower latitudes, including in the hot and dry south-central interior, agriculture is comprised extensively of fruit and grape growing compared to the south-western area of British Columbia where dairy and cash crops are key production items. This ability to grow a wide variety of produce is a function of the province's diverse topography, soil types, rainfall, climate and expansive range across the latitudes.

Despite the relatively small proportion of our province's landscape that is used for food production (compared to the total size of British Columbia), the resulting economic benefits are significant and account for about 1% of Gross Domestic Product (SmartGrowth BC 2004). The gross annual receipts constitute almost $3 billion dollars for farmers (Fig. 3.2) making it one of British Columbia's more important industries.

The effects of agricultural-landscape alterations on aquatic ecosystems in British Columbia (whether they be to the instream, riparian or upland zones) vary considerably depending on the region of our province and on the type of farming practiced (c.f., Nener *et al.* 1997). The most intensively farmed landscapes (and often the most destructive to fish habitat) in British Columbia are in the mild, generally moist, and highly productive south-western portions (lower mainland) of the province, despite being one of the geographically smaller areas for agriculture (Fig. 3.3). This is also where some of the most important stocks of salmon and steelhead reside, and where fish and farming often come in conflict (Rosenau and Angelo 2005).

The lower mainland area is also the most valuable in respect to the revenues generated from agriculture (Fig. 3.2). For example, farming in the Metro Vancouver regional district and the Fraser Valley Regional District, was valued at almost $1.4 billion in 2001 yielding an average of $16,887 per hectare for its agricultural lands (Olewiler 2004). For the Fraser Valley Regional District, 2,700 farms occupy almost 50,000 hectares and in 2001 earned almost $736 million, or 32% of the provincial total (Smart Growth BC 2004). Although the Okanagan and the Lower Mainland comprise, in aggregate, only 2.6% of the land base (Fig. 3.3), the combined numbers of people in these areas, and the farming activity therein, constitute 81% of the population in the province and 81% of the gross agricultural gate receipts (2001; SmartGrowth BC 2004).

Conflicts over urban development and maintaining the land for agriculture in the lower mainland have also emerged in recent decades.

Given that it is the activities within the intensely farmed landscapes of B.C.'s lower mainland that are most in conflict with fish, it is in this geographic area that this paper concentrates the remainder of the discussion in respect to landscape-level agricultural impacts to salmon and steelhead.

WHAT ARE THE HISTORICAL LANDSCAPE-LEVEL IMPACTS TO SALMON AND STEELHEAD RESULTING FROM AGRICULTURE IN THE LOWER MAINLAND OF BRITISH COLUMBIA?

The impacts of landscape-level activities affecting aquatic ecosystems, arising from intensive agriculture, are becoming better known and have been recently reported to a greater extent throughout the scientific literature. Rosenau and Angelo (2005, 2007) extensively discuss the impacts of farming on salmon and steelhead in the eastern Fraser Valley, concentrating on historical and current instream and riparian effects and dealing with some historical landscape-level perturbations.

Historically the first farming impacts to lowland ecosystems of the lower mainland began to occur in the mid-19th century as settlers moved into what is now known as British Columbia (Boyle *et al.* 1997, North and Teversham 1984). Local historians such as Orchard (1983) and Siemens (1968) have described landscape-level changes as they unfolded in the lower mainland during European settlement, much of this relating to the growth of agriculture in the Richmond/Ladner/Annacis Island areas and the eastern Fraser Valley. However, changes to habitats in these fish-rich landscapes became most noticeable when, around the turn of the 20th century, large-scale diking and draining ineffably modified large areas of lowlands from Hope down to Georgia Strait. This was largely due to the expansion of agriculture (Fig. 3.4; Ellis *et al.* 2004, Rosenau and Angelo 2007). For many of these habitats, the floodplain was forever severed from the active channel as a result of diking and ditching as farming took over these areas comprising rich soils.

In the 1920's, one of B.C.'s most catastrophic landscape-level impacts to fish habitat occurred when Sumas Lake was dewatered for farming (Rosenau and Angelo 2005). Cameron (1996) describes how Sumas Lake was diked and drained specifically for agriculture, and turned from a rich shallow-water aquatic landscape into a rich highly-productive agricultural landscape (Cameron 1996, Rosenau and Angelo 2005). There was little opposition to this action at the time it occurred, and it was largely seen by British Columbians as a sign of progress. This draining affected about 10,000 acres of wetland/lake (at base flows), which before draining would normally increase to about three times that size during spring freshet when the Fraser River would back up the Sumas Lake waters.

The great Fraser River flood of 1948 also had significant implications for fish habitat in the eastern Fraser Valley farmlands. This flood was the greatest measured discharge of all of the Fraser River freshets[1] in the post-European settlement period. It caused large-scale inundation across the floodplain throughout the Fraser Valley with considerable damage to agriculture and its infrastructure. After this flood, the floodplain was significantly modified and engineered through diking, ditching, and pumping to keep freshet waters from ever flooding the valley bottom again. These dikes have been continually upgraded ever since (Fig. 3.5).

[1] The 1894 spring-freshet flood on the Fraser River was thought to be much larger 17,000 cubic meters per second measured at Hope versus 15,200 in 1948, but the former was ungauged so there is some uncertainty regarding the exact volume of the earlier inundation.

As a result of these historical activities relating to flood protection and continued clearing of the landscape for farming and other purposes, much of the floodplain ecology and fish habitat of the area was forever lost or permanently altered (Rosenau and Angelo 2005, 2007). More recently, landscape clearing outside of the dikes, for agriculture, in the remaining functional floodplain has continued, albeit on the remaining fragments of this highly disturbed ecosystem.

DISRUPTION OF THE HYDROGRAPH TO FACILITATE FARMING IN THE LOWER MAINLAND

The disruption of the hydrograph in drainages flowing through developed areas, including farmland, comprises the greatest impact to aquatic ecosystems associated with development of landscapes (Stephens *et al.* 2002). That the hydrograph would be disrupted extensively in agricultural settings is understandable given that standing water, or waterlogged soil, on the farmer's fields is normally incompatible with growing crops and livestock husbandry; thus, farmers continually strive for improved drainage.

Extensive drainage of the farming landscapes was important to the historical development of the floodplain of the lower mainland for agriculture (Partnership Committee on Agriculture and the Environment 2001). As a result, over the past several decades of increasing agricultural presences, conflicts have been common between fisheries agencies whose mandate it is to protect fish habitat, and the farming proponents (including both farmers and the agricultural agencies) that support drainage development and maintenance (Fig. 3.6; Rosenau and Angelo 2005).

For the lower mainland, the surface elevation of much of the farmland in this area is below the normal flood levels (both fall and spring freshets, depending on the stream) of the Fraser River and many of the larger local streams. Thus, agriculture in this area is maintained through an extensive network of dikes (Fig. 3.4, 3.5; Rosenau and Angelo 2005, 2007), ditches (Fig. 2.6; Rosenau and Angelo 2005, Northcote 2001, Slaney and Northcote 2003), pump stations (Thomson 1999, 2000) and underground drainage networks (Figs. 2.6, 3.7, 3.8; Rosenau and Angelo 2005). Much of this drainage development has occurred in watersheds comprising salmon habitat that was historically superlative (Rosenau and Angelo 2005). Nevertheless, because most of this habitat began to be altered extensively shortly after the turn of the 19th century, it is difficult to know exactly the extent of the aquatic-ecosystem damage or what would constitute full habitat restoration.

Landscape-level drainage projects for agriculture in British Columbia were also extensively facilitated by governments during the latter half of the 20th century. This included supporting the agricultural community through the *Agriculture Land Development Act* (ALDA) and the Agriculture and Rural Development Subsidiary Agreement (ARDSA) programs. Along with agency and monetary support, drainage also became more efficient through advances in modern drainage technologies such as plastic perforated pipes.

The ARDSA initiative has been a joint federal, provincial and municipal program that gave money to farmers and local communities to improve drainage and irrigation on farmland. This has allowed increased construction of dikes, pumping stations and drainage infrastructure. To reiterate, prior to the development of these efficient drainage systems, many of these wetted areas across the lower mainland landscape would have been considered good fish habitat.

A sense of the magnitude of the landscape-level effects on aquatic ecosystems that have occurred in the lower mainland as a function of the Agriculture and Rural Development Subsidiary Agreement programs can be seen by examining the ARDSA criteria which were set to ensure that specific field drainage efficiencies based on risk assessment would be met. This included:

- Remove the runoff from the 10 year, 5 day storm, within 5 days in the dormant period (November 1 to February 28);
- Remove the runoff from the 10 year, 2 day storm, within 2 days in the growing period (March 1 to October 31);
- Between storm events and in periods when drainage is required, the base flow in channels must be maintained at 1.2 m below field elevation (Fig. 3.9).
- The conveyance system must be sized appropriately for both base flow and design storm flow.

This information can be reviewed at: http://www.agf.gov.bc.ca/resmgmt/publist/500series/535100-2.pdf

Once constructed, the partnership agreements included the criteria for continued maintenance of these drainage systems that was consistent with the specified designs (Partnership Committee on Agriculture and the Environment 2001).

The expansion of drainage in the lower mainland for agriculture widely impacted aquatic ecosystems, but it is difficult to know how great the impact has been since no comprehensive or scientific accounting of the effects has ever been conducted. Nevertheless, to get a sense of the landscape-level changes that have taken place, it has been observed that between 1946 and 1977 over 3 million metres of subsurface drains were installed in British Columbia (Figs. 2.6, 3.7, 3.8), and much of this was in the lower mainland. Lalonde and Hughes-Games (1997) felt that these installations resulted in the draining about 5,700 ha of wetlands or farmland with marginal attributes. Again, most or all of this activity would have compromised aquatic ecosystems in one way or another. In later years, the agency programs provided additional monetary support for another 2.75 million metres of drain tiles through to 1983.

A key aspect of the installation of the extensive sub-surface tile and perforated pipes is that under the policies associated with the agencies, there is criteria requirement of a 1.2 metre freeboard in outlet ditches (Fig. 3.9). Drainage systems constructed in this manner cause damage to aquatic ecosystems by drying and desiccating adjacent and connected wetlands. These drainage systems also disrupt the hydrology (rate of flow) insofar as the hydraulic storage in the water table is lessened (Fig. 3.8). Lowering the elevation of the stream bottom can also act as a barrier to juvenile fish passage into adjacent, higher wetland habitats.

Using pipes, tiles and ditches has not been the only way lower mainland farmers have disrupted the hydrology of these historical salmon landscapes. As farming has become more intensified throughout the lower mainland, the extensive levelling of farm fields, assisted by using laser technology and computers, has occurred over a substantial portion of this landscape (Fig. 3.10). This has had the additional consequence of removing and eliminating small wetlands which provide for the storage of water during low-flow periods, whereby water can be released through hyporheic discharge if isolated from the fish stream. If these small wetlands remain connected to streams during low flows, they can also be a source of food and nutrients (Rosenau and Angelo 2005). The aggregate loss of so many small wetted areas is unaccounted for, but is likely to have been significant and substantial in regards to lower mainland salmonid ecosystems.

FIGURE 3.1. Agricultural Land Reserve of British Columbia.
Adapted from: Agricultural Land Commission (2007).

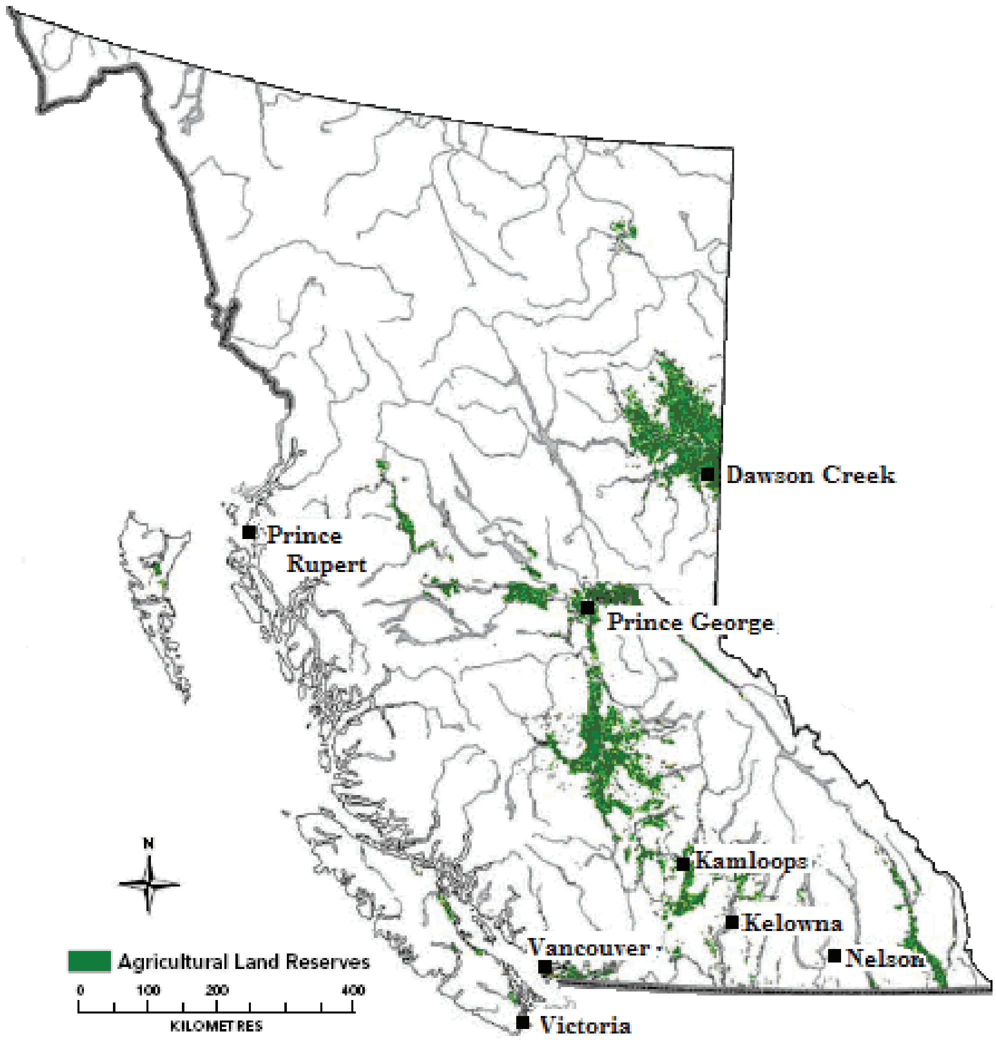


FIGURE 3.2. Economic value of farming, by region, in British Columbia.
Adapted from: SmartGrowth BC (2004).

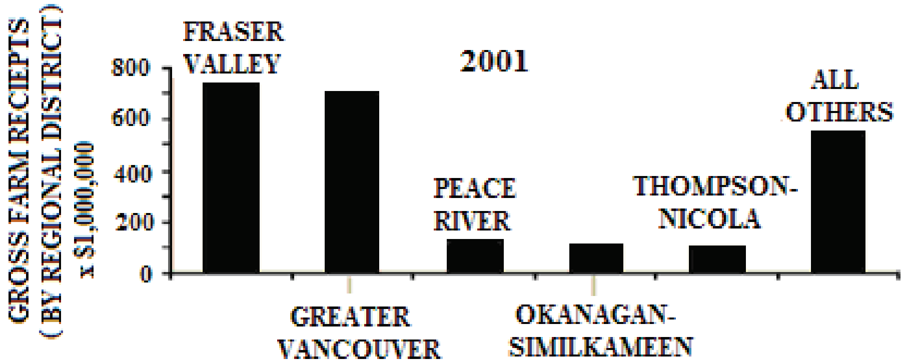


FIGURE 3.3. Area farmed, by region, in British Columbia.
From: SmartGrowth BC (2004).

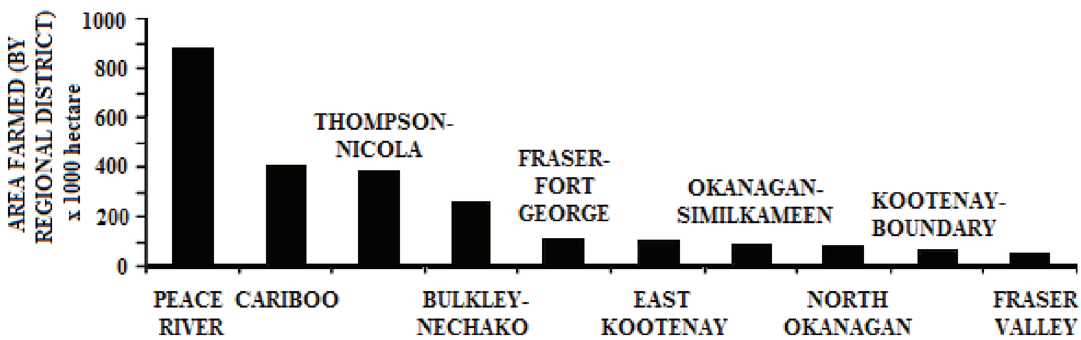


FIGURE 3.4. Fraser River in the eastern Fraser Valley showing current and active, versus historical floodplain now isolated from the stream by dikes.
Much of this floodplain was, and still remains, active farmland. Figure: Church and Ham (2004).

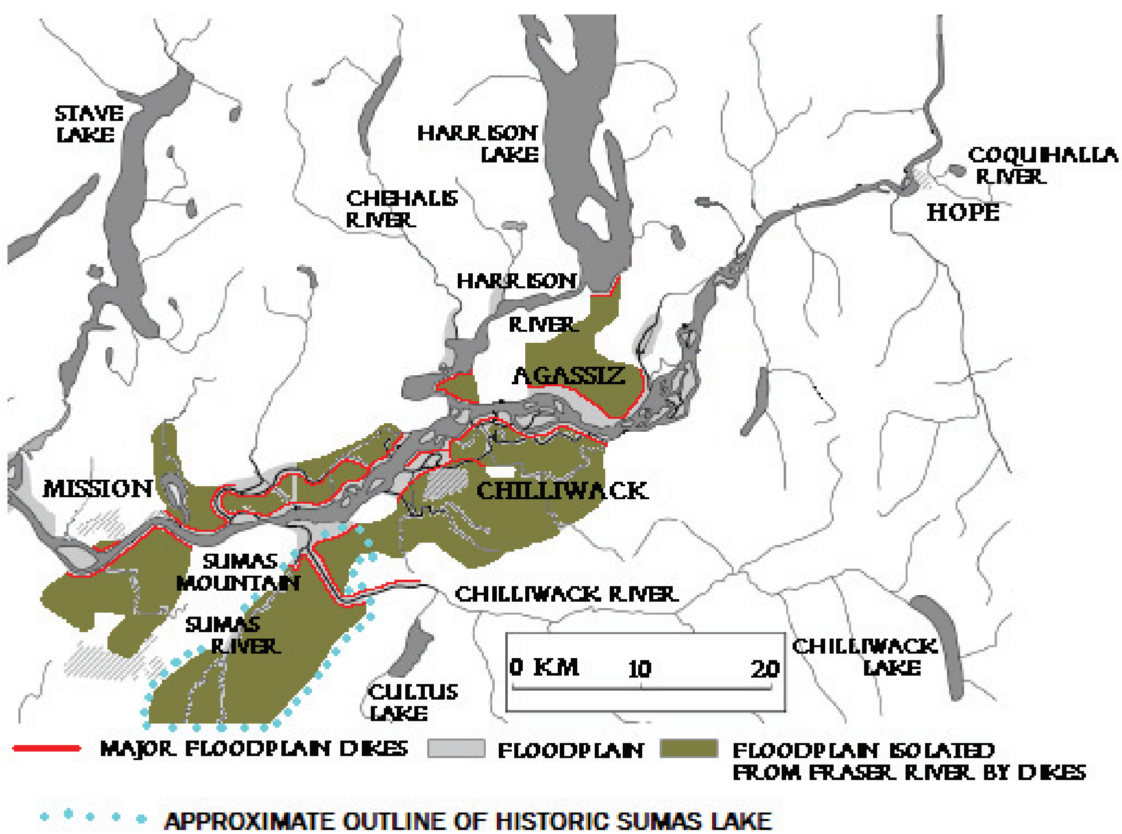


FIGURE 3.5. A newly upgraded (spring 2007) Fraser River dike protecting an extensive amount of farmland at Matsqui.
Photo: Danny Catt.

FIGURE 3.6. This cartoon appeared in a local newspaper in the eastern Fraser Valley in the late 1990's characterizing the feeling by some farmers towards the environmental agencies in regards to the protection of fish habitat impacts associated with drainage channel maintenance.
From: The Abbotsford Times (1998).

FIGURE 3.7. Total length of subsurface agricultural drains installed in southern British Columbia between 1946 and 1996.
See also Fig. 2.6. From: Lalonde and Hughes-Games (1997).

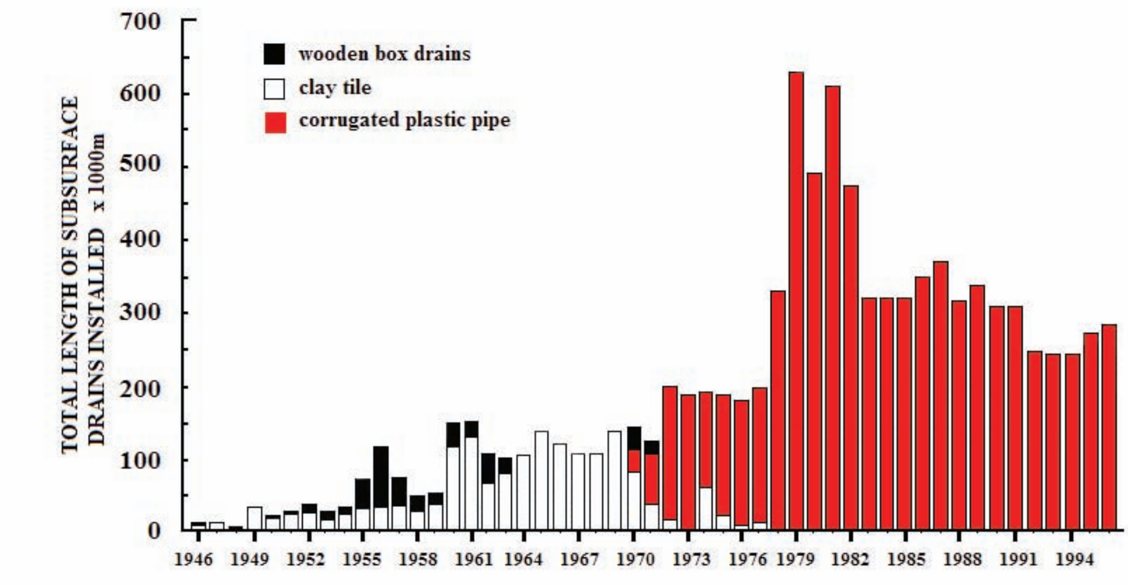


FIGURE 3.8. Effect of drain tiles and enhanced drainage on the groundwater levels in agricultural areas.

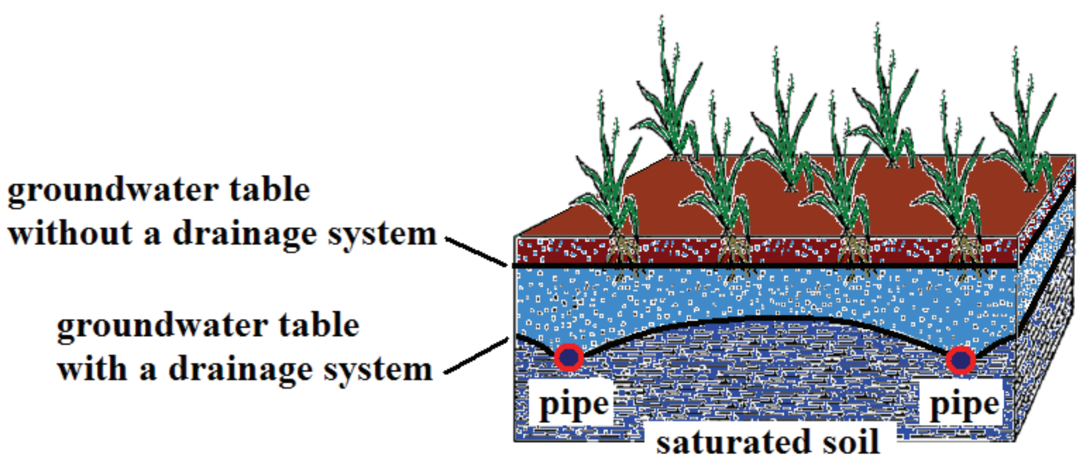


FIGURE 3.9. Agricultural field drainage criteria for British Columbia.
From: Ministry of Agriculture, Food and Fisheries (2002).

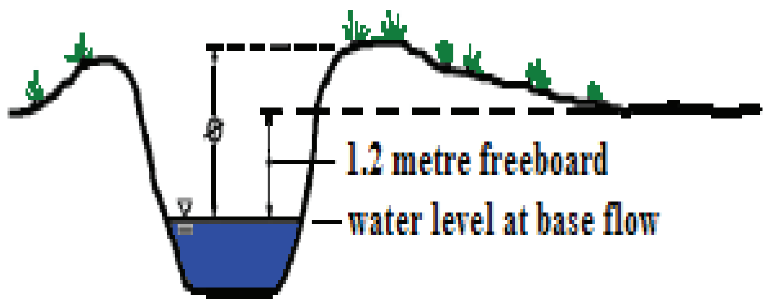
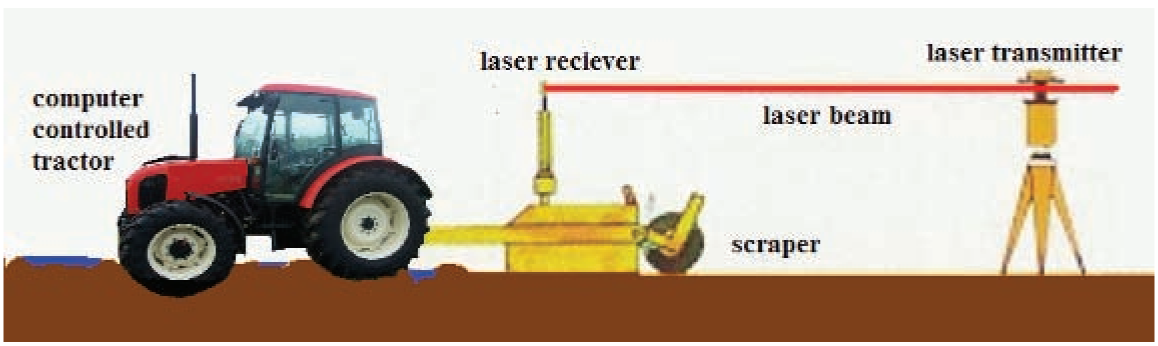


FIGURE 3.10. Laser-assisted levelling equipment removes any variability in landscape elevation in farm fields and destroys and eliminates any wetlands therein.



WATERCOURSE CONTAMINANTS (NUTRIENTS, PESTICIDES) APPLIED TO THE CULTIVATED AGRICULTURAL LANDSCAPES IN THE LOWER MAINLAND

A serious threat to natural ecosystems and the environment in the lower mainland of British Columbia arises in the form of pollutants from the "industrialization" of agricultural landscapes. Under these conditions, nutrients and chemicals are used to facilitate crop production without methods to properly treat or contain these products from entering non-target areas of the environment (Stephens *et al.* 2002, Olewiler 2004). In recent years, agricultural industrialization of the lower mainland has occurred in a number of ways including greater use of fertilizers and pesticides, increases in livestock densities, and contributions to non-point-sources of pollution of its landscapes (Brisbin and Runka 1995, Berka 1996, Berka *et al.* 2001, Quilty 2003, Wan *et al.* 2006). Indeed, commercial fertilizer use increased 164 percent between 1971 and 1991. Spraying and dusting of pesticides has risen substantially over the last several decades, and there have been significant changes from higher-nitrogen-uptake crops such as forage (e.g., hay, silage) to lower-uptake crops such as raspberries, which has also led to greater nutrient loading in watercourses (Olewiler 2004).

The effects of agricultural contaminants on salmon fisheries and other environmental attributes in the lower mainland have been of particular concern to the environmental agencies in recent years. During the previous decade, the Fraser River Action Plan assessed many of the sites in the lower mainland where agriculture and fish have come into conflict. The reporting of the studies can be found in the following web site: http://www.rem.sfu.ca/FRAP/PDF_list.

One of the important aspects in understanding the increased potential for the agricultural contaminants entering salmon streams in British Columbia is that riparian-area requirements, stipulated under legislation and regulation for forestry and urban development, are not in place for farmlands. Farmers in British Columbia are largely allowed to destroy salmon and steelhead streams because they are not required by law, or by enforcement of the law, to maintain buffer zones around fish-bearing streams. Good riparian buffers can extensively mitigate the effects of pesticide spraying and fertilizing (either manure or inorganic), but are not required to be integrated into lower mainland crop fields in British Columbia (Fig. 2.6).

For the Fraser Valley, nutrients from manure, combined with inorganic fertilizer use, routinely exceed the capacity of farmlands to assimilate the available nutrients (Ministry of Environment undated a). This process has been increasing over several decades and is currently contaminating both surface (Fig. 3.11) and groundwater (Fig. 3.12).

Nitrogen, a significant component of manure, is particularly worrisome because of its human health implications, as well as its effects on aquatic ecosystems. When too much manure and chemical fertilizers are used the excess nitrogen leaches into ground water or enters adjacent streams and eutrophication occurs (Fig. 3.11). Eutrophication is when more-than-normal amounts of nutrients from human activities cause unnaturally excessive aquatic algal plankton blooms, to the detriment of the aquatic ecosystem.

Increased nutrients entering watercourses can also occur at certain times of the year when farmers plough perennial-forage crops into the soil in order to condition the land. The decomposition of the plants, shoots and roots entrained into the soil through ploughing releases a flush of nutrients, particularly nitrogen, into the ground which can be mobilized into the landscape water and enter a stream inhabited by fish. For areas of high precipitation, spring is the best period of the year to plough under plants with high nitrogen content in order to reduce the risk of this nutrient leaching to watercourses or ground water; the live plants more quickly take up the nitrogen as part of their growth and it is sequestered before it leaves the field.

When applying organic or inorganic fertilizer to crops, surplus amounts of nitrogen should not exceed 50 kg per hectare per year, at the very most, in lower mainland farm fields (Fraser River Action Plan 1998). However, the British Columbia Ministry of Environment reports that this threshold is commonly exceeded and this is a problem in the Fraser Valley where it has been recorded at levels of between 300 and 400 kilograms of nitrogen per cropped hectare (Ministry of Environment undated a). In another recent study, nine of nineteen monitoring wells sampled in 2000 in the South Matsqui area, which lies over the Abbotsford Aquifer and is an area of high agricultural activity and manure spreading, significantly exceeded the national nitrate drinking water guidelines (BC Ministry of Environment, Lands and Parks and Environment Canada 2000; see also Fig. 3.12). This trend is consistent with other studies by Zebarth *et al.* (1998) and Hii *et al.* (1999) who showed elevated nitrate concentrations over a wide portion of the Abbotsford Aquifer.

The Fraser River Action Plan (1998) also cited studies that found large surpluses of nitrogen in areas that were being intensively farmed in the other parts of lower mainland as well. Indeed, the program demonstrated that the study farms exceeded the 50 kg/ha/yr maximum for 16 of the 20 zones assessed, and this represented 78 per cent of the total cropped area. Furthermore, 10 of the zones in the Fraser River Action Plan assessment, representing 57 per cent of the cropped area, had surpluses of more than 100 kg, or more than twice the maximum. Finally, three of these zones, representing 11 per cent of the cropped land, were at the top of the list including South Langley at 108 kg, West Matsqui at 202 kg, and, highest of all, South Matsqui at 308 kg, or six times the maximum.

Phosphorus is another essential nutrient, utilized by both terrestrial and aquatic plant ecosystems, and is often applied to crops via manure or inorganic fertilizer. Like nitrogen, it can both affect large areas of agricultural landscapes and pollute salmon and steelhead streams within the geographical catchment when applied at inappropriately high levels. It is also a major cause of eutrophication in streams and lakes.

Elevated phosphorus levels have also been shown to be a problem associated with many agricultural operations in the lower mainland. For the same fields that were assessed for nitrogen in the above-mentioned study, the Fraser River Action Plan (1998) report indicated that the lower mainland farming-levels of phosphorus were also often excessive. The Fraser River Action Plan (1998) report showed that phosphorus measured at least twice as much as removal in 18 of 20 zones. Even more concerning was the fact that these assessments found that there were more than four times as much of this nutrient, as removal, in six of the assessed zones. The conclusion by the Fraser River Action Plan (1998) evaluation of both nitrogen and phosphorus used by agriculture in parts of the lower mainland was unequivocal: there is a massive overloading of nutrients occurring in the Lower Fraser Valley as a result of farming.

To protect ecosystems and human life from agricultural nutrient pollution, there are various Acts, regulations and Best Management Practices that provide direction for farmers in the use of manure and fertilizers in British Columbia. This includes the *Agricultural Waste Control Regulation* (AWCR) of the *Environmental Management Act* (EMA) and the manure spreading advisories produced by the Nutrient Management Working Group (Rushworth and Younie 2006). The Environmental Farm Planning initiative (Brown *et al.* 2005) is also an opportunity for farmers to undertake Best Management Practices to protect the environment and aquatic ecosystems while still conducting farming. The *Reference Guide For Use with the Publication: Canada - British Columbia Environmental Farm Plan—Planning Workbook* has detailed recommendations in regards to the handling of manure on farms in British Columbia, including the lower mainland (Brown *et al.* 2005).

To minimize the landscape-level pollution to both land and water through the inappropriate storage, application of manure and inorganic fertilizers, there are a number of Best Management Practices actions that the farmers can undertake (Figs. 3.13, 3.14; Table 3.1). This includes properly timing the applications, controlling the loading of manure and fertilizer on the land, and using buffers to separate the application from water bodies. In contrast, if the nutrients are spread in the late fall and early winter, when the plants are less inclined to utilize the nutrients, the normally heavy-winter precipitation and high-surface runoff that occurs in the lower mainland can entrain this material into aquatic ecosystems (Table 3.1).

In order to address the issue of pollution to watercourses resulting from manure spreading in agricultural landscapes, the British Columbia Ministry of Environment conducts compliance audits. For a 2004 study in the eastern Fraser Valley, Rushworth and Younie (2006) found a 12% non-compliance rate with various aspects of manure storage, handling and application, indicating that there is still room for improvement in respect to the farm utilization of animal wastes in lower mainland farming landscapes.

Pesticides used in agricultural situations are also known to contaminate streams and impact aquatic ecosystems including those in the lower mainland (FRAP 1998, Wan *et al.* 2006, de Solla *et al.* 2002). This can occur as a result of spillage, improper storage, application too near (or into) ditches and streams, leaching from soils, or washed into surface runoff during rain or irrigation events (Ministry of Environment undated a). The effects of pesticides to aquatic ecosystems are generally at a landscape-level when contamination occurs due to the application taking place over broad areas such as crop fields. When the spreading of such pollutants (in respect to non-target organisms) is over such a large area, it is often easy for this material to be sequestered and entrained into watercourses.

Over the last half of the 20th century the use of pesticides for farming in British Columbia increased significantly with the area of agricultural cropland being treated going from about 425,000 hectares in 1971 to about 550,000 hectares in 1986 (Ministry of Environment undated a). These materials can also pollute surface and ground waters and a recent study, reported by the Ministry of Environment for the Lower Mainland's Abbotsford-Sumas aquifer, found traces of 16 pesticides in the water. Furthermore, as evidence of the persistence that pesticides can have, some of the detected compounds are either no longer used or their use is restricted (Ministry of Environment undated a). In order to minimize the impacts to aquatic ecosystems and other environmental concerns, farmers in British Columbia are being encouraged to adopt Best Management Practices and Integrated Pest Management (IPM) techniques which help reduce the overall use of pesticides while maintaining efficacy and profitability (Ministry of Environment undated a).

FIGURE 3.11. Excess nutrients from agricultural activities entering watercourses cause excessive eutrophication (plant and algae growth) such as has occurred here as evidenced by the solid light-green colour of the stream channel.
Photo: Fraser River Action Plan (1998).

FIGURE 3.12. Nitrogen contamination in the Fraser Valley suspected of being largely from agricultural practices.
Environment Canada (undated).

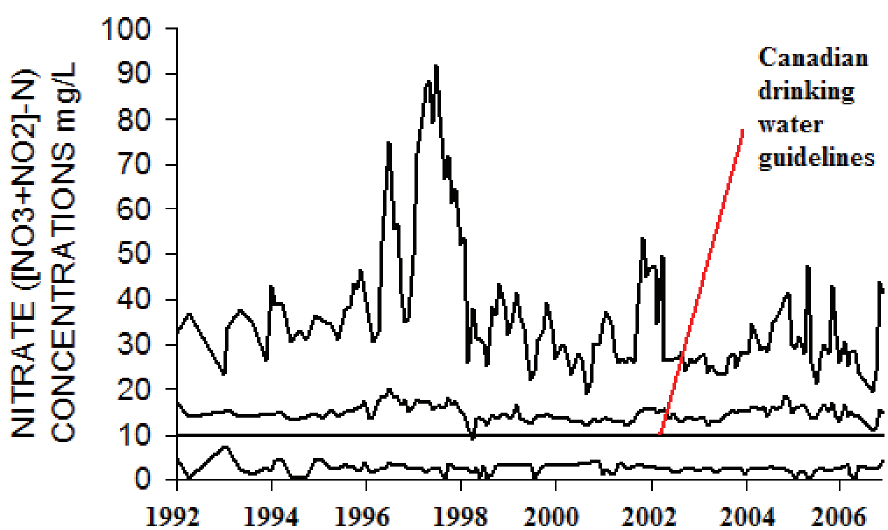


FIGURE 3.13. A recent audit of Fraser Valley manure handling found that although most farms were in compliance of best management practices, a small number refused to implement proper actions and these resulted in landscape-level damage and likely pollution such as occurred to the salmon stream in this photo.
Photo from: Rushworth and Younie (2006).

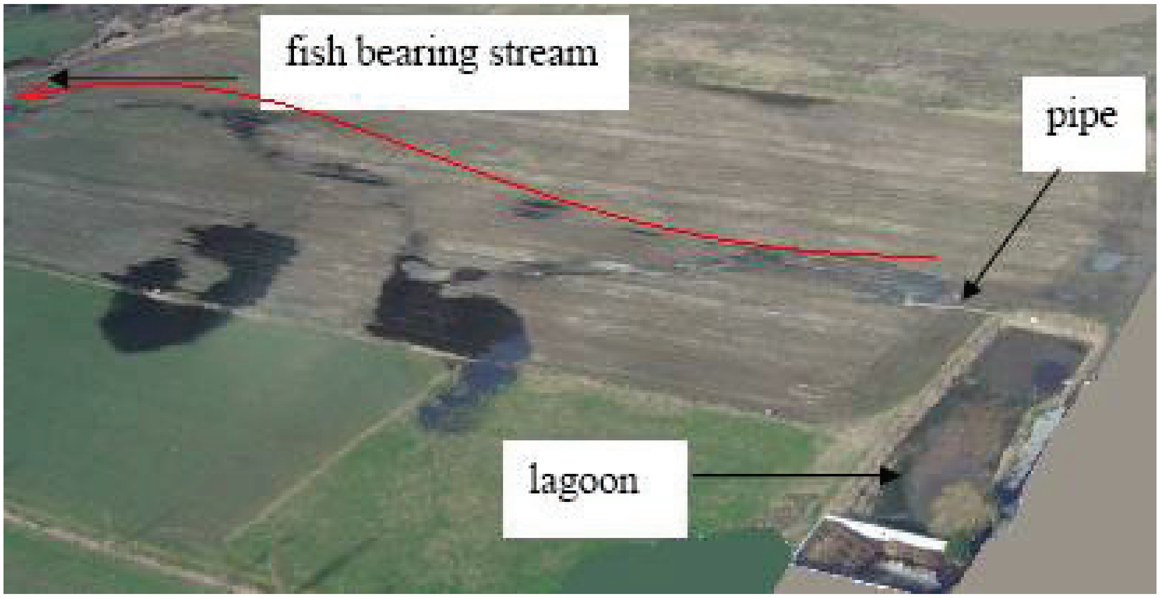


FIGURE 3.14. New technologies which direct agricultural activities into the soil reduce the entrainment into the surface runoff and lessen the opportunity for stream contamination.
Photo: Fraser River Action Plan (1998).

TABLE 3.1. Recommended monthly manure spreading practices in the coastal region of British Columbia. *Brown et al. (2005).*

September & October	November to January	February & March	April and August
Environmental Risks of Contaminating Surface and Drinking Water			
Moderate rainfall hence moderate risk	**High rainfall hence high risk**	**Moderate rainfall hence moderate risk**	**Moderate to low risk**
SPREADING PRACTICES	NO SPREAD PERIOD	SPREADING PRACTICES	SPREADING PRACTICES
Spreading on grassland to meet crop needs for this time of the year is acceptable.	MID NOVEMBER TO END OF JANUARY Spreading on any crop is not acceptable due to the extreme risk to surface and/or ground water.	For grassland and well established cover crops, it is generally recommended that the first application of manure as a fertilizer should occur near or after the Tsum200* has been reached and at a rate which meets crop nutrient needs. *Tsum at www.farmwest.com*	According to crop and soil conditions, apply manure throughout the growing season to meet crop nutrient uptake
When cropping after corn, cover crops or grassland planted after September 1 should not receive manure unless the need for nitrogen has been proven by a soil test. There is usually enough nitrogen remaining in the soil for a cover crop or newly seeded grass.	SHOULDER PERIOD	Spreading on berry or vegetable crops to meet crop nutrient needs for this time of year is acceptable after mid-February.	Avoid spreading on wet fields or saturated soils.
Not acceptable to spread on bare land (harvested corn, vegetables, berries, etc.) or cover crops that emerged after September 15th.	Spreading is not acceptable between mid-October to mid-November unless: · grass is actively growing (mean daily temperature above 5ºC), AND · soil is trafficable with no significant rain forecast for next 5 days.	Not acceptable to spread manure on bare land. Spreading can only occur if planning to plant a crop in the near future.	Manure applications should be planned to ensure that storage facilities will be as close to empty as possible by October.
Solid manure with high carbon-nitrogen ratios may be spread and incorporated into the soil as a soil conditioner. Manure should not be managed as a soil conditioner unless a manure test confirms a carbon-nitrogen greater than 30 to 1.	If spreading, apply only on grass fields which are not subject to flooding and/or runoff and only at rates matched to crop nutrient needs.	Not acceptable to apply manure: to fields that are subject to flooding or runoff; or to soils that are frozen or saturated.	To avoid food safety concerns, do not spread manure on berry fields between flowering and harvest or on vegetable fields after planting.
Manure not to be spread within 8 m or more of ditches or watercourses(suggested)—increase buffer width to avoid any contaminated runoff based on soil, soil cover conditions, slopes greater than 5%, and sensitivity of area being protected.	Manure not to be spread within 10 m or more of ditches or watercourses (suggested)—increase buffer width to avoid any contaminated runoff based on soil, soil cover conditions, slopes greater than 5%, and sensitivity of area being protected.	Manure not to be spread within 8 m or more of ditches or watercourses (suggested)—increase buffer width to avoid any contaminate runoff based on soil, soil cover conditions, slopes greater than 5%, and sensitivity of area being protected.	Manure not to be spread within 5 m or more of wet ditches or wet watercourses, or 3 m or more from dry ditches or dry watercourses (suggested)—increase buffer width to avoid and contaminated runoff based on soil, soil cover conditions, slopes greater than 5%, and sensitivity of area being protected.

IMPACTS TO AQUATIC ECOSYSTEMS THROUGH THE REMOVAL OF FARM LANDSCAPES FROM THE AGRICULTURAL LAND RESERVE

One of the most important pieces of legislation regulating the use of farm landscapes in British Columbia is the *Agricultural Land Commission* (*ALC*) *Act*. This legislation provides the framework to protect farmland from being converted into other uses such as development for urban, commercial or industrial properties. The *ALC Act* came about in the early 1970's as a response to the rapid development of a considerable amount of residential farmland throughout British Columbia, and mostly in the lower mainland, into subdivisions and other non-agricultural uses. For example, from 1961 to 1991 agricultural land in the lower Fraser Valley declined by 23 percent, and then declined a further 4 percent from 1991 to 2001 (from 111,120 to 85,825 to 82,361 hectares) (Olewiler 2004).

With the promulgation of the *ALC Act* in 1974, the province of British Columbia designated farmland in the province as an "Agricultural Land Reserve" (ALR). Under the Act, farmland was set into a "reserve" whereby the land cannot be used for anything other than agriculture. Agricultural lands were viewed by the government of the day as a "scarce and important asset." The Agricultural Land Commission (ALC) is the administrative body that makes decisions with regards to how this land will be used and where and when farmland will be removed from the Agricultural Land Reserve. The ALC has three objectives: a) to preserve agricultural land; b) to encourage farming on agricultural land in collaboration with other communities of interest; and c) to encourage local governments, First Nations, the government and its agents to enable and accommodate farm use of agricultural land and uses compatible with agriculture in their plans, bylaws and policies.

A key aspect of the Act is that it sets out procedures for land-use approvals including the inclusion or removal of land from the Reserve. Non-farm uses and subdivisions within the ALR are also under the purview of the ALC. The *Act* provides for the delegation of authority to decide non-farm use and subdivision applications to a local government or a public authority. Within this context, the *Agricultural Land Reserve Use, Subdivision and Procedure Regulation* defines permitted land uses within the ALR and provides the procedures for applications and enforcement and compliance activities for the Reserve.

Under the Agricultural Land Commission Act, the Reserve comprises about five per cent of the province's area. In recent years it has grown, but this increase has been at the expense of the more southerly farmland with additions to the less productive land in the northern parts of the province (Campbell 2006). While 90% of the farmland added to the reserve has been in the north 72% of land lost from the reserve has been in the south, and some of these locations included high-value salmon and steelhead habitats (Campbell 2006). Olewiler (2004) states that since the reserve was created, the Lower Mainland, Vancouver Island and the Okanagan have had net losses of more than 35,000 hectares.

Despite the fact that residents of British Columbia have consistently shown support for the Reserve, the quality of its land and the strength of implementation of the legislation protecting it have decreased over time (Cavendish-Palmer 2008). It is the view of Cavendish-Palmer (2008) that the Agricultural Land Commission often inappropriately approves application to exclude prime farmland from the Reserve for other purposes while including land into it that may never be suitable for agriculture.

In the last several years, the *ALC Act* introduced a greater spectrum of allowable land uses in the ALR. The Act also provided a great role for local governments through regulation. The concept was to balance community interests with farmland preservation. Through the new Section 13 of the Act, there is now a greater opportunity for development to occur on former farmland and a facilitator may consider social, economic, environmental and heritage factors of a community when making a recommendation on an application to the Commission (Curran 2007). It is the view of Curran (2007) that no such authority had been accorded to the Commission in Section 6 of the original Act. As a result, although it is not clear that the Commission has taken landscape-level perspectives to protect fish habitat as a result of the environmental components of Section 13, it seems that it could now do so if it wanted to.

While it is not the objective of this report to debate the issues of the management of farmland in British Columbia, what is important from an aquatic ecosystem and salmon and steelhead perspective is the type of farmland that is being lost in the lower mainland to development, through ALR exclusion. A number of large pieces of land, of extra-ordinary ecological and fisheries values, have been released from the Reserve in recent years without a clear rationale or explanation (Rosenau and Angelo 2005, 2007; Figs. 3.15, 3.16, 3.17). It is clear that although the new Section 13 of the *Act* has provided the ALC with the opportunity to protect these attributes and to encourage and allow farming, fish habitat is still being lost or compromised through these types of ALR exclusions.

FIGURE 3.15. Prior to being recently diked, this was an ephemerally flooded landscape comprising fish habitat. *It was recently removed from the Agricultural Land Reserve and developed into industrial land. During Fraser River spring freshet 2002 (top) and post-development in 2007 (bottom). Lower photo: Danny Catt.*

FIGURE 3.16. Former agricultural farmland was removed from the Agricultural Land Reserve and developed into industrial landscape with virtually complete loss of the aquatic attributes of the area.

FIGURE 3.17. Pre-development view of Vedder River riparian areas where Agricultural Land Reserve farmland was taken out of the Reserve and converted into urban lands with substantial effects to the riparian areas of salmon and steelhead habitat.
Subdivision to the right of the oval has expanded and now encompasses virtually all of its area. Photo: Google Earth (undated b).

4.0 INFLUENCE OF LANDSCAPE-LEVEL ACTIVITIES OF URBANIZATION ON STREAMS IN BRITISH COLUMBIA

OVERVIEW

With the current expansive growth rates of the human population in British Columbia (Fig. 1.3), the development of landscapes for urban, commercial and industrial uses is at an all-time high. At no time in history has the number of people in this province been this great, or has there been more human immigration.

To give some perspective of the human growth in British Columbia, between 1990 and 2000 the Metro Vancouver area had a 2.6% per-annum increase in population which, remarkably, was greater than that found in world-renowned mega-cities such as Cairo, Jakarta and Rio de Janeiro (Olewiler 2004). Even more recently, a 2001 census counted 1,986,965 residents in the Vancouver metropolitan area (this was about half of the population of British Columbia) but by 2006 the number of people in the same geographic area had increased to 2,116,581 representing a 6.5% growth since the previous assessment. The population density in the Metro Vancouver area is now estimated at 736 persons per square kilometer compared to 4.4 persons/km^2 throughout all of the rest of British Columbia. Growth rates in other urban centers of this province, including the lower mainland outside of Metro Vancouver, southern Vancouver Island, and the Okanagan, are also trending towards record levels.

To accommodate this influx of people landscapes in British Columbia are being developed for habitation, as well as for industrial and commercial uses, as never before. This has negative implications for both ecosystems, in general, and salmon and steelhead, in particular, especially for the fish-rich areas in the lower mainland, southern Vancouver Island and the southern Okanagan. Within the lower mainland, more than 600 hectares of rural land are converted to urban uses every year (Ministry of Environment undated b) and Olewiler (2004) suggests that for every 1,000 new inhabitants in greater Metro Vancouver, 28 hectares of land are being urbanized.

Over the last century, land development has had a clear impact on salmon and steelhead populations in the south-eastern part of British Columbia (which is the most heavily settled part of the province, as well as the historically most salmon-abundant). For example, of the almost 800 streams originally present in the lower Fraser Valley, 15% have been completely lost to development and another 72% are threatened or endangered Only about 100 streams (14%) remain in good condition (Fraser River Action Plan 1998). Furthermore, while the protection of aquatic values in respect to land development has increased, almost 1,000 hectares of wetlands were still lost in the lower Fraser Valley over the last 20 years or so (Olewiler 2004).

Development-related impacts to landscapes throughout British Columbia are still occurring so rapidly that resource managers are having great difficulty in ensuring the protection of the inherent key environmental attributes of urban streams in this province. Thus, many small populations of salmon and other species of fish, particularly in south-western parts of the province, are rapidly being driven into extinction as a result of development. The impacts relating to urbanization are not solely tied to fish; as an example, the Fraser River lowlands area now has the second-highest number of all species at risk in British Columbia (Olewiler 2004).

As an additional note, the phenomenon of human population growth and the collapse in salmon and steelhead populations is not tied only to British Columbia, but includes most of the west coast of North America from California up to central Vancouver Island. Population numbers in the Pacific Northwest of the United States are expected to increase dramatically throughout this century from the current 14 million, to between 40 and 100 million (including British Columbia) and will clearly affect these more southerly stocks of fish as well as those in our province (Lackey 2000).

In order to counter these development-related impacts to stream habitat, over the last several decades there have been considerable efforts on the part of government agencies and stewardship groups to deal specifically with the impacts of urbanization on salmon throughout British Columbia. These endeavours have included new legislation, policies, and regulations and an assortment of programs. A sub-set of examples of some of the more prominent and recent efforts undertaken includes the development and promulgation of the British Columbia *Fish Protection Act*, the Streamside Protection Regulations, Riparian Area Regulations, SEP (Salmonid Enhancement Program), USHP (Urban Salmon Habitat Program), SEHAB (Salmonid Enhancement Habitat Advisory Board), HRSEP (Habitat Restoration Salmonid Enhancement Program), Streamkeepers Program, and others. Despite these laudable efforts, the losses to aquatic ecosystems have continued across most urban environments.

As described throughout this report, there are a number of specific landscape-level effects to aquatic ecosystems which occur as a result of urban development. These impacts include the alteration of the instream, riparian and upland zones within the greater landscape (Fig. 1.9). It is important to note that although many of the highly productive streams in the urban landscapes of the lower mainland have been lost through channelization and culverting, there are other urban streams, where development has occurred, that have managed to retain relatively good insteam and riparian habitats. Yet in many of these instances, damage to aquatic ecosystems and salmon stocks has still occurred despite considerable rehabilitation efforts. For all intents and purposes they are often also functionally (biologically and hydrologically) destroyed due to the radically changed flow characteristics that they now exhibit both across the landscape and in the watershed streams. The results of studies in Puget Sound and reported by Stephens *et al.* (2002) suggest that in urban environments changes to the hydrology comprise the most damaging aspect of land development to aquatic ecosystems and this is largely due to the increase in Percent Impervious Cover (PIC), or the percentage of the landscape which will not allow infiltration of water (e.g., asphalt, roof tops, concrete, etc.).

Many of the watercourses in these developed landscapes throughout British Columbia are now so disrupted in terms of volume and pattern of their surface and groundwater flows, due to the hardening of the landscape and re-routing of the water, that streams have substantially restructured biological communities and reduced fish productivity. Understanding and addressing flow changes to urban streams in British Columbia in respect to salmon habitat will be the focus of the following discussions.

URBAN DEVELOPMENT IN BRITISH COLUMBIA AND MANAGEMENT OF THE HYDROGRAPH AND LANDSCAPE-LEVEL DISCHARGES

While many of the early efforts associated with managing fish habitat in developed environments concentrated on instream and, more recently, riparian restoration and protection, fisheries scientists in British Columbia, and throughout the world, have come to realize that the driving force for fisheries sustainability in urban streams relates to how landscape disturbances in upslope areas affect changes to the hydrograph. Intact instream and riparian structure becomes largely ineffective in maintaining aquatic ecosystems in urban environments if natural drainage patterns and normal hydrograph connections from the upslope areas, to the rearing and spawning streams, in these watersheds become largely disrupted (Stephens *et al.* 2002). That is, when precipitation falling on the upland area is physically constrained (Figs. 2.1,7) through enhanced drainage (e.g., impervious surfaces, piping, culverting, ditching), disrupting the all-important hydrograph patterns to which aquatic ecosystems are adapted, fish populations collapse (Stephens *et al.* 2002). As described above, 10% is the percentage of the landscape that is impervious to water infiltration (PIC) (Fig. 2.8) threshold for impacts to aquatic ecosystems in urban streams, associated with development of landscapes (and some of the studies showed that the impacts occur at even lower percentages PIC).

Until recently, the traditional engineering approach to the management of surface-water drainage in urban communities has been to remove runoff as quickly as possible from the landscape of developed areas. As a result, traditional urban-drainage designs in British Columbia are very efficient in collecting, concentrating, conveying and discharging rainwater to receiving streams (Stephens *et al.* 2002); this, and the extensive nature of the PIC found in most older communities, which often well exceed the 10 PIC (Table 4.1), has been to the detriment of salmon and steelhead ecosystems for the reasons discussed earlier in this report. Since urbanization gained a strong foothold in British Columbia almost a century ago, programs designed to deal with the quantity and quality of rainwater in lower Fraser Valley municipalities have been ineffective or non-existent from an ecological sensitivity perspective; this includes even the moderately developed watersheds (Langer *et al.* 2000).

However, in recent years changes have started to occur in the management of urban runoff both in British Columbia and in other jurisdictions. Indeed, amongst urban-drainage managers and scientists in province, there is now even a move afoot to shift the terminology of flow management in developed areas from “stormwater management” to “rainwater management” in recognition of the more comprehensive nature in dealing with the whole hydrograph and protecting aquatic ecosystems.

HISTORY OF RAINWATER MANAGEMENT IN DEVELOPED AREAS OF BRITISH COLUMBIA

The historical approach to rainwater management in urban environments in British Columbia has been outlined by Stephens *et al.* (2002) and is as follows. In the 1960’s the primary objective was to pipe and remove water as quickly as possible. Then as populations in the lower mainland began to rapidly grow in the 1970’s, developers and engineers moved towards detaining peak rain-event flows. Changes to rainwater management, throughout the 1980’s, included reactive mitigation of the impacts of rainwater (e.g., development of detention ponds). By the 1990’s, urban-stream management included stewardship groups which attempted to mitigate and restore some of the more egregious impacts associated with urban development (instream habitat placement, riparian planting). This, in turn, has now evolved into the current rainwater-management approach of the 21st century, described further below.

The need for a different approach to sub-division planning and rainwater management was recognized by both local and provincial governments by the early 1990's. In 1992, the Ministry of Environment, Lands and Parks published the *Urban Runoff Quality Guidelines* and the *Guidelines for Developing a Liquid Waste Management Plan* (LWMP) with the expectation that local governments would view the management of rainwater in a more environmentally responsible manner. Subsequently, in 1994 the Ministry of Environment, Lands and Parks issued a policy statement to local governments regarding the need to incorporate a stormwater component into LWMPs (Stephens *et al.* 2002). Following this, in 1998 the Ministry of Environment, Lands and Parks published a document titled *Tackling Non-Point Source Water Pollution in British Columbia—An Action Plan*, which identified a series of tools and strategies available to local government to reduce and prevent non-point source pollution in rural and urban areas. Local governments that had LWMPs were required by the provincial government to incorporate into the Plan a stormwater management component (Stephens *et al.* 2002).

While these efforts were laudable, problems relating to urban runoff still had not been completely resolved. Langer *et al.* (2000) recognized this by stating: "*In communities where land development is still occurring or about to occur, there is an opportunity to maintain healthy streams by implementing an ecosystem planning approach. We must consider the impacts of impervious areas, plan to concentrate development strategically instead of letting it sprawl, and protect natural watercourses (especially the headwaters). Without a watershed approach to providing the necessary level of stream protection, technical fixes such as sediment retention, stormwater detention, and riparian zone protection alone will not protect viable and productive streams in the long term. Where watersheds have been compromised by development, the remaining fish and fish habitat must be protected to maintain biological and genetic diversity and quality of life values*". Then one of the first real breakthroughs in regards to dealing with urban rainwater occurred in 2002 with the release of the document, *Stormwater Planning: A Guidebook for British Columbia* (Fig. 4.1; Stephens *et al.* 2002). This report outlined a framework for rainfall capture in urban environments and how to design ways to facilitate water movement through developed landscapes that lessened the disruption of natural fluvial and biological processes. One of the key paradigm changes in the thought process, as outlined in *Guidebook* report, was the view that rainwater was a resource rather than a liability. It was also recognized that there were technical solutions to dealing with most of the flows in a non-traditional (a "soft engineering" manner) as the bulk of rainfall in most urban areas in southern British Columbia urban areas is not threatening to life or infrastructure (Fig. 4.2).

The 2002 *Guidebook* provided a formalized integrated strategy for managing the complete spectrum of rainfall events rather than just the storms which destroy property and put lives at risk. The approach that Stephens *et al.* (2002) took was that that most of the rain volume that falls throughout the year comes down as light showers, and the bulk of the discharge (Fig. 4.1) can be dealt with from a technological and planning perspective in a far more environmentally responsible way that mimics the natural hydrograph (Fig. 2.2).

The primary thesis that the 2002 Guidebook put forward is that the urban planners and water engineers need a "design with nature" approach to rainfall-capture and runoff-control to achieve ecological objectives (Fig. 2.2). Ecological protection under these circumstances can only be reached by preventing land development and related human settlement activities in the urban environment from impacting the natural hydrograph.

Urban drainage has traditionally focused on managing surface runoff although the sub-surface flows of water are, in many ways, just as important in maintaining the natural hydrograph. British Columbia urban water engineers and planners now recognize the importance of the interflow discharge (interflow discharge = the component of water soaking into shallow ground and moving slowly through soils to streams, as compared to surface runoff or groundwater) (Marsh and Fraser 2005). Although the interflow portion of the hydrograph's character was first defined in the 16th century, its significance has been largely ignored for over 400 years in respect to land development. For urban developers, the primary objective must be to resist shifting interflow from under the ground to the surface in the face of the temptation to move it quickly overland, and into an outflow stream through conveyance technologies (such as culverts, ditches, drains, etc.) if an objective is to protect aquatic ecosystems. The Centre for Landscape Research (Marsh and Fraser 2005) suggests that: "*Stormwater is the component of runoff that is generated by human activities and is created when land development alters the natural Water Balance* [natural hydrograph]. *When vegetation and soils are replaced with roads and buildings, less rainfall infiltrates into the ground, less gets taken up by vegetation and more becomes surface runoff. The biggest increments of change—to the Water Balance in general, and to the surface runoff component in particular—occur when forested land is first cleared, then ditched, and finally paved or roofed over.*"

In order to maintain the natural hydrograph, and other physical and biological attributes relating to rainwater discharge in the face of urbanization, *Stormwater Planning: A Guidebook for British Columbia* (Stephens *et al.* 2002) provided the following objectives for healthy watersheds in our province in developed areas:

- **Objective 1:** Preserve and protect the water absorbing capabilities of soil, vegetation and trees,
- **Objective 2:** Prevent the frequently occurring small rainfall events from becoming surface runoff,
- **Objective 3:** Provide runoff control so that the Mean Annual Flood (MAF) approaches that for natural conditions,
- **Objective 4:** Minimize the number of times per year that the flow rate corresponding to the natural MAF is exceeded after a watershed is urbanized,
- **Objective 5:** Establish a total suspended solids (TSS) loading rate (i.e. kilograms per hectare per year) that matches pre-development conditions,
- **Objective 6:** Maintain a baseflow condition equal to 10% of the Mean Annual Discharge (MAD) in fisheries-sensitive systems,
- **Objective 7:** Limit impervious area to less than 10% of total watershed area,
- **Objective 8:** Retain 65% forest cover across the watershed,
- **Objective 9:** Preserve a 30-metre wide intact riparian corridor along all streamside areas, and
- **Objective 10:** Maintain B-IBI (Benthic Index of Biological Integrity) score above 30.

WHO IS IN CHARGE? RAINWATER LEGISLATION, REGULATION AND POLICY

Rainwater management in urban landscapes has traditionally been the responsibility of local governments and the developer's hydraulic and drainage engineers. Over the last 100 years they have developed the ability to move large volumes of rainwater very efficiently through the developed landscape and away from infrastructure. Nevertheless, as knowledge in the sciences of hydrology, hydraulics, landscape planning and urban fisheries biology becomes more sophisticated, rainwater management is becoming an increasingly shared responsibility, bringing other agencies (e.g., Fisheries and Oceans Canada, British Columbia Ministry of Environment), and scientific disciplines into the picture including land-use planners and fisheries biologists (Stephens *et al.* 2002). Still, statutory bodies, engineering departments and decision makers often have to be convinced of the need for a new way of doing business.

One issue, from a purely fisheries perspective that remains a major stumbling block to developing landscape-level changes to rainwater flows in urban areas in British Columbia, is that the fish-habitat legislation, policies and regulations have traditionally not dealt with activities outside of the active-stream channel or riparian areas. That is, cumulative and incremental effects outside of the active channel or riparian perimeters in the complete landscape have not generally been addressed at the statutory or regulatory level within the framework of the Canadian fisheries law which is predominantly federal under the Canadian Constitution (e.g., the Canada *Fisheries Act* and its No-Net-Loss (Net Gain) policies, the *Canadian Environmental Assessment Act*). This has somewhat changed in recent years with the inclusion of fisheries-enabling considerations within the legislation, policies and regulations available to provincial and local governments in respect to urban rainwater. As a result, Fisheries and Oceans Canada have now entered into dialogue with respect to municipal Liquid Waste Management Plans and are providing technical direction (Chilibeck *et al.* 1992).

In British Columbia, local governments or municipalities have their statutory basis to conduct business under the *Local Government Act.* Largely, it is the provincial legislation, the *Local Government Act*, that sets the framework, and the local governments who implement the *Act*, regulate development, and are primarily responsible in regards to how urban rainwater is managed (Table 4.2). Nevertheless, the local governments in British Columbia, often at the direction and urging of the provincial and federal governments, have now moved into alternative ways of dealing with rainwater management (Table 4.3).

As noted earlier, local governments have the legislative responsibility for drainage within their jurisdictional boundaries and this includes Division 6 of the *Act* (Sections 540–548) which gives the direct power to manage rainwater. Through the *Local Government Act* the local governments can also be held liable for downstream impacts that result from changes to upstream drainage patterns, flow rates and volumes as a result of development. In some respects this has made local government somewhat nervous to implement new and untried technologies. On the positive side, however, the *Local Government Act* permits the local governments to be proactive when implementing rainwater management solutions that are more comprehensive than past practices (Table 4.2). An important component of this is Liquid Waste Management Plans (LWMP's) which require the local government to also manage rainwater in developed areas.

LWMPs are created by local governments under a public process in cooperation with the province of British Columbia. Guidelines for developing a LWMP were first published in 1992 by the government of British Columbia and provide direction in order for a local government to initiate waste management control within their areas of jurisdiction. Once approval of the LMWP has been given to the local government by the provincial agency, the municipality can proceed with implementation measures contained in the plan. Within an LWMP is the management of rainwater, or urban storm water runoff. In addition, management options, including source control and treatments, are expected to be part of the Plan. As an example of the implementation of LWMP's, the local governments in Metro Vancouver region are now legally obligated to fully implement integrated rainwater management policies, plans and practices by 2012.

Other legislative tools that local governments in British Columbia can use to deal with rainwater include Regional Growth Strategies and Official Community Plans (OCP's) (Table 4.2). Section 849 (2) of the *Local Government Act* provides goal statements for protecting environmentally sensitive areas, reducing and preventing air, land and water pollution, protecting the quality and quantity of groundwater and surface water. Thus, a local government can use this part of the *Act* to ensure that developers undertake appropriate actions to mitigate rainwater impacts to aquatic ecosystems. The Zoning Section 903 of the *Local Government Act* also enables the prohibition of, or siting of, regulated land-uses that, for instance, can generate non-point source pollution in surface runoff; thus, Section 903 can prevent activities within the landscape of a community that might degrade a watercourse.

Another potentially important aspect of the *Local Government Act* includes Section 907 which enables the administration to set maximum percentages of areas that can be covered by impermeable material and to establish requirements for ongoing drainage management. Following from this, the District of Metchosin on southern Vancouver Island implemented the Protection and Management of Rain Water Bylaw 467 that prohibits new development to have greater than 10% Effective Impervious Area

(i.e., Percent Impervious Cover). Indeed, Metchosin has also developed some enlightened policy statements regarding the importance of rainwater management which includes the following: *"…Bylaw 467 specifically rejects the traditions of 'urban' storm water management and engineering, including the principles that advocate shedding runoff overland from a site as quickly as possible, or concentrating and discharging runoff via connected pipes, drains, ditches and roads. Conversely, the Bylaw requires the use of the natural hydrologic pathways at a site to maintain rain water, as this method is compatible with the 'rural' character of Metchosin.*"

The local government can also designate the Development Permit Areas within an Official Community Plan (see Section 919.1) that cannot be altered, subdivided, or built on without a development permit. This permit can contain conditions for the protection of the environment, of which drainage management can be a part.

Finally, when developing a subdivision, the Servicing Requirements Section 938 enables a local government to "require that, within a subdivision…a drainage collection system or a drainage disposal system be provided, located and constructed in accordance with the standards established in the bylaw". Again, these are all tools that a local government can adopt and use, under legislation, to protect aquatic ecosystems (Table 4.4).

The other important consideration in respect to the resistance to change on this issue is that the agencies (local governments) responsible for the management of rainwater have tended to be litigation-adverse and have generally opted for highly engineered, biologically unfriendly methodologies. This may reflect a fear by local governments that untried and untested technologies could result in a disaster to life or property and the authorizing local government might then be blamed or liable for damages (Stephens *et al.* 2002, Marsh and Fraser 2005). Such perspectives have started to change, however, albeit slowly and cautiously.

TECHNICAL SOLUTIONS TO RAINWATER MANAGEMENT AND PROTECTION OF FISH AND ECOSYSTEMS

In recent years there have been significant changes in respect to the development and implementation of various technologies and planning approaches. For British Columbia, this often involves creating "softer" developments that still meet engineering requirements for public safety. While the traditional approach to landscape-level water management in urban landscapes has been to remove run-off from developed areas as quickly as possible, the province has begun to look at alternative ways to deal with this issue.

For example, there are a number of new initiatives that are attempting to turn back the clock (retrofitting old subdivisions). Also, local governments are starting to instill new ways of planning and engineering pertaining to rainwater management in new developments (Stephens *et al.* 2002, Ham *et al.* 2007, Stephens and Dumont 2008). For a start, engineering departments and land-development designers are moving towards computer modelling to determine better approaches to managing rainwater. This includes a new multi-parameter internet computer Water Balance Model which allows communities and developers the opportunity to determine what is needed from a planning, design and technical perspective to meet local government policy and regulatory objectives. This model can be accessed at: http://bc.waterbalance.ca/.

Other initiatives include economic analyses for the undertaking of alternative models of community development for rainwater management in urban British Columbia areas (Marsh and Fraser 2005). A document produced by University of British Columbia's Centre for Landscape Research entitled "*An Economic Rationale for Integrated Stormwater Management*" suggests that money can actually be saved in the development costs, and a more protected environment obtained by using alternative, flow-friendly approaches towards development.

A number of such Low Impact Development practices include: (suggestions and text below excerpted from Marsh and Fraser (2005)).

Reducing Road Widths: Paved roadways are often larger than they need to be. Reducing road width not only reduces impervious area, but also reduces motor vehicle speeds, improves pedestrian and bicycle safety, reduces infrastructure costs and allows more of the paved surface to be shaded by overarching tree canopy.

Reducing Building Footprints: Building footprints can be reduced (thus reducing rooftop area) without compromising floor area by relaxing building height limitations. Taller, more slender building forms provide greater flexibility to develop building layouts that preserve naturally vegetated areas and provide space for infiltration facilities.

Reducing Parking Standards: Reducing parking standards reduces the amount of space devoted to parking (driveways, parking lots and parkades). In compact and/or high density communities where dwelling units are within walking distance to transit and services, parking standards may be reduced to 1.3 or even as low as 1 space per dwelling unit. There are other factors that could reduce the need for parking, including a high proportion of low income housing units, the implementation of transportation demand management strategies, and high parking costs. Reducing parking standards not only reduces impervious area, but also reduces parking-related development cost, and facilitates the provision of affordable housing.

Limiting the Amount of Surface Parking: The more parking provided within the building envelope (e.g. underneath other land uses), the less additional lot area will be needed for parking. For parking outside the building envelope, surface parking typically creates far more impervious coverage than parkades. There is also greater opportunity to mitigate the runoff from parkades using green roofs or rainwater re-use. Generally, underground parking only occurs where land economics favour residential or commercial development over surface parking.

Building Compact Communities: Building compact communities enables more natural area to be preserved, thus reducing impervious coverage at the watershed scale. In a compact community pattern, there can be up to 75% less roadway pavement per dwelling unit. The need for parking is also reduced in compact communities, as discussed previously.

Preserving Significant Natural Features: Preserving natural vegetation and soils in their undisturbed state is key to minimizing changes in the natural water balance. There are certain natural features that are especially important for maintaining the health of aquatic ecosystems, including riparian forests, wetlands, natural infiltration areas and floodplains. These features can also have significant benefits in terms of reducing flood risk and should be identified at the site design level, and preserved through creative site design practices that integrate significant natural features with community open spaces.

Another option used to address rainwater detention in urban areas includes green roofing (Fig. 4.3) which has the objective of increasing the amount of living biomass on infrastructure and which will slow the rate of movement of rainwater across the landscape. The British Columbia Institute of Technology School of Construction and the Environment is currently involved in research associated with such technology and is becoming a leader in this regard.

Finally, as part of their study on the economic benefits of better rainwater management, Marsh and Fraser (2005) assessed integrating these new approaches for a number of communities throughout British Columbia that were subject to development (e.g., East Clayton in Surrey). They found that there were positive benefits, both environmentally and economically, to managing urban rainwater through means that protected the integrity of the hydrograph. Marsh and Fraser (2005) also discussed political and legal issues surrounding the efforts to get local governments and their planning and engineering departments to embrace these different approaches to urban development, and suggest that the trepidation to embrace new ways of doing business can be resolved by taking an incremental approach to moving forward.

FIGURE 4.1. Urban rainwater management designed to address impacts associated with landscape development.
From: Stephens et al. (2002).

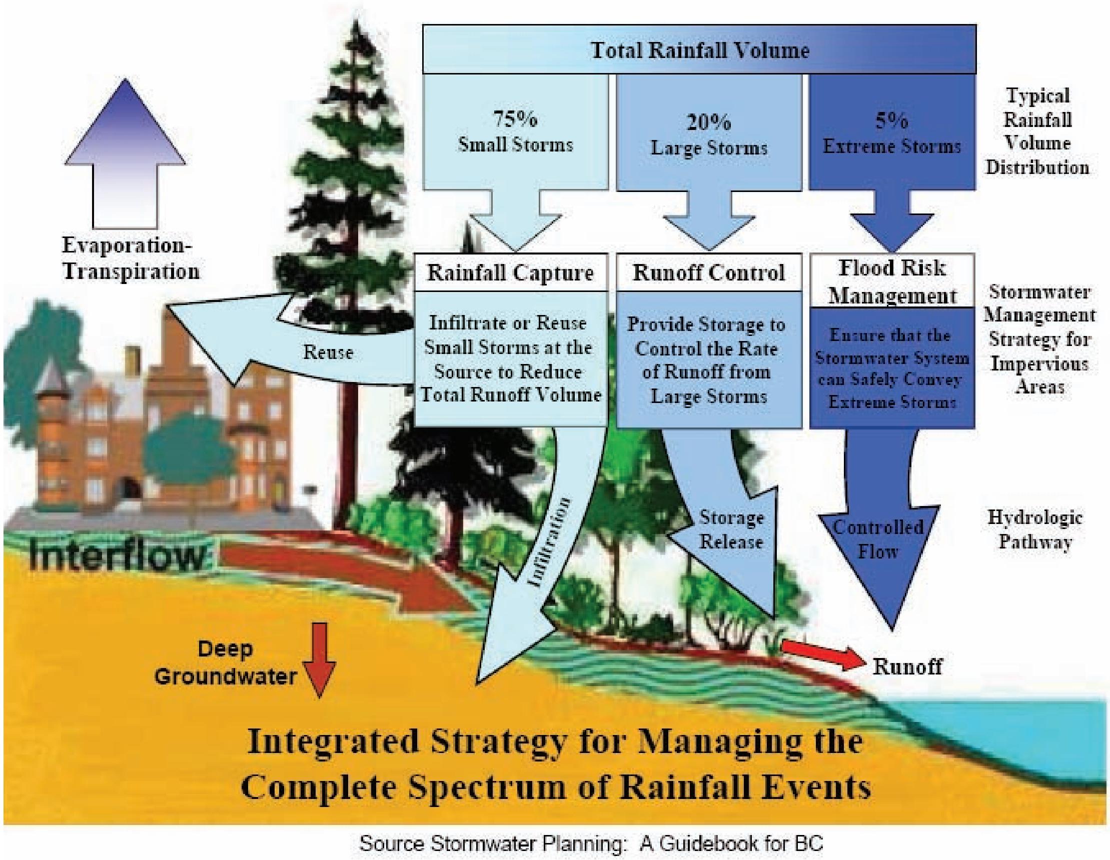


FIGURE 4.2. Percent of total annual rainfall in frequent, infrequent large and rare extreme storms in the Georgia Basin.
From: Stephens et al. (2002).

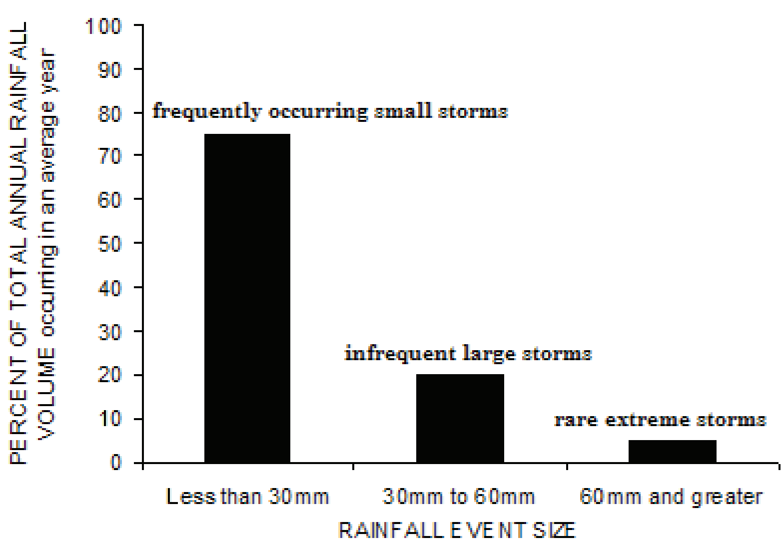


FIGURE 4.3. Green roof technology used to resolve some of the rainwater drainage issues in urban environments.
Figure from: Green Roofs (undated)

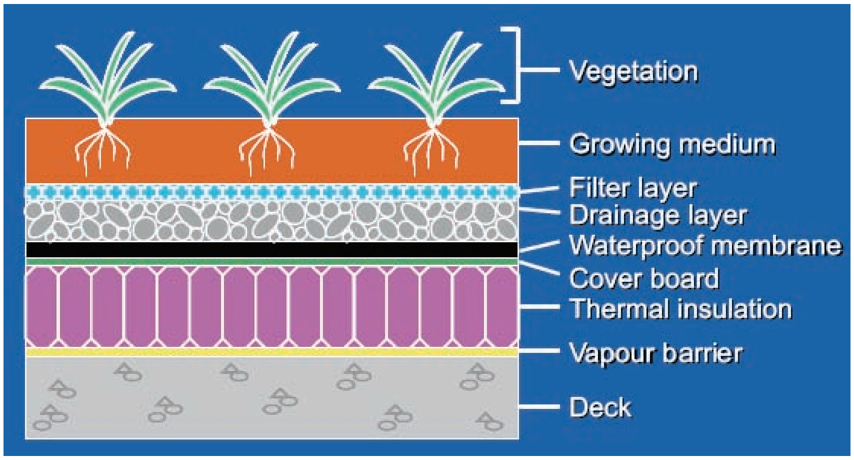


TABLE 4.1. Percent Impervious Cover (PIC) of four watersheds in the lower Fraser Valley.
Langer et al. (2000) from Rood and Hamilton (1994).

Watershed	City	Area of Watershed Percent Impervious Cover	
Byrne	Burnaby	9 sq. km	27%
Mahood	Surrey	38 sq. k	23%
Schoolhouse	Coquitlam	7 sq. km	33%
Willband	Abbotsford	13.5 sq. km	26%

TABLE 4.2. Legislation and planning opportunities for dealing with landscape-level rainwater management in urban developments in British Columbia.
From: Stephens et al. (2002)

Planning Scale	Description of Initiative	Opportunity for Implementing Stormwater Management
Regional	Regional Growth Strategy	Provide local government with enabling tools
Regional	Stormwater Component of Liquid Waste Management Plans (LWMPs)	Prioritize limited resources on key environmental stewardship issues
Regional	Official Community Plan (OCP)	Define over-arching community goals and objectives
Watershed	Watershed-Based Land Use Planning Process	Develop a stewardship-based “watershed vision” that reflects the OCP
Watershed	Integrated Stormwater Management Plan	Protect property, aquatic habitat and water quality
Neighbourhood	Neighbourhood Community Plan (NCP), or Local Area Plan (LAP)	Establish performance targets for subdivisions and site design
Site	Subdivision and Single Lot Development Plans	Implement performance targets for site design

TABLE 4.3. Paradigm changes in attitude and process needed towards rainwater management in urban environments in order to meet aquatic protection and other ecosystem objectives.
From: Marsh and Fraser (2005).

Integrated Stormwater Management Planning

From TRADITIONAL to		INTEGRATED:
Drainage Systems	→	Ecosystems
Reactive (Solve Problems)	→	Proactive (Prevent Problems)
Engineer-Driven	→	Interdisciplinary Team-Driven
Protect Property	→	Protect Property *and* Habitat
Pipe and Convey	→	Mimic Natural Processes
Unilateral Decisions	→	Consensus-Based Decisions
Local Government Ownership	→	Partnerships with Others
Extreme Storm Focus	→	Rainwater Integrated with Land Use
PEAK FLOW THINKING	→	**VOLUME-BASED THINKING**

Source Stormwater Planning: A Guidebook for BC

TABLE 4.4. Ten principles that define the relationship between stormwater management and land use for protecting aquatic ecosystems in urban environments.
From: Marsh and Fraser (2005).

1. **Ten percent impervious area is a critical threshold**—stormwater impacts increase dramatically when land use creates over 10% effective impervious area in a watershed or drainage catchment.

2. **Residential development has the greatest overall impact**—residential development often has the greatest cumulative impact on stormwater management because it covers the greatest land area.

3. **Greater population = greater impact**—the higher the population accommodated in a watershed or sub-watershed, the higher the likely water quantity and water quality impacts.

4. **Same population, greater density = less impact**—the greater the density of residential land use in a watershed for a given population, and the more remaining vegetated green space, the lower the likely stormwater impact.

5. **Rule of thumb is to maintain catchment effective impervious area (EIA) below 10%**—generally, stormwater best management practices (BMPs) to manage flows should be triggered for all developments that involve more than 10% total impervious area. The objective of the BMPs would be to reduce the effective impervious area, and to meet designated targets for rainfall capture and runoff control.

6. **BMPs are needed for residential densities exceed 1 unit per hectare**—most residential developments of densities greater than 1 unit per hectare will exceed the 10% impervious area trigger.

7. **Industrial/commercial = greatest impervious area**—medium density commercial and industrial developments have high impervious area that needs to be mitigated. However, these developments often represent a small portion of the watershed when compared to other land uses (e.g. residential).

8. **Large structures in forestry/agricultural areas may require mitigating BMPs**—very low density land uses such as agriculture or forestry will often have impervious area less than 10%, but can still have a major impact on watershed hydrology due to the consequences of clearing and ditching. In addition, local sites such as greenhouses or temporary industrial operations may trigger the need for specific stormwater management measures. At the same time, drainage from upland urban areas may have flooding impacts on agricultural lowland uses if not mitigated.

9. **The impacts of impervious area are cumulative**—an existing development that is not creating a problem may contribute to a future problem as adjacent development infills. For this reason, all development with >10% EIA should implement stormwater management, except in isolated cases where there is no likelihood of the total impervious area in a drainage catchment exceeding 10% (e.g., in completely rural areas).

10. **Compact communities are most compatible with stormwater objectives**—the most favourable land use pattern for minimum stormwater impacts is compact, dense, pedestrian-oriented development with effective stormwater BMPs, and with the majority of the watershed in vegetation and absorbent soils.

**EIA—Effective Impermeable Area. The area of impermeable surface whose runoff is directly connected to a stream or receiving water body, usually via a storm drain system. EIA is the total impermeable area (TIA) minus those areas which are not connected to a stream or water body.*

5.0 INFLUENCE OF LANDSCAPE-LEVEL ACTIVITIES OF FORESTRY ON STREAMS IN BRITISH COLUMBIA

OVERVIEW

One of the important agents of ecological change throughout the world, and often affecting salmon and steelhead stocks in British Columbia and the Pacific Northwest, has been the forest industry. This is an activity that extensively affects the environment at the landscape level. The history of forest harvest in British Columbia goes back into the 19th century, as Europeans began to settle this province, and prior to that, at a much lower level, by First Nations in regards to their cultural and sustenance requirements.

Forestry has been one of British Columbia's most important industries, generating a current provincial income of about $6.6 billion and employing 120,000 people directly and 60,000 individuals indirectly (Ministry of Forests and Range 2006a). Wood-based products account for about half of British Columbia's total exports as well as about half of Canada's softwood products (Ministry of Forests and Range 2006a). Forestry comprises about 7% of British Columbia's employment and 15% of all money-making activity when indirect and induced economic activities are included (Ministry of Forests and Range 2006a).

Forests cover 59 million hectares (Fig. 2.4), or about two-thirds of the province's total of 95 million hectares. About 83% of the forests in British Columbia are predominantly coniferous, 6% are mixed, 6% are broadleaved, and the remaining 5% are regenerating and have not, as yet, been declared by the British Columbia Ministry of Forests and Range in regards to their species composition; the dominant and widespread species of trees in these forests include lodgepole pine (*Pinus contorta*), the spruces (*Picea* spp.) and the true firs (*Abies* spp.) (Ministry of Forests and Range 2006a).

The forests of British contribute to the diversity of ecosystems, including the rich salmon and steelhead populations found in the province. Among the province's 3,201 plant and terrestrial vertebrate species, 1,324 (41%) are forest-associated, including 721 vascular plants, 303 birds, 189 mammals, 81 freshwater fish, 20 amphibians and 10 reptiles (Ministry of Forests and Range 2006a). This strong association with the forest, by British Columbia's flora and fauna, demonstrates how important wood ecosystems are to the fish, wildlife, avian and plant communities. Scientists have designated fourteen different biogeoclimatic zones for the province. Forests occur in all of these zones, and are dominating in most of them (Fig. 5.1; Medinger and Pojar 1991).

A LANDSCAPE AFFECTED THROUGH FOREST HARVEST PRACTICES

Forest harvest has disturbed the surface of more of British Columbia's landscape than any other human activity. Nevertheless, over time British Columbia's forest lands have also been lost to other uses. About 2% of the province has been converted to agriculture, reservoirs, urban areas and other land uses and this constitutes about 3% of the former forests (Ministry of Forests and Range 2006a).

As a result of forest harvest, the landscape of British Columbia is continuing to be changed. Undeveloped watersheds (i.e., forests without roads) covered 44% of British Columbia in the 1980s, but this has now dropped to an estimated 26% in 2005. Even more troubling—from an environmental view—is that this figure is expected to reach 18% in the foreseeable long term (Ministry of Forests and Range 2006a). Furthermore, it should be recognized that in recent years much of the disruption of the forested landscape in the north-eastern part of the province is due to oil and gas exploration (e.g., roads, seismic lines which are not necessarily related to forestry).

The geographic distributions for both the working forests and the salmon and steelhead populations overlap extensively. In particular, salmon and steelhead stocks along the coastal regions typically depend upon the attributes associated with a properly functioning forest. In addition, many exceptionally important interior stocks of anadromous fish, such as the Horsefly and Adams runs of sockeye in the Fraser River watershed, and the runs of salmon and steelhead in the Skeena River drainage, are also dependent on intact forest ecosystems at the landscape level.

At the broader level, many of the 14 forest-based biogeoclimatic zones are reasonably intact within British Columbia. Only the three smallest and warmest biogeoclimatic zones have had more than 10% of their former forests converted to other attributes (Ministry of Forests and Range 2006a). As an example of the greatest change, the coastal Douglas-fir zone has been the most perturbed and has had 46% of its former forests converted to other characteristics. Despite extensive efforts in the 1990's to protect a sufficient land base for each of these ecosystems of British Columbia, only five of the 14 of these biogeoclimatic zones have had more than 10% of their landscape-areas protected (Fig. 5.2). These landscape-levels of protection fail to meet the interpreted objectives that arose from the 1987 Brundtland Report, *Our Common Future*, that at least 12% of each representative ecosystem should be protected. One must also recognize, in addition, that even though at the macro-perspective a biogeoclimatic zone may be relatively protected to the 12% level, particularly sensitive ecosystem sub-units within that zone (e.g., riparian areas) may not be.

Subtle but wide spread man-made changes to forest landscapes in British Columbia have had, or will shortly have, profound impacts to salmon and steelhead. One of the major influences on the present ecological configuration has involved the disruption of normal burn cycles. From 1950 to 2000 active fire suppression significantly limited the amount of forested area in British Columbia disturbed by conflagration while, in turn, the amount of area that was harvested for timber dramatically increased (Fig. 5.3). Until recently, the combined area of disturbed landscape through fire and harvest equalled an average of about 170,000 ha per year (with some wide swings in the actual year-to-year amount depending on the fire season); this number is now forecast to increase to 190,000 ha annually partly due to mountain pine beetle infestations (Ministry of Forests and Range 2006a).

Wildfire suppression, wood harvest and climate change are thought to reduce ecosystem stability and resilience (including those effects on steelhead and salmon habitat), and disrupt economic activity (Ministry of Forests and Range 2006a). The mountain pine beetle epidemic is an example of where the synergy of all three of these human activities are likely to have facilitated the outbreak of this disease, resulting in large-scale landscape effects with major economic, social and environmental (including fish and fisheries) implications.

This report has discussed the importance of wood and intact vegetative cover, including fish communities, to ecosystems within landscapes; the amount of live, dead, and removed wood on or from a landscape can have major implications to the hydrology of salmon and steelhead spawning and rearing streams. An increase in the amount of forest cover due to reduction in logging or increased fire suppression, or loss of trees due to fire, disease or increased forest harvest, will affect the amount of water in salmon and steelhead streams via changes to interception, transpiration, albedo, etc. (Fig. 2.15). In recent decades climate change has been having wide-scale affects in regards to the amount of forest that will remain within British Columbia over time, and this issue is discussed in depth below.

FOREST HARVEST AND MANAGEMENT OF TREES ON FORESTED LANDSCAPES

The change in the rate and location of tree harvest in British Columbia since 1900 has been substantial, with the logging industry generally moving farther northwards along the coast as well as into the interior. The largest volume of wood harvested in British Columbia is now predominantly from the interior of the province (Fig. 5.4). Over the past century, the harvest of wood in British Columbia increased from just under 10 million cubic meters per annum in the early 1900's, peaking to just under 90 million meters in the 1980's where it has now roughly stabilized (Fig. 5.3). In the 1950's the provincial government first introduced the concept of Annual Allowable Cut (AAC) and embodied into legislation a rationalization of when and where to harvest wood, although the rate of cut continued to increase until the 1980's.

Most of the province's forests are publicly owned, Crown land (Fig. 5.5). The Province of British Columbia owns 93% of this landscape while the Government of Canada possesses 1%. Private owners hold 5% of the forests. In 2000, 0.2% of British Columbia's forests were granted to First Nations, mostly as Nisga'a treaty settlement lands.

These different ownership tenures of the working forests in British Columbia have implications for landscape-level impacts to fish and aquatic ecosystems. They are all managed and/or harvested, to a certain degree, somewhat differently. The fact that the provincial government owns most of the forest lands in British Columbia means that it has the biggest stake in how forest-based landscape-level activities will potentially affect salmon and steelhead and visa versa. This was clearly demonstrated when the provincial legislation, the *Forest Practices Code Act of British Columbia*, was implemented in the 1990's and, in all practicality resulted in the federal government relying on the provincial government to protect fish habitat. This is despite the fact that constitutionally the federal *Fisheries Act* has precedence over the provincial legislation in regards to fish and fish habitat.

RULES GOVERNING HARVEST

Not all of the trees in British Columbia are available for timber harvest. About 10% of the province's forests are protected landscapes which means they are in parks or in other areas where wood cutting is not allowed. However, most of British Columbia's crown forest land which is not within a protected-area status can be logged, is in some form of tenure (approximately 87%), and is managed under the British Columbia *Forests and Range Protection Act* (*FRPA*).

For areas available for forest harvesting, 95% of the Annual Allowable Cut (AAC) comes from just three types of tenure including Tree Farm Licenses (TFLs), Forest Licenses, and Timber Sale Licenses. The crown land in British Columbia, which is subject to wood harvest, is divided into Timber Supply Areas (TSAs) and this is laid out in the *Forest Act*. The total volume of timber that can be harvested each year is the AAC and this is determined by the Ministry of Forest and Range for each TSA. Within each TSA this ACC volume is divided up amongst the licensees. These types of tenures are considered to be 'volume-based' for the amount of wood that can be harvested. However, within TSAs individual areas of land can be granted to licensees and these areas are referred to as Tree Farm Licenses (TFLs). In contrast to the rest of the TSA, TFL tenures are referred to as 'area-based' and for each of these the AAC is determined separately. The TFLs holders have the most accountability for actions under their licences, and each form of tenure has varying rights and responsibilities.

The legislation, policy, regulation and management of the harvest of wood in British Columbia is covered under the aegis of a number of agencies, laws, agreements and initiatives. In British Columbia, the primary agency responsible for the management of crown forests is the provincial Ministry of Forests and Range, although the British Columbia Ministry of Environment and Fisheries and Oceans Canada have some influence and ancillary statutory responsibilities.

First and foremost in respect to legislation is the provincial *Forest and Range Practices Act* (*FRPA*) of British Columbia. Its regulations took effect in 2004 and moved into transition throughout 2005 from the *Forest Practices Code Act of British Columbia* and its primary regulatory vehicle, the Forest Practices Code. It should be noted that forest harvest activities in private forests are regulated under the *Private Managed Forest Land Act,* and this legislation is markedly different from the *FRPA*.

Under *FRPA* the provincial government shifted to a results-based approach from a prescriptive, rule-based approach that was the predominant way of doing business under the *Forest Practices Code Act of British Columbia*. Under the code, the government outlined objectives and prescribed ways to meet these objectives. The intent of the new *Act* was to focus less on government-set prescriptions and more on whether or not a company is meeting the specific objectives such as to conserve fish habitat and water quality. Under the new way of doing business, the government no longer receives site plans for approval, and minor amendments can be unilaterally made to the plan by the proponent. Rather than having agency (Ministry of Forests and Range, Ministry of Environment) staff review and discuss and agree to the details of how wood should be taken out of the forest, there is currently heavy reliance on the companies to deliver appropriate results.

This new-era approach towards forest harvest practices has been severely criticised by some (WCEL 2004, 2007) for giving forest companies an inordinate amount of leeway in regards to their activities and allowing them to largely police their own actions. In commenting on this shift from the older *Forest Practices Code Act of British Columbia* to the new *FRPA*, West Coast Environmental Law has stated: "*Environmental protection requires strong laws, an effective way to ensure those laws are being followed, and strong sanctions in the event that they are not. Numerous commentators, academics, and law enforcement agency staff have emphasized the importance of enforcement of laws, clear standards and transparency of information to achieve environmental objectives…It appears that the* [Provincial] *government has moved towards a potentially difficult to enforce "results-based" regulation system, without implementing an adequate check and balance system. While further research needs to be done, it seems that when easier-to-enforce, more prescriptive laws were dismantled, and replaced with laws which require more data and effort to enforce effectively, the government failed to ensure that a fully developed and adequately funded monitoring, compliance and enforcement program was in place.*" (WCEL 2007). As part of this reliance on self-regulation, government-compliance inspections of forest practices have dropped dramatically since the implementation of FRPA, from a decade ago (Fig. 5.6).

In an attempt to ensure that the forest industry is meeting environmental and other aims set out by legislation, regulation and policy, the Forest Practices Board, a quasi-independent group of professionals provides oversight to various aspects of forest industry activities. The Forest Practices Board acts as a watchdog with the objective of ensuring that the forest companies meet environmental legislation and regulations, and public, industry and government concerns are discussed and addressed. Much of what the Forest Practices Board reviews is related to environmental objectives, in which salmon and steelhead protection figure significantly. It is not clear, however, that the board is able to meet the objectives of protecting the forests and their ecosystems, particularly in the face of the declining compliance inspections.

FIGURE 5.1. Distribution of forests in British Columbia and in respect to its biogeoclimatic zones.
Figure: Ministry of Forests and Range (2008a).

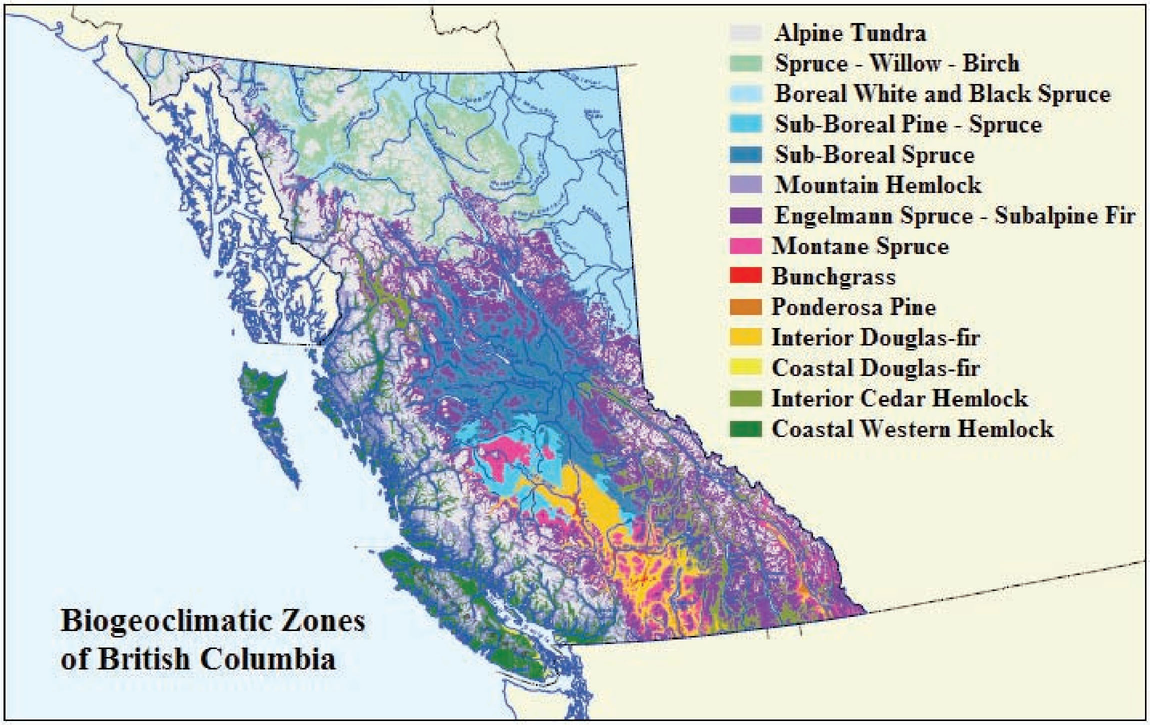


FIGURE 5.2. Percent British Columbia forested area protected for the various biogeoclimatic zones in this province.
Figure adapted from: Ministry of Forests and Range (2006a).

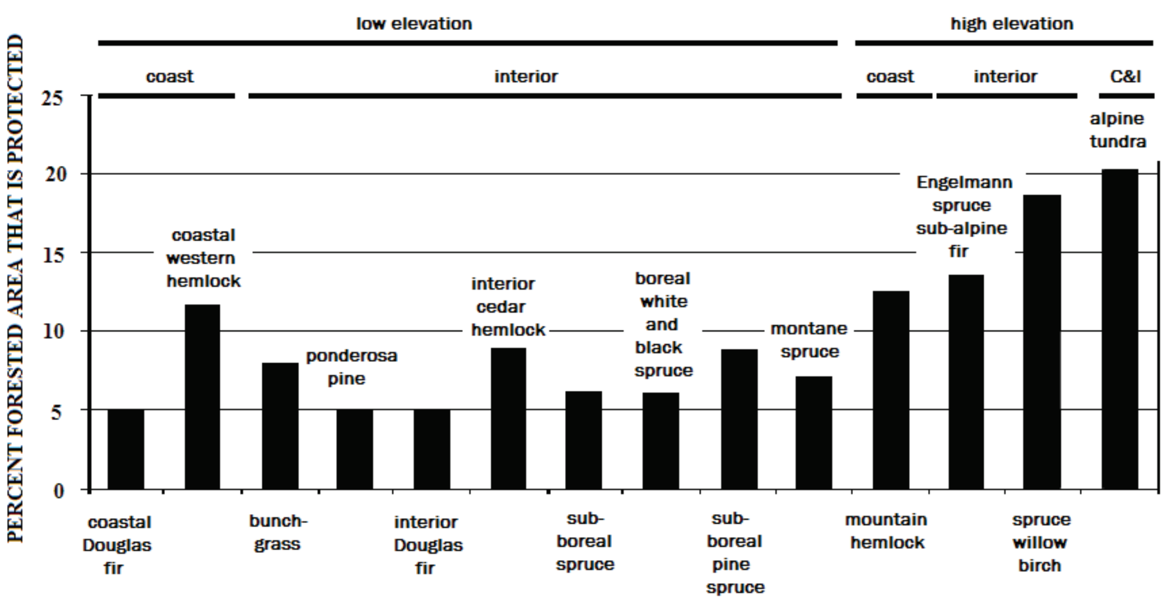


FIGURE 5.3. Cut of wood in British Columbia forests in the 20th century.
Figure adapted from: Ministry of Forests and Range (2006a).

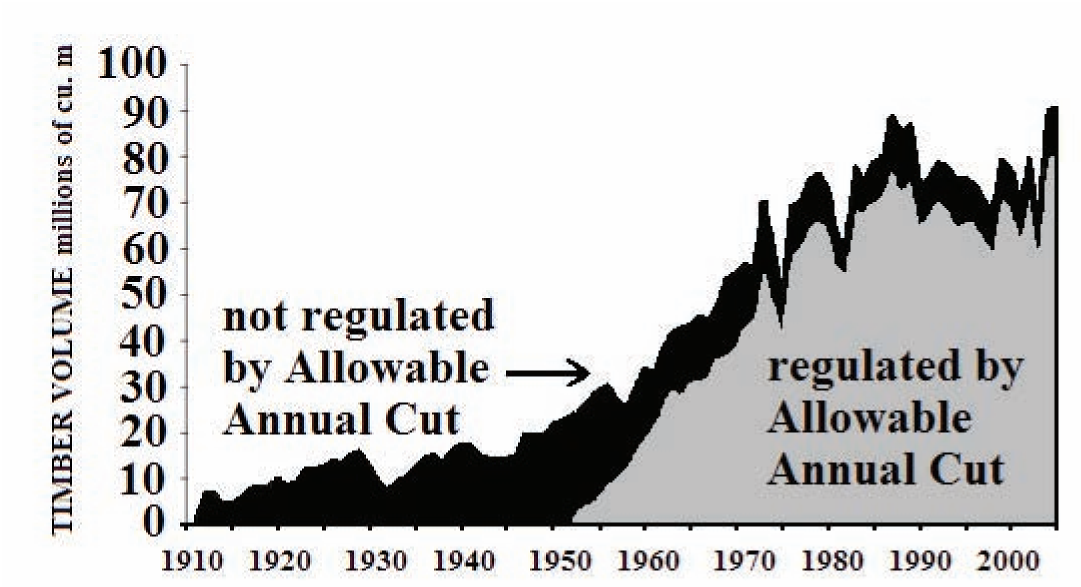


FIGURE 5.4. Comparison of British Columbia's wood supply, coastal versus interior.
Figure: Ministry of Forests and Range (2006a).

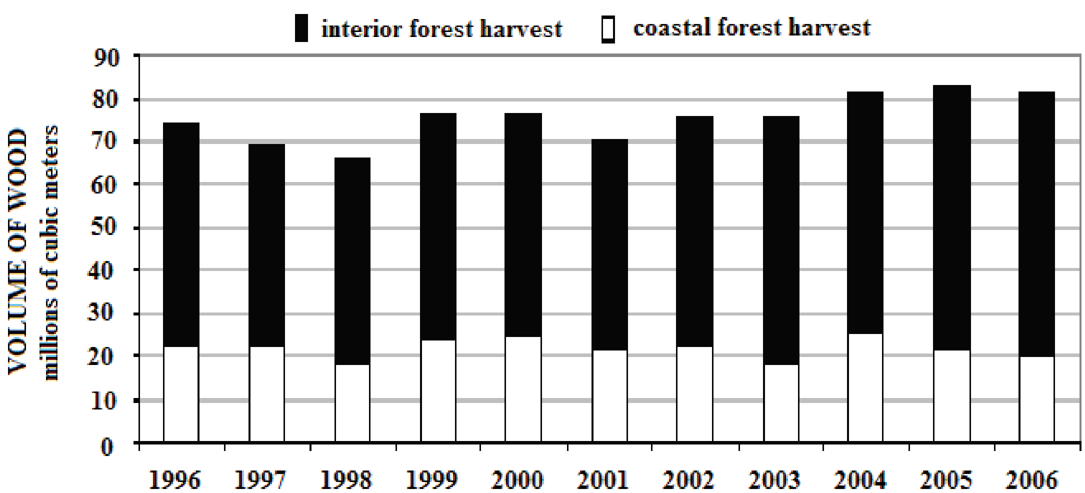


FIGURE 5.5. Ownership of forest-harvest lands in British Columbia.
Figure adapted from: Ministry of Forests and Range (2006a).

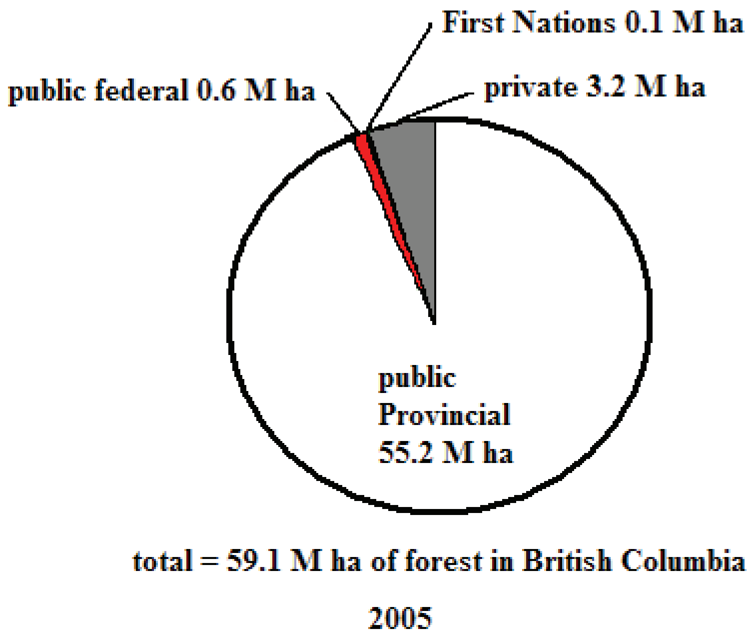
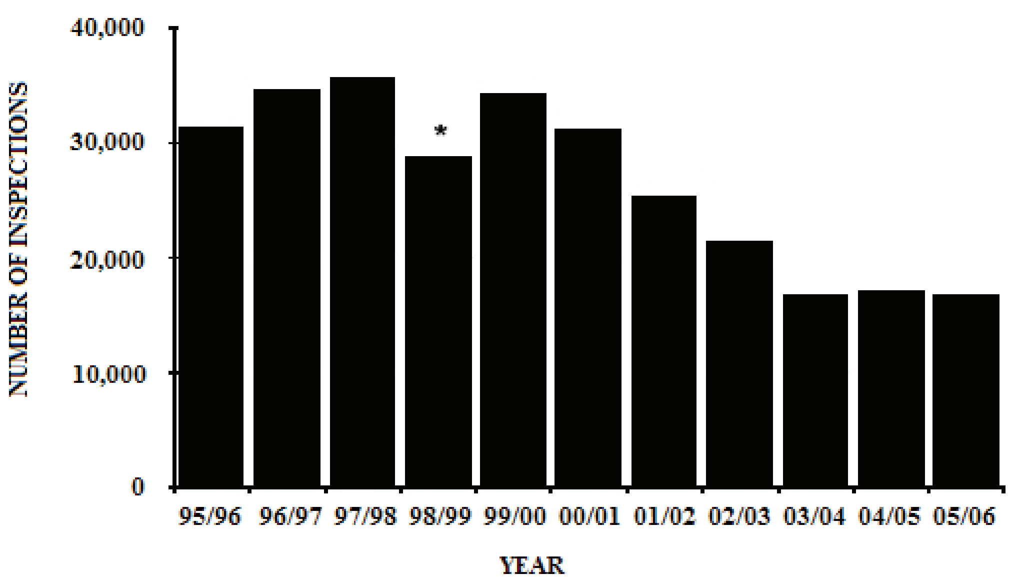


FIGURE 5.6. Ministry of Forests and Range compliance inspections.
Figure adapted from Ministry of Forests and Range (2006a).



TWO LANDSCAPE-LEVEL CONSIDERATIONS RELATING TO FOREST MANAGEMENT IN BRITISH COLUMBIA

MANAGEMENT OF LANDSCAPE-LEVEL LANDSLIDES DUE TO FOREST HARVEST

The episodic landscape-level movement of sediments and vegetation into streams via natural landslides enables the regular, although usually infrequent, recruitment of gravel, as well as other classes of sediment, and large woody debris, into watercourses for the continuous revitalization of instream and riparian habitats (Fig. 1.14). While this phenomenon often causes short term negative impacts to fish and other aquatic features (e.g., entrainment of fine sediments into streams which can reduce survival of incubating embryos in redds, smother insects, destroy algae, block fish migration), it is often vital for the long-term maintenance of salmon and steelhead habitats. However, activities surrounding forest harvest can often also accelerate the rate of landslides to levels that become highly detrimental to salmonid ecosystems, especially in British Columbia where logging of steep-sided hill slopes and heavy rainfall often occur together (Fig. 2.3). Geographically, these landscape-level landslide events are most commonly found in areas of steeply sloping terrain and high precipitation, such as along the coast of British Columbia including much of Vancouver Island (Jordan and Orban 2002). In the interior of the province, landslides are much less frequent (Jordan 2002).

Throughout the history of logging in British Columbia, as forest harvest became more extensive (Fig. 5.3) and moved into increasingly more difficult terrains, logging-related landslides resulted in greater impacts to salmon and steelhead streams. The causes included inappropriate logging practices and associated inadequate road building (Jordan and Orban 2002, Fannin *et al.* 2007a). Indeed, the building of poor roads has been particularly responsible for precipitating large-scale landscape movements (Fig. 5.7) and, for example, is the single most important anthropogenic cause of landslides on Vancouver Island (Guthrie 2002).

The act of road building on mountainous terrain can over-load and over-steepen slopes; roads, and/or their associated drainage channels can also redirect and unnaturally concentrate water flows that exacerbate land erosion (Schwab 2002, Guthrie 2005). Furthermore, logging roads often fail many years or decades after they have been constructed and the logging companies have left the area (Fig. 5.8). In addition, the removal of ground-stabilizing vegetation through logging has also been implicated in large-scale landslides and ground movement (Guthrie 2002, 2007).

As forestry-terrain science increased in scope and depth throughout the latter part of the 20th century, the link between tree-harvest practices and adverse impacts from landslides on water supplies, fish and fish habitat, landscape aesthetics, soil productivity, and private property became more obvious (Hartman 1982, Schwab 1988, Tripp 1994, Fannin *et al.* 2007a). One of the key studies assessing landscape-level physical impacts to salmon and steelhead habitat, and relating to logging, was a 35 year assessment, starting in the 1970s, at Carnation Creek on the west coast of Vancouver Island (Fish Forestry Interaction Program undated). While significant impacts to riparian clearcutting along the banks of Carnation Creek were observed, the studies found that the longer-term, landscape-level processes between the steep hillslopes and the stream channel network overwhelmed the effects of these impacts to the riparian areas (Fish Forestry Interaction Program undated). For example, significant changes to the stream channel came about as a result of increased frequencies of landslides and debris torrents after logging. The studies inventoried over 80 small landslides and three major debris torrents in the logged portions of the watershed (Fish Forestry Interaction Program undated). Another revealing fact was that the overall volume of landslide material at Carnation Creek increased twelve-fold after logging. These slides still cause major channel alterations and fish habitat loss more than two decades after their initiation (Fish Forestry Interaction Program undated).

Another British Columbia effort to assess landscape level effects relating to logging in was the Queen Charlotte Islands Fish-Forestry Interaction Program which was started in the early 1980's. This program was an interdisciplinary study of timber harvesting operations and mass wasting, and their effects on fish habitat (Fish Forestry Interaction Program undated). The program began after conflicts between forestry and fisheries resource interests escalated in the late 1970s following a series of winter rainstorms in 1978 that triggered hundreds of landslides throughout the Queen Charlotte Islands' forest land base (Fish Forestry Interaction Program undated).

Some of the key landscape-level findings impacts to salmon and steelhead resulting from logging included (quoted from: Fish Forestry Interaction Program undated):

> *Logging activities accelerated the frequency and yield of mass wasting on steep slopes. Mass wasting events occurring in clear-cut and road cut areas resulted in a greater volume of material entering streams, compared to those that occur in forested terrain. (Rood 1984).*
>
> *Debris torrents delivering organic material to streams reduced the quality and quantity of juvenile salmonid rearing habitat in first- and second-order streams, especially those below 7% gradient. In torrented streams, pool depth and area decreased, as did the amount of cover provided by undercut banks and large organic debris (Tripp and Poulin 1986a).*
>
> *The size distribution and orientation of large organic debris were altered in older logged and torrented streams, resulting in decreased fish habitat value. No significant morphological differences were observed in unlogged watersheds compared to those logged by modern methods and not torrented (Hogan 1986).*
>
> *Landslides delivered sediment and debris to streams in an episodic manner but logging on steep slopes was found to accelerate their occurrence. This increased the number of in-stream debris jams and influenced the frequency and magnitude of sediment wedges in receiving streams. Debris jams had specific effects on channel morphology and negative impacts on fish habitat. Stream morphology and fish habitat were drastically transformed during the first 10 years subsequent to landslides, but most began to resemble undisturbed conditions after ~ 30–35 years (Hogan 1989, Hogan and Schwab 1991, Hogan et al. 1998).*
>
> *Logging and mass wasting events increased fine sediment levels in streams. This decreased the quality of salmonid spawning gravel, resulting in a decline in egg-to-fry survival rates. Streams affected by logging and mass wasting exhibited an increase in gravel scour, and an associated increase in egg losses (Tripp and Poulin 1986b).*
>
> *Unlogged reaches had more undercut bank cover than logged reaches. Reaches subject to logging and mass wasting contained less undercut bank cover, fewer and shallower pools, fewer glides, less large organic debris, and a lesser wetted width relative to channel width. In mass-wasted streams, fish benefited from faster growth rates, and attained larger size. Gains in fish production were cancelled out by poor egg-to-fry and overwinter survival rates due to excess gravel scour and loss of overwintering habitat. Overall, mass wasting events had negative effects on salmonid populations through declining overwinter survival rates and smolt yields (Tripp and Poulin 1992).*
>
> *Logging operations increased hillslope sediment yield, and have altered the supply and characteristics of woody debris input to stream channels. The total number of large woody debris pieces found in logged and unlogged stream basins did not differ. In logged areas, the size of woody*

debris delivered to channels was smaller and more transportable when compared to forested areas. Logged stream channels displayed different woody debris arrangements, resulting in less channel complexity, decreased pool area, more homogeneous channel depth and width, and more sediment texture variability. Forested streams had greater channel stability than logged channels, due to the more uniform distribution of stored sediment along the length of the stream (Hogan 1984, Chatwin and Hogan 1990).

Comparisons of logjam sites in logged and unlogged stream channels showed more variability in fish habitat above and below the jams than between the jams. Patterns and rates of change were comparable between unlogged and logged reaches. Increasing the intricacy of logjams depended upon the continued recruitment of woody debris. New debris was not as readily available in logged systems as it is at forested sites. Fish habitat in debris-torrented zones lacking logjams was more homogeneous (Tripp 1998).

As a consequence of the increased science and understanding, the public and conservation advocates pushed the governments and forest companies to implement better practices when working in the forests (Fannin *et al.* 2007a). Following from some high profile incidents where large-scale landslides relating to logging significantly affected fish habitat, public pressure began to influence governments to resolve these issues, and the Coastal Fish/Forestry Guidelines were developed by the agencies.(BC Ministry of Forests 1993). These Guidelines were put together to provide direction to the agencies and proponents in regards to where and how to conduct logging activities with the objective to reducing the number of impacts to fish and fish habitat, including landslides.

Nevertheless, while the development of Coastal Fish/Forestry Guidelines were an improvement over historical logging practices in this province, it became apparent over time that they were still were not sufficiently rigorous to meet the desired environmental objectives, including aspects relating to road building and landslides. One of the main problems was that these Guidelines were only Best Management Practices (BMP's) and, thus, legally unenforceable; furthermore, little monitoring took place by the agencies to ensure compliance (Fannin *et al.* 2007a). Then, as logging-related fish habitat problems continued to occur in British Columbia's coastal forests, a forest-harvesting practices audit, commonly referred to as the "Tripp Report" (Tripp 1994), was released. This report clearly demonstrated that the logging industry was not meeting appropriate standards in its environmental practices and areas of particular concern related to road building, riparian protection and harvesting on steep slopes. It was time for new ways of doing business to be implemented in the forest industry, particularly since the environmental and international conservation lobbies had become so politically strong. Both public pressure and science stimulated the government of the day to develop, and put into practice, the *British Columbia Forest Practices Code Act* and its associated regulations and guidelines under the Forest Practices Code. In many respects the *British Columbia Forest Practices Code Act* and the Forest Practices Code can be viewed as the first landscape-level environmental legislation for forest harvesting for which the management, and minimization, of landslides was an important component.

In 1995 the provincial government promulgated the *British Columbia Forest Practices Code Act*. It remained in effect from June 1995 to January 2004. The accompanying Code was considered to be comprehensive and was viewed as having "some of the strictest forestry protection rules in comparison to the vast majority of US soft wood lumber producing states" (Cashore 2001). Fannin *et al.* (2007a) related that prior to the Forest Practices Code being implemented, information governing and guiding the conduct of the forest industry was contained in a multitude of policies, procedures, and guidelines that did not have a solid legal framework; however, once the Forest Practices Code was put in place, the modes of operation were codified into a legal framework that included a plan and supporting regulations.

Nevertheless, a number of problems relating to implementation seemed to be connected with this *Act* and the Forest Practices Code, and were largely, but not exclusively, concerns voiced by the forest industry. Firstly, the implementation of the Code in the field was viewed by some as being cumbersome. For example, the Code included 19 regulations, and 42 guide books comprising seven legally binding guide-books, and 35 guide books in the non-legal realm that specified non-binding management practices (Fannin *et al.* 2007a). Furthermore, government staff were required to "sign off" the plans and actions put forward by the industry before wood could be taken out of the forest, and this was often seen, by the forestry companies, to cause unnecessary delays.

Despite the perceived problems by the forest industry, the *Forest Practices Code Act of British Columbia* met many of its environmental objectives. For example, the Forest Practices Board found that "significant improvement in the reduction of landslides from forest practices after the code [FPC] took effect" (Chatwin 2005; Forest Practices Board 2005). There seemed to be agreement by most, if not all, that the Forest Practices Code was largely effective from an environmental perspective even though some of the deliverables, in respect to industry efficiency, were found still wanting (Fannin *et al.* 2007a).

In 2002 the provincial government decided to take an alternative approach to the *Forest Practices Code of British Columiba* and become more industry-friendly. The new government made a commitment to change the perspective in regards to how the environment was going to be protected in the face of forest harvesting in British Columbia. The new model and its legislated basis (Fig. 5.9) were embodied in the new *Forest and Range Practices Act* (FRPA) and its regulations were implemented in January 2004 (Fig. 5.10).

Shifting from the *Forest Practices Code Act of British Columbia* to the *Forest and Range Practices Act* changed the way the forestry industry was allowed to do business. Harvesting trees in British Columbia's forests moved away from a planning and process-oriented regime under the former legislation to the "results-based" regime under *FRPA* (Fig. 5.9). The argument by government is that the environmental provisions of the *FRPA* legislation have not been watered down simply because the forest industry has more flexibility to undertake more innovative practices. Some critics suggest that "innovative practices" is simply a euphemism for cutting corners under circumstances when auditing is less likely (Fig. 5.6)). Under *FRPA* the forest industry also has an increased level of individual accountability (liability) for results and outcomes of their actions, including a maintained level of environmental protection relating to road building and protection of landscapes from landslides.

As part of this new era of doing business in British Columbia's forests, professional accountability is now especially required by the field staff (company employees and consultants) in respect to planning and implementing the ways in which wood is harvested (Fig. 5.10). The new regime specifies that an end result (e.g., there shall be no increase in landslides) must be achieved with the expectation that different proponents might, and will, choose different ways to get to that environmental end point (Horel and Higman 2006, WCEL 2007).

An important component of the *Forest Practices Code Act of British Columbia* was that terrain where logging was to take place in British Columbia be managed in order to prevent unnatural landslides (Horel and Higman 2006). To that end Terrain Stability Field Assessments (TSFAs) were required for unstable or potentially unstable landscapes. Thus the design of roads, where trees would be harvested, and replanting of trees (silviculture plans), had to mesh with the recommendations in TSFAs. Under the *Forest Practices Code Act of British Columbia* government staff were required to approve assessment reports, plans, and documents that were submitted by the forest companies. That is, they provided a watchdog and decision-making role to oversee the management of landscape-level activity that has profound implications for salmon and steelhead in British Columbia. As a result, under the *Forest Practices Code Act of British Columbia* the provincial government, therefore, assumed much of the landslide hazard responsibility.

With the *Forest and Range Practices Act* (FRPA), the legislation sets objectives for the protection of soil and water. However, the licensee does not have to submit for approval of road designs or undertake TSFAs for harvest areas (Horel and Higman 2006). Instead, the forest company decides who to consult and what assessments to complete in order to meet Section 37 of the Forest Planning and Practices Regulation which states: *An authorized person who carries out a primary forest activity must ensure that the primary forest activity does not cause a landslide that has a material adverse effect in relation to one or more of the subjects listed in section 149 (1) of the Act.*

Fannin *et al.* (2007a) suggest that with the new legislation, a greater emphasis is placed on landslide-risk management rather than simply following by a set of rules. Rather than having in-house government agency staff doing the analysis, there are terrain-stability professionals, hired by the forest companies involved in the planning. They have to analyze and design for the situation, and sign off on, the planning aspects of slope stability for clearcut harvesting, and wood removal around gullies and on fans. These specialists are also involved in determining how road construction and deactivation will occur. Following from this, Fannin *et al.* (2007a) make the statement*: "In effect, forest companies that build, maintain, or deactivate a road, or harvest timber, on steep slopes must not cause a land slide or a gully process, or fan destabilization, that has a material adverse effect on FRPA values. However, and in contrast to the FPC, the FRPA will not specify when or how terrain stability mapping or field assessments should be conducted. Rather, forest companies will have the ability to decide whether to conduct these types of investigation.*" In order to achieve this end, terrain-stability mapping is a routine aspect of forest development planning with a focus on potential landslides (APEGBC 2003). As a result, the provincial government has moved from a process that prevents hazards from occurring to one that risk-manages these impacts (Fannin *et al.* 2007b).

Like much of the decision-making in natural-resource management, however, the science surrounding terrain assessment is often weak and professional opinion may be limited or inconsistent in its interpretation of hazard levels and tolerable risks (Horel and Higman 2006, Fannin *et al.* 2007b). To resolve this, the industry and/or government need to develop criteria for what constitutes acceptable risk (Chatwin 2005). Fannin *et al.* (2007b) state that: "*From a government perspective, a common understanding of acceptable risk is expected from the decisions of the Forest Appeals Commission and the courts*…[and that]..[t]*his approach is consistent with that of the Joint Practices Board of the APEGBC and the Association of BC Forest Professionals (Joint Practices Board 2007), which observes that accept able risk is a matter for standards set by government, including precedents set in law.*"

While the new legislation is logical in theory, it is not clear whether or not the results[2] that the provincial government says the forest companies are required to achieve are, in fact, being met. Furthermore, given the substantially reduced levels of auditing (Fig. 5.6) and the fact that landslides will often occur many years after the forest activity has taken place (Fig. 5.8), it is difficult to say with any confidence that the objectives are being achieved given that the logging company may be long gone before any impacts are realized. Finally, shifting ways of doing business from hazard prevention (which, under the Forest Practices Code, was shown to be effective in significantly reducing landslides relating to forest harvest practices; Chatwin 2005) to managing risk, has provided proponents with little guidance in respect to how to do business (Fannin *et al.* 2007b).

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[2] WCEL (2007): *"To use an analogy from traffic regulations, a 'results-based' standard would be: 'Every driver must drive with due care and attention so as to avoid causing accidents.' This is the result that the government hopes to achieve. By contrast, a prescriptive (non-results based) standard would be requirements such as 'Do not travel faster than the posted speed limit.' Driving at the posted speed limit does not guarantee that one's driving is safe; but at the same time, we recognize the need for rules of this type."*

The question must then be asked: if a professional engineer, or geomorphologist, signs off on a road design, or the harvesting of trees on a steep slope, and a major landslide occurs as a result, will that individual realistically be liable for the remediation or compensation for lost habitat if the landslide damages a salmon stream? And, who will be responsible if that slide occurs a decade from now when the authorizing professional may be long retired and moved away (Table 5.1)? We think that these scenarios of responsibility are unlikely.

FIGURE 5.7. Improperly-designed road and drainage at Donna Creek, 1992, showing considerable erosion. This was a pre-Forest Practices Code event.
Photo and information: Schwab (2002).

FIGURE 5.8. Change in frequency of landslides in the Nahwitti River watershed after the commencement of logging.
Note that while the Forest Practices Code was put into effect in the mid 1990's, impacts continued well past the implementation of the more environmentally stringent legislation and regulations showing that affects will often have a considerable lag from time of logging or road construction to slope failure. Figure adapted from: Guthrie (2002).

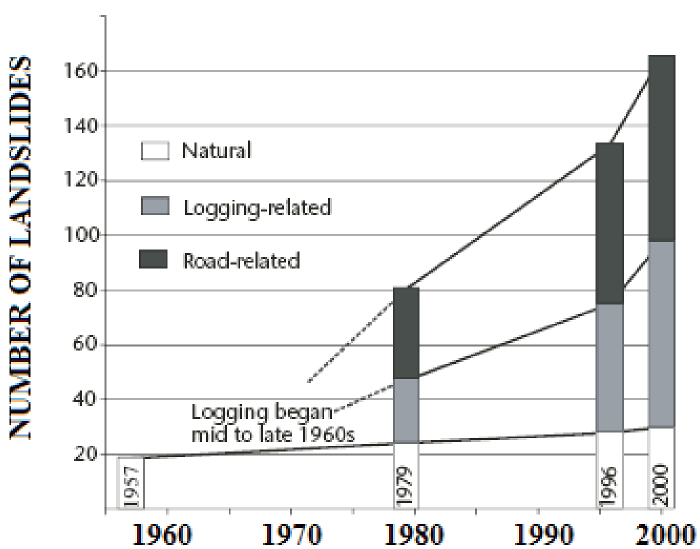

FIGURE 5.9. Differences in the implementation of the *Forest Practices Code Act of British Columbia* and its successor and current legislation, the *Forest and Range Practices Act*.
Figure: Fannin et al. (2007a).

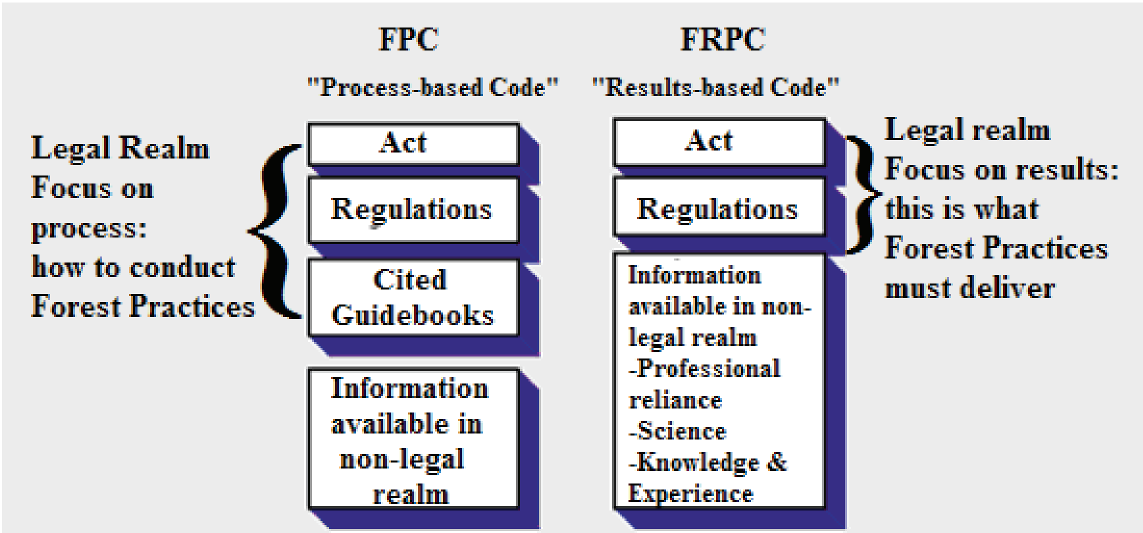

FIGURE 5.10. *Forest and Range Practices Act* framework to address landslides during forest harvest.
Figure: Fannin et al. (2007a).

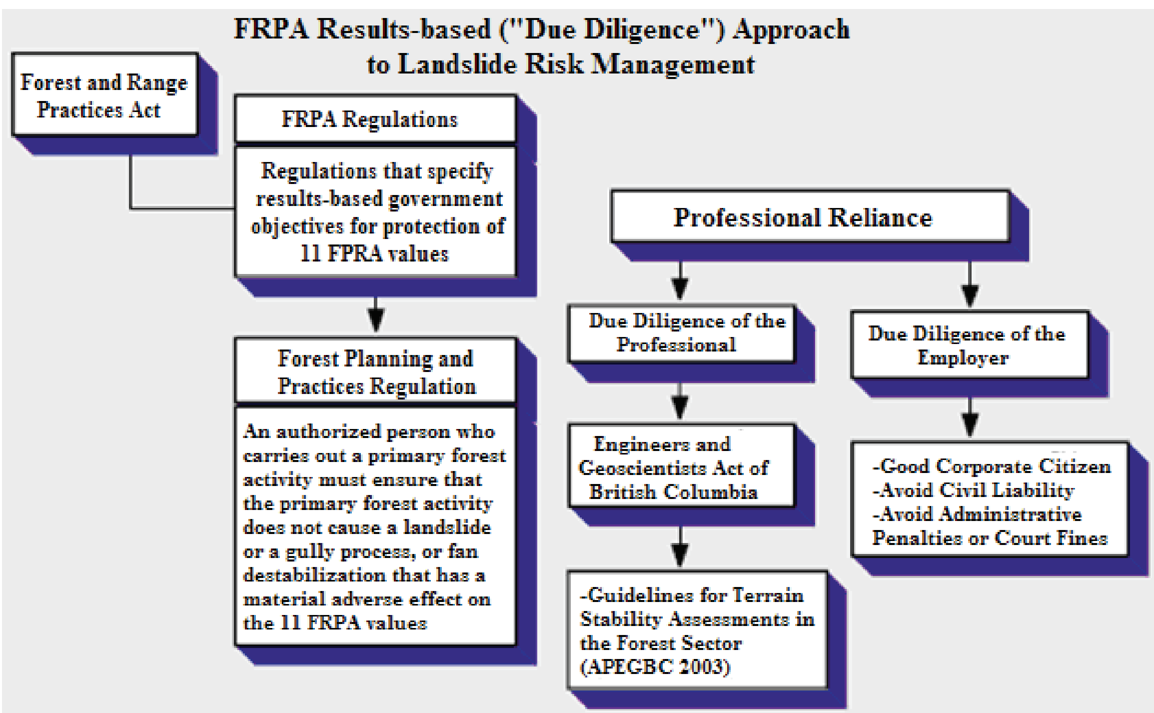

TABLE 5.1. Difficulties in evaluating and enforcing compliance with a "results-based" process in the forest industry in British Columbia.
From: WCEL (2007).

- If the "result" is not carefully and specifically identified, it can be difficult to determine whether it has been achieved or not, even by experts;
- Determining if an environmental result has been achieved usually requires considerable information about what the environment was like before the change. If the information is not available, no one can tell if the result was achieved; and
- Evaluations of compliance require going into the field and may involve complicated assessments as to whether a result has been achieved. As a result, government inspections require more staff time and expertise. In a geographically large province, such as BC, it also requires considerable travel, with the resulting drain on staff and resources.

MANAGEMENT OF PINE BEETLE INFESTATION

One of the most serious challenges in the history of forestry management in British Columbia is the current mountain pine beetle (*Dendroctonus ponderosae*) outbreak and governments' response to this phenomenon. The mountain pine beetle infestation (Fig. 5.11, 5.12, 5.13) is now sweeping the interior of British Columbia resulting in an unprecedented die-off of lodgepole pine (*Pinus contorta*) and, to a lesser degree, other species of trees. The official position is that climate change and forest-fire suppression have been primary facilitators of this phenomenon (Ministry of Forests and Range 2006b). The landscape level and salmon impacts are significant.

The ecological effects of the mountain pine beetle on lodgepole pine in British Columbia are enormous (Ministry of Forests and Range 2006b). Computer modelling forecasts the pine beetle disturb an average of 2,000,000 ha per year from 2001–2050 (in this calculation an area may be disturbed more than once) (Ministry of Forests and Range 2006b). This is 40 times the 1951–2000 average historical mortality and 10 times the expected area for fire and harvest disturbance. In 2005, the amount of forest killed by mountain pine beetle amounted to 8,700,000 ha. The Ministry of Forests and Range projects that 80 per cent of the merchantable pine in the province's central and southern Interior will be killed by 2013 (Fig. 5.14). This has major economic ramifications to the forest industry, since lodgepole pine comprises over half of British Columbia's annual timber harvest (Ministry of Forests and Range 2006b).

Lodgepole pine forests are a major landscape-level feature of many ecosystems in the interior region, and this includes areas of key salmon habitats. The distribution of anadromous (sea-going) fish stocks in the interior of British Columbia and the actual, or potential, mountain pine beetle infestations extensively overlap in many of their drainages (c.f., Figs. 5.12, 5.15). To get a sense of the potential effects in a watershed of important salmon habitat, consider that the Fraser River watershed has about 7.8 million hectares of potentially infected lodgepole pine contained within its drainage (Schnorbus 2007). The salmon and steelhead in the Skeena River drainage are also being extensively affected.

The landscape-level effects of mountain pine beetle on salmon and steelhead habitat range from the directly physical (instream and riparian affects, whereby the recruitment of large woody debris may be disrupted or increased erosion may occur due to changes in hydrographs and stream flows), to the chemical (nutrient-budget shifts), to the hydrological (re-arrangement of surface and groundwater flows) (Table 5.2). Thermal changes to streams might also occur as a function of the hydrological and radiation effects to forests when the trees die, as well as via logging to harvest these dying forests (Forestry Fish Interaction Program undated). Note also that the impacts associated with mountain pine beetle can affect fish rearing, spawning or migrating many hundreds of kilometres away from the actual zone of dead or harvested trees due to downstream effects.

The British Columbia provincial government has now taken the position that the current mountain pine beetle infestation is epidemic and must be addressed though a variety of initiatives and policy changes (Ministry of Forests and Range 2006b). Those changes have major implications to salmon and steelhead populations.

One of the ways that the British Columbia government is dealing with the forest die-off is to facilitate “salvage logging” of areas where large areas of lodgepole pine have been killed due to mountain beetle infestations. This includes significantly increasing the Allowable Annual Cut to harvest the dead wood, or trees which are about to be killed, before they become unusable for lumber. This is of concern due to the consequences to the ecology of the forest from the tree die-off as well as the removal of the wood through logging over expansive landscape areas (Winkler *et al.* 2008).

Extensive research has been conducted in British Columbia and around the world on ecological and environmental impacts associated with logging, and the relationship between the size of the area harvested and the effects on ecosystems. Although it is not the intent of this report to review the extensive body of literature, Salonius (2007) has commented that forestry in Canada can probably be seen to have been largely sustainable as long as the harvest cut-block openings are sized to approximate natural-disturbance dynamics. Nevertheless, biodiversity and forest ecosystem stability appear to have, in some cases, been compromised in this country where there have been unnaturally large harvest sites (Perera *et al.* 2004, Salonius 2007).

With the interest in accelerating the removal of dead and about-to-be-killed wood before it becomes unmarketable, the logged (cutblocks) have been increasing in magnitude (Sierra Legal Defense Fund 2001, Winkler *et al.* 2008). The normally-recommended maximum size of the area that can be cut in the interior of British Columbia is 60 hectares (Sierra Legal Defense Fund 2001), however, under the regime of “salvage” logging, companies can get exemptions (Hughes and Drever 2001) and this has resulted in some cutblocks in British Columbia being as large as 1,300 hectares, or over 20 times the recommended maximum (Sierra Legal Defense Fund 2001). Thus, for the mountain pine beetle situation, both the extent of the dead forest and the expanded harvest rates have now become a concern with respect to landscape- and watershed-level hydrological effects on streams (Sierra Legal Defense Fund 2001).

While at least 20% of the forest canopy needs to be killed or removed before there will be any measurable increase in annual runoff in the Rocky Mountains (Stednick 1996, Stednick and Troendle 2004) this scenario has now happened in many beetle-kill areas of British Columbia with potential major effects on hydrology. Alila (2007) suggests that since the most heavily affected areas of mountain pine beetle kill constitute 60% of the watersheds draining the Fraser River, it is important to consider whether or not the dead lodgepole pine, and its treatment by salvage logging, has any downstream consequences in flooding, whether in the Fraser itself or its many tributaries.

A number of studies are now being conducted in British Columbia to determine the effects on the hydrology relating to mountain pine beetle kill of lodgepole pine. Uunila *et al.* (2006) suggested that changes to the hydrology of forests affected by mountain pine beetle have already occurred in north-central British Columbia. For the Vanderhoof Forest District it has been observed that groundwater levels have risen in mountain pine beetle-affected areas (Rex and Dubé 2006). From a forest-harvest perspective this has changed the behaviour of the logging in the area, requiring the use of low-ground-pressure harvesting equipment, additional site preparation, and change in logging operations from summer to winter.

Perhaps one of the most startling recent assessments in this regard was the report released by the Forest Practices Board (2007) entitled "*The Effect of Mountain Pine Beetle Attack and Salvage Harvesting On Streamflows—Special Investigation*" which modelled the influence of the beetle kill, and logging of the dead trees, on the hydrology in the Baker Creek watershed in the central-north part of the Fraser River drainage (Fig. 5.16). The computer model of the Baker Creek hydrology, which is in an area of high mountain pine beetle influence, showed that an attack of 75% of the mature pine stands, plus the past conventional harvesting, resulted in annual peak-flood increases of 60% over recent historic flows, and annual total-water yield increases of 30%. Then, by adding a salvage-harvesting-of-the-dead-pine scenario to the model, there was a further increase in annual peak streamflows which was significant over and above simply leaving the dead trees standing. For Baker Creek, the modelling of salvage-harvesting of all pine-leading stands, (but retaining 20% of the watershed in reserves), increased annual peak flows by 92 % and flood frequency also increased: a former 20-year return interval peak flow discharge can now be expected every 3 years.

It was the view of the Forest Practices Board (2007) report that these modeled changes represent major shifts in the stream flow regime. An important consideration of this report included the empirical observations that changes to the Baker Creek flows patterns are already being seen. Perhaps even more important are the statements made by the report about watershed planning and landscape-level watershed assessments in mountain pine beetle kill areas as follows: "*The FRPA legislation and the Cariboo-Chilcotin higher level plan (CCLUP) do not require landscape level watershed assessments or planning for most MPB* [mountain pine beetle]-*affected watersheds. Government needs to develop policy and strategies for protecting drinking water and fish habitat in the MPB-attacked watersheds*."

There is some recent empirical evidence for these modelled trends by the Forest Practices Board (2007). In a study in the Fraser Lake area of British Columbia, Boon (2007a) measured variations in snow accumulation and ablation (the loss of snow through both melt and vaporization) between green, grey/red (mountain pine beetle infested) and clearcut stands, and assessed the impacts of both inter-annual variability in snow accumulation and changes in forest canopy, and suggested implications for runoff and hydrology. Boon (2007a) found that April 2007 snow depth increased magnitude from the young to the beetle-killed dead to clearcut stands, which the snow-water equivalents (a measure of the amount of water in the snowpack if the snow melted instantly) for the same period was the same in the green and dead areas but 25% higher in the clearcut areas (Fig. 5.17). This appears to be important insofar as leaving dead pine *in situ* can mitigate some of the changes to the hydrology of an area; however, Boon (2007a) provides a cautionary statement whereby she suggested that while changes in canopy structure will affect snow-water equivalents between stands, snowfall amount and type need to be considered and this varies from site to site and year to year. Boon (2007a) found that differences in snowpack can both mitigate and complicate the effects of canopy change in this part of British Columbia where a high snowpack results in minimal differences between live and dead stands, while the opposite is true in years with a low snowpack (Boon 2007b). However, her conclusion was also that salvage-harvested areas will accumulate more snow-water equivalents than forested stands regardless of annual snow conditions. Therefore, under the circumstances that Boon assessed, changes to hydrology in a beetle-kill area may be mitigated to a certain degree by retaining both live and dead forest structure to reduce ground snow accumulation and minimize the risk of enhanced spring floods.

In a similar study, Beaudry (2007) attempted to document the differences in snow accumulation and melt rates among three types of forest sites located in the heavily infested mountain pine beetle areas near Prince George, British Columbia. Beaudry's (2007) assessments included recent clear-cut areas, stands with mostly dead pine trees and stands with mostly live conifers. The forests with dead, but standing trees, were intermediate in their snow-water equivalents, and between clearcut areas and green stands (Fig. 5.18), suggesting that leaving dead trees standing mitigates some of the changes to the hydrology of a pine beetle infested area.

Other studies also looked at the rate of recovery of hydrologic conditions to the pre-beetle-kill period. Teti (2007) suggests that, in terms of transmitted solar radiation and snow ablation rates, the hydrologic recovery of pine stands on the Fraser Plateau is low for the first 12 years after logging. Teti (2007) also indicates that, under the right conditions, after 35 years, recovering cutblocks tend to be close to old healthy forests for these parameters. Teti (2007) also suggested that the net hydrologic condition of old attacked pine stands is around 50% of healthy forest within 3 years of the insects infesting the trees, but there may not be much more recovery until net changes begin two to three decades after attack (although this was based on a relatively small sample size). As a result, by harvesting mature, dead pine, there will be net increases in snow ablation rates for at least a dozen years.

Winkler (2007) has also been undertaking pine-beetle related forestry work in the central part of British Columbia, and she found that differences between forested versus open areas for pre-melt snow water equivalents vary from insignificant to 40% less in the treed areas. She also found that reductions in average ablation rates can be as large as 60% and, on average, snow persisted for 8 days longer in the forest than in the open (Winkler 2007).

While there is considerable concern regarding the effects that mountain pine beetle kill of lodgepole pine is having on the hydrology of affected areas in British Columbia, superimposed upon this is the effect of climate change (itself considered to be a causal agent for the mountain pine beetle kill) on the hydrology of forested areas in the locations of this epidemic. Mote *et al.* (2005) have shown that the snowpack in western North America is declining as a function of climate changes with consequent effects of tree mortalities. Morrison (2001) demonstrated that the Fraser River now discharges more of its total annual flow earlier in the year, and this appears to be linked to climate change. Climate has affected various parts of British Columbia in different ways: Firstly, for coastal regions, the wet season has become shorter and wetter while the dry season has become drier and longer. Secondly, for the southern interior, the hydrologic spring is now earlier and summer is extended, resulting in low fall flows. And thirdly, in northern regions, streamflows have increased throughout the year (Whitfield 2001).

Gayton (2008) suggests that limited observational records indicate that, between 1935 and 2000, snow depth and snow water content decreased in some parts of British Columbia. Furthermore, the lakes and rivers increasingly became free of ice earlier in the spring between 1945 and 1993, and these provincial trends are consistent with global trends (Gayton 2008). Still, the ways in which these constantly shifting conditions will affect the ultimate hydrologic patterns is unknown.

Rodenhuis *et al.* (2007) discussed the inter-relationship between climate change and mountain pine beetle kill in British Columbia in relation to hydrology. It was their view that streamflow may be impacted by changes in ground cover occurring as a result of the epidemic and that climate variability and climate change may shift future streamflow responses. However, they cautioned that information about impact of the lodgepole pine's die-off to the various watersheds is still limited and knowledge of industry responses (i.e., salvage logging) is unknown and they call for more research (Rodenhuis *et al.* 2007). They also suggested that the pressing questions to address in the studies would be of cumulative hydrologic impacts of the infestation with future climate conditions which might influence other landscape changes, including forest fires and logging, both of which, in turn, will also influence hydrology (Rodenhuis *et al.* 2007).

The British Columbia Ministry of Forests and Range appear to now be concerned that the die-off of lodgepole pine via mountain pine beetle infestations is a significant issue in terms of landscape-level changes to flows, hydrological changes and flooding (Tables 5.3, 5.4). In March 2007 the Chief Forester for British Columbia, Jim Snetsinger made a public statement by letter stating that: "*The unprecedented level of mortality due to MPB* [mountain pine beetle] *in combination with accelerated salvage harvesting does present a significant risk of hydrological problems. This is a complex issue involving a myriad of interactions between harvest levels, road densities, understory vegetation, local physiographic features, and climate…*". The letter went on to describe a variety of initiatives that the British Columbia Ministry of Forests and Range are undertaking (Table 5.5).

While it is difficult to assess at this time whether or not the response by the Ministry is sufficient or in the right direction, it is worthwhile to note that the Chief Forester, in his letter, also gave the licensees direction by stating: "*Licensees conducting large scale salvage* ***need to be mindful*** *of the risks identified by their professionals for this type of operation in both their planning and practices. Practices which contribute to stream bank stability, mitigate erosion or risk of landslide, minimize roads or other ground disturbance and enhance hydrologic recovery of the watershed will contribute towards a successful salvage program.* ***Please encourage resource professionals to take into consideration*** *relevant guidance and research information available on MPB impacts when preparing operational plans and when guiding others who are conducting operations on the ground, in order to mitigate the inherent risks associated with these special circumstances…*". [our bolding and underline emphases] While the concerns of the Chief Forester are well expressed, this position may be insufficiently forceful in setting the direction spelled out in policy and legislated authority to ensure that the proponents of wood harvesting licences do what is required to protect fish habitat in the face of such massive landscape changes.

FIGURE 5.11. Mountain pine beetle adult and larvae attacking wood.
Left photo: Ministry of Forests and Range (2008b). Right photo: Ministry of Forests and Range (2006c).

FIGURE 5.12. Pine beetle infestation distribution in British Columbia.
Figure: Ministry of Forests and Range (2006b).

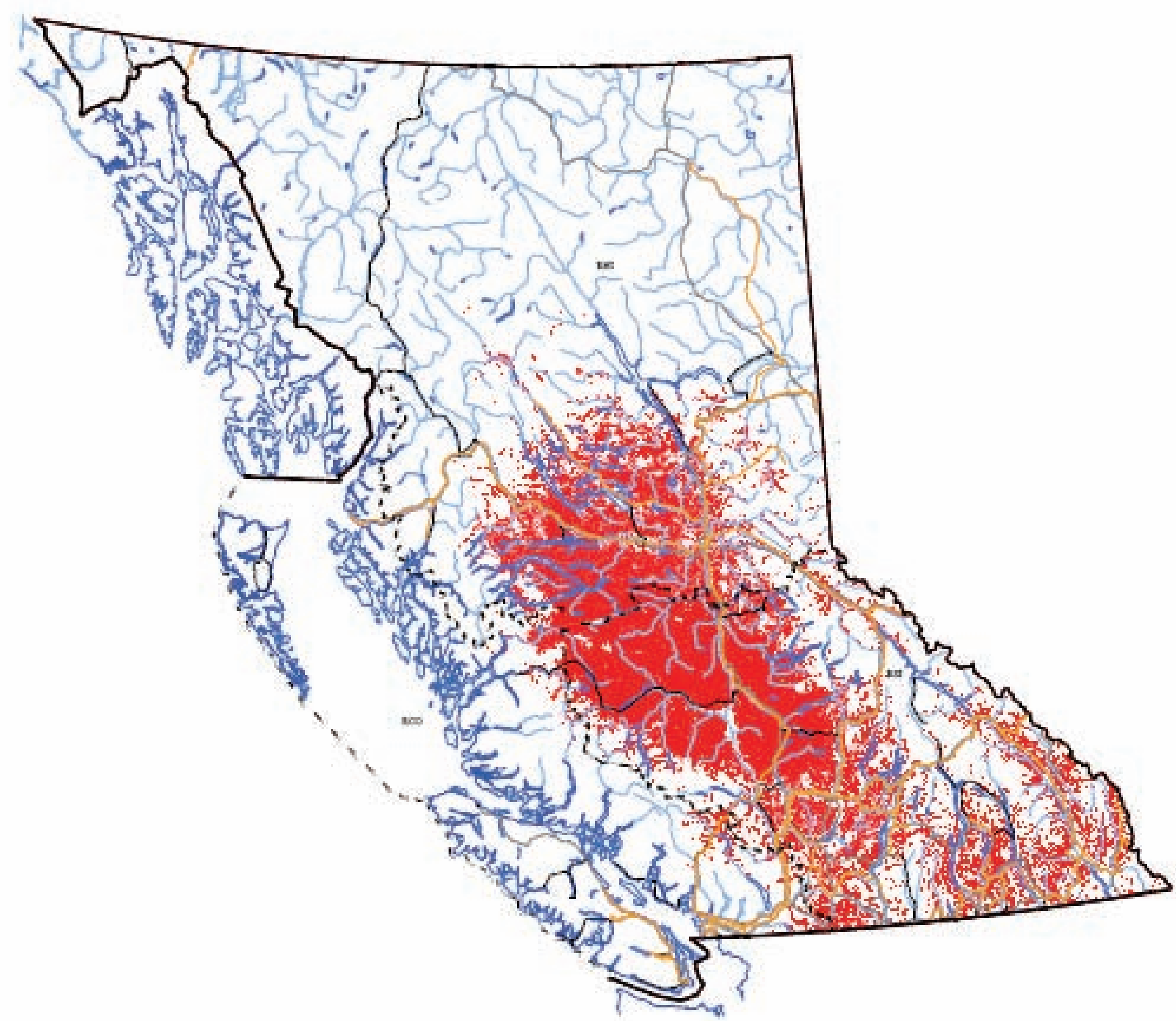

FIGURE 5.13. Pine beetle infestation in British Columbia (upper), and with clearcut "salvage" (lower).
Top photo: Ministry of Forests and Range (2006b); bottom photo: Ministry of Forests and Range (2006c).

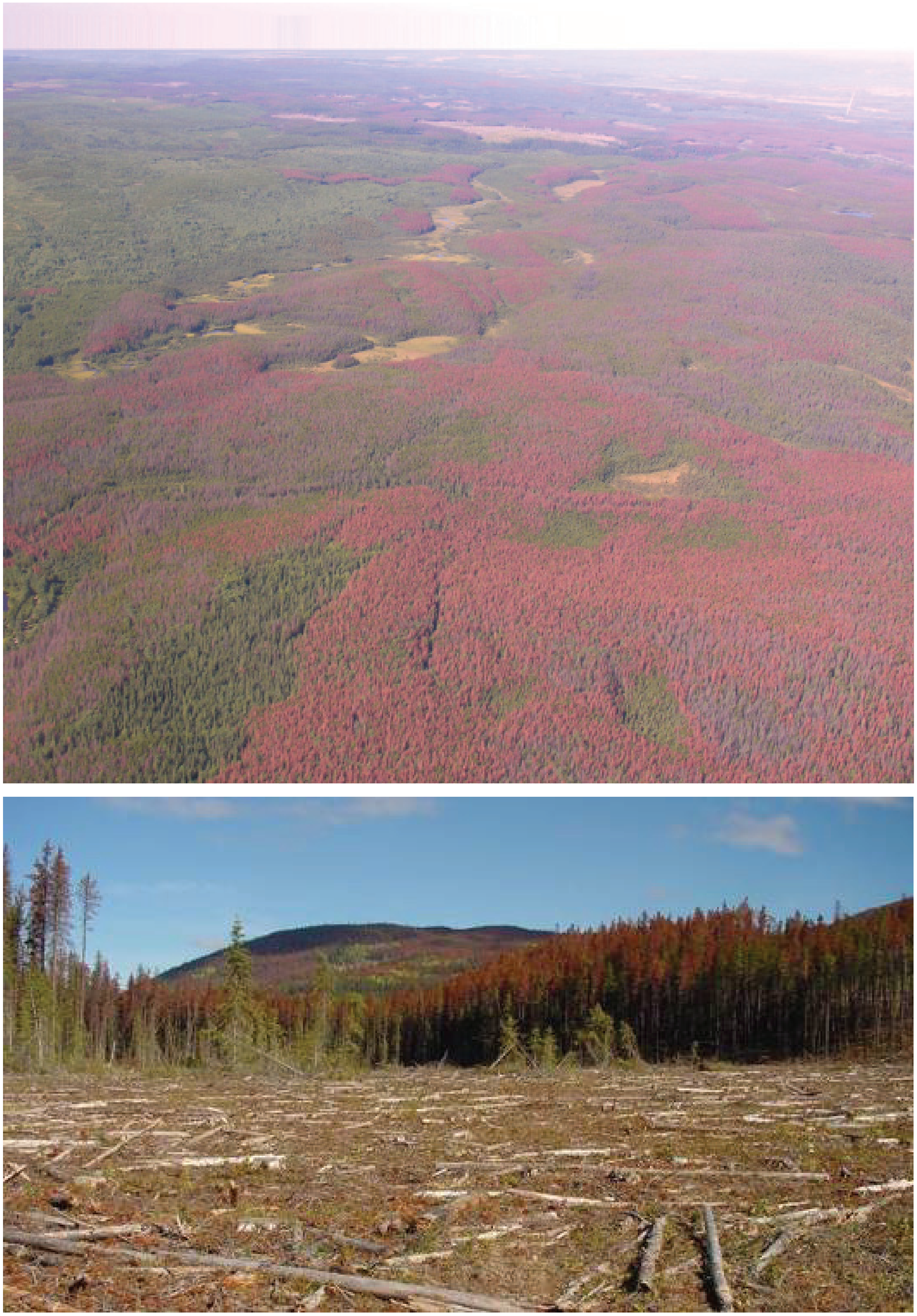

FIGURE 5.14. Projected cumulative volume of lodgepole pine killed by mountain pine beetle on British Columbia's timber harvesting land base.
Figure adapted from Walton et al. (2008).

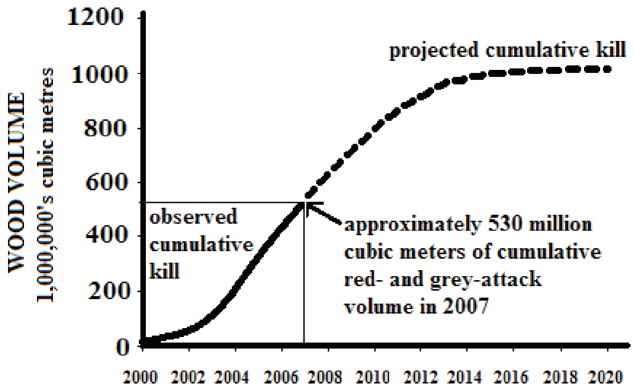

FIGURE 5.15. Distribution of sockeye rearing lakes (red) in the Fraser River watershed.
Figure adapted from: Pacific Salmon Commission (undated). Note the extensive overlap with Fig. 5.12 showing the mountain beetle kill areas within the Fraser River watershed.

FIGURE 5.16. Return-period flows for treatment of past conventional harvest plus mountain pine beetle attack of 75% of remaining forest (treatment), compared to pre-harvest baseline (control) for Baker Creek, central British Columbia.
With 95% Confidence Bands on control. Figure: Alila et al. (2007).

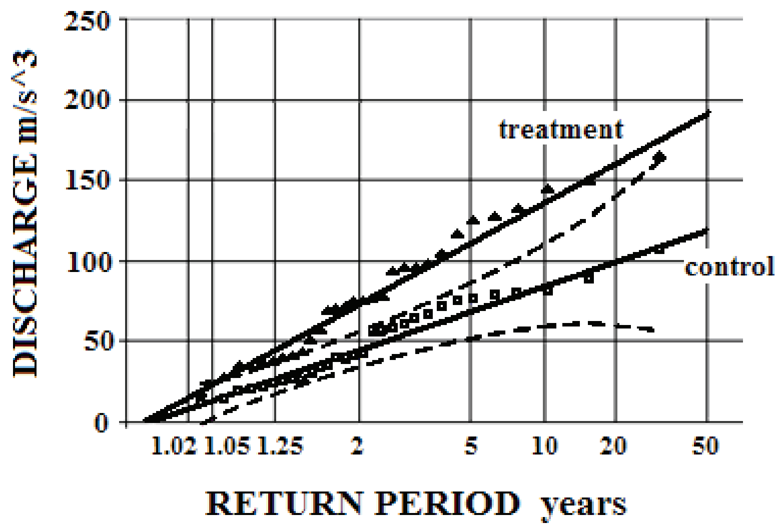

FIGURE 5.17. Differences in snowpack snow-water equivalents at the end of winter in the Fraser Lake area of British Columbia, 2007.
Data collected April 8, 2007. Figure adapted from: Boon (2007a).

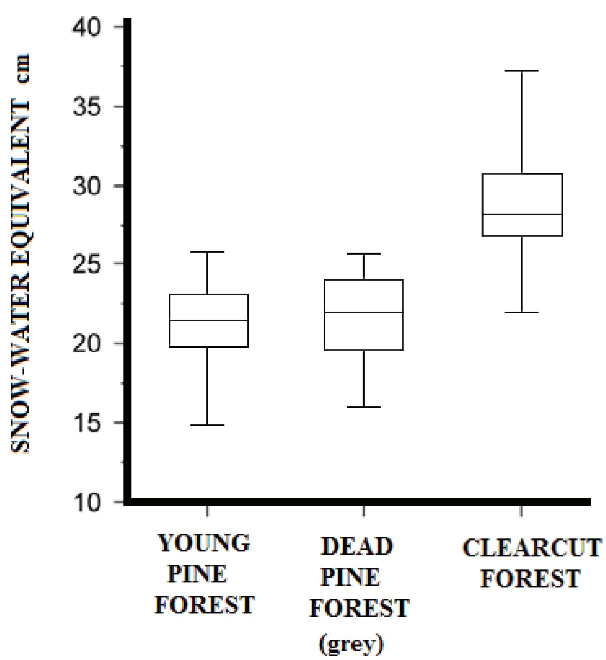

FIGURE 5.18. Differences in snowpack snow-water equivalents at the end of winter in the Prince George area of British Columbia, 2007.
1400 South Road area, 26 February 2007. Figure adapted from: Beaudry (2007).

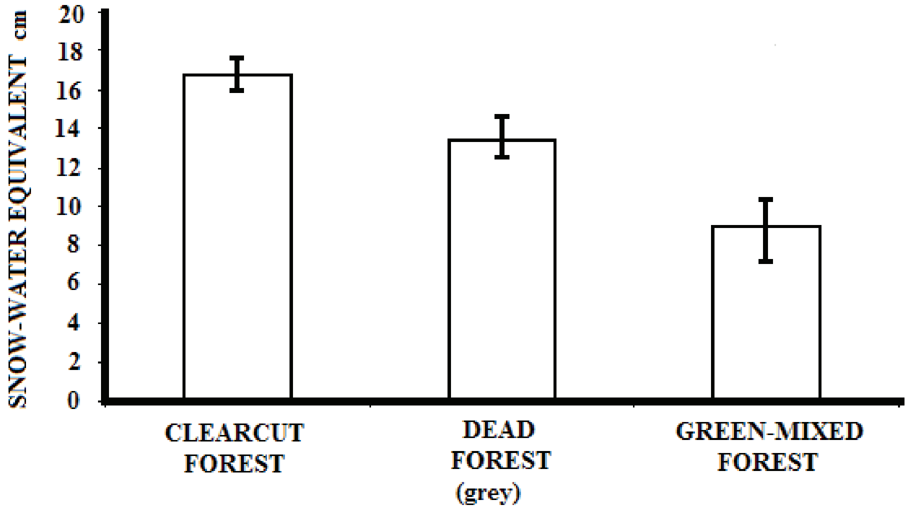

TABLE 5.2. Potential hydrologic impacts associated with mountain pine beetle mortality and salvage logging.
Winkler et al. (2008).

- Increased peak flows and water yield
- Increased surface erosion
- Damage to forest road surfaces, cuts and fills, and drainage structures
- Channel destabilization
- Loss of fish habitat
- Increased landslide activity
- Elevated water tables
- Loss of soil and site productivity
- Loss of water quality

TABLE 5.3. Objectives of the Ministry of Forests and Range Mountain Pine Beetle Action Plan 2006–2011. Note that ecosystem or fisheries viability are not particularly well represented in this list.
From: Ministry of Forests and Range (2006b)

1. Encourage immediate and long-term economic sustainability for communities.
2. Maintain and protect worker and public health and safety.
3. Recover the greatest value from dead timber before it burns or decays, while respecting other forest values.
4. Conserve the long-term forest values identified in land use plans.
5. Prevent or reduce damage to forests in areas that are susceptible but not yet experiencing epidemic infestations.
6. Restore the forest resources in areas affected by the epidemic.
7. Maintain a management structure that ensures effective and coordinated planning and implementation of mitigation measures.

TABLE 5.4. To mitigate the effects of the mountain pine beetle infestation on hydrology and other critical aspects of infected watersheds, the Ministry of Forests and Range Forest Science Program recommends that the following should be considered by forest resource planners where practicable.
From: Winkler et al. (2008)

- Identify watersheds and values at risk.
- Salvage log in stages using various cutting intensities and retention strategies distributed over the landscape to desynchronize runoff.
- Maintain a diversity of cover types and minimize post-salvage reforestation delays through single-tree or patch retention to protect advance regeneration and by retention of non-pine and broadleaved forest vegetation.
- Delay or interrupt surface runoff by leaving fine and coarse woody debris in openings where possible.
- Avoid sensitive terrain and soil types, and develop erosion control plans.
- Minimize harvesting within riparian areas, particularly in systems that are woody debris–dependent.
- Construct, inspect, and maintain roads to ensure that natural surface and shallow subsurface drainage remain intact both during and post-salvage.
- Upgrade drainage networks on permanent roads before salvage logging as necessary to accommodate expected increases in peak flows.

TABLE 5.5. Chief Forester's high priority knowledge gaps for hydrology, geomorphology, and fisheries relating to mountain pine beetle in British Columbia.
Table adapted from: de Montigny et al. (2007).

- Impacts of mountain pine beetle infestation and salvage harvesting on the hydrological cycle (snow accumulation/melt, rainfall, evapo-transpiration, groundwater regime, water yield, and peak flows) at the watershed and landscape scale.
- Impacts of mountain pine beetle infestation and salvage harvesting on riparian and stream channel physical processes (water quality, large woody debris dynamics, shade, air and water temperatures, understory vegetation, sediment production and delivery, channel stability/destabilization, and water chemistry).
- Modelling of potential impacts and generation of risk analysis for the hydrological, geophysical, and aquatic resources of mountain pine beetle infested areas at the watershed and landscape scales.

6.0 DISCUSSION

BACKGROUND

British Columbia is currently undergoing unprecedented human-induced physical, biological and cultural changes at the landscape level and much of this activity is thought to have had/is having profoundly negative impacts on many of the province's salmon and steelhead populations. Indeed, it has become clear that human-population growth rates, along with elevated economic expectations and associated natural-resource consumption, are incompatible with long-term salmon and steelhead sustainability or recovery. Furthermore, many of the activities that affect these fish are directly related to the re-arrangement of landscapes in the face of resource extraction (Lackey *et al.* 2006, 2008). This report provides specific examples from urban, forestry and agricultural activities where this issue of landscape-level changes has affected these species.

Landscape-level effects are now recognized around the world to be an important component of environmental sustainability. As a result, the planning and management, and the scientific inquiries assessing the impacts of such activities, are starting to be undertaken at the landscape level in various countries in order to ameliorate impacts to ecosystems. For example, places as diverse as Africa (Muruthi 2005), Europe (Helming *et al.* 2008), the United States (Polis *et al.* 2004), and eastern Canada (Harvey *et al.* 2002) are embracing landscape-level initiatives to protect or restore ecosystems at risk. As part of these efforts, landscape-level management of impacts to ecosystems can connect community-based initiatives to protect the environment with wider national or regional policies and perspectives to reach the objective of sustainability. It is in this context that this report addresses the effects of landscape-level impacts on salmon and steelhead populations in British Columbia.

ROLES AND RESPONSIBILITIES AND HISTORIC LANDSCAPE-LEVEL INITIATIVES IN BRITISH COLUMBIA

The Province of British Columbia has engaged in a number of landscape-level initiatives to protect various biological values over the past several decades. While these have been intended to serve broad environmental purposes, some have had direct and indirect benefits to fish. Most of these initiatives have come from the provincial government although it is the regional and municipal level where action could be most effective. It is in this local jurisdictional realm that the key landscape-level issues must be addressed more extensively now and in the future.

The jurisdiction surrounding the management of land and activities thereon in Canada is constitutionally and largely within the local and regional domain. Under the Canadian Constitution Act of 1867, the legislation of natural-resource extraction and land-development activities is generally of provincial and often, by extension, local government responsibility rather than under the aegis of the federal government. This has important implications for fisheries since it is the federal government that has the constitutional responsibility for the protection of fish and their habitats. Landscape-level impacts to fish habitat are normally of a more "diffuse" nature (as compared to instream or riparian activities), because they are often spread across these larger geographic areas. Moreover, there is still often little understanding as to how fish are affected by landscape-level activities; thus, at the operational level, the habitat provisions of the Canada *Fisheries Act* often carry little weight in regards to regulating the broader landscape-level activities. This puts the onus on the provincial government to recognize and manage these larger-geographic effects if we want to save salmon and steelhead ecosystems.

Various provincial administrations have, over the years, recognized that landscape-level activities are often detrimental to ecological and social sustainability. Indeed, in order to counter broader effects to the environment, the British Columbia government has, in recent decades, moved towards engaging its citizens in various landscape-planning, management exercises and legislation for certain parts of the province and specific types of landscapes.

Some of these efforts have had clearly directed and demonstrable benefits to salmon and steelhead, while other planning or legislative initiatives have had only ancillary positive effects to these species. It is useful to examine some of these past efforts to show how recent experiences in landscape-level planning and legislation can serve as valuable examples, including both successful and unsuccessful scenarios, so as to provide templates for developing new initiatives.

In terms of governance of landscape-level impacts in British Colombia, one shortcoming is that efforts to date have been focused on specific types of activities as compared to being focused on a combination of activities affecting watersheds. This is especially true where urban settlement is involved. The best approach to deal with landscape-level impacts to salmon and steelhead would be through a governance structure that ensured coordinated action within government ministries and between various levels of government, landowners and other organizations. Some jurisdictions such as the Conservation Authorities in Ontario and the Alberta Watershed Planning and Advisory Council's are steps in the right direction. Obviously it would take time to establish such an approach in BC. Accordingly, the following sections deal with some thoughts as to how to best manage impacts from agriculture, forestry and urban activities that affect our landscapes at this current time.

AGRICULTURAL LAND RESERVE

Arguably the most controversial landscape-level legislation ever introduced into British Columbia was the *Agricultural Land Reserve Act* in 1973. Its basic premise was to protect farmland under threat from urban, commercial and industrial development. Over the years, it has been amended to become the *Agricultural Land Commission Act*, and it is administered by the Agricultural Land Commission. The Agricultural Land Reserve (ALR) currently covers approximately 4.7 million hectares of the province.

The basic thesis of the *Agricultural Land Commission Act* is that privately owned property that is designated as food producing (farmland) should be protected from development regardless of the owner's wishes. At the time of its implementation, many farmers were extremely unhappy because they viewed their property as a nest-egg for revenue from development once they retired. Furthermore, many controversies and impacts to agricultural landscapes remain as a result of weaknesses in the ALR legislation and implementation; nevertheless, this initiative has largely stemmed the tide of egregious development of farmland in British Columbia.

In protecting farmland from intensive development, a side benefit of the ALR has been that at some locations ecological functions have been retained and provide protection for fish habitat. That is, farmland along streams has often provided a level of respite from urban, commercial or industrial development; thus, there have been ancillary benefits to fish and aquatic ecosystems from this landscape-level planning and its regulations. However, this symbiotic aspect between the protection of farmland and aquatic ecosystems is changing in areas where intense industrial-level farming activities have now become the norm. "Intensification" of farming to the land means that every reasonable opportunity to use all of the landscape for agriculture is undertaken, and that efficiencies in drainage, fertilizer and pesticide application, etc., are maximized. For British Columbia there is a lack of regulations and legislation to maintain scientifically defensible riparian boundaries between farmed fields and their streams, particularly compared to what would normally be required in an urban-development scenario. Farmers are largely allowed to cultivate right to the stream bank in this province. Furthermore, as farmers attempt to increase production, farm fields are increasingly treated with fertilizer and pesticides at landscape-level applications, and these pollutants can compromise fish ecosystems when applied inappropriately.

Finally, while the ALR has largely been successful in preventing all but the most extreme pressures to remove farmland for development, the protection of ecological values is not mandated when considering the exclusion of some farmland. Thus, some very valuable aquatic habitats have been lost in recent years in south-western British Columbia because the owners were able to remove them from the ALR and have them developed into urban or industrial property. The ALR legislation needs to be revised to ensure that criteria to protect ecological values is applied, including aquatic and fish impacts.

Despite some of its weaknesses, the ALR has merit, with some modifications, for providing landscape-level protection of aquatic ecosystems. By amending the ALR to include ecological values much would be gained for salmon and steelhead. Such environmental amendments for ALR lands, combined with tax breaks or other innovative measures, would help take the burden off farmers for environmental protection within their individual agricultural landscapes. Given the rapid loss of landscape-level ecological integrity, for both agriculture and urban settings, amendments to the ALR are a realistic means to develop environmental sustainability in the face of rapidly disappearing aquatic and other ecosystems.

As a stopgap measure, salmon and steelhead, and other sensitive ecosystem values, in agricultural (and urban) areas need immediate and special protection. An example of a current and very promising way is the Heart of the Fraser initiative that purchases private property containing sensitive ecosystems between Mission and Hope on the Fraser River to protect them from further development. Many of the riparian landscapes within this initiative include farmland. The Heart of the Fraser initiative is being facilitated by The Nature Trust and provides one such model for this concept. Currently, many of the land purchases by the Nature Trust are a result of contributions from the private sector. Given the extensive costs associated with such a concept, there is also a need to build leverage from it through private-public partnerships. This new approach to purchase land to protect ecosystem attributes, including fish habitat, is currently being undertaken by a number of other non-government institutions such as The Nature Conservancy and Ducks Unlimited, and largely comprises efforts from the private sector.

FORESTRY AND RESOURCE-EXTRACTION LANDSCAPE-SCALE MANAGEMENT INITIATIVES

In 1987 the Brundtland Commission report entitled “Our Common Future” took a position that 12% of a terrestrial landscape should be protected. This report is thought to have strongly influenced the approach British Columbia would use to protect ecosystems.

The history of landscape-level planning for environmental values in British Columbia started in earnest in the 1990’s with the Clayoquot Sound conflict. This issue predominantly centred on how forests would be harvested and managed in areas of high ecosystem and tourism values on the west coast of Vancouver Island. However, it became a rallying point for more extensive conservation for the rest of the province.

In 1991, the Commission on Resources and Environment (CORE) was created with a mandate to develop a provincial land use strategy. This was to take place through regional land-use-planning decisions built on consensus amongst diverse perspectives and stakeholders. The creation of new protected areas became a focal point of the land-use planning processes and was intended to address landscape-level impacts to the environment arising from human activities. Throughout the 1990’s land-use plans were initiated for the majority of public land on Vancouver Island and then the Cariboo-Chilcotin and Kootenay–Boundary regions.

In June 1993, the government released *A Protected Areas Strategy (PAS) for British Columbia* this document set a commitment to "expanding a protected areas system that will protect 12% of the province by the year 2000". As part of the PAS efforts, and in parallel with CORE and during the same decade, the *Forest Practices Code of British Columbia Act* was implemented and this allowed for a better landscape-level management of wood-harvest in British Columbia. In short, this new legislation for forest harvest was also seen as a tool to ease conflicts amongst resource agencies, industry, First Nations and the public and help protect the environment at the landscape level. The *Forest Practices Code of British Columbia Act* has now been replaced by the *Forest and Range Protection Act (FRPA)*, and while the latter appears to be not as rigorous in protecting the environment, it is still a planning tool and framework to meet ecosystem-protection needs while still allowing forest harvests.

The CORE experience shows that British Columbian's are willing to negotiate sustainability of ecosystems at an ecosystem level. It subsequently provided the opportunity to undertake changes in the ways land use planning was going to be undertaken in other parts of this province. The Land Use Coordination Office (LUCO), reporting to the Finance Ministry, replaced the CORE in 1995 and the efforts facilitated by this agency involved the development of smaller "sub-regional" scale of planning in the form of Land and Resource Management Plans (LRMPs). The current Integrated Land Management Branch has defined Land and Resource Management Planning (LRMP) as *"...an integrated sub-regional consensus-based process requiring public participation that produces a land and resource management plan for review and approval by government. The plan establishes direction for land use and specifies broad resource management objectives and strategies.*" One of the deliverables of LUCO was to provide protected landscapes to meet the PAS target of achieving 12% protection.

A number of LRMP's were largely completed around the turn of the millennium and have now been supplanted by a system of local-level plans known as Sustainable Resource Management Plans. These have typically focussed on watershed-sized areas. Planning activities have largely included identifying biodiversity conservation zones and objectives (e.g., old-growth management areas, riparian areas, wildlife management areas) and have been incorporating First Nations interests. And while LRMP's were a good start, the weakness from a salmon and steelhead perspective is that they do not go far enough, don't cover certain fish-important parts of the province, and don't include landscapes that are not Crown land.

The agency through which much of this planning is undertaken is currently known as the Integrated Land Management Bureau. It is responsible for developing strategic direction for the management of Crown land and natural resources as well as maintenance of British Columbia's existing strategic land and resource planning legacy. The advantage that British Columbia has over many other jurisdictions in this regards is that 92% of the land base is still owned by the Crown, or the citizens of the province. This means that agency land managers are encouraged to ensure that the interests of all stakeholders are met.

These broader-based landscape-level planning exercises that British Columbia has already been engaged in (i.e., PAS, CORE, LRMP, *FRPA*) provide a good opportunity to provide better models to obtain resolutions to impacts to aquatic ecosystems and salmon and steelhead habitats as well as modifying existing frameworks. That is, for the Crown lands of interest where these types of planning initiatives most aptly apply, "tweaking" of existing planning initiatives is probably all that is required to provide that extra protection that is needed to protect many more critical ecosystem attributes, including aquatic values.

URBAN LANDSCAPE ISSUES

The issues of urban impacts to fish and aquatic ecosystems due to developing land for housing, commercial and industrial property are the most problematic of the three landscape-level topics (urban, agriculture, forestry) that we have discussed. Once a landscape is developed to the point where greater than 10% of the land cover becomes impervious to water flows, aquatic ecosystems are irrevocably impacted as a result of these hydrological changes. Moreover, most urban development in British Columbia in high-density human-population centers affects a far greater impervious area than 10%. Added to this are the issues surrounding contaminated run-off and disruption of fluvial processes whereby streams are confined. In such instances habitat is simplified, and there is limited recruitment of woody debris and coarse sediments from the surrounding lands, combining for a scenario that is highly disruptive for salmon and steelhead sustainability.

On a positive note, for those areas of British Columbia where high rates of development are occurring, and where high salmon and steelhead values exist, regional growth strategies have been implemented or are in development (e.g., Metro Vancouver, Fraser Valley Regional District) and this has the opportunity to address these fisheries issues. These planning exercises are derived from the British Columbia Local Government Act. The purpose of a regional growth strategy, found in section 849(1), is to *"promote human settlement that is socially, economically and environmentally healthy and that makes efficient use of public facilities and services, land and other resources"*. While the concept of this legislation and the accompanying Official Community Plan (OCP) provisions of the Local Government Act is that the local governments have to manage the landscapes, it is clear that the implementation of these statutory aspects have not met any reasonable expectations of protection of aquatic ecosystems. Salmon and steelhead ecosystems in urban settings in British Columbia continue to be lost. Perhaps the resolution to this problem includes enhanced education of local councils so that they will direct their planning staff to be more protective of aquatic ecosystems. Alternatively, perhaps the local political pressures are simply too great to provide the needed "push" to realistically protect fish habitat in urban environments.

What makes the issue of protecting landscapes in the urban environment in British Columbia more difficult, compared to forest-harvest lands and agricultural farmland, is that for the former it comprises little crown land and the values and costs of property purchase of these locations is very high for either development or protection. However problematic and costly it may be, landscape-level legislation, that has specific mandates to protect ecosystem values and secure land in urban settings and is rigorously implemented, may be the only way of adequately protecting salmon and steelhead ecosystems in British Columbia in the face of high rates of land-development activity. To make progress in this direction we recommend that the Minister of Environment appoint an independent expert panel to review mechanisms to protect and preserve environmental values in urban environments.

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