Biophysical Sustainability in a Mountain Ecosystem: Resource Use in the Columbia River Valley near Nakusp, British Columbia

By

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BIOPHYSICAL SUSTAINABILITY IN A MOUNTAIN ECOSYSTEM: RESOURCE USE IN THE COLUMBIA RIVER VALLEY NEAR NAKUSP, BRITISH COLUMBIA

BY

GORDON JAY ANDERSON

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University

of Manitoba in partial fulfillment of the requirements of the degree

of

MASTER OF NATURAL RESOURCES MANAGEMENT

Acknowledgements

A project of this size owes its success to many people without whom it would have been impossible to complete. The willingness of the individuals we contacted in southeastern British Columbia to provide us with advice, encouragement and access to information inspired the project when it was at its most uncertain moments. This summary of results is more a reflection of the fruits of their work and effort than of mine.

Within the University of Manitoba and particularly the Natural Resources Institute I found information and encouragement of a different sort. My effort was but one of many thousands of thesis, research projects, and course assignments which characterize an educational institution, yet I found an environment that admired, encouraged and rewarded work and thinking, seeming to be able to view each work-in-progress with enthusiasm. Librarians, classmates, professors, technicians and even the support staff seemed to always have a moment to listen to an obsessed student.

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But Judy was the glue that held it all together. She bent or gave up plans to accommodate my study schedule, writing (endless writing!), library camp-outs, absences and frustrations. She kept dinner waiting on late nights and provided companionship, advice and love when is was most needed. She accepted the time spent away from her, the late nights, the never-ending hours on the computer and the uncertainty of long-range plans. She cajoled when necessary, gave advice and listened to inane ideas and helped make them sensible. She was just the recipe for a successful practicum. I heartily recommend a good marriage—twenty five years of it—before studies begin.

Thanks to you all for your time in my life. I hope your world has been enriched in return with at least a little of what you gave to me.

Jay

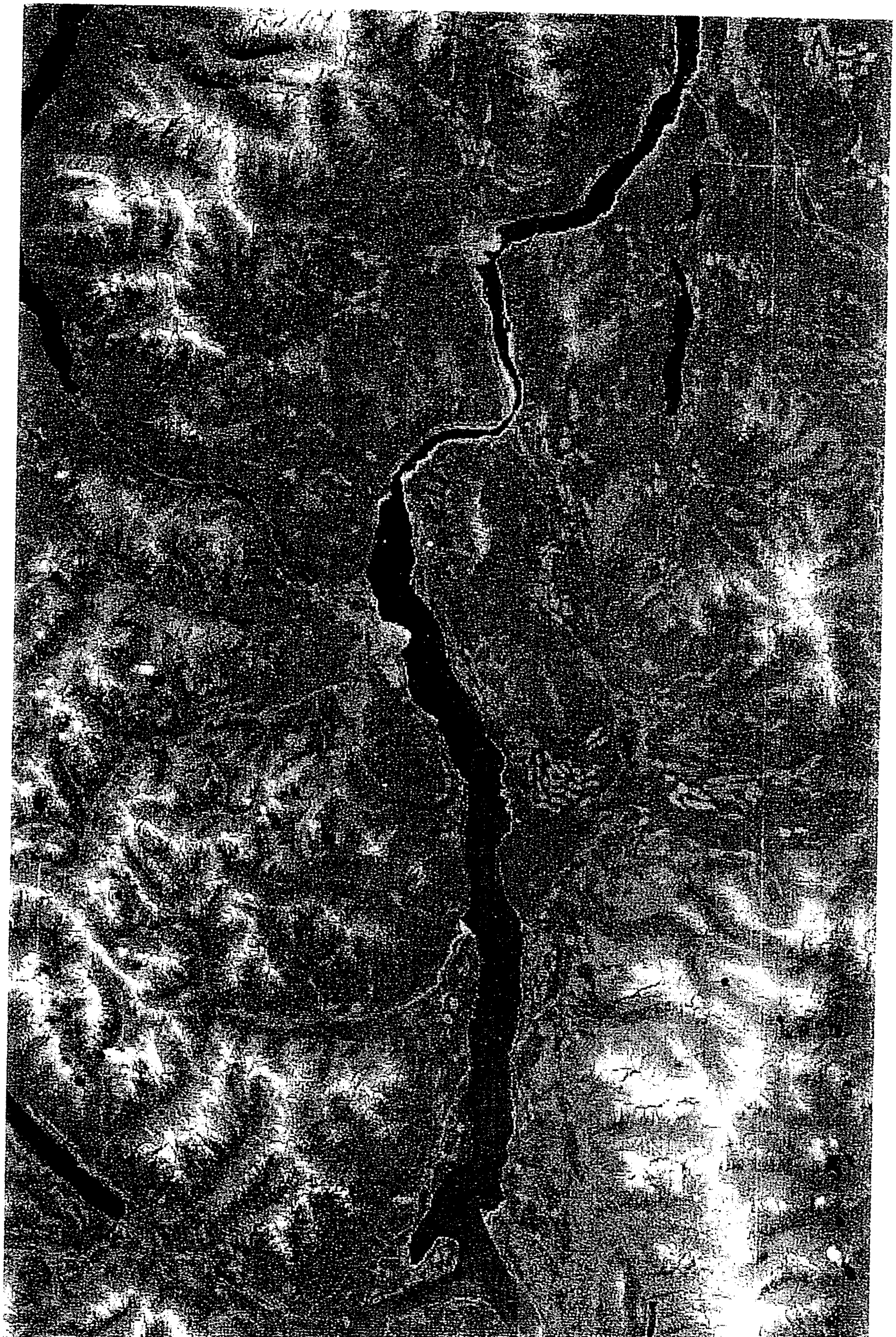

Figure 1: Landsat MSS satellite image of the study area acquired in June 1992. Resolution of the image is 80 metres.

At top centre is Upper Arrow Lake; the north end of Lower Arrow Lake appears at bottom centre. Nakusp is located on the east shore of Upper Arrow Lake at the centre of the image where a prominent alluvial fan extends westward into the lake. Snow outlines the peaks of the Selkirk Mountains on the right, while the Monashees are found on the left. Trout Lake lies at upper right, and Whatshan Lake can be found at the lower left.

Older forests appear as deep shades of red and green. Regenerating clearcuts are shades of lighter red with tones which reflect their age. Light green "rice grains" such as those on the west side of Upper Arrow Lake northwest of Nakusp, are cuts which are less than 20 years old (see also Figures 7, 10, 10a, and 14 for additional details which will aid in interpretation). A string of clearcuts is faintly visible along the length of Kuskanax Creek northeast of Nakusp while extensive old and new cutblocks can be discerned around and north of Whatshan Lake. Primary areas of old growth forest lie east and north of Nakusp.

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1. Introduction

Mountains are a special place.

Not only for the grandeur and the imposing vistas that they provide for those willing to visit, but for their climate, forests, streams and waterfalls, minerals, animals, plants, and a heady wilderness experience which seduces the human spirit. Bharati (1988) ascribes the popularity of the Himalayas to three attractions which market themselves: the "air conditioned part of the Indian summer", alpinist dreams, and a quest for the sacred, mysterious or holy. These enticements - for climate, grandeur, or mystery - are not the totality of the attraction of mountains, but are surely universal elements, equally at home in the Alps or the Rockies or the Himalayas.

Mountains are also a place of fragility. Thin soils, steep terrain and meteorological extremes often dictate an ecological brittleness which constrains the extent of human exploitation. Yet as the 20th century comes to a close, the demands for resources and living space are pushing human populations ever deeper into mountainous regions around the globe. Groetzbach (1988) describes current population trends in the mountains of North America and Europe as "tourism", surely an understatement of the scale of events. In many parts of Asia, Europe and North America, mountain valleys are being settled by a permanent population of new residents as advances in transportation and communication overcome the traditional isolation imposed by the terrain (Lichtenberger 1988). "The principal feature of the mountains, slope, has been overcome by motive power" (Allan 1988, 215).

Because mountains compress in the vertical, the climatology of half a globe, they are rewarded with an immense variety of physical and biological forms. The fragility of this variegated living space can place a large number of organisms at risk if it is mistreated. For centuries humans have adapted to the constraints of living in mountainous regions, modifying the terrain, or adopting new crops and livestock (Whiteman 1988; Brush 1988). These adaptations were learned during the permanence of settlement or repeated seasonal visits.

Mountain cultures are defined in part by the pattern and scope of their use of the landscape. In older and somewhat isolated cultures, adaptation reached a state of quasi-stable (though not static) coexistence as humans responded to a prolonged history of interacting with a demanding environment and the limits of their technology. Agriculture and husbandry were matched to soils, solar exposure, water, seasons, slope and social structures (Whiteman 1988; Brush 1988). Resources were generally harvested in a pattern and cycle which reflected the characteristics of the natural world. Social and economic customs developed in response to the limits of that harvest and to the lessons of history, and the use of the mountain slopes was broadly sustainable.

Newcomers do not always have the indigenous traditions of an earlier era to constrain the scale of their resource harvests. In many cases they come with technologies which permit riskier behaviour, or attitudes which devalue the adaptations of previous cultures. The new arrivals may come with a more economic focus—instead of lifestyle, they seek opportunity. They may use wealth and political influence to incorporate themselves into the local population (Moser and Peterson 1988) and short-circuit the conventions which protect the social and natural environment. In some cases the newcomers may be the poor, seeking new opportunity, but driven by the need for survival, strain the capacity of the resource base instead.

Under such pressures, questions arise about the permanence of the resource base—its sustainability. It is not an easy question to answer, requiring a strong gaze at the past and present, and a peek into the future. It requires examination and measurement. In the words of Carpenter (1994): "If we cannot measure whether a given management practice is sustainable, or predict whether an alternative would be more or less sustainable, how can we move toward sustainability?" This question becomes more urgent in our modern era where the advance of technology and increase in population drives an exploitation of alpine resources on a scale which has never been seen in the past.

1.1 The Purpose of this Study

This project is a part of a larger study by the University of Manitoba and the University of Delhi, sponsored by the Shastri Indo-Canadian Institute, supported by the Canadian International Development Agency, entitled "Sustainable Development of Mountain Environments in India and Canada". The objectives of this larger study are:

> 1) to develop integrated methodologies best suited for the comparative study of land resource management policies in forested mountain watersheds
>
> 2) to study the successes and failures of mountain environment resource management policies, and their social, economic and historical context
>
> 3) to evaluate and develop criteria for assessing and monitoring sustainability in mountain environments, and, in particular to examine some of the relevant cross-cultural dimensions of sustainable development in these watersheds
>
> 4) to interact with policy-makers in resource management and sustainable development so that the policy implications of the study are communicated to the appropriate agencies and people (Berkes *et al.* 1995, 4).

As part of this study, a large amount of work has already been completed in the Himalayan Mountains near the Indian community of Manali. Much of this earlier work has examined the social and economic forces which constrain exploitation of the mountain resources near Manali, and identified new pressures which are changing the traditional structures (K. Davidson-Hunt 1995, I. Davidson-Hunt 1995, Ham 1995). A number of sustainability indicators and the current state of sustainability are evaluated (Duffield 1995) for the Indian site.

This work extends the Shastri study to the mountain watersheds of North America. It has as its purpose the broad assessment of the state of the environment and the characteristics of land and resource use at a site in the Canadian Cordillera—in effect to define a part of the natural architecture of a small community. It focuses on an examination of the biophysical components of sustainability, leaving the economic and social dimensions to others.

1.2 Objectives and Scope

The goal of this study is to take a number of existing resource databases and assess the state of resource use within a site in British Columbia from a sustainable perspective. To evaluate the extent of land and resource use and its long-term sustainability, this project proposes the following objectives:

1. To gather and analyse available satellite imagery, government and cadastral records, air photos, and commercial records to ascertain the biophysical patterns of land use and resource exploitation near the town of Nakusp in the Columbia River Valley.

2. To construct maps showing the pattern and history of land use

3. To relate quantitative measurements of resource use to local impressions and attitudes.

4. To develop quantitative measures of the sustainable use of land and resources using the information contained within the database

5. To make recommendations to foster the development of a sustainable biosphere.

This study limits itself to evaluation of biophysical parameters, leaving the assessment of social and economic factors to another day and another study. To go further, into economic and social factors, would require a huge and long-term commitment. Nevertheless, satellite imagery, geographic information systems (GIS), and the power of computer analysis give even this overview a considerable level of detail and credibility. Even at this, the sheer size of the biophysical world confines this study to a broad overview of the Arrow Lakes ecosystem.

1.3 Description of the Area

The interior mountains of British Columbia are a land of imposing coniferous slopes, mysterious dark lakes, misty morning valleys, hot and bright summers and grey foreboding winters. Back country roads amble endlessly to unexpected pleasures: glacial waterfalls, forgotten ghost towns, sudden icy vistas, mountain goats and grizzly bears. Forests are a quilt of greens and browns, occasionally starkly geometric, a testament to the vigorous logging industry which is the backbone of economic activity. Tourists in silvery boats dot the lakes, enticing kokanee salmon and bull trout to the hook, while highways crawl with summer RV's and purposeful wood chip trucks. It is a land where the hand of man and the hand of Nature are never far apart.

Nature is the provider along the Arrow Lakes. Prosperity waxes and wanes with the international markets for timber and paper, the dry statistics of construction starts, gasoline prices and border crossings. But it is also a delicate land, poised between survival and sudden destruction. Trees and streams, fish and wildlife come and go as humans dig and cut and build and plant and cut again. An uneasy truce teeters and totters between the looming hills and the politics of resource use as conservationists and loggers compete for public sympathy.

The hand of humanity was gentle on the land up until about a century ago. Early explorers found a lightly inhabited landscape, used by several groups of aboriginal harvesters. The terrain required tough men and women. Settlers were few until the discovery of silver in the central reaches of the Columbia River (Barlee 1971) enticed an entrepreneurial population to begin settlement and exploitation. Now, after little more than a century, the mountains are pockmarked by mines and clearcuts. This ready evidence of harvest, development and exploitation has turned public attention to future impacts and the question of sustainability.

This study was carried out in the summer of 1995 in the mountains along the Columbia River valley near the community of Nakusp (Figure 1). The location was chosen for its topographic similarity to a comparable study site in India, its recent history of evolving resource use, changing population and for logistical reasons.

The study area stretches for 100 kilometres along the river valley (Figure 2), from the Galena Bay ferry terminal in the north to the Fauquier ferry terminal in the south. On the east side its boundaries are defined by the heights of the Selkirk Mountains, while western limits are marked by the Monashee Mountains. The Columbia River flows from north to south along the valley bottom, widening to form the Upper and Lower Arrow Lakes. The river has been completely tamed by a series of dams built in the 1970's, inundating flatter parts of the river bottom and increasing the size and depth of the Arrow Lakes, a project which was accompanied by considerable controversy at the time. Many families were forced from fertile valley bottom land as farms and towns were flooded. All of the communities along the shores of the Arrow Lakes have been affected by the new water levels, and some such as Fauquier, are recent replacements for completely drowned communities.

The valley bottom is sparsely settled; the town of Nakusp (pop. 1374) is the only sizeable community. Revelstoke to the north and Castlegar to the south are the nearest communities of significant population; each are a little more than an hour away by car. Smaller communities along the shores of the Arrow Lakes include Beaton, Burton, Fauquier, Apple Grove, Needles, and Deer Park. Nakusp lies at the junction of Highway 6 and Highway 23, two paved roads which provide year-round access along the valley, and to the east and west. In addition, there is an extensive network of resource roads (primarily logging roads) which allow vehicles ready access to all but the remotest parts of the watershed.

Though relatively uninhabited (especially in comparison with the nearby Okanagan Valley and with the Project's study site in India) the valley has vigorous local exploitation of the surrounding mountain resources. The region's silver rush in the 1890s (Barlee 1973), left the mountain sides dotted with the remains of hopeful shafts but today only a few ore bodies are being exploited. Tourism is a growing industry, in large part because of the mining history of the area, and the population is beginning to increase as low land prices attract migrants from Vancouver, the Okanagan Valley, and Calgary. On the steep-sided slopes which contain the Arrow Lakes and on the watershed beyond, the heights flatten to rolling mountain valleys with some of the finest timber and access in the province. However the Monashees have been heavily logged in the past decades, and most of the easily accessible timber is now gone.

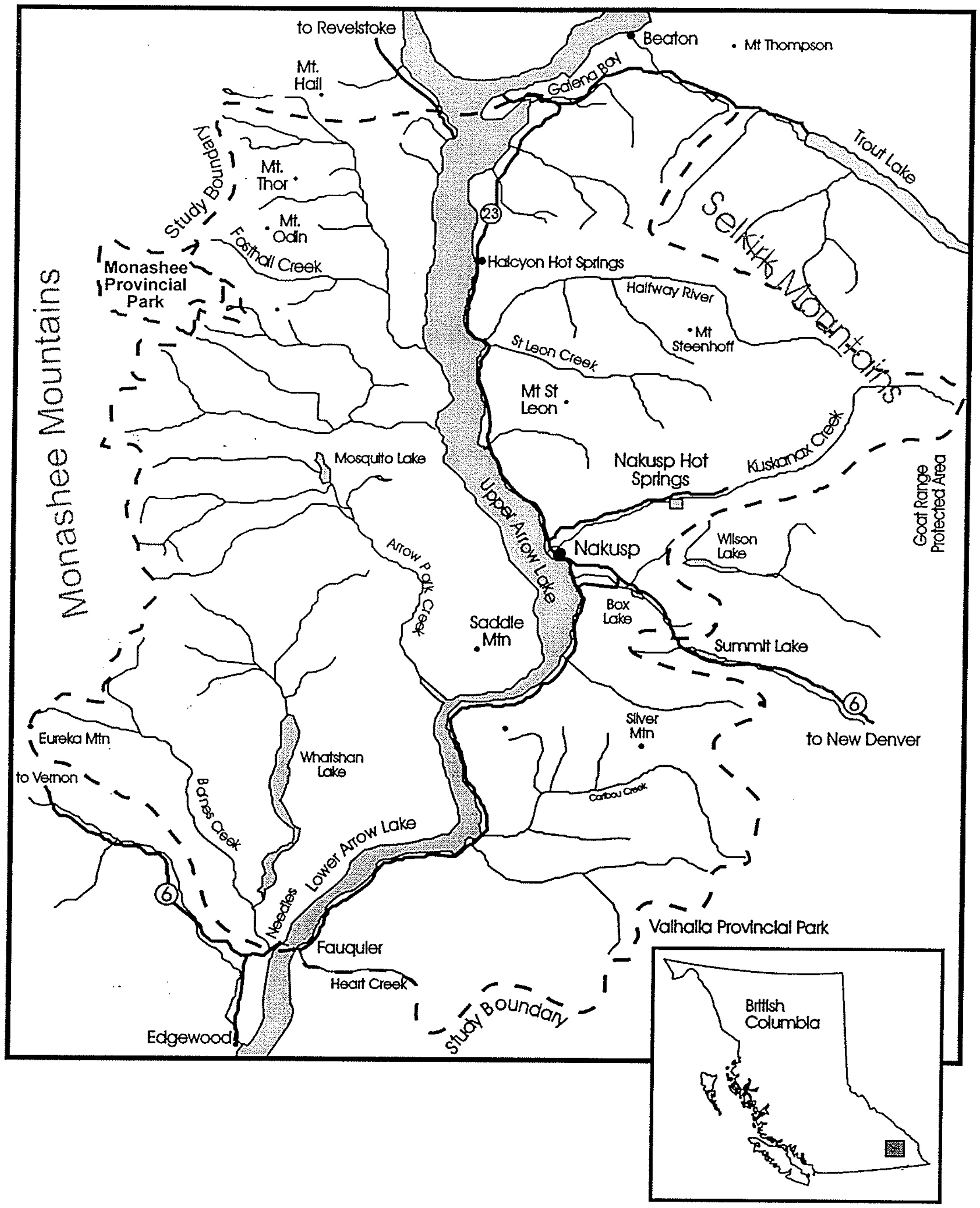

Figure 2. The Arrow Lake study area. The boundaries of the study area are outlined by a dashed line.

The study area has a cool snowy climate in the winter and a warm summer, with a mean annual precipitation of just over 600 mm. Snowfall is common from November to March, with higher accumulations on the middle and upper slopes. Melting of the snowpack can occur at any time during the winter, but typically begins to retreat in mid April and is mostly gone by mid July (Figure 20). Rain can occur at any time of the year, but is more commonly found at lower elevations in the winter.

The lake elevation, which is regulated, is about 420 metres in spring and 438 metres in mid summer (Figure 33). The valley slopes rise 2200 m to craggy peaks above the lake with glaciers on the highest terrain to the northwest of the study area (Figure 1). The local meteorology is controlled by the north-south trend of the valley; rain reaches the area from the south, while snowfall typically come from northerly flows. The valley is both wetter and cooler than the heavily populated Okanagan valley to the west, a factor which no doubt contributes to its much lower population. Winter months tend to be dull and grey at lower elevations as strong inversions trap cloud and moisture in the valley bottom.

2. Measuring the Human Impact

2.1 Sustainability and Sustainable Development

The Brundtland Commission (WCED 1987) defined sustainable development (SD) as development which "meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED 1987, 8). This deliberately vague description has allowed SD to be both embraced and criticized by a wide spectrum of society, from the exploiter to the exploited. One of the more succinct evaluations of this definition is expressed by Rowe (1991, 328):

> "...the Commission elevated Sustainable Development to the position of unquestioned virtue recently vacated by motherhood. Conversion to the faith, when it means all things to all people, is easy. Nevertheless, Sustainable Development is a useful rallying call."

Redclift (1987, 2) mirrors this jaundiced view of the concept: "sustainable development seems assured of a place in the litany of development truisms." In the juxtaposition of these two opposing words, the goal of sustainability usually becomes lost in the contradiction of development.

Such ambiguity has made sustainable development the subject of extensive discussion and philosophical dissection (Redclift 1987), turning it into a cliche in some circles, an ideology in others, and the subject of much scepticism in yet another. This ideological schizophrenia has allowed the concept to be captured by political forces and promoted for political gains. Though perhaps callous, this is a necessary process, as the vagueness of the concept of SD requires further definition which can only come through political sponsorship (Stokke 1991, 8).

According to Braat (1991, 61), SD can be though of as "the process of related changes of structure, organization and activity of an economic-ecological system, directed to maximum welfare, which can be sustained by the resources to which that system has access". In this wordy definition he has gone only a small step beyond the generalizations of the Brundtland Commission. In Braat's mind, most definitions of SD are little more than "anthropocentric welfare optimization schemes" (*ibid.* 61). He is giving voice to one reason why SD is acknowledged with a considerable amount of disdain by the public at large, who appreciate that the "business as usual" approach which Braat's sceptical comment incorporates does not promise much new for the environment.

Carpenter (1994) addresses SD in a similar light. In his mind implementation of SD implies a continued utilization of natural resources and increased productivity for a rising population. Protection of ecological structures is a secondary ideal.

Both Braat and Carpenter follow the Brundtland Commission in viewing sustainable development as an economic vessel. The Brundtland Report and many other discussions before and after have developed SD into an incomplete but wide-ranging normative philosophy. In particular, it includes very strong elements of wealth redistribution, especially from rich first-world countries to the third world. In Stokke's (1991, 9) interpretation the "needs of the present" reflect "the essential needs of the world's poor, to which overriding priority should be given...". SD implies, but doesn't state outright, that the richer world must adopt a lower (likely much lower) standard of living, as there are not sufficient resources to allow all the people of the world to attain the generous living standard of the industrial nations. Others have seen it as a method of encouraging gender equity, and sponsoring better treatment for indigenous peoples.

The essential character is perhaps best described by Lee (1993):

> "Sustainable development is not a goal, not a condition likely to be attained on Earth... Rather it is more like freedom or justice, a direction in which we strive."

The philosophy of sustainable development is as much an application of inter-national equity as it is of inter-generational equity. This begets the question: could the world have sustainability without the elements of international equity? Could the globe go on quite unhappily with the rich staying rich, the poor, poor, and the resource base sustained? The course would be more difficult, but there seems no *a priori* reason why it could not happen—it is after all the stuff of history. Such a scenario is most likely if population growth is curtailed, technology successful, and regulation aggressive. But it would not be sustainable development as Brundtland defined it.

Sustainable development has a grudging acceptance of environmental limits, mostly forced by the weight of limits and population. It is essentially a philosophy of wealth redistribution which has been accepted piecemeal by various forces in society and interpreted to their individual goals. There is no particular reason why ecological concerns need be linked to the formal view of sustainable development (though of course they are), other than as a mediator of what is achievable.

In an opposing vein, Holmberg and Karlsson (1992, 96) view sustainable development as "a defence against humankind's destruction of the ecosphere". In their analysis, "development" refers to human society and "sustainable" to natural systems. In contrast to Duffield (1995), but in concert with Holmberg and Karlsson, this study also makes the distinction between "sustainable development" and "sustainability". The first is primarily a concept of economic and social justice which mandates the continued use of natural resources to redress society's ills until there is a risk that it cannot be continued without a decline in productivity. Sustainable development may perhaps be better described as perpetual harvesting.

Sustainability on the other hand refers to the maintenance of a landscape and lifestyle in some agreed-upon form which includes both a space for human economic activity and a space to preserve the ecosystem under natural controls and rhythms. It makes no judgement about how resources are distributed, only whether they can continue to be harvested.

To be sure, the concept of sustainable development and the concept of sustainability are not independent. There is considerable room for conservation and preservation within the philosophy of sustainable development; it is the importance and application which is lacking. The science of economics has developed the concept of existence value (Randall 1987, 412) which permits the protection of habitats because humans prize their presence and potential. Sustainability as used in this study presumes a certain value in the landscape "as nature managed it" and seeks to preserve a healthy functioning remnant of that world under the pressure of the human presence. The role of economics is seen primarily as a motivating factor.

Sustainability is a modern name on an old practice. For millennia the human race has planted and harvested and cut and dug and collected and hunted with greater or lesser impact on the natural world. It is a truism that human beings modify environments. This occurs at all scales and is the inevitable consequence of the presence of the human animal within the environment, as indeed it is with all organisms. Sometimes the modification is relatively minor, as in the spread of diseases or the ruination of a small ecosystem. Sometimes it is widespread, as in the settling and ploughing of the prairies or the burning of forests to provide fodder for horses (Langston 1995, 46). The essential factor, and the reason why concepts such as sustainability and sustainable development are even necessary today, lies with the modern scale of human intervention in the ecosystem.

Some years before the Brundtland Commission, the International Union for Conservation of Nature and Natural Resources (IUCN 1980) outlined three fundamental objectives necessary to achieve sustainability:

- maintain essential ecological processes and life-support systems
- preserve biological and genetic diversity
- ensure the sustainable use of species and ecosystems

It is noteworthy that the first two entirely, and the last partially, emphasize the protection of the natural environment, without economic compromises. These objectives encompass the meaning of sustainability as used in this work.

The science of economics also recognizes the primacy of resource protection over economic development, at least as far as sustainability is concerned. Pearce and Atkinson (1995) develop simple measures of sustainability which account for both human and natural capital (ie. development and environment). In their approach capital assets are partitioned between man-made capital (K_M), human capital (K_H) and natural capital (K_N). Natural capital includes "any natural asset yielding a flow of ecological services with economic values over time" (*ibid.*). By requiring that net capital ($K_M + K_H + K_N$) remain at least constant, they propose a basic condition for sustainability:

$$\frac{S}{Y} - \frac{\delta_M K_M}{Y} - \frac{\delta_N K_N}{Y} \geq 0$$

where S is savings, Y is income, and δ refers to depreciation so that $\delta_N K_N$ refers to the depreciation in natural capital. To Pearce and Atkinson this is the "weak sustainability rule", in large part an economic definition of sustainable development. Most ecologists would question this equation because it assumes complete substitutability between natural and man-made capital, a substitutability which does not exist across many facets of the environment. Also inherent in the dispute is the question of the value of natural capital stocks.

Pearce and Atkinson go on to develop the "strong sustainability rule" which requires only that K_N remains at least constant (and that K does not decrease). A more detailed analysis by Turner (1993) develops four levels of economic sustainability. His "strong sustainability" criteria are similar to those of Pearce and Atkinson in requiring that K_N be constant, noting that "the rule would be monitored and measured by physical indicators". While the strong rule has deficiencies in that it permits free substitutability between the components of natural capital, it is an economic justification for the biogeophysical analysis conducted in this study.

Having made the argument in favour of evaluating the ecological component of sustainable development separately, we must now admit the impossibility of doing so. Though the environmental constituent can be extracted for concentrated study, influences of its two travelling companions will always accompany the analysis. In this examination occasional reference will be made to economic and social consequences, in recognition that a large and complex interlocking relationship must exist outside of the major view of this research.

Nevertheless, the luxury of a wide range of economic and social interactions in sustainable development is only possible where sufficient resources are available to fuel the effort. Once resources become constrained, social and economic options are correspondingly limited. The reverse is not true.

Perhaps the shortcomings in the philosophy of sustainable development with respect to the status of the environment are being increasingly recognized in more recent application. Hardi and Pinter (1995, 4) note that "there are strong scientific arguments for a category of compulsory biophysical indicators as *minimum* [sic] requirements of sustainability". It is these indicators which the present study attempts to evaluate.

2.2 Environmental Indicators

Many SD and sustainability indicators have arisen as an extension of the development of a class of closely related measures known as environmental indicators. The demand for environmental indicators gained considerable impetus with the publication of a number of "State of the Environment" reports in Canada (Canada 1991; Environment Canada and the Province of British Columbia 1993) and elsewhere in the late 1980s and early 1990s. Many of the initial conceptual studies about indicators were conducted in support of these works.

Sheehy (1989, 2; 1991) discusses several definitions of environmental indicators gathered from various authors. These definitions have a number of common characteristics. They are often aggregates of several measurable variables, a surrogate representation of the environment, or combinations of other indicators. They may be defined in terms of the use to which they are to be put, such as project evaluation, identification of an area for action, monitoring, or communication with the public or with policy makers. Some of Sheehy's indicators are biophysical in nature and some are social and economic.

Opschoor and Reijnders (1991, 18) suggest that the aggregated approach is preferable, but not always feasible due to the vast amount of data which must be assessed and the formal difficulties in aggregation. Most authors however reject the idea of a single number representation of the state of the environment (Environment Canada 1991, 4). Polls of community leaders (*ibid.*, 4) showed that people want indicators with the following characteristics:

- related to things they do or value
- credible and widely accepted
- simple
- responsive to the short range
- sensitive to regional variations
- able to accommodate new scientific information

Aggregate indicators would have difficultly with many of these suggestions, particularly the need for simplicity, credibility and adaptability.

To Opschoor and Reijnders (1991) environmental indicators are "quantitative descriptors of changes in... environmental pressure or in the state of the environment". They identified two types of indicators - pressure indicators and effect indicators. The pressure indicators include levels of pollution, emission, deposition, discharges and so on in an area; they are a kind of chemical surrogate for economic activity. Effect indicators reflect the consequences of environmental quality changes in terms of their impact on some natural receptor. This latter class includes biological diversity, human health, population sizes, niche sizes and so on.

2.3 From Environmental Indicators to Indicators of Sustainability

The step from environmental indicators to indicators of sustainable development (and sustainability) is a short one and the two types are often used interchangeably. But sustainability indicators have one additional character trait: they are defined with respect to a reference value, a value whose relevance and appropriateness "should be beyond doubt and dispute" (Braat 1991, 60). This is a more difficult concept to apply than it might appear, as the reference state is often unknown or guessed.

Consider, for instance, the release of anthropogenic CO_2 into the atmosphere, one of the gases believed to contribute to global warming. If we make the reasonable assumption that the appropriate level of release is one that causes no detectable increase in global temperature, then we are not much further ahead, for there is considerable debate as to whether even current high levels are responsible for existing patterns of temperature increase. Not even considered is the idea that a limited rise in global temperature may bring a net benefit to many ecosystems (Monastersky 1996); perhaps the Earth is too cold! The reference or benign level for carbon dioxide emission is therefore essentially unknown, or at least has no unambiguous scientific value, and will depend on personal preferences and educated guesses.

When the concept of reference level is applied to economic and social values the uncertainty is even greater. What is an appropriate level of income distribution between the wealthy and the poor for instance? Sustainability indicators (as this work defines them), being primarily focussed on scientific ecosystem measurements, are on firmer ground than many social and economic indicators. Nevertheless there are many shortcomings as far as sustainability indicators are concerned, and so most indicators are directional rather than absolute. That is, they are environmental indicators. Thus we have measurements that suggest increasing or decreasing emissions per capita, or nationally, without an indication of the optimum or sustainable level.

Economic theory has many problems with appropriate measures of SD. Victor et al. (1991) examined five economic theories[1] for measures of sustainability. Each one had fundamental flaws, though the authors ventured bravely onward to suggest suitable measures of SD for each school. One of the major problems for all economic theories is the question of substitutability. If a resource has a substitute there is no particular economic reason to conserve it (Opschoor and Reijnders 1991, 16), unless the aesthetic value can be counted and added into the sustainability equation. In this case the valuation becomes a problem - how much is it worth and to whom? Recent events in BC forests have lead to the preservation of old growth forests by provincial decree because they were highly valued by a small but very active segment of the population (Kay 1995). And values change over time —the last member of a species becomes very much more valuable than its predecessors.

Wherever a reference level can be ascertained, relating the SD indicator to it becomes essentially a normalization process, a procedure which facilitates comparison of indices and agglomeration of component parts. In effect they measure the distance between the current state and the reference state or in economist Herb Daly's words, act as a "Plimsoll line". To

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[1] The NeoClassical School, Post-Keynesian School, London School, Natural Capital, and the Thermodynamic School.

a large extent it allows the minutia of reductionist measurements of environmental health to be combined into a more holistic evaluation of an ecosystem. However Opschoor and Reijnders (1991) caution that because sustainability indicators are normative, they can be subject to the prejudices of goals, biases, audience and available data.

Holmberg and Karlsson (1991, 100) note that normalization can be accomplished in several manners. The reference level can refer to the critical load of a pollutant, beyond which the environment has no further absorptive capacity (a risk index). The normalization may refer anthropogenic flows to natural flows (a disruption index). Indicators may also be referenced to possible or potential flows, especially if used to show improvements in environmental stresses (an efficiency indicator).

The one reference level which is often readily available is the current state of unperturbed natural ecosystems (that is, a disruption index, as noted above). Given the uncertainties which envelop any assessment of ecosystem impacts, the safest and most fundamental reference level is nature itself. The effect of human activities on a sensitive species for instance could then be referenced to the wild population, and as more information became available about impacts on the species and its sustainable characteristics, the reference level could be adjusted. Such an approach imposes large constraints on resource exploitation until ecosystem impacts can be evaluated.

Braat (1991, 60) lists a number of requirements for indices which pertain to their scientific adequacy:

- indicators must be representative for their chosen system
- they must have a scientific basis
- they must be quantifiable
- they should provide information free of social bias
- they must represent reversible and manageable processes
- they should have predictive meaning

These requirements have a number of elements in common with the selection criteria outlined by Environment Canada (1991b, 4) for environmental indicators:

- be scientifically valid
- be supported by sufficient data to show temporal trends
- be responsive to changes
- be understandable
- be relevant to goals
- have (ideally) a target or threshold level [2]

For an entire ecosystem in which the reference lines are unique to each measurement, overall assessment of the overall sustainability becomes a task of deciphering and interpreting a tangle of distance indicators. This seemingly onerous task is accomplished in an ingenious fashion by ten Brink (1991) who constructs wind-rose-like diagrams from individual (reductionist) measures of environmental health. ten Brink incorporates only biological indicators into his discussion, but there is no particular reason why separate or combined diagrams could not be constructed for the three components of sustainability: environment, economics, and social well-being. In ten Brink's "AMOEBA" [3] approach, the circumference of a circle represents the reference level for sustainability, which he defines as "the desired state of the biotic

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[2] becoming, in effect, an SD indicator

[3] AMOEBA is the Dutch acronym for "a general method of ecosystem description and assessment".

component... defined by government" (*ibid*,. 76). Those elements which exceed sustainability criteria extend beyond the circle, while those with shortcomings lie within (Figure 3). ten Brink then adds the distances of each element from the reference circle to derive a single-valued indicator of sustainability which he denotes "the Ecological Dow-Jones Index". Parameters which exceed the reference limit are accorded a value of 100 (%).

The AMOEBA approach has the disadvantage of weighting each indicator equally rather than according to some measure of impact. There is some benefit to this as it avoids dispute about the relative importance of each measurement, if indeed the ecosystem is well enough understood that the importance can even be determined. For this reason there is some doubt as to whether weighting should be incorporated, though it could be done so easily enough. The AMOEBA technique lends itself to ready disaggregation when required, an important characteristic of indicators which has been noted by several authors (cf. Ruitenbeek 1991, 10).

The AMOEBA strategy also satisfies many of the desirable characteristics outlined above for indicators: the graphics are easily modified to present new data or reflect new understandings, and can accommodate temporal trends by incorporating rates of change. They are easily understood, even by a public which is unfamiliar with the scientific or economic underpinnings of the measurements. Future status of an ecosystem can be depicted by constructing additional diagrams based on regression or modelling. And the historical status of the ecosystem can be displayed by constructing AMOEBA diagrams for the past. The diagram combines, in one view, both aggregate and individual performance measures. Another source of sustainability indicators moves outside formal scientific disciplines and evolves from the

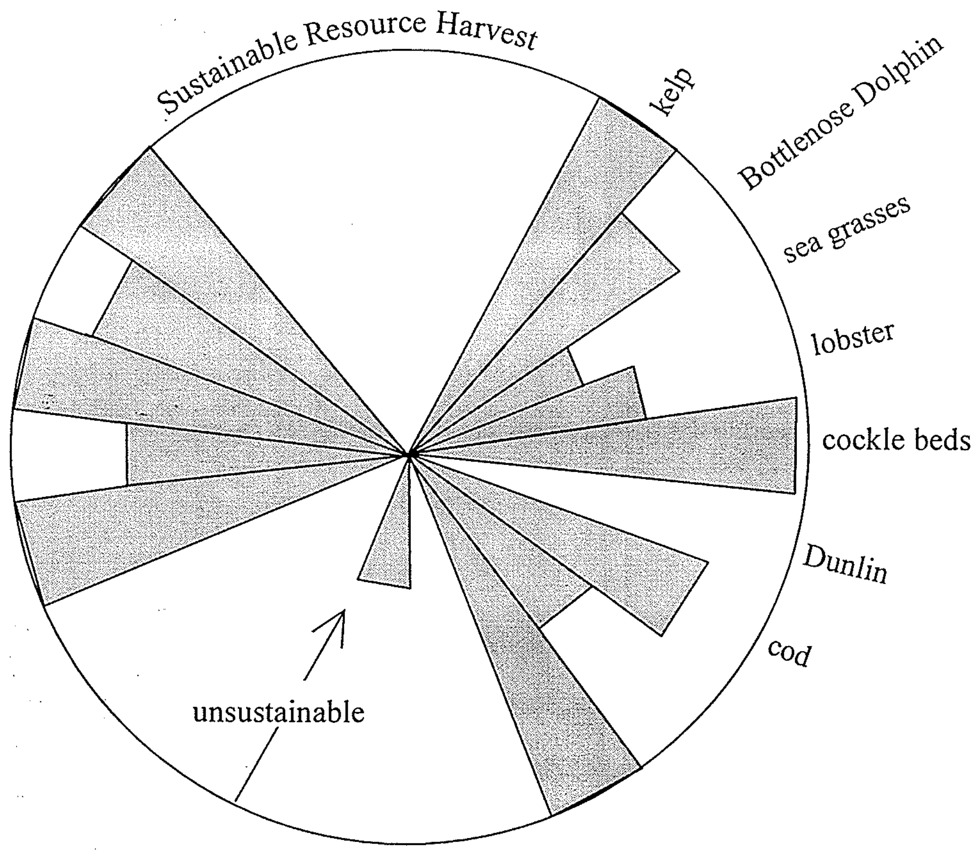

Figure 3: Schematic of a modified "AMOEBA" diagram, after ten Brink (1991). The sustainable reference level is indicated by the circle. Those species which are being harvested or otherwise impacted at a level which is not sustainable are placed within the interior of the circle, according to their "distance" from sustainability.

desires and impressions of the humans living within and utilizing the ecosystem. The earlier work in India by members of the Shastri project team found the following local biophysical "yardsticks" of sustainability of a mountain ecosystem (Duffield 1995):

- the extent of forest cover
- the forest density, quality and proximity
- stable water flow
- amount of erosion
- the number of landslides and avalanches

Duffield (1996) conducted a similar study for the Arrow Lakes study area in 1995. Environmental concerns there were less specific than those found in the Indian survey: land cover patterns and ecological health received top billing. Concerns were also expressed about timber harvest levels and silvicultural practices.

The concerns expressed in both India and British Columbia provide valuable clues for incorporation into this study. These "populist" indicators can be related to the IUCN objectives and to Rowe's criteria. On a broader scale, biological and genetic diversity is reflected in forest quality, the mix of tree species, and harvest levels. Changes in the extent of forest cover and water flows may reflect the stable and sustainable use (or misuse) of ecosystems, the increase or decrease of habitat for other species, or the excessive appropriation rate of materials from the resource base. Landslides and erosion may reveal natural processes or the "poisoning" of the ecosystem described by Rowe (1991).

A premise of this project is that many sustainability indicators are amenable to study from aircraft and satellite, and from legal and commercial records of land use. They can be assessed on an activity-specific basis: mining, forestry, and fishing for instance. They can be compared to reasonable reference values, or to a range of values. And they can be easily understood and used by managers and citizens concerned about their surrounding environment.

3. Research Method

Two visits were made to the study area during the summer of 1995. The first, in late May and early June, was a scouting trip made to meet with local managers and owners of various resource databases and make arrangements for their acquisition and use. Broad discussions of resource use and local impressions were initiated. The second visit, of several weeks duration, took place in July and early August. At this time a number of databases were collected, and more detailed interviews with resource technicians, managers, and local users were conducted. Much of the discussion centred around interpretation of the databases, and identification of important environmental issues and management responses to these problems.

Discussions were guided by the results of the India study and the sustainability criteria identified by the inhabitants of that mountain study site. Contact with the residents of Nakusp and other regional towns provided invaluable insights into resource management problems in the B.C. mountains.

Site visits were made to view forest harvesting operations, fish hatcheries, hydrologic sites, and a broad exploration of the local topography, economic activity, history, hazards, and land use was conducted. Some informal ground verification of satellite imagery was attempted, though most of this information was obtained from GIS databases and aerial photographs. Local contacts provided information and data very freely, with a broad and enthusiastic encouragement for this project.

Discussions were informal as the intent of this study was to examine objective measures of sustainability. Nevertheless local input provided a valuable source of information by identifying regional environmental concerns and providing leads to additional databases.

A Landsat 3 band MSS satellite image of the Columbia River valley (Figure 1) was purchased from a commercial source [4]. These images cover a 185 km wide swath on the Earth with a resolution of approximately 80 metres. The MSS wavelengths sample two bands in the visible portion of the spectrum and two in the near-infrared (NIR). Analysis techniques for these images are well documented in the literature and commercial software is readily available for analysis and interpretation. The technology is mature and robust, and the processing and classification algorithms are well-established (cf. Drury 1990, McKendry *et al.* 1992, Mather 1987). Initial plans called for an extensive analysis of the satellite imagery, but the available GIS databases proved to contain a much higher information content and more than supplanted the satellite data.

Aerial photographs of the British Columbia landscape are available beginning in the 1930s (Gardner[5], pers. comm.) and continuing at irregular intervals to the present. They are panchromatic images in red wavelengths with high resolution. Two sets of high altitude air

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[4] Radarsat Inc, Richmond B.C.

[5] Dr. James Gardner, Dept. of Geography, University of Manitoba.

photos, one dating from 1970 and the other from 1987, were purchased from the B.C. government, along with a selection of thematic and topographical maps. High altitude images were selected in order to keep to a manageable number of photos; the two years above were the only ones available.

An extensive follow-up to local data collection was conducted by telephone and electronic mail. Eventually an extensive and eclectic database was assembled from a variety of private, commercial, professional, federal and provincial sources (Table 1). Several of the data collections were redundant, as most of the owners shared information with the others, but the most useful were selected for study. Data analysis was conducted at the University of Manitoba. Satellite and GIS data were processed at the Centre for Earth Observation Science (CEOS) in the Department of Geography. Purchased and donated commercial software was used for statistical and GIS analysis.

Geographic Information Systems (GISs) are computer-based systems used to store, combine, classify and display geographical information. Order-of-magnitude increases in computing power in the past decade have fuelled the development of the GIS, and systems are beginning to spread widely through government, business, and research agencies (Aronoff 1993) which require the data manipulation characteristics of the software. In Eastman's (1992) words "GIS has had an impact on virtually every field that manages and analyses spatially distributed data". GISs are capable of combining a wide variety of datasets and producing task-specific maps for decision-making where geographical position is important. Most GISs are wedded to remote sensing systems in order to take advantage of the large amount of information typically found in aircraft or satellite acquired data.

The GIS software selected for this study (Pamap™) was dictated by the database selected for exploration—that maintained by B.C. Environment for the Kootenays. This database incorporates B.C. Forestry data as well as a number of environmental maps. Pamap™ was donated to the University of Manitoba by the manufacturer for this study and proved to be of major benefit in the assessment of human impacts.

4. The Impact of Forestry

4.1 Introduction

Forests are the economic backbone of the Arrow Lakes study area. The extent of this resource harvest is evident throughout the valley, with variegated patches of green and occasional brown marking regrowing and freshly-harvested slopes. Backroads reveal vigorously growing even-aged stands, and the growling sound of old timber being cut. The economic benefits are evident in nearly all of the small communities along the lakeshore, most especially at Nakusp, where lumber, pulp, and associated businesses bring jobs and prosperity.

But few events in resource extraction bring more public condemnation than the cutting of our forests. Humans are deeply attracted to the sight, smell and feel of forests—perhaps an awakening of primeval emotion? And while wood and paper are essential components of our economy and lifestyles, the vision of Canadian and American forests being denuded for these products evokes reactions from mild to extreme dislike. There is nothing attractive about the cutting of forests, even to control disease and insects, and so logging is likely treated as a necessary evil by the majority of Canadians.

Table 1. Databases and data sources evaluated for incorporation into the study. Those used are marked with an asterisk.

Database	Comments
satellite image*	Landsat 3 band MSS image, June 25, 1992
air photos*	high altitude coverage from 1970 and 1983
hydrological data*	Hydat CDROM dataset, Environment Canada
climatological data*	Environment Canada (B. Fehr)
GIS land use data*	B.C. Ministry of Environment, Lands and Parks (MoELP)
GIS land use data	B.C. Forestry, Forest Inventory Branch (D. Gilbert)
GIS land use data	Pope and Talbot Ltd.
endangered species	COSEWIC (C. Paige)
forest insect disease data*	Forestry Canada
earthquake database	Energy, Mines and Resources Canada
caribou habitat data*	Canadian Heritage, Parks Canada
bull trout catch data*	Glen Olson, Olson's Marine, Nakusp
kokanee CPUE data*	B.C. MoELP, Grant Thorp, Senior Fishery Technician
kokanee population data*	MoELP, S. Sebastian
Arrow Lake water quality*	B.C. Hydro
trap line harvest data*	MoELP, Nelson
B.C. fur auction prices*	North American Fur Auctions, Winnipeg
sewage discharge inventory*	Environment Canada, Conservation & Protection
land use data*	CORE report and background (CDROM)
air quality*	B.C. MoELP, Nelson
municipal water use	Environment Canada, Conservation and Protection

Much of the effort to obtain data for this study concentrated on the acquisition and assessment of forest data bases (Table 1). Of those available, the GIS database provided by B.C. Environment in Nelson contained the entire Ministry of Forest database, a total of over 65,000 map polygons, each one containing descriptions of the major tree species, their ages, and characteristic geographical data for each map unit.

In the evaluation of sustainable use of natural resources within the Arrow Lakes study area, the forestry component is the most important. The reasons are self-evident: most of the landscape is forested, the forest industry is the largest employer, it has the most obvious visual effect on the landscape, and forest health is intimately tied to the other components of the ecosystem.

4.2 Elements of Sustainability in the Forest

The human presence within the complex ecology of forests brings a very large number of questions about sustainability, most of which are barely visible in the mists of ignorance and the absence of data. The scales of these questions range from global to microscopic, and so this treatise can only begin to examine the most visible of consequences. Many of these are grounded only in speculation and surmise, as the lack of data, at present and especially in the past, limits the scope of the evaluation. Nevertheless, there is still considerable meat on the bones and food enough for a scientific meal.

The major environmental issues in timber harvesting are well known and widespread in the literature (Postel and Ryan 1991; CCFM 1995; Hammond 1993):

- declines in forested areas
- loss of old-growth forests
- loss of habitat for wildlife, plants, birds and fish
- erosion
- decline in water quality
- decline in biodiversity within the forest ecosystem
- decline in ecosystem health and productivity
- increasing global climatological threats driven in part by timber harvesting

These categories are sufficient to describe the broad questions of forest management and resource extraction, but do not get at the fundamental operational practices which must be addressed in the evaluation of sustainability. For instance, decline in biodiversity incorporates subjects such as the type of tree cut and replanted, the effect of roads on caribou habitat, and the size of a stream buffer strip as it relates to bull trout populations. Ecosystem health is made up of concerns such as buffer strips, loss of soil fertility in clearcuts, and the population of insect-eating birds. Global climate effects must address the use to which timber is put, the debris left in the forest, and how the land is prepared. Water quality is a condition of road building techniques, timber harvesting techniques, and the size of buffer zones. In the end, each area of concern is a collection of dozens or hundreds of individual questions, many without any substantive answer.

The question of sustainability in the study area can be decomposed into three components. The first of these is the question of economic sustainability as it relates to the extraction of wood from the forest. The second is ecological sustainability, which might also be described as the preservation of biodiversity. The third and perhaps most difficult is the interaction between the two and the question of whether ecological and economic costs and benefits can be balanced across the Arrow Lakes landscape.

Cutting down the forest has inevitable ecological consequences. Whether these are manageable and mitigatable so that the whole of the renewable resource base and its biological inhabitants are sustained is an intriguing question.

4.3 Timber History and Administrative Structure of the Valley

The first Europeans arrived in the Arrow Lakes area in the 1830's but timber harvesting did not begin until late in the century when settlers began to purchase land in the valley bottoms along the Columbia River. Mining in the nearby Slocan Valley and sawmilling were the main industries as markets for agricultural produce were limited by a poor transportation network.

The first sawmill was established in Nakusp in 1893 (Pope and Talbot 1994a, App. I (c)), operating as the White Pine Lumber Company until it burned down in 1929. The Big Bend Lumber Company built on the same site six years later and operated for another 25 years until 1960. A new mill at Castlegar was under construction at that time, and many small operators along the Arrow Lakes made their living supplying that mill. One of the largest cutting areas was at Fosthall, across Upper Arrow Lake and 19 kilometres north of Nakusp.

In 1952 the Celanese Corporation of America applied to the B.C. government for a forest management license for the Arrow Lakes forests. The construction of the mill at Castlegar was a condition of that license, and building of a combined saw and pulp mill began in 1958. The mill began operating in 1961 with a capacity of 10 million board feet per year. In the late 1980's the mill and forest license was sold to Celgar Pulp. A 1000-tonnes-per-day pulpmill was constructed in 1991 by the new owners.

Large-scale forestry in British Columbia is divided between two administrative structures: Tree Farm Licenses (TFLs), and the Timber Supply Areas (TSAs). Private holdings represent a small percentage of the timber base. Within the boundaries of this study almost the entire forest land base is taken up by two holdings: TFL 23 and the Arrow TSA (Table 2; Figure 4).

TFL 23 is a provincial forest administered by the Ministry of Forests (MoF) under the authority of the Forests Act. Tree farm licenses arise from "an agreement entered into with the provincial government which provides for the establishment, management and harvesting of timber by a private firm on a described area of Crown land" (MoF 1994). TFL's are area-based forest tenures.

The Arrow TSA makes up approximately one-third of the study area (Figure 4). TSA's are defined by a meaningless phrase as "an area of Crown land defined by an established pattern of wood flow from the forest to the primary timber-using industries" (MoF 1994), but are essentially the areas for which volume-based forest tenures are issued (CORE 1995, 15106). Within the Arrow TSA and TFL 23 a small land base is set aside for the Small Business Forest Enterprise Program. In this program, small cut blocks are reserved for auction and harvesting by smaller firms. In TFL 23 this area represents approximately 12% of the area to be harvested between 1994 and 1998 (P&T 1994, 1).

Forest Management License 23 (the precursor of TFL 23) was awarded to Celgar Development Company in 1955. It covered an area of just over one million ha, one of the largest in the province at the time. About one-third was estimated to be loggable. In the

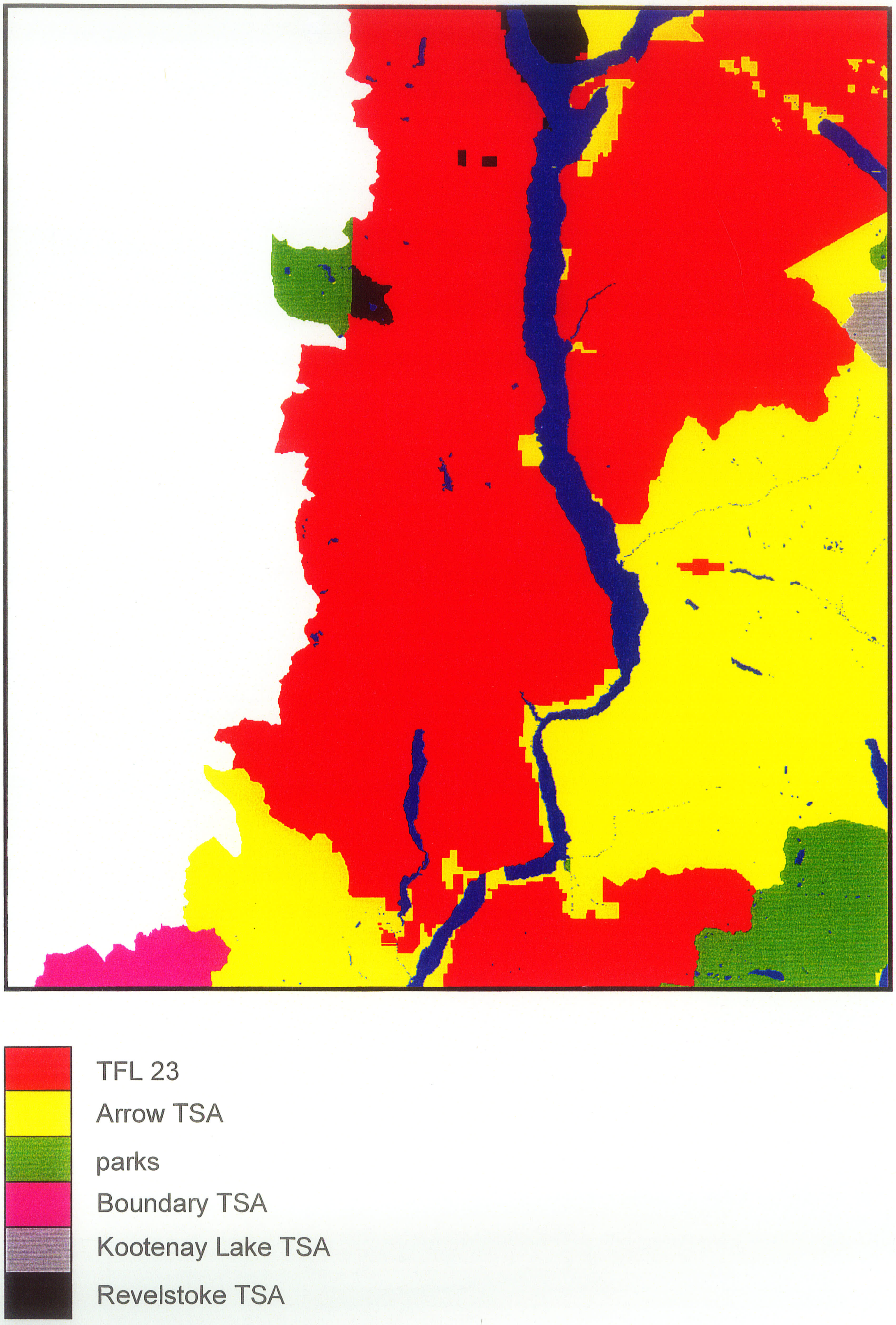


Figure 4: TFL and TSA boundaries in the study area.

ensuing years, FML 23 has become Tree Farm License 23 and ownership has changed several times, resting since 1992 with Pope and Talbot, Inc. The original TFL 23 has been reduced in size several times in the intervening years, first to remove bottom land for the Columbia Reservoir and then by transfer of two blocks of land to the Revelstoke timber supply area. Several smaller removals were awarded for homesteads, parks, lookout towers, and communication sites in the years between 1955 and the present. The current area of the TFL is now less than half its initial size (Table 2).

Presently the Arrow TSA has a total land base of 754,000 ha, of which 201,000 ha compose the timber harvesting land base. TFL 23 comprises an area of 555,000 ha of which 371,000 ha is productive forest. The land base which is not part of the "productive forest" is made up of environmentally sensitive areas, private land, roads, steep slopes with unstable soils, inoperable land, non-merchantable timber and other similar limitations. The two forestry tenures make up about 80% of the study area; the study area itself comprises about 20% of the land occupied by the TSA and the TFL together.

Early cutting patterns along the Columbia River consisted of small clearcut blocks surrounded by leave strips; this gradually evolved into larger clearcuts using crawler tractors and skidders. Cable harvesting was introduced in the mid 70's and feller-buncher harvesting shortly afterward. In TFL 23, 36% of the harvest volume is now done by cable logging, a system in which trees are lifted off the forest floor and carried to a landing area where they are trimmed and loaded onto trucks. This method reduces damage to the forest floor during logging operations.

Element	Arrow TSA	TFL 23
Area	754,079 ha	554,997 ha
Productive forest	404,263 ha	371,300 ha
Timber harvest land base	216,760 ha	236,095 ha
NSR (not sufficiently restocked) land	7,481 ha	6,381 ha
Primary tree species	Douglas-fir, larch, pine	Douglas-fir, larch, pine
Annual Allowable Cut	619,000 m^3	680.000 m^3
Environmentally sensitive area	31,395 ha	134,789 ha
Visually sensitive landscape	40,595 ha	117,647 ha
Annual losses to fire and insects	34,259 m^3	–
Watershed zone	30,384 ha	11,229 ha
Wildlife zone	20,162 ha	8,209 ha
Long term sustainable harvest	422,000 m^3	534,000 m^3

Table 2. Description of the Arrow Timber Supply Area and Tree Farm License 23.

Clearcutting is currently the main form of timber harvesting in the TFL. Recent years have seen a reduction in the size of the area cut, to the so-called patch cutting system. Pope and Talbot has stated that alternatives to clearcutting, such as seed tree and shelterwood cutting procedures (MoF 1995c), will be promoted (P&T 1994, 32) in the 1994 -1998 harvest plans. Their silvicultural goal is to "regenerate an even-aged stand of shade intolerant species, ie. conifers that regenerate best in full sunlight."(P&T 1994, 323).

Silviculture in the early 1950's was designed to encourage natural regeneration. The first seedlings, 3,200 Douglas-fir, were planted in 1957. Planting increased to 50,000 seedlings in 1961, and continued at a modest rate through the mid 70's. By this time it was realized that more aggressive silviculture was needed, so herbicide application and cutting to control competing brush were combined with an increased rate of planting. In the years from 1957 to 1993 the Arrow forest district replanted over 20,000 ha of land (Figure 5) representing over 26 million trees, mostly at the expense of the provincial government.

Responsibility for replanting passed to the license holder in 1987 and more intensive silviculture was instituted. A government and industry funded plan, the Forest Renewal Initiative began the restocking of 12,000 ha of NSR (not sufficiently restocked) land in TFL 23 in 1989. Pope and Talbot replanted 13.7 million seedlings between 1990 and 1993; over 90% survived (P&T 1994, 6). In the same time, 6,217 ha were logged. The backlog was essentially completed in 1995 with only 785 ha of the most difficult land remaining to be planted.

Today in the West Kootenays, forest harvests amount to 4.3 million m^3 of which 84% is

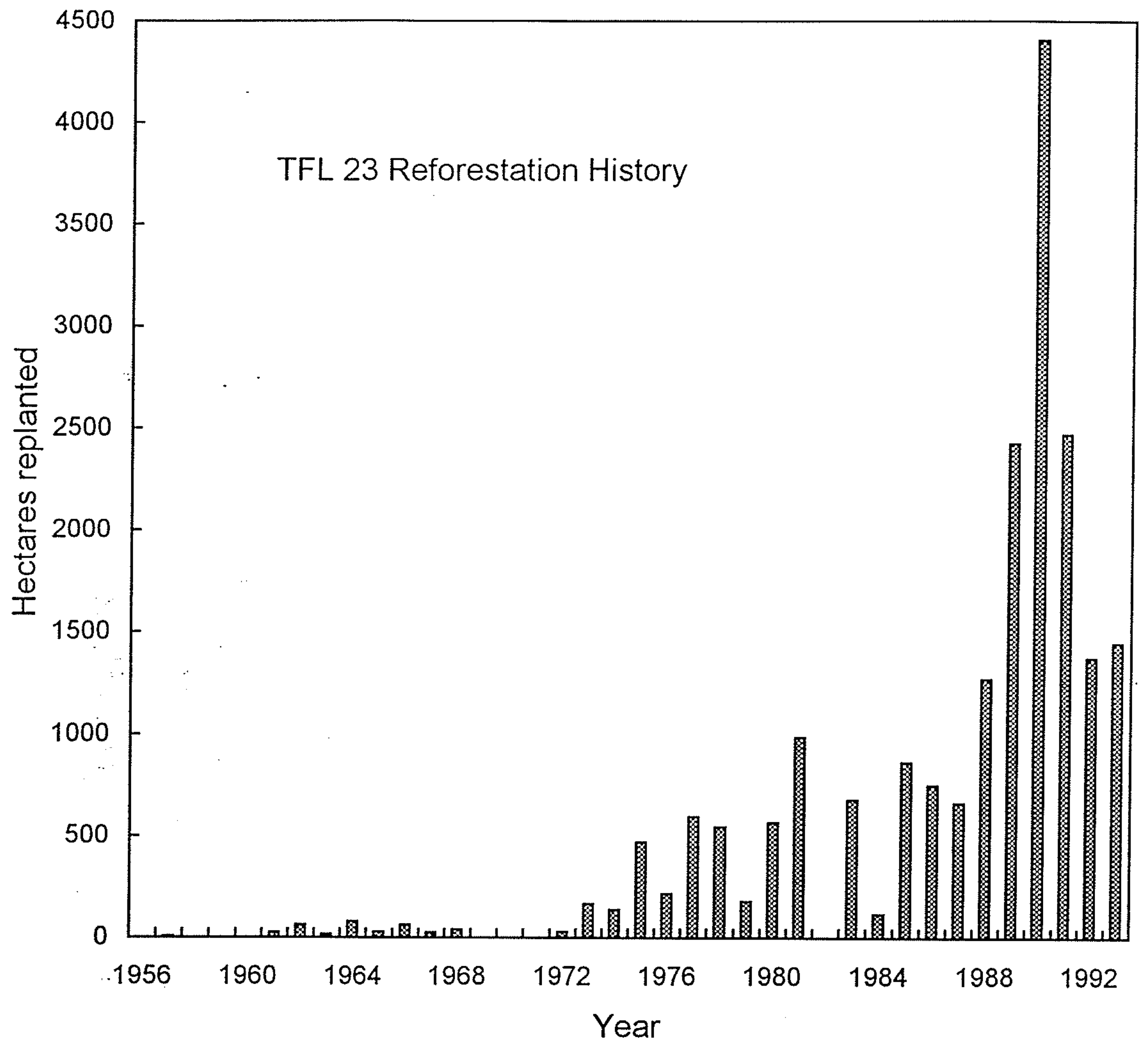


Figure 5: Replanting history for TFL 23.

Crown harvest and the remainder private forest. Most of the private forests lie outside the study boundary, so that for the Arrow Lakes area, nearly all of the harvest comes from government land. Overall, the Arrow TSA has an annual allowable cut of 619,000 m^3 and TFL 23 has an allowable cut of 700,000 m^3 (Ministry of Forests 1994b).

The present forest is managed as a large farm. Land has been set aside for competing interests —fish, caribou, grizzly bear, watershed protection, recreation, scenic viewpoints and so on. The remainder is available for harvest, replanting, and harvesting again. The existing inventory of trees is removed at a rate which will exhaust it in time for the second crop to begin providing timber (Figure 9). The age structure of the second crop is planned so as to provide a steady and indefinite supply of marketable lumber of a certain size and species. Because land for rival environmental interests has already been removed from the harvest tenure, sustainability has been converted to an economic issue rather than an environmental one.

4.4 Climatology and Biology

The study area is located almost entirely within the moist climatic region of the interior wet belt (Braumandl and Curran 1992, 30). In this region, the valley bottom and lower slopes comprise the Interior Cedar Hemlock (ICH) biogeoclimatic zone with engelmann spruce-subalpine fir (ESSF) biogeoclimatic zones (*ibid.*, 31) above. At the highest levels, Alpine Tundra (AT) dominates (Figure 6). The ICH and ESSF biogeoclimatic zones are further divided into various subzones and variants according to temperature. The lower zone of most importance to this study is the Columbia-Shuswap Moist Warm ICH subzone (ICHmw2),

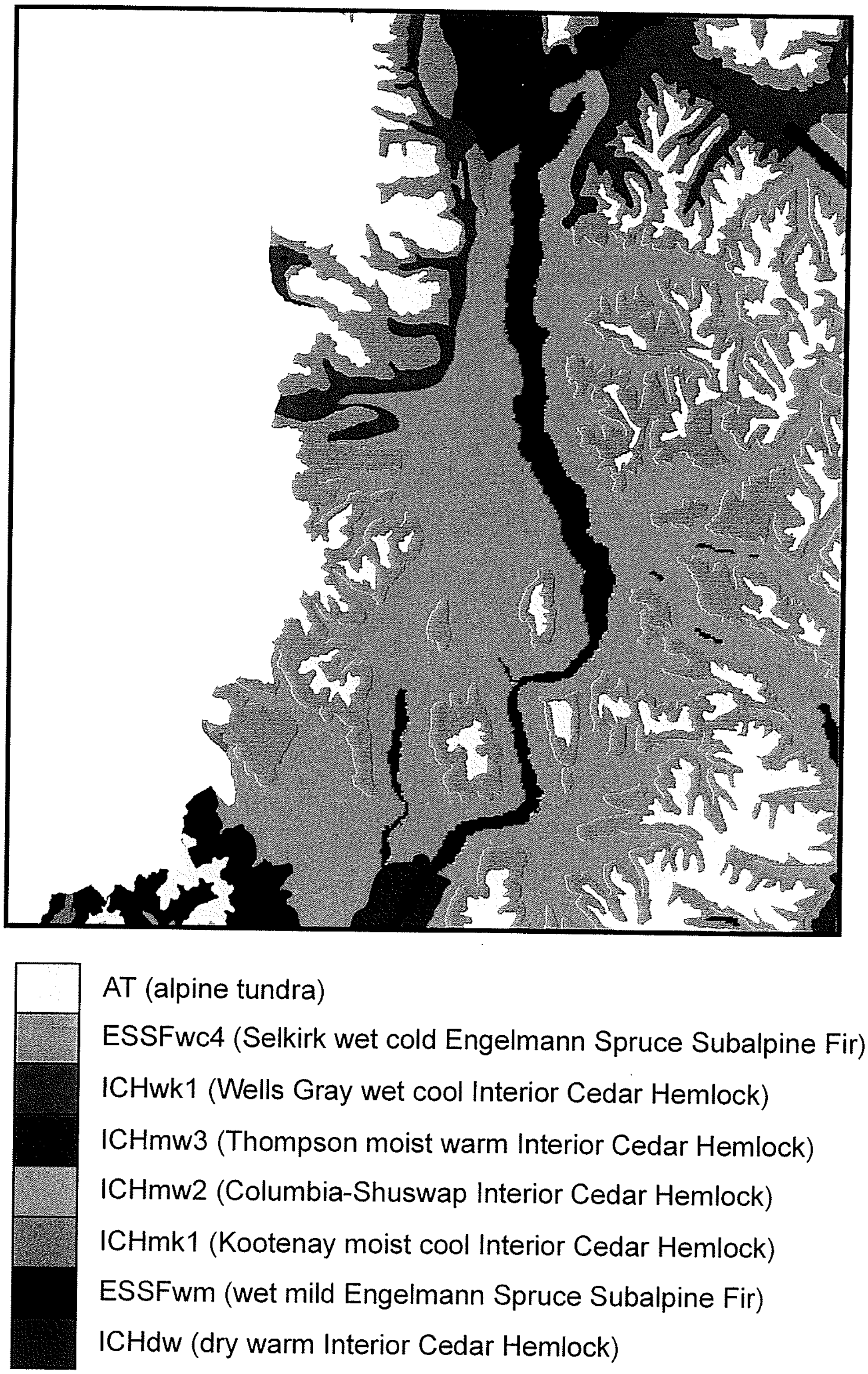


Figure 6: Biogeoclimatic Zones (Braumandl and Curran 1992).

found at elevations up to 1450 m. It is an area of hot and moist summers and warm winters with light snowfalls. Climate is not a major limitation to tree growth.

The ICHmw2 subzone has a mosaic of climax and seral stages due to recurrent fires. Old growth remains where extensive fires have been absent. Western red cedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylia*) are the most common tree species in climax sites (Figure 7). Seral stands contain in addition, Douglas fir (*Pseudotsuga menziesii*), white spruce (*Picea engelmannii x glauca*) and larch (*Larix occidentalis*). In general, the lower sites contain mixed species of trees, but cedar and hemlock progressively dominate at higher elevations. The lower seral stages provide important habitat for a wide variety of species, including cavity nesting birds, grizzly bear, deer, moose and elk. Valley bottoms are important winter range for elk and moose.

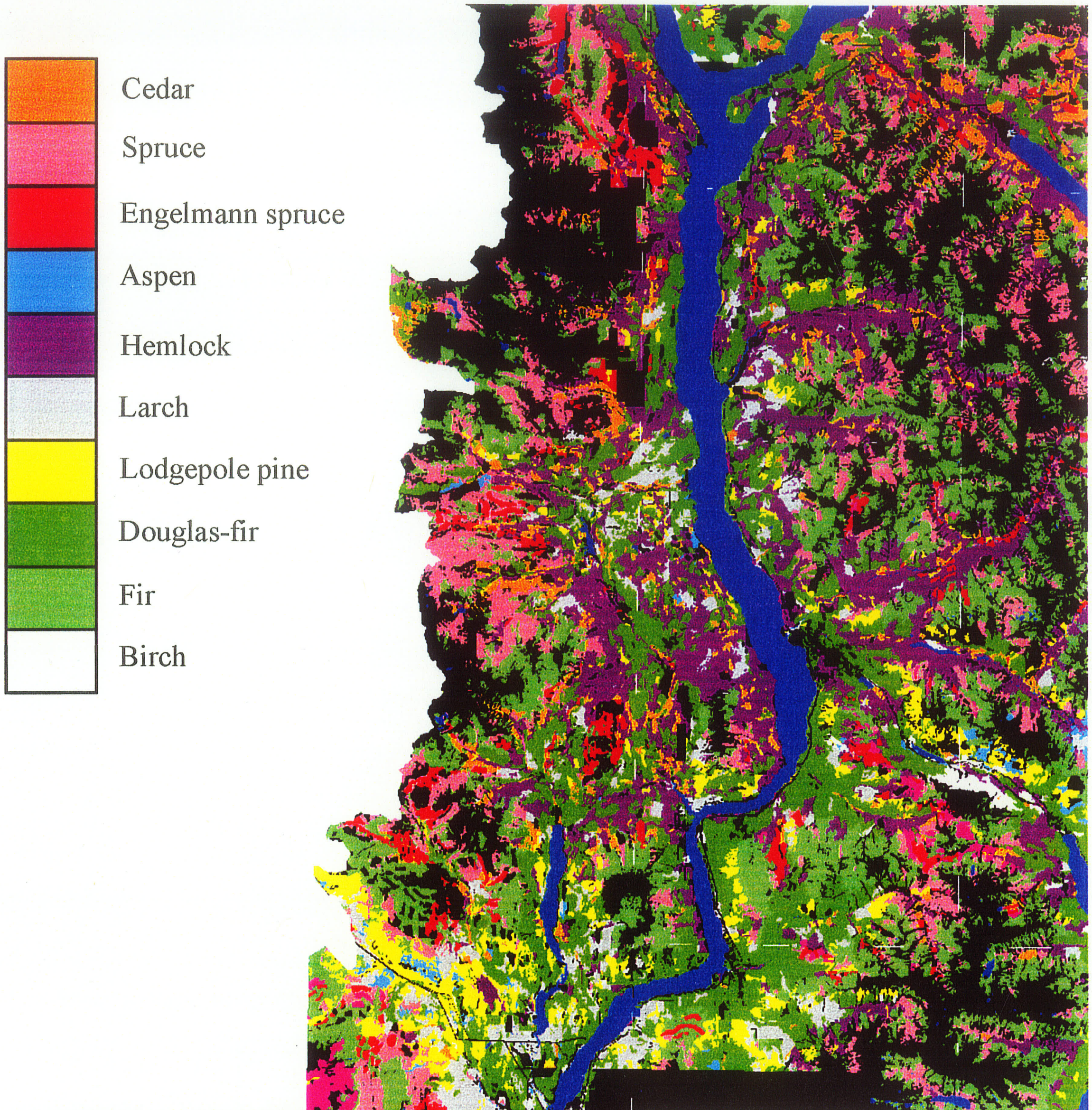
The higher subzone is the Columbia Wet Cold ESSF variant (ESSFwc1), colder and wetter with more snow than the ICH zone, as indicated by its name. The main climax tree species in this zone are the engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*). This zone has a long fire return period and there are relatively few seral stages. Most damage to stands comes from insects, wind and disease; in particular, the mountain pine beetle is common in the zone (MoF 1982; Unger and Stewart 1994). It is an area of extensive old-growth forest with a range of dependent wildlife species (Braumandl *et al.* 1992, 149).

The Nelson Forest Region, of which the Arrow Lakes are a part, provides a home for over 70% of the species known to occur in British Columbia. It contains one of the largest breeding colonies of osprey in the world. Mountain goats are the most common ungulate, but mule and white-tailed deer, elk and moose are also abundant. Relict populations of caribou inhabit the old-growth spruce forests at mid and high altitudes; the Selkirk herd is the most southern population of caribou in the province. (Steeger and Fenger 1992, 200). Grizzly and black bears can be found throughout the area.

There are eight red-listed species in the Forest Region—that is, species with low abundance which are threatened or endangered. All are birds except for one species of bat and a ground squirrel. Blue-listed sensitive or vulnerable species are more common, with a total of 47 species listed in the region. The best known are the grizzly bear and caribou. Of the 55 red and blue-listed species, 12 depend on old-growth forests for some aspect of their lifestyle (Steeger and Fenger 1992, 207-12). Most dependant are marten and woodland caribou, though the marten is not threatened.

4.5 Economic Sustainability: The Annual Allowable Cut

One of the issues at the heart of the question of sustainability in the forest industry is the size of the allowable annual cut (AAC), the government-authorized rate of timber harvest from the land base. The focus of the calculation of the AAC is economic: the maximum number of trees that can be cut in a year and still guarantee a supply for industry in the future. It is a short-term measure, looking only for one or two or three centuries ahead. Adjustments for other components of the forest ecosystem are a significant part of the calculation, but little or no attempt is made to examine the sustainability of these components in themselves. Instead it is hoped that the forest set aside for non-harvest uses will be large enough to ensure their viability through the millennia.



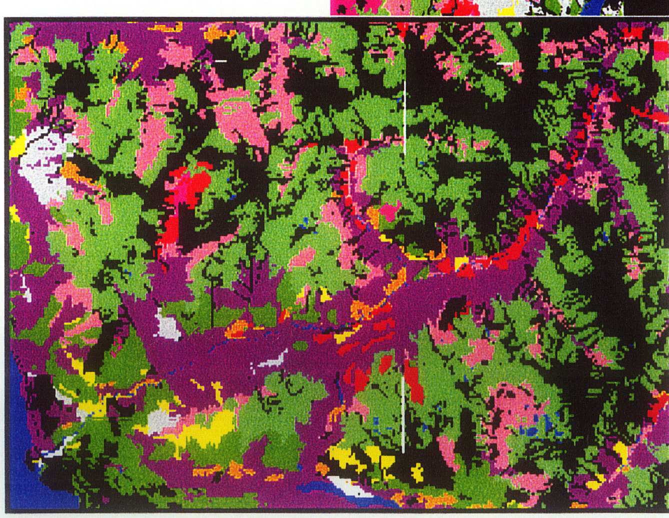


Figure 7: Distribution of tree species in the study area. The species depicted at each location is the primary species in that stand. The inset shows the area around Kuskanax Creek. Note the replacement of hemlock by Engelmann spruce, lodgepole pine and cedar in replanted clearcuts along the creek. Clearcuts can be identified by comparison with figure 14.

An essential tool used in determining the size of the AAC is a timber supply model, a mathematical representation of the biological characteristics, uses, and future evolution of the forest. The timber supply model gives a level of quantitative detail to questions about the future supply of wood which the human mind cannot achieve. Timber supply models are not new to the industry in B.C., but their sophistication has grown considerably in the last decade as more detailed land databases and scientific knowledge have become incorporated into their algorithms. Several models are in use by the B.C. Forest Service (BCFS), each with advantages and disadvantages (Ministry of Forests 1994a, 10-13; Ministry of Forests 1994c, 4; Pope and Talbot 1994b, 3-8).

The AAC for the Arrow TSA is 619,000 m^3 annually; for TFL 23 it is 700,000 m^3, both of which have undergone recent review. The annual allowable cut for TFL 23 has changed dramatically over the years since 1955, from a low of 218,000 cubic metres to a high of over a million cubic metres (Figure 8). In most years, the actual harvest falls below the AAC, in some by as much as 59%.

Harvest models used to develop the allowable cuts show that current assumptions about silvicultural practices, fires, pests, stream protection, restocking, growth rates, and other management practices will allow the current level of harvest for the Arrow TSA to continue for seven decades (MoF 1994a, 14) and that of TFL 23 for four decades (Pope and Talbot 1994a, 17). After these periods the cutting rates will decline by approximately 30% over a period of 30 to 40 years and then be maintained indefinitely, or at least to the end of the model simulation 200 years in the future. This set of events is known as the base case scenario or Status Quo (Figure 9). In effect, the base cases allow harvesting above the sustainable limit

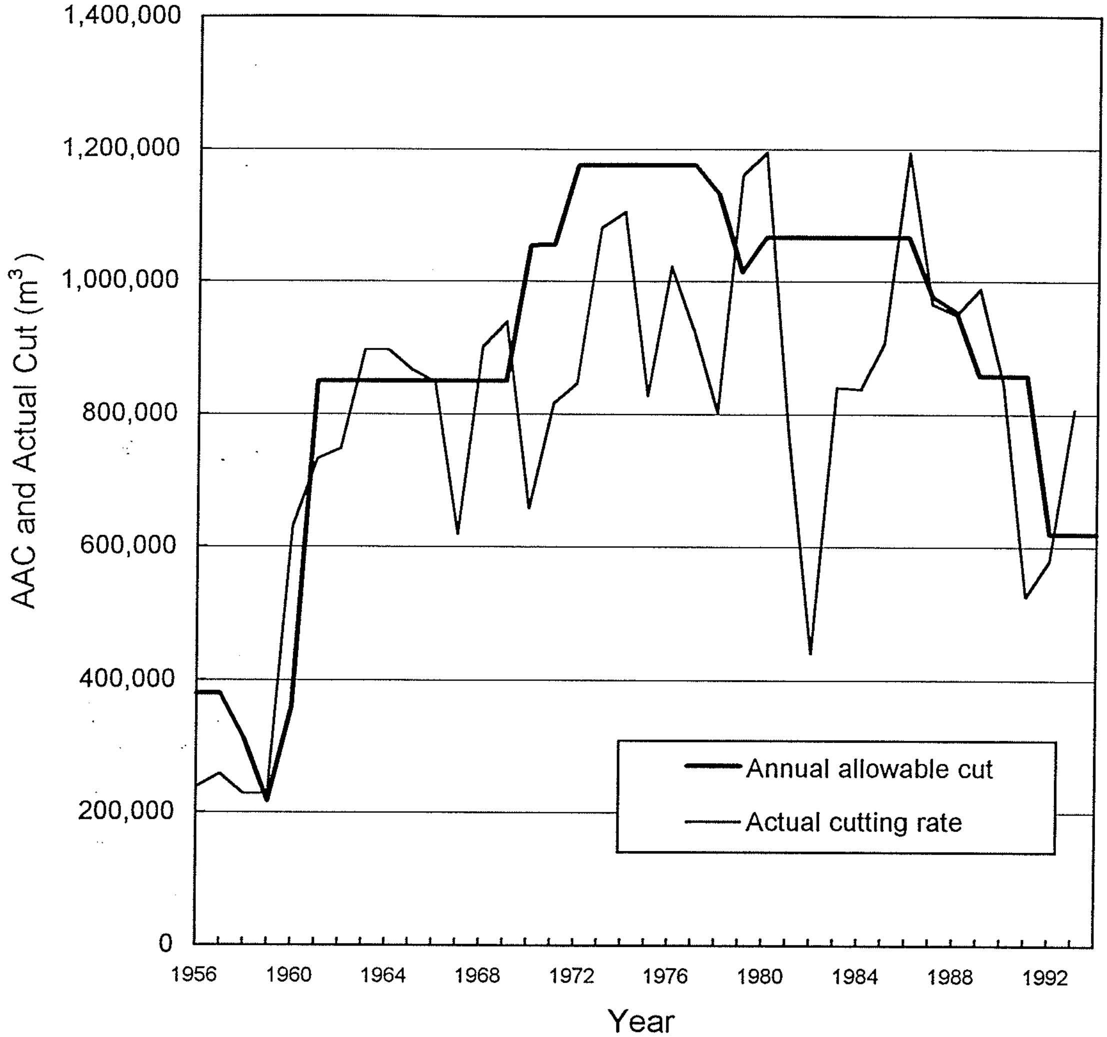


Figure 8: History of the TFL 23 annual allowable cut (Pope and Talbot 1994a)

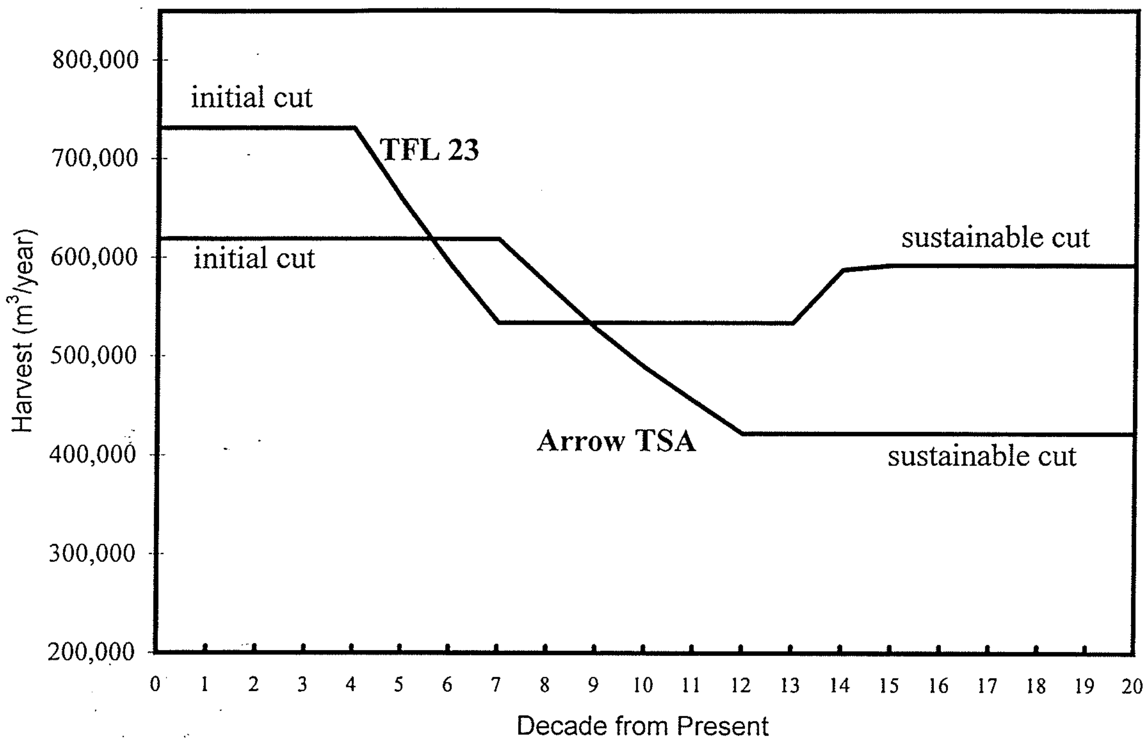


Figure 9: Base case cutting scenarios for TFL 23 (Status Quo Option) and the Arrow TSA (Pope and Talbot 1994b, Ministry of Forests 1994b). The initial cut is not sustainable over the long term and declines after several decades to the long term sustainable rate. The long term rate is increasingly derived from regenerated second growth forests.

for several decades to remove existing "overmature" forest, followed by a decline to a level consistent with the expected productivity of the land base.

In the Arrow TSA, the base line case continues the present AAC of 619,000 m^3 per year for 7 decades, followed by a four decade decline to the sustainable annual limit of 422, 000 m^3. This scenario (one of many possible) was chosen so as to maintain current levels as long as possible, reduce cutting gradually, and avoid temporary drops below the long term level. Using these cutting levels, the B.C. Ministry of Forests estimates that growing stock will stabilize at 54% of its current level in a century. The stock above minimum harvestable age will decline more sharply to 23% of current levels [6] at the end of the 2100s. The inventory will recover to about one-third of existing levels late in the second century. The Arrow TSA Timber Supply Analysis did not consider alternative scenarios in the same fashion as the Pope and Talbot analysis.

The initial harvest rate and flow is an 'open' parameter, in that it can be chosen for a specific management objective. Lower initial rates can be maintained for a longer period of time. Higher rates must decline to the sustainable harvest sooner. A lower present harvest rate permits more management flexibility in future years, especially to address questions of aesthetics, forest fires, and land use. This option comes with a penalty however: a loss of economic benefits and a forest more prone to fire and disease (MoF 1994b, 24). One of the greatest advantages of a lower harvest rate is its value as a safety cushion, not only against environmental extremes but also future social pressures.

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[6] B.C. Ministry of Forests notes (MoF 1994a) suggest that levels will fall to "one-third of what exists now", but an examination of their figure 8 (p. 15) shows that the actual value is 23%.

The time scale of forest resource planning is also a strong complicating factor in the assessment of harvest quotas. Global warming is expected to bring major changes in the world's forests, though the effect may be to increase yields in the western mountains rather than reduce them (Kerr, 1995) as temperate zone forests replace alpine meadows. The response to global warming is likely to be slow, but the projected warming of 1 to 3.5 °C that is anticipated at the end of the next century, is only halfway through the projection period used in the TFL 23 and Arrow timber supply analyses.

Given the uncertainties in our understanding of forest ecology, future social restrictions or allowances, and the economics of the industry, forecasts of the physiology of the 200 year forest can never be a certain undertaking.

4.5.1 Sensitivity of the AAC Calculations

One of the greatest advantages of the forest harvest models is their facility in conducting sensitivity analyses of the basic assumptions which were incorporated into the base case scenario. The models are very complex, and so there are a large number of parameters which can be adjusted to answer "what-if?" questions. In fact the number of permutations and combinations of these parameters can become so large that the prospect of investigating them all is impossible. Fortunately, in many cases the sustainable harvest levels are not particularly sensitive to adjustments in one or two inputs and further investigation can be truncated. In other cases the adjustments are very significant and deserve a higher level of attention and management as small variations may substantially change harvesting conclusions.

A distinction must be made between sensitivity and uncertainty in evaluating harvest modelling results. The models may be sensitive, that is respond with large changes in harvestable volumes, to parameters which are well known. Under such circumstances, the sensitivity analysis offers little practical guidance on future harvest levels. On the other hand many elements which go into the calculation of cutting limits are uncertain or even unknown. If the models do not respond significantly to changes in these parameters, then little management effort need be expended on their elucidation. The most important parameters are those which are uncertain and which will have a larger impact on the cutting levels.

Both Pope and Talbot and the Ministry of Forestry have conducted a series of sensitivity tests to determine the reliability of the base case scenario. Table 3 summarizes the variables which were tested in an assessment of the Arrow TSA's allowable cut, along with the effects on the current and future cutting levels (MoF 1994a, 22-36). Table 4 does the same for the Pope and Talbot model.

Tables 3 and 4 indicate the areas in which the models' responses are most sensitive to small perturbations in the initial inputs. Logically, those factors which are most important are the ones which have an impact on the present-day cut. Factors which have significant impacts, but delayed into the future, allow time for response and adjustment. In the Arrow TSA, Table 3 indicates that the largest and most important sensitivities come from cutblock adjacency rules, the size of the harvest land base, and visual and watershed cover requirements. It is noteworthy that these factors are the ones which also require that harvest volumes begin to decline to the long term sustainable limit in the immediate future. Early declines to the long term limit are also sensitive to two other factors — green up periods and forest cover requirements.

Pope and Talbot modelling identified a set of sensitive parameters for the commercial forest in TFL 23, but most of these were the same as those in the MoF assessment of the Arrow TSA. Specifically, the Pope and Talbot model results for TFL 23 indicate that the present cut is sensitive to existing stand volume estimates and green up period, and in the immediate future, to cutblock adjacency rules. Differences in the results between the MoF and Pope and Talbot likely represent the subjective nature of initial harvest assumptions.

4.5.2 Examining Critical Uncertainties in the Modelling Assumptions

In addition to the status quo option, Pope and Talbot modellers conducted three additional model runs (Pope and Talbot 1994b, 2) which evaluated the effects of different forest land use options. These options (Table 5) assessed the impact of changes which might occur in the utilization of the forest land base as a result of scientific, management, political, social and administrative changes. In contrast to the sensitivity analysis, these options represent adjustments for uncertainties about future operating conditions but assume no uncertainty in internal model parameters:

- The Status Quo: a continuation of current management practices on the land base which is presently available
- The Wildlife Habitat Option: additional forest cover requirements for wildlife habitat result in removal of some of the land base from the Status Quo scenario
- The Decreased Utilization Option: overmature hemlock and balsam are removed from the harvest land base. Pope and Talbot believes that these areas are harvestable.

Element of Uncertainty	Imposed change on the base line case	Effect on present-day cut	Effect on time until sustainable cut begins	Effect on size of sustainable cut
Uncertainty in minimum harvest ages [a]	20 years more	none	20 years sooner	none
	20 years less	none	10 years later	none
Uncertainty in existing stand volume [b]	10% higher	increase 10%	none	none
	10% lower	none	30 years sooner	none
Uncertainty in forest cover required [c]	10% higher	none	50 years sooner	5% less
	10% lower	none	10 years later	none
Uncertainty in green-up period [d]	5 years more	none	50 years sooner	6% less
	5 years less	none	none	none
Uncertainty in cutblock adjacency rules	5 passes	none	60 years sooner	8% less
and the number of harvest passes [e]	6 passes	decline 19%	50 years sooner	16% less
Increased old-growth requirement [f]	10% more	none	30 years sooner	4% less
Uncertainty in available land base [g]	20% higher	increase 12%	none	21% more
	20% lower	decline 5%	60 years sooner	23% less
Cover requirements in visually sensitive	15% less	none	10 years later	none
areas and watersheds [h]	15% more	decline 5%	60 years sooner	13% less

[a] In the baseline model, trees were assumed to be harvestable at ages from 70 to 140 years.

[b] Existing stand volume is the present volume estimate of merchantable timber on a site. Errors arise from poor site surveys and the amount of old decaying timber.

[c] Forest cover requirements limit the percentage of an area which can be cut at any one time, usually to preserve old growth and other wildlife habitat. This can be changed if new habitat needs are identified, or by public pressure.

[d] Green-up period is the time for new growth to reach 3 metres in height, normally 17 years. Harvested stands must reach green-up before the adjacent block of forest can be cut.

[e] Cutblock adjacency rules limit the percentage of adjacent areas that can be cut, usually to 25% or less. In practice the area cut is often less than 25% so that four or more passes are required to harvest a stand.

[f] Public pressures and increased scientific knowledge are leading to increased protection of old-growth forest.

[g] Old and poorly done surveys of the forest leave considerable uncertainty about the actual volume of timber available.

[h] Forest cover is required to protect visually pleasing areas and critical watersheds.

Table 3. Critical components of uncertainty in the Arrow TSA annual allowable cut. (Source: Ministry of Forests 1994a, 1994b)

Element of Uncertainty	Imposed change on the base line case	Effect on present-day cut	Effect on time until sustainable cut begins	Effect on size of sustainable cut
Uncertainty in minimum harvest	10 years longer	none	20 years less	8% higher
age [a]	10 years shorter	none	10 years longer	none
Uncertainty in existing stand	10% higher	none	30 years longer	none
volume [b]	10% lower	27% lower	20 years longer	none
Uncertainty in green-up period [c]	5 years more	10% less	30 years less	none
	5 years less	none	none	10% higher
Uncertainty in cutblock adjacency	+ 5%	none	10 years longer	23% higher
rules & the number of harvest passes [d]	- 5%	none	30 years less	none
Uncertainty in regenerated stand	10% higher	none	10 years less	none
volume [e]	10% lower	none	10 years less	none
Species conversion [f]		none	50 years more	19% higher
Site Index Redistribution [g]		none	20 years more	19% higher

[a] Minimum harvest ages are approximate. The effects of permitting harvest 10 years earlier and later are examined.

[b] Existing stand volume is the present volume estimate of merchantable timber on a site. Errors arise from poor site surveys and the amount of old decaying timber.

[c] Green-up period is the time for new growth to reach 3 metres in height, normally 17 years. Harvested stands must reach green-up before the adjacent block of forest can be cut.

[d] Cutblock adjacency rules limit the percentage of adjacent areas that can be cut, usually to 25% or less. In practice the area cut is often less than 25% so that four or more passes are required to harvest a stand.

[e] Regenerated stand volumes can be mis-estimated for a number of reasons. This analysis examines the effects of a 10% over- and under-estimate of future site productivity.

[f] Once a site is harvested, it may be replanted with a different species of tree, one that grows more rapidly. This "species conversion" will produce a greater volume of timber in the future than would occur if the original species were regenerated.

[g] The productivity of sites with overmature timber (>150 years) appears to be underestimated. New timber planted on these sites will likely grow more rapidly than the existing timber. This analysis adjusts for the more productive expectations.

Table 4. Critical components of uncertainty in the calculation of the TFL 23 annual allowable cut. The "status quo" (Table 5) assumes that the present cut will continue for 40 years and then decline by 27% to a sustainable level. (Source: Pope & Talbot 1994b)

- The Wilderness Option: lands outlined in the 1992 Protected Areas Strategy are removed from the Status Quo landbase

Only the Decreased Utilization option cannot sustain the current harvest — it must decline by 10% immediately if "overmature" (ageclass 8 and 9) hemlock and balsam cannot be harvested. Over a 70 year period, there is a 16% reduction in the harvest volume under this option compared to the status quo. Since Pope and Talbot is already cutting these trees, the option would seem to be unwarranted. However, as these ageclasses constitute old growth forest, there is considerable pressure for their preservation and the future harvest base cannot be guaranteed. This concern is reinforced by the present study. The MoELP GIS database shows that the last large area of old growth forest is found above Kuskanax Creek (Figures 10, 10a), an area targeted for increased cutting in the next few years (Stevens[7], pers. comm.). This area is also prime habitat for a large group of woodland caribou (McLellan, Flaa and Woods 1994). Parts of the Wilderness Option became reality in the summer of 1995 when additional park areas were announced by the provincial government. These areas lie outside the boundaries of the area examined for this study, but remove part of the land base available to the Arrow TSA (MoELP 1994).

Pope and Talbot research suggests that stand productivity estimates used by the Ministry of Forests are about 10% too low (Lang, pers. comm.; Pope and Talbot 1994b, 21) for stands older than 150 years. This results in an underestimate of the volume of timber available in future years in the forest model. This factor has little impact on the present harvest level, but permits an additional 20 years of cutting at current rates and an 11% increase in the long term

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[7] Greg Stevens, Natural Resources Institute, University of Manitoba.

	Effect on immediate cut	Effect on time until sustainable cut	Effect on size of sustainable cut
Harvest Options			
Status Quo	731,172 m^3	40 years	534,000 m^3
Wildlife Habitat	none	20 years less	none
Decreased	reduced 13%	30 years less	none
Wilderness Area	none	10 years less	none

Table 5: Options to the Status Quo timber model for TFL 23. The three additional options are described as:

Wildlife Habitat Option: additional forest cover constraints are required for the protection of wildlife habitat.

Decreased Utilization Option: overmature hemlock and balsam stands will continue to be unavailable for harvest.

Wilderness Area Option: wilderness areas outlined in the 1992 Protected Areas Strategy will be removed from the harvest land base (ie new parks created within the TFL).

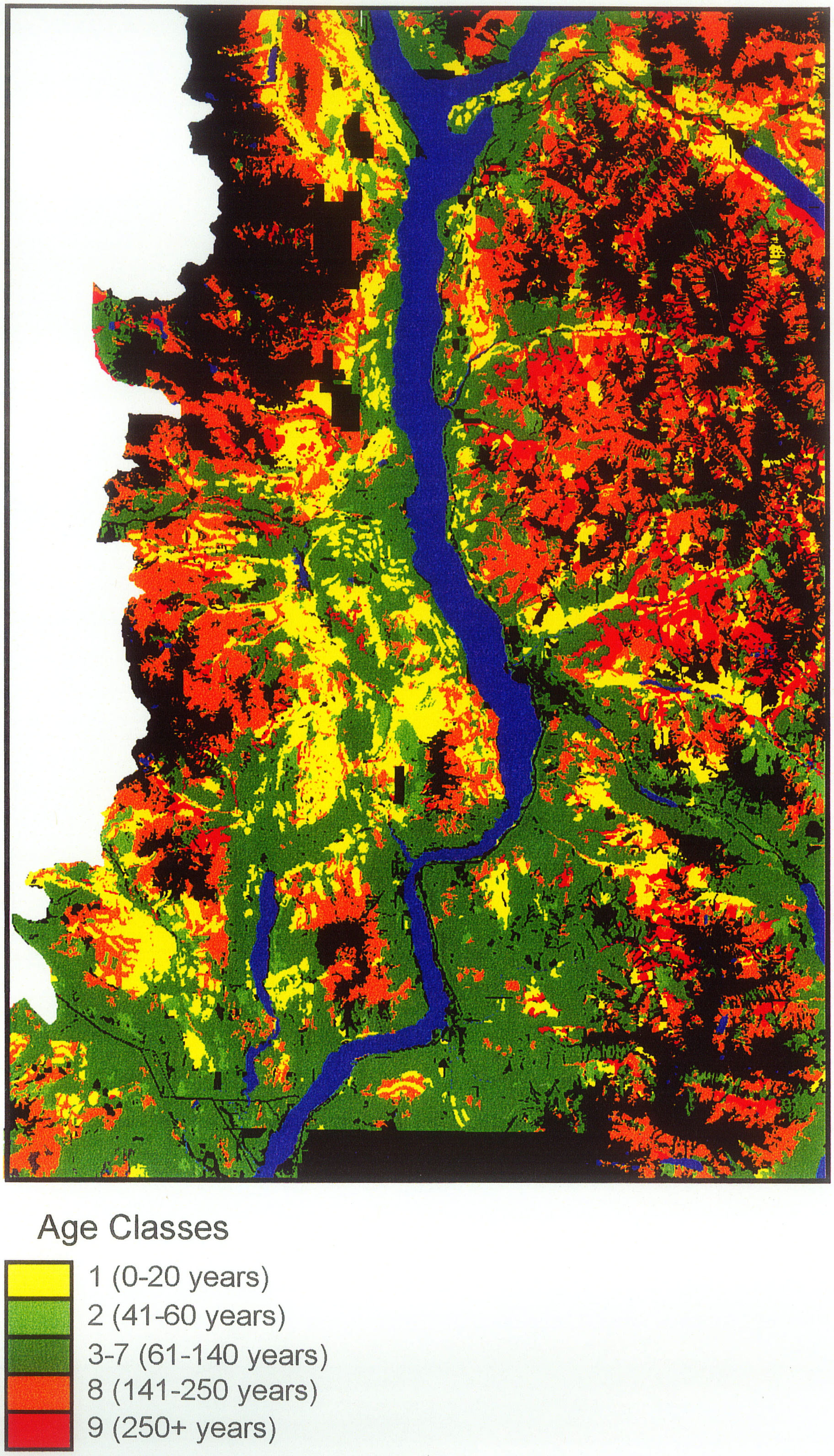

Figure 10: Age class map of the study area. Note the relatively small abundance of ageclass 9, the large abundance of ageclass 8 and the distribution of younger trees (ageclasses 1 and 2)

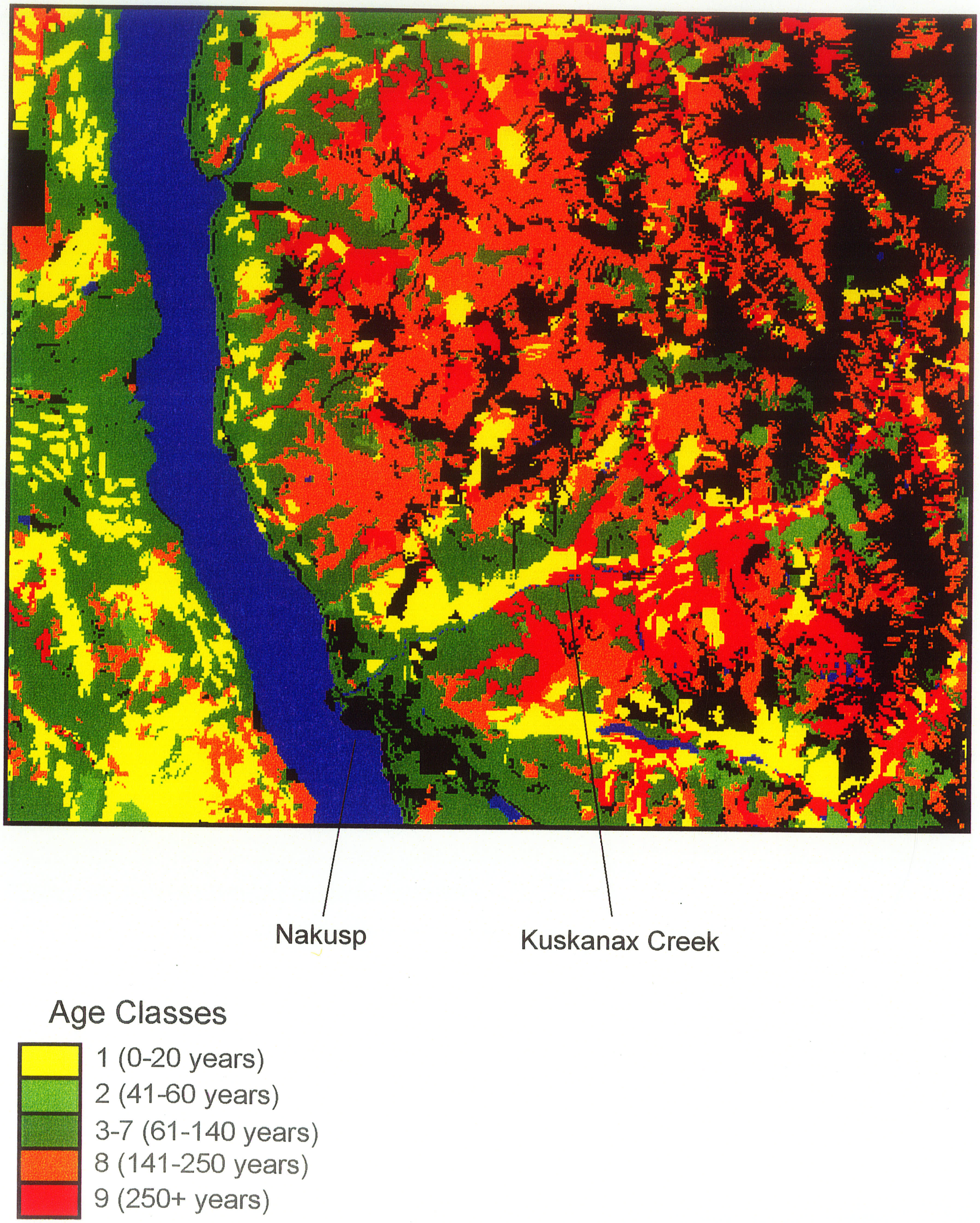

Figure 10a: Enlargement of Figure 10 (age class distribution) showing the area between Kuskanax Creek and Halfway River. Note the relative abundance of old growth forest (age class 9) east of Nakusp, the string of young clearcuts along Kuskanax Creek and Halfway River, small clearcuts west of Upper Arrow Lake, and the large amount of ageclass 8 forest. The two older age classes are prime caribou habitat in this area.

sustainable rate.

In all management areas, stands adjacent to recent cut-overs cannot be harvested until a "green-up" height of three metres is attained by the regrowing forest, in order to provide habitat for wildlife. MoF staff have noted that second growth is often slower than assumed in the models, primarily due to brush competition, thus lengthening the green-up period. Both P&T and MoF modelling results are particularly sensitive to this parameter, and suggest an adjustment to lower cutting rates within 10 years – perhaps by the end of the century. Pope and Talbot's analysis requires an immediate reduction in the present cut. All or part of the effect may be manageable by aggressive brush cutting and herbicide use, but these measures are expensive and have substantial environmental impacts on their own.

A companion issue with this factor is the cut block adjacency rules which permit only 25% of an area to be cut at one time. Subsequent cutting cannot occur until green-up of the previous cut, a process which requires at least 17 years (Ministry of Forests 1994a, 56), or longer if the concerns of MoF foresters about second growth noted above are confirmed. Most areas will thus require at least four passes spread out over nearly seven decades in order to remove all of the available timber. In actual practice however, it is often impossible to cut the forest in 25% chunks, and often five or even six passes are needed to remove the timber.

In the TFL 23 analysis, only the effects of a three-pass versus a four-pass harvest were evaluated. In view of the cut block adjacency rule, a four-pass harvest is the minimum required condition, and five or six passes are not out of the question. The Pope and Talbot model found that declines would have to begin by the end of the decade (Table 4) for a four pass system. By extrapolation, a five or six pass system would require immediate restriction of the AAC. This is confirmed by the results of the Arrow TSA sensitivity study, in which adjacency rules and the number of harvest passes are the greatest constraints on present timber supply volumes. In view of these results, the pressures on Pope and Talbot's annual allowable cut are much more stringent that their modelling would suggest.

MoF foresters have noted a number of other concerns about the Arrow TSA modelling assumptions. Land for watershed protection is not adequately removed from the model, caribou habitat is not sufficient, old-growth protection and forest ecosystems require that more land be set aside, woody debris and uncut trees left for wildlife habitat are not included, and the new Forest Practices Code [8] is not fully incorporated into the planning. All of these would remove land and timber from the Arrow TSA allowable cut. And while comments were directed to the results of the Arrow TSA modelling exercise, there are strong implications for TFL 23 as well.

The new Forest Practices Code (FPC) brings legal restrictions on management procedures within the Arrow Lake forests, but are only partially represented in the models (MoF 1994b, 10). The code regulates riparian zones, regeneration standards and practices, road-building and rehabilitation, silviculture, accommodation for wildlife and recreation, and a myriad of other factors. Pope and Talbot managers estimate that the FPC will reduce their harvest volumes by 22% (Lang, pers. com.), a result which is borne out by more formal estimates

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[8] The Forest Practices Code (FPC) is a body of provincial legislation which governs the forestry industry throughout British Columbia. Through a series of regulations, rules and guidebooks, the FPC controls forestry even as far as day-to-day operations. Its guidebooks contain many provisions for other non-consumptive values in the forest, including mitigation of impacts on wildlife, water flow and quality, and human access. One of its major conditions is the requirement for a silviculture prescription or detailed set of plans before cutting begins. These plans are used to evaluate compliance with the FPC.

(Nelson and Hackett 1995).

Some mitigation of the effects of constraints on the timber supply could come from harvesting presently inoperable areas (P&T 1994b, 29; MoF 1994b, 11), promoting the growth of regenerating forests, using smaller diameter trees, and correcting underestimates of regeneration potential. Whether or not these are sufficient to overcome the concerns which remove timber from the harvest base is unknown, but the trend of present public sentiment would seem to suggest that current modelling exercises are much too optimistic.

The biggest deficiency in both modelling exercises may be the failure to incorporate multiple impacts (MoF 1994b, 11). Cumulative impacts may be additive, or have impacts which are greater or smaller than the additive case. Most of the single impacts discussed here work to decrease the short and long term cuts, and so the effect of cumulative impacts would be greater—perhaps much greater—than any single item. The cutting scenario proposed by Pope and Talbot fully utilizes the available forest resources, as evidenced by their inclusion of over-mature hemlock in the Status Quo scenario (and its exclusion in the Decreased Utilization Option). By implication then, there is little room for absorbing even small negative impacts and a strong possibility exists that the current AAC in both TFL 23 and the Arrow TSA is in excess of the sustainable limit.

4.6 New Forestry versus Old

In recent years, a new philosophy of forest management has arisen in the American Pacific Northwest. The new paradigm espouses the same values as conventional forest management, but accords them a different emphasis. According to Sample *et al.* (1993, 4) :

> "The evolution from a sustained yield management of a relatively small number of commercial tree species to the protection and sustainable management of forest ecosystems is changing some of the fundamental premises of forest management."

The main difference between the two approaches lies in the greater weight given to ecosystem values by the proponents of New Forestry. Disciples of the new philosophy place their emphasis on these ecosystem values rather than economic and social returns, though they admit that "an emphasis on biophysical features with little or no consideration of social and economic needs is doomed from the start." (*ibid.*, 7). In the litany of New Forestry "It is no longer enough simply to sustain timber yields if it is ultimately the forest that one wants to sustain (Sample *et al.*, 11)."

The new forest ideology implies that other values are protected even if their economic value is less than the timber resources which are affected. The proponents of this extended ecosystem approach reflect an ideology which accords a high "existence value" to the forest environment (Pearce and Turner 1990, 131). "An alternative view of biodiversity, and perhaps the unspoken majority view among biologists and environmentalists, is that biodiversity is an end in itself (Noss 1993, 18)."

New Forestry philosophy is still young, a creature of the 1990's, with many aspects of its nature still being defined. The movement owes its origins to concepts developed by Jerry Franklin (1993). He proposes two principles (*ibid.*, 128) for maintaining the physical and biological health of the forest:

a) no net loss of productive capacity
b) no loss of genetic potential (preserve genetic diversity)

These are certainly values which are acceptable to conventional forest managers, so where does the difference between the old and the new arise?

Franklin's defining view of sustainability is the "maintenance of the *potential* [sic] for our land and water ecosystems to produce the same quantity and quality of goods and services in perpetuity (Franklin 1993, 127)." The emphasis on ecosystem quality is perhaps the most significant aspect of what has come to be called New Forestry, for it makes biodiversity more than just raw numbers of trees and animals. Instead of being satisfied with the faster regrowth of commercial timber, or increased numbers of deer or fur-bearing animals because of clearcutting, foresters must now ask what has been lost, and how it can be retained.

Brush cutting, for instance, is a detrimental aspect of conventional forestry, for it removes a component of the successional stages which is valuable to other components of the ecosystem. Among other factors, early seral stages of regrowing forests provide berries and other vegetation for grizzly bears. In coastal forests of B.C. silvicultural practices have removed so much brush that B.C. Environment has recommended that stocking standards be reduced in order to restore this food supply (B.C. Environment 1995b), and a restoration project has begun. In effect forest managers have counted the increased value of wood generated by brushing while largely ignoring the noncommercial components of the forest, such as grizzly bear food resources.

Kimmins (1992, 167) notes that New Forestry owes much of its philosophy to sentiments of the past century. In his view, the new paradigm is itself bedevilled with the same uncertainties which plague current management. Diverse structural components such as multi-layered tree canopies do not necessarily support a greater diversity of plant, insect and animal life. Coarse debris may sequester nitrogen needed by a newly growing forest. Forest fragmentation can be controlled by varying the size and density of openings. But Kimmins misses much of the point of New Forestry. Its intent is not to enhance new diversity or favour one size of forest opening, but to mimic the conditions which are found naturally in the mountain forests and preserve the existing diversity, however rich or poor. A fundamental precept of New Forestry is that it is not how much, but what kind of diversity that is important.

In Franklin's opinion, traditional forestry sees productivity mostly in terms of soil productivity. This point of view is exactly that of Kimmins (1992, 169), who defends current practices on B.C.'s managed forests. Throughout his defence Kimmins notes the highly variable nature of the forest environment, the uncertainties in knowledge, and the difficulty in predicting a specific outcome, and also the willingness of tenure-holders to adapt to new knowledge and requirements. His arguments are greatly weakened by this continuous expression of uncertainties, for then the question becomes: why are we managing the forests in such an "experimental" fashion when so little is known of the consequences? At the very least the posits of safe minimum standards should apply (Toman 1993, 274). Given the importance of existence values to New Forestry, it is doubtful that even the limitations of a safe minimum standard are completely acceptable.

If resource users are to manage a forest in a fashion so that all ecosystem values are preserved, and that uncertain consequences are controlled, then the only reference level which is known to provide reliable measures of long term productivity and ecosystem health is the natural forest itself (Langston 1995, 287). New Forestry compels forest managers to duplicate or at least mimic the natural ecosystem processes in the forest. Indicators of forest health and the consequences of management practices should be measured against natural values "since settlement or logging began" (Noss 1993, 33). This relationship then creates a disruption index as defined by Holmberg and Karlsson (1991, 100).

That this philosophy (to reference human interventions to natural processes) arose in the U.S. Pacific Northwest is not surprising. The U.S. Forest Service has a history of conflicting resource management goals and disastrous failures (Langston, 1995) which are not yet fully matched in the Canadian experience. To some extent this is can be blamed on climate, for the forest practices of the two countries are not all that different. The wetter climate of British Columbia forests modifies some of the ill-fated consequences of managed tenures (Kimmins 1992, 177). New Forestry is criticized for its theoretical nature and lack of specifics (*ibid.*, 179), but this may be more a function of the age of the movement (three years at the time of Kimmins' writing) than lack of ideas.

Even in the few short years since Kimmins' criticisms, New Forestry has adopted more practical underpinnings, and is gaining influence within the U.S. political system. Forest practices under the new paradigm are designed to prevent biotic impoverishment; "habitat changes which exceed the adaptive capacities of at least some native species" (Noss 1992, 22). Factors which reflect "trajectories of impoverishment" include younger forests, simplified stands, smaller forest patches, isolated patches, fewer forest fires, more roads and more endangered species. These are discussed individually below.

4.6.1 Old Growth Forest

The New Forestry paradigm requires preserving all existing old growth forest, and allowing younger forest to return to an old growth condition (Noss 1993, 27). This bold goal is complicated by the observation that old-growth forest has no single definition. Steeger and Fenger (1992, 205) provide the following characteristics, extracted from the Old Growth Strategy Project (CORE 1995, 6304):

> "Old growth forest contains live and dead trees of many sizes and species, in a slowly changing but dynamic ecosystem. Ages and structures differ considerably from one biogeoclimatic zone to another."

In short:

- large trees for species and site
- wide variation in tree sizes and spacing
- accumulations of large size dead standing and fallen trees;
- multiple canopy layers;
- canopy gaps and understory patchiness
- decadence in the form of broken or deformed tops or boles and root decay

More specifically, but less usefully, the Old Growth Strategy Project defined old-growth stands as "natural stands of old trees and their associated plants, animals and ecological relationships which have remained essentially undisturbed by human activities" (CORE 1995, 11689).

The B.C. Ministry of Environment, Lands and Parks uses an age of 120 years for Lodgepole pine and 140 years for other species (CORE 1995, 15091) as a rough estimate of old growth forests, but qualifies the estimate by noting that "not all forests in this category possess the required attributes" (MoELP and EC 1994, 52). Some forests may take as long as 250 years to achieve old-growth status (CORE 1995, 15092). In the Arrow Lakes study area this would mean forests in age classes 8 and 9, and possibly only age class 9 (Figures 10, 10a), especially at higher elevations. These older forests can be critical habitat for some species: aerial lichens used by woodland caribou are not abundant in forests younger than age class 9.

Prior to European exploration, forests in the Pacific Northwest are estimated to have contained 60-70% old growth forests (Franklin and Spies 1984). Percentages in British Columbia may have been even higher in view of the wetter climate which suppresses fires more readily (Pope and Talbot 1994a, 55). Currently (Figure 11) 30% of the forest in the study area is in ageclass 8 (141-250 years) and only 6% contains old growth forest in age class 9 (251+ years) . In Pope and Talbot's long-range plans for TFL 23 and in the Arrow TSA, there will be no managed forest older than 105 years after two centuries (Pope and Talbot 1994b, 13; MoF 1995b, 17). Management plans for the Arrow TSA are not quite as focussed (Ministry of Forests 1994a, 17), and a small 200 year old forest regrows after two centuries.

Extending the rotation times to long periods would have a major impact on harvest rates in TFL 23 and the Arrow TSA. In the Arrow TSA a significant part of the landscape was burned for mineral exploration in the last century (Ministry of Forests 1994b, 3; Gardner 1986, 227). This forest, now in ageclass 8, constitutes about one-third of the harvest base in the Arrow

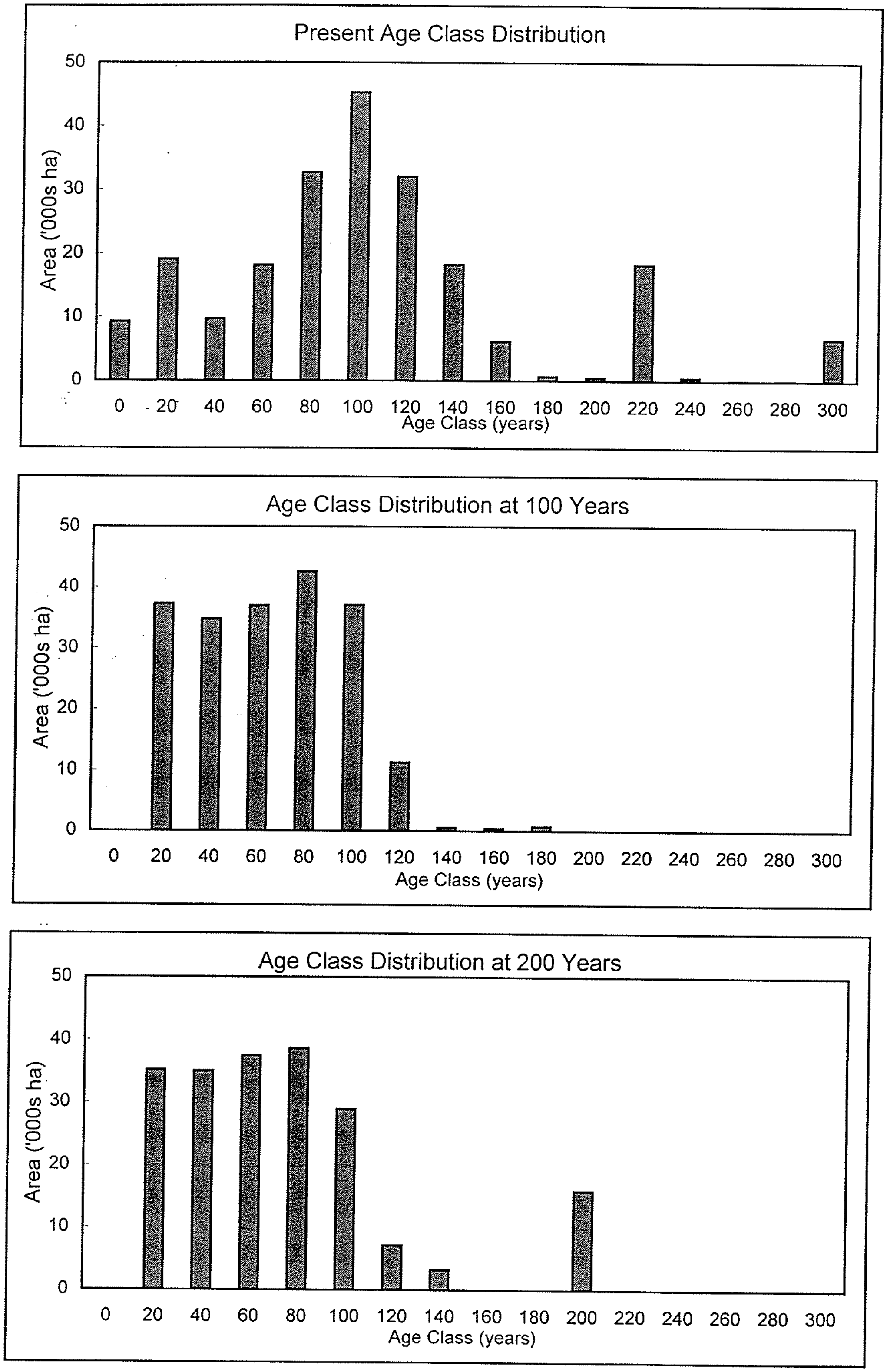

Figure 11: Changes in age class distribution on the timber harvest land base over time, assuming base line harvesting (from MoF 1994a, 17).

TSA and would have to be considered out-of-bounds for between 20 and 60 years at least, and possibly as much as 170 years under new "old growth" rules. While discussions of inter-generational equity tend to be largely theoretical in the sustainable development discussion, here we have an example of inequitable practices in the past which would impose economic burdens on the current generation of Columbia River valley residents!

4.6.2 Structural Complexity

Noss (1992) describes simplified stands as those with little or no coarse woody debris, reducing habitat for birds, mammals and amphibians (Hansen et al. 1991). Kimmins (1992, 171) largely agrees, but notes that the availability of nutrients and habitat is not certain, and depends on climate, soil and the type of forest. He notes that forests which are allowed to grow through longer rotations usually produce a significant amount of coarse debris. Both of his arguments favour New Forestry viewpoints, that forests should be managed to mimic natural processes. The Forest Practices Code also encourages, but does not mandate, the maintenance of complex stands in order to protect biodiversity (Ministry of Forests/B.C. Environment 1995b, 25).

In the New Forestry, maintaining structurally complex stands means retention of coarse woody debris and mature green trees (about 30%) in the cut-over, both scattered and in clumps. These wood residues contribute a large number of environmental services: increased moisture retention, sites for nitrogen fixation, substrate and nutrients for fungi, seedlings and microorganisms, and habitat and food for animals (Crow 1990, 50).

New Forestry ideas about stand structure are already making their way into forest management practices in the Pacific Northwest states. The need for spotted owl habitat protection resulted in the formulation of the 50-11-40 rule: 50% of the forest land base outside of the spotted owl preserves should be maintained in stands of timber with 11 inch DBH (diameter at breast height) and at least 40% canopy closure. While this maintains some structural components for owl habitat, it was not enough for a general application in Washington and Oregon forests. This requirement was modified by the Scientific Panel on Late-Successional Forest Ecosystems (often referred to as "the Gang of Four") to require as a minimum, the additional retention of at least 15 large live trees, 5 large snags, and 5 large downed logs on each hectare (Franklin 1993, 142). A group of industrial forest companies agreed to these New Forestry limitations in exchange for a holiday from lawsuits and litigation by environmental groups.

4.6.3 Patch Size and Isolation

As the managed forest is harvested, older natural forests are gradually isolated in small patches. Initially, in a four pass rotation, the clear cut areas are small islands within the mature forest. At the second pass, there is an equal division between mature and young forest. At the end of the third pass, older forests exist only as the 25% patches, to be removed with the final cut. Ecological and riparian reserves remain, isolated from each other and the uncut older forest by wide expanses of younger and more open trees. Adjacency constraints promote this fragmentation and the effects are readily visible from the air on the slopes and plateaus above the Columbia River valley especially within the Monashee Mountains (Figure 2). Much of this forest has been subjected to the first pass, and is now awaiting the passage of a 17 year interval for the second harvest.

Isolation has long been known as a modifier of the character of biological communities (Crow 1990, 54) since the days of Darwin and earlier. Fragmentation acts more as a destroyer of living organisms than as a modifier and has been linked to the decline of a large number of species. The exact mechanism is often uncertain, but edge effects, changes in interior forest character, and increased plant-animal interaction have been advanced as possible causes (Crow 1990, 53).

The older style of cutting was one of progressive clearcuts, which, while it opened vast continuous areas, left the remaining forest relatively intact. Because neither solution offers clear advantages, both the new and old forestry have problems with habitat fragmentation and isolation. There are two possible solutions. One is to disperse the clearcuts as small openings within the older forest fabric, but not permit succeeding cuts until the first has returned to old growth or at least mature, forest. This is equivalent to amending adjacency requirements to require that surrounding forest patches not be at green-up but instead at some much longer age. The second is to confine cutting to the edges of previous cuts, but in much smaller patches than was the case in the past, and with much longer times between adjacent cuts.

New Forestry tends to favour the second approach (Noss 1992, 29), in part because the requirement for extensive road networks is also reduced by adjoining cuts. Dispersed cutting is also favoured, provided later harvests do not open the intervening spaces. Kimmins (1992, 176) notes that traditional forestry, at least as mandated by the FPC, is evolving toward a mixture of forest openings which leave large parts of the forest intact.

Connectivity corridors in the Columbia River valley tend to lie along watersheds (Figure 12). Many of these are already extensively harvested as access routes follow the creeks up the slopes (Figures 1, 13, 14). This process linearly fragments an important component of the ecosystem. One solution would be to apply adjacency rules to linear structures as well as over areal measures, allowing only one quarter or less of the land along a streambank to be harvested at one time.

4.6.4 The Role of Fire

One of the major differences between traditional and new forestry is the role that the proponents see for fire. The forest manager who measures success by timber volumes will see fire as the ultimate enemy, to be suppressed and discouraged at every opportunity. New Forestry proponents see fire as a part of the natural environment, accepted even though it may be devouring valuable timber, suppressed only when threatening life or property. Consequently New Forestry proposes a return to more natural fire regimes, even though commercial losses can be expected.

Fires certainly have had a role to play in shaping the forest along the Columbia River. The existence of mature Ponderosa (yellow) pine stands is evidence of fire suppression of competing species (Langston 1995, 29). Lodgepole pine requires the heat of fire to remove old forests and release serotinous cones for new growth (Kimmins 1992, 109; Parish and Thomson 1994, 28).

The suppression of fire denies the natural ecosystem of one of its major controls, though in

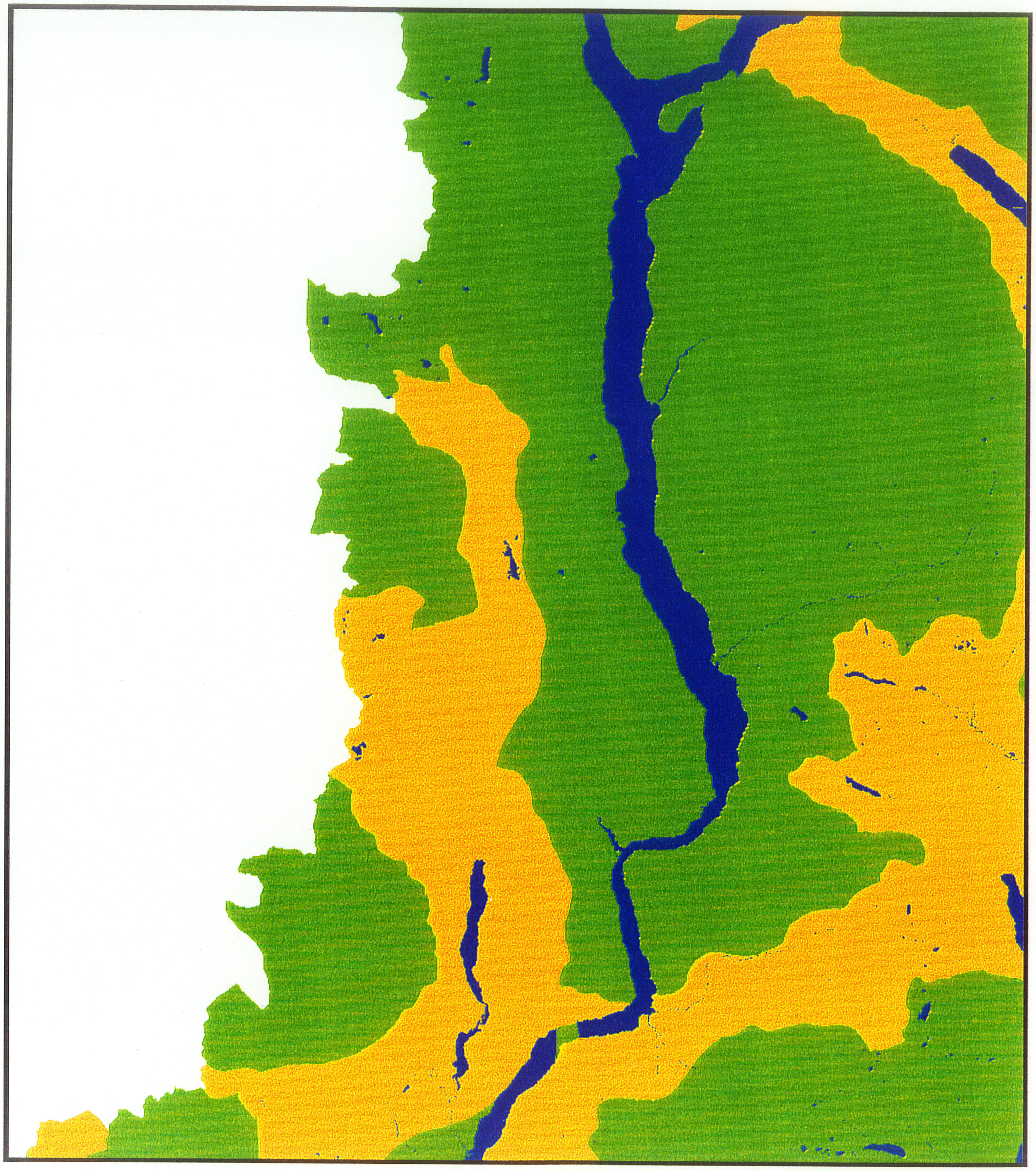

Figure 12: Connectivity corridors (yellow) in the study area. These corridors represent the primary routes for wildlife to move throughout the Arrow Lakes valley. The corridors represent a range of elevations and valley bottoms, but in general conflict with roads and settlements at lower elevations.

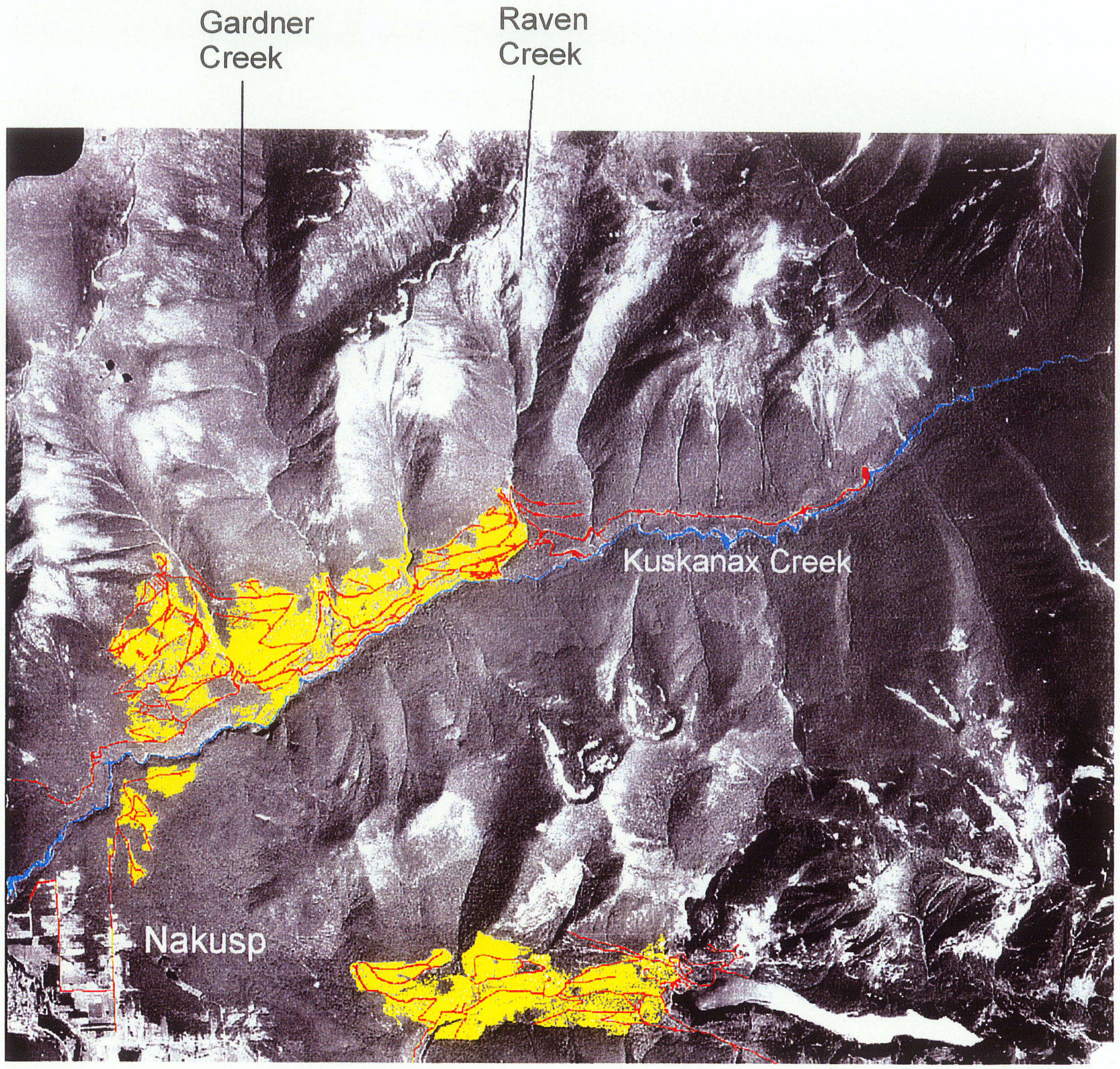

Figure 13 (above): High altitude air photo of lower Kuskanax Creek taken in August 1970. Clearcuts are highlighted in yellow, roads in brown, and the creek in blue.

Figure 14 (next page): High altitude air photo of the length of Kuskanax Creek taken in July 1987. Colours are the same as those in Figure 13. Note the string of clearcuts extending almost the entire length of the creek, and the roads leading off to new cutting areas. Asterisks (*) mark the locations of caribou sightings during a reconnaissance flight in 1994; numbers beside the asterisk indicate the number of animals sighted. The 37 animals found between Nakusp and Wood Creek are in the largest block of old growth timber in the study area (Figure 10, 10a).

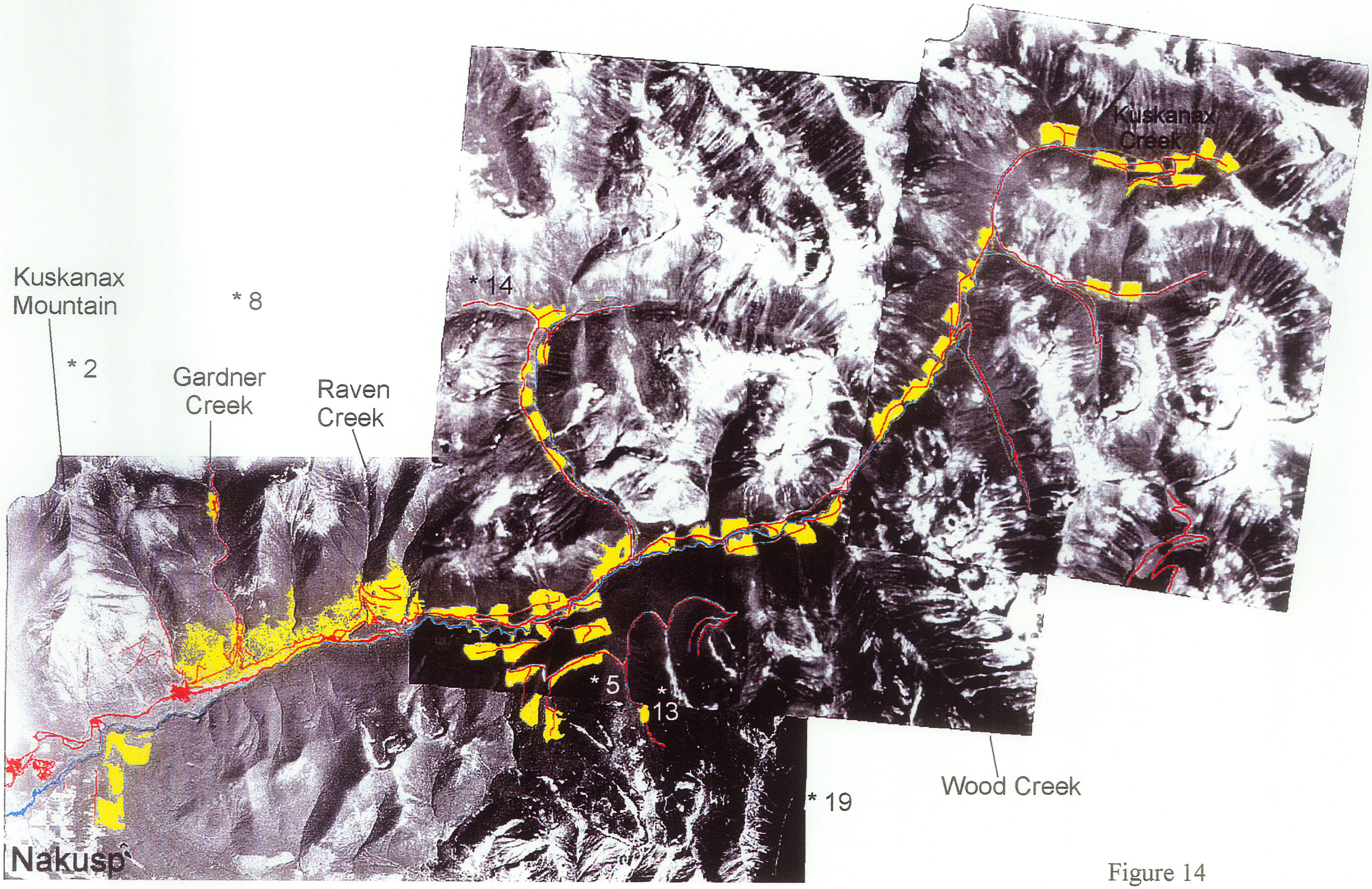
Kuskanax Mountain
* 8
* 2
Gardner Creek
Raven Creek
* 14
Kuskanax Creek
* 5
* 13
Wood Creek
* 19
Nakusp

Figure 14

the relatively moist climate of the Columbia River valley the effect is likely considerably muted compared to drier ecozones to the south (Figure 6). Numerous studies have shown that the primary consequences of the human presence is a decrease in fire frequency and a reduction in the average size of the burn area. Both Day (1990) and Agee (1990) found that fires in Quetico Provincial Park (Ontario) and Oregon were more frequent and burned larger areas in the past, and attributed the cause to modern forest management. Agee (ibid., 36) noted that in the very bad fire year of 1987, the total of burned and slashburned forest in Oregon was only one-third of the historical annual average. In contrast, Masters (1990), in a study of fire frequencies in Kootenay National Park, attributes a reduction in the fire cycle from 60 years in the 15th and 16th centuries to the current 2700+ years to the Little Ice Age and a recent wet climate. While climatic variability is undoubtedly responsible for some of the changes in fire frequency, most researchers tend to put the blame on human management.

Fire has wide-ranging effects on an ecosystem. Noss (1993, 25) gives several examples of tree species mixes affected by fire suppression and proposes prescribed burns which mimic natural wildfires to reestablish traditional species in Pacific Northwest forests. But the use of fire in the managed forest is a difficult endeavour, with many balances and compromises (Walstad et al. 1990) depending on whether it is used in the growing forest, the cut-over forest, to control slash, or to slow the spread of insects and diseases. Burning to mimic natural processes has strong economic implications as jobs disappear in smoke. Nevertheless, the Association of Forest Service Employees for Environmental Ethics also favours an increased role for fire in the interior Columbia River Basin. While the AFSEEE recognizes that occasional intense stand-clearing fires are a natural occurrence, their recommendation to Forest Service managers is more circumscribed: to "increase the opportunity for fire to play its natural role..." (AFSEEE 1996).

Agee (1990) describes how Western hemlock/Douglas-fir forests are completely renewed by intense fires; Douglas-fir can not dominate the stand unless hot burns occur. In cool and moist subalpine forests, fires convert forest to shrub and herbaceous species and may take a century or more to recover. Walstad and Seidel (1990) outline how light fires which remove heavy duff layers can promote coniferous growth, but note that burning on natural regeneration is "inherently variable because of differences in fire intensity, [and] variation in microsite conditions...".

The effect of fire goes well beyond the survival or demise of competitive tree species. Insect populations also react to fire, with some perishing in the fire while others attack the weakened and damaged trees. In lodgepole pine stands, downed and partly decayed trees allow smouldering fires to heat the soil and kill or weaken living trees. The stressed trees are then subject to further attack by mountain pine beetles, and on dying, become the vectors for smouldering trunks in a future fire (Agee 1990, 33). Ground dwelling insects are most vulnerable to light fires, while defoliating insects can move into weakened stands following a burn (Mitchell 1990). In general however, the main effect of burning on insects seems to be caused by the absence of fire—insects can spread into new niches when fire suppression changes the seral stages and climax forests in the western mountains (Mitchell 1990, 115).

The B.C. Ministry of Forests blames the suppression of fire for the "unchecked spread of insects and diseases" (Ministry of Forests 1982, 1). In the Arrow TSA in 1992, the mountain pine beetle alone destroyed over 100,000 m^3 of white and lodgepole pine (Unger and Stewart

1992). By 1994 the outbreak was coming to an end and mortality was reduced to 28,000 m^3. In the natural lodgepole pine forest, fires and infestations would normally kill older stands before beetles became a serious problem. The deliberately-set fires at the end of the last century started many large lodgepole stands which are now reaching an age in which they are susceptible to attack. Between 1977 and 1981 the number of trees attacked increased nearly twenty-fold (Ministry of Forests 1982, 3).

Thies (1990) suggests that wildfires have little impact on coniferous diseases, but leads to short-term decreases in soil organisms (Borchers and Perry, 1990). The susceptibility of soil organisms depends on the intensity and duration of the fire, and is likely to be low in the moist climate of the Arrow Lakes study area. Fire has a small impact on larger species of wildlife which can escape the flames and on smaller which can reproduce quickly. Fish however are impacted more dramatically when the streamside forest is lost (McMahon and deCalesta 1990).

A major effect of fire is to remove nutrients from the ecosystem, primarily nitrogen. Burning of old-growth forests results in particularly heavy losses, as these forests accumulate high levels of the nutrient (McNabb and Cromack 1990, 128). Wildfires in old-growth forest also tend to be hot because of the volume of downed fuel and the multi-storied canopies which allow flames to grow beyond the forest floor. In the wetter climate of the Columbia River valley, such fires would tend to occur mostly during drought conditions.

Fire makes a mosaic out of the forest ecosystem. Consequences are difficult or impossible to predict, with every possible combination of soil, moisture, temperature, vegetation, insect, nutrient and wildlife response, depending on the microsite circumstances. There is, however, ample evidence of the effects of fire in forest ecosystems. The complexity of responses and the uncertainty of prediction dovetail well with New Forestry's call for a more natural fire regime. By using nature as the model, responses are more predictable.

It is most unlikely that a policy of allowing lightning-induced fires to burn naturally will be introduced in the Arrow Lakes, though such an approach is common in the northern forests of Manitoba. Instead some form of prescribed burning with careful controls on fire intensity, size and timing will be used to control some aspects of the fire-sensitive ecosystem.

4.6.5 Road Density

The biggest pressure on the Arrow Lakes ecosystem of the future may not be forestry.

Modern two- and four-wheel drive vehicles can travel mountain logging roads with the same despatch as the log-hauling trucks and current regulations require that all logging roads be open to the public (Pope and Talbot 1994b, 31). Pope and Talbot managers indicate that restricting public access to the logging roads could be one of their toughest problems (Lang, pers. com.). Significant human presence in the backwoods often causes environmental harm, especially to grizzly bear and caribou populations, and to bull trout stocks. Humans tend to favour the most sensitive landscapes, particularly lakesides and streams (Pope and Talbot 1994b, Appendix VII, iv).

Both traditional and new forestry admit the detrimental effects of the road network which accompanies modern forestry (Lang 1994, pers. comm.; Noss 1993, 31). Noss suggests that the major impact is the access that is provided to hunters, suggesting that "the single most effective restoration measure for sensitive wildlife species would be road closures (Noss *ibid.* 31)." Roads consume space, eliminating production on a significant fraction of the landscape. Parker (1993, 210) counts a reduced road density along with longer rotations and changing the spatial pattern of harvesting as the most beneficial changes that can be made to managed forests to promote long-term sustainability.

Wilderness roads lead to more than increased hunting. Movements of some species of animals are curtailed by roads, adjacent streams may be polluted with silt and other runoff, new animal and plant species may invade previously inaccessible areas and modify the natural habitat, and diseases travel into the backwoods on vehicles and equipment (Norse 1990, 175). Deer and other ungulates are stressed by the presence of trucks and humans. In mountainous terrain, roads tend to be confined to valley bottoms and stream sides, extending gravel tentacles to the head of watersheds—a process dramatically depicted in Figures 13 and 14. Riparian areas and roads do not coexist well, leading to risk of landslide and mass wasting into the streambed. Norse (1990, 172) describes silt as "the most widespread pollutant in streams...". The B.C. Ministry of Forests (1982, 3) notes that roadways increase the frequency of blowdowns which in turn attract the spruce beetle and promote its migration into new stands.

The AFSEEE (1996) recommends that "no new roads... shall be built within riparian areas." The Forest Practices Code mandates the rehabilitation of at least a part of the road network once harvest has been completed, but long-lived road networks are inevitable in a harvest scheme which distributes the cut across the landscape. Studies by the U.S. Forest Service show that one area logged by cable had three times the erosion rate of an unlogged slope nearby, but that a roaded and logged site lost 109 times as much soil to the stream (Hirt 1994, 149). Hirt also reports that studies of road and skid trail permeability by Weyerhaeuser showed that water infiltration was reduced 35% on logged areas and 92% on roads. Some experiments in road closure and restriction in British Columbia have not proved successful because of public pressure, and some rehabilitated roadways have had to be reopened (Lang, pers. comm.).

Restricted access to the backwoods is not acceptable to residents of the Arrow Lakes valley, and there seems to be little controversy on this point. Environmentalists, hunters, recreationists and fishers all want to be able to enjoy the wilder side of nature. While several admitted to the need for restrictions on backcountry access, all suggested that it would be nearly impossible to attain. Until residents and tourists are prepared to give up the pleasure of backwoods travel, forest ecosystems will come under severe pressure from an increasing human presence. Pope and Talbot's five year plan (1994a, 1) calls for the construction of 900 km of road and 57 bridges.

Roads are a difficult problem for both old and new forestry advocates. The dispersed clearcuts which are currently mandated by adjacency and green-up rules lead to an extensive network of roads in order to harvest sufficient volume to maintain mill productivity. Larger aggregated clearcuts, harvested in small areas over an extended period of time, and then left to regenerate to old-growth status, offer many solutions and are currently favoured by some New Forestry researchers (Parker 1993, 210). Such cutting patterns reduce the network of roads, limit edge effects, slow fragmentation, and create relatively large areas of mature forest in future years. Such a pattern of cutting, bearing much resemblance to the huge clearcuts of past harvests, might find vociferous opposition from environmentalists.

The question of roads and watersheds will require very careful management, and is probably not solvable without considerable compromise. In Manitoba, some forestry roads are barricaded to the public, and access is not permitted for any reason, though there are numerous attempts to circumvent the barriers. In contrast, Pope and Talbot maintains an "open road" policy in TFL 23 (Pope and Talbot 1995a, 64), though recognizing the need for access management, including deactivation. Since roads are very difficult to restrict once being opened to the public, a good first step should be to close all new roads to public travel. Increased cable logging, perhaps over distances much greater than currently practiced, or logging from balloons or helicopter may become a part of the ultimate solution.

4.6.6 Endangered Species

The Arrow Lakes watersheds are home to a number of endangered and threatened species which varies according to the agency conducting the evaluation. The Ministry of Environment, Lands and Parks defines seven West Kootenay (and TFL 23) species as red listed (candidates for legal designation as endangered) and 24 as blue listed (vulnerable and threatened). Most of these are birds, many of which do not have a significant presence in the study area. Six of the blue-listed species are mammals: the southern red-backed vole, wolverine, fisher, black bear, grizzly bear and woodland caribou. For the most part this endangerment comes from habitat destruction and modification.

Wildlife reserves and parks are not always the answer as these tend to occupy higher elevations where soils are less fertile. Such reserves tend to protect only one component of the ecosystem. There are calls for a more balanced series of reserves and parks, spread across elevations rather than atop the landscape. This would be a difficult achievement in the Columbia River valley, as much of the land along the Arrow Lakes on the east side is given over to highways and cottages. Watersheds are logged along the streams, isolating the lower riparian zones from the slopes above (Figure 14). On the west side of Arrow Lake where cutting is more extensive, a network of logging roads divides much of the terrain into small blocks.

While North American stewardship of the forests in all its guises now proposes the protection of other values in the woods, the continued decline of species from present and earlier management suggests a considerable distance to travel. Noss' version of New Forestry calls for the active rebuilding of endangered habitats, but other passive aspects of his philosophy—more snags, more down timber, more standing trees, larger cutting and regrowing blocks, and longer rotations—will all contribute to the rehabilitation of plant and animal biodiversity. Because natural processes are more faithfully mirrored in New Forestry, the need for reserves may eventually be reduced, at least in the long term.

Pope and Talbot five year plans call for the retention of snags and large trees, similar to the New Forestry proposals. In critical habitat, cut blocks are to be kept to 10 ha or smaller, and slash piles may be left for marten and other species. Cutting patterns however continue to be dispersed into a mosaic with substantial edge effects (Pope and Talbot 1995a, 76).

The gradual loss of species can often not be controlled by management, especially when a large part of the forest habitat is set aside for cutting. Because animals are usually habitat specific, the pattern of cutting has very selective impacts. Clearcuts favour some animals such as deer, and depress populations of others, such as caribou. There is often no provision for wildlife in present management practices beyond the reservation of large parts of the landscape for a few particular species. In contrast, New Forestry ideals attempt to duplicate the most important natural processes, and in doing so, protect habitat over a much wider segment of the landscape. In New Forestry humans and animals share the whole ecosystem with appropriate levels and patterns of harvesting to preserve biodiversity.

With few exceptions, measures to protect threatened species can only be done through habitat renewal or preservation. And as species become extirpated in other parts of North America, pressure to preserve habitat in the Columbia River valley increases, even though local populations may be relatively secure. By reducing some of the pressure on the existing limited habitat, the ideas of New Forestry may eventually make good economic sense by opening up some currently reserved areas for harvest.

New Forestry comes with considerable economic cost and considerable ecological benefit—the classical trade-off of sustainability. This impact has been examined in some detail by Hansen *et al.* (1995) who model a spectrum of harvest and silvicultural regimes with various retention schemes and rotation schedules. They begin by simulating a 500-year forest with no human impacts, and then impose harvest rotation schedules which range from 40 to 240 years and retention cutting schemes which leave from zero to 150 trees per hectare after each cut. With each of these scenarios they examine economic impacts.

Their analysis finds that "wood production drops substantially with canopy tree retention and longer rotation lengths. (*ibid.* 548)". However the stand structure of the regenerating forest looks more like the natural forest when trees are left behind in the cut and rotation periods are lengthened. This also results in a higher bird species richness, though not all species fare equally. Tree species are also strongly influenced by rotation lengths, with quick-growing sun-loving varieties such as Douglas-fir dominating.

Economically, the value of the larger trees in the long-rotation forest partly offsets the greater operating and opportunity costs of delayed harvests. Rotation age has a relatively small impact compared to retention level. In particular, clearcutting with a 240 year rotation age retains 98% of the value of an 80-year rotation. However, retaining 30 trees/ha reduces the value of a 240 year old forest to 56% of the clearcut short-rotation case.

4.7 Summary

There is no question that the treatment of the forests of the Columbia River valley is unsustainable from a New Forestry viewpoint. Indeed, the arrival of the first human, and certainly the first European began a modification process which has culminated in the forest we see today. A new forest is under construction, one with a different mix and arrangement of tree species, one with a constrained or absent underbrush, a forest with short-circuited seral stages. It has a network of roads to allow the passage of humans. Streams and brooks are necklaced by stands of young growing trees instead of the stooping gloom of old forest (Figure 14). Fires are rare and quickly suppressed. Pests and fungi are treated and controlled. The tangled mess of a blowdown is quickly harvested, while plugged streams are gently cleaned and an new stand planted, all within a few years.

Is the forest sustainable in its current form under the canons of conventional forestry? Possibly not, in view of the discussion of the AAC in section 4.5, which strongly indicates that too much is still being removed from the licensed areas. But the AAC and forest models have little insight to offer in an evaluation of biodiversity and its future survival. If the future proves that the timber volume is just not available to sustain the mills and lumberyards, humans may adapt by closing a firm or two, or restricting working hours, or eliminating jobs—not favourable for sustainable development, but perhaps appropriate for some minimal maintenance of biological sustainability. Sustainability as defined by the AAC is overwhelmingly economic in its outlook: "to achieve a maximum even-flow of timber while addressing the requirements of other resources and users of the landbase." (Pope and Talbot 1994b, 3).

If current management practices continue, what will the future forest look like?

The 34% of TFL 23 in ageclass 8 and 9 (old growth forest) will decline to 6% within a century. The oldest trees will barely reach 100 years (Figure 11). A network of roads will reach to the source of every primary watershed. From the air, openings will dot the landscape, spangling the winter landscape with bright snowy jewels in a dark green background as 10% to 20% of the landscape awaits green-up. Mono-, di- and tri-culture stands will struggle with pests and diseases, watched over by foresters, and genetically manipulated to grow ever more quickly to harvest age. Recreationists will visit the secret valleys of the Selkirks and Monashees, marvelling at the wilderness vistas, and unloading snowmobiles to travel to the alpine meadows and the deep snows of winter or fishing rods to sample the cold alpine streams and lakes.

One element which will be lost from this future forest is change. Ecosystems are in a continual state of flux: building, sustaining, destroying, rebuilding in cycles of days to millennia. In a biologically diverse environment, life is seldom static, though on human lifescales it may appear to be so. Forestry imposes a great disturbance on the mountainside, but then attempts to stabilize the landscape against further change, building the ideal even-aged forest. This stable and somewhat sterile landscape holds no attraction for an increasing number of foresters, and no guarantee of permanence, and so the New Forestry movement has evolved.

Under the guidance of the New Forestry philosophy, the next forest should look much like the one being harvested, at least theoretically. It is more likely to be sustainable because it is modelled on an ecosystem already known to be sustainable—the natural one. It still imposes a change on the Arrow Lakes landscape, but perhaps a more gentle and persistent one. The cost will be largely economic: more forest must be left behind for a longer time. Because the current land base of the Arrow TSA and TFL 23 is fully subscribed, annual harvest levels will have to decline, jobs lost and plants closed or reduced to make room for the new forestry. This "cutting back in the present to ensure future availability" is a fundamental component of sustainable development, even when defined in strictly economic terms. In the words of the Brundtland Commission (WCED 1987, 9): "sustainable global development requires that those who are more affluent adopt life-styles within the planet's ecological means."

Given the uncertainty about the sustainability of present forest practices, the pressures from professional foresters to protect biodiversity, and public sentiments about forestry, it would be surprising if the forest industry along the Arrow Lakes did not move toward the New Forestry paradigm. There is no indication as yet that this will be acceptable to environmentalists, and the pressures for additional habitat preservation may continue unabated. In a sense New Forestry may represent the final opportunity for the forest industry to retain control of its own house.

5. Wildlife

5.1 Background

British Columbia has an impressive number of wildlife species, in large part because of the varied topography, climate and biogeoclimatic zones that the province has to offer. The study area along the Arrow Lakes is not so well endowed, being restricted to species which prefer alpine and steep forested slopes. The loss of bottom land due to flooding has removed an area of high biological productivity and rich biodiversity from the region, possibly resulting in the loss of some species from the area and the migration of others to new habitats. The presence of human hands in this relatively uninhabited part of the central mountains has placed a number of other species in endangered or threatened status.

British Columbia assigns species and subspecies to "red" or "blue" lists which designate the level of threat to their continued survival in the province. Red-listed species are candidates for legal designation as threatened or endangered; blue lists are for sensitive or vulnerable species. Within the Central Columbia Mountain (CCM) ecosection there are three red-listed

Common Name	Scientific Name	Status
Painted Turtle	*Chrysemys picta*	B
Western Grebe	*Aechmophorus occidentalis*	R
American White Pelican	*Pelecanus erythrorhynchos*	R
American Bittern	*Botaurus lentiginosus*	B
Great Blue Heron	*Ardea herodias*	B
Oldsquaw	*Clangula hyemalis*	B
Surf Scooter	*Melanitta perspicillata*	B
Turkey Vulture	*Cathartes aura*	B
Bald Eagle	*Haliaeetus leucocephalus*	B
Swainson's Hawk	*buteo swansoni*	B
Sandhill Crane	*Grus canadensis*	B
Lesser Golden Plover	*Pluvialis dominica*	B
American Avocet	*Recurvirostra americana*	B
Red-Necked Phalarope	*Phalaropus lobatus*	B
California Gull	*Larus californicus*	B
MacFarlane's Western Screech Owl	*Otus kennicottii macfarlanei*	B
Short-Eared Owl	*Asio flammeus*	B
Lewis' Woodpecker	*Melanerpes lewis*	B
Townsend's Big-eared Bat	*Plecotus townsendii*	B
"Selkirk" Least Chipmunk	*Tamias minimus selkiri*	B
"Western" Wolverine	*Gulo gulo luscus*	B
Fisher	*Martes pennanti*	B
Badger	*Taxidea taxus*	B
Grizzly Bear	*Ursus arctos*	B
Caribou (southeast)	*Rangifer tarandus montanus*	B

Table 6: Threatened and endangered species in the Central Columbia Mountains (Paige, pers. comm.). "R" indicates red-listed species (threatened) "B" indicates blue-listed (vulnerable).

species and 22 blue-listed species (Paige [9], pers. com.). Seventeen of the threatened species are birds (Table 6). Not all of the species are found in the Arrow Lakes study area as it comprises only the western third of the CCM ecosection. Within the study area, the most prominent threatened species are the mountain caribou (*Rangifer tarandus caribou)* and the grizzly bear (*Ursus arctos*), both of which are blue-listed. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) considers the Selkirk herd to be endangered (Kelsall 1990, 1).

5.2 Mountain Caribou

Mountain caribou are found mostly within the Southern Interior Mountains, numbering some 1700 animals in all (EC/MoELP 1993, 76). Within the study area, they are found at higher altitudes on the east side of the Arrow Lakes, on the slopes of the Selkirk Mountains above Nakusp (Figure 15). They are a poorly studied population with considerable uncertainty about their range and preferred habitats. They are designated an "old growth dependent species" because much of their winter grazing depends on arboreal lichens which are most commonly found in the oldest forests, greater than 250 years of age (McLellan, Flaa & Super 1994).

Caribou "usually have low reproductive levels, and because they are creatures of traditional habit and are highly gregarious and curious, they are particularly vulnerable to hunting and to changes or destruction of habitat (Kelsall 1984, 1)." Traditionally, their range extended through the length of the British Columbia mountains as far south as northeast Washington, the Idaho panhandle, and northwest Montana (Kelsall 1984, 11). Today the southern limits

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[9] Kathy Paige, Coordinator, Ministry of Environment, Wildlife Branch, Victoria, B.C.

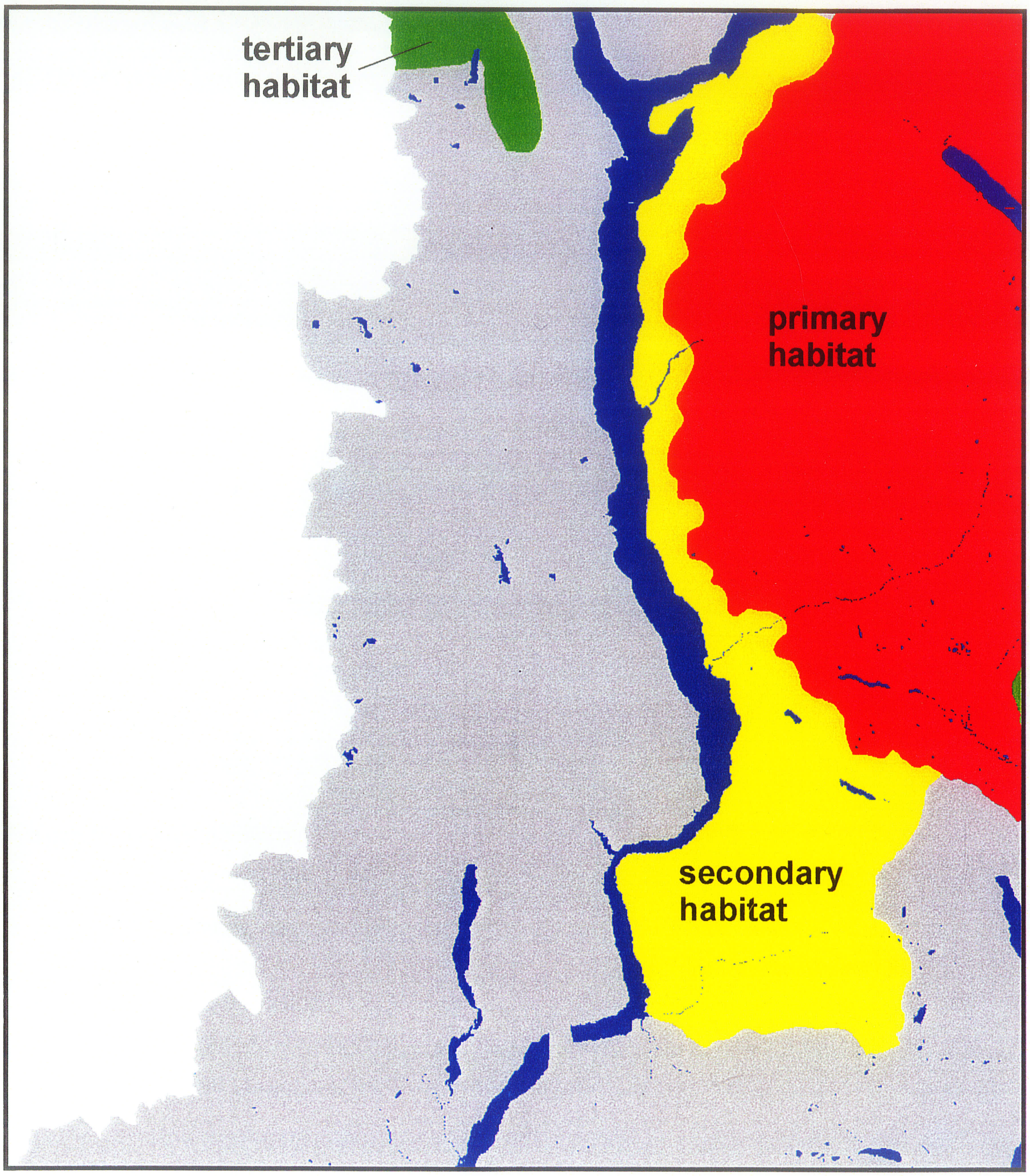

Figure 15: Woodland caribou habitat quality. Grey areas are not utilized by caribou. Source: Environment B.C.

have become fragmented, and a small remnant population of 25-30 animals (in 1980) can be found straddling the Washington, Idaho and British Columbia border (Kelsall 1984, 27).

The heights above Nakusp contain the Selkirk Mountain herd (Figure 15) at the southern limit of the caribou's continuous range in B.C. (Kelsall 1984, 18). Censuses of mountain caribou in the Nakusp area are limited to a single study in March 1994 (McLellan, Flaa and Woods 1994). This aerial survey showed significant caribou populations on the heights along Kuskanax and Gardner Creeks in bands of 4 to 19 individuals (Figure 14). In this survey a total of 59 animals were sighted near the creek, and a further 32 were found north of Halfway River. Animals in other locations nearby brought the one-day total to 131 sightings, from which a population of 141 animals was estimated. Thirteen of the individuals sighted were calves, implying a relatively low recruitment rate within the population.

Surveys conducted in the Revelstoke area over a six year period tentatively suggest that caribou populations in the area have increased slightly. The same may also be true of the Selkirk herd above Nakusp. Ken France[10] (pers. comm.), an alpine guide who spends considerable time flying above the Selkirks in winter, stated that caribou sightings seemed to be growing in frequency in recent years. Kimmins (1992, 92), in contrast, mentions a "dramatic decline" in the abundance of caribou in central B.C. which he blames on wolves and the spread of moose, but this does not seem to be the case in the southern Selkirks on the basis of the current (short term) evidence.

McLellan, Flaa and Super (1994, 12) discovered that caribou within the Selkirks tend to make

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[10] Ken France, Senior tour guide, Kootenay Heliski, Nakusp.

significant use of low elevation cedar-hemlock forests in the spring and early winter. This movement seems to be related to snow depth, with the animals seeking higher elevations as the snowpack deepens; the amount of movement depends on the character of the winter. By the late winter the higher subalpine parkland was the preferred habitat. In both seasons there was a marked preference for older forests (Figure 16).

This pattern of use has not been noted in other British Columbia herds and brings a greater potential for conflict with the forest industry along the Columbia River. Figure 14 suggests that this conflict is already underway in the Kuskanax Creek watershed, where clearcuts are infringing on the forests used by a significant caribou population on the south side of the creek. This forest is one of the few large patches of ageclass 9 spruce forest remaining in the study area (Figure 10). Older low elevation cedar and hemlock forest is even less common, and mostly found in the area north of Nakusp between Kuskanax Creek and Halfway River (Figure 10a).

During the low snowfall winter of 1992-93, McLellan and Flaa (1993) studied caribou diets and found that the animals fed most often (46%) on the shrub falsebox (*Paxystima myrsinites*). Forty percent of the diet was old growth lichens The balance was food obtained by digging through the snow cover. These results may not be typical of winters with deeper snowcover, where aerial lichens would take on additional importance.

Preserving the environment of the woodland caribou will have dramatic consequences for the forestry industry. Because the animal has a critical reliance on older forests, wandering habits that range from high to low elevations, low populations, a general intolerance of disturbance,

age class	Season: early winter	late winter	spring	summer
	Percent frequency found in ageclass			
1	0	1	0	0
2	0	2	7	1
3	1	1	3	2
4	4	1	0	2
5	3	1	0	0
6	3	2	10	1
7	2	0	0	4
8	56	57	34	66
9	31	36	45	26

20% 40% 60% 40%

Figure 16: Percent of caribou found inhabiting forests of various age classes in each season. Contours at 20% intervals have been drawn to emphasize the year-round preference for older forests. From McLellan and Flaa, 1993.

and low fecundity, protection will have a major impact on harvesting and will likely require a reduction in the operable land base. Caribou are also threatened by hunting, fragmentation of populations by forest operations, and hydro developments. Logging roads now allow snowmobiles into the alpine environments of the Selkirk Mountains during winter, disturbing the herds even further. The same roads permit the migration of predatory species such as wolves and diseases spread by moose (Kimmins 1992, 92).

McLellan, Flaa and Super (1994, 12) offer three alternatives to the forest industry for management at the stand level:

- excluding harvesting from caribou habitat
- longer rotation periods so that one-third of the timber is in age class 9
- selective uneven age stand management

To these they also add protection of connectivity between the populations, a feature which is particularly important with the low population figures of the Selkirk herds. In the Arrow study area, harvesting above the south slopes of Kuskanax Creek and between Kuskanax Creek and Halfway River should be stopped until herds and habitat are more fully examined. This recommendation draws some support from Ministry of Forest staff who note that "the old growth forest requirement for caribou winter range does not appear to be adequate in the timber supply analysis" (Ministry of Forests 1994b, 8). And while it is outside the scope of this study, McLennan, Flaa and Woods' (1994) population measurements suggests that there is an opportunity to introduce caribou into prime habitat between Trout Lake and Revelstoke (their Akolkolex region).

These recommendations mesh well with the suggestions of New Forestry proponents. Wildlife habitat protection is a strong component of the Forest Practices Code as well, but here the approach is one of permitting the largest possible cut while preserving "sufficient" space for the species instead of the much safer position of first protecting the caribou.

The 1995 CORE[11] land use plans predict a continuing loss of caribou habitat, with herds declining in most areas. Smaller remnant populations, among them the Central Selkirk herds, are expected to continue to be viable, though declining, (CORE 1995, 40247), an optimistic view for such a small herd. Though full implementation of the Forest Practices Code would bring some improvement in the outlook for caribou herds, the small amount of habitat remaining along the Arrow Lakes and the increasing levels of exploitation in that habitat would suggest that it is time to pause for reflection. The proximity of the caribou herds to tourist facilities already developed along the Kuskanax would also seem to offer alternative resource development opportunities which might otherwise be lost.

5.3 Grizzly Bear

Grizzly bears are referred to as a "flagship species" for their charismatic appeal to the public and as an umbrella or landscape species for their wide ranging habitat requirements, which if protected, would also provide living space for many other animals and plants (Newcombe[12],

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[11] CORE (Commission on Resources and the Environment) is a regional planning and land use allocation body established by the provincial government to integrate stakeholders and land-users into planning decisions across the Kootenays. Over 18 months of public round-table meetings, CORE attempted to partition the West Kootenays into land-use strata according to multiple levels and types of resource use. The program was recently terminated by the provincial government.

[12] Charles Newcombe, Habitat Protection Branch, MoELP, Victoria.

pers. com.). Bear populations in the Nakusp study area appear to be relatively stable, but other nearby areas, and North America in general, have suffered extensive losses in the past two centuries (MoELP 1995a, 11). The same pressures which caused these losses—primarily an increasing human population—are continuing to build along the Arrow Lakes.

The extirpation of the grizzly from its previous wide range across the continent now limits management options in the Selkirk Mountains, for the remnant populations command a level of protection which must atone for those past declines. Protection of the grizzly is now an objective of several environmental groups, and strong political pressures are being applied to government. The Province of British Columbia recently adopted a grizzly bear conservation strategy (MoELP 1995b) which lists among its policy goals the objective to "maintain in perpetuity the diversity and abundance of grizzly bears and the ecosystems on which they depend...".

5.3.1 Population

The Selkirk Mountain grizzly bears are part of a population which extends north and south along the mountain chain, reaching across the international border into the United States (MoELP 1995, 13). Current grizzly populations in the West Kootenays are believed to be between 700 and 1000 individuals (CORE 1995, 39237), a significant number in global terms. Within the Selkirk Mountains, the estimated density of bears is one per 127 km^2 (Banci 1991, 16), a figure which puts approximately 40 bears within the study area. Density calculations based on MoELP tables (MoELP 1995a, Table 2) suggest a density of one bear for every 51 km^2, or nearly 100 within the study boundaries.

Grizzlies, like all bears, have a low reproductive rate, with the average female giving birth to about eight cubs in a lifetime (MoELP 1995a, 4). The female has the capacity to prevent implantation of the embryo if fat reserves are low, and so habitat quality is critical for robust survival of the species. Survival of the cubs is most threatened in the first year. The primary cause of mortality in this time has been attributed to predation and malnutrition (Banci 1991, 43). The Selkirk Mountains appear to be a modestly lush habitat, with one study showing a mean litter size of 2.1 cubs (*ibid.*, 44). For adult bears hunting is the primary cause of death.

Within the B.C. portion of the Cool Moist Mountain Grizzly Bear Zone (Banci 1991, 4) which includes the study area, COSEWIC (*ibid.* 138) estimates a population of 2210 bears in a habitat with a potential for 5000. Base on the ratio between the two, COSEWIC has assigned a status of "vulnerable" to the grizzly. Past losses of grizzly bear habitat, primarily on the Prairies, require extra caution when managing the Selkirk population, or any remaining population in Canada. Past losses have absorbed the capacity to be flexible, and now remaining grizzly populations must be more aggressively protected. According to Banci (1991, 25) this means that the integrity of small isolated populations must be protected, and that there should be no further reductions in status.

The minimum size of a sustainable bear population is uncertain. Banci (1991, 47) quotes estimates of 30 to 125 bears for short term survival and 393 to 500 for indefinite preservation. The protected area required for survival over "evolutionary" time frames ranged up to one million km^2. In the Selkirks, given typical bear densities, survival of 500 bears would require a protected habitat five to twelve times larger that the study area (about 5000 km^2). Such a large area of land could not be set aside exclusively for bear habitat and so some form of multiple use management must be instituted.

5.3.2 Habitat

Habitat studies by the Ministry of Environment, Lands and Forests (1995a, Figures 6-8) suggest that the Selkirk Mountains are prime grizzly bear habitat, but only populated to about half its potential. Grizzly bears are omnivores, able to exploit a wide variety of foods in many habitats. This is advantageous for survival in a capricious climatic regime, with human impacts and large seasonal swings in food supply. Their ability to utilize the resources of the entire landscape allows them to coexist with some of the changes brought by resource development but at the same time greatly increases the likelihood of contact with humans and requires that large areas of diverse habitat be protected. In the Selkirks the home range for adult bears covers over 700 km^2 while that of females is limited to about 225 km^2 (Banci 1991, 46).

Favoured habitats range across all elevations, from alpine meadow to river bottom, but riparian areas, seepages, lake shores, and streams and rivers are the most valuable sites. After emergence from the den in spring, bears tend to congregate at lower elevations to take advantage of the earliest emerging vegetation and winter-killed ungulates. Later in the season they tend to move to higher elevations, foraging on plant species as they emerge from winter dormancy. As fall approaches, the bears return to lower sites for salmon and berries. Denning typically occurs before late October and the bears are dormant until May. According to CORE, (1995, 48304), most grizzly bears feed intensively on huckleberry species to build the annual fat reserves required for hibernation. Grizzlies are thus extremely dependent on the maintenance of vegetative seres that support this forage.

Modern silviculture usually tries to remove brush from a regenerating clearcut in order to give the growing crop trees a head start. The managed trees often reach a stage of crown closure much earlier than naturally regenerating stands, cutting off an important food supply for an extended period of time. This has removed so much habitat in coastal areas of the province that a specific government program to enhance shrub growth by reducing stocking standards has been introduced (B.C. Environment 1995b). Use of forage areas is also subject to availability of adjacent thermal and security forest cover. Forests also provide movement corridors, edge habitat and support a variety of understory forage species.

The extensive logging road networks which develop as a result of forestry operations bring humans into direct contact with the bears (Figure 14), presenting several problems including habitat loss, harassment, displacement, human-bear conflict, poaching and biological impacts such as reduced fecundity and survival. On the other hand, clear cutting opens areas of the forest which can provide additional valuable habitat for the grizzly bear (MoELP 1995a, 40). Grizzlies are not particularly attracted to old growth forests (Banci 1991, 42).

5.3.3 Threats

The primary reason for habitat loss along the Arrow Lakes at present can be attributed to forestry, hydro development, and settlement, each with its own complications (Table 7). All of these are likely to continue to reduce bear habitat in the future, along with largely unknown effects from global warming, pesticides and herbicides.

The impact of forestry begins with logging itself, which leaves a patchwork of open areas across the landscape. These patches may provide the brush and berry habitat necessary for a healthy bear population, especially if managed to provide open areas over a relatively long time period. This can be done by replanting in clumps which leave intervening open spaces for brush to grow (B.C. Environment 1995b). In the West Kootenays, forest operations are expected to result in a small increase in bear numbers, in large part because of the open habitat provided by clearcuts (CORE 1995).

But clearcuts also bring roads and more humans into bear habitat. The habitat itself is fragmented and disrupted. There is a loss of security and thermal cover, possibly denning habitat, and an alteration in the type of food available. There may be direct killing of bears which interfere with humans. Fire suppression results in a reduced habitat diversity, and fragmentation of the landscape by fire-guards and access roads. Clearcut patterns, such as those along streams, may also restrict bears from a critical part of their habitat (Figure 14).

In the Arrow Lakes ecosystem, hydro development has likely had the most serious impact on the grizzly. Because the Arrow Lakes existed before the dams were constructed, the effect of the flooding of valley bottom habitat was limited in area after the construction of the Keenleyside dam. The main effect of the dam was to raise the lake level rather than create a new lake. What bottom land there was was largely taken up by farms and settlements which limited much of the habitat for bear use. But lower slopes and valley bottoms were inhabited by a rich population of deer and other ungulates which was displaced to less favourable habitat higher on the slopes. Olson[13] (pers. comm.) tells of white tailed deer moving upslope into mule deer habitat, a process which is now largely completed. The white tailed deer have

[13] Glen Olson, owner, Olson's Marine, Nakusp

Land Use Activity	Present Impact	Future (5 year) Impact
Agriculture	L	L
Ranching and Grazing	M-H	M-H
Forestry	H	H
Herbicides/Pesticides	L-H	H
Mining		
Petroleum	H	H
Hydroelectric Power	H	H
Commercial Fisheries		
Land Alienation	H	H
Access	H	H
Recreation and other human activity	M-H	M-H

Table 7: Present and future impacts of land use activities on Grizzly bear habitat within the Southern Interior Mountains of British Columbia. L = low impact, M = medium impact, H = high impact. A blank means the impact is absent or has already occurred (as for mining, above) (from MoELP 1995a, 19)

taken advantage of clearcuts to provide part of the lost valley bottom habitat. According to Olson, white tails are "now seen 30 km back in the valleys where they've never been seen before." In his opinion hunting for deer, moose and elk is better than ever.

But blocking the Columbia with the Grand Coulee dam did remove the salmon runs from higher levels of the river, with consequences for the grizzly population which can only be guessed. After the inundation of the Columbia River in Washington, grizzlies returned to traditional salmon spawning grounds for years afterward, searching for the salmon which disappeared with the construction of the dam (Banci 1991, 43). Hydro development also brings linear corridors for power lines, corridors which allow additional human access, though the early seral habitats which develop also provide additional food for the bears, especially if managed to protect this food supply.

Settlement and the movement of humans in the valley have also had a serious impact on bear populations. Grizzly bears are viewed with considerable fear by most people, and bear-human contact usually results in the death of the bear. Settlement brings larger towns and agriculture, highways and occupation of prime valley bottom habitats. A highway along the east side of the Arrow Lakes blocks ready access to the water. This alienation of the waterfront is reinforced by the proliferation of cottages and houses in flatter areas and creek outwashes.

Humans bring livestock, a tempting prey species for bear. Though ranching is very limited in the study area, one resident of Trout Lake, told of the slaughter of a number of cows by a single grizzly one night. In his mind it was the grizzly that should be controlled, in spite of the general unsuitability of the area for livestock. Local residents who come into contact with grizzlies treat the bears as a dangerous nuisance. Encounters with grizzlies are certainly not rare in this prime habitat, and there is no thought that the species is threatened.

Recreation brings humans into wilderness habitat used by the bears. Sometimes this is by hiking, but more often it is by vehicle in the myriad of logging roads which lace the hills. According to Banci (1991, 64) roads have a major effect on bear populations and habitat use. Bears tend to avoid roads, but may be attracted to roadside vegetation when food supplies are scarce.

Increasing demand for the "wilderness experience" brings more fear of bears (Banci 1991, 58) so that aggressive encounters with bears almost always result in the removal of the bear, by trapping or killing. One sad note, left at a kiosk at the head of the hiking trail into Kokanee Glacier Park, complained that the trail was closed because of the presence of feeding bears and queried "are you going to let a few bears keep you off of the trail?", then suggesting that "they all be shot"! In areas where hunting is permitted, grizzly bears tend to avoid humans and may be displaced from traditional habitat by hikers. In "no hunting" areas bears may become habituated, challenging hikers for food. Winter recreation is becoming increasingly popular, with snowmobiles using logging roads to reach high elevation alpine slopes (France, pers. comm.). In this habitat they run the risk of disturbing denning areas.

Humans bring garbage, and bears are quick to associate this new food supply with humans. Killing of garbage bears is a major source of mortality in denser populated areas (Banci 1991, 65). None of this is necessary, as management techniques to prevent bear access to garbage are well known, though expensive. Control often requires little more than fencing.

5.3.4 Hunting

COSEWIC estimates that a 4% harvest rate annually is the maximum sustainable hunt. Reported kills in the Kootenays are below this critical limit. But reported kills are only part of the story. During 1990, 5 of 28 radio-collared bears in the Selkirk Mountains were killed illegally (COSEWIC 1991, 29). Assuming that unreported kills are 50% of those reported, then the Kootenays, including the Nakusp study area, have a harvest rate of 4.4% (Banci 1991, 19), 10% above the sustainable limit. Nevertheless, current attrition rates are lower than those in the past.

In the Cool Moist Mountain Grizzly Management Zone, annual kills range from 72 to 83 bears in the 1980s (Banci 1991, 142). Recently the proportion of female bears in this kill has climbed to 40%, higher than the 33% recommended (*ibid.* 69). Deaths for other reasons, primarily poaching, but also including traffic injuries, accidents, problem bears, and research, are often difficult to measure, but are important for sustainable management. B.C. now assumes an additional 50% mortality for these causes (MoELP 1995a, 56), but in some jurisdictions it may reach 100%.

Protection against hunting may not be far off. A strong lobby to prevent all bear hunting in British Columbia is finding strong public favour and political support in the province (Globe and Mail (Toronto), 13 July 1996, A4). Locally within the Columbia River and Slocan Valleys environmental movements are very strongly in favour of the establishment of parks to protect bears. Establishment of Valhalla Provincial Park several years ago, and the Goat Range in 1995, were both inspired by the demand for additional bear habitat.

5.3.5 Protected Areas and Habitat

The B.C. Provincial government has recently adopted a strategy which addresses the concerns outlined above (MoELP 1995b). The main points of this policy are to establish grizzly bear management areas, place all hunting licenses on a limited entry lottery system (MoELP 1992), increase enforcement and penalties, regulate garbage disposal and compost and educate the public to view the bears more favourably.

Management areas will contain quality bear habitat in which hunting, but not other resource use, is prohibited. Recreational access by vehicles, bikes and hiking will be controlled. The management areas will be linked by corridors, wherever possible, to other management areas. The Forest Practices Code also contains provisions to protect wildlife habitat, and these will be meshed with the Grizzly Conservation Strategy. Newcombe[14] (pers. comm.) suggests that riparian habitats should be managed as grizzly bear habitat, since bears interact with streams, mostly within the closest 200 m. Preservation of bear habitat would also protect the biology of the streams.

Because the grizzly bear is an omnivorous landscape species, the opportunity for co-existence with human activities and resource extraction is good, particularly with the forest industry. Establishment of protected habitats and the restriction of human-bear contact should be a primary goal of all activities which take place within the bear's environment. A strong grassroots movement in British Columbia is now collecting names to force a plebescite on bear hunting with an eye to a complete ban on hunting within the province. Provincial

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[14] Charles Newcombe, Habitat Protection Branch, MoELP, Victoria.

politicians have indicated their willingness to support the plebescite if proponents can obtain the necessary votes to force the issue onto the ballot.

5.4 Other Wildlife

The slopes surrounding the Arrow Lakes contain a wealth of fur-bearing animals: lynx, marten, bobcat, beaver, mink, muskrat, weasel, wolverine, otter and racoon among others. Of these, the wolverine (*Gulo gulo luscus*) is on the blue list of vulnerable or sensitive species (Paige, pers. comm.). A small trapping industry harvests these animals; marten is by far the most desirable fur with 80% of the total harvest confined to this one animal (Harrison[15], pers. comm.).

In 1991 an exceptionally heavy harvest of marten was followed by two years of decline, to only half the earlier harvest. The harvest was not related to the fur prices (Bewick[16], pers. comm.) , and its explanation remains elusive. Biological or climatological factors do not seem to be important, as no other fur-bearing species showed any change in harvest levels in that year, and presumably in population (Figure 17).

From 1988 to 1994, a total of 2748 fur-bearing animals were trapped within the study area (Table 8). Six of these were wolverine. It is impossible to say whether the harvest is sustainable, but the small numbers and considerable annual variation in harvest would suggest that the catch for species other than marten is more one of opportunity than intensive

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[15] G. Harrison, MoELP, Wildlife Branch, Nelson, B.C.

[16] David Bewick, North American Fur Auctions, Winnipeg

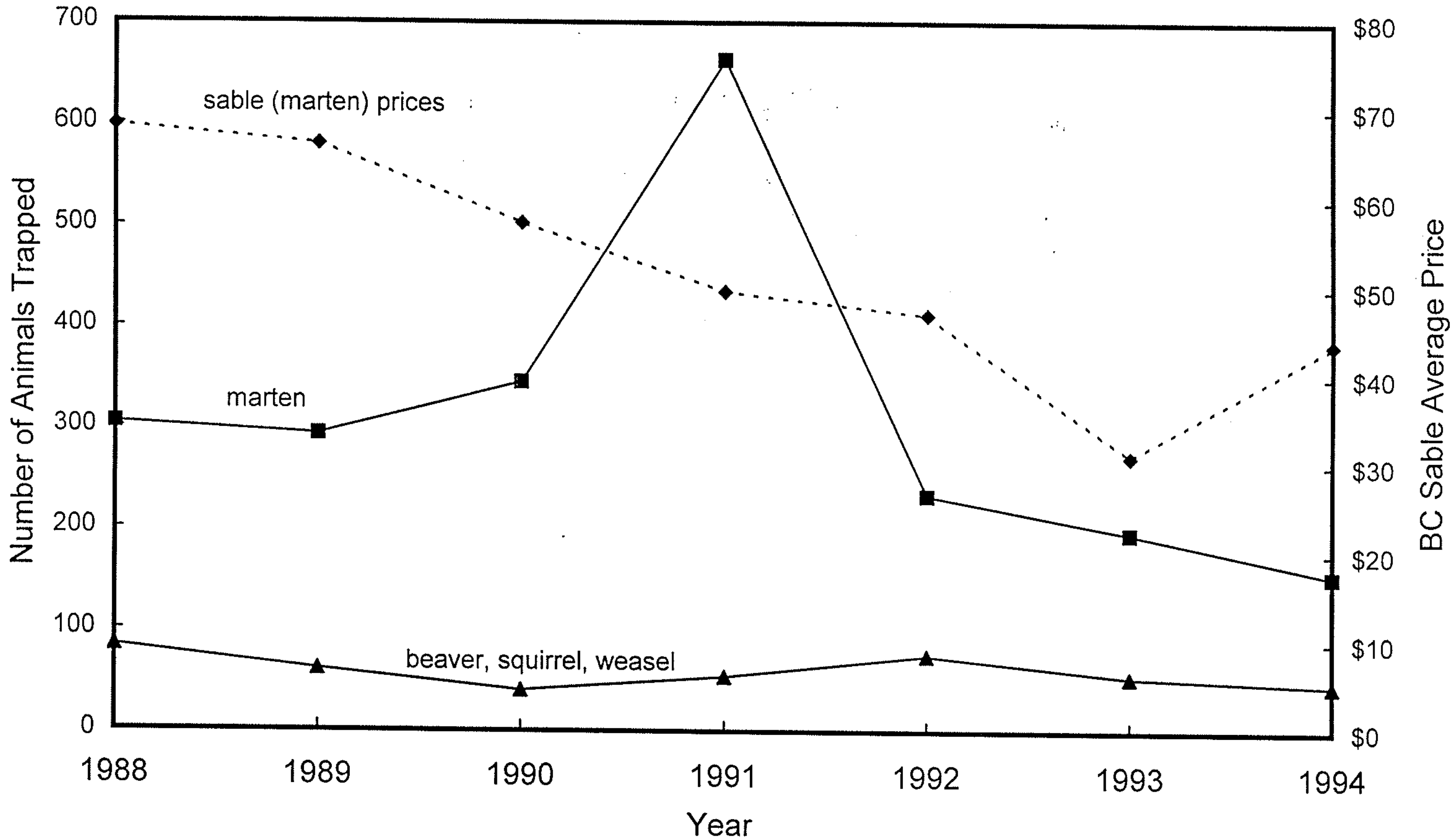

Figure 17: Harvest of marten and other species in the Arrow Lakes watershed, 1988-94 (Harrison, pers. com). The sharp rise in the harvest of marten does not seem to be related to environmental factors as it is not mirrored by increases in trapping rates of other species in the habitat. Prices (Bewick, pers. com.) for marten (sable) do not seem to provide the impetus for the large harvest in 1991.

trapping. Wolverine should not be trapped in view of their vulnerable status. The decline in catch of marten in 1992 and 1993 may be an indication of overtrapping in 1991, but examination of the individual records does not support that hypothesis. Most of the additional capture came from only a few traplines. There was no correlation between the size of the 1991 catch, and the change in harvest before and after that year.

Forest silviculture and vegetation management along powerlines has the capacity to harm small mammals through application of herbicides in clearcuts (Ministry of Forests 1994; B.C. Hydro undated). Herbicides can affect small mammals by alteration of the shrub habitat or by direct contact with the poison. Tests done for the Ministry of Forests from 1987 to 1992 on sub-boreal spruce forests showed that herbicides had little effect on herbs but a pronounced effect on shrubs. Shrub growth remained depressed for at least five years after treatment. Plant species richness was also reduced in the shrub seral stage by herbicide application.

The effect of these habitat changes was to reduce the population of deer mice and red-backed voles for two years after application. Meadow vole populations were not affected by the herbicide-induced changes. The population of mice and voles showed more annual variation in the control block than was caused by herbicide application. Weasel populations responded to the small mammal populations. Other studies showed that hare populations did not respond to herbicide applications.

The studies did not show long-lasting effects of herbicide application except to reduce the number and type of shrub species (as desired). Herbicides did not seem to have a major impact on small mammal populations, at least in the short term. However the study did

Animal	**Number trapped, 1988-94**
Beaver	166
Bobcat	3
Lynx	8
Marten	2188
Mink	19
Squirrel	123
Weasel	125
Coyote	44
Muskrat	47
Wolverine	6
Otter	12
Racoon	5
Skunk	2

Table 8: Species trapped in the study area (from Harrison, pers. comm.), 1988-1994.

recommend staggered application of herbicides, and development of a mosaic of different-aged blocks. Leaving untreated spots in an area of herbicide application also provided some habitat diversity. Under the tenets of New Forestry, herbicide applications are largely unneeded.

Overall, fur-bearing species in the study area seem to have a stable population, or at least the available evidence does not show declining populations.

One of the great success stories of the Arrow Lakes is the osprey. The construction of power lines along the lakeshore provided nesting habitat for these birds, which they were quick to adopt. Interference with the lines lead B.C. Hydro to begin a program to build nesting platforms. Now the nests and birds are a common sight along Highway 6, occupying a jumbled nest of sticks every dozen or so utility poles. The stable kokanee fishery provides them with an adequate food supply, and the lakes now support one of the densest breeding populations of osprey in the world.

5.5 Summary

Wildlife populations along the Arrow Lakes are subject to increasing stresses from human activities. Logging has the most profound impact on caribou populations and will have to be managed carefully or restricted to preserve the Selkirk herds in a viable condition. CORE land use decisions and the Forest Practices Code will go some way to providing these limits, but CORE documents suggest that the long term survival of the caribou are still subject to considerable uncertainty. The doctrine of safe minimum standards (Randall 1987, 413-4) would argue for stronger limits until future populations can be predicted with more certainty. To some extent, protection of grizzly bear habitat will provide overlapping protection of caribou.

Timber management guidelines for caribou habitats have been prepared by the Nelson Forest Region, but have not often been accepted because they bring substantial declines in short term timber supply (McLellan, Flaa and Super 1994, 12). In particular the mature cedar/hemlock forests must be protected because of their heavy use in winter especially those above Kuskanax Creek. Caribou in the Arrow Lakes area spend more time at low elevations than those elsewhere in the province, and the potential for conflict with the timber industry is very high. Recreational access to caribou winter habitat should also be restricted or forbidden - there are alternative sites in the Southern Interior Mountains for these activities.

While grizzlies are modestly abundant in the study area, the habitat can support a larger number of bears and there is concern that the future will leave them in a more threatened position. For the moment population growth is low and the main threats come from road access, forestry, and recreation. Since forestry can be managed to co-exist with bears (since they are not old-growth dependant), the main management impact should be directed toward reducing unwanted contact between humans and bears. However removing access to the wild backcountry may prove to be a difficult social endeavour.

6. Hydrology of the Arrow Lakes

6.1 Introduction

Liquid water is the circulation system of the environment. From falling drop, to intermittent trickle from a leaf, by percolating subsurface drainage and rushing torrent into a quiet lake and eventual drainage to the Pacific, this liquid part of the hydrologic cycle touches the entire ecosystem which comprises the Arrow Lakes watershed. Water affects all living organisms, collecting nutrients and pollutants and chemicals from the crest of the watershed to the lake bottom in the valley. In the cold season, winter snowfalls regulate the climate next to the ground, providing a haven for small animals and dormant plants, enabling overwinter survival and hibernation. Snow affects the mobility of larger mammals and limits the choice and amount of food available, such as arboreal lichens by mountain caribou.

Water also shapes the physical appearance of the Columbia River valley. Surface and subsurface flows bring many scales of mass wasting. At one end, the gradual slumping of hillsides responds to soil moisture, while at the other, gullies and other forms of erosion, or sudden landslides, bring abrupt changes to the landscape. In winter, snow avalanches remove vegetation year after year from favoured chutes, holding the forest at bay and bringing a patchwork ecosystem which contributes to biodiversity.

As much as any other factor, the health of the hydrologic system is a reflection of the sustainability of the Arrow Lakes.

The distinctive character of the Columbia River valley is shaped by water, itself controlled by topography and climate. This is easily seen by even a casual comparison with the nearby Okanagan Valley, lying 100 km to the east of the Arrow Lakes. Where the Okanagan is a semi-desert ecosystem, with sparsely treed brown hills at the height of summer, the Arrow Lakes valley is a dark green carpet of spruce, fir and cedar. This difference is a result of the greater atmospheric moisture supply which reaches the Columbia River valley from the south and the cold and snowy winters brought on by the valley's proximity to the source of Arctic air on the Canadian Prairies. Even humans respond to the presence of water, avoiding the wetter Columbia River valley for the drier and sunnier retirement communities of the Okanagan.

6.2 Available Data

This study of the hydrology of the Arrow Lakes watershed requires quantification of human effects on the water levels, flow and quality in the streams, lakes and rivers which surround the lake. To a great extent, the depth of this analysis is limited by the paucity of available data, a factor which is all-too-common in this valley. Within the study area there are only five active hydrometric stations (Environment Canada, 1986a). Two of these measure the levels of Upper and Lower Arrow Lake. The remaining three are streamflow gauges - there are no sediment measurements. Indeed sediment measurements seem to be a considerable rarity, with only six gauging sites in all of southeast British Columbia; three of them are concentrated near the town of Creston.

Two of the streamflow gauges are located on Kuskanax Creek and the third on Barnes Creek.

One of Kuskanax Creek's gauges is located near Nakusp on the lower part of the watershed while the other is at the 1040 m level. The lower gauge samples an area of 337 km^2, the upper, 113 km^2. These two sites afford a comparison between flows in the upper and lower courses of one of the larger rivers in the Arrow Lakes watershed.

Upper Arrow Lake water levels are measured at Nakusp; Lower Arrow Lake has a gauge at Fauquier, near the south end of the study area. Since water levels in these lakes are almost entirely regulated by the Hugh Keenleyside Dam at Castlegar, there is a nearly perfect correlation between the two lake level measurements, and either one is sufficient to characterize the water level of the lakes.

Data for the hydrographic sites were acquired from Environment Canada in the form of a CDROM disk (Environment Canada 1992). On the disk, records were available from 1964 to 1992 for the lower Kuskanax Creek, 1951 to 1992 for Barnes Creek and from 1974 to 1992 for the upper Kuskanax Creek site. The data consist of streamflow measurements, dates and times of extreme events, and station and watershed characteristics. The CDROM disk also contains water level measurements for Upper and Lower Arrow Lakes since 1974.

Meteorological information was acquired from Environment Canada, provided by the Manitoba Environmental Service Centre (MENSC) in Winnipeg. Nakusp is the only climatological site in the study area, with daily data available on a semi-continuous basis for the period of record of the streamflow data. The available measurements are maximum and minimum temperature and precipitation amount in water equivalent for 1964 and beyond. These measurements are taken at the Nakusp townsite.

6.3 Description of Hydrology

The hydrologic cycle is "a concept which considers the processes of motion, loss, and recharge of the earth's waters" (Gray, 1970, 1.2). It consists of four phases: precipitation, evaporation, streamflow, and groundwater (Linsley *et al.* 1982). While each one of these processes is affected by human activity, it is the runoff process and associated elements which are of most interest in this study. Changes in precipitation are affected by larger scale processes which largely occur outside the boundaries of the Arrow Lake watershed. Evaporation processes and groundwater movement can certainly be influenced by local alterations of the landscape, and will come under some evaluation here, but only in so far as they are related to streamflow. This restriction is due mostly to the data which are available.

Streamflow is a part of the runoff cycle, a phenomenon which refers to the processes which occur between precipitation and discharge through stream channels ((Linsley *et al.* 1982, 240). The runoff cycle is controlled by climatic and physiographic factors. Climatic factors include the various forms of precipitation, interception, transpiration, and evaporation. Physiographic components include geometric factors, physical factors, and channel characteristics (see Table 9 for a complete listing).

In the study area, the major impacts on the watersheds come from forestry with its attendant changes in vegetation type, cover and size. These changes in turn impact interception, transpiration, evaporation, melting, and some channel characteristics (Table 9). For convenience, streamflow changes can be evaluated according to the impact on the runoff cycle in winter and summer, or more specifically, on the supply generated by rainfall and

Climatic factors		Physiographic Factors	
Precipitation	form	Basin Characteristics	size
	type		shape
	intensity		slope
	duration		orientation
	time distribution		elevation
	antecedent precipitation		stream density
	soil moisture		land use and cover*
Interception	vegetation species*		surface infiltration*
	composition*		soil type
	age*		permeability
	density of stands*		groundwater capacity
	season		topographic conditions
	storm size		artificial drainage*
Evaporation and Melting	temperature*	Channel characteristics	carrying capacity
	solar radiation*		storage
	wind*		shape and size
	precipitation		slope
	soluble solids		roughness
	nature of surface*		length
Transpiration	temperature*		tributaries
	solar radiation*		
	wind*		
	humidity*		
	soil moisture*		
	vegetation type*		

Table 9: Factors affecting runoff in a stream (from Chow 1964, 14-5). Those factors most affected by human exploitation of the watershed are marked with an asterisk.

Logging practices have the capacity to measurably alter the streamflow characteristics of a watershed, often to great disadvantage to the client ecosystems. The major effects on ecosystem health from increased water flows are sediment transport and scouring. These are not necessarily negative—sediments may settle to fertilize lower ecosystems or provide habitats. Scouring may flush out sediments which interfere with spawning or tumble bankside trees to create sheltering backwater habitats. Increased water flows can provide access to otherwise unreachable sites, especially for late season spawning runs. The important aspect of human modification of the forest and stream hydrology is whether it changes the natural snowmelt. regime to which the biota has become adjusted.

6.4 The Relationship Between Rainfall and Runoff

A raindrop falls, but never reaches the surface. It is intercepted, perhaps by a leaf, or a branch, or by buildings. Its moisture is returned to the atmosphere by evaporation and transpiration, or it may be joined by other drops, remain for a time, and then drip to the ground, or flow down stems, trunks and walls. Another drop falls, this time reaching the surface, but landing in a depression where it is captured, joined later by others to form a puddle, and becoming a part of the depression storage which is removed from the runoff process.

Another drop falls, infiltrating the ground. The rate of infiltration is variable, depending on soil type and the antecedent moisture. This drop may become part of the soil moisture, remaining near the surface, or percolating downward to the water table to become part of the groundwater system. The shallow soil moisture, or throughflow, moves downhill, responding to gravity until being discharged into a stream to become part of the channel flow (Emmett 1979, 146).

6.4.1 Infiltration

The nature of the soil itself and the rate of infiltration determines the ability of the soil to conduct water away from the surface. It is most efficient when the soil is wet or when large voids between the particles which make up the soil promote the entrance of water. In open areas, heavy rains can affect the permeability of soil by creating small particles which are then washed into the voids (Knapp 1979, 56). Penetration and decay of tree roots also provided a very efficient mechanism for infiltration (Lull 1964, 6-14), but rates are strongly reduced by soil compaction due to animal and human use of the hillside.

When vegetation is removed from the land, infiltration rates decline and soil erosion rates increase. As the vegetation returns, infiltration increases until a stable balance is achieved. The type of vegetation does not seem to be as important as its density, though rates in forests are higher than those in pastures. Much of these differences may be due to other components of the ecosystem such as the activity of soil-disturbing animals.

Infiltration also seems to respond to the age and density of trees. Lull (ibid., 6-16) reports that plantations of black locust and sassafras have shown progressive improvement in infiltration as trees became older. The rates approached those of the natural forest once trees had grown for 25 years or more. In the Pacific Northwest, the percolation rate of the soil only recovered slowly over a 20 to 25 year period after logging and burning. The most important factor seems to be whether or not the forest floor is significantly disturbed. In mountain logging, roads and landing areas substantially modify the soil permeability. Trimble and Weitzman (1953) found that it took more than 600 times longer for water to penetrate the soil of a skid road than that of undisturbed forest soil.

6.4.2 Evaporation and Transpiration

Water evaporates most readily from dark compact soils, and the opportunity for evaporation is much less under forest cover. The difference can be considerable - up to a factor of five between open grassland and dark forests. Transpiration depends on temperature, wind, humidity, solar energy, and plant physiology. In times of plentiful moisture, the larger part of solar energy goes into evaporation, but as drier conditions develop, more energy goes into sensible heat and temperatures rise. Winds increase evapotranspiration by 50% as they increase from calm to 25 km/h.

Different species of trees and herbaceous plants make widely different demands on soil moisture. For tree species of the Arrow Lakes ecosystems (eg. Lodgepole pine, Engelmann spruce, white pine and aspen), annual evapotranspiration rates range from 40 to 80 cm of water (Lull 1964, table 6-7, 6-22). Clear-cutting eliminates all transpiration, subject to the amount of understorey vegetation left behind. Loss of forest cover can be expected to increase streamflow at least equal to the transpiration capacity removed. Experiments in Colorado in which 30% of the forest cover was removed resulted in increases in runoff of about 37%, some of which was due to changes in snowfall interception, and some to reduced transpiration.

6.4.3 Overland Flow

Though overland flow begins when the infiltration limit is reached, it may not reach stream channels for some time, depending on the retention and detention characteristics of the land. Numerous bogs, marshes and lakes may accommodate much of the surface flow until their storage capacity is reached.

Overland flow is the orphan of hillside hydrology. Even in fairly heavy rains there is often little evidence of surface water in hillside drainage (Whipkey and Kirkby 1979, 121; Chorley 1979, 12), except where vegetation is sparse and soils thin. According to Lull (1964, 6-14), "Rarely under forest conditions are evidences of overland flow visible except in those areas that have been disturbed and compacted by roads or logging." For the most part, flow within the watershed seems to occur in the subsurface layer, except where water is forced to the surface by hydrologic pressures. Nevertheless, though there is some argument on the point, surface flows do have some empirical support for their importance.

In particular, Emmett (1979) reports on the results of field investigations in Wyoming in which overland flows were tracked by means of dye tracers at several locations in a site inundated with artificial rainfall. Surface detention is an important aspect of the study, which showed that the flows proceeded in a series of steps, forced by the continuing application of rainfall. Sediment concentrations in the overland flow were shown to be inversely correlated with vegetation cover, as might be expected. Some of this sediment appears to come from splash erosion by raindrop impact (Miller 1977, 187) .

Overland flow is greatest at the base of slopes where the saturation level is highest and subsurface water emerges. In a long wet period, the surface flow at the bottom of a hill will reach a steady state in which the discharge is proportional to the drainage area and the rainfall rate. Velocities of the flow lie in the range of 10 - 500 m/hr (Dunne 1979, 230) so that flow from a 100 m hill can reach the stream channel in as little as 12 minutes or as much as ten hours. Where the forest has been removed from a slope, rainfall may be reflected in stream flows very quickly.

6.5 Hydrographs

A graph showing the stage (water surface elevation), discharge, velocity or other properties of water flow over time is know as a hydrograph. Hydrographs give an integrated measure of the physiographic and climatic characteristics of a watershed, combining the complex nature of a catchment in a single series of measurements. A typical hydrograph of a rainfall event consists of three parts: the approach segment, the rising segment, and the recession segment (figure 18). The shape of the rising segment depends on the duration and intensity of rainfall, antecedent conditions, and the physiographic characteristics of the watershed. The peak runoff is displaced in time from the rainfall, reflecting the time to fill soil and groundwater storage capacities, and other delaying factors.

The recession segment represents the withdrawal of water from storage after inflow has declined or ceased. It is mostly independent of the character of the rainfall, but sensitive to the ground conditions. Since these have a seasonal variation, the shape of the hydrograph often changes with the progress of the year. The hydrograph is often thought of as being composed of segments representing the various sources of streamwater: subsurface runoff, groundwater runoff and surface runoff. Surface runoff, or at least subsurface runoff, is most responsible for the rising segment of the hydrograph (Chorley 1979, 19) while groundwater runoff is the main factor in the shape of the recession limb.

The major impact on watersheds within the study boundary comes from logging operations. Logging practices, especially in the past, favoured large clearcuts with substantial removal of the overlying vegetation and exposure of the soil. Such soils dry more quickly and thoroughly in the dry spells between storms, and the infiltration capacity of the soil is increased. Interception by vegetation is reduced or eliminated, at least until some stage of regrowth is reached. Surface runoff likely increases in view of the relationship between vegetation and surface water noted above.

In this study, evaluation of the runoff record is a surrogate for changes in sediment loading of streams and creeks. Variable streamflows are a normal characteristic of the Arrow Lakes physiography, and the ecosystems are developed to cope with the natural pattern. The main impact of variable streamflows on aquatic organisms comes from siltation and sedimentation, both natural and augmented. Variations in the flow of water, unless very different from natural values, will have little effect, but increased debris flow brought on by human activities may be much more serious (Kerr 1995, 3). In the absence of sedimentation measurements, streamflow values will have to suffice.

6.6 Snowfall and Runoff

In the Canadian Rockies, and especially the Columbia River valley, winters bring frozen soils

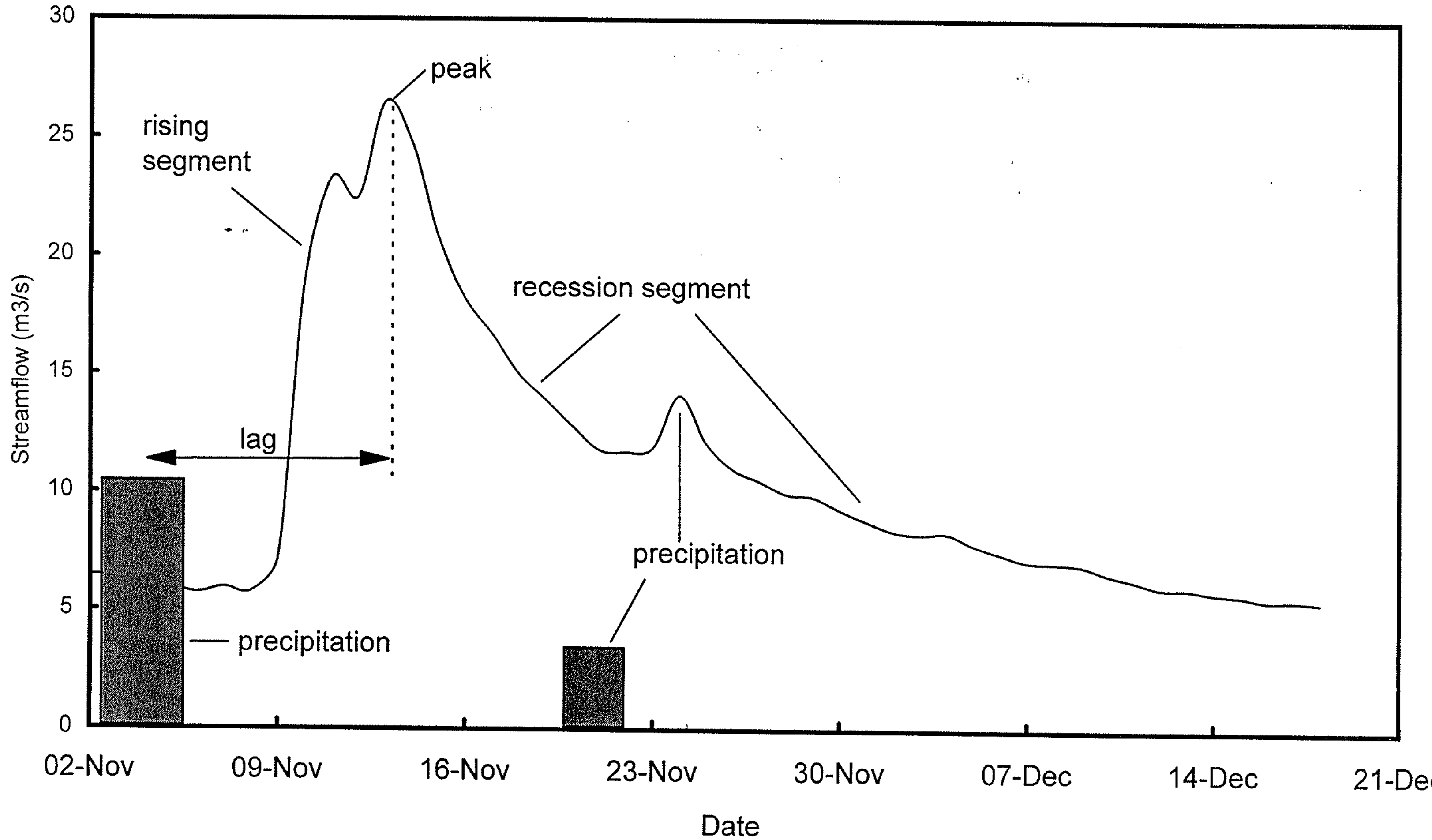

Figure 18: Schematic example of a hydrograph and its constituent parts.

and low streamflows. Temperatures, while they frequently climb above the freezing point in the valleys, do not usually reach levels which would permit a significant snowmelt during the cold season. Most runoff thus comes in the springtime when the returning sun brings steadily rising temperatures.

The amount of runoff at any particular time is related to the available heat energy, amount of snow, snowpack characteristics, site conditions, and rainfall during the melt season. The energy for melting comes from net solar radiation, conduction and convective transfer of sensible heat from the air, condensation of water vapour, conduction from the soil, and heat supplied by rainfall (Linsley *et al.* 1982, 251). Snowmelt is primarily a thermodynamic process, with energy fluxes and balances determined by the season and the character of the reflecting, emitting and absorbing surfaces.

Net radiation from the sun is a complex balance of short and longwave incident radiation, reflected short and longwave radiation, and emitted longwave radiation from the atmosphere. Clean snow reflects 80 to 90% of the incident shortwave radiation, dropping to 50% or less as it ages and becomes contaminated by dirt (Davar 1970, 9.5). Snow radiates as a blackbody, re-emitting absorbed long and shortwave energy as longwave radiation to the atmosphere and the surrounding surfaces. These in turn re-radiate energy back to the ground and to the sky, eventually resulting in a complex energy balance. A major complicating factor in the energy balance is the presence of clouds, which reduce shortwave radiation, but trap longwave energies and re-emit to the ground. Thus albedo and cloud cover are the two major controls on net radiation.

In forests, dark coniferous trees absorb considerably more short wave energy than the snowpack, heating the surrounding air which then transfers the energy to the snow through processes of conduction and convection. This is modulated by any snow which may adhere to the trees, but the process results in substantially higher air temperatures in treed habitats. This feature of the forest thermal regime can be seen in the climatological record for many locations in Canada - sunny late winter days tend to be warmer in northern communities where surrounding forests absorb more energy from the sun than on the flat prairie landscapes of the south.

Winds bring air into contact with the snow surface where sensible heat can be transferred to snowpack by conduction and convection. Condensation of moisture in the air also supplies heat for melting. Rain falling on snow also transfers heat to the pack, but this tends to be a rather small amount. Heat produced by conduction from the ground is also very limited, especially at the end of a cold Canadian winter.

During rain-free periods, solar and terrestrial radiation are the most important melt-producing parameters, moderated by forest cover. The effects of these interacting factors are represented in equations (Davar 1970, 9.11) developed by the U.S. Army Corps of Engineers (USCE):

Heavily forested areas (>80%):

$$M = 0.074\ (0.53\ Ta + 0.47\ Td)\ \text{inches/day}$$

Forested areas (60-80%):

$$M = k'\ (0.0084\ u)\ (0.22\ Ta + 0.78\ Td) + 0.029\ Ta$$

Partly forested areas (10 - 60%):

$$M = k' (1 - F) (0.004 R_{si}) (1-a) + k (0.0084u) (0.22 Ta + 0.78 Td) + F (0.029 Ta)$$

Open areas:

$$M = k' (0.00508 R_{si}) (1 - a) + (1- N) (0.0212 Ta - 0.84) + N (0.029 Tc) + k (0.0084 u) (0.22 Ta + 0.787 Td)$$

where

M	= melt in inches/day
Ta	= difference between air and snow temperatures (~ 32°F)
Tc	= difference between cloud base and snow temperatures
Td	= difference between dewpoint and snow surface temperature
u	= wind speed in mph
R_{si}	= insolation on surface in ly/day
a	= average snow albedo
k'	= shortwave melt factor (~ 0.9 to 1.1)
k	= condensation melt factor (0.3 - 1.0)
F	= estimated forest cover
N	= estimated cloud cover

These relationships can be used to investigate the effects of forest cover on snow melt using values representative of the Arrow Lakes environment.

During melting conditions the snow surface temperature is very nearly the freezing point (Miller 1977, 175). A reasonable assumption would be that dry bulb (air) temperatures are likely only 5 to 8 degrees C above freezing in view of the energy extracted by the melting pack. Dew point temperatures are only a few degrees lower because of the moisture source at the snow surface, provided light wind speeds are assumed. Insolation at Arrow Lake latitudes amounts to 830 ly/day in early May (Garstka 1964, 10-28) under clear skies. Cloud base temperatures are more difficult to estimate but are likely relatively small since a few degrees of inversion usually develops over a melting snow surface, and lower clouds are most likely if melting is significant. Values of 8 to 20 degrees would seem most appropriate, but in any event, the equations are not sensitive to cloud base temperature.

Figure 19 shows the results of solving the USCE equations with the parameters above. Quite clearly, snowmelt (and runoff) in the Selkirks is inversely related to forest cover to a significant degree. These calculations are not without quantitative support: experiments in a clear-cut watershed in New Hampshire showed that cumulative streamflow for the clearcut area was about 25% higher than for a control watershed, in a year in which snowmelt was episodic and prolonged. In the following year, when the melt was much more rapid, streamflow differences were almost nil (Federer 1968). Similar but stronger patterns were observed by Hendrick (1971) in a New England setting, who also tested the accuracy of the USCE equations.

Hornbeck and Pierce (1969) followed up on Federer's (*ibid.*) early analysis of the New Hampshire experiment. They concluded that the cumulative streamflow from a south-facing clear cut was advanced by four to eight days on average, and up to 17 days during periods of strong melting. Peak flow volumes increased during the early part of the melt season and declined in the latter, so that total volume was not significantly different. They did note that the relative influence of the clearcut slope - 27% of the total area - disappeared quickly when the stream joined flows from unaffected watersheds.

In addition to a rapid melt, opening the forest canopy may also result in a change in the depth

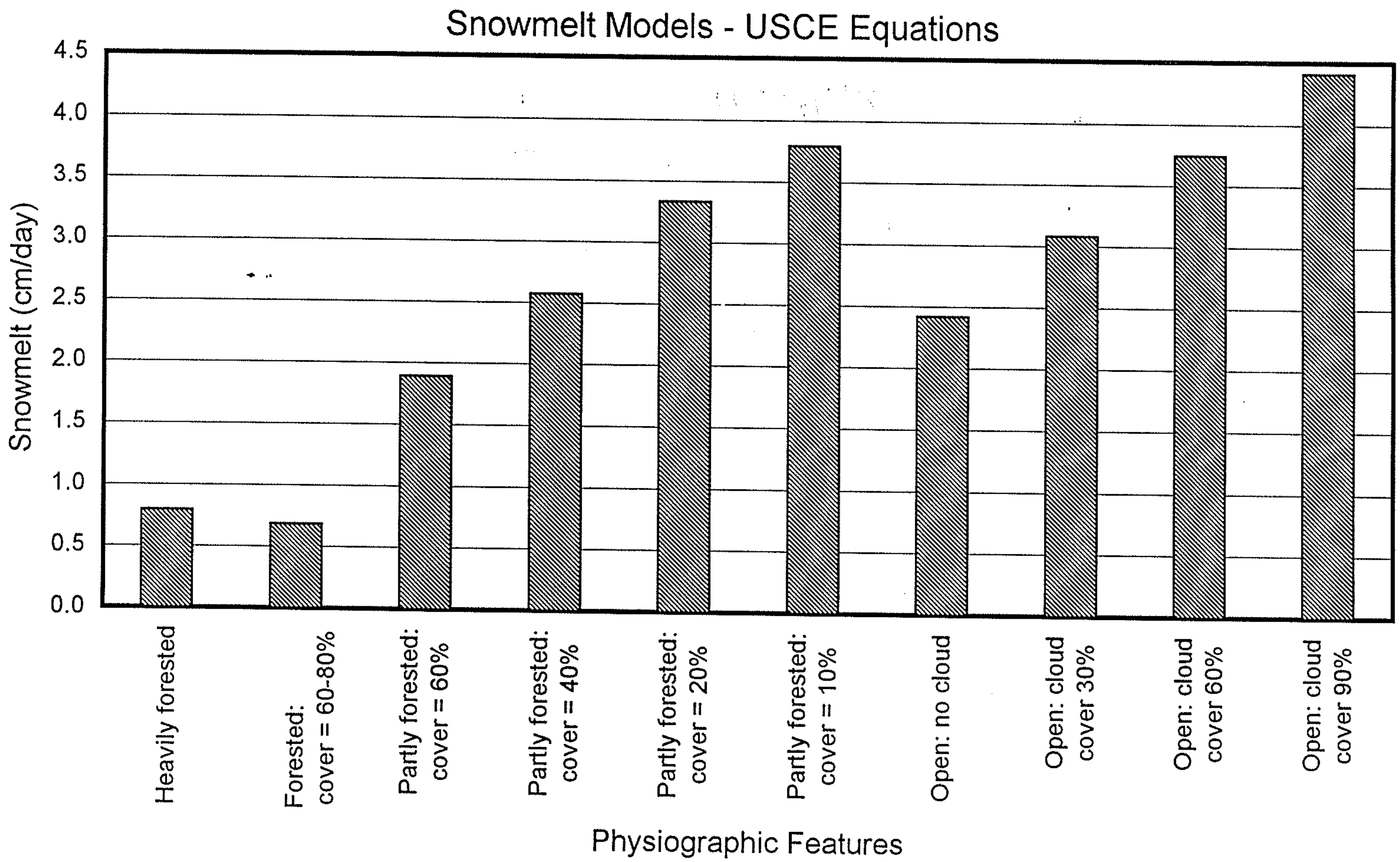

Figure 19: Snowmelt rates according to USCE equations. The equations show that snowmelt increases as a forested area is opened up. The discontinuity in the rate of melting in going from lightly forested to open terrain is a feature of the equations.

of the snowpack which accumulates over the area. A bibliography of snow accumulation studies conducted between 1909 and 1965 compiled by Meiman (1968) shows that all but one of 24 studies showed an increase in snow pack within open areas when compared to denser forest canopies (Table 10). The dissenting study showed no change.

Snowmelt follows a typical daily pattern, with runoff rising and falling with the diurnal temperature wave. Cloud cover will suppress daytime peaks and nighttime lows, bringing a more even flow, a feature which is often unwelcome in flood-prone areas where the overnight minimum brings relief from the flood threat (Miller 1977, 177). Winds serve to mix the warmer air into the forest cover, or prevent the development of microscale inversions against the snow surface as well as carrying sensible heat into the melting zone. Whether from insolation or advection, temperatures are the most significant parameter in melting snow, a conclusion readily evident in the USCE equations.

The amount of snow available depends on climatology, terrain, altitude, and ground cover. The size of openings is critical to snow deposition (Miller 1977, 171) since they determine how readily the wind can reach the ground. In general, small forest openings do not change the accumulation of snow, but serve to redistribute it. In particular, forest edges to the lee of large openings often collect much of the snow swept from the exposed area. This pattern has implications for the ecology of small animals who rely on the protection of an overlying snow pack. Larger animals can choose among the differing snow ecosystems.

Study	Percent change	Study	Percent change
Mattoon 1909	81	Anderson *et al.* 1958	54
Jaenicke & Foerster 1915	0	Anderson & Gleason 1959	30
Maule 1934	41	Anderson & Gleason 1959	37
Maule 1934	48	Anderson & Gleason 1959	14
Maule 1934	51	Anderson & Gleason 1959	31
Maule 1934	122	Weitzman & Bay 1959	4
Maule 1934	140	Weitzman & Bay 1959	28
Connaughton 1935	38	Weitzman & Bay 1959	60
Wilm & Collet 1940	80	Weitzman & Bay 1959	80
Niederhof & Dunford 1942	61	Lull & Rushmore 1960	38
Niederhof & Dunford 1942	45	Lull & Rushmore 1960	24
Dunford & Niederhof 1944	30	Lull & Rushmore 1960	23
Dunford & Niederhof 1944	14	Packer 1962	32
Wilm & Dunford 1948	11	Rothacker 1965	35
Wilm & Dunford 1948	13	Berndt 1965	40
Wilm & Dunford 1948	20	Stanton 1966	21.5
Wilm & Dunford 1948	26	Stanton 1966	10
Goodell 1952	17	Stanton 1966	14.6
Goodell 1952	23	Stanton 1966	46.4
Kittredge 1953	441	Stanton 1966	3
Kittredge 1953	154	Hoover & Leaf 1967	22
Kittredge 1953	55	Gary & Coltharp 1967	1
Kittredge 1953	125	Gary & Coltharp 1967	39
Sartz & Trimble 1956	8	Gary & Coltharp 1967	7
Miner & Trappe 1957	143	Gary & Coltharp 1967	1
Baldwin 1957	13		

Table 10: Change in snow accumulation in open areas versus forested areas. These data are reported by Meiman (1974) in a bibliographic survey of 24 studies of snow accumulation. In all cases but one, snowpack water equivalent was higher in open areas then in the forested control area. The single discrepant report indicated no change between the study areas. See Meiman (1968) for references.

6.7 Kuskanax Creek

Kuskanax Creek rises in the Selkirk Mountains northeast of Nakusp at an altitude of 1930 m, flowing southwestward to enter Upper Arrow Lake just north of the town. The stream drains the area between the Goat Range in the south and the Lardeau Range in the north, a distance of 20 km at its widest point. Within its 45 km length the river drops 1490 m in altitude; a large part of it in the last third of its length (below Nakusp Hot Springs Provincial Park).

Maxey (1964, 4-43) suggests that the "first step in drainage-basin analysis is the designation of stream orders...". In this type of analysis, the smallest tributaries are given an order of 1. Where two tributaries join, a channel segment of order 2 is created. When two segments of order 2 meet, a segment of order 3 is created, and so on. Stream order is proportional to the area of the contributing watershed, to discharge, and to channel size, and is modified by the topography in which the drainage occurs.

The ratio of the number of segments of order N to those of order N+1 is called the bifurcation ratio. This value will tend to be constant through the series, though with some random variation due to the geometry of the watershed. Following Horton (1945), the various orders can be related by the *law of stream numbers*:

$$N_u = R_b^{\,k-u}$$

where N_u is the number of segments of order u, k is the order of the trunk segment, and R_b is the ratio of the number of sequential orders. Semi-log regression of the data for a particular watercourse allows the determination of the bifurcation number R_b. Using 1:20,000 topographic maps, N_u was determined for Kuskanax Creek (Table 11), giving a value for R_b of 5.54. This is slightly higher than the range described as "characteristic" (3.0-5.0) by Maxey (1964, 4-44), but not unexpected in view of the mountainous terrain in the area. High values of the bifurcation ratio can be expected in terrain in which stream courses are confined to narrow valleys with short tributaries. While Kuskanax Creek has elements similar to this along portions of its course, there are a number of important tributaries which break up the linear character of the stream. An analysis for the portion of the creek above the 1040 m gauge gave a value for the stream order of 3.9.

An order number of 5.45 suggests that the hydrograph for Kuskanax Creek will show moderately sharp peaks, a feature which lends itself to easier detection of changes which might be due to human activity in the watershed.

Nakusp Hot Springs Provincial Park lies at about the 15 km mark along Kuskanax Creek, measured from the mouth. The park is reached by a good quality paved road. Development is spotty along the creek, with occasional buildings and small industry, except at the Hot Springs where there is a small cluster of cottages, the hot spring pool and a large parking lot. A good quality gravel road continues up the creek beyond the hot springs, but there is no significant human habitation beyond that point.

Evidence of logging is visible at many sites along the hot spring road, much of it regenerating. More recent cuts lie above the Hot Springs, strung out along the creek like jewels on a necklace. Air photos taken in 1970 (Figure 13) show that cutting extended only as far as

Creek	Order number	N_{order}	Log (N)	Bifurcation ratio
Kuskanax at Nakusp	1	162	2.21	
	2	32	1.505	
	3	5	0.699	
	4	1	0	**5.54**
Kuskanax at 1040 m	1	62	1.792	
	2	11	1.041	
	3	3	0.477	
	4	1	0	**3.93**
Barnes (dry)	1	24	1.380	
	2	7	0.845	
	3	1	0	**4.90**
Barnes (wet)	1	44	1.643	
	2	10	1.000	
	3	1	0	**6.63**

Table 11: Calculation of stream order for Kuskanax and Barnes Creeks

Ruben Creek, a kilometre short of the Provincial Park. Except for a few areas near the town of Nakusp, all of the cutting was confined to the north side of the creek. None of the tributaries had been harvested, though some of the cutting had spread well back of Kuskanax Creek in areas below Gardner Creek.

By 1987, cutting extended to within 4 kilometres of the headwaters of Kuskanax Creek (Figure 14). Most of this was confined to the immediate vicinity of the stream, but now on both sides, though the north continued to be the heavier cut. Some of the tributaries were being exploited as well: several clearcuts extended deep into Rogers Creek, and more than 6 km up another unnamed creek above the Hot Springs. The area cut by the newer logging represents approximately 50% of the land lying along the margin of Kuskanax Creek, extending back along the lower slopes for distances of 100 to 150 m. Most of the cuts leave a buffer strip along the creek.

The later (1987) air photos show a distinct change in the cutting pattern, with chains of smaller cuts replacing the continuous large cuts of the 1970 era. In 1987 the earlier cuts were still visible after 17 years of regeneration, though much less distinctly. Faint traces of the switchback cutting roads remained visible within the regrowing clearcuts. The larger access roads were still in use.

6.8 Barnes Creek

Barnes Creek arises in the Whatshan Range in the Monashee Mountains (Figure 2) near 1700 m altitude. For most of its 34 km length it tumbles down a steeply-sloped gully, eventually flattening toward the end of its run and meandering the final 8 km to empty into the Whatshan River. The river travels a further 5 km to reach Lower Arrow Lake at Needles. The Barnes Creek watershed has an area of 201 km^2.

In contrast to Kuskanax Creek, most of the tributaries to Barnes Creek are seasonal, with flows becoming intermittent after snow melt has finished. Because of this Jekyll and Hyde character, Barnes Creek has a stream order 4.9 in dry spells, and 6.6 in wet (Table 11). These values imply a relatively flat response to rainfall events in the dry season, and sharper hydrographs in the wet.

Air photos from 1970 show no cutting on the lower reaches of Barnes Creek (pictures are not available for the upper half of the watershed). By 1987 the upper half of the watershed has been extensively harvested - perhaps 80% - and the lower reaches show more than half a dozen recent clearcuts in the area between Whatshan Lake and the creek. The older cuts show a medium gray tone which implies greening-up of secondary growth. Approximately 10% of the cut-over area is a light tone which implies recent cutting, and the skid trails are easily visible within these clearcuts.

6.9 Hypothesis

The discussion above has shown that melting snowpacks and runoff from rainfall are both influenced by the extent of vegetation on the land. In particular, the literature suggests that open areas show increased snow accumulation and more rapid snowmelt. The effect on rainfall in warmer seasons is less distinct. While lower infiltration and interception rates promote runoff, higher evaporation and lower transpiration serves to decrease it. Transpiration is mostly from water resources drawn from the water table, not surface and sub-surface runoff, and so has little impact on streamflow. It is possible that trees actually increase sub-surface soil moisture supplies through the process of hydraulic lift (Langston 1995, 144).

Summarizing the above findings, the following working hypotheses will be examined:

1) Logging will cause springtime hydrographs to show higher and earlier peaks in years following cutting in the watershed.

which implies:

2) Logging will cause a stronger correlation between melting temperatures and streamflow in the springtime hydrograph.

The testable null hypotheses are the opposite of these: logging has no effect on streamflows. Since streamflow does not respond instantaneously to water inputs or to melting temperatures because of subsurface storage and the time for transport, it is anticipated that the maximum correlation between temperature and runoff will be delayed one or more days.

In short, if logging in the watershed has an effect on runoff, it will show up as higher and earlier hydrographic peaks and as a stronger correlation between temperature and streamflow. By extension, such an impact will bring higher sediment transport with detrimental effects on fish habitat.

6.10 Data Analysis

Hydrological and meteorological data from the observation sites were transferred to an Excel® spreadsheet and explored graphically. Construction of a mean hydrograph for the 20 year period of record indicated that rising branch of the streamflow increased most rapidly in the period between April 15 and June 5 (Figure 20). After June 5, in spite of the continuing rise in mean temperatures, runoff begins to decline, demonstrating that (on average) much of the snowpack has disappeared by that date. The recession branch of the hydrograph represents the gradual draw-down of subsurface and watershed moisture, supplemented by frequent rainfall in the normal course of summer weather. This pattern indicates that searches for the relationship between streamflow and environmental parameters are best confined to the time of year in which the response is most dramatic. Based on the mean hydrograph, the streamflow record from April 15 to June 5 was selected for evaluation.

Correlation between streamflow and temperature was calculated using routines available in Microsoft Excel®. The correlations were repeated lagging the streamflow record from one to six days. Highest correlations were found with lags of two or three days, representing the time for the streamflow record to respond to rising temperatures in the watershed. Dates of maximum flow were extracted from the CDROM disk using an ancillary program, Streamflow Toolkit© (Shiau 1993). Further statistical analysis was conducted in SPSS 6.1 (SPSS Inc., Chicago, IL).

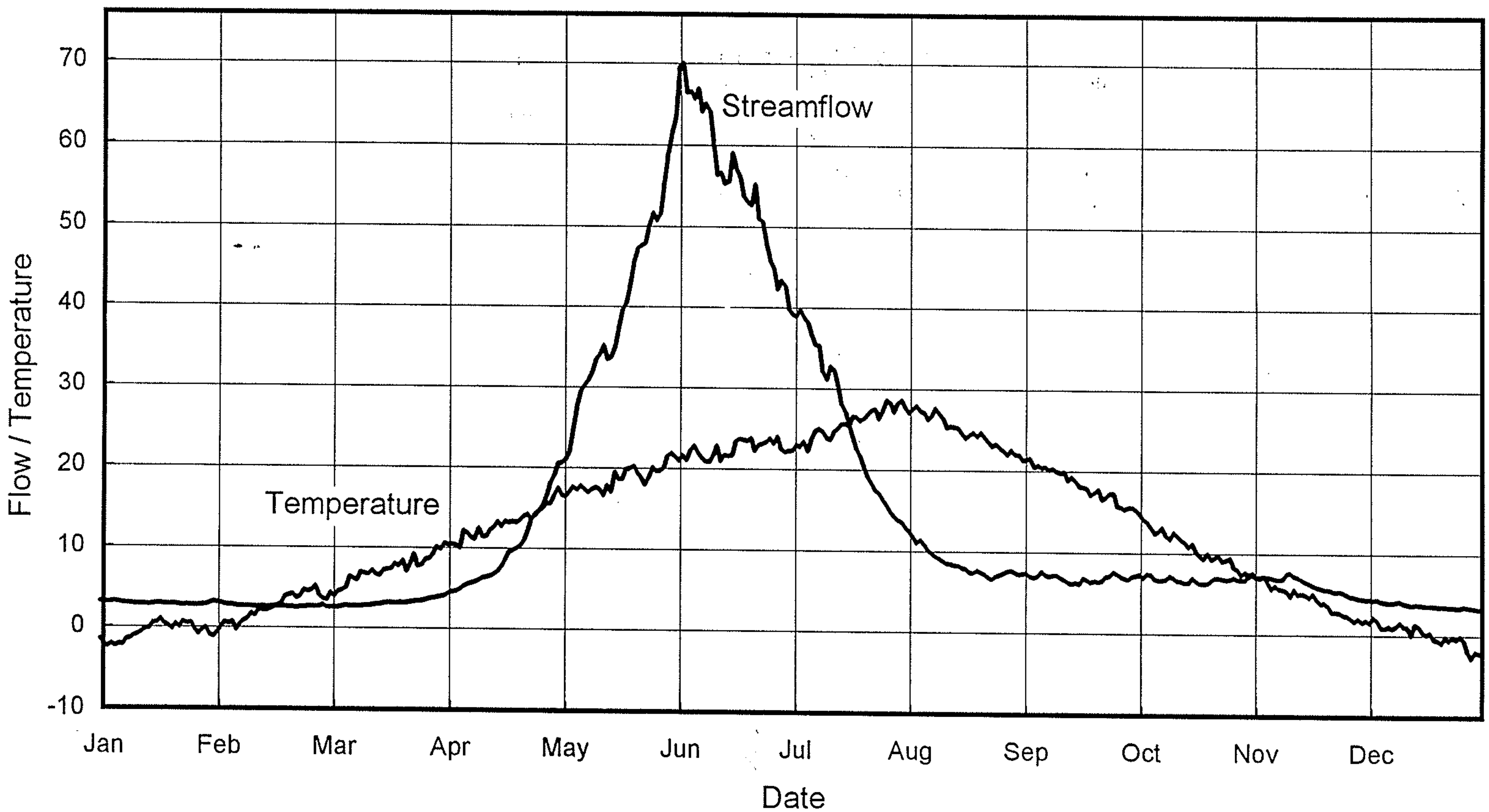

Figure 20: Mean annual hydrograph for lower Kuskanax Creek and mean annual temperature for Nakusp. The streamflow gauge is located near the town of Nakusp.Turn-on of snowmelt occurs in mid April at an average temperature of 13°C.

Climatological data were collected only at Nakusp, close to the lower Kuskanax gauge in both altitude and distance. The Nakusp climate station lies well below the 1040 m level of the upper Kuskanax gauge, but in the mean the pattern of temperatures at the townsite should accurately reflect those at the higher altitude. This approach assumes that there is a constant temperature difference between the lower elevations and the melting snowpack. This is not accurate, as the catchment has a highly variable topography, and the zone of melting snow will move upward as spring advances. Both these factors will serve to reduce the correlation between temperature and streamflow compared to an analysis done with more representative local temperature measurements.

The Barnes Creek site is still more of a problem, since it lies well south of Nakusp— nearly 100 km. Nevertheless, in the narrow north-south Columbia River valley, weather arrives mostly from the north or south, and the Nakusp record should reflect the overall sequence of events within the valley with perhaps some delay for the time for warm and cold airmasses to travel from one site to the other. Summer precipitation tends to propagate from the south, carried on moist winds from the Columbia Plateau in Washington, but since rainfall tends to be convective in nature, differences from one locality to another could be very large. All-in-all, temperatures should be well correlated between the sites, with perhaps a small difference in lag introduced by the different distances to the thermometer. Precipitation should exhibit a similar lag, but overall correlations between temperature and rainfall are expected to be lower for Barnes Creek compared to the Kuskanax sites in view of the convective and variable nature of summer rainfall.

6.11 Results

6.11.1 Kuskanax Creek

The lower Kuskanax hydrograph outside Nakusp shows a regular annual cycle dominated by the snowmelt runoff in the spring (figure 21). Spikes of higher flow embedded in the annual trend represent spells of warmer temperature, with melting often enhanced by rainfall which accompanies the warmer weather. During the recession stage of the hydrograph, particularly after July when the stored water from the snow pack is depleted, peaks in the streamflow are related entirely to rainfall. Some years are dry, with little late season precipitation, others experience a resurgence in runoff as wet days stretch into weeks.

For lower Kuskanax Creek (the Nakusp hydrograph), correlations for a two-day lag showed no significant trend with time, ranging generally between 0.8 and 0.5 for each spring season (Figure 22) between 1966 and 1992. The lowest correlation, in 1984, was discounted because of a large amount of missing data (31 days out of 47). The next lowest correlation and the only one more than two standard deviations from the mean is in 1990. The occurrence of this deviation is within expectations for a statistically random event.

Such high correlation values are not unexpected. Many authors stress the point that temperature is the most significant factor in determining snowmelt. In fact, the values seem to be somewhat on the low side, as Jolly (1972) reported a coefficient of correlation of 0.985 in a study of a partly-urbanized watershed. It is likely that the unrepresentative Nakusp temperature used in this study has reduced the correlations to those noted above.

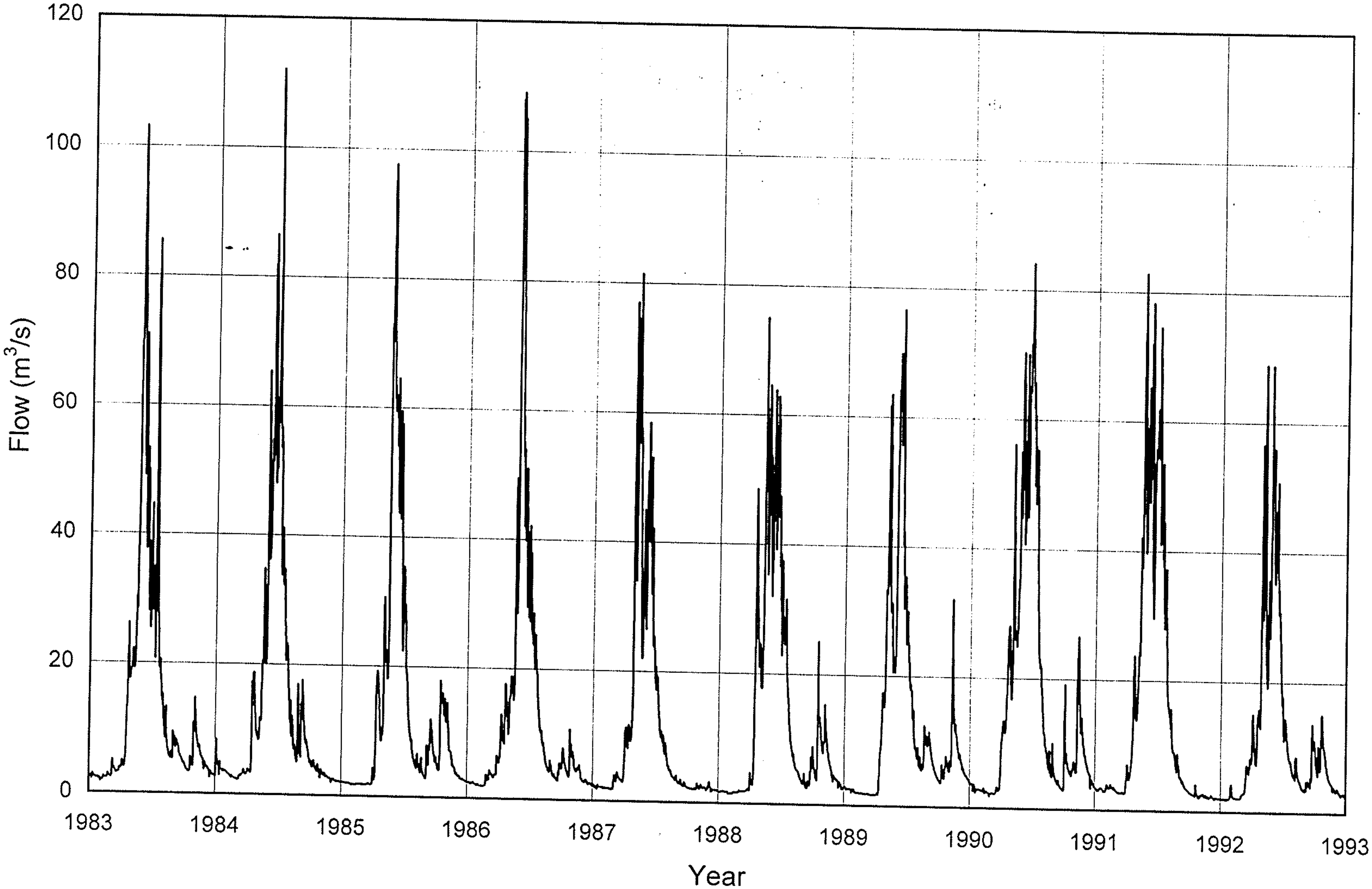

Figure 21: Lower Kuskanax Creek hydrograph 1983 - 1992.

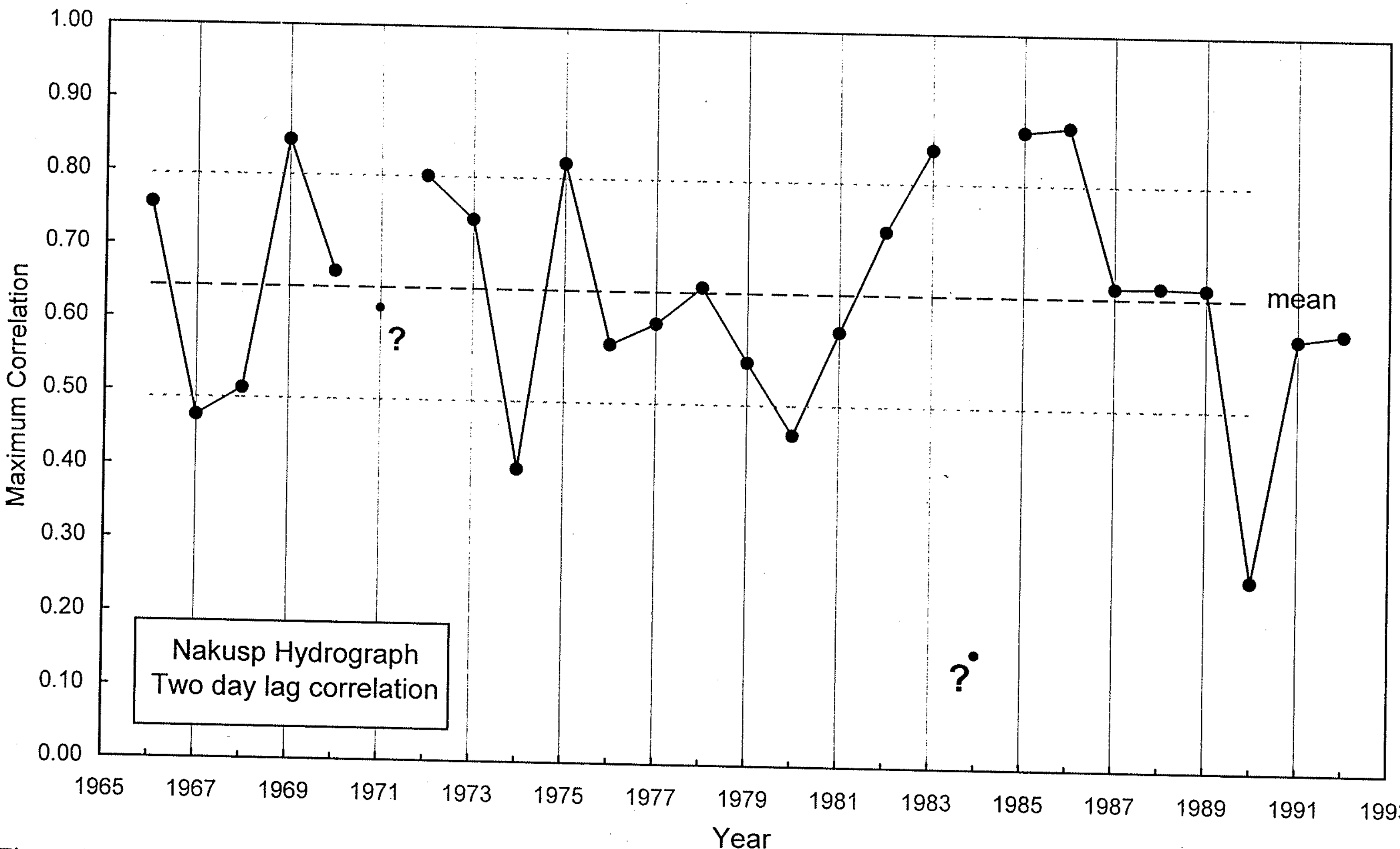

Figure 22: Two day lag correlation between temperature and streamflow (April 15 - June 5) for the lower Kuskanax Creek hydrograph. Dashed lines are mean +/- 1 standard deviation. Single points with question marks show correlation value for years with significant amounts of missing data. The relatively constant character of this relationship over the years, despite increasing cutting, suggests that forestry has had no impact beyond natural variability at this scale.

Much of the variation in the lag correlations may be traced to natural events and the character of the weather. Figure 23 shows temperature and streamflow trends for 1985, a year with a two day lag correlation (r) of 0.868. The association and lag between the temperature pattern and the runoff is quite obvious, with temperature peaks matched by subsequent streamflow increases three days later (maximum correlation occurred at 3 days in 1985). Temperatures above 15°C seem to be required for significant snowmelt. Experience with prairie snowpacks suggests that widespread melting does not begin until temperatures rise above about 10°C (usually with a good south or west wind). Since most of the Kuskanax Creek watershed lies well above the town of Nakusp, and thus at lower temperatures, it does not seem surprising that a 15°C threshold is identified at the townsite. If the daily low remains above 15°C, melting should continue around the clock.

The 1985 streamflow graph in figure 23 shows an abrupt runoff turn-on in the third week of May when temperatures abruptly climb into the mid-twenties. This pattern seems to be a feature of most years, reflecting the switch-over to summer temperature regimes. While the higher summer sun plays an important role in this increase, the declining snowpack in late May also has a strong influence with the lower albedo of bare ground allowing the absorption of a greater amount of shortwave solar radiation.

Examination of the 1990 temperature-streamflow correlation (figure 24), a year with low r-values, shows the turn-on of the runoff without a corresponding jump in temperature. The rising streamflow is certainly not immune to jumps in temperature, as can be seen in early May when the mercury rose to 26°C for a day and on 25 May when cooler temperatures were reflected in a down-turn of streamflow two days later. What is different about the 1990 record

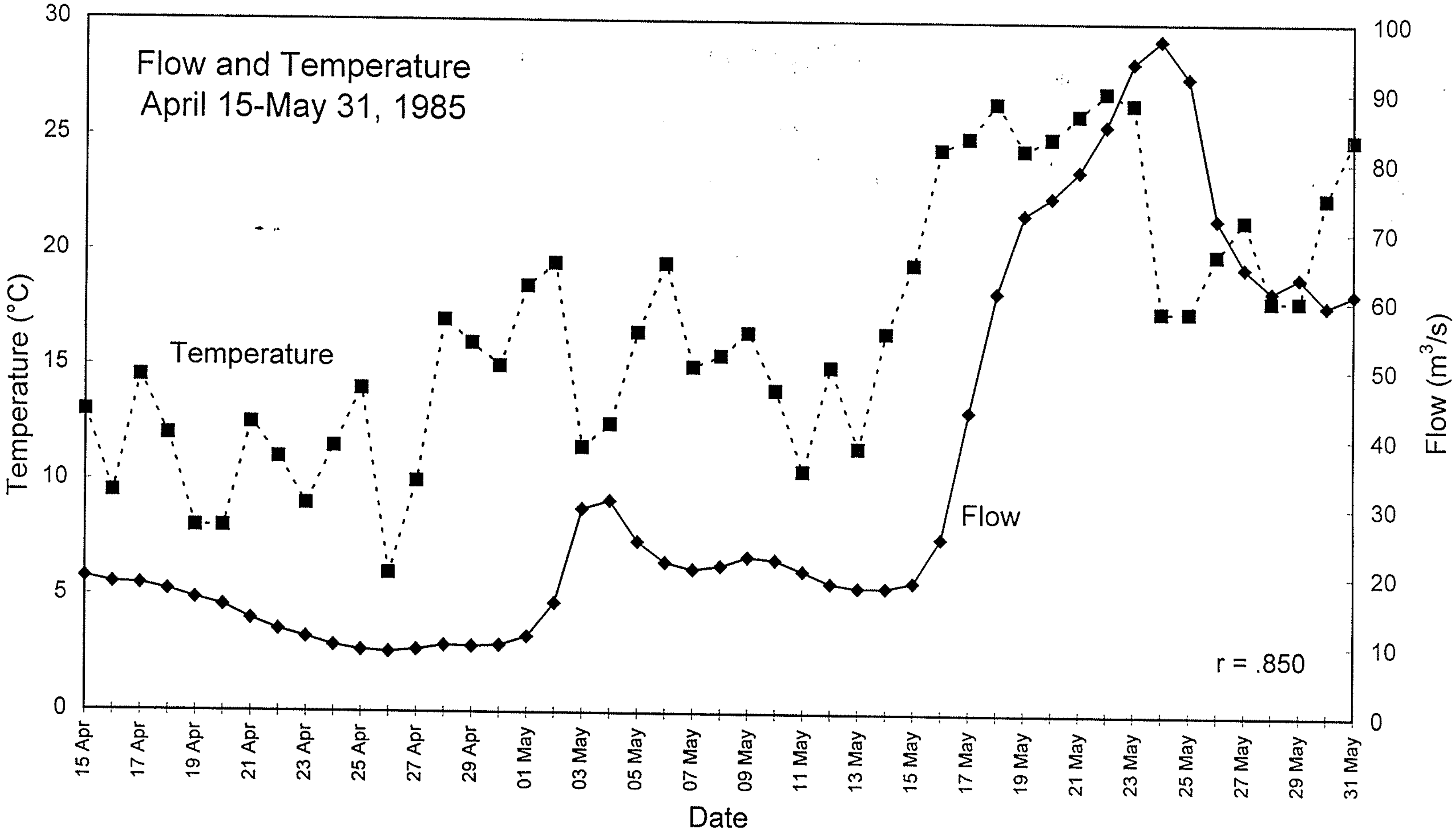

Figure 23: Temperature and streamflow for lower Kuskanax Creek in 1985. The correlation between flow and air temperature is clearly visible. The formal coefficient of correlation is 0.850.

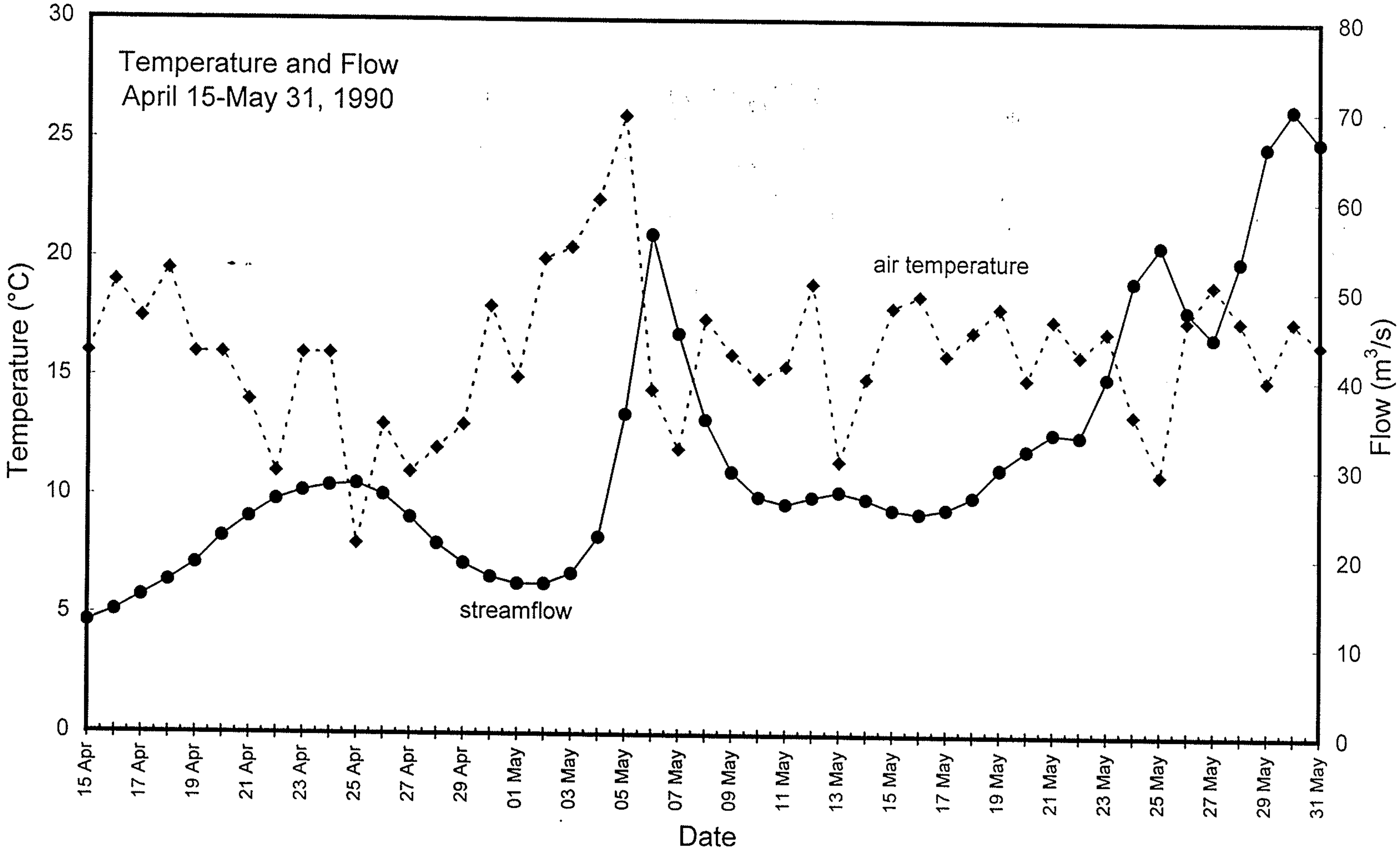

Figure 24: Streamflow and temperature for lower Kuskanax Creek in spring 1990. In contrast to figure 23, the relationship between flow and temperature is not so obvious. The prolonged spell of moderate temperatures after May 7 is responsible for the subsequent increase in streamflow.

is the prolonged spell of steady temperatures for a three-week period beginning on 08 May and continuing with little variation to the end of the month. One can speculate that the slow but steady melt associated with this pattern eventually overwhelmed the storage capacity of the watershed and the streamflow responded.

The 1040 metre gauge on Kuskanax Creek, though limited by a shorter period of record, shows very similar results (Figure 25). This is not altogether surprising, since water in the upper gauge appears in the lower less than a day later. The two are obviously correlated to a very high degree. Nevertheless, one can postulate that if there is an effect from logging, and in view of the fact that logging occurred much later in the higher parts of the watershed, though with relatively greater impact, then the correlation between temperature and streamflow might show a gradual rise (possibly followed by a return to earlier values) which reflects the influence of humans. This is not at all apparent in the correlation graph for the upper gauge (Figure 25).

In one last attempt to detect a trend in the behaviour of the upper and lower watershed, Figure 26 was constructed to show the difference in two day lag correlations between the upper and lower Kuskanax gauges. The premise here is the same as earlier. If clearcutting makes a watershed respond more rapidly to temperature, and if one catchment has more cutting than the other, then the difference between their streamflow-temperature correlations should reflect differences in vegetation cover. In the records, only the two extreme peaks are beyond two standard deviations from the mean, in 1978 and 1987. While the results in 1977 and 1978 are intriguing, the absence of an underlying trend suggests there is no effect from cutting, though the possibility remains that harvesting has an effect for only one year before

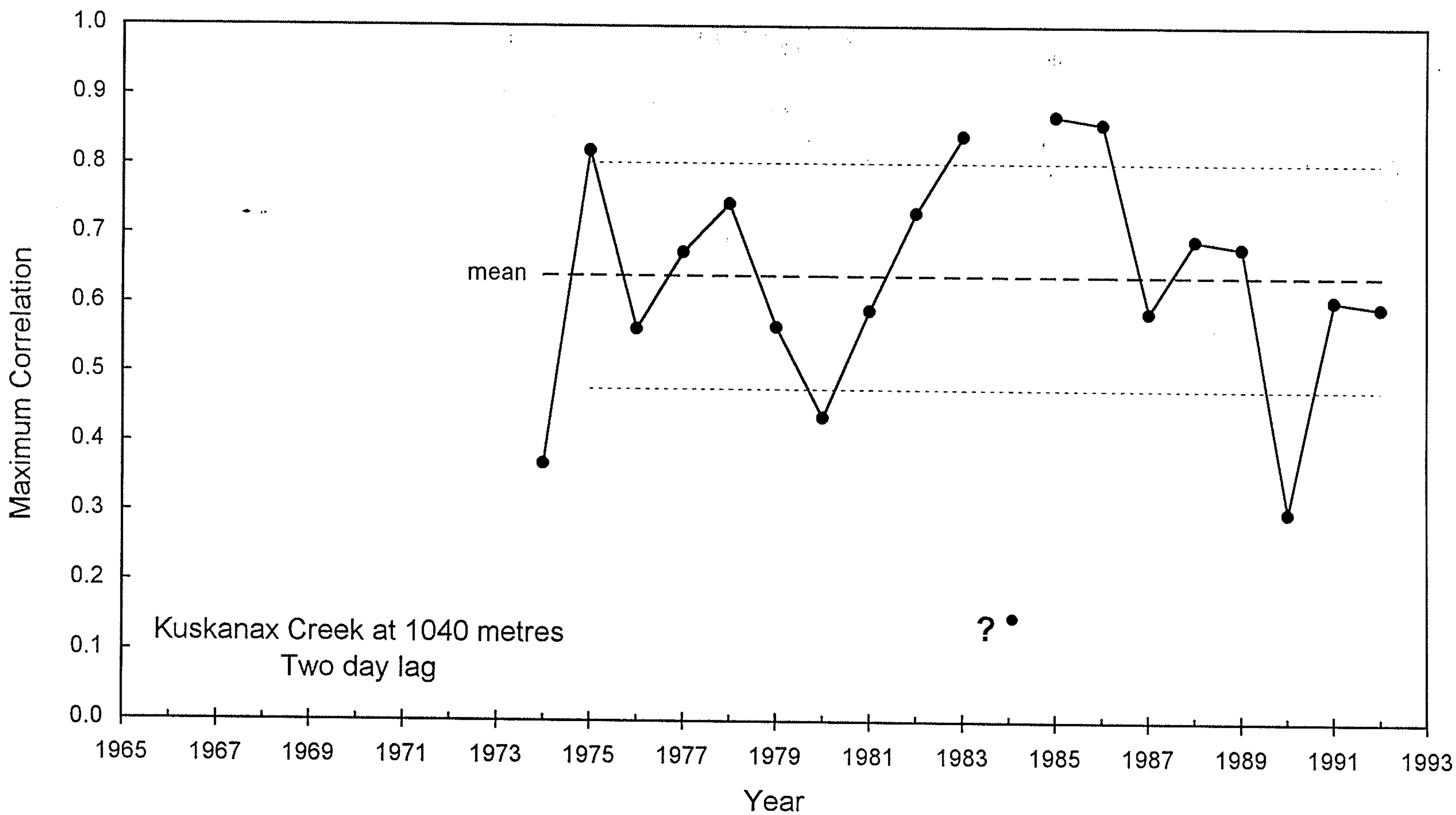

Figure 25: Two day lag correlation between temperature and streamflow (April 15 - June 5) at the upper Kuskanax hydrograph. Dashed lines are mean +/- 1 standard deviation. The single point with a question mark shows the correlation value for 1984, a year with a significant amount of missing data.

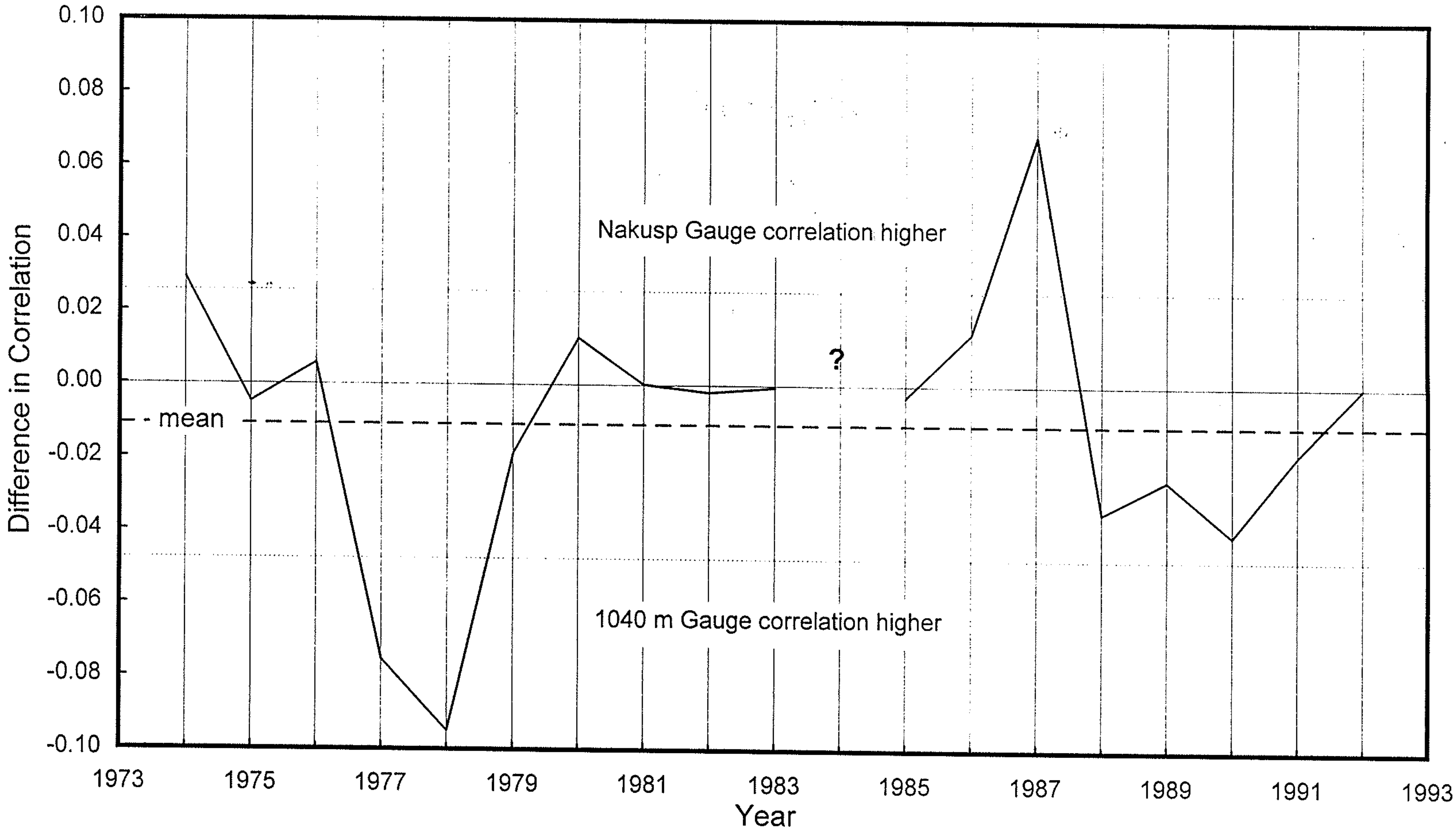

Figure 26: Difference in springtime temperature-streamflow correlation for the upper and lower Kuskanax Creek hydrographs. The dashed lines indicate mean and standard deviation. Differences are not significant, implying a similar response to springtime temperatures, at least on the scale of the entire watershed.The lack of a trend as higher elevations are progressively harvested suggests that forest operations have little impact on streamflow at the watershed scale.

new growth masks the impact. Such a pattern seems unlikely in view of the ongoing timber harvesting in the Kuskanax watershed.

More directly, examination of the date of peak flow from year to year may shed some light on responses of Kuskanax Creek to the presence of humans. Figure 27 is a plot of the date of maximum flow for the two gauges on Kuskanax Creek, along with the linear regression trend line for the Nakusp site. The date of maximum runoff shows a steady decline to earlier dates, advancing by 20 days between 1974 and 1992. One explanation is that the graph is showing the effects of global warming, which had its largest effect in the late 1980s. But there is a danger in drawing too strong a conclusion from this graph, as the trend line explains only 16% of the variance (r = 0.407), and may be little more than an artefact.

Examination of the trend in annual peak runoff volume is a little more ambiguous, though still not indicative of human alteration of the landscape. Since 1972 there has been very little variation in the maximum annual streamflow (Figure 28) in lower Kuskanax Creek. During this period between 1970 and 1987 airphotos showed a considerable expansion of logging along the upper reaches of the creek (Figures 13, 14). In 1967 and 1972 large streamflow peaks were measured. The latter is a year noted for high springtime precipitation (second highest in the record) and the highest recorded streamflow, but 1967 has no corresponding distinction.

On the upper Kuskanax, where the effects of logging might be expected to be more dramatic in view of the smaller size of the watershed and the relatively large intrusion of forest operations, the peak annual flows show a gradual trend upward from 1977 to 1986 before

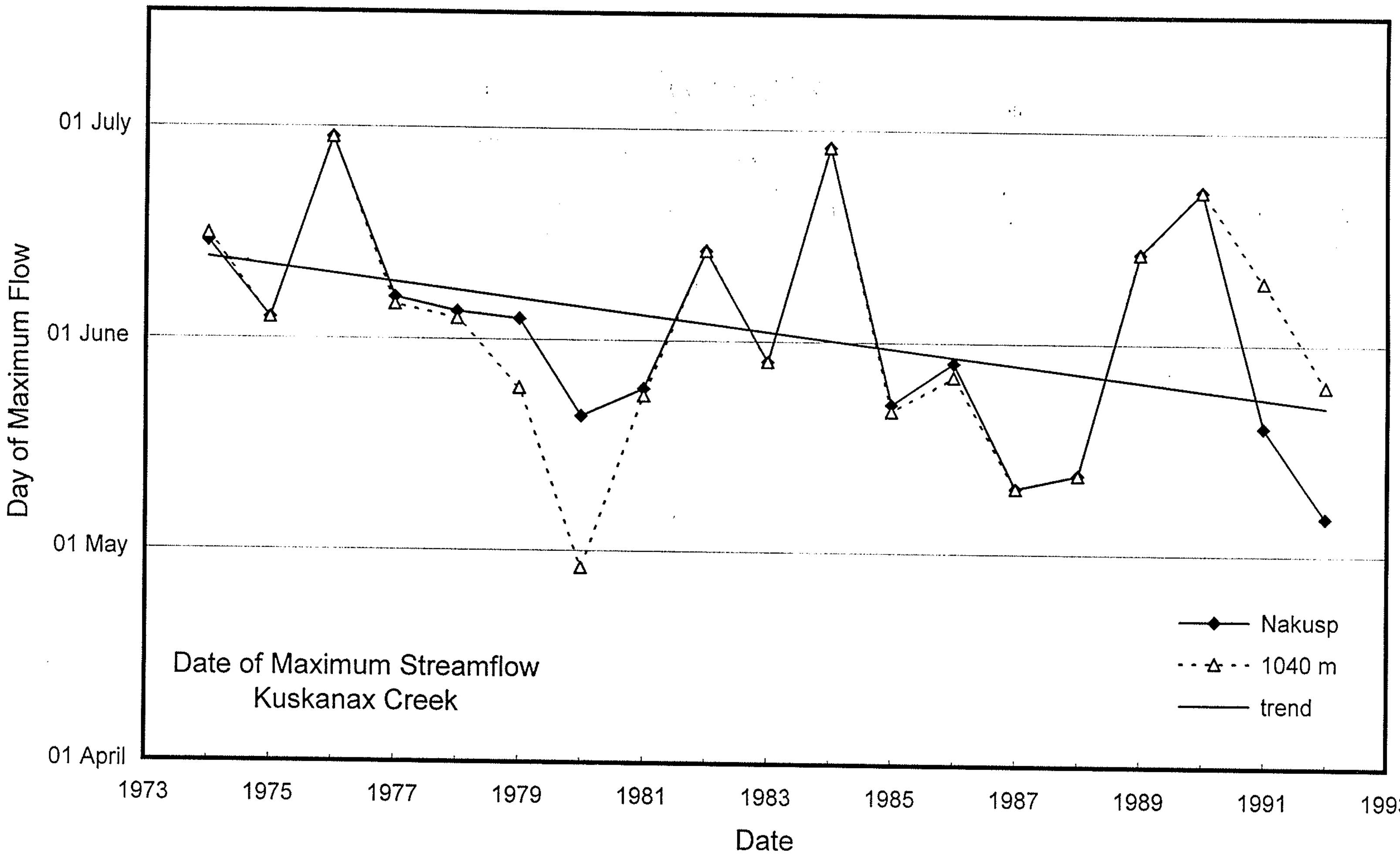

Figure 27: Date of maximum flow in Kuskanax Creek for both upper and lower gauges. Though the trend line shows a gradual shift to an earlier snowmelt over the years, the change is not statistically significant ($r^2 = 0.16$).

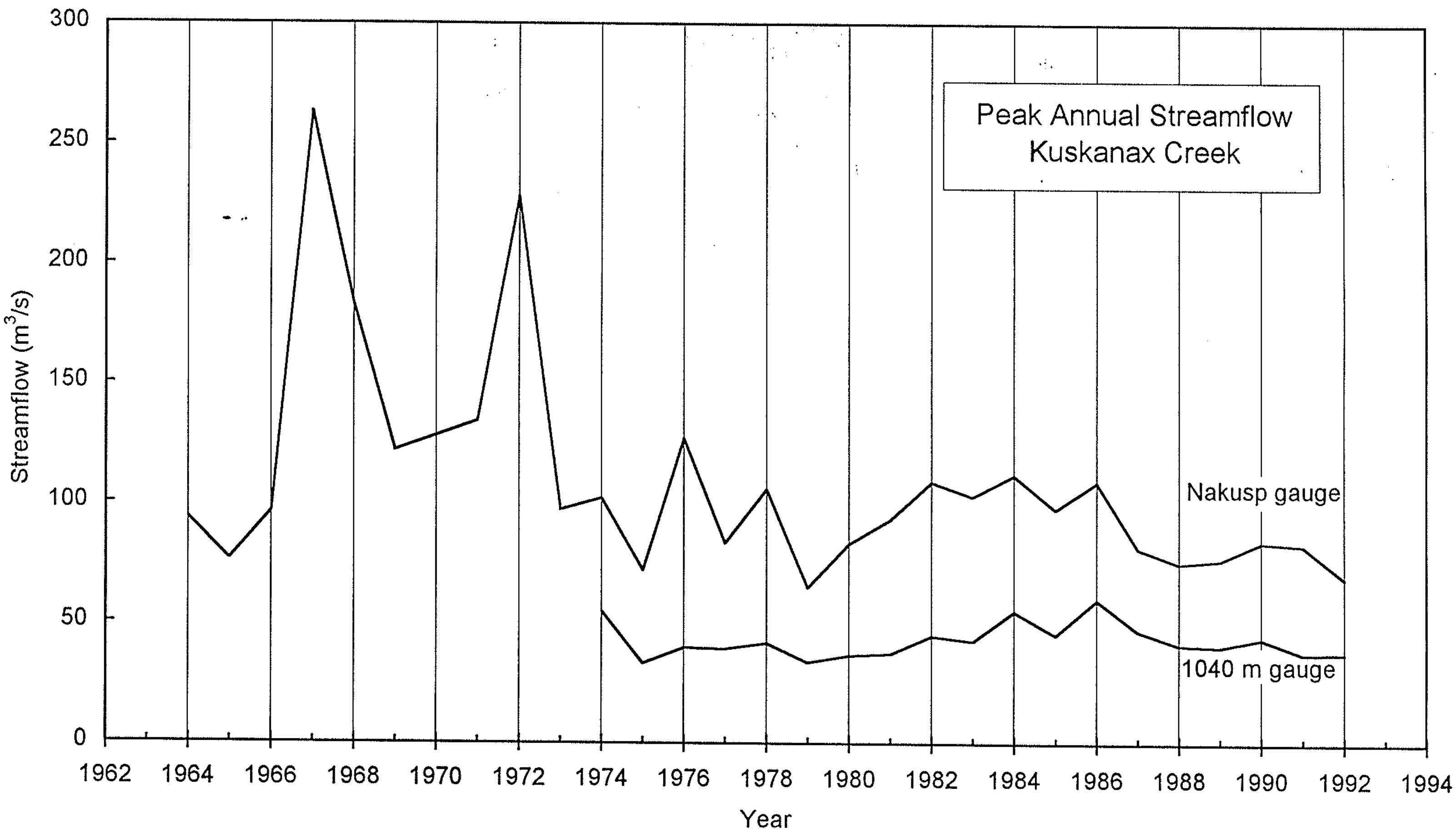

Figure 28: Peak annual streamflows on the upper and lower Kuskanax Creek gauges. The strong peak in 1972 is likely due to heavy springtime precipitation. No significant trend is apparent in the past two decades.

declining. This trend is not statistically significant, as with the lower Nakusp gauge.

6.11.2 Barnes Creek

The Barnes Creek hydrograph represents the drainage over terrain considerably different than of Kuskanax Creek. The watershed is smaller, flatter and lower, with a considerably greater portion influenced by timber harvesting. In spite of this, the annual hydrograph is very similar to that for Kuskanax Creek (Figure 29), an unexpected result in view of the difference in stream orders calculated earlier. Barnes Creek displays a rising segment which is slightly steeper than that for Kuskanax Creek.

The correlation between temperature and streamflow for Barnes Creek (Figure 30) is a close copy of that for Kuskanax Creek. This should not be too surprising, as precipitation inputs and temperature regimes in the two watersheds are very highly correlated, as noted earlier. None of the annual correlation values lies more than 2σ from the mean.

Trends in the date of maximum flow and the annual peak flow for the creek are shown in Figures 31 and 32. An intriguing aspect of the annual peak flow is the apparent decline in variability after 1973, approximately the time at which cutting began in the watershed. This variability was quantified for a given year by subtracting the flow in the following year from that in the current year. However analysis of this variability showed that the differences between pre and post 1973 years was not significant at the two sigma level.

Figure 31, the dates of maximum flow, shows the same slow trend to earlier peaks

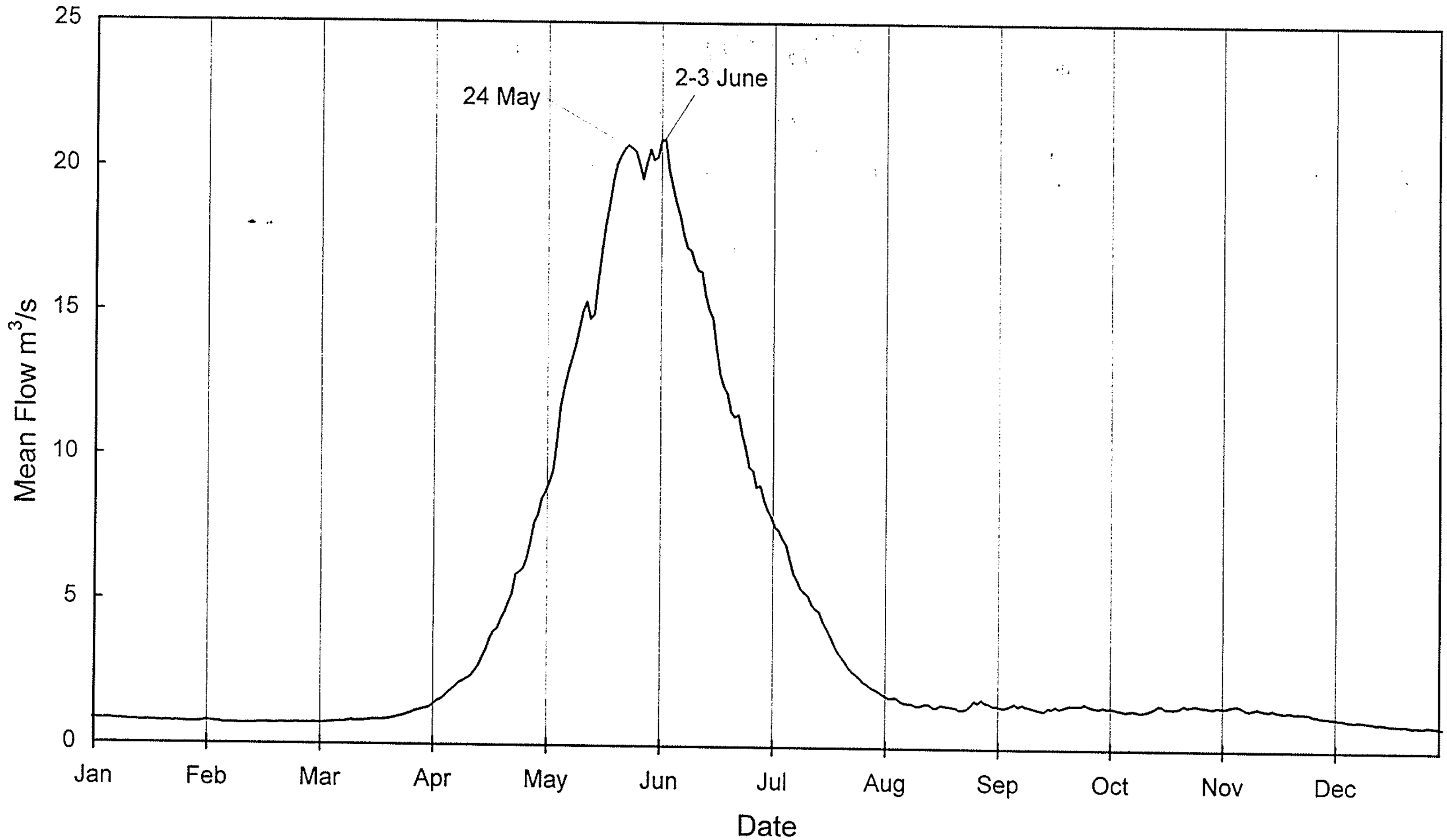

Figure 29: Mean annual hydrograph for Barnes Creek, 1954 - 1992.

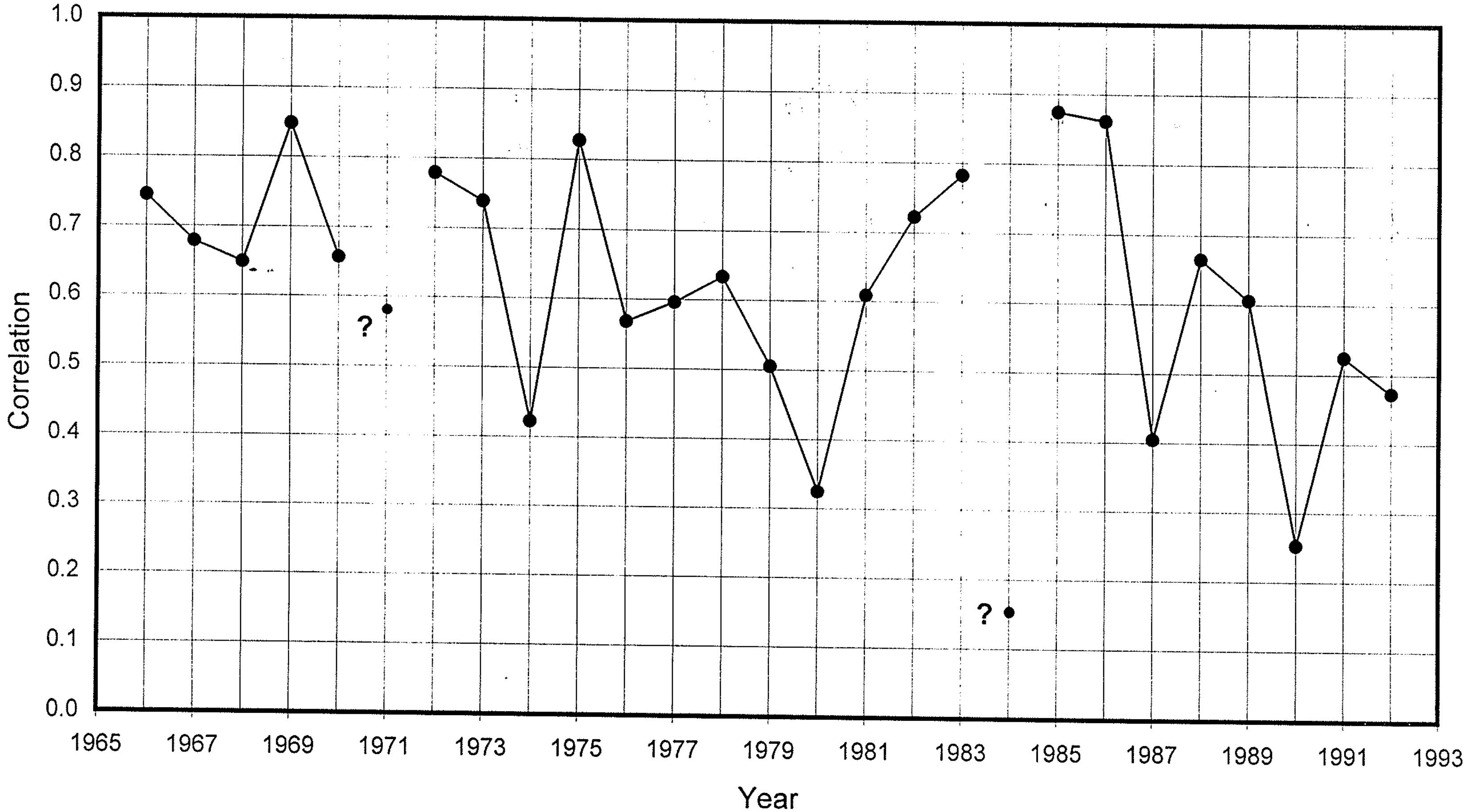

Figure 30: Correlation between Barnes Creek streamflow and two-day-lagged Nakusp air temperatures. Data points with question marks are those in years with significant missing data. The absence of a statistically significant trend in this correlation suggests that ongoing forest operations have had a minimal impact on streamflows at the watershed scale.

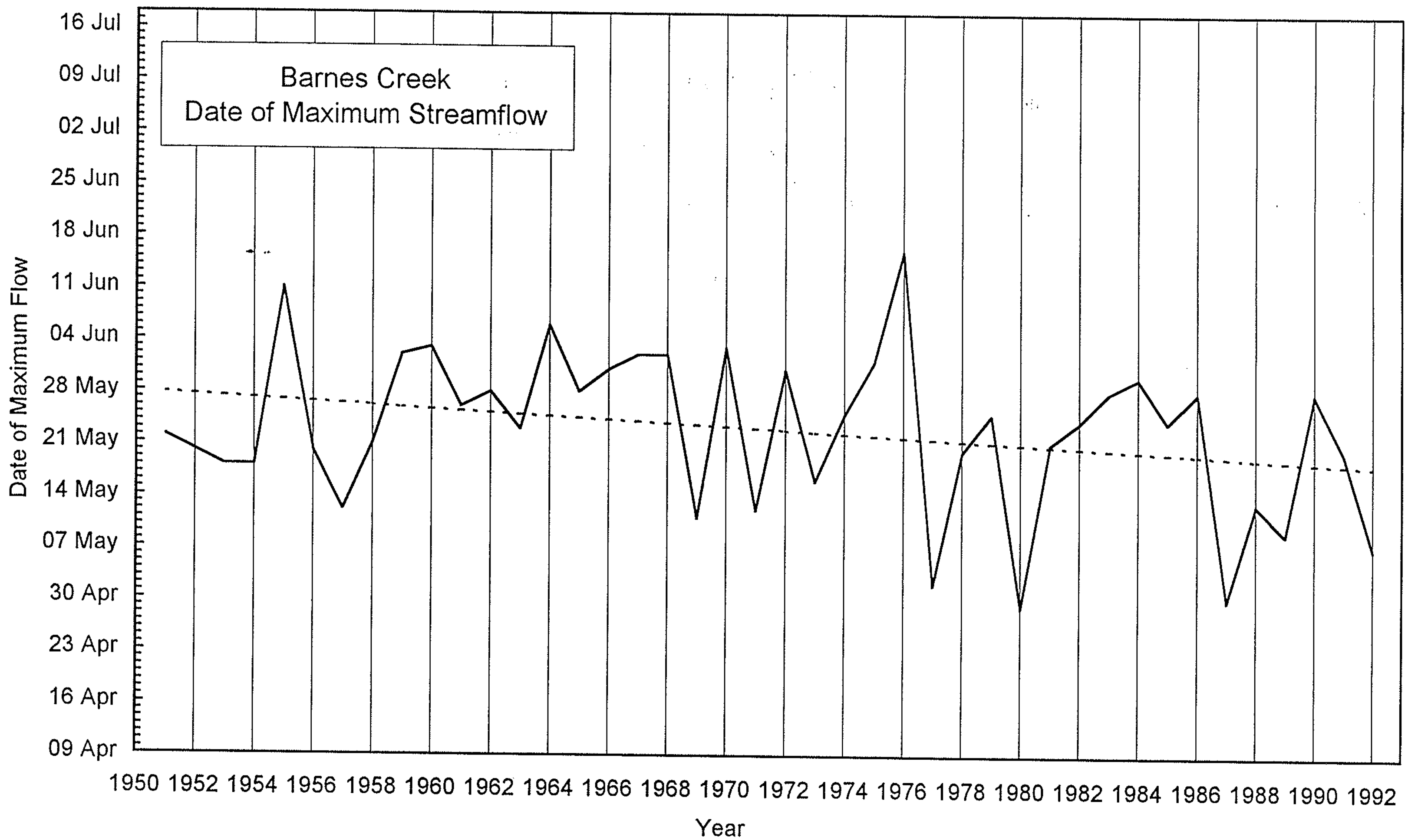

Figure 31: Dates of maximum flow at Barnes Creek from 1951 to 1992. The linear regression trend is shown by a dotted line. It is not significant ($p = .09$), though it has advanced by nearly two weeks in the 40 year period of record. Some of the change may be an impact of global warming. Source: Environment Canada (1992).

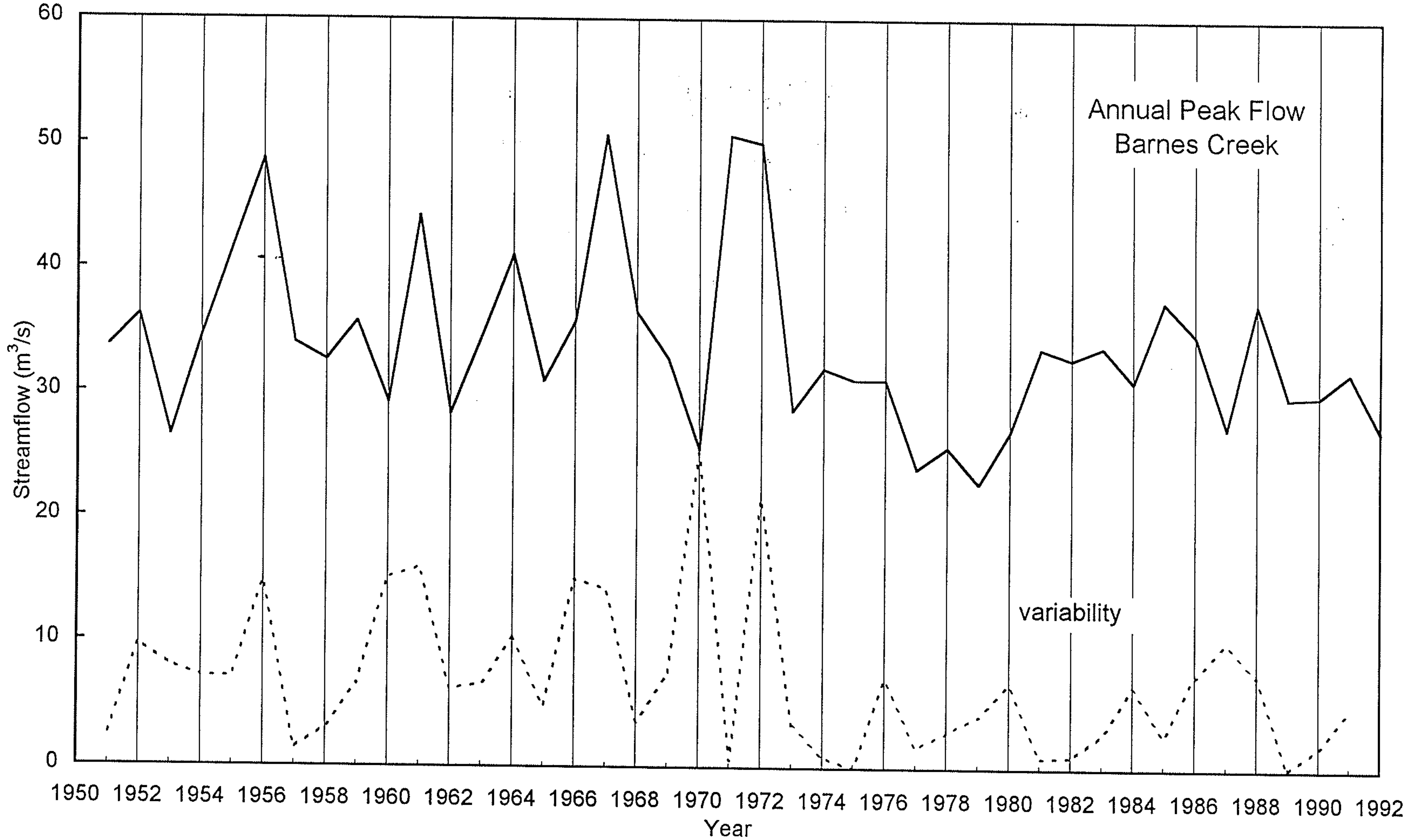

Figure 32: Annual peak flow for Barnes Creek. Variability is the difference in flow one year from that in the following year. Only the two largest streamflow peaks are significant at the two sigma level.

demonstrated in the Kuskanax Creek record. Since their cutting histories are dissimilar, the trend must be the result of a larger scale process, if indeed it is real at all. The trend amounts to 10 days in four decades.

6.12 Discussion and Conclusions

The high correlation between springtime streamflow and temperature in the Columbia River valley is of considerable advantage in examining the record for evidence of the human presence. Such a strong relationship between melting temperatures and the torrents of water flowing down the slopes facilitates the detection of alterations in the hydrology of the valley wrought by humans. Both the physics and the published literature suggest that logging (and other impacts) will decrease the time for the watershed to respond to melting temperatures and increase the peak flow. The inability to see such changes in the hydrology in these two streams argues against any substantial human impact, at least on the watershed scale. The working hypotheses have not been confirmed and the only acceptable conclusion is that logging is having no impact beyond natural variation on these creeks.

But runoff in a steep mountain environment is a dramatic event when there is a generous supply of water. It is probable that the impact of humans is so completely swamped by the natural variation that the consequences only show up over a long time, or in a different fashion. These might show as ongoing erosion, or landslides which alter the terrain and make it unfit for further growth, but which do not substantially alter the hydrological character of the watershed. Certainly this has occurred along Kuskanax Creek, which has noteworthy examples of rock slides and washouts, some of which will regrow only very slowly.

By examining the hydrographic record, we are really attempting to evaluate a more serious problem— that of increased sediment and debris in the stream. In truth little can be said about this since the essential character of the streams has not changed. These results do not allow any conclusion other than that the stream conditions remain within natural limits, though the conclusion is not very strong. The matter is of some concern, as several resource managers have suggested the presence of increased sediment loads as a factor in the decline of some fishes (Newcombe, pers. comm.; Lindsay, pers. comm.; Thorp, pers. comm.). Sediment measurements would have allowed a much stronger judgement.

6.13 Dams and Water Levels on the Arrow Lakes

Arrow Lake is a controlled body of water. The Keenleyside Dam near Castlegar regulates water levels in response to demands for water by the state of Montana. Arrow Lake levels follow an annual pattern typical of storage reservoirs - a gradual drawdown through the winter months to a minimum in early April followed by a sharp rise to a peak in July (Figure 33). The average amplitude ranges from 425 to 438 metres, with extremes at 420 and 441 metres. Before regulation, Arrow Lake varied between 417 and 429 m with an average summer peak of 425 m (BC Hydro 1993), levels now only reached during the springtime low water.

The rise and fall in lake level is not entirely regular (Figure 34). In 1970, 1977 and 1992 it remained at a low level, rising and falling through less than half the normal range. These were drought years, and so the reservoirs were drawn down to provide water for American use (Newton, 1991). In about one year in five the reservoirs fail to fill completely. Because the

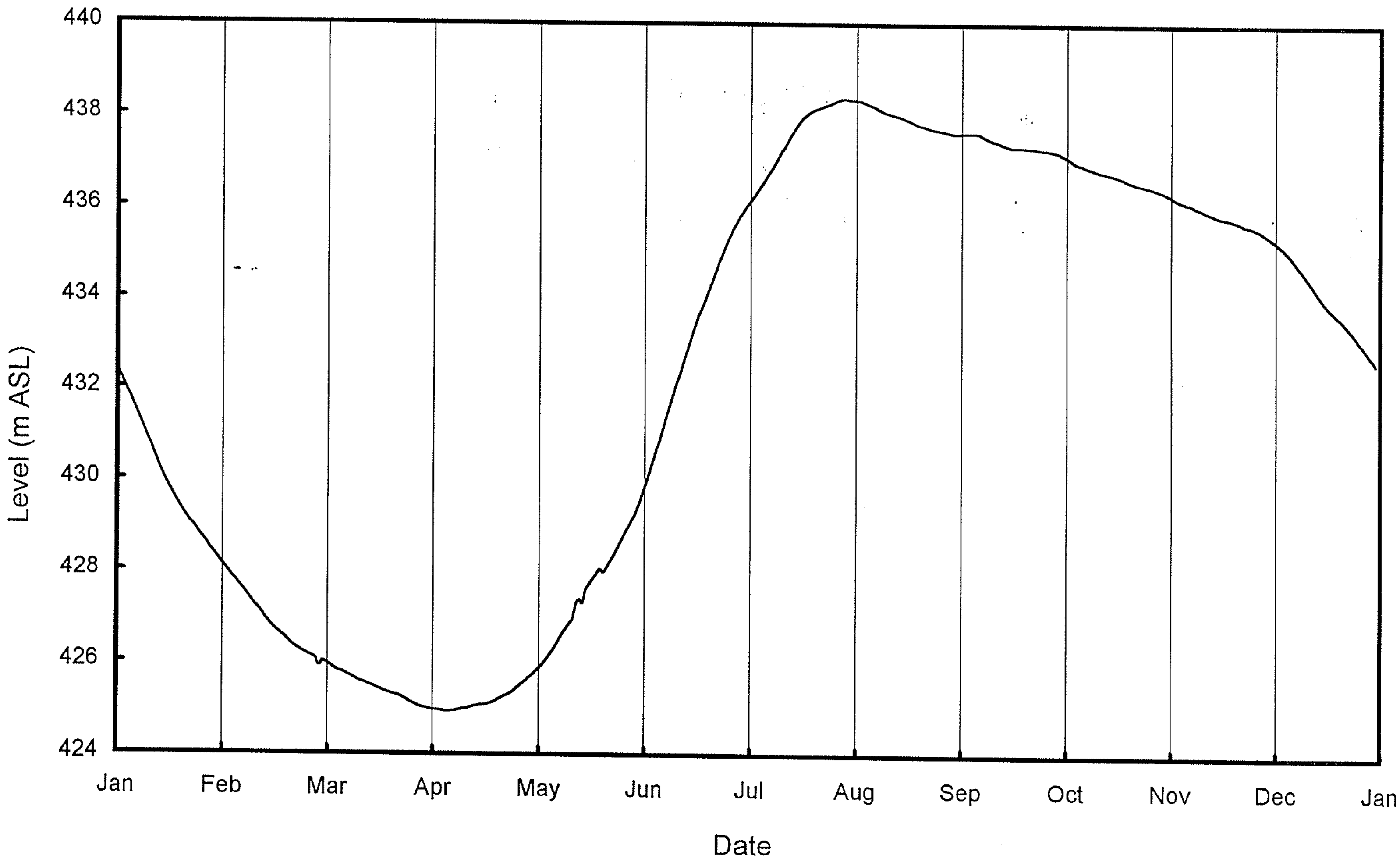

Figure 33: Mean annual level of Upper Arrow Lake, 1972-92, measured at Nakusp.

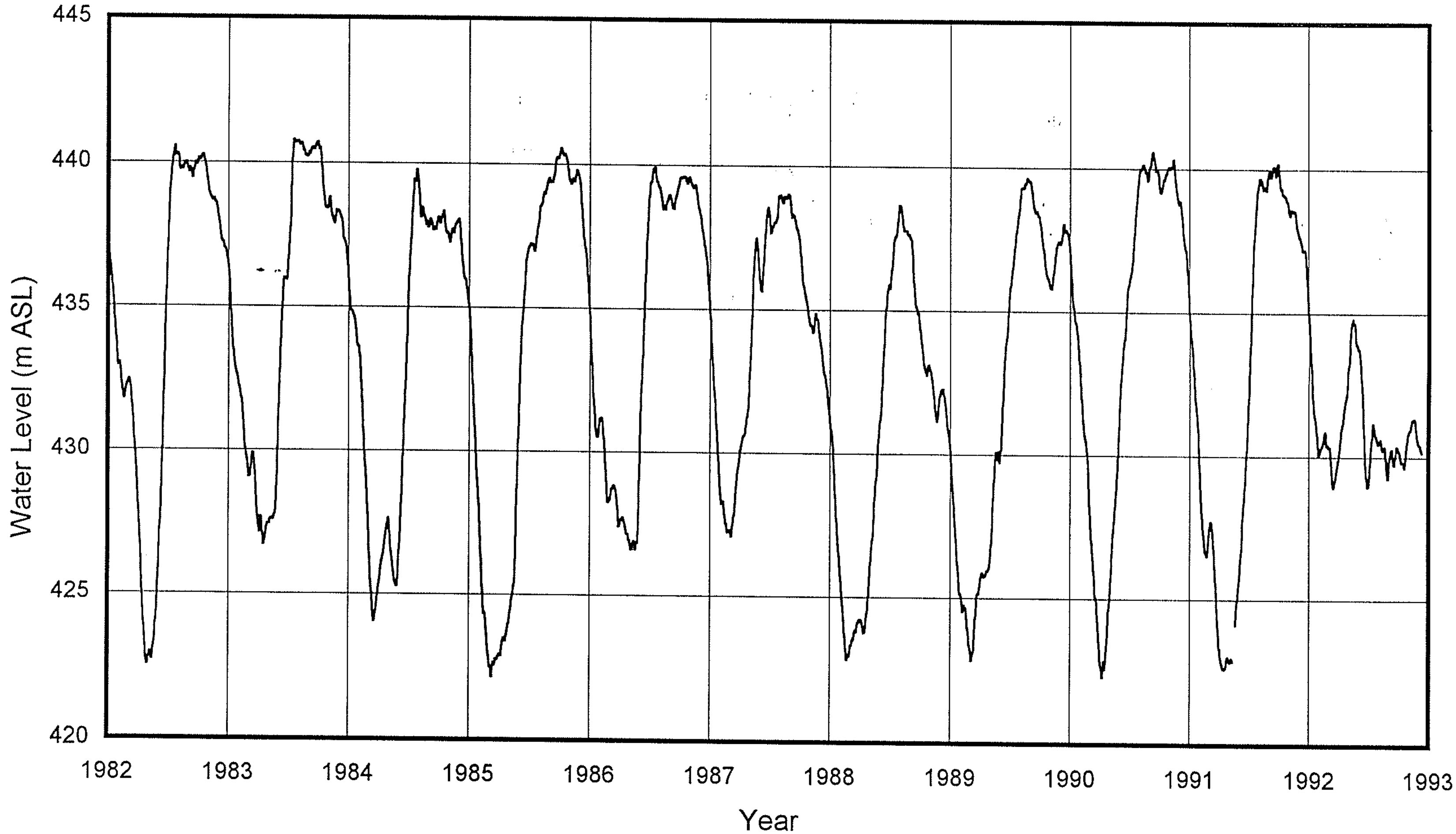

Figure 34: Arrow Lake elevation measurements, 1982 - 93, measured at Nakusp. Note the effects of drought in 1992.

purpose of the dams is to provide a downstream supply of water, reservoirs may be emptied to especially low levels in years with a light snowpack.

The original rise of the lake, present high amplitude annual variation, and the slow winter discharge all have implications for sustainability. The original flooding destroyed a bottom-land ecosystem of farms and forest, bringing a considerable burden of human grief and displacing or destroying an unknown number of animals. Forests were cut and left *in situ*, clogging the new waterway with debris, leaving a tangle of snags, stumps, and trees. A maze of sub-surface traps for boats was created, becoming visible as ghostly forest skeletons when water levels fall to the April minimum. Today, fluctuating water levels affect the aesthetics of an attractive part of British Columbia, and limit recreation opportunities, tourism, and fish habitat, bring erosion to steeper lakeshores, and interfere with birds and mammals.

For the most part the 25 years since the Columbia was dammed has cleared the lake of woody debris, though bleached stumps at low water still tell of former forests. Today most debris comes from overflowing streams as the winter snowpack melts. Abetted by logging operations, the steep slopes surrounding the Arrow Lakes create numerous "slashy" creeks which deposit their debris into the lake. BC Hydro maintains a small debris removal program on the Arrow Lakes to collect much of the floating debris, in part because of its threat to boating operations and dam operation (BC Hydro 1992). Booms at the Keenleyside Dam also collect floating timber.

The debris on the Arrow Lakes has ceased to be an environmental problem, though a small Hydro program to remove stumps in Upper Arrow Lake continues. For the most part this is for aesthetic reasons, as the stumps now provide cover for fish and mammals, and help to stabilize the shoreline (Lewynsky[17], pers. com.). Occasionally debris is simply tethered in place, to retain these values.

Nesting shore birds, primarily geese, are occasionally flooded by the rapidly rising water levels in the spring, but considerable attempt is made to delay the rise until the nesting is mostly completed. Those nests which are flooded out are usually later second attempts (Callewaert[18], pers. com.). The birds are attracted to an area of lakeshore which has been planted in grass to control blowing dust in exposed mudflats (BC Hydro 1994, 10).

Much of the bottomland flooded in the early 1970s was the habitat of white-tailed deer. This species has adapted by moving into the new and higher lakeshore habitat, in turn displacing the mule deer which formerly occupied the location to higher slopes. This adjustment seems to be largely completed according to local outdoorsmen (Olson, pers. comm.), though the loss of prime habitat must have considerably reduced one or both of the deer populations.

Fish species which inhabit the Arrow Lakes do not seem to be overly affected by the varying levels. For the most part they are deep water fish which do not spawn in the foreshore. Kokanee salmon are known to shore spawn on rare occasions, but even this seems to be at levels below the lake's low water mark (Lewynsky, op. cit.). Fishermen occasionally complain about poor access to fishing sites during low water, but a Hydro compensation program usually sets this right. In view of the recreational fishing pressure on the lake, the access

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[17] Vic Lewynsky, Southern Interior Environmental Coordinator, B.C. Hydro.

[18] D.G. Callewaert, B.C. Hydro, District Manager, Nakusp.

restrictions are likely a small contribution to sustainability, rather than a debit. Changing lake levels bring changes in turbidity, at least along the shorelines, but the effects are unknown (Thorp[19], pers. comm.)

The single biggest loss to the Columbia River system is the disappearance of the Pacific salmon, due entirely to the construction of the Grand Coulee dam in Washington. The lake is now populated by kokanee, the trapped spawn of the original Pacific adventurers. Since no data are available on fish populations before the dam construction began, only speculation remains to evaluate the effect on other fish species, bears, birds, and other consumers of the rich salmon resource. The loss of these species must have been a blow for sustainability.

Discussion of the consequences of damming and the annual wave of high and low water would not be complete without inclusion of the impact on human inhabitants. Emotions still rise when the subject of the original flooding and compensation is broached. Remaining members of the original families retain memories of farms long drowned, of graves hidden or moved, of a lifetime of work flooded. Compensation was meagre, often without substantial discussion, and often barely enough to begin again. Still, many of the original families continue to inhabit the valley, with new jobs and roots. Sustainability may be lost, but adaptability remains.

Evaluating the sustainability implications of the new lake cycle is confronted with the observation that most humans and animals have adapted to this *fait accompli*. Hydro managers have indicated that it would certainly would not be done in the same fashion again,

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[19] Grant Thorp, Senior Fisheries Technician, BC Environment, Nakusp.

but this is not to say that it would not be done. Forests would not be left to rot in the rising waters, but would be cut first. Salmon might be accommodated, though their demise came with American construction, and Canadians did not have to confront the consequences when construction began on our side of the border. Humans would be treated more honestly, and perhaps compensated more handsomely. But none of these would halt a project, merely address some problems recognized in hindsight.

Are the Arrow Lakes sustainable in the era of dams and fluctuating water levels? This question reveals a fundamental dilemma in the measurement of sustainability. Viewed from the era before Europeans arrived, the answer is certainly no, in large part because of the loss of the Pacific salmon, and the blocking of spawning runs. But the ecosystem has been gradually adjusting since the 1970s and has achieved a rough level of balance, with the possible exception of bull trout. Some of this is because of active management, such as the construction of the Hill Creek hatchery, some by the gradual disappearance of species which formerly used the lake and valley bottom.

7. Fish

7.1 Introduction

The Arrow Lakes contain a rich fishery, with kokanee salmon (*Oncorhynchus nerka*), bull trout (*Salvelinus confluentus*), and rainbow trout *(Salmo gairdneri*) attracting anglers from across North America, with about 2400 fishing licenses issued annually from outlets along the Arrow Lakes. There is no commercial fishery. Local residents tell of readily available catches of bull trout, the most sought-after species, which are fished primarily in winter months when the tourists have departed for home.

But resource managers have a different view, talking of the fishery with a sense of unease, half-expecting a decline of fish populations in the coming years. In this they are casting their eyes on the decline of kokanee stocks in nearby Kootenay Lake. There kokanee populations have been reduced since 1978 due to competition from an introduced species, shrimp-like *Mysis relicta* (as food for angling species), reduced phosphorus levels below a dam, and pollution controls which reduced inputs of man-made phosphorus (EC/MoELP 1993, 81; BC Hydro 1994)). Managers are also concerned about population levels of bull trout and signs on public wharfs request that anglers release Arrow Lake rainbow trout when they are caught; the species is on the verge of disappearing from the lake.

7.2 Kokanee

Kokanee salmon are the hallmark species of Arrow Lakes fishes. They have a high public profile (a popular beer is named after them) and are the most commonly fished species by visitors (Olson[20], pers. comm.). Other species have more appeal to the connoisseur, but kokanee are the bread and butter fish of the valley. The species is the confined remnants of the anadromous Pacific sockeye salmon, restricted to the fresh water lakes of the Columbia valley by dams constructed in Washington state, in particular the Grand Coulee dam.

The fragmentation of the Columbia River by a series of Canadian and American dams and the

[20] Glen Olson, owner, Olson's Marine, Nakusp

loss of spawning habitat from logging has forced construction of the Hill Creek Hatchery, near the north end of the study area. One estimate suggests that the construction of the Revelstoke and Mica dams removed over 100 km of kokanee spawning habitat from contact with the Arrow Lakes (Spence [21], pers. comm.). Lindsay [22] (pers. comm.) estimates that 4000 adults spawned above the Revelstoke dam and were completely isolated once the dam become operational. This figure represents about 50% of the Arrow Lakes' recruitment. In the early years after construction of the dam, the sport catch declined dramatically, but has subsequently recovered and levelled off since the construction of the hatchery (Lindsay). Hatchery costs are largely underwritten by B.C. Hydro.

Currently, the Revelstoke dam is not operated with fish populations in mind, bringing unnatural flow regimes to the Upper and Lower Arrow Lakes (Thorp[23], pers. comm.), and flow-related changes in lake turbidity. The effect of rising and falling lake levels on fish populations, with attendant inundation and exposure of mud flats is controversial. In Olson's estimation, fishing is best in low water years, when food supplies are low and fish are "hungry". And kokanee will shore spawn occasionally, but this is rare and usually deep enough that low water levels would not expose the eggs (Lewynsky[24], pers. comm.). The major effect of falling lake levels may be the creation of creek mouth "waterfalls", which, in the precipitous terrain along the valley, limits fish access to their spawning grounds (*ibid.*).

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[21] Colin Spence, Senior Program Scientist, B.C. Environment, Nelson, B.C.

[22] Bob Lindsay, Senior Fisheries Scientist, B.C. Environment, Nelson.

[23] Grant Thorp, Senior Fisheries Technician, B.C. Environment, Nakusp

[24] Vic Lewynsky, South Interior Environmental Coordinator, B.C. Hydro

Logging is surmised to have had a detrimental effect on fish numbers, but this was offered as conventional wisdom rather than with objective evidence. Even here, attitudes were divided. Olson considers that logging has had a beneficial effect on fish numbers by washing nutrients ("food") into the lake. According to Thorp, a ten metre riparian buffer strip left during logging does not provide sufficient protection for fish spawning habitat. Lindsay also considers that the loss of habitat is a critical factor in the decline of wild fish.

Loss of habitat and sediment loading were the two problems mentioned most often by fishery resource managers. Sediment can have a dramatic impact on fish, from mild avoidance reactions to death, depending on the concentration (Newcombe 1994, 11). Habitat losses come from both the removal of stream debris and the addition of large amounts of new debris, and the smothering of spawning grounds or other habitats. However Lewynsky noted that forestry has both positive and negative impacts. While logging likely added to the debris in creeks (providing habitat for young fish), logging roads and culverts increased sediment loads and increased the mortality of the fingerlings. The Forest Practices Code regulates the design of roads and stream crossings to the extent that these problems will likely decline in the future.

During our tenure in Nakusp we observed logging operations in a two year old blowdown which left several creeks choked with debris and fallen trees. Under the tenets of New Forestry, this debris should be left largely untouched, and this seemed to be the intent of Forest Service staff (Anderson[25], pers. comm.). Only large root balls which threatened to add a significant sediment load to the creek were being removed, in several cases by cutting them

[25] Harry Anderson, Field Office Supervisor, B.C. Forest Service, Nakusp

away from the trunks which were lying in the watercourse. The maintenance of slashy creeks is a component of New Forestry, and is encouraged by the Forest Practices Code.

Local fishermen give mixed opinions about kokanee populations, allowing at one moment that the fishery is "not good" and the next that kokanee are "easy" in July and August (Olson). Olson thought that 1995 would be a bad year for kokanee, but that the fish were still there "eating worms in newly flooded areas" (the Arrow Lake reservoir had just filled to normal levels after several years of low water). According to Olson, fishing was "great" in the first five years after flooding (in the early 1970s), because of food released by the inundation of flats and banks. However he is persuaded that there is little pressure on kokanee stocks at present, preferring to ascribe poorer catches to fish behaviour and inexperienced anglers.

Fisheries managers largely felt that kokanee populations were stable, in large part because of the influence of the Hill Creek hatchery. The hatchery contains a sufficient number of spawning channels to maintain the population of kokanee salmon in the Arrow Lakes, and also provides a limited amount of habitat for bull and rainbow trout (Thorp). Annual releases of fry are determined by the mean size of fish in the lake, with managers aiming for an average of 25 cm, an attractive size for anglers. If sampling shows that the fish are exceeding this mean, additional fry are released in order to increase the competition for food, with a subsequent decline in size (Thorp).

Kokanee populations have been monitored by creel surveys (exit surveys) since 1992 and sporadically before. The effects of the Hill Creek Hatchery can be seen quite dramatically in the catch per unit effort (CPUE) statistics provided by Thorp (Figure 35). These surveys

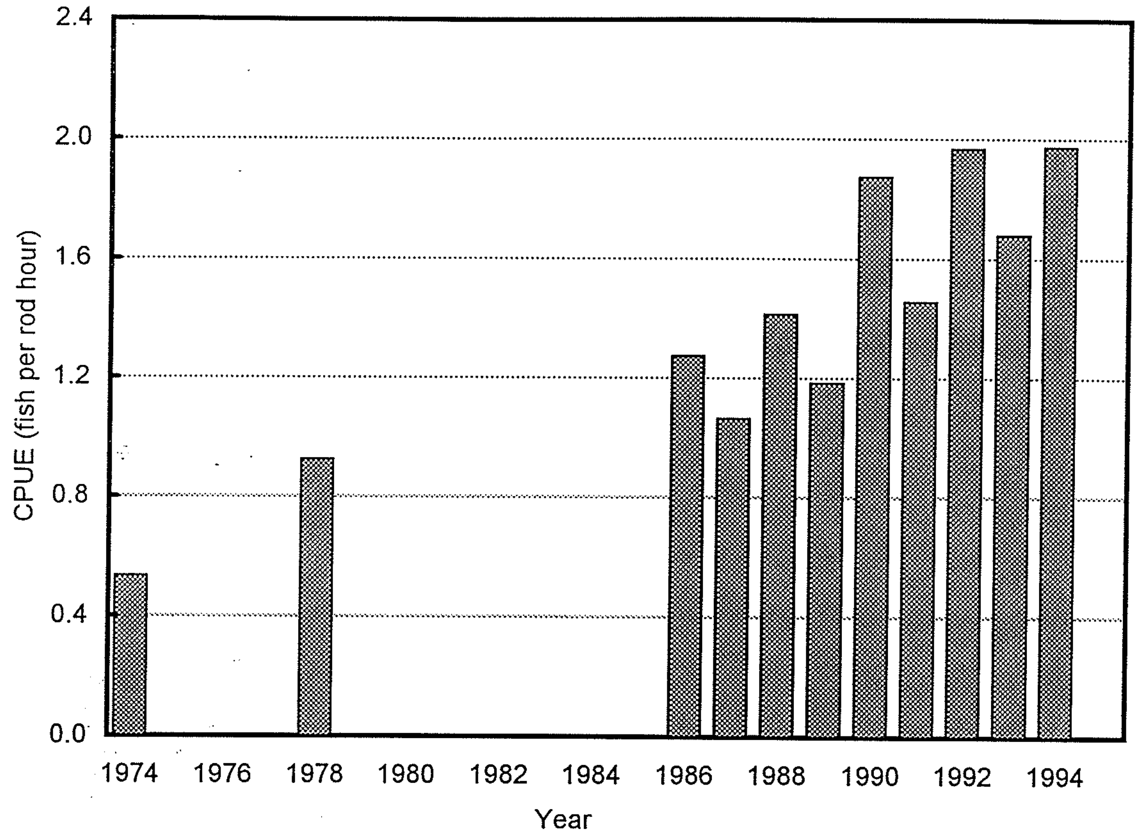

Figure 35. Catch per unit effort statistics for kokanee salmon landed along the Arrow Lakes (Thorp, pers. comm.). Statistics were collected by interviewing anglers on five randomly-chosen days each month. The Hill Creek Hatchery came on line in 1983.

sample effort and catch at the Nakusp dock on five randomly-chosen days each month (Olson). Before hatchery came on line in 1983 the CPUE (fish per rod hours) for kokanee salmon was less than 1.0, increasing to 1.27 in 1986 and to nearly 2.0 in the 1994. During the same period the average fish size arriving at Hill Creek declined from nearly 28 cm to 22 cm, indicating a larger number of fish were competing for food. While CPUE statistics have a limited ability to monitor fish populations, because of the confounding influence of technology and increasing experience of the fisher, the evidence of a rising catch and smaller fish suggest a healthy kokanee population.

More extensive sonar surveys of kokanee populations are conducted annually along 15 transects of the Upper and Lower Arrow lakes using an echosounder. This instrument allows fish populations to be counted according to the size and strength of the echo return (D. Sebastian[26], pers. comm.). Preliminary data analysis shows strong populations in both lakes (Figure 36) , though the period of record is relatively short. In 1992, the number of kokanee in the two lakes was estimated to be over two million. Catch for the year (Thorp) was estimated at just over 60 thousand fish.

These numbers suggest that the kokanee are in sustainable condition in the lakes, and in little danger of decline as long as the hatchery is maintained.

[26] Dale Sebastian, Fisheries Biologist, B.C. Environment, Victoria

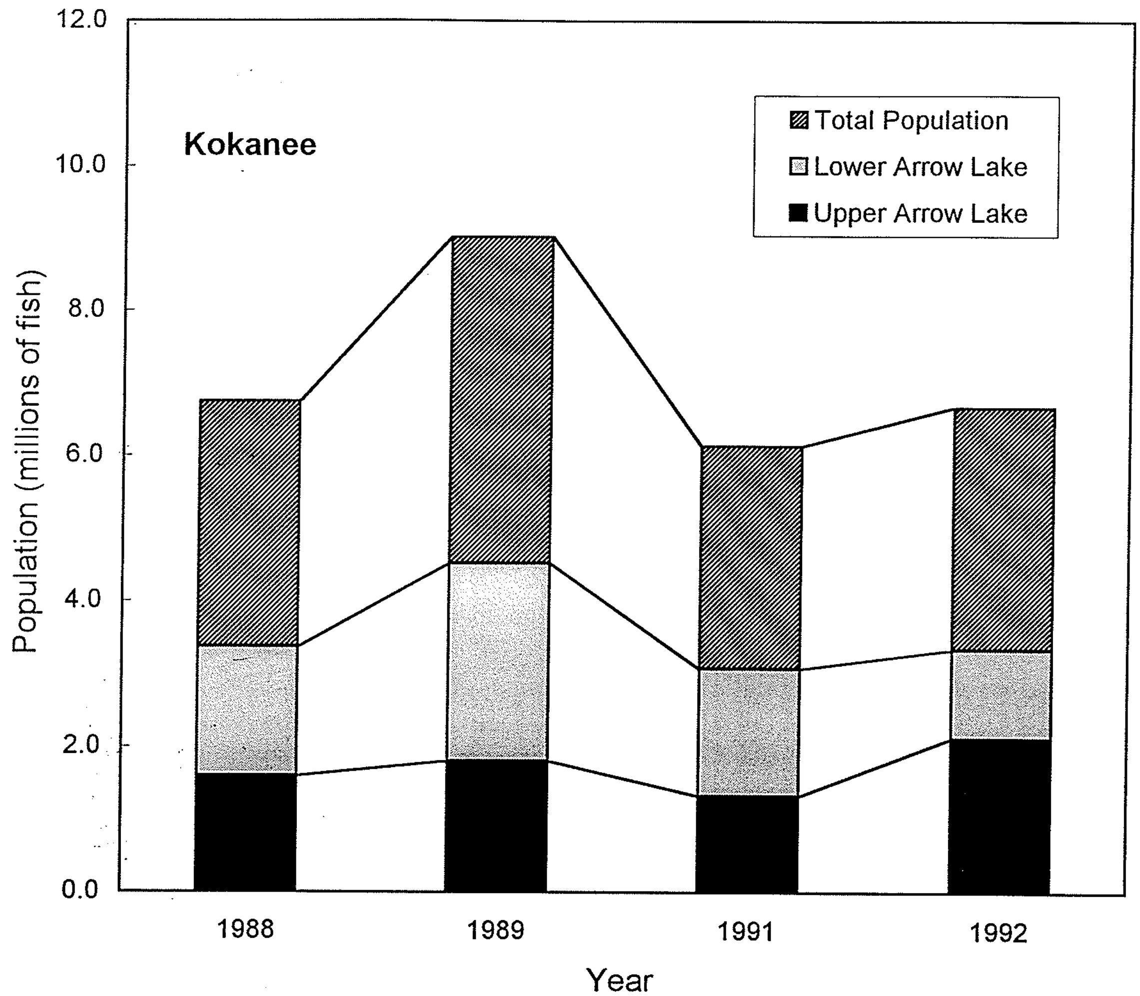

Figure 36: Kokanee salmon populations of the Upper and Lower Arrow Lakes measured by echo sounder along 15 transects. From D. Sebastian, pers. comm.

7.3 Bull Trout

7.3.1 Local Impressions

In contrast to the professional and public opinions about kokanee populations, bull trout population numbers elicit more concern and caution. Part of this is because the size of the population is largely unknown (Lindsay, Lewynsky). Few adults show up in the Hill Creek hatchery (Lindsay) and the fry that are released seem to have little effect on the lake population (Thorp). Local fishing opinion maintains that populations are healthy, but describe increased effort and "knowing where to go" as important factors in fishing (Olson), a tacit admission of a decreasing catch per unit effort. Lindsay also noted that the method of fishing has become more intensive over the years, with individual anglers deploying more lines than was the case in the past.

Bull trout can reach a length of over 100 cm and a weight of over 14 kg. The biggest fish landed at Nakusp and recorded by Olson was 8.2 kg. Fish over 6 kg are uncommon in the lake. Over the years there has been a significant reduction in the range of the bull trout (Rieman and McIntyre 1993), especially in Alberta. They feed primarily on insects and other fish, but are known to consume small mammals, including mice (Van Tighem 1995).

Bull trout spawn in the highest reaches of the streams flowing into the Columbia River, where the water is coldest. Young remain in the stream for several years before descending to the Arrow Lakes (Lindsay), though the species is known to have resident (which remain in the stream) and migratory populations (Rieman and McIntyre 1993). During their tenure in lakes they feed on kokanee and other smaller species. The few adults that show up at the Hill Creek Hatchery are generally five to seven years at first spawning (Lindsay). Adults spawn two to three times per lifetime.

Lindsay speculates that Arrow Lake bull trout had significant spawning habitat which was cut off by the construction of the Mica dam above Revelstoke. This has likely most affected the migratory segment of the population (Rieman and McIntyre 1993, 2), the heaviest and most desirable fish. This loss of this trout habitat was unexpected and not factored into the design of the Hill Creek Hatchery, so that only a few fish reproduce there each year. Tagged fingerlings are recovered very rarely and the hatchery seems to have little impact on the lake population of the bull trout. Because of this, there was no collection of spawning adults from tributaries in 1995 to add to the hatchery stock.

Lindsay notes that Arrow Lakes population figures for bull trout are not really known, making management difficult. The species is regarded as especially important in the Arrow Lakes watershed because of its attractiveness to anglers. Up until 1995 bull trout could be fished freely, but catch limits have been imposed for the 1996 season and beyond. Originally these were to have been a possession limit of one bull trout over 50 cm in length, but enforcement difficulties have modified this to a seasonal limit. Nakusp fishers complain that restriction of creek mouth fishing would have been a more palatable protective measure (Olson), but Lindsay notes that signs restricting fishing often have the effect of attracting anglers.

Resource managers attribute most of the suspected decline in the population to overfishing and habitat destruction during logging operations (Lindsay). Most of the sport fishing for bull trout is done locally, in the winter season when tourists have left the valley. One fish biologist estimated that the best fishers in Nakusp, perhaps a dozen, catch 50 - 70 fish per year. This seems an overestimate, as records kept by Olson show an average of 170 fish caught and weighed at Olson's Marine between 1987 and 1993. Olson estimates that 80 to 90 percent of the anglers weigh in their bull trout at his store during the winter season.

The bull trout is especially sensitive to over-fishing and habitat loss in the tributaries of the Columbia River as they occupy the steepest (up to 23% grade) and highest parts of the stream courses (Ministry of Forests/BC Environment 1995b, 8). Because these sites are also the coldest parts of the watershed, the bull trout has a large appetite—an appetite which makes it easy to catch (Van Tighem, 1995). Streams at this level are often narrow and unable to tolerate even small amounts of disturbance by logging operations. The tendency to log along streamcourses (Figure 14) provides access to high elevation habitat by anglers.

Temperatures more than any other factor affect bull trout distribution, with optimum values for incubation around 3° C (Rieman and McIntyre 1993, 77). Logging can raise water temperatures by exposing the stream and the surface runoff flow to sunlight. Changes in peak flow can scour streambeds, particularly in spring runoff. Spawning runs in the fall often depend on rainfall and high water surges to allow access to the higher reaches of the watercourse. Because access to and survival in the high elevation habitat is sensitive to normal climatic variations, year class failure are common (Rieman and McIntyre 1993, 20) and additional pressures should be avoided.

Private records of bull trout catches kept by Glen Olson (Olson's Marine) show that the weights of the heaviest fish have not changed significantly since the mid 1980s (Figure 37). The ability of records of fish weights to monitor population changes is extremely limited, but if we assume that falling populations would result in a gradual increase in fish weights and sizes as competition for food is reduced, then the record suggests a relatively stable resource. Fisheries biologists did not provide us with more rigorous population statistics, but the concern about bull trout numbers was pervasive among all we interviewed.

7.3.2 Protecting the Bull Trout Stock

Rieman and McIntyre (1993) identify several factors which characterize the relative risk of extinction of local and regional bull trout populations. Local impacts include several stochastic natural events – frequent flood or drought, debris torrents, or large fires – but the consequences can be modified by human activity in the watershed. It is important that management of riparian and stream habitats be conducted with extreme natural events in mind, and not just average climatological values. In particular, the as-yet unknown effects of global warming could have a major impact on temperature and precipitation characteristics of bull trout habitat, and long term protection under such conditions must be planned and carried out.

Under the pressure of declining bull trout stocks, logging operations must be especially constrained. Even though declining numbers may be due to other resource users, particularly fishers, forestry practices must be prepared to respond. Resource management cannot function in a vacuum—just as ecosystems are complex interlinked networks, so too is

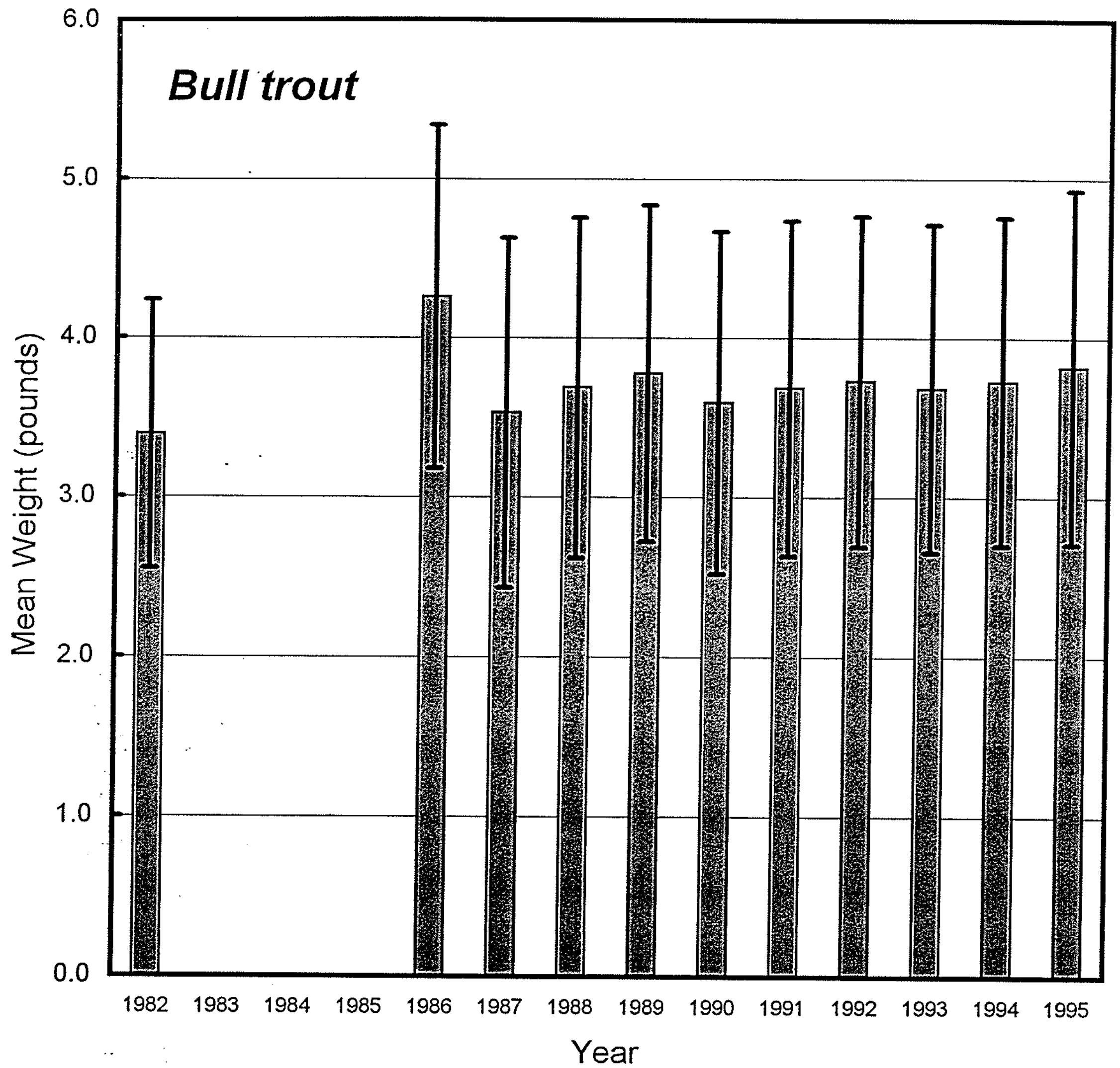

Figure 37: Mean weights of bull trout measured at Olson's store, Nakusp. Most of these fish were caught by residents of Nakusp and nearby areas during the winter months. Error bars show standard deviations. From Olson, pers. comm.

resource management. Catch limits may begin to restore *Salvelinus* populations, but until the evidence is available that such is the case, preservation of biodiversity requires response by all resource sectors. In logging, this may mandate larger riparian buffers, protected or reserved habitats, and active management to overcome natural disturbances (fire is already largely suppressed). Hydrological management may require the amendment of lake level changes, though no specific evidence of harm from the large changes in lake level were presented to us. More widely, protection of bull trout may require the construction and operation of a dedicated hatchery.

These are very similar to the conservation practices proposed by Rieman and McIntyre (1993, 19). They suggest that habitats with the strongest populations should be selected for preservation, not necessarily in a pristine condition, but managed in a way to protect "the quality, complexity, or ecological and hydrological processes". Along the Arrow Lakes, the prime bull trout habitat includes the Incomappleux River (which has been extensively logged), Hill Creek, Halfway River, St. Leon Creek, Kuskanax Creek, Slewiskin Creek and Arrow Park Creek (Lindsay).

Rieman and McIntyre (*ibid.*) also note the need to manage for long term trends, including climate change and the cumulative effects of fishing, predation, competition from other fish species, and hybridization. Migratory corridors are a critical component of their conservation strategy; it is not enough to protect just the upper spawning beds, but the route to them as well. Furthermore, bull trout are biologically diverse species, and protection of only a single watershed will result in some loss of genetic and phenotypic variation. Protected areas should be distributed through the Arrow Lakes watersheds, a process which would also protect against deterministic threats. Too large a dispersal would not allow populations to interact; they suggest that distances between protected watersheds should be 30 to 50 km. This scale is comparable to the separation of the watersheds noted above.

The poor knowledge of bull trout distribution and population in the Arrow Lakes watershed is a critical deficiency in management and protection. This information is required in considerable detail if the goal of protecting diversity is to be merged with the need to exploit the timber and fish resources of the Columbia River (Rieman and McIntyre 1993, 24). While the Forest Practices Code has strong measures to protect fish habitat, the pressure of sport fishing, road building and other aspects of human presence make the sustainability of the bull trout populations a questionable endeavour.

7.4 Pacific Salmon

The single biggest loss to the Columbia River system was the disappearance of the Pacific salmon due to dam construction in Washington, now reinforced by dams on the Canadian side. Since no data are available on fish populations before dam construction, effects on the other components of the ecosystem - bears, birds, and other salmon consumers - remains speculative. The loss of the salmon was a decided blow to sustainability, not only along the Arrow Lakes, but in the Pacific Ocean ecosystem as well. Now that ocean fish populations are dwindling, the loss of the Canadian spawning grounds, in retrospect, has been a severe blow. Construction of a single ill-considered barrier has had a disastrous impact on inland and ocean populations which have never been tallied.

7.5 Summary

Fish populations are showing mixed responses to human development and presence along the Columbia River. While kokanee numbers are sustainable, in large part because of enhancement by the Hill Creek hatchery, bull trout numbers seem to be declining from over-harvesting and habitat loss. Further declines are likely without a significant restriction in harvest levels, as now seems imminent. And the new Forest Practices Code (CORE 1995) requires riparian buffers which may go farther than past practices in protecting spawning habitat. In view of the threats to some fish species, rigorous management, ongoing population data collection, regulation and involvement of local fishers and resource users, perhaps in the form of community management, would seem to be obvious next steps.

8. Summing Up: A Return to the AMOEBA Diagram

In the previous pages we have examined the question of the sustainable use of some of the renewable resources surrounding Nakusp in the Arrow Lakes region of British Columbia. Numerous conclusions have been advanced, some tenuous, others firm and supported by convincing measurement.

This exploration has been one from an conservationist's point of view, focussed mostly on the biology and hydrology of the region. Early on, arguments were presented which defended this viewpoint. In essence, this study has probed a part of the foundation of the economic and social activities which take place in the valley. And while we have relegated the social and economic aspects of sustainable development to a secondary role, their importance has been evident by the frequency in which they entered the discussion.

To summarize our results we return to the AMOEBA diagram of ten Brink (1991). With this we attempt to show to what extent the harvesting of Arrow Lake resources is sustainable, and to satisfy our objective "to develop quantitative measures of sustainable use..." (section 1.2). Figure 38 summarizes the status of sustainability within the study area along the Arrow Lakes. Each sector represents an ecosystem component or species which was evaluated in this study; sustainability refers to biophysical sustainability. In some cases the quantitative value of the sector's sustainability is largely subjective; in others it is based on specific measurements or calculations. The following sections explain the evaluation, sector-by-sector.

8.1 Sustainability in the Forest

Hansen *et al* (1995) provide the route to assess the sustainability of current harvest levels in the Arrow Lakes area. Their model calculations show the volume (actually basal area) of wood produced in a Northwest Pacific forest under various conditions of rotation age and canopy tree retention. For our purposes, we have selected the sustainable forest as one with one-quarter of the trees in a 240 year rotation and three-quarters with a 120 year rotation (Table 12). In both cases we have assumed a retention of 10 trees per hectare, a value comparable with that suggested in the modified 50-11-40 rule (§ 4.7.2). The current (unsustainable) forest is assumed to be one which is clearcut with a rotation age of 100 years.

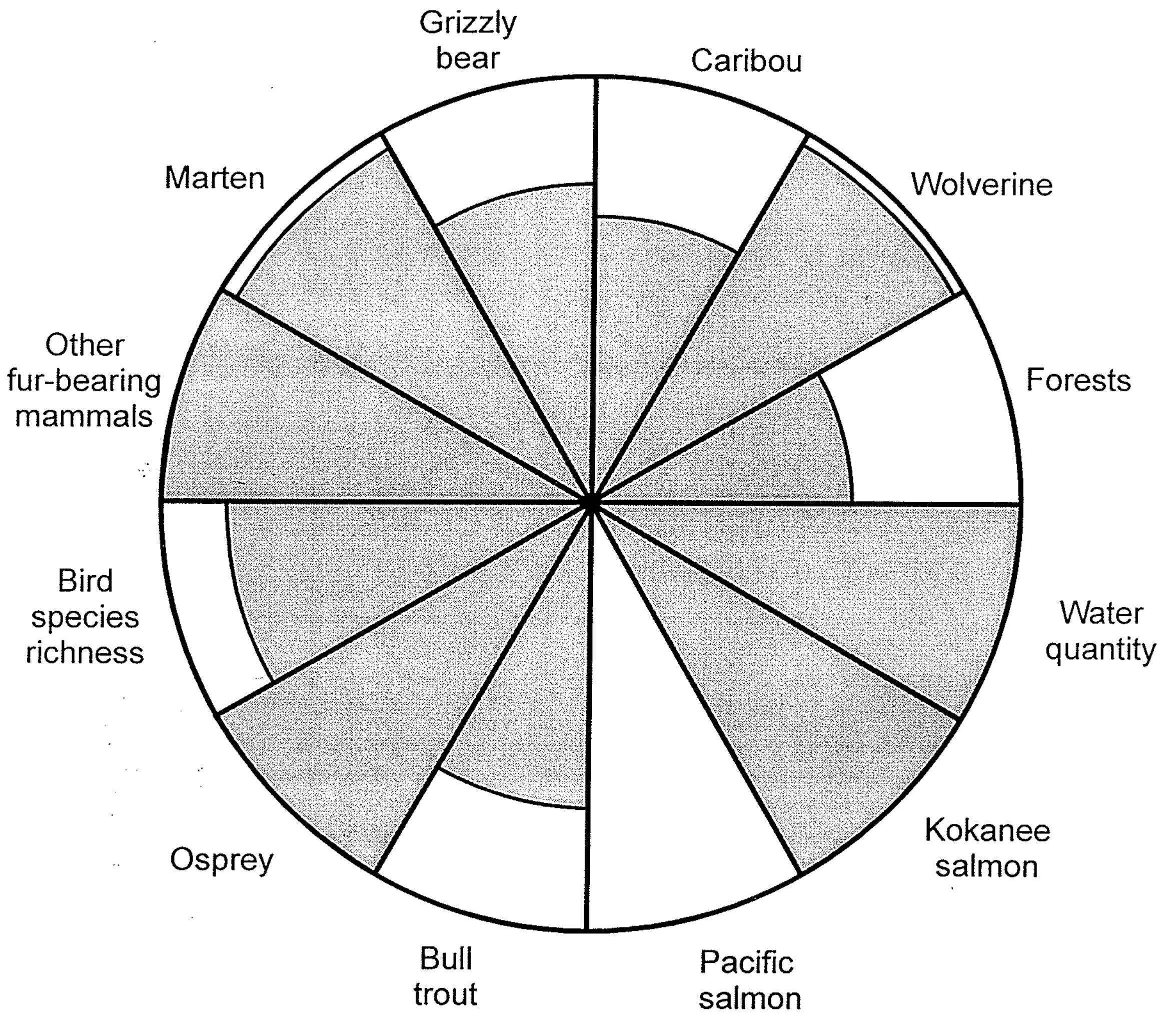

Figure 38: An AMOEBA diagram, modelled after ten Brink (1991), for the ecosystem of the Arrow Lakes study area. Resources which are being managed and utilized in a sustainable fashion are represented by a sector which reaches the full radius of the circle. Resources which are being utilized in a less-than-sustainable manner have a sector length which is proportional to the degree of sustainability.

Table 12: Percent change in forest productivity under a variety of tree retention and rotation ages. The base line case (100) depicts a mean basal area at 240 years of 347.1 m^2/ha (after Hansen *et al.* 1995). This represents a clearcut area (retention = 0) with a rotation age of 100 years between harvests, and is chosen to represent the current situation in the forest. Other values are expressed as a percentage of this case.

One sustainable option assumes that 10 trees/ha are retained, that 25% of the trees have a rotation age of 240 years, and that 75% have a rotation age of 120 years, giving a productivity (sustainability ratio) of 64% of the base case (0.25*51.0 + 0.75*67.9). Under this assumption, the forest is being over harvested by 36%. Under the above rotation age assumptions the sustainability ratio ranges from 85% to 53% as tree retention ranges from zero to 30 trees/ha.

Retention Level (trees/ha)	Rotation Age		
	240	120	100
0	65.3	91.6	100
5	53.2	70.4	76.0
10	51.0	67.9	73.4
30	43.6	56.2	60.1
100	30.0	30.0	30.4

This choice of 100 years is likely slightly low, as the Ministry of Forests indicates that the mean cutting age of trees in the Arrow TSA will eventually settle at 120 years (MoF 1994a, 19) though Pope and Talbot (1994b, 13) models predict an eventual forest for TFL 23 in which no trees are older than 105 years.

Under the assumptions above and using the data from Hansen *et al.* (1995), it is possible to derive the ratio of sustainable forest production to current forest production (Table 12). From these data, a "sustainability ratio" is derived in turn and amounts to 63.7%. That is, the sustainable cutting rate according to the tenets of New Forestry is 64% of that currently being harvested. This result is incorporated into Figure 38.

There are several questions about this approach, including the applicability of results from Douglas-fir forests to the Arrow Lakes, the accuracy of the modelling experiment, and the many items in forest management which are not included in the calculation. These are questions which must be left for further analysis and measurement, but the efficacy of the calculation is supported by the similarity of the result to those estimated by forest managers in the Nakusp area as the penalty for the imposition of the Forest Practices Code. Many of the elements of New Forestry are reflected in the FPC, though perhaps more weakly specified. Demonstration forests south of Kokanee Glacier Park in the Nelson Forest Region which used retention values similar to those assumed in the calculation above were visited by the author in September 1996.

8.2 Sustainability of Water Resources

Water quantity was assessed at the watershed scale on two creeks within the study area. One, Barnes Creek, has been heavily cut-over, while Kuskanax Creek is still in the early stages of an increasing timber harvest. No effects above natural variation of the human presence in the forest could be detected , and so sustainability must be assumed to be maintained. Finer scale analyses or measurement of sediment levels may change this conclusion in the future.

Lake level fluctuations have had a considerable impact on the human population and to the animals which shared the flooded bottomland habitat, but most adjustments to this environmental affront have been completed. Humans, deer, waterfowl, and fish now exist in acceptance of the changing lake levels, and much of the debris and erosion problems have diminished. The future looks largely sustainable, though the view from 1965 would have been much more negative. For this reason, and the fact that social and economic consequences would likely prevent a return to the previously undammed state, we chose to accept that the impact of the current fluctuations in reservoir level does not impact sustainability, and to reflect this in the AMOEBA diagram (Figure 38). However, as we have noted in earlier passages, the question of past and present viewpoints on sustainability is one of the most confounding issues in the assessment of sustainable development.

8.3 Sustainability of Fish Populations

Bull trout are threatened according to the opinion of most fishery managers, though the dearth of knowledge about the size of their population prevents the determination of a quantitative reference level against which to evaluate sustainability. Instead, newly applied catch limits are used as a order-of-magnitude estimate for their level of sustainability. These limits (5 per season) will reduce the seasonal catch of Nakusp anglers, perhaps to one-half of 1995 captures. The species has been given a moderately unsustainable value in Figure 38 to reflect these factors, though we must admit to a considerable uncertainty in its actual value in view of the lack of information about bull trout populations.

Kokanee salmon on the other hand, seem to have stable populations which are well managed, providing a significant economic, environmental and social resource. Pacific salmon have been extirpated, and so are assigned a value of zero in Figure 38.

8.4 Sustainability of Wildlife Populations

Grizzly bear populations are under threat because of contact with humans and hunting pressures. We picked a value larger than the ratio of the actual population to the population which the ecosystem is capable of supporting (0.44) because this latter statistic reflects the situation over a much wider area of British Columbia and Alberta (section 5.3.1). The isolation and low population of the Arrow Lakes ecosystem suggests that the influence of human activity is less than over the Cool Moist Mountain Grizzly Bear Zone (Banci 1991, 4).

Caribou are a more difficult problem. Their numbers are estimated at 140 animals (section 5.2), and appear to be stable, though recruitment is slightly below the averages for other nearby habitats. The caribou are threatened by the cutting of their old-growth habitat; clear-cuts are now encroaching on that forest (Figure 14). In the end, caribou were assigned a value which is higher than that for the grizzly on the basis of evidence for a stable population.

We have found little evidence for unsustainable harvesting of fur-bearing animals other than wolverine and marten. The sustainability ratio for these two species are discounted only slightly: marten because of the possibility of over-trapping in 1991, and wolverine because they are a blue-listed species and should not be trapped at all. However the number of wolverine trapped is very small (Table 8) and so their sector remains close to the sustainable limit. The effects of habitat loss, if any, are not included. This question is likely to be addressed only by suitable ecosystem models when they are developed and tested.

Bird species richness as derived by Hansen *et al.* (1995) is used as another measure of the impact of the timber harvesting. Using an approach very similar to that proposed for evaluating forestry, Hansen *et al.* calculate a mean species richness of 10.9 for a clearcut forest with a 100 year rotation and a richness of 14.0 for the sustainable forest as defined above (§8.1), giving a sustainability ratio of 0.78.The inclusion of their results is justified because most of the 16 species they modelled are also found in the Columbia River valley (Robbins *et al.*, 1966). The assessment is somewhat limited, as it examines only those species which are found in the montane forests. BC Hydro studies (BC Hydro 1994, 21) indicate that wetlands, river-bank forest and grasslands are most in need of protection for bird habitat. A significant portion of this type of habitat was lost during the initial rise of the Arrow reservoir. Were this sector to be more inclusive, the sustainability ratio would decrease for bird species richness.

One bird population which is faring very well is the osprey. The construction of nesting sites on hydro towers along the shores of the Arrow Lakes and the maintenance of a healthy population of kokanee salmon has allowed the growth of one of the densest populations of osprey in the world.

9. Conclusion

This study began with the goal of assessing the state of resource use in the Arrow Lakes area from a sustainability perspective. At this stage four of the five objectives have been completed:

- air photos, cadastral records, satellite photos, and GIS databases which apply to the study area have been assembled, manipulated, and evaluated
- maps of land use patterns and graphs of resource trends have been constructed to show the pattern and history of human impact on the natural environment
- local impressions, knowledge, and attitudes have provided critical insights into the Arrow Lakes ecosystem, economic, and social structure, and have been extensively incorporated into the research
- quantitative measurements of the extent of the sustainable use of the land and resources have been developed and presented

Notwithstanding the rough and occasionally arbitrary nature of the sustainability measurement, it is disheartening to find that a relatively sparsely-settled valley performs so poorly when measured against stringent sustainability criteria. There is some encouragement in the fact that public pressure is gradually moving governments toward increasing protection of the environment and of habitat. The Forest Practices Code is one example of this trend, as are the various parks and wilderness areas which are being set aside. This study has sampled only a dozen factors out of a possible number in the hundreds or thousands.

Despite this study's concentration on biogeophysical aspects of sustainable development within the Arrow Lakes ecosystem, it has proved impossible to divorce this element from the other two components of the SD troika. Time and time again the social and economic implications of resource management have entered the discussion. Fish represent tourist dollars, access to wilderness brings peace and solitude, political realities dictate movement in one direction or another, clearcutting brings wealth and well-being. The SD trinity, linked inextricably by humanity's biological place on the globe, brings a fuller but less deterministic discussion to resource use.

The evaluation of sustainable development has many philosophical reefs, some of which have become apparent in this study. A few of the most contentious were avoided by emphasizing biogeophysical components, thus mostly avoiding the measurement of inter-generational and inter-national equity which fascinated the Brundtland Commission. This approach also bypassed the question of an appropriate level of poverty and population and a number of other contentious social and economic issues, though not completely. Some of the reefs which were encountered are outlined below:

SD is a snapshot. In 1995 the rising and falling levels of the Arrow reservoir had little impact on the sustainability of the ecosystem. However had this study been conducted in 1970, the conclusion would have been very different, in view of the extensive loss of habitat, including that for humans, the potential for mass wasting along the shorelines, the effect of debris in the watershed and the loss of spawning grounds. This reflects no more than the passage of time for an event which is a *fait accompli*, and the nearly endless adaptability of nature.

This characteristic of SD is not only a part of the past, but is also a pattern of the future the future. Cutting forests in a manner envisaged by the AACs will result in a very different habitat, favourable to some animals and unfavourable to others. This is certainly a sustainable option once it is reached, but it is not the same sustainable forest as currently exists. Looking backward, the situation will be comparable to the manner in which we now view the results of the construction of the Keenleyside Dam.

If the evaluation of sustainability and sustainable development is always coloured by the viewpoint of the present, why bother with quantitative assessment? If sustainable development is viewed as a trend line, the measurement of sustainability such as we have conducted here serve as the "anchor points" along that trend. Mathematically such lines are defined by both slope and intercept. "Snapshots" of sustainability define the intercept (the result of selecting a reference standard), while environmental indicators define the direction of change. Periodic measurements such as that conducted here verify the trends predicted by the environmental indicators. By concentrating on biogeophysical components the integrated effects of many trends become more visible.

Sustainable development is a value judgement. Were the Arrow Lakes valley to be given over to settlement and population in much the same fashion as the nearby Okanagan Valley, a perfectly logical sustainable future in which humans dominated the landscape could be readily imagined. Since the "living wage" for the population in such a scenario would come from outside the Columbia Valley (from retirement income, or non-resource businesses), it is a sustainable future, though it passes the resource base needed for our specie's survival to other parts of the globe (which cannot be continued indefinitely). But it is not the same sustainable future as currently exists, with heavily wooded slopes, quiet highways, limited economic opportunities, and a largely viable wildlife population.

By selecting the reference measurement and the biophysical component which is to be evaluated, a value judgement has been imposed which reflects the author's viewpoint (a conservationist's viewpoint). There is no way around this selection effect, unless society as a whole (or government as its agent) reaches a consensus and dictates the long-term status of the ecosystem. This is essentially the rationale for parks and wilderness areas. Of course adoption of such an a restriction on the Columbia River would involve substantial economic penalties, especially on the residents of the valley. In short, SD can only be reasonably evaluated when the question of "what is to be sustained" can be answered.

The three components of SD are not separable. Though this report has attempted to concentrate on biological and geophysical sectors of the Arrow Lakes, economic and social components make many cameo appearances. Roads cannot be closed because of a widespread demand for access to wilderness areas. Hunting and fishing bring a considerable economic benefit, more valuable because some of the species being harvested are rare elsewhere. Forest harvests are driven by the AAC and the need to supply wood for a mill which has been built on the assumption that generous wood supplies will be available for the foreseeable future.

Some reflection of this factor can be found in the current fashion for multiple-use planning and resource exploitation, in which social and environmental values are entitled to share with economic values(for example, the CORE process). Since much of the Arrow Lakes valley is given over to timber harvesting, this implies more pressure on the lumbering industry than on the other components, though it can also imply the acceptance of limited timber cutting or hunting within parks. Such a scenario can be accommodated within the constraints of New Forestry, though probably not without a considerable fight from environmentalists who can be expected to defend their interests with the same vehemence as the forestry industry.

SD measures cannot be viewed in isolation. The caribou above Kuskanax Creek number about 140 animals and lie at the southern edge of the caribou's range, fragmented and vulnerable to disturbance. More southerly groups of even smaller numbers still linger, probably doomed to eventual extirpation. Larger numbers of mountain caribou can be found to the north, surrounding Revelstoke, protected by a series of parks and wilderness areas. What then is the value of the Kuskanax herd and of its sustainability?

The herd could be sacrificed to lumbering, skiing and snowmobiling since caribou populations generally may not be substantially threatened by the loss of such a few animals. If the study area had been larger, or differently placed or shaped, it may have included the Revelstoke caribou or conversely, avoided all caribou, with reduced effect. The scale at which sustainability is evaluated leave a large impression on the final results, though regional scales such as the one used in this study would seem to incorporate at least some part of all of the ecosystem values.

Grizzlies, also in relative abundance in the study area, have been extirpated from a large part of North America and now demand ongoing protection in order to preserve what remains.

More endangered species, such as the bull trout or the Arrow Lake rainbow trout require even more protection, while deer and black bears may be safely harvested without substantial restriction. Wolverine are threatened in southern British Columbia, and so the Arrow Lakes wolverine are assessed strictly. By selecting only a portion of the whole habitat for study this work will reach conclusions which are only locally applicable and miss larger problems or solutions which are available from a regional or global perspective.

The measurement of SD is limited by unknowns. Population trends of bull trout are largely unknown in the Arrow Lakes, as are the number of fur-bearing species and the sedimentation levels of watercourses. The growth rates of second- and third-generation forests are subject to dispute. Social and environmental demands and technological trends in the future are unknowable. Yet all of these impact the calculation of sustainability, in some cases making major revisions in the conclusions. Grizzly bears may not have a threatened status within the study boundary, bull trout populations may be healthier than indicated, and caribou may co-exist comfortably with certain types of forestry.

The measurement of SD is constrained by conflicting data. Caribou populations seem stable on the basis of limited information, yet caribou habitat is being eroded. Bull trout catches continue as in the past at Olsen's Marine, yet fisheries managers impose catch limits. Kokanee populations seem stable and healthy in the Upper and Lower Arrow Lakes, yet some managers express fears for the population. What conclusions can be drawn from such conflicting data?

One solution lies in the collection of more information, though the evaluation of a complex parameter such as sustainable development will always have data limitations. Acceptance or rejection of a dataset becomes another value judgement, hopefully founded in scientific objectivity. This is the approach adopted here—to pass judgement on the quality of the data and accept that which seemed most reliable.

Simple measurement indices cannot incorporate all factors in evaluating SD. Marten, wolverine, bear, caribou and bull trout are all subject to stress from habitat destruction. While such processes are occurring in the study area, primarily from forestry, the factor is not incorporated into the sustainability ratio. This is primarily because of the lack of quantitative measurements even though there is qualitative knowledge of many factors. Complex models, similar to that demonstrated by Hansen *et al.*(1995), utilizing spatial information from a GIS would be able to provide the necessary measurements and at the same time link reductionist and holistic views of the mountain ecosystem.

SD measurement should include humans as a component of the ecosystem. The presence of human beings within the study area is treated as a disturbance rather than an essential element of the environment. This is a deficiency which is justified by reserving their presence for economic and social evaluation. Yet humanity could be treated as other biological components. Are populations declining (they are stable)? How has the amount of agricultural land changed, or urban areas increased (their habitat)? What is the state and trend of their health, especially for ailments related to environmental factors? Much of this could be derived from economic measurements, but the main reason for ignoring human biology is that the species is unlikely to be endangered!

In spite of these limiting characteristics, this study has derived a measurement of the degree of sustainability within a Canadian mountain ecosystem. That sustainability has been found to show mixed results: some areas show successful and sustainable management, one species has been extirpated, and the balance show shortcomings in resource management which will limit long-term harvesting. But sustainable development is not a forgiving philosophy and demands that resource exploitation be enduring—a value of the sustainability ratio of less than 1 implies eventual extinguishment of the resource. Improvements are required in two of the four components studied—forestry, and wildlife—while one component of the fishery has an uncertain future.

In the larger context, these results also show the fragility of mountain ecosystems, with easily damaged habitats and yet considerable economic opportunity. The result is equally at home in Canada and India though some of the elements will change from one locale to the other. Previous work by Shastri investigators in India has shown a suite of similar problems, including overharvesting of timber, streamflow changes, conversion of fragile forest slopes to agriculture and grazing, and a general human assault on the terrain. No doubt these complaints could be found around the globe.

Mountains are a magical place. Keeping that magic requires a more willing acceptance of limits, and an appreciation of non-material values. Those are the challenges for the social and economic acceptance of sustainable development.

10. Recommendations

10.1 Forestry

1. Expand forest models to include ecosystem values. The state of knowledge and the power of habitat algorithms are now at a stage where this has become a viable task, as demonstrated by the work of Hansen *et al.* (1995). To do so, the forest model must extend beyond the legal boundaries of the harvest land base, and evaluate the impact on sustainability on at least a regional basis. Such a task, a combination of GIS and computer technology, biological knowledge, and modelling algorithms, is well within current capabilities. Once begun, the evolution of knowledge and technology will lead to increasingly precise and useful evaluations, in much the same way as meteorological modelling is now forecasting our weather.

2. Use only one forest model to evaluate annual allowable cuts, and eventually, habitat impacts. Development and use of different models makes comparison difficult, and is open to strategic manipulation. Only one GIS database should be compiled to initialize the forest and habitat models. Proprietary data, either for government, research, or industry, robs society of the most accurate information on which to formulate its development plans.

3. Test the sensitivity of forest models and calculation of annual allowable cut by examining multiple impact scenarios. Where the models are sensitive to unknown or poorly known parameters, conservative values should be substituted in order to limit or prevent irreversible impacts.

4. Begin economic and social preparations for the conversion to a fully sustainable resource harvest in the fashion of New Forestry principals. Community involvement will be an important component of this adjustment. There are pivotal opportunities in recreation, sightseeing, fishing and secondary industry based on the existing forest resources. At the very least, significant community initiatives should be encouraged.

5. Prevent public access to new forestry roads, and begin closing existing roads to unimpeded travel.

10.2 Wildlife

1. Stop harvesting in the old growth ageclass 8 and 9 forests above Nakusp until caribou populations are known, caribou behaviour is understood, and habitat models predict sustainability. Limit the cutting of ageclass 8 forest so that a substantial portion can reach the old-growth status of ageclass 9.

2. Modify the siting of protected habitats to include a ranges of elevations, from valley bottom to alpine meadows. Current practice is to reserve poorer high elevation habitats for wildlife while constructing barriers such as roads and clearcuts along lakes and streams.

3. Apply cut block adjacency rules along creeks and rivers to prevent a string of continuous or semi-continuous clearcuts along the water course. Wildlife require corridors to all parts of their habitat. Expand protected riparian habitat according to wildlife needs rather than just for water quality objectives.

5. Limit snowmobile access to high country to prevent impacts on caribou and grizzly.

10.3 Water

1. Begin monitoring stream sediment levels in both pristine and harvested watersheds.

2. Model 100-year extreme precipitation events (drought and flood) within the watershed, and adopt harvest methods and riparian set-backs to protect against the impact of century-scale events.

10.4 Fish

1. **Begin measuring and monitoring bull trout populations with the same degree of effort as that for kokanee.** Since large predator fish are not numerous in the habitat, the most cost-effective measurement would be an aggressive collection and evaluation of catch-per-unit-effort data.

2. **Rigorously protect all riparian bull trout habitat to allow for natural regeneration of the population.**

11. Further Research

Most of the elements discussed in this study would benefit from further measurement, a task which can only be accomplished by the ongoing accumulation of scientific data and data manipulation. GIS models were useful in the macroscale investigation techniques of this project, and could be more stringently applied to construct habitat models for some of the wider-ranging species such as grizzly bear and caribou. For fine-scale studies such as those of stream sediments or forest regrowth, the GIS lacks the required level of detail. Computer models which reflect the latest in scientific understanding offer the best avenue for this examination. It is likely that in the near future cosmopolitan computer models will offer society the ability to more completely evaluate the current state of sustainability and predict the future in the same fashion as the timber supply analyses.

To further advance the understanding of complex relationships between biology, economics and society, this study should be continued by examining the economic and social sustainability factors in the Arrow Lakes valley. In India, where social and economic studies have been accomplished, a biogeophysical examination such as this may provide additional fruitful insights into the limits of sustainability.

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