APPENDIX E

EVALUATION OF WATERSHED DEFORESTATION AND HARVESTING PRACTICES IN THE OKANAGAN BASIN

Reprint of Preliminary Report
on Task 180, Water Quantity Studies

by

ROBERT P. WILLINGTON, PH.D.

AND

D. S. JAMIESON, R.P.F.

M. D. GODFREY, R.P.F.

FACULTY OF FORESTRY
THE UNIVERSITY OF BRITISH COLUMBIA
VANCOUVER 8, B.C.

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Summary

Forest harvesting in the Okanagan Basin can have a wide variety of effects on that area's water quality, quantity and regime. Many of the effects can be related to the intensity of forest removal or, in other words rotation length. It must also be stressed that forestry has earned a poor reputation in the Basin through the proliferation of certain mythological aspects of its effect on streamflow such as: logging dries up the streams, logging causes floods. Albeit logging may have adverse effects on terrestrial waters, but for the most part they are usually very localized and on a Basin basis are not highly significant.

This report concerns itself mainly with the effects of forest harvesting on water quality - a characteristic of major importance in the arid Okanagan Basin. In this respect, the Basin can be grossly stratified into three water yield increase zones:

- South of Penticton
- North of Penticton below 4000' elevation
- North of Penticton above 4000' elevation

Within these areas, an appraisal of water yield increases from forest harvesting is possible.

<u>South of Penticton.</u> In this zone, any water yield increases accruing from high elevation forest harvesting will not be reflected in increased streamflow. This is due to in situ redistribution of water from surplus sites to deficit sites. Thus, any forest harvesting in this zone, as in all other zones, should be concerned with minimizing water quality deterioration - especially sediment discharge from haul and skid roads and thermal pollution by stream exposure. Any increase in harvesting intensity would be reflected in localized site improvement by increasing available soil water.

<u>North of Penticton below 4000' elevation.</u> This zone is typified as the Ponderosa pine-parkland community and is a water deficity hydrologic system. As such, any forest harvesting would not reflect in any water yield increases to streamflow. Localized harvesting is probably best directed towards improving the carrying capacity of incorporated range lands. However, in this region soils are particularly sensitive to the disturbance effects of harvesting activities and extreme caution should be exercised in the location and construction of roads to ensure that adjacent streams do not receive high discharges of sediment. This area, because of its generally close proximity to Okanagan Lake,

is particularly sensitive to stream temperature increases (approaching lethal limits for fishery) following their exposure by forest removal. In this respect, buffer strips should become a necessary component of forested-range and forest land management.

North of Penticton above 4000' elevation. It is in this zone that the greatest potential for water yield increases as a consequence of forest harvesting exists. It is also the region of most intensive forest harvesting, both presently and in the predictable future. Within this zone, snowpack management considerations are an important aspect of land use hydrology.

Water yield increases accruing from forest harvesting in the Okanagan Basin were estimated using modelling techniques and extrapolations of research findings from comparable regions. This was dictated by a shortage of data on the hydro-meteorology of the Basin. Interpretation of the data must be carried out very cautiously to avoid proliferation or creation of any more myths.

It has been estimated by the B.C. Forest Service that there exists approximately 1.2 million acres of merchantable forest land in the Okanagan Basin in Canada. Of this only about 300,000 acres are in the zone north of Penticton above 4000 feet. Assuming a constant volume of timber per acre, the existing sustained yield management of these lands on a 120 year rotation (i.e., 1/120th of the total harvested per year) yields an annual cut of 10,000 acres for the Basin. This compares with an actual annual harvest of 10,145 acres in 1971. This harvesting rate has been followed since 1963, before which harvesting rates were erratic and less than 25% of sustained yield levels. For clarity, a 40 year rotation (i.e., 1/40th of the total harvested per year) would result in an annual harvesting of approximately 30,000 acres.

Water yield increases accruing from forest harvesting in the approximately 300,000 merchantable forest acres of the Okanagan Basin in the zone north of Penticton above 4000 feet on a 120 year rotation have been estimated to be between 3.31% and 4.20%. These increases would only be realized within this zone (Englemann spruce and Subalpine fir forest type) and would likely be consumed in water deficit sites at lower elevations. This includes correction for sequential regrowth effects on increasing evapotranspiration: a period of approximately 40 years for most sites. Similarly, for a hypothetical 40 year rotation the increases are between 9.93% and 12.60%.

Forest fire may effect an increase in water yield through reduction of evapotranspiration. The average annual acreage burned over in the Okanagan Basin is 5,377 with a range between 81 acres (1964) and 25,856 acres (1970). Yield increases, calculated on the basis of water yields from the area north of Penticton and above 4000 feet, have been estimated to be between 1.24% and 1.55% annually.

However, as large as these streamflow increases may be, they are only for that area designated as merchantable forest north of Penticton above 4000 feet (approximately 1/4 the total merchantable forest and 15% the total area of the Okanagan Basin). Forest harvesting in other zones of the Basin would have no net effect on streamflow quantity. By adjusting the reported percentage water yield increases to a Basin basis for a 120 year rotation, levels by which comparisons can be made and effects evaluated are made possible. Thus, on the basis of the total Okanagan Basin annual water yield increases accruing from forest harvesting range from 0.50% to 0.64%. Similarly, the figures for the effect of fire are adjusted to be between 0.19% and 0.23%. Respective figures for the hypothetical 40 year rotation are 1.50% and 1.91% for forest harvesting and 0.19% and 0.23% for wildfire. These reported annual increases are not cumulative due to the effects of regrowth on evapotranspiration consumption.

Since the values reported for the 40 year rotation are never likely to be achieved since a 40 year rotation is too close to the regrowth time of 40 years, it is only relevant to discuss the values reported for the existing and future 120 year rotation forest harvesting rates, The following limitations must be noted with respect to the reported increase in water yields following forest harvesting and/or wildfire:

a. Reported increases are too small to be measured by existing streamflow measurement techniques.
b. Total water yield increases in major tributaries of the Okanagan Basin will very likely go undetected due to the low percentage yield increase from sustained yield forest management. Any yield increase would only be reflected in a very small (50 km) basins over which significant portions (75%) have been harvested or burned.
c. Water yield increases accruing from forest harvesting in this area only become usable if they reach a stream channel. Increased water transmitted downslope through the soil mantle would likely be consumed in water deficit sites below 4000 feet elevation, thereby proving useless in augmenting water supplies for other purposes. It has been shown that most of the annual water yield increase occurs in the spring and fall months thereby necessitating improvement an/or extension of reservoirs to hold water over to peak demand periods in the summer season.

In conclusion, it can be safely stated that although streamflow increases will accrue from forest harvesting in the Okanagan Basin, the reliability and predictability of these increases will be inhibitory to planning for water supply. The authors feel that forest harvesting, with respect to water supply, should be concentrated in the area of minimizing water quality deterioration and increasing the general environmental stability of those lands upon which forest land management is occurring.

APPENDIX E

EVALUATION OF WATERSHED DEFORESTATION AND HARVESTING PRACTICES IN THE OKANAGAN BASIN

(Reprint of Task Report 180)

E.1 INTRODUCTION

The cooperative Canada British Columbia Okanagan Basin Agreement has provided a framework by which a comprehensive, multi-disciplinary study of a selected watershed can be accomplished. This study, which constitutes a small part of the Agreement, has as its objective a preliminary appraisal of the Okanagan Basin Watershed, in terms of vegetal cover and hydrologic characteristics by major biophysical zones, and an outline of the effects of timber harvesting on water quantity and water quality within these zones.

The complete realization of this objective is recognizably idealistic, especially in view of the scope involved which is as follows:

1. Using existing data supplemented by some field reconnaissance, characterize a selected watershed into major biophysical zones and tabulate, by zone, the present and future harvesting rates. Also, to tabulate present and future cover changes in forested range.
2. To provide a preliminary evaluation of the effects of timber harvesting on water quality and quality by zone. Limitations to harvesting rates imposed by sustained yield to be incorporated insofar as assigning significant effects (10%) on water quantity and quality to the various zones.
3. To indicate zones in which forest harvesting might incite major problems of erosion and nutrient leaching as a consequence of roads and/or harvesting technique. Also, the recommendation of special harvesting practices for certain zones.
4. To outline zones where timber harvesting or afforestation have produced conflicts of interest such as fishery, domestic water supply and grazing.

This report is an account of the existing state-of-the-art of forest land use hydrology of the Okanagan Basin within the limitations stipulated by the objectives and scope of Task 180. In order to most effectively document the findings, this report has been structured as follows:

Summary

Section I Introduction

Section II Hydrologic Characteristics of the Okanagan Basin

-the data base upon which any hydrologic evaluation of land use in the Okanagan Basin must be formatted.

Section III Forest Management Effects on the Okanagan Basin Hydrology

- detailed analysis of available and applicable data with respect to the time and spatial effects of forest harvesting on water quantity and quality.

Appendix E.I The Role of the Forest in the Hydrologic Cycle

- a short survey of the significant aspects of the terrestrial phase of the hydrologic cycle in a forested environment with particular emphasis on the Okanagan Basin.

Appendix E.2 The Effect of Forest Management on the Hydrologic Cycle

- an evaluation of the impact of forest harvesting on the hydrology of environments similar to those of the Okanagan Basin. Presented to complement those effects determined from data analyses.

It is hoped that this report win be used not only as a source of information regarding land use hydrology in the Okanagan Basin, but also as a guide to the establishment of priorities in future work undertaken in the area.

E.II HYDROLOGIC EFFECTS OF FOREST MANAGEMENT IN THE OKANAGAN BASIN

1. REQUIREMENTS FOR HYDROLOGIC IMPACT EVALUATION

Methods for finding out the effects of natural or cultural changes on the hydrological regimen have been strongly oriented towards demonstrating that effects do occur, without providing much quantitative information that can be used elsewhere. The translation of the research results can therefore be done. only by implication and be applied only to study basins that are closely comparable to the research basins. To aid the translation of results to other basins, hydrologic characteristics can be determined. This might help to establish not only that effects are observable, but also the magnitude of these effects.

For a statistical analysis of the hydrological effect of natural and cultural changes, it would be necessary to replicate and to change treatments from one basin to another. In experimental basin research this procedure is too costly, too time consuming, and too impractical. Evaluation procedures are therefore dependent on time trends of flow after precipitation and other climatic factors have been taken into account. For the study of the effect on the hydrological regimen of cultural changes several years of calibration (pre-treatment), a treatment period, and finally a period of years of evaluation of the treatment effect are required. This is not always feasible for the study of the effect of natural changes, but alternative successful techniques are not yet available.

a) Desirable Hydrologic Conditions

The most pressing and practical objectives for the setting up of experimental basins are the study of the effects of cultural changes on the hydrologic regimen. Cultural changes involve the artificial change of one or more basin characteristics, with a resulting change in some hydrological characteristics and include any changes in land use and/or land management and the influence of the use of the water resources.

This type of research can be carried out on individual basins or on a network of basins. It is sometimes thought that research on the effect of a cultural change on the hydrologic regimen is speeded up if duplicate basins are set up, on one of which the basin characteristics are kept as constant as possible during the investigation period. This basin is called the control basin. In some cases multiple replication is advocated. This is not always desirable; the control basin is frequently a changing base, as it is difficult to keep basin characteristics constant for a period of time and the utilization of one or more control basin(s) fosters the tendency to calibrate the experimental basin after only a few years of observation. This does not necessarily give a representative record of the typical local climate. The climate during the calibration period, may, for instance, have been abnormally wet. Moreover, the use of replication may give statistically valid results, but it does not necessarily contribute to the problem of translating the results to other basins.

b) Selection of Experimental Basins

In the case of a single basin, selection is subject only to the conditions set out below. The size should be as large as possible to increase the likelihood of measurable subsurface flow and to approach more closely a natural basin with the proviso that the maximum size should be less than 50 square miles. Single basins are not recommended because no possibility exists for comparing results.

In the case of basin replication, normally two basins are selected, one of which is to serve as a control during the period of the experiment. The two basins should be as similar as possible with respect to climate, geomorphology, pedology and geology. The most important geomorphological factor is the aspects of the basins; similarity of aspect will increase the likelihood of similarity of climate. The maximum sizes of the individual basins are somewhat less than those for single basins; in some areas it may be difficult to find similar basins of a reasonable size. Two relatively large basins will, moreover, extend instrumental and observational problems. The two basins need not be the same size. Mean monthly discharges of two similar basins may correlate reasonably if the difference in size is no greater than a factor of ten.

Important items for selection of basins are listed below.

1) Ownership of basin. The first requirement of an experimental basin is that it can be manipulated at will since the purpose of an experimental basin is, a *priori,* the artificial change of one or more of its basin characteristics.
2) Operation of basin. The topographical and access conditions must be such that the required land-use and land-management practices to be used can be carried out. Access must be good for detailed research observations and in some cases opportunity must exist for buildings to be erected. Since experimental basins are, by definition, small basins, roads within the basin can have a very large effect on the hydrology and unless constituting part of the desired research results, should be kept to an absolute minimum and be installed before the experiment is started.
3) Uniformity of soil, vegetation and geomorphology. Where possible a basin should be a simple soil-vegetation complex based on broad soil-vegetation groupings. While a definite methodology for research on experimental basins is not clear, the selection of a basin on a soil-vegetation complex which is typical of a large area will aid in the ultimate translation of the research results.

To facilitate research, a basin with simple geomorphological characteristics must be selected if possible. Many depressions (small swamps) win, for instance, create storage problems which are difficult to handle in analysis.

4) Deep percolation and channel infiltration. Deep percolation is relatively large on small basins, especially on the more permeable soils, and must be accepted as a variable factor. The prevention of channel infiltration is relatively more important on small basins and, if channel infiltration occurs, either an alternative basin must be selected or the channel sealed.
5) Aspect and climatic variability. In mountainous regions it is desirable that the basin aspect is such that very shady and sunny faces do not exist simultaneously in the basin, since moisture conditions may be entirely different faces and make analysis of data very complicated.
6) Flow measurement. Where possible perennial or intermittent flow is preferred to provide a measure of subsurface flow during periods of runoff. Where conditions are such that only ephemeral streams are encountered, it is important that the basin size be large enough to ensure that during and shortly after storms the total flow measured at the gauging station includes some interflow. A sharp distinction between surface and subsurface flow is artificial and some interflow must be measured to carry out basic research and to aid in the ultimate translation of the research results to other areas.

It is important that the study period be of sufficient length to ensure that the climate during the study is representative of the long term climatic pattern. If the study period is excessively wet or dry or hot or cold the results may not be suitable for application in a normal period.

If all that is desired from an experiment is whether the land use of the basin under study affects streamflow, then all that is required is a reasonably accurate measure of that parameter. However, if an understanding of the phenomena resulting in the change of streamflow from a particular land use and or extrapolation of the results to other areas is desired the various types and intensities of basin parameters is required.

c) <u>Available Conditions and Data</u>

At this time no suitable single or paired watershed experiments, by which the hydrologic impact of deforestation can be evaluated, exist in the Okanagan Basin. This required that the effect of forest harvesting on water quantity and water quality be evaluated on the basis of available data of acceptable or candidate basins. However, this proved to be of little utility as the following instructive outline of available conditions indicates.

Precipitation

According to data available from Atmospheric Environment Service, twenty stations with sufficient length of record to be included in the 1931-60 normals for precipitation lie within the Okanagan Basin. By Canadian standards this is a fairly dense network (150 sq.mi./gauge). However it is heavily biased toward the valley floor with 75% of the sites below 2000 feet and only three stations above 4000 feet, which is near the mean basin elevation. In 1970, 24 precipitation stations were either added or re-activated for the Okanagan Basin Study, and of these 8 are above 4000 feet elevation. Thus, the emphasis of precipitation measurement was maintained at a low elevation and clustered distribution. Precipitation in the form of snow has been measured at snow courses, however no recent data concerning snowmelt are available. Most of the data collected from the recently installed (1970) stations has yet to be summarized and reported in a usable form.

Temperature

This parameter has been measured at only some 15 stations in the Okanagan Basin with sufficient length of record to be included in the 1931-60 normals for temperature. As with precipitation, the emphasis of station location was at low elevations and clustered in areas of high population density. The expansion of the network and the re-activation of old stations within the Okanagan Basin resulted in the addition of only two more stations recording temperature at elevations greater than 4000 feet. As with precipitation data, only a fraction of the total temperature data has been rendered to an easily accessible and usable form.

Other Climatalogical Parameters

In order to get a reasonable estimate of the water lost from the Okanagan Basin by vapor transport, data required in the calculation of this flux according to physical processes or direct measurement from sufficient stations to provide an acceptable basis for extrapolation to the entire basin are necessary. However, the following list of types and numbers of such instrumentation is indicative of the lack of suitable data:

TYPE	NUMBER
Hygrothermographs	6
Sunshine recorders	3
Net radiometers	2
Class "A" evaporation pans	6
Anemometers (totalizing)	10
Anemometers (recording)	2

Many of these are located in remote sites at elevations above 4000 feet and are serviced through the cooperation of either the B.C. Water Resources Service and Water Survey of Canada or by contract.

Streamflow

While it is true that both the Water Survey of Canada and the B.C. Water Resources Service maintains significant number of stations for the measurement of either stream stage or discharge, most of them are located on major streams in the basin near their mouths (Okanagan Lake). Most of those stations for which long term records are available are located on streams whose watersheds have undergone extensive cultural changes such as forest harvesting, grazing, various agricultural activities and reservoir installations on either the main stream or several of its major tributaries.

Of further note is the fact that many of the stream gauging stations are so constructed and installed as to monitor streamflow as compared to total watershed yield. That is to say that only surface water flow is measured while groundwater or subsurface flow, which can be very significant in the outwash terraces of the Okanagan Basin, goes undetected. Of those stations instituted as part of the expansion program for the Okanagan Basin Study, many are desirably, from a landuse hydrology viewpoint, located on small high elevation forested watersheds; however the records from these stations are not yet long enough to adequately establish streamflow response normals for the watershed in an undisturbed state against which streamflow response normals of the same watershed following land use can be compared.

Unfortunately, presently available data for the evaluation of the hydrologic effect of watershed deforestation is inadequate. In addition to those aspects previously noted, the major disadvantage is having no tributary watershed within the Okanagan Basin bearing a full complement of instrumentation. If sufficient data is lacking to get a handle or even a crude estimate on the water balance of a watershed, then the likelihood of developing any meaningful cause and effect relationships between land use activity and the quantity, quality and timing of stream flow is somewhat tenuous.

2. DESCRIPTIVE AND HYDROLOGIC CHARACTERISTICS OF THE OKANAGAN BASIN

a) Location and Extent

The Okanagan Valley is situated in southern British Columbia, near the east side of the Interior Plateau region. In a northerly direction it extends from north latitude 49°20' (the south tip of Skaha Lake) to 49°38' (south of Shuswap Lake), and has a mean longitude of 119°30' west.

In length the Okanagan Basin stretches 89 miles and occupies an area of 3100 square miles. The southern half of the basin varies between 3 to 6 miles wide while the northern part near Armstrong is 12 miles wide.

b) Drainage

In its northern part, the Okanagan Valley is drained by the Salmon and Shuswap Rivers which flow into Shuswap Lake. The Salmon River enters the Okanagan Valley at Glenemma and flows northward. The Shuswap River originates in the Monashee Mountains near Revelstoke and, after passing through Sugar and Mabel Lakes, enters that part of the Okanagan Valley known as the Spallumacheen Valley at Enderby.

A significant feature of the Okanagan Drainage is a low divide approximately one mile east of Armstrong in the Spallumacheen Valley. South of this point the waters are tributary to the Columbia River.

In the main trough of the Okanagan Valley lies Okanagan Lake. Stretching some 69 miles in length and approximately 2 miles in width, the lake occupies. an area of 127.3 square miles. Low water in the lake is 1120 feet above mean sea level. With the south end of the valley 227 feet lower than the north end, Okanagan Lake drains into Skaha Lake and thence into Vaseux and Osoyoos Lakes.

c) Climate

The climate in the Okanagan Basin is responsive to two major gradients; latitude and elevation. With respect to latitude, it is generally accepted that the southern part of the basin (near Penticton) receives less precipitation and has higher mean monthly temperatures than its northern parts (near Enderby).

The mean annual temperature in Armstrong is 44.6°F, while southward at Oliver it is 47.9°F. (Climate of B.C. 1970). In the southern half of the basin only 50% of the winters have short periods of below-zero temperature, while in the north, below-zero temperatures are more frequent. During these periods of below-zero temperatures, the smaller lakes are covered by ice, although Okanagan Lake is generally ice free.

Precipitation in the Okanagan Valley is supplied primarily by low pressure systems passing from west to east. During the summer months these systems are more widely spaced, and any precipitation occurring is from thunderstorms or localized convectional storms.

Within the Okanagan Basin, precipitation distribution is strongly expressed with respect to elevation and latitude. At the north end of the Basin (Armstrong), mean annual precipitation is approximately 17.2 inches with a decreasing trend southward to Oliver, which annually receives approximately 10.8 inches. At any latitude precipitation on the ridge tops (4000 feet elevation) may be as much as double that occurring at the lake elevation.

A significant proportion of the precipitation input to the Okanagan Basin is in the form of snow. This proportion varies between 50% at the lake level to 140% at the 5000-foot elevation.

The quantity of snow input to the Okanagan Basin is sufficient to warrant intensive snow surveys at the time preceding snowmelt runoff.

To examine the change in climate with elevation, a profile of the east side of the Basin, midway in latitude (near Kelowna) has been constructed (Figure 2.1). To determine the relative values of precipitation and temperature with elevation, the following climatic stations were selected:

STATION	ELEVATION	EXTENT OF RECORDS
Kelowna	1100 feet	30 year normals to 1970
Joe Rich Creek	2870 feet	-do-
McCulloch	4100 feet	-do-
Big White	6050 feet	-do-

Values of monthly potential evapotranspiration were derived from the mean monthly temperatures of the selected stations using Thornthwaite's equation.

d) Soils and Topography

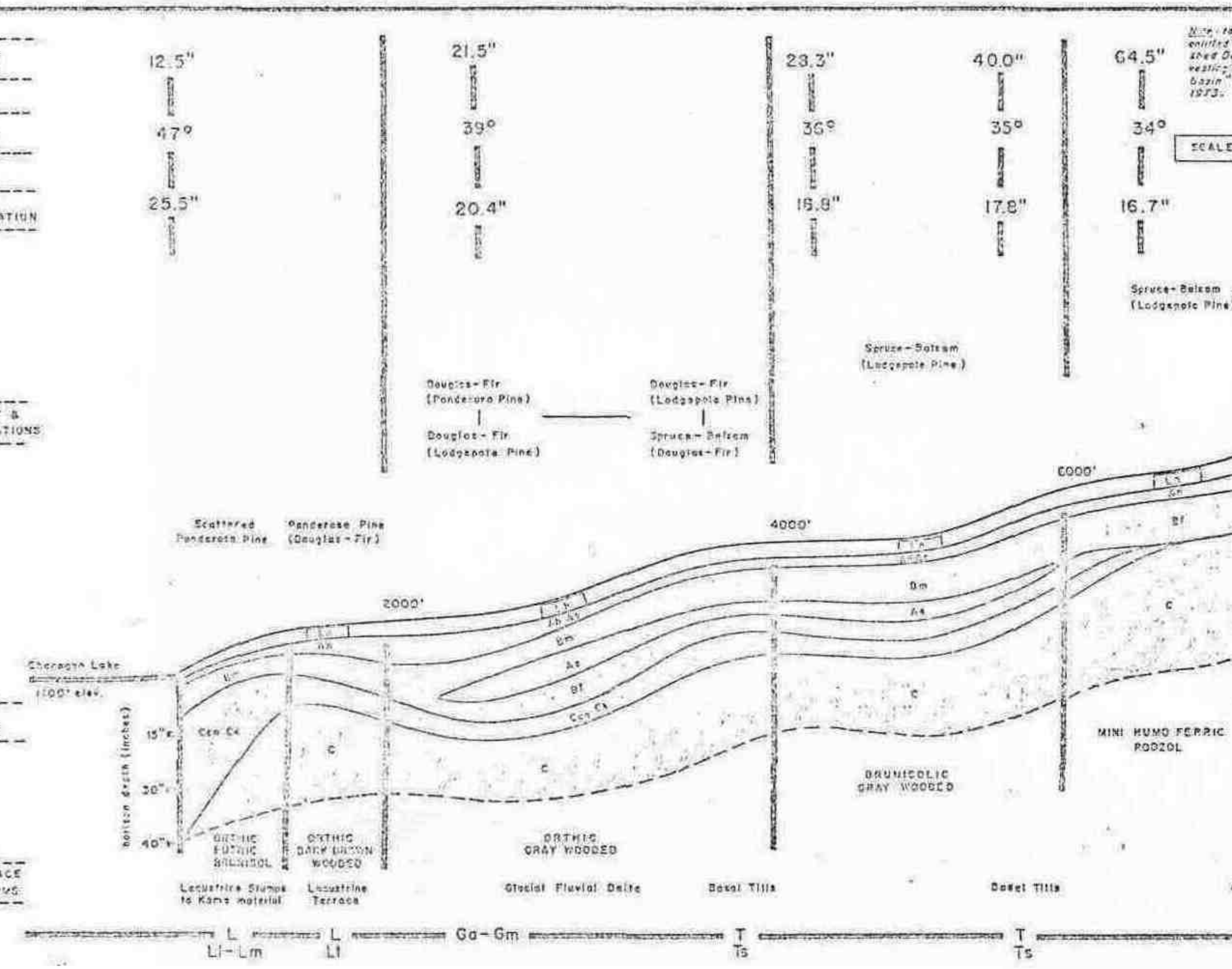
i) Origin. The parent material from which the Okanagan soils are derived is primarily glacial till, left during the decay of the Cordilleran ice-sheet in the Pleistocene Period. Tributary streams to the main Okanagan Valley later transported sorted till materials, laying down gravelly, sandy terraces over the lateral moraines left by the ice-sheet (Figure E.1). The material deposited by the post-glacial erosion cycle on fans and flood plains consists mainly of freshly worked till and reworked terraces.

ii) Formation and Zonal Distribution. There is general agreement among soil scientists that geographic areas controlled by the same macro-climate have their own Zonal Soil Great Groups. In the Okanagan, these soil groups can be divided into two broad categories: those developed under grass and those developed under forest.

The grassland soils are characterized by an accumulation of organic matter in the surface mineral horizons. The forest soils have a layer of organic litter on the soil surface. The natural grassland soil group separations are the Dark Brown and Black Soils. The forested soils can be separated into the following groups based on the degree of weathering. In order of increasing weathering and leaching they are:

Brown Wooded Soils Gray
Wooded Soils
Podzol Soils

In Figure E.1 the Orthic Eutric Brunisols are found under grassland and in the transition between the grassland and the Ponderosa pine forest type. The



BIOGEOCLIMATIC PROFILE ---- OKANAGAN LAKE (KELOWNA)

Figure

substratum is composed of primarily lacustrine deposits forming deep beds of stratified silt, clay and fine sand. Humus accumulation is small and the profile is marked by a strong calcarious development.

The Brown Wooded Soils also represent soils of little weathering. Found under stands of Ponderosa pine and mixed Ponderosa pine - Douglas fir, with an annual precipitation of approximately 15 inches, these soils are characterized by a horizon of free lime which has been leached to a depth of 15 to 20 inches. Under the influence of the forest, humus has accumulated in the upper two inches to form an Ah horizon. This soil is high in lime and other bases, but is droughtly due to climate and exposure.

Increasing elevation and precipitation give rise to the Orthic Gray Wooded and Brunisolic Gray Wooded Soils (Figure E.1). Developed under 25 to 35 inches of annual rainfall, these soils are of grayish color and are characterized by an Ae horizon from which most of the clay and sesquioxides have been leached to the Bf horizon. If the soil developed from a calcarious parent material a horizon of calcium carbonate may also be present.

The soils are slightly to moderately acidic in reaction, but still retain a moderate base status. They can develop under Douglas fir or mixed Douglas fir - Lodgepole pine stands, but commonly under a dense Spruce - Balsam or mixed Spruce - Balsam - Lodgepole pole pine stand. A thick moss layer (2-3 inches) is often present on the organic litter.

A further increase in elevation results in increased weathering, particularly in the primary materials with a high ferromagnesium content. Other more soluble basic materials are leached completely from the profile, leaving the characteristic Bf horizon of the Mini-Humo Ferric Podzol. The parent material of these soils is moderately acidic and medium to coarse in texture. These soils are often found in association with the Alpine Dystric Brunisol (Figure E.1).

e) <u>Vegetation</u>

The distribution of Climax Forest Vegetation in the Okanagan is represented in Figure E.1. Similar to the development of soils, climax forests are responsive primarily to climatic influences and can therefore be classified zonally. Within each zone variation from the mesic habitats due to soil and topography adds a third dimension to the phytoceonotic component. The net effect is to vary the zonal (mesic) interval.

Figure E.1 represents three basic Climax Forest Types in the Okanagan. They include:

Ponderosa pine Type

Douglas fir Type

Spruce – Balsam Type

Mixed stands of the above species occur in the transition between zones. The extent of these mixed stands depends on the variation of soils and topography which modifies the zonal or mesic habitat.

Lodgepole pine, because of its dependence on fire, can occur in all zones as a subclimax and is often present in mixed composition with all climax types.

E.III FOREST MANAGEMENT EFFECTS ON THE OKANAGAN BASIN HYDROLOGY

1. EXISTING LEVELS OF FOREST LAND USE IN THE OKANAGAN BASIN

a) Forest Cover Removal by Forest Harvesting

Tables E.1 to E.8 show the development and present state of forest resource management in the Okanagan Basin. Generally, timber harvested in the Okanagan Basin can be separated into two major groups: that cut on Crown Land administered by the B.C. Forest Service and that removed from Tree Farm Licence land managed by private companies.

Timber on Crown Land within the Okanagan Public Sustained Yield Unit (P.S.Y.U.) is dispossed of primarily by Timber Sale and Timber Sale Harvesting Licence, to the limit of the annual allowable cut. The calculated allowable annual cut in the Okanagan Public Sustained Yield Unit was 17,756M cubic feet in 1971 (Table E.1). The actual annual cut in 1971 was 14,595M cubic feet from 6,623 acres (Tables E.2 and E.3) An increased actual annual cut, to the limit of the allowable annual cut as determined by sustained yield policy, would result in cutting on 8,057 acres of forest land.

TABLE E.1
ALLOWABLE ANNUAL CUT (M c.f.)

YEAR	LICENSEE'S A.A.C.s	C.U. INCREASE	APPROVED 3rd BAND	F.S. RESERVE	TOTALS
1963	8633			167	8800
1964	8633			167	8800
1965	8633			167	8800
1966	8633			167	8800
1967	8630			170	8800
1968	8630	548		170	9348
1969	8862	1052	1300	170	11384
1970	8876	1925	2535	425	13761
1971	8876	2914	5541	425	17756
TOTALS	78,406	6,439	9,376	2,028	96,249

The cut from Tree Farm Licences #9 and #15 accounts for the remainder of the forest harvest in the Okanagan Basin, excluding unregulated cutting such as

TABLE E.2

ACTUAL ANNUAL CUT (M c.f.)

Okanagan Public Sustained Yield Unit

YEAR	TOTAL VOL. M c.f.	FIR	SPRUCE	YELLOW PINE	LARCH	LODGE-POLE PINE	BALSAM	CEDAR	OTHER SPECIES
1960	10,357)								
1961	12,375}	Before Regulation							
1962	10,212)								
TOTAL	32,944								
1963	12,040								
1964	9,533								
1965	8,897	2,710	1,735	500	179	3,127	574	38	1
1966	9,013	2,397	3,254	169	156	2,039	926	61	11
1967	5,816								
1968	6,148								
1969	9,258								
1970	11,924								
1971	14,595								
TOTAL	87,224								

TABLE E.3

ACREAGE CUT OKANAGAN PUBLIC SUSTAINED YIELD UNIT

YEAR	TOTAL	CLEAR CUTTING	SELECTIVE CUTTING
1963	No figures available - established in 1963		
1964	7,737		
1965	6,125		
1966	6,168		
1967	3,336		
1968	2,844		
1969	4,328		
1970	3,717		
1971	6,623	2,907	3,716
TOTAL	40,878		

TABLE E.4

ACTUAL ANNUAL CUT TREE FARM LICENCE #9 AND #15 (M c.f.)

YEAR												
1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	TOTAL
2,006	2,424	3,084	3,562	4,882	4,369	4,412	3,944	2,693	6,307	3,916	9,393	49,992

Since 1963 Inclusive 42,478

TABLE E.5

ACREAGE CUT TREE FARM LICENCE #9 AND #15

YEAR	TOTAL	CLEAR CUTTING	SELECTIVE CUTTING
1971	3,522	1,416	2,106

N.B. You may assume 1.2 M.c.f. cut per acre, and complete acreage tables on this basis.

TABLE E.6 ACREAGE BURNED BY WILDFIRE

YEAR	MERCH. TIMBER	IMMATURE TIMBER	NOT SATISFACTORY STOCKED	NON COMMERCIAL COVER	GRAZING OR PASTURE LAND	NON PRODUCTIVE SITES	TOTAL ACRES
1963	26	132	89	72	104	93	516
1964	3	2	3		62	11	81
1965	2	41	10	14	71	47	185
1966	66	14	3	13	18	19	133
1967	654	775		69	126	11	1,635
1968	249	416	4	238	355	29	1,291
1969	5,015	2,225	1,818	832	3,083	1,611	14,584
1970	6,563	8,905	511	1,458	5,438	2,981	25,856
1971	1,005	735	25	309	29	2,009	4,112
TOTAL	13,583	13,245	2,463	3,005	9,286	6,811	48,393

that from Indian reserves. The actual cut in 1971 and Tree Farm Licences #9 and #15 was 8,393M cubic feet, from 3,522 acres (Tables E.4 and E.5).

Table E.2 shows the breakdown by species of the actual annual cut in the years 1965 and 1966. The relative importance of the forest types, in terms of volume removed is: spruce-balsam Douglas fir Lodgepole pine Ponderosa pine.

The major silvicultural systems of forest management employed in the Okanagan Basin are single or group tree selection and clearcutting. Selective cutting has been primarily applied to Ponderosa pine and Douglas fir forests where silvicultural requirements are precluded by the uneven aged nature of the stands. Clearcutting is more compatible on the more even aged stands of spruce-balsam and lodgepole pine. Of the 10,145 acres logged in 1971 43% were clearcut and 57% were selectively cut.

b) <u>Catastrophic Vegetation Alteration</u>

Insect and pathogen attacks on forest vegetation in the Okanagan tend to be localized in their extent and influence. Although a variety of insects and pathogens are endemic to the area, little data is available on the extent of losses.

Wildfires are the most prevalent and serious form of natural disturbance in the Okanagan Basin. Table E.6 documents the amount of forest land decimated by forest fires in recent years. Ah average of 3,254 acres of forest land is burned annually and in some years fires remove more forest cover than harvesting.

c) <u>Possible Trends to Future Land Use in the Okanagan Basin</u>

The influence of future forest management on water yield will center on:

- expanded production to attain the allowable annual cut under present sustained yield policy.

- reduction in rotation lengths.

The achievement in equality between actual annual cut and allowable annual cut will result in an increased amount of forest land harvested annually. The actual annual cut in the Okanagan Public Sustained Yield Unit in 1971 was 14.595M cubic feet from 6,623 acres. The calculated 1971 allowable annual cut was 17,756 cubic feet from an estimated 8.057 acres. Under present rotation lengths, cutting to the allowable annual cut would raise annual water yield increases by an additional 22 percent of existing yield increases.

Present forest land use in governed by a sustained yield forest management policy based on a 120 year rotation length. Any decrease in rotation length would increase the percentage of time the area is contributing to a yield increase.

Maximization of wood production from forest land occurs at a rotation determined by the culmination of the mean annual increment (M.A.I.) Table E.7 shows the results of Stanek's (1966) investigation of some interior species.

TABLE E.7

AGES OF MEAN ANNUAL INCREMENT CULMINATION BY SPECIES AND SITE IN THE OKANAGAN BASIN

SPECIES	AGE OF M.A.I.	CULMINATION BY SITE	
	Good	Medium	Poor
P1	35	50	80
S	70	120	130

P1 = lodgepole pine, S = Spruce

In consideration of optimum rotation lengths for maximization of the value of forest products, the use of financial rotations is necessary. Haley (1964) and Smith and Haley (1964) found financial rotations for coastal Douglas fir were generally shorter except on the poorest sites.

Golding (1967) suggests financial rotations of 50 years for lodgepole pine and 80 years for spruce and Douglas fir as being realistic, especially in a pulpwood economy. These rotations would give approximately twice the annual water yield increase realized under present management.

2. STREAMFLOW EFFECTS OF EXISTING FOREST LAND USE IN THE OKANAGAN BASIN

a) Pearson Creek Analysis

As a direct consequence of the inconsistencies of available data by which a straightforward analysis of the effects of forest harvesting on streamflow quantity could be carried out as discussed in previous sections, a small watershed within the Okanagan Basin was selected for detailed process analysis. Pearson Creek, a 29-square-mile tributary watershed to Mission Creek (Figure E.2), was selected on the basis of the following criteria:

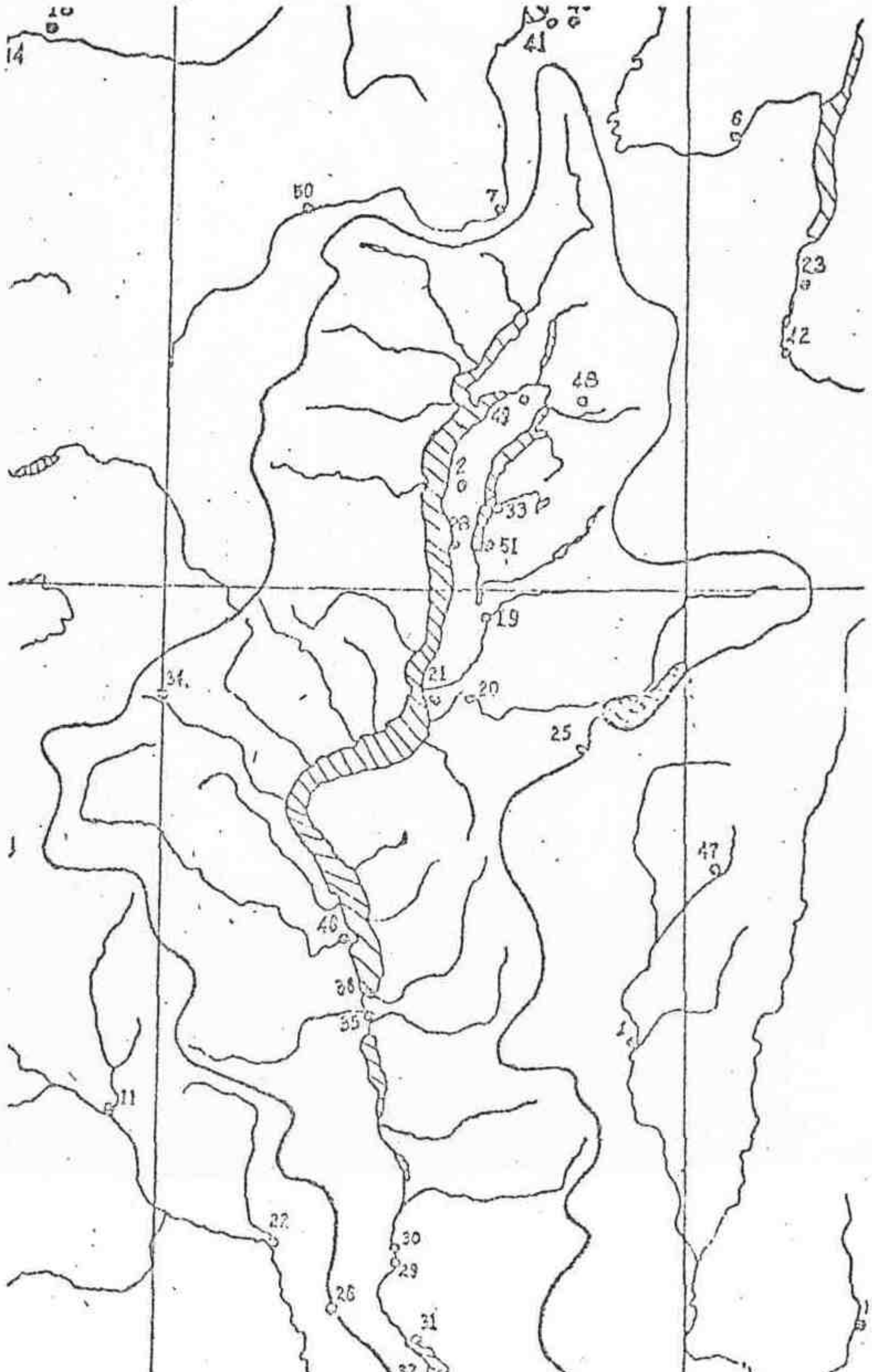
i. Most of the watershed area was forested and amenable to commercia1 forest harvesting.

ii. The area had yet to experience any major land use changes.

iii. A reasonable spatial representation of the climate, soils, forest cover and drainage was available.

iv. Preliminary analysis indicated that the main part of the watershed exhibited conditions of water surplus with no major portions exhibiting water deficits.

v. The watershed was of a nature whereby the possiblity existed for establishing it as a research basin for future studies.



LOCATION OF PEARSON CREEK

Figure E.2

To overcome the inherent problems of short-term data on an upaired, untreated watershed a simulation model was developed in order to permit the potential changes in streamflow quantity resulting from deforestation and forest harvesting practices. The model had as its base the fundamental water balance equation:

$$Q = P - E +- AS$$

where Q = streamflow (inches)

P = rainfall and snowmen (inches)

E = all evaporative losses from the system (inches)

•S = change in soil water storage (inches)

Thus, given an adequate description of each of the parameters on the right hand side of the equation, streamflow, or more appropriately, basin yield, can be computed over a predetermined time interval. For purposes of consistencies the model was constructed to operate on a monthly basis. The computerized simulation model does nothing much more than carry out a very fast budgeting of a large array of inputs and outputs and compute a monthly total discharge. However, in order to identify the ecosystem components influencing the effects of forest harvesting on water quantity and thereby permit the extrapolation of the results, several physical processes were incorporated into the model. The most notable of these processes was the realization of actual evapotranspiration as a function of the following system parameters:

i. Calculated potential evapotranspiration on a monthly basis.

ii. Characteristics of initial vegetative cover and successional trends following the removal of the original cover by fire or forest harvesting.

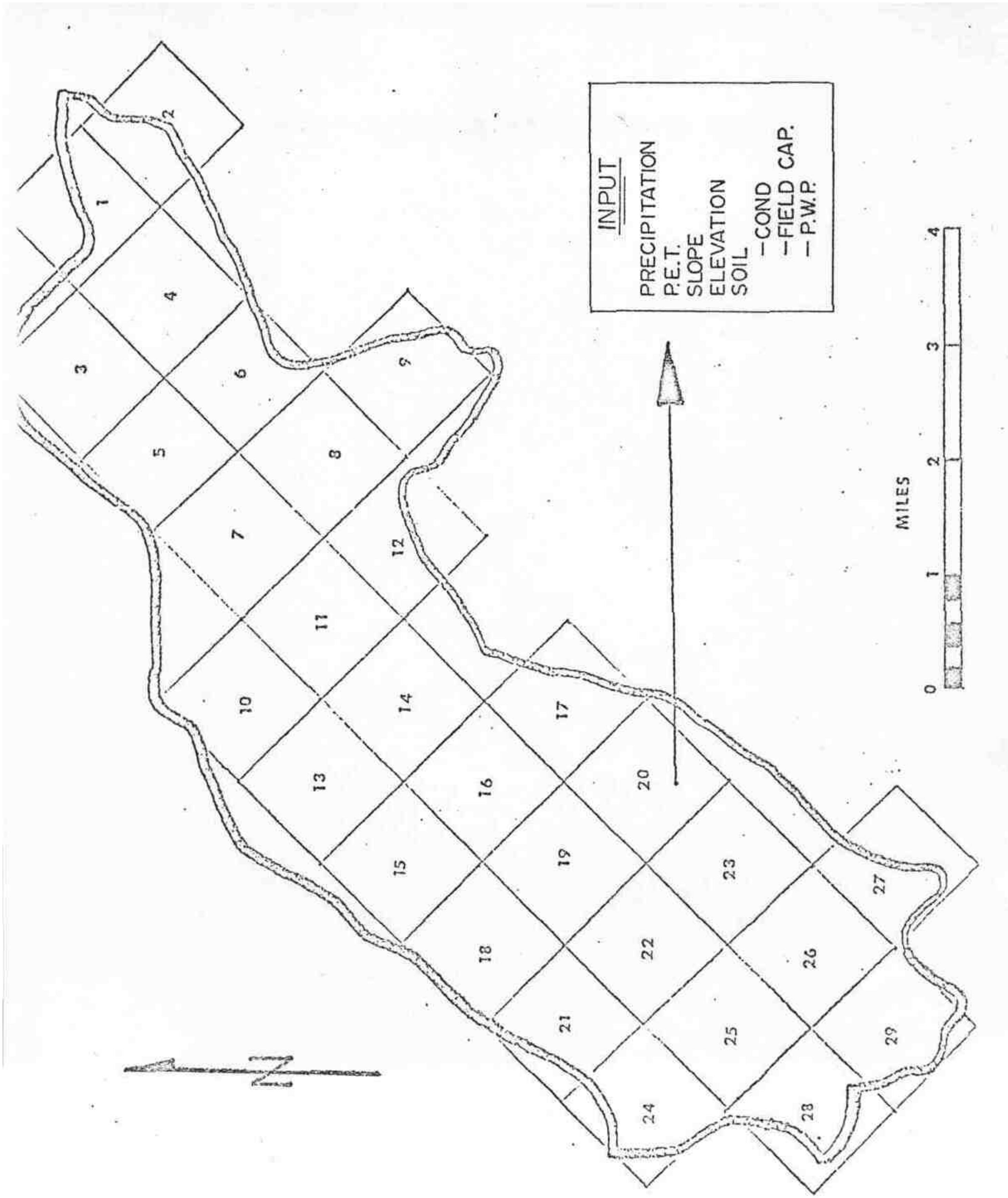
iii. Upper and lower limits of soil water storage by soil type.

iv. Soil water conductivity by soil type and site slope position and angle.

Within the limits of the functional relationships between each of these parameters and their effect on the ultimate relationship between potential evapotraspiration and actual evapotranspiration within a given month, an iterative process is carried out within the model.

In order to have the model as closely as possible simulate the real watershed the inputs were stored on a grid square method. A one-square-mile grid square was superimposed on the watershed as close as possible to the natural watershed divide (Figure E.3). Each of the squares was characterized hydrologically by assigning appropriate input values of precipitation and snowmen potential evapotranspiration, slope percent, elevation, soil hydraulic conductivity, field capacity and permanent wilting point.

Precipitation for each square was assigned on the basis of the elevational extrapolation of the precipitation data presented in Table E.8 and E.9. Since no simple model of snowmelt has yet been developed, snowmelt input for each



PEARSON CREEK WATERSHED – GRID ANALYSIS

Figure E.3

TABLE E.8

MONTHLY AND ANNUAL PRECIPITATION IN INCHES

BIG WHITE Elev. 6050

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	TOTAL
1967-68	9.91	3.39	10.16	7.05	3.35	4.89	9.32	40.5	4.88	m	m	m	m
1966-67	2.90	7.83	8.26	11.03	6.39	8.07	6.54	2.41	1.65	1.25	0.53	1.40	58.26
1965-66	0.86	2.57	5.83	4.58	5.43	2.65	3.45	2.51	3.63	2.91	m	1.58	m
1964-65	m	m	m	m	m	3.80	m	m	0.40	1.92	5.05	2.55	m

McCULLOUCH Elev. 4100'

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	TOTAL
1967-68	3.42	1.58	2.88	3.08	1.24	1.50	1.75	3.04	3.81	0.84	3.25	2.19	28.58
1966-67	1.50	3.37	3.83	4.40	1.73	2.24	1.34	1.21	1.36	0.87	0.23	0.54	22.62
1965-66	0.45	1.84	3.08	3.12	1.91	1.33	1.44	1.68	0.84	2.00	1.76	1.60	20.95
1964-65	0.57	2.50	2.61	4.76	4.16	0.68	1.26	1.31	2.24	2.07	4.00	1.05	27.21

JOE RICH Elev. 2870'

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	TOTAL
1967-68	3.82	1.59	2.59	1.91	1.05	0.84	1.27	2.81	3.34	0.47	3.18	1.99	24.86
1966-67	1.42	3.02	2.34	2.36	2.06	2.27	1.20	1.21	0.95	0.83	0.13	0.62	18.42
1965-66	0.51	1.68	1.78	2.23	1.74	0.65	1.55	2.33	1.46	1.80	1.96	1.75	19.44
1964-65	0.31	1.91	1.95	2.84	2.08	0.40	1.43	1.53	1.80	1.19	3.33	1.39	20.16

TABLE E.9

PRECIPITATION NORMALS

BIG WHITE* Elev. 6050’

TYPE	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	TOTAL
Rain	3.29	0.57	0.30	0.11	0.25	0.83	3.45	3.13	4.83	2.62	2.31	2.95	24.64
Snow	2.32	4.61	7.83	6.29	7.62	6.28	4.30	0.50				0.16	39.91
Sum	5.61	5.18	8.13	6.40	7.87	7.11	7.75	3.63	4.83	2.62	2.31	3.11	64.55

5000-6000'Elev.*

TYPE	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	TOTAL
Rain	1.97	0.36	0.18	0.07	0.14	0.47	1.83	2.24	3.31	1.93	2.31	2.08	16.24
Snow	1.39	2.96	4.74	3.97	4.35	3.59	2.29	0.36				0.11	23.76
Sum	3.36	3.32	4.92	4.04	4.49	4.06	4.12	2.60	3.31	1.93	2.31	2.19	40.00

McCULLOCH Elev. 4100'

TYPE	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	TOTAL
Rain	1.29	0.28	0.12	0.05	0.08	0.27	0.81	2.07	2.86	1.87	1.55	1.88	13.13
Snow	0.91	2.26	3.16	2.94	2.46	2.04	1.01	0.33				0.10	15.21
Sum	2.20	2.54	3.28	2.99	2.54	2.31	1.82	2.40	2.86	1.87	1.98	28.34	

JOE RICH Elev. 2870’

TYPE	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	TOTAL
Rain	1.61	0.84	0.43	0.19	0.16	0.67	1.19	2.16	2.45	1.65	1.55	1.89	14.79
Snow	0.10	0.79	1.87	1.79	1.17	0.79	0.19	0.02					6.72
Sum	1.71	1.63	2.30	1.98	1.33	1.46	1.38	2.18	2.45	1.65	1.55	1.89	21.51

square was assigned on the basis of the elevational extrapolation of the snow depletion rate as determined from snow course data presented in Table E.10. From these tables it can be seen that the recent precipitation inputs are in close agreement with the longer-term records.

TABLE E.10

SNOW COURSE SUMMARY

(a) McCULLOCH-Elev. 4200

	YEAR												
	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	Mean
Feb 1	3.1	3.7	7.6	2.5	5.8	5.2	4.6	5.8	4.8	5.0	4.3	4.9	4.8
Mar 1	5.2	5.7	8.3	2.8	7.7	8.2	6.0	6.7	5.1	7.8	5.0	7.1	6.3
Apr 1	3.1	4.4	9.3	3.4	8.9	7.4	5.0	8.2	5.0	8.2	5.8	8.0	6.4
May 1	0.5	1.6	2.8	0.8	4.7	2.8	0.9	5.3	1.5	1.1	4.6	2.7	2.4
May 15	0.0	0.5	0.8	0.4	1.8	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.3

Depletion percent 61.81 33.02 5.16

(b) MISSION CREEK-Elev. 6000

	YEAR												
	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	Mean
Feb 1	11.0	8.2	15.9	9.6	14.4	14.3	10.5	17.7	15.0	16.7	9.6	18.4	13.4
Mar 1	14.1	14.2	16.8	12.0	18.5	20.5	14.7	21.0	19.3	21.1	11.1	22.9	17.2
Apr 1	15.7	18.7	20.9	14.7	22.7	22.7	17.5	24.2	20.3	22.5	14.0	25.1	19.9
May 1	17.3	22.3	17.8	18.4	23.9	21.1	18.9	26.1	23.6	21.1	18.3	24.9	21.1
May 15	14.5	23.9	18.8	20.2	23.2	18.8	9.1	18.2	17.0	18.2	16.2	17.5	18.0
June 1	14.9	11.1	12.1	4.6	20.5	12.6	0.0	0.0	0.0	5.4	10.5	15.3	11.9

Depletion percent 15.00 28.76 56.24

*Source: British Columbia Snow Course Data Summary. B.C. Water Investigations Branch, Victoria, B.C.

Potential evapotranspiration was calculated according to the method developed by Thornthwaite (1948) using the information presented in Tables E.11 and E.12. The calculated values of potential evapotranspiration were then assigned to each of the squares on the basis of the elevational and aspect extrapolation. The actual values of potential evapotranspiration by month for four stations near Pearson Creek are presented in Table E.13. As might be expected, on the basis of available energy potential evapotranspiration decreases with elevation

TABLE E.11

MEAN MONTHLY AND ANNUAL AND NORMAL TEMPERATURES

BIG WHITE Elev. 6050’

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1968	16	29	28	28	41	43	m	m	m	m	m	m	m
1967	20	33	22	29	39	m	55	62	54	33	25	17	m
1966	17	21	22	33	44	45	m	m	50	35	25	22	m
1965	m	m	19	m	m	48	55	54	42	41	m	19	m
Norm	12	18	22	32	42	45	54	54	48	35	24	18	34

McCULLOCH Elev. 4100'

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1968	21	26	32	35	44	50	57	53	49	37	29	14	37
1967	24	28	26	32	44	54	56	60	54	39	27	20	39
1966	20	24	28	35	44	48	54	53	52	39	28	26	39
1965	22	22	21	36	43	51	58	57	43	43	30	22	37
Norm	15	20	26	36	45	50	56	54	49	39	26	20	36

JOE RICH Elev. 2870

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1968	23	30	38	39	47	53	60	55	51	40	31	15	40
1967	27	30	31	39	48	58	59	63	57	43	31	21	42
1966	21	28	33	40	49	52	58	57	55	42	31	30	41
1965	22	27	26	42	47	54	61	61	47	45	31	24	41
Norm	17	22	30	41	49	54	59	57	51	41	30	23	39

5000-6000 Elev.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Norm	14	19	24	34	43	47	55	54	48	37	25	18	35

TABLE E.12

ANCILLARY CLIMATOLOGICAL DATA*

McCULLOCH Lat. 49°51' N Long. 119°08'W

PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
No. of days with measurable rain	0	1	2	4	10	14	9	9	9	7	2	0	67
No. of days with measurable snow	14	12	11	6	1	0	0	0	0	4	11	14	73
No. of days with measurable precipitation	14	12	12	9	11	14	9	9	9	11	12	15	137
Maximum precipitation in 24 hours	1.10	1.70	1.00	1.95	1.15	2.28	1.66	1.08	1.19	1.40	0.90	1.20	2.28

JOE RICH CREEK Lat. 49°48' N Long. 119°12' W

PARAMETER	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
No. of days with measurable rain	1	1	3	6	10	12	7	7	9	8	4	2	70
No. of days with measurable snow	10	8	6	1	0	0	0	0	0	1	5	10	41
No. of days with measurable precipitation	11	9	8	7	10	12	7	7	9	8	9	11	108
Maximum precipitation in 24 hours	1.00	1.55	1.25	1.20	2.29	2.50	1.49	1.41	1.27	1.48	0.85	1.50	2.50

*Source: Temperature and precipitation Tables for British Columbia. 1967. Canada Dept. of Trans. Meteor. Branch.

TABLE E.13

POTENTIAL EVAPOTRANSPIRATION IN INCHES*

LOCATION				
MONTH	BIG WHITE	5000-6000'	McCULLOCH	JOE RICH
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	0	0.58	0.91	1.44
May	2.38	2.46	2.02	2.96
June	2.89	3.19	3.48	3.80
July	4.23	4.26	4.31	4.42
August	4.23	3.79	3.73	3.91
September	2.52	2.55	2.52	2.59
October	0.74	0.96	1.18	1.20
November	0	0	0	0
December	0	0	0	0
TOTAL	16.99	17.79	18.75	20.38

*Calculated according to Thornthwaite's method

In order to assign to each of the squares the appropriate soil parameters, a standard biophysical land type map of the Pearson Creek Watershed was developed by the B.C. Department of Agriculture Soil Survey Division (Figure E.4). Using the descriptive information of the land types (Tables E.14, E.15 and E.16) weighted values on an area coverage of a square were determined and assigned to that square. Whereas it is recognized that this is somewhat dangerous and that boundary hydrologic conditions between adjacent land types are not fully accounted for, the scale of mapping and model limitations prevented alternative methods of incorporating the soil information.

The other major parameter required as an input to the initialized state of the model is that of vegetation cover by species and density. These data were obtained tram a standard forest cover map (B.C. Forest Service) and stratified into mature forest cover and immature forest cover (Figure E.5) and detailed area and volume information by cover type was collated in Table E.17.

Given all the required input data by square, the model was run and the output of total monthly basin yield was compared to the measured streamflow for the same time interval (Figure E.6). Although the agreement is generally good on a year basis, a relatively large difference exists between predicted (simulated)

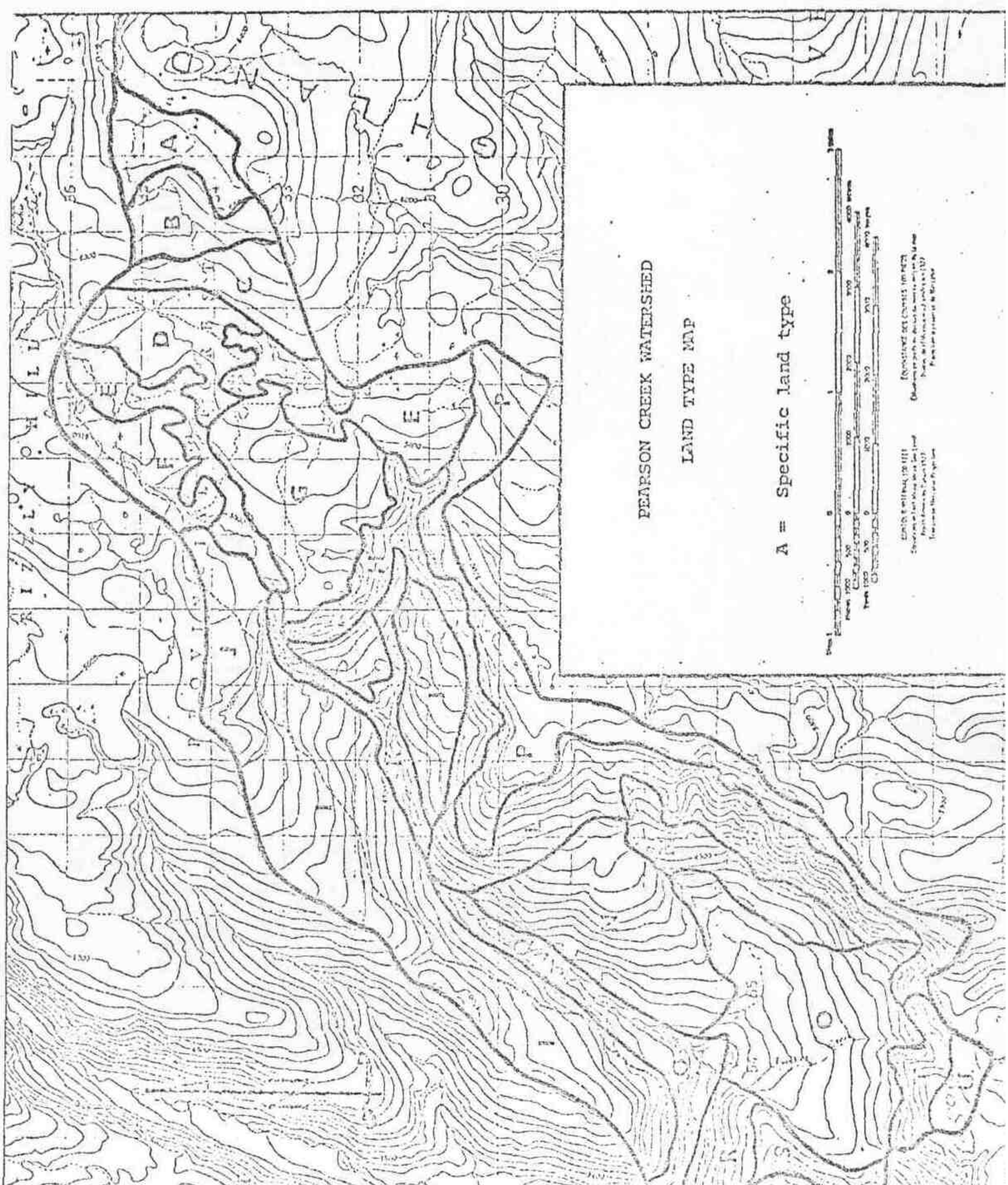


Figure E.4

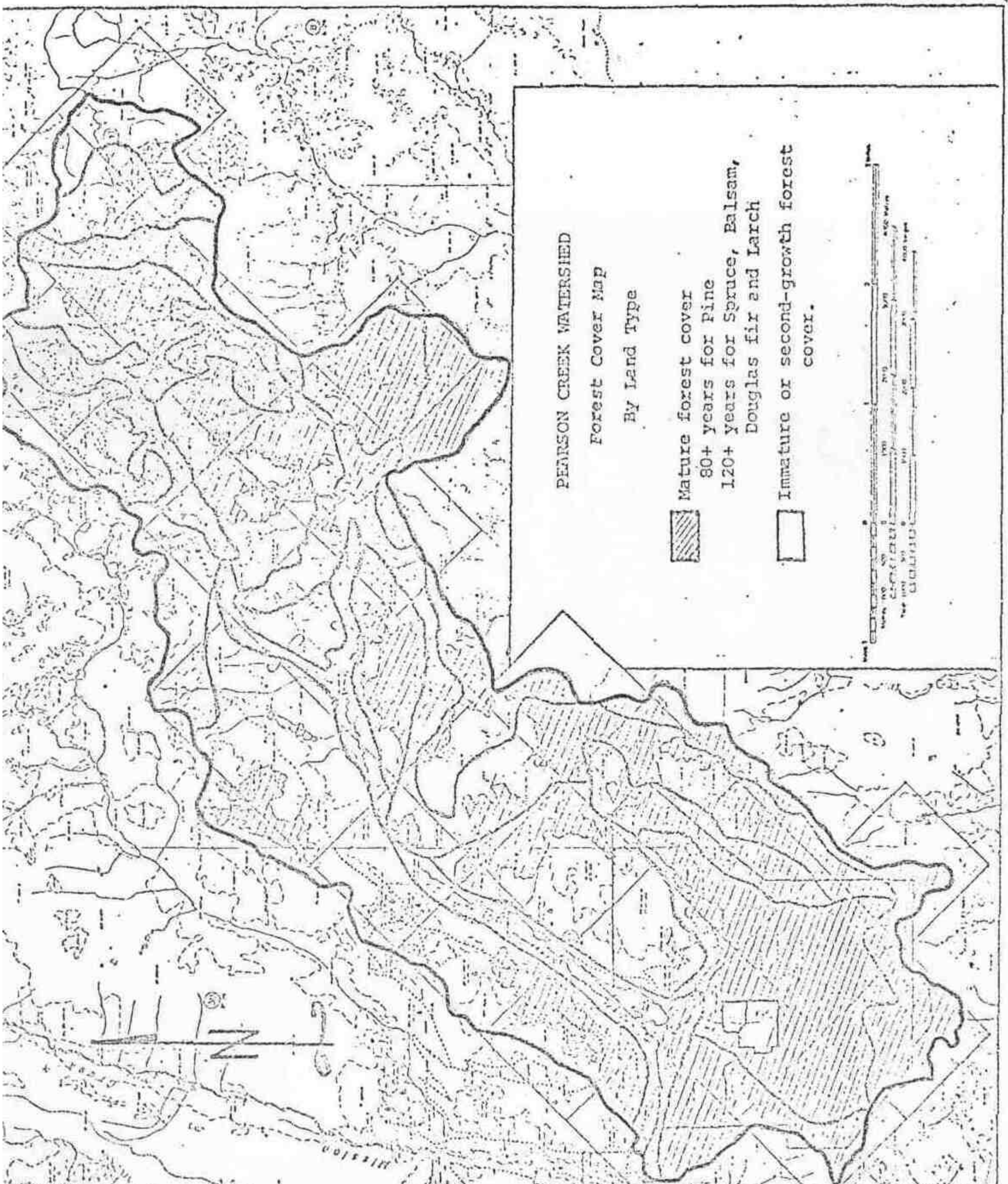

PEARSON CREEK WATERSHED
Forest Cover Map
By Land Type
Mature forest cover
80+ years for Pine
120+ years for Spruce, Balsam, Douglas fir and Larch
Immature or second-growth forest cover.

Figure E.5

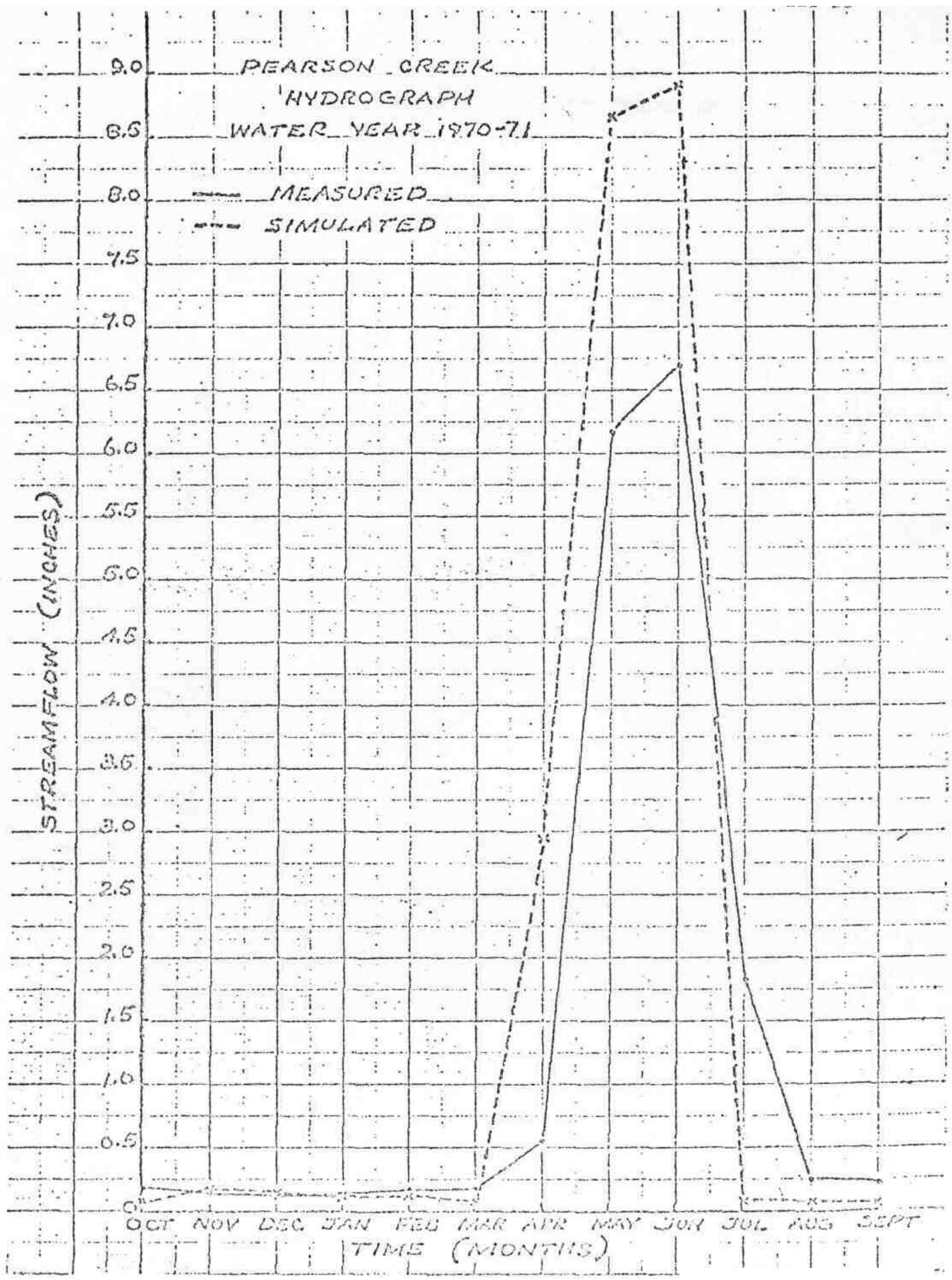

PEARSON CREEK
HYDROGRAPH
WATER YEAR 1970-71
MEASURED
SIMULATED
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
STREAMFLOW (INCHES)
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEPT
TIME (MONTHS)

Figure E.6

TABLE E.14

DESCRIPTION OF SOIL TYPES AND FOREST COVER FOR LAND UNITS[1] IN PEARSON CREEK

EXAMPLE:

LAND USE	SOIL TYPE	FOREST COVER
Z	$\dfrac{\mathrm{GR}_1^8 - \mathrm{JU}_1}{\mathrm{T/R\ -T\ :ef}}$ — soil catena / topography / landform symbols	$\mathrm{BS}_m^8 - \mathrm{Pl}_i$ (mature / immature) — 80% of land unit covered by mature Balsam, spruce; 20% by immature lodgepole pine

LAND UNIT	SOIL TYPE	FOREST COVER
A	$\dfrac{\mathrm{GR}_1^8 - \mathrm{JU}_1}{\mathrm{T/R\ -T\ :ef}}$	Alpine forest
B	$\dfrac{\mathrm{JU}_1^6 - \mathrm{GR}_2^4}{\mathrm{T\ -\ T/R\ :ef}}$	BS_m^4 - Alpine forest^6
C	$\dfrac{\mathrm{GR}_2}{\mathrm{T/R\ :\ ef}}$	BS_m
D	$\dfrac{\mathrm{LA}_1^7 - \mathrm{PE}_2^3}{\mathrm{A\ :\ de}}$	$\mathrm{BS}_m^6 - \mathrm{BS(Pl)}_i^4$
E	$\dfrac{\mathrm{PE}_2}{\mathrm{A\ :\ d}}$	Pl_i
F	$\dfrac{\mathrm{JU}_1^6 - \mathrm{LA}_1^4}{\mathrm{T\ -\ A:\ ef}}$	$\mathrm{Pl}_i^8 - \mathrm{BS}_i^2$
G	$\dfrac{\mathrm{LA}_1^6 = \mathrm{JU}_1^4}{\mathrm{A\text{-}\ T\ :\ ef}}$	$\mathrm{BS}_m^7 - \mathrm{PlSB}_i^3$
H	$\dfrac{\mathrm{LI}^8 - \mathrm{KF}_1^2}{\mathrm{C\ -\ C/R\ :H}}$	$\mathrm{PlSB}_i^7 - \mathrm{SB}_m^3$
I	$\dfrac{\mathrm{HY}_4^6 - \mathrm{HR}_4^4}{\mathrm{G\ -\ Ts\ :f}}$	$\mathrm{PlSB}_i^7 - \mathrm{Pl}_m^2 - \mathrm{FLS}_i^1$
J	$\dfrac{\mathrm{GR}_1^6 - \mathrm{HO}_1^4}{\mathrm{T/R\ -\ G\ :ef}}$	BS_i
K	$\dfrac{\mathrm{HO}_2}{\mathrm{Gm\ :\ g}}$	PlSB_i
L	$\dfrac{\mathrm{TY}_1^7 - \mathrm{KF}_1^3}{\mathrm{Ts\ -\ C/R\ :\ H}}$	$\mathrm{Pl}_m^3 - \mathrm{SB}_m^2 - \mathrm{PlSB}_1^4 - \mathrm{Fs}_i^1$
M	$\dfrac{\mathrm{TY}_2}{\mathrm{Tg\ :\ G}}$	$\mathrm{Pl}_m^4 - \mathrm{SF}_i^4 - \mathrm{SB}_i^2$
N	$\dfrac{\mathrm{HR}_1}{\mathrm{Ts\ :\ f}}$	$\mathrm{SF}_i^3 - \mathrm{Pl}_i^3 - \mathrm{BSPl}_i^2 - \mathrm{Pl}_m^2$
O	$\dfrac{\mathrm{HY}_3^7 - \mathrm{OR}_3^3}{\mathrm{G\ -\ T\ :\ f}}$	$\mathrm{SFL}_m^7 - \mathrm{Pl}_m^2 - \mathrm{LF}_m^1$
P	$\dfrac{\mathrm{TY}_1^7 - \mathrm{GR}_1^3}{\mathrm{T\ -\ T/R\ :\ f}}$	$\mathrm{Pl}_m^3 - \mathrm{SB}_m^4 - \mathrm{Pl}_i^3$
Q	$\dfrac{\mathrm{HY}_3}{\mathrm{Gmt\ :\ gf}}$	$\mathrm{SF}_i^5 - \mathrm{Pl}_i^3 - \mathrm{Pl}_m^2$
R	$\dfrac{\mathrm{OR}_3 - \mathrm{MO}_1}{\mathrm{Ts\ -\ T/R\ :\ G}}$	Pl_m
S	$\dfrac{\mathrm{JR}_1^7 - \mathrm{HR}_2^3}{\mathrm{T/R\ -\ T\ :\ fg}}$	$\mathrm{SFL}_m^7 - \mathrm{Pl}_i^3$
T	$\dfrac{\mathrm{MO}_1 - \mathrm{CR}_3}{\mathrm{T/R\ -\ Ts\ :\ gh}}$	PlL_m
U	$\dfrac{\mathrm{HR}_1^6 - \mathrm{JR}_1^4}{\mathrm{T\ -\ T/R\ :\ f}}$	$\mathrm{Pl}_m^8 - \mathrm{Pl}_i^2$

[1] Land units delineate areas of land that are relatively uniform as to vegetation, physiography and soils. They represent the most fundamental units into which land may be divided.

The soils found in any one land unit are similar in parent material and profile development.

TABLE E.15

SOIL SYMBOLING SYSTEM DESCRIPTION

A. General Origin of Landforms	Symbol	B. Surface Form or Pattern of Landforms	Symbol
Aeolian	E	Beach	b
Colluvium	C	Channelled (ridge and swale)	c
Fluvial (alluvial)	F	Delta	a
Glacial Fluvial	G	Drumlin (ized)	d
(Glacial) lacustrine	L	Eroded (active) or Dissected (non-active)	v
(Glacial) Marine	M	Eskers (s), crevasse filling	e
Glacial Till - Basal	T	Fan	f
Glacial Till - Ablation	A	Fluted	u
Bedrock	R	Hummocky	h
Organic	O	Kame	m
		Kettle (d)	k
Overlays less than 5 feet deep should be symboled as such.		Plain	p
		Talus Cone	r
		Terrace	t
		Slump (ed)	s
		Meltwater channel	w
		Steepland (G-H)	l

TOPOGRAPHY SYMBOLS

SIMPLE TOPOGRAPHY SINGLE SLOPES (regular surface)	COMPLES TOPOGRAPHY MULTIPLE SLOPES (irregular surfaces)	SLOPE %
A depressional to level	a nearly level	0 to 0.5
B very gently sloping	b gently undulating	0.5+ to 2
C gently sloping	c undulating	2+ to 5
D moderately sloping	d gently rolling	5+ to 9
E strongly sloping	e moderately rolling	9+ to 15
F steeply sloping	f strongly rolling	15+ to 30
G very steeply sloping	g hilly	30+ to 60
H extremely sloping	h very hilly	over 60

SOIL DEVELOPMENT ABBREVIATIONS

BGW	Brunisolic Gray Wooded
DB	Dystric Brunisol
DDB	Degraded Dystric Brunisol
DEB	Degraded Eutric Brunisol
DGB	Dark Gray Chernozem
EB	Eutric Brunisol
OGW	Orthic Gary Wooded

DESCRIPTIONS OF LANDFORMS (CORDILLERA AND PACIFIC COAST)

G.G. Runka

A. GENERAL ORIGIN OF LANDFORMS (GENETIC)

1. Aeolian
   - materials laid down by wind
   - sand and silt
   - poorly to moderately well sorted

2. Colluvium
   - loose material accumulated on and at the foor of slopes by the various processes of mass movement 9gravity0
   - highly variable textures depending on source material (often boulder-sized material)
   - unsorted to crudely stratified

3. Fluvial (Alluvial)
   - Materials laid down by recent streams and rivers
   - variable textures (few boulders or coarse fragments)
   - moderately well to well sorted and moderately well to well stratified.

4. Glacial fluvial
   - materials deposited by glacial meltwater
   - gravel and sand
   - ranges from well sorted and well stratified to poorly sorted and poorly stratified.

5. (Glacial) lacustrine
   - materials deposited in quiet fresh water
   - sand, silt and clay
   - well sorted and well stratified.

6. (Glacial) Marine
   - materials deposited in salt or brackish water
   - variable textured (most often silt, clay and sand)
   - moderately well sorted and moderately well stratified, often containing shells

7. Glacial till (basal)
   - materials deposited by ice directly without intervening transportation by water
   - variable textures (most often heterogeneous mixture of sands, silts and clays - some often stony and bouldery)
   - unsorted and unstratified.

8. Glacial till (Abaltion)
   - materials deposited directly by ice with some modification and transportation by glacial meltwater
   - variable textures (often stony and bouldery)
   - poorly sorted and partially stratified

9. Bedrock
   - exposed consolidated bedrock of various types
   - no surface mantle.

TABLE E.16
SOIL CATENA DESCRIPTIONS

CATENA SYMBOL	CATENA ZONE	LANDFORM	DEPTH TO BEDROCK	DOM. SOIL DEVELOPMENT	SIG. SOIL DEVELOPMENT	H_2O HOLD. CAP.	VEGETATIONAL ZONE	FOREST CAP.	ELEVATION
OR_3	Orofino	Basal till	5	Orthic Grey Luvisol	Brunisolic Grey Luvisol	High	Douglas fir-Spruce Balsam	4M -3S P1 - P1 Df ES	2500-4000'
HR_1	Hester	Basal till	5'	Brunisolic Grey Luvisol	-	High	Douglas fir-Spruce Balsam	3S P1 ES	3500-4000'
HR_2	Hester	Basal till	5'	Brunisolic Grey Luvisol	Orthic Grey Luvisol	High	Douglas fir-Spruce Balsam	3S 4M P1 Df ES	3500-5000'
HR_4	Hester	Basal till	5'	*Brunisolic* Grey Luvisol	*Orthic Dystric* Brunisol	High	Douglas fir-Spruce Balsam	3S 4M P1 P1 ES Df	3500-5000'
TY_1	Troy	Basal till	5'	Mini Humo Ferric Podzol	-	High	Spruce Balsam	3S ES	4500-6000'
JU_1	Jubilee	Basal till	5'	Orthic Humo *Ferric Podzol*	-	High	Spruce Balsam Alpine	5H 6H ES ES	6000-7000'
MO_1	Mission	Till/Rock	5'/R	Orthic Grey Luvisol	Lithic Subgroup	Medium	Douglas fir	5^{m} 6^{B}_{R} P1 P1 Df Df	2500-4500'
JR_1	Joe Rich	Till/Rock	5'/R	*Brunisolic* Grey Luvisol	*Lithic* Subgroup	Medium	Douglas fir-Spruce Balsam	4^{M}_{R} 5^{M}_{R} P1 P1 Df ES	3500-5000'
GR_1	Graystoke	Till/Rock	5'/R	Orthic Humo Ferric Podzol	Lithic Subgroup	Medium	Spruce Balsam Alpine	6^{M} 8^{R}	5500-6500'
GR_2	Graystoke	Till/Rock	5'/R	Orthic Humo Ferric Podzol	Alpine Dystric Brunisol	Medium	Spruce Balsam	6^{M} 7^{M} 8^{R} 8^{R}	6000-75000'
LA_1	Larson	Ablation	5'/R	Orthic Humo Ferric Podzol	-	Low	Spruce Balsam	5H 6H ES ES B B	6000-7000'
PE_2	Pearson	Ablation	5'	Alpine Dystric Brunisol	Glayed Alpine Dystric Brunisol	Low	Spruce Balsam	5H 7^{W}_{H} ES B B	6000-7000'
HY_1	Hardy	Glacial Fluvial	5'	Orthic Dystric Brunisol	-	Low	Douglas fir	4M P1 Df	*3000-4500'*
HY_3	Hardy	Glacial Fluvial	5'	Orthic Dystric Brunisol	Orthic Eutric Brunisol	Low	Douglas fir	4M 5M P1 P1	3000-4500'
Hy_4	Hardy	Glacial Fluvial	5'	Orthic Dystric Brunisol	Orthic Homo Ferric Podzol	Medium	Spruce Balsam	3M P1 ES	4500-6000'
HL_1	Hull	Glacial Fluvial	5'	Orthic Eutric Brunisol	-	Low	Douglas fir	5M 4M P1 P1 Df Df	*2500-3500'*
HO_2	Hoodoo	Glacial Fluvial	5'	Orthic Humo Ferric Podzol	Degraded Dystric Brunisol	Medium	Spruce Balsam	3M P1 ES	4500-6000'
L_1	Loak	Colluvium	5'	Mini Humo Ferric Podzol	Orthic Regosol	Low	Spruce Balsam	3M P1 ES	4500-6000'
FN_2	Flatiron	Colluvium /Rock	5'/R	Orthic Dystric Brunisol	*Orthic Eutric* Brunisol	Low	Douglas fir	4M 3M P1 P1 Df Df	*3000-4500'*
KF_1	Kloof	Colluvium /Rock	5'/R	Lithic Humo Ferric Podzol	Orthic Humo Ferric Podzol	Low	Spruce Balsam	4M 3M P1 P1 ES	4500-6000'
FP_1	—	Fluvial-Floodplain	5'	Orthic Eutric Brunisol	Orthic Dystric Brunisol-Orthic Regosol	Low	Douglas fir	5M 3S P1 ES Df	2500-3500-

[1] This water holding capacity reflects the textural class of the parent material. ie. G, Gm, Gmt = High; FP, Colluvium = Low

[2] Forest capability: M.A.I. Potential

4M 3S ----- Subclass limitations
P1 P1 ----- Forest species
Df Df
ie. This land unit has the potential to grow bet 50-70 and 70-90 cu.ft. per acre per year of lodgepole pine and Douglas fir.

M.A.I. CLASSES	
3	70-90 cu.ft./ac./yr
4	50-70
5	30-50
6	10-30
7	0-10

Subclass Limitations
A –arid climate
M – soil moisture def.
R - bedrock
S – combination of soil factors
U - exposure

TABLE E.17

FOREST COVER INFORMATION

Volume (less decay) MCF

TYPE	ACRES	FIR	CEDAR	HEMLOCK	BALSAM	SPRUCE	LODGEPOLE PINE	LARCH	COTTONWOOD	ALDER	TOTAL
F	4	15				2	1				·18
LF	210	338				9	17	542			906
SFPIL	87	137			30	307	24	31	2		531
SF	102	56	143	18.	62	257	26	117			679
SFL	1,216	629	1,750	125	750	3,036	301	1,428			8,019
BS	2,590	4	17	1	5,201	3,543	230				8,996
SB	1,208	24	2		1,341	2,373	640				4,344
SBP1	130	1	1		149	305	90				546
P1	2,486	112	1		383	584	7,031	2	1	14	8,128
P1L	427	249			75	115	1,038	89			1,566
P1S	174	6	1	5	57	106	473				643
TOTALS											
Mature	8,634	1,571	1,915	144	8,048	10,637	9,835	2,209	3	14	34,376
Immature*	7,993										
N. Forest	1,800										
N.C.C.	5										
	18,432										

* By 1980 approximately 1920 acres of the Immature will be Mature (especially P1).

and measured basin yield. However, the nearly 3 inch monthly flow difference during the peak flow months of April, May and June can be accounted for since the stream is influent at the gauging site. The following are additive reasons for the flow difference:

i. the peak flow during this time period is predominantly a function of snowmelt, which was crudely estimated in the model as monthly ablation with no account of the effect of rain-on-snow events.

ii. as a influent stream upon which the streamflow gauging station did not have a complete cutoff wall, the discharge difference of 3" could flow beneath the cutoff wall and the outwash gravels in the cross-sectional area of 2000 sq.ft. for one month.

Since the major flow differences could be accounted for, it was felt to be a futile exercise to match up the simulated flow with the measured flow by introducing 'correction factors' to the simulation model. Also recognized was the fact that the simulation model predicted total basin yield rather than streamflow. For the purposes of simulating the hydrologic effects of land use, it was further felt that differences in basin yield provide a better index of land use effects rather than streamflow since usable water supplies frequently involve more than that water realized as a surface expression of watershed response to climatological and land use effects.

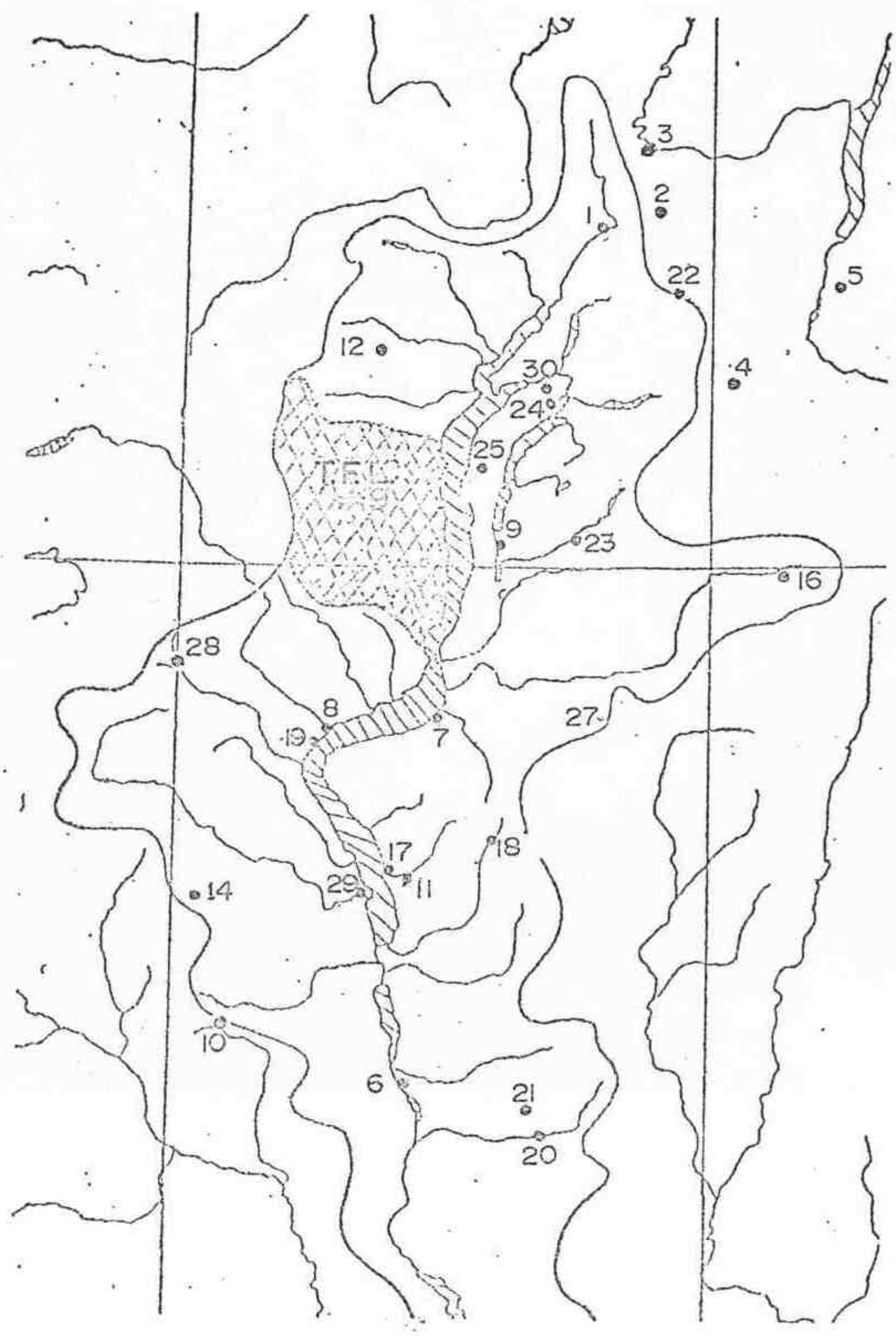
In order to simulate the effects of forest harvesting on the Pearson Creek Watershed, a systematic cutting pattern was followed on the model. This involved the removal of forest cover at the rate of one grid square of mature forest (640 acres) per year for the 17 years for which mature timber was available for harvesting. Using a clearcut and slashburn harvesting system and accounting for sequential changes in regrowth of cutover areas, the yearly incremental and total basin yield were calculated by the model (Table E.18). After 17 years of sequential forest harvesting in the Pearson Creek Watershed, a total basin yield increase of 2.91 inches or 13.68% was obtained. In this particular watershed the realized streamflow increase would decay as a result of a gradual increase in the evapotranspiration consequent with forest regrowth. First year yield increase is the largest with subsequent years reflecting the effects of gradual regrowth of the cutover areas and the redistribution of water surpluses from the cutover areas to the water deficit areas supporting vegetal growth.

Further to the understanding of the realization of water yield increases following forest harvesting is the examination of the monthly yields after 17 years of forest harvesting in Pearson Creek (Table E.19). The increase in monthly yield during the snowmelt period is reflective of the evapotranspiration reductions incurred, not during those months, but during the growing season. The same applies to the fall season when the highest percentage yield increases are realized. The increased yields during both these seasons is in response to the higher soil water contents originating in the growing season and subsequently carried into those seasons when high precipitation and snowmelt occur. Given that the storage component of the watershed is fuller after cutting than before, more of the inputs to the watershed are realized as basin yield or outputs other than evaporative ones.

b) <u>Tree Farm Licence No. 9</u>

The Okanagan (West) Tree Farm Licence (#9) is located, as its name indicates, to the west of Okanagan Lake, approximately from Lambly Creek in the south to the northern watershed of Naswhito Creek in the north. To the east, the area is bounded by the height of land between Okanagan Lake or lands adjacent to it and to the west, by the height of land between the watersheds of Okanagan Lake and the Nicola River. The key map (Figure E.7) shows the relationship of the area to Okanagan Valley communities.

By judiciously extrapolating the findings of Goodell (1958, 1964) and Love (1960) of the Fool Creek watershed cutting trails conducted in a physiographic and climatic community similar to that of the Okanagan Basin, Golding (1967) determined to possible increases in streamflow resulting from sustained yield



T.F.L. #9

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Figure E.7

TABLE E.18

STREAMFLOW RESPONSE TO SEQUENTIAL LOGGING OF PEARSON CREEK

YEAR	SQUARE LOGGED	AVERAGE ELEVATION	ΔQ(in.)	ΔQ(in.)
0	0		21.28	0
1	28	4250'	21.57	0.29
2	29	4800'	21.72	0.15
3	24	3450'	21.89	0.17
4	25	3800'	22.04	0.15
5	26	4250'	22.18	0.14
6	27	5100'	22.35	0.17
7	23	4150'	22.51	0.16
8	20	4800'	22.65	0.14
9	17	5300'	22.83	0.17
10	14	4900'	22.97	0.14
11	8	5800'	23.14	0.17
12	9	5900'	23.30	0.16
13	6	5990'	23.48	0.18
14	4	6175'	23.75	0.17
15	18	4600'	23.90	0.15
16	19	4400'	24.05	0.15
17	21	4000'	24.19	0.14

QNET after 17 years = 2.91 in. or 13.68% yield increase

TABLE E.19

MONTHLY STREAMFLOW RESPONSE OF 17 YEARS OF LOGGING ON PEARSON CREEK

MONTH	Q(in.) LOGGED	Q(in.) UNLOGGED	ΔQ(in.)	% INCREASE
J	0.111	0.111	0	0
F	0.111	0.111	0	0
M	0.085	0.085	0	0
A	3.102	2.914	0.188	6.45
M	9.530	8.669	0.861	9.93
J	9.680	8.896	0.784	8.81
J	0.138	0.046	0.092	200.00
A	0.127	0.088	0.039	44.31
S	0.215	0.042	0.173	411.90
O	0.577	0.062	0.515	830.60
N	0.327	0.142	0.185	130.28
D	0.188	0.115	0.073	63.48
TOTAL	24.190	21.280	2.910	13.68
ET	11.51	15.01	3.50	
			0.59 in. = Soil Moisture Recharge	

harvesting of T.F.L. *99.* The particular information used in the determination includes:

- lodgepole pine when clearcut effected a 67% yield increase in the first year following cutting on the cutover area.
- spruce-balsam when clearcut in alternate strips effected a 40.2% yield increase on the cutover area in the first year following cutting.
- Douglas fir in the drier habitats such as those found in the Okanagan Basin were predicted (U.S. Senate, 1960) to result in a yield increase of 7-14% (average 10% on the cutover area).

Using the Terrace and Esperon Creeks as a basis for his extrapolation to the entire T.F.L. #9, Golding (1970) assumed a 40 year increase yield period and a 120-year rotation length. His yield increases were developed on a forest cover basis which, with the exception of lodgepole pine which grows on almost all soil types and throughout the full range of forested elevations, related reasonably well to groupings of similar biophysical zones (Figure E.1). His findings are summarized as follows:

COVER TYPE	ANNUAL YIELD INCREASE (ac.ft.)
Lodgepole pine	3045
Spruce-balsam	3980
Douglas fir	488
Ponderosa pine	nil
Aspen	nil
	7513 acre feet/year

This represents an annual yield increase of 4.9% on the entire T.F.L. #9 land area. Table E .20 summarizes the possible effect on water yield increase for the entire T.F.L.#9 area resulting from forest harvesting for a range of rotation lengths.

TABLE E.20

WATER YIELD INCREASES FROM FOREST HARVESTING

ON THE FOREST LAND OF TREE FARM LICENCE *#9*

FOR DIFFERENT ROTATION LENGTHS

ROTATION LENGTH	TREE FARM LICENCE #9 YIELD INCREASE %
120	4.9
100	5.8
80	7.3
60	9.8
40	14.7

c) Extrapolation To Obtain Entire Basin Effects

In order to determine the total annual effects of existing forest harvesting in the Okanagan Basin on water yield increases, the data developed in the Pearson Creek and Tree Farm Licence #9 analysis can be judiciously extrapolated. In addition to the development of streamflow yield increases on the basis of existing actual annual cut and different rotation lengths is possible. It is also possible to arrive at an estimate of the annual yield increase for the Okanagan Basin as a result of wildfire.

Using the Pearson Creek analysis, an annual cut of 640 acres by clearcutting can be assumed which on a 120-year rotation would necessitate 120 square miles of merchantable forest land under sustained yield policy. Also assumed is a 40-year period of increased yield. From the simulated 17-year cutting results in Pearson Creek an average yield increase of 0.17 in./square mile cut or 23.3% square mile cut was realized. On the basis of a 40-year regrowth period an increase of 11.65%/square mile cut accrues. This results in an average annual basin yield increase (120 square mile basin) of 3.87%. Table E.21 summarizes the extrapolation of this data to the entire Pearson Creek Basin for different rotation lengths.

TABLE E.21
WATER YIELD INCREASES FROM FOREST HARVESTING
ON PEARSON CREEK
FOR DIFFERENT ROTATION LENGTHS

ROTATION LENGTH	BASIN YIELD INCREASE %	BASIN YIELD INCREASE acre-feet
120	3.87	5269
100	4.64	6323
80	5.80	7904
60	7.74	10538
40	11.60	15808

Extrapolating these results to the entire Okanagan Basin is relatively simple. In 1971, 4323 acres were clearcut and 5822 acres-were selectively cut. Assuming that the selective cut has 75% the effect of the clearcut then the actual annual cut on a clearcut basis was 8689 acres. Once again the rotation length of 120 years and the 40 year period of increased yield are used. On the basis of the 11.65%/year per clearcut square mile and correcting for the effects of selection harvesting, an average annual water yield increase for the forest land north of Penticton and above 4000 feet under sustained yield management is 3.3%. The comparable value for yield increases on a hypothetical 40 year rotation are 9.935S and 12.60% respectively.

As has been pointed out, however, many areas within the Okanagan Basin would nor reflect an increased water yield following forest harvesting. The percent yield increases reported are for only that area designated as merchantable forest north of Penticton above 4000 feet (approximately 1/4 the total merchantable forest and 15% of the total area of the Okanagan Basin or about 300,000 acres.)

By adjusting the reported percentage water yield increases to a <u>Basin</u> basis for two rotations, the existing one of 120 years and the hypothetical one of 40 years, levels by which comparisons can be made and effects evaluated is made possible. Yield increases on a Basin basis are summarized in Table E.22.

In addition to the water yield increases experienced from forest harvesting in the Okanagan Basin are those as a result of wildfire. The average annual acreage burned over in the Okanagan Basin is 5,377 with a range between 81 acres (1964) and 25,856 acres (1970). The possible effects of this on water yield increase are presented in Table E.23.

<u>TABLE E.22</u>

<u>INCREASE WATER YIELDS ACCRUING IN; THE OKANAGAN BASIN</u>
<u>FROM FOREST HARVESTING ON TWO ROTATION LENGTHS</u>
<u>EXTRAPOLATED FROM TWO METHODS</u>

ROTATION LENGTH	YIELD INCREASE %		APPROXIMATE WATER YIELD (ac.ft.)			
			Dry Year*		Wet Year**	
	Low	High	Low	High	Low	High
120 yrs.	0.50	0.64	400	512	3,715	4,755
40 yrs.	1.50	1.91	1,200	1,536	10,145	14,376

* 1931
** 1948

<u>TABLE E.23</u>

<u>WATER YIELD INCREASES FOLLOWING WILDFIRE</u>
<u>IN THE OKANAGAN BASIN ON AN AVERAGE ANNUAL BASIS</u>

METHOD	YIELD INCREASE % MAXIMUM YIELD ZONE BASIS	YIELD INCREASE % BASIN BASIS
Pearson Creek Extrapolation	1.24	0.19
T.F.L. #9 Extrapolation	1.55	0.23

It should be noted that these yield increases accrue independently of the length of rotation.

3. RECOMMENDED ALTERNATIONS IN FOREST LAND USE FOR INCREASED WATER YIELD

a) Changes in Rotation Lengths

As is evident from the previous section, the greatest potential for increasing water yields from forest harvesting exists within the area of shortening the rotation length. In a pulpwood economy it is realistic to work on a 40 year rotation on the better growing sites. For other levels of merchantibi1ity, shorter rotations than 120 years may be possible, especially on the higher elevation, water-rich growing sites. Any reduction in the rotation length is a rotation length of 40 years three times the volume of timber would be harvested over that for a 120-year rotation. If the volume per acre is held as being constant, then this means three times the acreage would be removed in a 40 year rotation over that for a 120-year rotation.

b) Harvesting Intensity and Method by Forest Cover

Increasing water yields, by forest harvesting, above those already reported may have some promise with respect to altering biophysical zones developed in the Pearson Creek analysis into management zones, areas where special concern for increasing water yield through forest harvesting can be outlined. Table 3.24 presents the stratification of the Okanagan Basin into water yield management zones.

TABLE E.24

WATER YIELD MANAGEMENT ZONES OF THE OKANAGAN BASIN

ZONE	BIOPHYSICAL TYPES	ELEVATION RANGE (FEET)	SPECIES	WATER YIELD INCREASE* inches	
1	A,B,C,D	6000+	S+B	0.47	67
2	U,P,H,L,E,F,G	4000-6000	S,B,Pl	0.35	47.7
3	O,K,N,T,S,R,M,I	3500-4500	Pl,Df,S	0.32	43.6
4	Q	all	riparian	0.40	54.5
5	all	3000	all	nil	nil

* First year increase only/cutover area.

APPENDICES

TO

(Preliminary Report Task 180)

E.1 THE ROLE OF THE FOREST IN THE HYDROLOGIC CYCLE

The hydrologic cycle is the continuum of the processes of motion, loss and recharge of the earth's waters. The presence of forest vegetation influences certain of the processes in the hydrologic cycle. The most important of these are precipitation interception and redistribution, evapotranspiration and indirectly, streamflow. Figures A.1 and A.2 illustrate the hydrologic cycle and the role of the forest therein.

a) PRECIPITATION INTERCEPTION

Interception loss is the portion of the gross precipitation which is collected by the vegetative cover and subsequently evaporated. Total interception loss (on a storm basis) may be represented as follows (Horton, 1919):

$$I\% = \left(\frac{S + RET}{iT} \times 100 \right)$$

where: I = total interception loss for the projected area of the canopy (in.)

S = storage capacity of the vegetation for the projected area of the canopy (in.)

R = ratio of vegetal surface area to its projected area

E = evaporation rate from the vegetal surface (in./hr.)

i = precipitation intensity (in./hr.)

T = duration of storms (hrs.)

Measurement of interception loss requires quantification of the terms of the following equation:

$$I = P - T - S$$

where: I = interception loss (in.)

P = gross precipitation above canopy (in.)

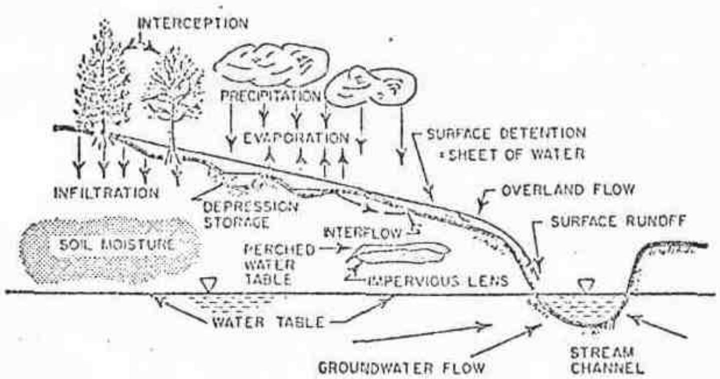
T = throughfall (in.)

S = stemflow (in.)

In general, the S component is quite small and is a function of bark roughness: 0.01P - 0.15P for smooth barked species and 0.02P - 0.03P for rough barked species (Chow, 1964).

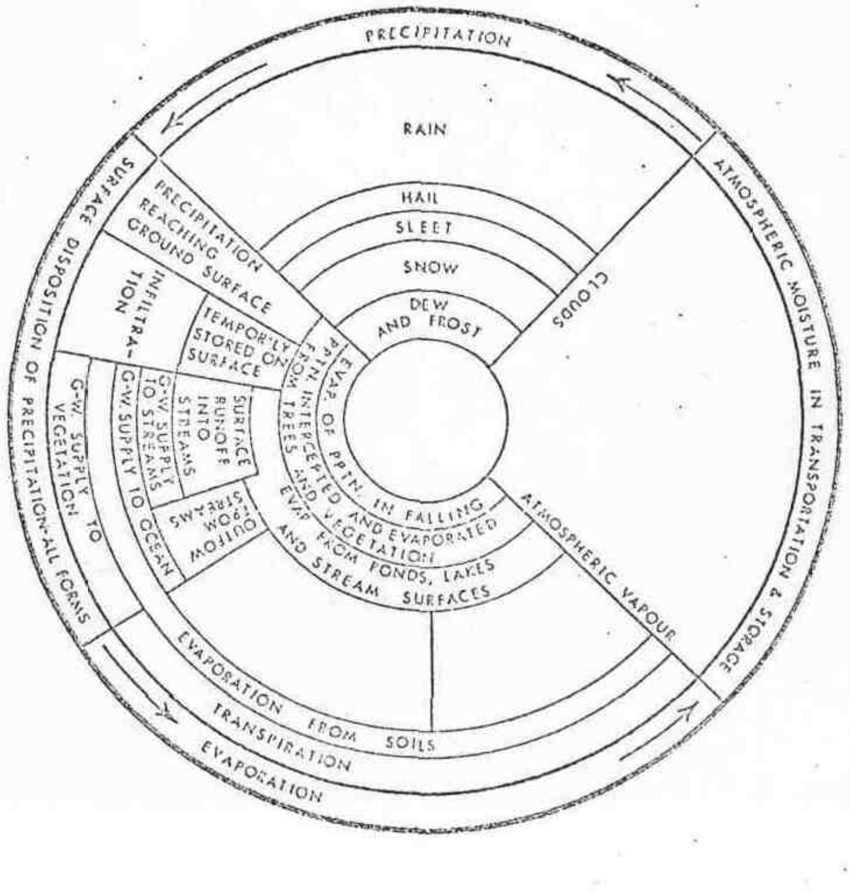
Climatic Influences

Climate has a marked effect on the magnitude of interception loss which may be summarized as follows:



A SIMPLE REPRESENTATION OF THE RUNOFF CYCLE

Figure E.8



THE HYDROLOGIC CYCLE – A QUALITATIVE REPRESENTATION

Figure E.9

i. temperature effects on evaporation rates.
ii. wind effects on vapor pressure gradients.
iii. duration of storm (the shorter the storm the greater the relative interception loss).
iv. intensity of precipitation (the most pronounced effect is with short, low intensity rainfalls).
v. form of precipitation (interception losses from rain are much less than from snow.)
vi. seasonal distribution of precipitation.

Vegetative Influences

The interception loss is a function of the biomass and the spatial arrangement of vegetation, particularly the surface area of the foliage and the geometry and physical properties of the vegetation. These vegetation parameters are influenced by species, age, density of cover and seasonal changes.

Quantitative Significance

Zinke (1967) summarized the North American literature pertaining to Interception losses from various forest covers. The result is shown in Table E.25. The figures apply to interception of rain.

b) EVAPOTRANSPIRATION

Methods of Evaluation

Evapotranspiration is the consumptive use of soil water by cover vegetation. Potential evapotranspiration (P.E.T.) is the amount of water which would be transpired by the vegetation under the limiting factor of available energy. The actual evapotranspiration (A.E.T.) is governed by the combined effects of available energy and available soil water.

A variety of methods of estimating evapotranspiration losses have been proposed. Most are limited by the difficulty in the extrapolation of results of single tree or single plot analysis to stand conditions, or in the sophistication of the data required. These methods include:

i. soil moisture depletion
ii. lysimeter studies
iii. ground water fluctuation
iv. water balance
v. energy budget
vi. soil moisture budget
vii. environmental factors
viii. effective heat

TABLE E.25

SELECTED INTERCEPTION ESTIMATES FOR CONIFEROUS STANDS

Abies lasiocarpa (Hook.) Nutt., single tree
S_f in cubic inches = 3583 P_r − 387

Picea abies (L.) Karst, 20-year old plantation.
I_v = 58%

Pinus banksiana Lamb.

P_r (storm)	0.05	0.1	0.3	> 0.3
P_{rn}%	60	70	80	80 + 2/3% per 0.1 increase in P_r

Picea engelmannii Parry, single tree
S_f in cubic inches = 1035 P_r − 301

Pinus contorta Dougl.
S_f < 0.01 in. per tree for 43 summer rainstorms

Type of stand and residual volume in board feet	P_{rn}%	
1. Virgin, 11,800 bd.ft./acre	69.1	P_{rn} = 0.8046 P_r − 0.0290
2. Cutover, 8000 bd.ft/acre	80.1	P_{rn} = 0.8677 P_r − 0.0149
3. Cutover. 4000 bd.ft./acre	85.1	P_{rn} = 0.9055 P_r − 0.0131
4. Cutover, 2000 bd.ft./acre	86.5	P_{rn} = 0.8933 P_r − 0.0074
5. Clear cut (all trees over 9.5 in. d.b.h.)	92.8	P_{rn} = 0.9897 P_r − 0.0153

Treatment effects: in second growth

Treatment	100% canopy none	40% canopy crop tree	40% canopy single tree
Summer P_{rn}	3.68 in.	4.17 in.	4.33 in.
P_{rn}% increase	0	13.3	17.7
Winter P_{sn}	10.03 in.	11.72 in.	12.34 in.
P_{sn}% increase	0	16.8	23.0

Pinus ponderosa Laws.

Mature stand, 120 ft. tall, California
I_{si} = 14.5, 5-year average.
I_{si} = 0.10 P_s + 0.09.

Young stand, 14 ft. tall, 79 percent crown coverage, California
I_{si} = 15.4%, 5-year average.
I_{si} = 0.11P_s + 0.01

65-75-year-old stand, fully stocked, California
I_{si} = 12% range < 7% to > 80%
T_h = 84%
S_f = 4%
I_{si} = 0.06 P_s + 0.09
I_{ri} = 0.06 P_r + 0.12
I_v = 0.06 P + 0.11, all storms > 0.5 in.

Stands in Colorado
S_f = nil.
I_v = 16%, average of snow and rain storms

Pinus resinosa Ait.
Plantation, 17 years old
I_{si} = 35%
Plantation, 85 percent canopy density, twenty-one storms

P_r	I_{ri}		T_n		S_f	
in.	in.	%	in.	%	in.	%
13.4	2.5	18.7	10.7	80.1	0.1	1.2

Plantation, 31 years old, 31 ft tall, stand improvement by prunings.
Interception loss as percent of various storm sizes in pruned and unpruned.

Storm size (in.)	0.00-0.01	0.011-0.04	0.041-0.16	0.161-0.77	0.771-0.381	Average
Unpruned %	85	74	59	25	14	21.4
Pruned %	48	28	27	19	16	17.6

Pinus strobus L.
96 percent canopy I_{ri} = 43%
I_{si} = 37%, 20 year old plantation
I_{si} = 35%, 21-30 years old
I_{si} 59%, 61-80 years old

Single tree (average of 6 storms).

Distance from trunk in feet	0	4.5	6	9
	25%	38%	48%-11.2% (attributed to edge of crown drip).	

Pseudotsuga menziesii
Old growth, 199 to 248 ft tall, Vancouver Island, B.C.
I_v = 44% annual ignoring stemflow, 57% summer with nil stemflow; average of 5-1/2 years.
Old growth, 147 to 175 ft tall, Vancouver Island, B.C.
I_v = 31% annual ignoring stemflow, 49% summer with nil stemflow; average of 5-1/2 years.
Old growth, 87 to 116 ft tall
I_v = 28% annual ignoring stemflow, 39% summer with nil stemflow; average of 5-1/2years.

Dense old growth, Oregon
S_f = 0.27% of P_n considered insignificant.
I_{ri} = 14% winter, 24% summer.

Storm size in inches	0-0.5	0.05-0.5	0.5-1.0	1.1-1.3	1.5-2.0
I_{ri}%	100	32	23	21	19

Pseudotsuga menziesii (Mirb.) Franco -- Tsuga heterophylla (Raf.) Sarg.
Old growth, 144 to 209 ft tall
I_v = 34% annual, 51% summer.

Old growth, 77 to 110 ft tall
I_v = 20% annual, 30% summer.

Thuja plicata Donn.
Old growth, 125 to 196 ft tall
I_v = 33% annual, 40% summer
Average of 5-1/2 years with stemflow ignored.

$_r$ = depth of storm precipitation (rain)
$_s$ = depth of storm precipitation (snow)
$_v$ = total interception loss
$_{ri}$ = rain interception loss
$_h$ = throughfall
P = gross storm precipitation
P_{rn} = net precipitation (rainfall)
P_{sn} = net precipitation (snow)
I_{si} = snow interception loss
S_f = stemflow

Evapotranspiration losses on an annual basis are reliably estimated by the water balance method simply stated as follows:

$$ET = P \pm Q \pm S$$

where: P = net precipitation

Q = runoff

S = change in soil water storage

This method requires a calibrated watershed and long-term hydrometeorological records.

Theoretical energy budget approaches can be used to estimate the potential evapotranspiration. The most commonly used method was proposed by Penman (1948) who simplified the daily heat balance as follows:

$$R_n - K + ET$$

where: R_n = net radiation

K = sensible heat exchange

ET = energy used for evapotranspiration

Solution of this equation requires proportioning the net radiation (R_n) into its components as follows:

$$ET = f(u)\ (e_o - e_a)$$

$$K = Vf'(u)\ (T_o - T_a)$$

where: $f(u)$, $f'(u)$ = functions of wind speed

e_o = saturated vapor pressure at the surface temperature T_o

e_a = actual vapor pressure of the air

T_a = mean air temperature a

V = constant = 0.27 mm. Hg/°F

It is obvious that the Penman equation has limited application because of the complex meteorolgical observations required.

A more easily derived estimate of potential evapotranspiration can be obtained using simple climatic data, shown by Thornthwaite (1948). The formulae developed are:

$$P.E.T. = cT_m^a$$

where: c = coefficient

T_m = mean monthly temperature (°C)

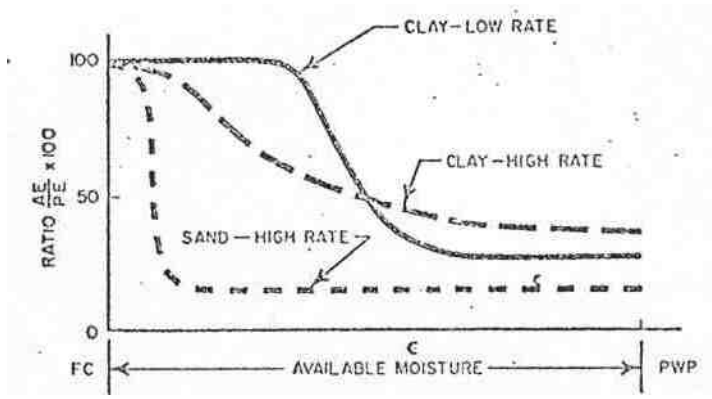
a = exponent

which simplifies to:

$$E = 1.62 \left(\frac{10\ T_m}{I} \right)^a$$

where: I = Heat Index = $\sum_{m=1}^{12} (T_m)1.51$

Potential evapotranspiration estimates must be modified to represent actual evapotranspiration rates since, in reality, soil water becomes an important limiting factor. Plants cannot use the available water (amount of water held In the soil at field capacity minus the amount held at the permanent wilting point) at a constant rate. Holmes (1961) showed that the ration of actual evapotranspiration (A.F.T.) to potential evapotranspiration (P.E.T.) changes at the soil dries and is a function of the soil texture and the drying rate (Figure E.10).



Schematic drying curves showing ratio of AE/PE plotted with soil moisture content for different soils and drying rates.

Figure E.10

Actual evapotranspiration is usually calculated using potential evapotranspiration rates altered in consideration of the soil moisture budget.

<u>Edaphic and Climatic Influences</u>

Evapotranspiration losses are determined by certain climatic and edaphic factors which include:

i. solar radiation intensity and duration, wind, relative humidity, cloud cover and precipitation.

ii. length of growing season

iii. soil texture and structure

iv. soil depth

In general, situations of abundant precipitation distributed uniformly throughout the year mainly as rain results in A.E.T. = P.E.T. In situations of low summer rainfall and low yearly precipitation mainly in the form of show A.E.T. << P.E.T.

Vegetation Influences

The nature and extent of forest cover governs the evapotranspiration losses. Generally, vegetation influences include:

i. density - evapotranspiration loss per unit area increases with density until all the available energy is utilized.

ii. age - highest evapotranspiration occurs during the period of culmination of mean annual increment.

iii. species - albedo, height, crown depth and geometry and surface roughness are species specific. Actual differences may not be great between full stands of different composition except on dept soils (Jeffrey, 1969).

c) STREAMFLOW

Quantity

Water quantity is usually the difference between precipitation and vaporization losses. The role of the forest in the determination of water yield is best evaluated in terms of the effects of forest removal on streamflow.

Regime

The effects of a forest cover on the distribution of annual streamflow can be summarized as follows:

i. reduce peak flows by soil water depletion through evapotranspiration losses.

ii. reduce peak flows through retardation of snowmelt within the forest stand.

Quality

The maintenance of an adequate and continuous cover of vegetation is the greatest deterrent to surface soil erosion (Woolridge 1968). Streamflow from undisturbed forests is generally clear except during periods of high discharge that accompany heavy rainfall or rapid snowmelt.

Vegetative influences which promote high water quality include:

i. precipitation interception

ii. reduction of the force of raindrop impact

iii. incorporated and unincorporated organic matter are sources for cementing agents which promote the formation of large water stable soil aggregates (Dyrness 1967).

iv. organic matter is abundant in soil micro-organisms which often improve already high infiltration rates (Martin *et al.* 1940).

Vegetative cover appears to be a key factor in slide resistance on steep slopes (Swansten, 1967) by the following mechanisms:

i. depletion of soil water through evapotranspiration and its influence on the piezometric head

ii. structural strength resulting from the presence of roots in the soil and their penetration of cracks in bedrock.

Chemical water quality is strongly influenced by vegetation. Nutrients are added to, lost from, and utilized by, forested ecosystems. Nutrients may be added by:

i. The atmosphere, in precipitation, dust or fixation by organism (alder trees).
ii. Mineral weathering (cations and phosphorus).
iii. Biological inputs including those influenced by man.

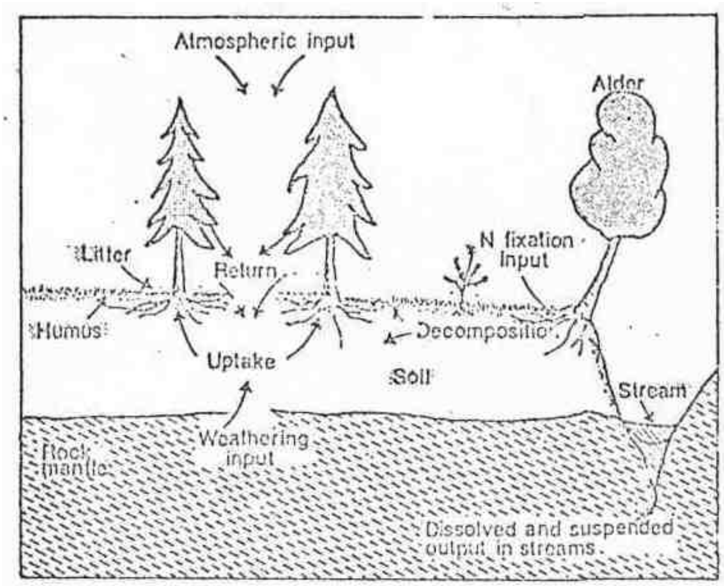
Losses from the system may occur:

i. As dissolved and suspended constituents in streams.
ii. By removal of materials from the land.
iii. By release of N. P. and S. to the atmosphere by volatilization.

The balance between inputs and losses to the forest determines the quantity of each chemical retained.

Cycling and reuse of chemicals (Figure E.11) is an important function in the nutrition of the forest. A certain fraction of the nutrients taken up by trees and shrubs and returned to the forest floors. Acted on by micro-organisms, the nutrients released are stored in humus or soil layers or taken up again by the vegetation. This return and reuse phenomenon is often called the inner cycle. A certain amount of nutrient elements taken up by vegetation are retained in woody tissue. The amount retained accumulates from year to year and can become an important fraction of that contained in the forest as the stand approaches maturity (Ovington, 1962).

Streams draining undisturbed forest systems contain chemical constituents not taken up by vegetation, either lost by leakage from the inner cycle or released by weathering. Nitrogen loss from undisturbed forests is very small (Cole et a1. 1968). Losses of cations are also small and controlled by the quantity of mobile anions which enter the soil solution. Because there must be a balance of charge in ionic solutions, the loss of cations (K, Ca, Mg, NH_4) must be balanced by equivalent amounts of anions (McColl and Cole, 1968). Bicarbonate anions formed by the hydrolysis of carbon dioxide released by respiration of organisms - primarily the roots of higher plants and decomposer organisms - are the principal anion source. Both nitrate and phosphate anions are present in small be detectable amounts.



Major elements and processes in a forest ecosystem Figure E.11

Chemical constituents also enter the forest system in precipitation. Nitrogen, phosphorus and potassium inputs may nearly balance losses from the system in drainage water (Cole et a1. 1967). Anions in precipitation may accelerate leaching losses since anions are not readily held on exchange sites within the soil. Fortunately, concentration of anions in precipitation is generally small. However, sulfate may become an important anion near sources of industrial pollution, and chloride occurs in important amounts adjacent to the ocean (moodie, 1964).

The effects of forest cover, especially riparian vegetation, on maintaining cool stream water is better discussed in Appendix E.2 where differences between exposed and covered streams are presented.

E.2 EFFECT OF FOREST MANAGEMENT ON THE HYDROLOGIC CYCLE

a) Water Quantity

The goals of management for maximum water yield are to reduce the water consumed by the forest, maintain the permeable soil structure, and rearrange snow-fall so that it more effectively contributes to streamflow. The forest environment and the processes governing it are important, not the trees themselves. Enough foliage must be grown to protect the soil, but it can come from small trees or other plants. Shorter plants expose a thinner layer of foliage for evaporation. Shallow-rooted plants take less water from the soil. Patterns of tail forest alternating with patches of smaller vegetation create a honeycomb that tends to concentrate snow and rain where it is less subject to evaporative loss.

The processes involved are complex and difficult to quantify. It appears easier to develop satisfactory energy and water budgets for continents than for a small forested mountain watershed with its complex plant patterns and exposures to sun, wind, precipitation and sky.

The need to know what happens to water when forest conditions are changed has led to a long series of tests on a watershed basis. The first started 60 years ago at Wagon Wheel Gap, Colorado, on the headwaters of the Rio Grande. Streamflow, sediment yield and precipitation were measured on two adjacent drainage basins, each covered with young aspen and conifer forests. Air temperatures, soil temperatures, relative humidity, wind-free water evaporation, soil moisture and snow accumulation were also measured. After a 9-year calibration period the trees on one basin were cut, with minimum soil disturbance. The complete report, published 41 years ago, showed a sizable increase in total streamflow, a slight increase in sediment and no effect on height of flood peak (Bates and Henry, 1928).

This pioneer experiment set a pattern for the watershed experiments that followed for research methods, findings and the application of results in forest land management. The paired watershed method was effective for determining changes in streamflow. The measurements of climatic factors and soil moisture were interesting, but not helpful in explaining the results. The absence of overland runoff (now known to be characteristic of forest soils) was considered unusual and readers we're warned against applying results to other forest lands in the region.

Beginning about 35 years ago, a series of watershed tests were started which confirm that streamflow can be changed by changing forest conditions. A excellent report was presented by Hibbert (1965) appraising the results of 39 watershed experiments throughout the world. He concludes (Table E.26) there is no doubt that forest reduction increases water yield. The indicated practical upper limit of yield increase from cutting high forest on small watersheds is 18 inches of runoff per year. This can be expected only from areas of abundant precipitation, with deep porous soils, a long growing season and an originally dense forest cover.

As would be expected, results varied considerably over a wide range of climates, forest cover types, and geomorphic situations. For the United States, there were two broad groups of data - one from the eastern hardward forest region and one from the western coniferous forest. Increased yields about equal to the estimated maximum of 18 inches per year have been measured in both the Southern Appalachian and Cascade Mountains. In the hardwood region, the increased runoff dies away quickly as new growth is established. Appreciable effects last no longer than 5 to 15 years unless natural plant succession is controlled. Effects are more persistent in the West, and some experiments were closed before the time trend was established. Obviously, the persistence of the effects and the cost of measures to perpetuate it are basic to economic evaluation of watershed management.

For streams fed primarily from melted snow, the size and arrangement of cut areas are important A pattern creating protected openings appears most effective. These openings trap more snow than the surrounding unbroken forest, and a higher proportion is converted to streamflow because of earlier and more rapid melting and lower soil moisture deficit (Hoover and Leaf, 1967). On a watershed in the Fraser Experimental Forest, where 50 percent of the commercial timber was cut in a checkered pattern of cut and uncut blocks, annual water yield has increased an average of 3.7 inches for the 12 years after treatment (an increase of 30 percent) and there has been no decrease with time. Effects are largest in years with abundant precipitation. This indicates that weather modification and forest watershed treatments may combine in a synergistic manner to favor water yield.

Even though much remains to be learned, present empirical knowledge is sufficient to select areas where vegetation management can increase water yield. It is important to consider the nature of past experiments carefully before proceeding to larger-scale action programs. Experimental treatments consist of holes or windows cut into essentially continuous forest. The area treated is subject to the effect of the surrounding forest. The largest clearing tested in the East is less than 100 acres, and in the West 240 acres. Action programs should not make larger openings, but rather numerous small openings. The desired pattern is a mosaic of tall forest with interspersed areas of lesser vegetation.

TABLE E.26

LOCATION, DESCRIPTION. AND RESULTS OF WATER-YIELD EXPERIMENTS (HIBBERT 1967)

AREA ne	MID-AREA ELEV. m	SLOPE x 100 ELEV. DIFF. / LENGTH %	ASPECT	VEGETATION AND SOILS	MEAN ANNUAL PRECIP- mm	MEAN ANNUAL STREAM FLOW mm	DESCRIPTION OF TREATMENT (percentage refers to portion of area treated unless otherwise stated)	WATER YIELD INC YEARS FOLLOWING 1st	2nd	3rd	4t
16.1	810	26	NE	Mixed Hardwoods. Basal area about 24 m^2/ha. Granite origin deeply weathered sandy clay loam; up to 6 m deep base rock tight	1829	792	1940, 100% clearcut, no removal, regrowth 1962, experiment repeated	370 371	283	279	2
13.5	885	44	NW		1895	775	1941, 100% clearcut, no removal, regrowth cut annually except years 3,4 & 5	408	361	256	1
34.4	1035	35	N		2063	1275	1955, 50% poisoned in alternate 10m strips no removal, regrowth restricted 4 years	198	155	130	1
28.7	960	32	NW		2001	1222	1949, 22% basal area cut (understory only), regrowth	71	64	55	
16.1	840	34	S		1725	739	1954, 25% poisoned (cover hardwoods), regrowth restricted 3 years, 1956-7, 100% clearcut, partly burned, pine planted, regrowth restricted	152	48	46	
9.2	825	32	SE		1814	607	1940, 100% area cleared for agriculture	127	25	59	1
85.8	975	24	SE		1854	1072	1942 to 1956, 30% basal area cut by uncontrolled logging, regrowth	averaged 25 mm p			
28.7	1065	46	SE		2029	1085	1955, 35% basal area cut by selective logging, regrowth	averaged 55 mm p			
20.3	1035	42	SE		1946	1052	1955, 27% basal area cut by selective logging, regrowth	nonsignificant			
8.8	790	35	NW		1821	831	1942, (July), 19% clearcut (streambank vegetation), regrowth	immediate small significant on a			
43.7	1200	47	NE		2244	1583	1963, 100% clearcut, no removal, regrowth	236			
144.2	1200	31	NE		2370	1532	1962-4, 51% clearcut, timber removal, 26% thinned, regrowth	200 (approximate			
29.9	755	23	NE	Mixed Hardwoods. Basal area about 24 m^2/ha. Sand stone & shale, stony silt loam, 1 to 1.5 m deep.	1524	584	1957-8, 85% basal area removed by commercial clearcut, regrowth	130	86	89	
15.4	780	15	S		1500	660	1957-8, 36% basal area removed by diameter-limit cut, regrowth	64	36		
36.4	780	14	NE		1473	762	1957-8, 22% basal area removed by extensive-selection cut regrowth	36			
34.4	805	13	S		1500	635	1957-8, 14% basal area removed by intensive-selection cut, regrowth	8 (nonsignific			
24.2	800	13	NE		1469 (some snow)	788	1964, 50% (upper half) area cut, timber removed, regrowth not permitted	92 (growing sea			
95.9	700	28	NW	Coniferous Volcanic tuffs and breccias, clay loams, Shallow & deep			1962-3, 40% commerical clearcut 1963-4, 40% additional commercial clearcut	small increase f small increase ,			
101.2	760	32	NW		2338	1346	1959, 8% area cleared for road construction 1962-3, 25% clearcut & burned	small increase f small increase f			
354.1	640	17	S	Chaparral with wood and riparian vegetation along streams. Granite, rocky sandy loam, generally shallow	648	64	1958, 1.7% cut (riparian vegetation only), sprouts controlled, grases encouraged 1959, additional 2.6% cut (canyon bottom vegetation) sprouts controlled, grasses encouraged	May - December 5 January - April May - December 5			
40.5	885	32	S				1959, 40% poisoned (chaparral on moist sites) repeated application of herbicide	June - September			
100.4	2225	17	SW	Coniferous (ponderosa pine). Quartzite, clay loam up to 5 m deep.	813 (some snow)	86	1953, 1% cut (riparian vegetation only), sprouts controlled 1958, 32% cleared (moist site) grass seeded	nonsignificant 13	51	15	
128.7	2165	8	NW		813	87	1953-5, 30% basal area cut by selective logging 1955, 6% basal area cut by thinning 1957, 9% basal area cut reduced by burnning	nonsignificant nonsignificant nonsignificant			

TABLE E.26 (CONT'D)

LOCATION, DESCRIPTION. AND RESULTS OF WATER-YIELD EXPERIMENTS (HIBBERT 1967)

9.0	3200	18	N	Coniferous (lodgepole pine, spruce-fir). Granite, sandy loam. 2.5m deep	762 (75% snow)	283	1954-7, 40% commercially clearcut in strips, regrowth	86 53 79 97
1.1	3110	37	NE	84% Forested(aspen & Conifers) Augite, quartzite, rocky clay loam.	536 (50% snow)	157	1919, 100% clearcut, some removal, slash burned, regrowth	34 47 25 22
400				Conifers (spruce)	265		1941-6, insects killed up to 80% of timber on 30% of area	58 (average for 5 y
2.5	200	40	E	Conifer 60%, broad leaf 40%. Tuff shale	2116 (40% snow)	2075	1948, 100% cut, annual recut of sprouts	110 (average for 3
8.0	2200	5	NW	High montane & bamboo, Phenolite lava, deep friable clay	1905	416	1959-60, 34% cleared for tea plantation, clearweeded 1956, 100% cleared, pine planted, cultivation of vegetables for 3 years	103
5.2	2440		S		2014	568		457 229 173 Reduced water yield
8.0	520	30	SW	Sclerophyl scrub (chaparral type)		475	1940, 53% afforested with pine	104 (4-yr mean) at
0	365	30	SW			490	1948, 98% afforested with pine	142 (4-yr mean) at
7.6	350	14	SW	30% hardwoods in 1938. Sedimontary, silt loams	970 (little snow)	300	1938-9, 70% reforested, mostly pine	135 (after 19 years
5.7	160	5	E	23% mixed hardwoods & pine in 1934 Limestone, cherty silt loams	1230	255	1940, 75% reforested, mostly pine	76 to 152 (after 16
4	410	6	SE	65% mixed hardwoods	1184	460	1934-42, 34% reforested, mostly pine	no detectable chang
1	525	15	SE	Mixed Hardwoods & conifers	974	535	1932, 47% reforested, conifers	106 (after 26 years
1	365	35	S	Shales & sandstones overlain by glacial till, sandy loam 1m deep	1030	616	1934, 35% reforested, conifers	172 (after 24 years
8	520	5	S		1030	627	1931-9, 9.58% reforested, conifers	130 (after 24 years
200	575	1		Northern hard woods with conifers. Glacial till, sandy loam 1 m deep	1143 (some snow)	770	1912 to 1950, basal area increased from 17 to 28 m^2/ha	196 (after 38 years
45	275			Douglas-fir, western hemlock, Silty-clay loam & stony loam, 2m deep	3300	2696	1916 to 1954, 64% area logged at rate of 2% per year, regrowth	no detectable chang

In snowpack country, such as the Colorado Rockies, the openings should not exceed 8 times the heights of the surrounding trees and should be round or square to best protect against wind of varying direction.

Most forest land is managed primarily for wood production. Sometimes, wood-producing practices will benefit water yield and the increased flow would require no charge to water users. Where maximum water yield is important, practices desirable for water flow may conflict with maximum wood production (Trimble et al. 1963). In these circumstances, the general public or those directly receiving the water benefit will have to pay the costs.

Knowledge is now available to bracket the upper and lower limits of water yield increase possible from forest land management. Much research is needed to fully understand the processes involved, but that need not delay application of what is known. Those concerned with water resources should consider forest land management along with other alternatives for increasing water supply (Hoover, 1969).

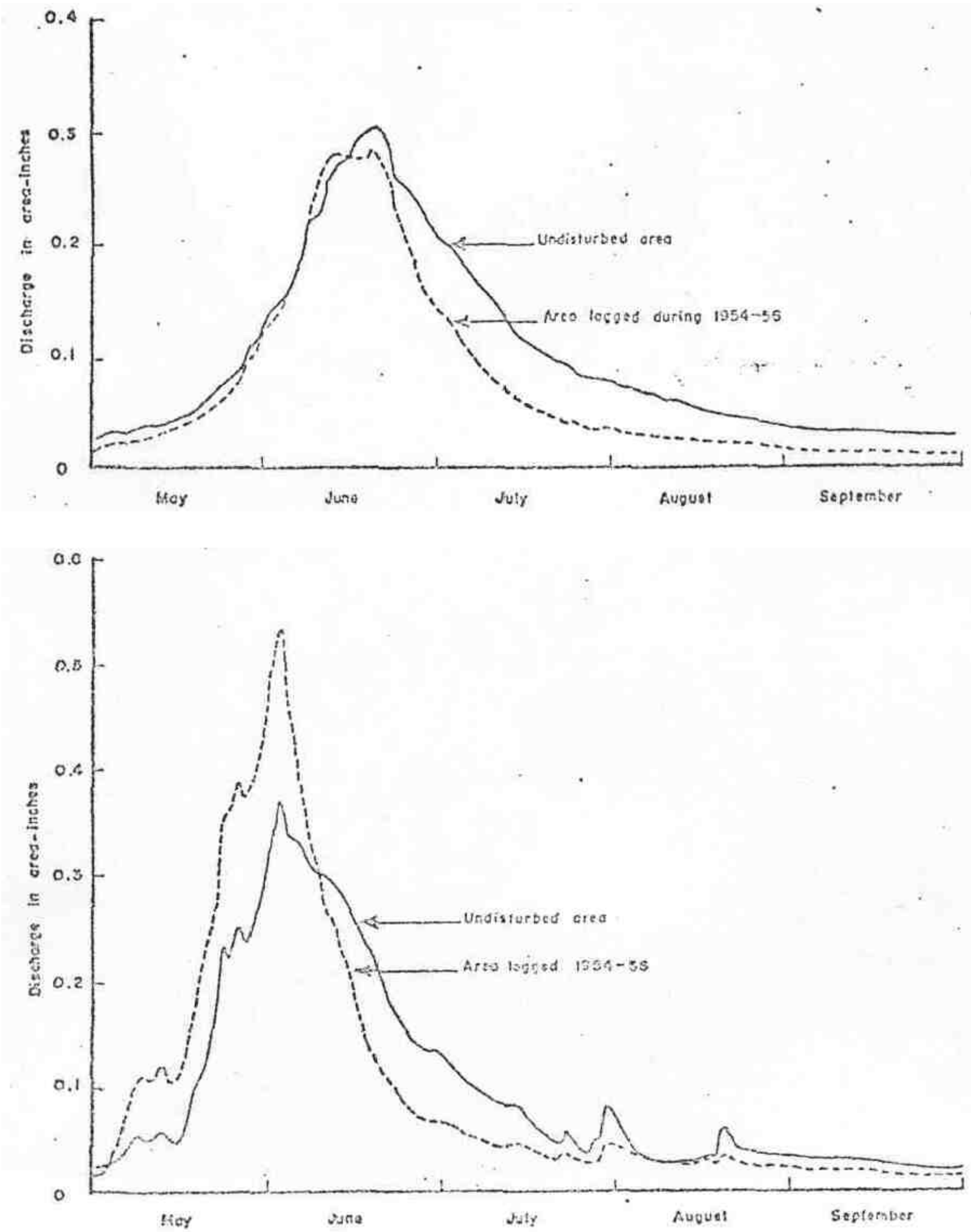
b) REGIME

Removal of forest cover will, as described, result in some increase in basin yield. Much of this yield will occur as a marked increase in peak flows. Information derived from the Fool Creek study (Goodell, 1958) is indicative of the type of flow regime that may be experienced on the Okanagan Basin and is shown in Figure E.12.

The influence of forest management of low flows is unpredictable (Johnson, 1967). Documented cases where logging increases low flows exceed cases where low flows have decreased.

Prolonging spring runoff to coincide with periods of increasing water demand depends, to a large extent on influencing snow accumulation and melt rates. Techniques of forest harvesting accumulation of snow and retardation of melt rates are described by Golding (1966). The main parameters involved are aspect, slope, tree height and direction of maximum solar radiation. He recommends:

i. on north aspects strip width 1.5H (where H = mean tree height) for slopes <20% and 2-4H on slopes >20% with strip orientation E-W.
ii. on south aspects strip width 1.5H for slopes <20%, 0.75H on slopes greater than 20% with strip orientation E-W.
iii. on east and west aspects strip width 1.5H oriented NE-SW and NW-SE respectively.



HYDRO
GRAPHS ON FOOL CREEK and CONTROL WATERSHED BEFORE CUTTING (UPPER) and in the FIRST YEAR AFTER CUTTING
(LOWER)

Figure E.12

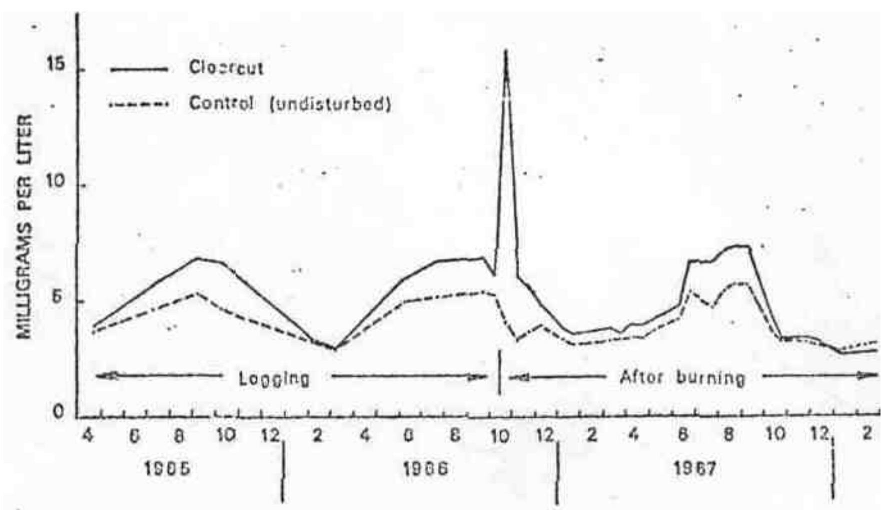
c) QUALITY

Forest land use, as it affects water quality, involves timber cutting, logging, clash disposal, road construction and chemical spraying.

Timber Cutting

Timber cutting alone does not result in any appreciable increase in sediment even though water yield may increase following cutting (Hoover 1944). However, direct effects on chemical water quality and stream temperature may accrue.

One of the few studies of the nutrient status of streams for which data are available was conducted on the H.J. Andrews Experimental Forest in Oregon (Rothacher et al. 1967). Nutrients in two treated watersheds were compared to nutrients in a control watershed. The concentration pattern of the cations sodium, potassium, calcium and magnesium followed closely the concentration of bicarbonate, the dominant anion in the Stream (Figure E. 13). The annual cycle of bicarbonation reached maximum concentrations during the warm season coincident with maximum respiratory activity and minimum during the cold season. The increase due to timber harvest occurred mainly during the warm season and the maximum flux of cations and phosphorus followed slashburning, but the flux of nutrients subsided rapidly.



Bicarbonate carbon concentration of streams after logging and after broadcast burning on the clearcut watershed.

Figure E.13

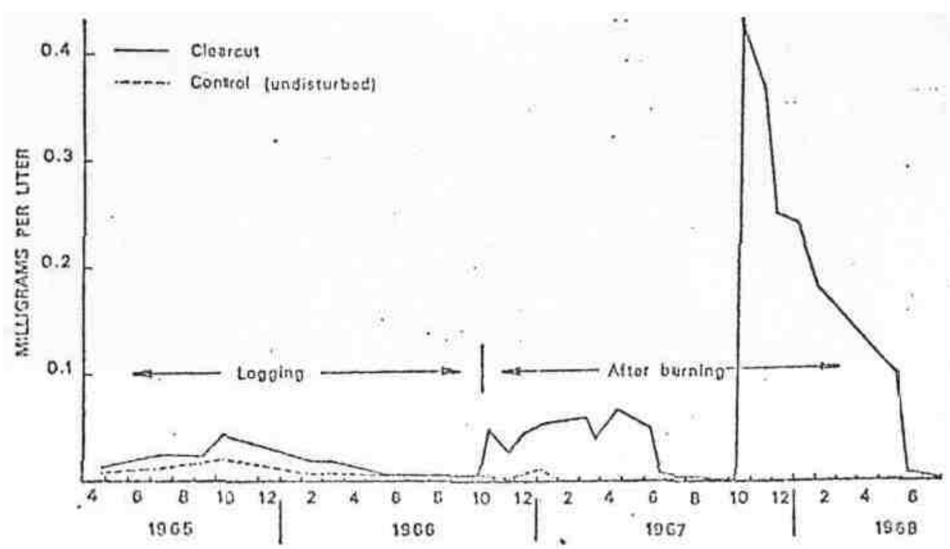
Mean annual concentrations of cations and bicarbonate in the stream of the clearcut watershed consistently exceeded the concentrations in the control stream (Table E.27). Concentration of a11 chemicals increased markedly following slashburning, with the largest increase for the dicalent cations of calcium and magnesium.

TABLE E.27

MEAN ANNUAL CONCENTRATION OF DISSOLVED CHEMICALS
OF STREAMS DRAINING CLEARCUT AND. CONTROL WATERSHEDS
(milligrams per liter)

	LOGGING ONLY		FOLLOWING SLASH BURNING			
	1966		1967		1968	
CHEMICALS	CLEARCUT	CONTROL	CLEARCUT	CONTROL	CLEARCUT	CONTROL
NH_3-N	-	-	.110	.003	.001	.000
NO_3-N	.020	.010	.050	.003	.200	.001
Na	2.700	2.600	2.600	2.000	-	-
K	.430	.420	.430	.330	.380	.220
Ca	4.800	3.300	5.800	2.800	5.000	3.000
Mg	1.200	.700	1.900	.800	1.300	.600
PO_4-P	.024	.026	.039	.016	-	-

The concentration of the two forms of nitrogen and phosphorus is about two orders of magnitude lower than the dominant cations. Nitrogen appears in the control stream as nitrate. Concentration rise in the clearcut was small during logging, but rose following burning and increased to even greater levels the second year following burning. Minimum nitrate concentrations occur in both streams during the summer months when organisms of the forest and the streams actively use nitrogen (Figure E.14).



Nitrate concentration. Figure E.14

Losses of dissolved chemicals were calculated by the product of concentration and streamflow. Annual streamflow from the clearcut watershed was nearly 1.5 times the control watershed. Annual losses calculated in this manner exceed the previous concentration data due to increase in streamflow (Table E.28). Although the amounts involved are quite large, the increases are moderate.

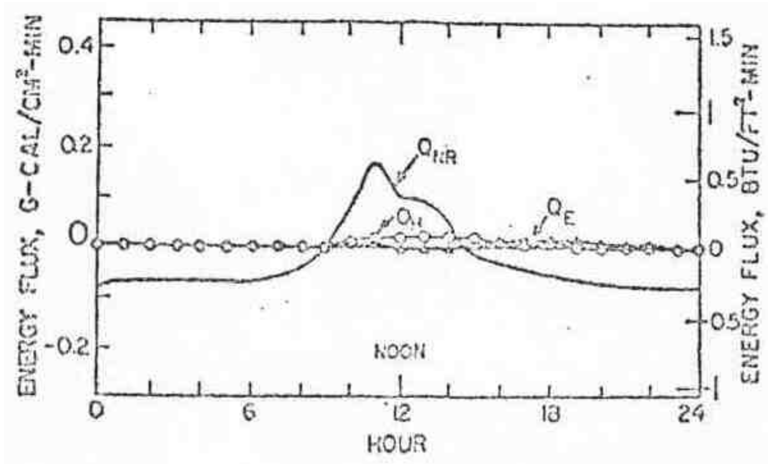
Nutrient chemicals also enter the stream attached to sediment or contained in organic sediment material. Amounts of sediment and the amount of sediment entering the stream. It is noteworthy that the loss of manganese on sediment (Table E.29) was the principal mechanism for loss of this element which was essentially absent from these streams in dissolved form. Although increases were large, "the amounts lost were small compared with dissolved chemical losses except for nitrogen and potassium.

Forest cutting has been shown to have a detrimental effect on the temperature of streams. Greene (1950) studies the effect of clearcutting on trout streams. He noted that maximum weekly temperatures recorded during May on the clearcut stream were 13°F higher than those recorded on a nearby forested stream. Meehan et a1. (1969) reported a maximum temperature increase of 9°F after logging along an Alaskan stream. Patric (1969) reported a maximum temperature increase of 7°F when the lower half of a small watershed was clearcut. The greatest changes in stream temperature caused by clearcutting were recorded during the Alsea Watershed Study in the Oregon Coast Range (Brown and Krygier, 1970). No increases in temperature attributable to logging could be detected in the patchcut watershed, where buffer strips continued to provide shade for the stream. In the clearcut watershed, mean monthly maxima were increased by 14°F during the first summer after logging debris was cleared from the channel. The annual maximum was increased by 28°F during the same year.

The principal source of heat for these small streams is solar energy striking the stream surface directly. Very little heat exchange at the surface as small streams results from convection, conduction or evaporation. Riparian. vegetation plays the greatest role in the rate at which solar energy reaches small, forested streams. An energy balance for a shaded stream is shown in (Figure E.15). All of the energy balance components are very small compared to the energy balance components of a small stream with no shade above it (Figure E.16). The factor which changes most is Q_{nr} , the net radiation, or in simpler terms the direct solar heat load. Variation in the degree to which the stream is exposed to direct sunshine, therefore, accounts for much of the magnitude of the temperature change of the stream following logging.

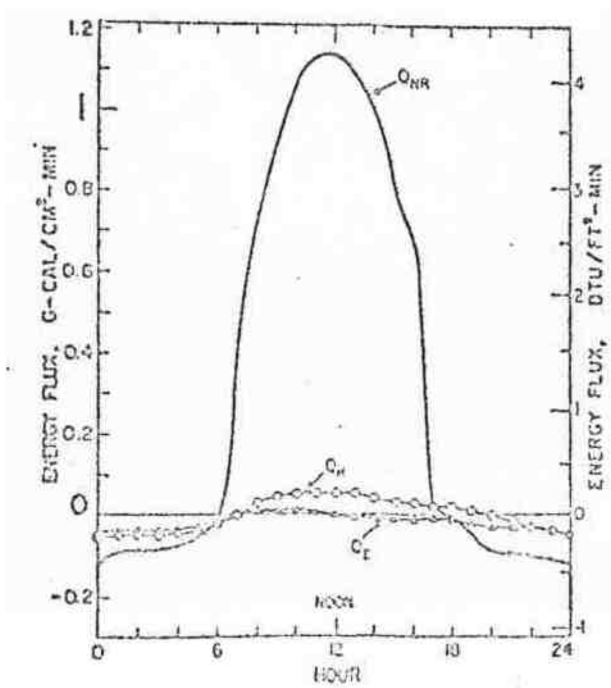
Logging

Extraction of timber from forested areas involves the use of heavy machinery, often on steep slopes, which can result in serious surface soil disturbance and compaction. Lowered infiltration rates results in increased surface runoff and



THE DAILY PATTERN IN NET THERMAL RADIATION (Q_{nr}) EVAPORATION (Q_e) and CONVECTION (Q_n) FOR A FORESTED STREAM (AFTER BROWN 1969)

Figure B-4



THE DAILY PATTERN IN NET THERMAL RADIATION (Q_{nr}) EVAPORATION (Q_e) and CONVECTION (Q_h) FOR AN EXPOSED, NON-FORESTED STREAM, (AFTER BROWN 1969)

Figure E.16

TABLE E.28

TOTAL ANNUAL DISSOLVED CHEMICAL LOSS

IN STREAMS DRAINING CLEARCUT

AND CONTROL WATERSHEDS

(pounds per acre)

	LOGGING ONLY		FOLLOWING SLASH BURNING			
	1966		1967		1968	
CHEMICALS	CLEARCUT	CONTROL	CLEARCUT	CONTROL	CLEARCUT	CONTROL
NH_3-N	-	-	1.34	.025	.010	.000
NO_3-N	.23	.07	.62	.025	2.150	.007
Na	30.80	18.60	31.70	16.800	-	-
K	4.80	3.00	5.40	2.800	3.100	1.600
Ca	54.30	23.60	72.70	23.500	54.700	21.400
Mg	14.00	5.00	23.40	6.700	14.300	4.300
PO_4 P	.27	.19	.49	.130	-	-
HCO_3-C	51.30	25.00	64.00	31.000	35.500	20.700

TABLE E.29

ANNUAL LOSS OF CHEMICAL CONSTITUENTS ABSORBED ON MINERAL SEDIMENT

PLUS THAT CONTAINED IN SUSPENDED ORGANIC MATERIAL

(pounds per acre)

CHEMICALS	CLEARCUT	CONTROL	CLEARCUT	CONTROL
Organic N	3.4	.140	1.7	.140
K	1.1	.023	.7	.022
Ca	2.8	.200	1.4	.400
Mg	1.7	.027	1.0	.027
Mn	1.4	.020	.7	.020

a related increase in sediment discharge. The relation of disturbance to runoff and erosion depends primarily on the kind, degree, location and continuity of disturbance (Packer 1967).

Tractor or skidder logging results in the greater disturbance because of the presence of heavy equipment on the site during the extraction process. The quality and location of skidroads determines the amount of sediment provided by tractor logging. A study at the Fernow Experimental Forest (Reinhart et al. 1963) showed how quality and planning of skidroads effects the amount of sediment in streams. Maximum streamflow turbidity was as follows:

Control watershed	15 ppm
Intensive selection-forester planned	25 ppm
Extensive selection-forester planned	210 ppm
Diameter limit-logger's choice	5200 ppm
Clearcut-logger's choice	56000 ppm

Cable logging is much less destructive than tractive logging for the obvious reason that heavy equipment remains on the haul road. Compaction and soil disturbance occur on yarding 'roads' which often become sources of sediment production. The disturbance from downhill yarding tends to be greater than uphill yarding. Since there is a lower vertical lift component in downhill yarding the operator has less control over the logs and yarding 'roads' tend to concentrate overland flow at the landing.

Road Construction

Of man's activities that disturb vegetation and soil in forests, few cause more damage to water quality than road construction. By exposing raw mineral soil, compacting soil surfaces, altering surface and subsurface drainage patterns and reducing slope stability, road construction initiates increased surface erosion and mass movement. Table E.30 shows some values of increased sediment loads attributable to road construction in road construction in forested watersheds.

TABLE E.30

SOME EXAMPLES OF SEDIMENT PRODUCTION ATTRIBUTABLE TO ROAD CONSTRUCTION

LOCATION	CONTROL	MAXIMUM TURBIDITY AFTER ROAD CONSTRUCTION	SOURCE
H.J. Andrews Exp. Forest	200 ppm	initial 2 1/2 yrs. later	Fredrickson, 1963
Zena Creek	nil	89-17400 tons/sq.mi.	Copeland, 1963
Cowceta Exp.	4-8-ppm	94-5700 ppm	-
Fool Creek	nil	1.5 ft. ^{3}/ sq.mi.	Goodell, 1958

The extent of the detrimental effects of road construction is a function of the climate, geology, soils, slope, area extent of roads and road gradient.

Road construction tends to increase the incidence of mass movement, particularly on steep slopes and weathered till soils having a low cohesive strength such as those of the upper elevation of the Okanagan Basin. Such incidents include roadfill failure, backslope failure and soil movement by concentration of drainage waters.

Slashburning

Slashburning can affect the soil physical properties which control infiltation capacity. The adverse effects of slashburning on soil properties influencing infiltration are related to the severity of the burn. Severe burns reduce macroporosity, destroy water stable aggregates, remove organic matter and can lessen soil wettability. Reduced infiltration capacity increases the possibility of the occurrence of overland flow and subsequent increases in surface erosion.

Chemical Spraying

The spraying of insecticides, pesticides and herbicides is not a common forest management practice in the southern Interior and is usually undertaken only when other forms of control are inadequate.

Indiscriminant application of biocides to large forested areas has resulted in water quality deterioration, particularly detrimental to indigenous fish populations. Examples include:

- aerial spraying of 11.5 million acres of spruce in New Brunswick with 1 lb./acre of DDT for the control of spruce budworm which resulted in severe reductions in Atlantic salmon and brook trout populations (Keenleyside, 1959).
- aerial spraying of 155,000 acres of forest land on northern Vancouver Island for the control of black-headed budworm with lb./acre of DDT which resulted in severe damage to resident trout and salmon populations (Crouter and Vernon, 1959).

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