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Alberta Watershed Research Program Symposium Proceedings, 1977

compiled by R.H. Swanson and P.A. Logan

Northern Forest Research Centre • Edmonton, Alberta • Information Report NOR-X-176

ALBERTA WATERSHED RESEARCH PROGRAM

SYMPOSIUM PROCEEDINGS, 1977

31 AUGUST - SEPTEMBER 1977

COMPILED BY

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INFORMATION REPORT NOR-X-176
NOVEMBER 1977

NORTHERN FOREST RESEARCH CENTRE
CANADIAN FORESTRY SERVICE
FISHERIES AND ENVIRONMENT CANADA
EDMONTON, ALBERTA, CANADA
T6H 3S5

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* Published as A policy for resource management of the Eastern Slopes and available for $1.00 from Alberta Energy and Natural Resources, Resource Information Services, 9915 - 108 Street, Edmonton, Alberta. T5K 2C9.

WHO WANTED MORE WATER?

In October of 1947, the Eastern Rocky Mountains Forest Conservation Board set out the following as one of the goals to be pursued in the management of the forest reserve area of the Saskatchewan River headwaters:

> To conserve, develop, maintain and manage the forests in the area with a view to obtaining the *greatest possible flow* in the Saskatchewan River and its Tributaries. [italics mine]

Obviously someone had expressed a need for more water and felt that the headwaters should be managed to provide as much as possible.

The Alberta Watershed Research Program developed specifically to provide possible forest management schemes to fulfill this objective. As the program nears this goal, we seek assurance that the asked-for research will be used. I can find no written evidence that any water resource agency in Alberta, Saskatchewan, Manitoba or the Government of Canada has even planned to use watershed manipulation to augment water supply in the Saskatchewan River system. Nor can I find evidence that any agency has even seriously considered the possibility!

The results from our research program, coupled with those from experimental watershed research elsewhere, provide reasonable grounds to believe that carefully designed forest harvest can indeed increase watershed yield by about 25% without deteriorating water quality. The purpose of this symposium is to draw the attention of water resource agencies to a few of the results of this program. A second purpose is to ascertain the use pressures being applied to the Saskatchewan River headwaters.

This symposium will be partially successful if only these two purposes are attained. But the most important purpose is to rouse interest in watershed management, and this cannot be fulfilled until the findings of the Alberta Watershed Research Program and those of forest hydrology research elsewhere are evaluated with respect to augmenting water supply in the Saskatchewan River system. This evaluation should result in either proposals to manage the watershed for increased yield or dismissal of watershed management as irrelevant for augmenting water supply from the Saskatchewan River watershed.

R.H. Swanson
Research Coordinator
Alberta Watershed Research Program

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THE ALBERTA WATERSHED RESEARCH PROGRAM
1959-1977

R.H. Swanson

ABSTRACT

A continuing problem of timely water supply exists in the Saskatchewan River Basin. Management of the forested headwaters to enhance water yield, regime, and quality is a partial solution. The Alberta Watershed Research Program (AWRP) was founded in 1959 to provide techniques for carrying out forest management to modify water variables.

The AWRP is a cooperative program involving 13 federal and provincial agencies directly and numerous others indirectly. Notable achievements are a description of the basic hydrological characteristics of the Saskatchewan River headwaters, two harvest treatments on the Marmot Experimental Watershed, an evaluation of the effect of large-scale commercial clear-cutting on water yield, continuing impetus for application of findings to operational water management, and cooperation among agencies and individuals with diverse interests in water.

THE ALBERTA WATERSHED RESEARCH PROGRAM 1959-1977

R.H. SWANSON[1]

RESEARCH PROGRAM

Problem

The basic reason for initiating the Alberta Watershed Research Program (AWRP) was (and still is) a problem of timely water supply to users of Saskatchewan River water. Seasonal water shortages and/or surpluses prompted the formation of the Eastern Rockies Forest Conservation Board in 1947. An integral part of the board's responsibility was watershed management, conservation, and restoration. Lack of specific techniques to solve these problems prompted the board to request research directed toward their solution. The result of that request is the existing AWRP formed in the period 1959-1963.

Objectives

The objectives of the AWRP were stated orginally as:

1. To provide ways of improving the flow (quantity), quality, and timing from the watershed

2. To provide a better understanding of hydrologic processes both locally and in the whole (East Slopes) area

3. To provide methods of protecting and monitoring the watershed while forest and other resources are being utilized

4. To provide ways of restoring damaged watersheds

Although these objectives are still in effect in 1977, a simpler summary was adopted in 1970:

> To determine how to manage wild land areas under public control in Alberta for water production and water supply protection.

Physical Areas of Interest

An 23150-km^2 area was administered by the Eastern Rockies Forest Conservation Board. This land (apart from that within Waterton, Banff, and Jasper national parks) is the manageable headwaters for the entire Saskatchewan River. These headwaters were then further divided upon vegetation-hydrologic lines for specific water yield research. A small catchment was chosen from each zone as a representative type for intensive study. The area in each zone and its representative are shown in Table 1. Of these,

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[1] Research coordinator, Alberta Watershed Research Program.

the spruce-fir-alpine is the most important in terms of water yield for streamflow and thus for study directed toward eventual manipulation for altered water production for downstream users.

Table 1. Vegetative-hydrologic zones of the Forest Reserve.

Type	Area*	Annual Water yield	Representative
Alpine-krumholz	7252 km^2	380-760 mm	Marmot
Spruce-fir	5853	178-508	Marmot
Lodgepole pine	4351	0-125	Deer Creek
Aspen-grasslands	4351	0-125	Streeter

* Does not include area in the national parks

In 1969 the scope of the up-to-then East Slopes Watershed Research Program was expanded to include the entire province of Alberta, and the name was changed to reflect this. One effect of this expansion was to allow the AWRP to be involved in the industrially oriented forest management areas in west-central Alberta and in lands being converted from forest or bush to agriculture. Both Marmot and Deer Creek were slated for the testing of the effects of some commercial harvest on water yield. However, a study to ascertain the effect of some 20 years of harvest activity on the North Western Pulp and Power Company Ltd. lease near Hinton satisfied the commercial harvest objectives for Deer Creek. This study verified to the satisfaction of most AWRP members that forest removal does increase streamflow. Three of the papers given in this symposium are based on data obtained during this study.

The Forest as a Hydrologic System

Most of the activities of the AWRP are centered in the forested portion of Alberta. Forests generally occur in areas of high precipitation and these are areas of high water yield. About half of the research of the AWRP has been devoted to understanding and describing the hydrology of the East Slopes, while the remainder has dealt with the interrelations between forest and water.

In forest hydrology research, a forest represents a particular kind of physical system that is studied more from the standpoint of its time rate of water yield (hydrograph) rather than its wood fiber production. The characteristics of a forest that make it an interesting and unique hydrologic entity are the physical presence of a canopy, its spatial arrangement, and the associated forest floor. In these respects the vigor, species composition, physiological condition, to some extent age, applicable silviculture, and marketability of the trees are unimportant. The important thing is that the dimensions of the canopy are physically significant in altering aerodynamic and energy processes. The silviculture and marketability of the wood becomes important only when the economics of a particular watershed management strategy are being considered.

It is this consideration of a forest as a physical system that modifies precipitation-runoff relationships, rather than as a physiological system that produces wood, which makes forest hydrology a discipline unique from either forestry or water resources. Forest hydrology necessitates interaction between those familiar with the forest biological system and those familiar with streamflow. Because of this need for interaction, the research program of the AWRP involves a number of federal and provincial agencies.

RESEARCH ORGANIZATION

The AWRP is organized around three functional components: steering, coordination, and cooperation.

Steering

Broad direction and final approval of all AWRP research is provided by a Steering Committee. The members of this committee are directors who have the authority to commit manpower, finances, and equipment within their respective agencies to carry out approved research. The membership of the Steering Committee is fixed and consists of the following agencies:

Northern Forest Research Centre (Edmonton)
Alberta Forest Service (Edmonton)
Canadian Wildlife Service (Edmonton)
Atmospheric Environment Service (Edmonton)
National Parks Branch (Calgary)
Alberta Fish, Wildlife and Parks (Edmonton)
Water Survey of Canada, Inland Waters Directorate (Calgary)
Research Council of Alberta (Edmonton)
Hydrological Sciences Division, Inland Waters Directorate (Calgary)
Prairie Farm Rehabilitation Administration (Regina)
Technical Services Division, Alberta Environment (Edmonton)

Coordination

Coordination in the sense used here means the day-to-day management of research effort. This function is divided between a research coordinator, furnished by the Canadian Forestry Service (Northern Forest Research Centre) and a management coordinator, furnished by the Alberta Forest Service. Their duties are outlined as follows: The research and management coordinators, in cooperation with the agency (s) concerned, are responsible for planning, developing and initiating a research program to resolve a particular problem, with the concurrence of the steering committee. The research coordinator looks after the research planning, the management and research coordinators jointly or separately outline a particular problem, and their joint efforts are directed toward developing and implementing the plan through the cooperation of the concerned research and/or management agencies.

Most research conducted within the AWRP is cooperative, that is, an agency that wants to do a particular piece of research would likely carry it out whether or not the AWRP existed. However, to be effective, some research requires the combined efforts of several agencies, or their input at scheduled times. An example is the conduction and evaluation of a harvest treatment on a catchment. In this case, four different agencies measure streamflow, and groundwater, weather, and forest parameters, while a fifth agency is responsible for the actual timber removal. Both coordinators must play an active role to ensure that the data collected and/or studies conducted fulfill the objectives set forth in the research plan approved by the Steering Committee.

Cooperation

Cooperation within the AWRP is sought by involving as many concerned individuals as possible in its research. A Research Coordinating Committee meets as needed to provide a vehicle for individual and/or agency cooperation. The research and management coordinator are co-chairmen of this ad hoc committee, which has no fixed membership list. Any person or agency interested in the interaction between land use, hydrologic parameters, streamflow, or water quality is welcome to join and participate. The functions of the Research Coordinating Committee are:

1. To provide advice and assistance to researchers

2. To facilitate cooperation among agencies

3. To become familiar with and remain informed on research done by other agencies locally, nationally, and internationally

4. To ensure awareness of available data, reports, and published reports relevant to the watershed research program

The large manpower commitment by the federal Forestry Service tends to mislead outsiders into thinking that the research program is being conducted by the Northern Forest Research Centre for the Canadian Forestry Service. It is not! The program is being conducted for water users. The goals of the AWRP are water oriented: one of its basic goals is to provide forest management systems designed to enhance water production. The basic reason for initiating the AWRP was and still is a problem of water supply to users of Saskatchewan River water. It may be reasonably inferred that the seasonal water shortages and/or surpluses that prompted the formation of the federal-provincial Eastern Rockies Forest Conservation Board in 1947 are even more crucial in 1977, as evidenced by the recent flurry of activity at both the federal and provincial level to prepare drought contingency plans. The water shortage problem still remains to be solved.

OPERATION OF THE AWRP

Perhaps the best way to illustrate how the AWRP functions is to use a specific example. The most obvious and well-known example is Marmot basin. Because the subalpine forest is so important as a water-yielding area, and because Marmot represents it, the entire AWRP has at times seemed to be one and the same as the Marmot program. However, Marmot is just one of several similar research efforts in which the AWRP is engaged.

Description of Marmot Basin

Marmot is a 9.4 km^2 catchment near Seebe, Alberta composed of 3 subbasins (Cabin, Middle, Twin) and a confluence area. It is partially timbered with old growth spruce and pine, with a large proportion of alpine at the high altitude portion, and some recent fire-origin new growth lodgepole pine near the bottom.

Marmot is an outdoor laboratory in which to conduct hydrological experiments. It represents a type of forest complex that is repeated many times throughout the subalpine forest areas of Alberta and the Rocky Mountains in general. It is both a place to carry out experiments, and upon harvest, an experiment itself.

Objectives

1. To establish the subalpine forest zone hydrology, particularly relating to precipitation, runoff, and groundwater, and their interrelationships within the basin

2. To establish the effect of commercial timber harvest and subsequent regrowth in subalpine spruce-fir forest upon water yield and regime and groundwater

3. To develop methods and establish the effects of purposeful manipulation in high-elevation protected spruce-fir forest upon water yield and regime (from plot study results)

These were the objectives stated by Jeffrey in 1964. In each, the effect on water quality is also implied even though not originally stated.

Research Strategy

The strategy that the present research coordinator has adopted to satisfy the Marmot as well as other AWRP objectives is:

1. To provide quantitative conceptual models between forest stand parameters and the various hydrologic cycle elements for eventual synthesis into an overall watershed simulation model

2. To use our own, as well as other watershed simulation models, to simulate the effect of changes in hydrologic cycle elements, such as snowmelt, evapotranspiration, infiltration, etc. on generated runoff and to test the results of such simulations through plot or watershed manipulation trials.

3. To use our own or other simulation models and test results to produce practical forest management prescriptions to improve the water-yielding characteristics of the Saskatchewan River headwaters

Marmot Basic Hydrology

The principal inputs to any hydrologic research effort are basic hydrologic data, i.e. weather, watershed parameters, and streamflow and groundwater flow. The description of these characteristics has been largely the responsibility of the Meteorological Branch, Atmospheric Environment Service; Water Survey, Canada Department of Fisheries and the Environment; and the Groundwater Division, Alberta Research Council, respectively. These agencies have installed precipitation gauge, climatic station, stream gauge, and piezometer-groundwater well networks throughout Marmot. The Water Survey of Canada has compiled all of these measurements into an annual publication for distribution to both AWRP cooperators and to interested parties elsewhere upon request.

The Atmospheric Environment Service has conducted special climatology studies that add to the basic hydrologic description. Among these are maps giving the theoretical point solar insolation for any point on the basin and energy budget studies to evaluate the overall water balance for the basin.

The Water Survey of Canada has also computed calibration equations for any of the three subbasins against one or more controls. The Research Council of Alberta has prepared a water balance based on groundwater information.

To 1974, the investment of money, manpower, and equipment by these agencies towards describing basic hydrology amounted to $740,000, approximately 50% of the $1.5 million then attributable to Marmot research. In additon, Alberta Environment, the Eastern Rockies Forest Conservation Board, and the Alberta Forest Service had invested an additional $161,000 directly relevant to basic hydrology in the form of maps, topographic descriptions, timber inventory, etc.

The Canadian Forest Service has also contributed to basic hydrologic inventory. Beke (1969) has described the soils in hydrologic terms and recommended upon those suited for watershed management. Kirby and Ogilvie (1969) prepared timber and habitat maps for the whole of Marmot, and the Insect and Disease Survey conducts an annual survey of the status of these dangers to the forest. These activities may be considered directly applicable to basic hydrologic data.

There are also a number of Northern Forest Research Centre studies that contribute indirectly to basic hydrology. These are ordinarily studies conducted for some other reason, but data are applicable to the hydrologic inventory as well. For instance, a measure of the snow distribution under the existing canopy is necessary to an evaluation of any change in distribution that might occur upon harvest. The Northern Forest Research Centre initiated a 1500-point sample in the spring of 1969 to ascertain this distribution. These same data were used to improve the precipitation data base for the entire basin as well. Likewise, the data from Northern Forest Research Centre surveys of air temperature, snow accumulation and melt (snow pillows), local groundwater regime, and depth to bedrock are useful in describing basic basin hydrology too.

The Northern Forest Research Centre also maintains a full-time technician at Kananaskis Forest Experiment Station to service Marmot instrumentation. He checks stream and precipitation gauges for the Atmospheric Environment Service and Water Survey of Canada and piezometer-groundwater installations for the Alberta Research Council. He also collects water samples for chemical analysis by the Water Quality Branch, Canada Department of Fisheries and the Environment. Approximately one-half of his time is devoted to matters related directly to basic hydrologic data collection.

Inorganic water quality has always been a basic hydrologic parameter collected for the Marmot program. Recently, organic water quality has also received attention from the University of Calgary, Environmental Sciences Centre. These data are also part of the basic hydrologic inventory.

It is often difficult to specify that part of any participating agency's data that contributes directly to basic hydrologic inventory. Most data, regardless of why or by whom it is collected, is applicable toward this objective.

Marmot Experimental Program

Manipulative timber harvest trials marked the end of the time when Marmot was simply a place to do research and became an experiment. The descriptive work done in establishing the hydrology of Marmot was necessary but not sufficient for evaluating these experiments.

The experiment represented by some timber removal from a watershed is evaluated by comparison of some altered parameter such as streamflow, sediment, snow accumulation, etc. against the same parameter on an unaltered watershed. Two such experiments were planned for Marmot, thus necessitating at least three subwatersheds: two for manipulation, one held for control. The descriptive hydrologic data most directly relevant to the evaluation of these experimental manipulations are streamflow and precipitation on the control and treated watershed. However, those data necessary to evaluate the change in microclimate, local groundwater flow patterns, etc., caused by forest harvest were not part of the basic hydrologic data gathering program. Nor could they be until such time as the physical placement of harvested areas was designated.

The two experiments that were planned for Marmot are:

1. An evaluation of an application of the existing commercial harvesting guidelines with respect to their effect on sediment and chemical water quality.
   This harvest was conducted in 1974. There were some modifications from the commercial practice of 1974 that were intended to bring this harvest more into line with that which existed between 1947-1970; i.e., all standing material not harvested from a block was knocked down. However, the cut-block size is as presently practised. Thus, this harvest's effect on water quality should be a sample of that now occurring in this vegetation zone.

2. A test of a harvest pattern designed to increase postpeak recession streamflow.
This harvest, in 1-tree height diameter circular opening, is being done at present, with completion scheduled for late 1978. The design is the integrated result of plot studies near Sundre and on Marmot itself. The Steering Committee approved this harvest in March 1977.

The Northern Forest Research Centre is conducting several studies on Marmot specifically designed to evaluate the effect of both the commercial and noncommercial harvest. These are:

1. Snow distribution and accumulation patterns in and surrounding the harvested blocks

2. Moisture movement in the saturated and unsaturated soil profile as affected by harvest

3. Soil disturbance and erosion following harvest

The Atmospheric Environment Service has conducted a special study of wind pattern in the cleared areas of the Marmot commercial harvest. The Water Survey of Canada has maintained its stream gauges on the three subbasins and intensified its sediment sampling program to coincide with the harvesting operation. The Canadian Wildlife Service has stepped up its program to ascertain wildlife usage of the Marmot area. These, as well as the organic water quality program of the University of Calgary, are continuing through the evaluation phase of both the commercial harvest on Cabin and the research harvest on Twin.

APPLICATION OF FINDINGS

All this research would be for naught if not applied. The work defining basic hydrology is being used in streamflow forecasting and modeling by Alberta Environment and the Water Survey of Canada. However, this could have been done with data from a far less comprehensive program than the AWRP. Certainly this limited use would not be sufficient to justify our existence.

The goal that really made the AWRP different from most watershed research programs is that of providing ways of improving streamflow quantity, water quality, and regime from the East Slopes watershed. This goal implies some thought toward an active program of streamflow augmentation through watershed management. Some "ways of improving flows" were known in 1962; these same "ways" plus a few others are available today. A model to apply these "ways" to land management became available with the publication of the Stanford IV watershed model in 1964; even more are available today. Yet, none of these models has received much attention or application in Canada, largely because of a reluctance upon the part of hydrologists to accept the results of small watershed studies as applicable to large basins. Our experimental watershed test results will strengthen the convictions of the already convinced but do little toward gaining application. Apparently a test on a river basin scale is necessary to achieve this.

One of the AWRP's research efforts approaches the "river basin" scale. The streamflow increase from the presently harvested areas on the 7800-km^2 North Western Pulp and Power Company Ltd. lease near Hinton was measured in 1974. Nine catchments 7-24 km^2 from 35 to 85% clear-cut were gauged, and the resulting areal water yield was compared with that from 9 unlogged controls. The logged catchments yielded 186.6 mm versus 147.4 mm from the controls. These results substantiate those from experimental watershed experiments throughout the world. This still does not demonstrate applicability to increasing yield from a single large watershed, but it certainly increases the probability of doing so.

CONCLUSION

This, then, is the AWRP, a mix of foresters, engineers, biologists, chemists, hydrogeologists, meteorologists, climatologists, and others. Our principal goal is to learn how to produce more timely and useable water in the Saskatchewan River System through a better understanding of the hydrologic system and by forest management in the headwaters. Some techniques for altering water supply are available now and more will be available in the near future as a result of this program's research. However, our goal as a research program can only be partially satisfied until these techniques are evaluated and used to enhance the water yielding-characteristics of this watershed.

An extensive bibliography from the AWRP to 1977 is attached.

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THE EXTENT OF WATER LICENCING IN TWO RIVER BASINS IN THE EAST SLOPES WATERSHED

BY

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THE EXTENT OF WATER LICENCING IN TWO RIVER BASINS
IN THE EAST SLOPES WATERSHED

ABSTRACT

Two river basins on the East Slope Watershed in Alberta, the Elbow River above the Glenmore Dam and Willow Creek above the mouth, have been analysed to determine the extent to which the median annual runoff has been allocated to water users. A computer model simulated the licencing procedure used by the Alberta Department of Environment, Water Rights Branch.

The median annual runoff volume was selected as the level of available water. The extent to which water in an area is licenced is a function of:

(a) the amount granted to the applicant at a given diversion point
(b) the amount of water already allocated to other users both upstream and downstream
(c) the volume of available water from the drainage area

The results of the project showed that water in some small local areas has already been totally allocated up to the median annual runoff level. However, major portions of the investigated basins still have some water available. The main problem encountered by users at this level of allotment would be one of time distribution rather than of the absolute unavailability or deficiency of water.

EXTENT OF WATER LICENCING IN THE WILLOW CREEK AND ELBOW RIVER

Introduction

Demands on the water generated from the East slope of the Rocky Mountains extend back to before the turn of the nineteenth century and have been steadily increasing since that time. Recent growth of demands has produced much anxiety over possible shortages. With its increase, the necessity for knowing how much, when and how often the water supply is generated has become more urgent. Through cooperation with the Water Rights Branch of the Department of Environment, the Hydrology Branch has modelled the licencing procedure and incorporated into it appropriate hydrological parameters that would help to evaluate the extent to which a watershed had been licenced.

Hydrologic Consideration in Determining the Extent of Licenced Water in a Basin

An awareness of hydrologic criteria in a watershed is required to evaluate the interaction of water uses (licencing) on the water supply in a basin.

This paper outlines the general assumptions and procedures of the method used in analysing the extent of water licencing in Alberta watersheds. In developing the current model, four major points of water licencing and hydrologic interaction were considered.

(A) The method of setting priority of water rights in the watershed.
(B) The water rights in relationship to the time of year when water is available.
(C) The criteria used in allocation of water within the basin.
(D) The extent to which an area is licenced.

A. The Method of Setting Priority of Water Rights Within a Watershed

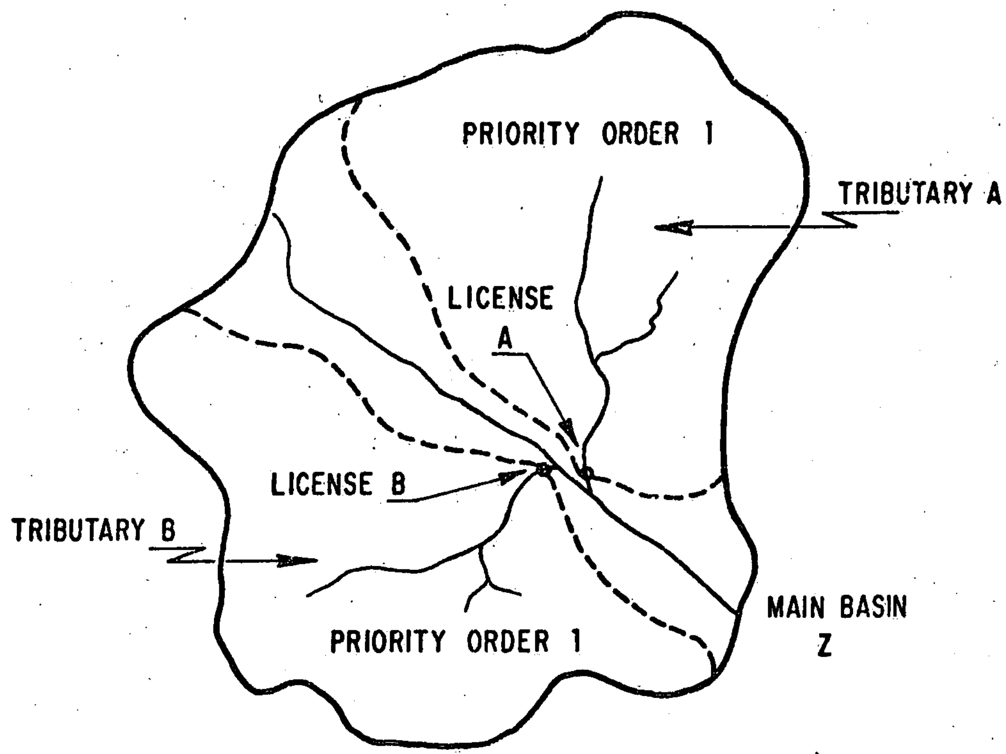
The water rights priority is established by the date of application, as stated in Section 11:2 (1) of the Alberta Water Resources Act.

> "Such applications have precedence according to the dates of their filing with the Minister, and they shall be numbered consecutively in the order in which they are filed."

A unique licencing number, based on the date of application, determines the priority of a licence. Within a given watershed, however, actual priority of use is subject to two considerations: one is the date of application, and the second is the physical location in the basin relative to other licenced diversions. For example, two licences on different tributaries of a main drainage system would have equal priority of use within their respective tributaries. Mathematically these can be described as complementary areas. In Figure 1, licences A and B are complements of each other within the "universal" main basin Z. As they are the first licences granted on the respective tributaries their priority of use would be of the same order. Water from A is not available for use by B and vice versa because of their physical location in the system.

LICENCING PRIORITY

FIG. 1



B. <u>The Water Rights in Relationship to the Time of Year When Water is Available</u>

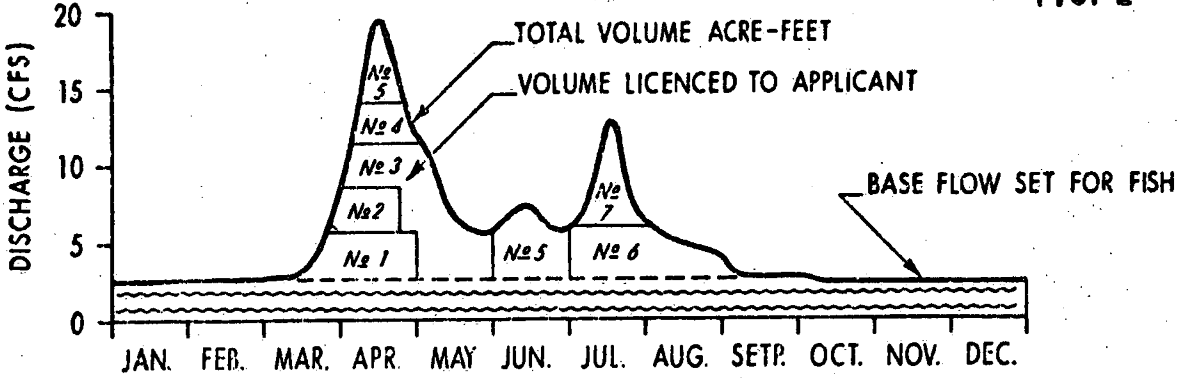
Section 37:1 (1) of the Water Resources Act states:

> "Licensees have priority among themselves according to the number of their licences, so that each licensee is entitled to receive the whole of the supply to which his licence entitles him before any licensee, whose licence is of a higher number, has any claim to a supply."

This created a hydrologic problem in deciding who should take water when. Does the #1 licence have the right to take his entitlement out of the system at anytime of the year he wishes, or is his entitlement the first available water? This situation is illustrated in Figure 2.

3

FIG. 2



HYDROGRAPH OF AVAILABLE WATER AS RELATED TO PRIORITY OF WATER USE

This concept becomes important in basins where most of the annual runoff is generated in the spring, i.e. at a time when its usefulness is not always at its prime. Does a higher priority licence have the right to wait and take the water at a more convenient time, passing water earlier in the year, and thereby forcing lower priority users out of water supply during prime use times?

Licences are awarded on an annual basis. As our objective in this study was to determine how much of the supply was being used, we were not totally concerned with the problem of distribution within the year. The manner or pattern of use is a problem of water management; who takes water when for largest benefit to all. The criteria accepted in our present analysis is that the total volume licenced cannot exceed the total generated on an annual basis.

To obtain a more complete insight into the extent of water use relative to supply, the range of expected annual runoff in the watershed is required. This may be achieved through the analysis of the frequency distributions of annual runoff for the area. These distributions for several metered locations in the Willow Creek and Elbow River basins constituted the data basis applied to estimate the specific runoff yields used in the analysis. The range of water supply availability includes the median, the 1:5 year, and the 1:10 year drought runoff. When the quantity of water allocated in a system approaches the median supply, management of that supply is needed. Observe the conflicts between water users if everyone licenced in figure 2 wanted to take water during June. If all licencees claimed their water rights in June there would be a water shortage. When allocation reaches this proportion, water rights move from the licence issuing stage to the water management stage of the resource.

C. The Criteria Used in Allocation of the Water Within the Basin

Water in the province of Alberta is allocated to a licencee "X", up to 100% of the available water for licencing, provided other licencees of higher priority can obtain their water allocation from some other portion of the watershed than the drainage area above "X". As the basin becomes progressively licenced, areas of total allocation increase until a point is reached where one more licence prevents the highest priority licencee from having sufficient water to meet his allocation sometime during the year. In effect, the area contributing to his licence is reduced in size until the mean annual runoff from that area is equal to his water allocation.

The method employed in keeping track of the licencee's priority and location relative to other licences is facilitated by describing the drainage areas as sets and subsets of each other. The method is relatively simple. In hydrologic terms, a licence is located geographically at its diversion point, which becomes the licence reference point. The drainage area and mean annual runoff (ac.ft.) are determined for that licence. Other licences are divided into two categories relative to the reference point.

(a) Those licences, within the watershed, upstream of that point of higher priority.

(b) Those licences of higher priority downstream of that point. Licences considered downstream are only those that are on the main stream as one travels downstream from the reference point.

When a new licence is being considered, licences of higher priority are checked to see whether they will have sufficient available water for their present allcation, and whether there is any water remaining for future consideration. The procedure is continued until all water generated in the year is allocated. The balance left for licencing is then printed out for all reference points in the drainage system.

D. The Extent to Which an Area is Licenced

For this study, a watershed is considered fully licenced when the total water allotment equals the median* annual runoff. At this level of licencing, the total water allocated is expected to be equal to or greater than the amount generated half the time. Amount of water generated half the time is actually physical equivalent of the statistical notion of median. During drought years water management would be needed to insure maximum utilization of water in the basin. The low priority licencees could be completely out of water if higher priority licencees were consuming all water allocated to them. By this time complaints of water shortages are usually occurring because available streamflow is out of phase with the habits of water users. Most want water in August when flows are low.

* In our hydrological conditions the median of annual runoff volumes is invariably smaller than the mean of annual runoff volumes.

Study Results

The objective of this study was to evaluate the relationship between the amount of water available annually and the quantity of water allocated to users. Several diversion locations were selected to represent the general condition of the basin and are shown in Tables 1 to 4.

A summary of water availability versus licencing, for 29 licences in the Elbow River Basin, is given in Table 5. A section of the Elbow drainage basin is shown in figure 3. Drainage basin, basin priority number, and a file number are plotted to establish relationships among licences. Of the four points selected for discussion, two are located at the mouth of the basins. The other two points are areas where the allocated water exceeds the availability.

Table 1, Elbow River at Glenmore Dam, indicates that flows at the mouth of the basin are in excess of the present allocation at least up to the 1:10 year return drought runoff. Local areas such as the licence user at location NE-12-24-04-5 (Table 2), are short of water. Even though the user would like 720 ac.ft. of water, the drainage area can produce only 93 ac.ft. of water during a year with median runoff conditions. This local area would not support any other water users and has no future potential for water licencing.

TABLE 1
EXTENT OF WATER LICENCING - ABOVE GLENMORE DAM

CRITERIA	MEDIAN 1:2 YEAR RETURN PERIOD	1:5 YEAR RETURN PERIOD	1:10 YEAR RETURN PERIOD
Estimated annual runoff (ac.ft.)	235,450	188,850	172,305
Amount allocated to licences above this reference point (ac.ft.)	91,727	91,702	91,692
Riparian flow to pass reference point (ac.ft.)	50,665	50,665	50,665
Total assigned water (ac.ft.)	142,392	142,367	142,357
Balance left for future licencing (ac.ft.)	93,058	46,483	29,948

TABLE 2
EXTENT OF WATER LICENCING - LOCATION NE-12-24-04-5
ELBOW RIVER BASIN

CRITERIA	MEDIAN 1:2 YEAR RETURN PERIOD	1:5 YEAR RETURN PERIOD	1:10 YEAR RETURN PERIOD
Estimated annual runoff (ac.ft.)	93	70	61
Volume of water requested (ac.ft.)	720	720	720
Amount allocated to licences above this reference point	93	70	61
Riparian flow @ this reference point	0	0	0
Total assigned water	93	70	61
Balance left for future licencing	0	0	0

TABLE 3
EXTENT OF WATER LICENCING - WILLOW CREEK @ MOUTH

CRITERIA	MEDIAN 1:2 YEAR RETURN PERIOD	1:5 YEAR RETURN PERIOD	1:10 YEAR RETURN PERIOD
Estimated annual runoff (ac.ft.)	100,425	67,202	48,812
Amount allocated to licences above this reference point (ac.ft.)	11,065	10,494	9,722
Riparian flow to pass reference point (ac.ft.)	0	0	0
Total assigned water (ac.ft.)	11,065	10,494	9,722
Balance left for future licencing (ac.ft.)	89,360	56,708	39,090

TABLE 4
EXTENT OF WATER LICENCING - LOCATION NE-25-13-01-5
WILLOW CREEK BASIN

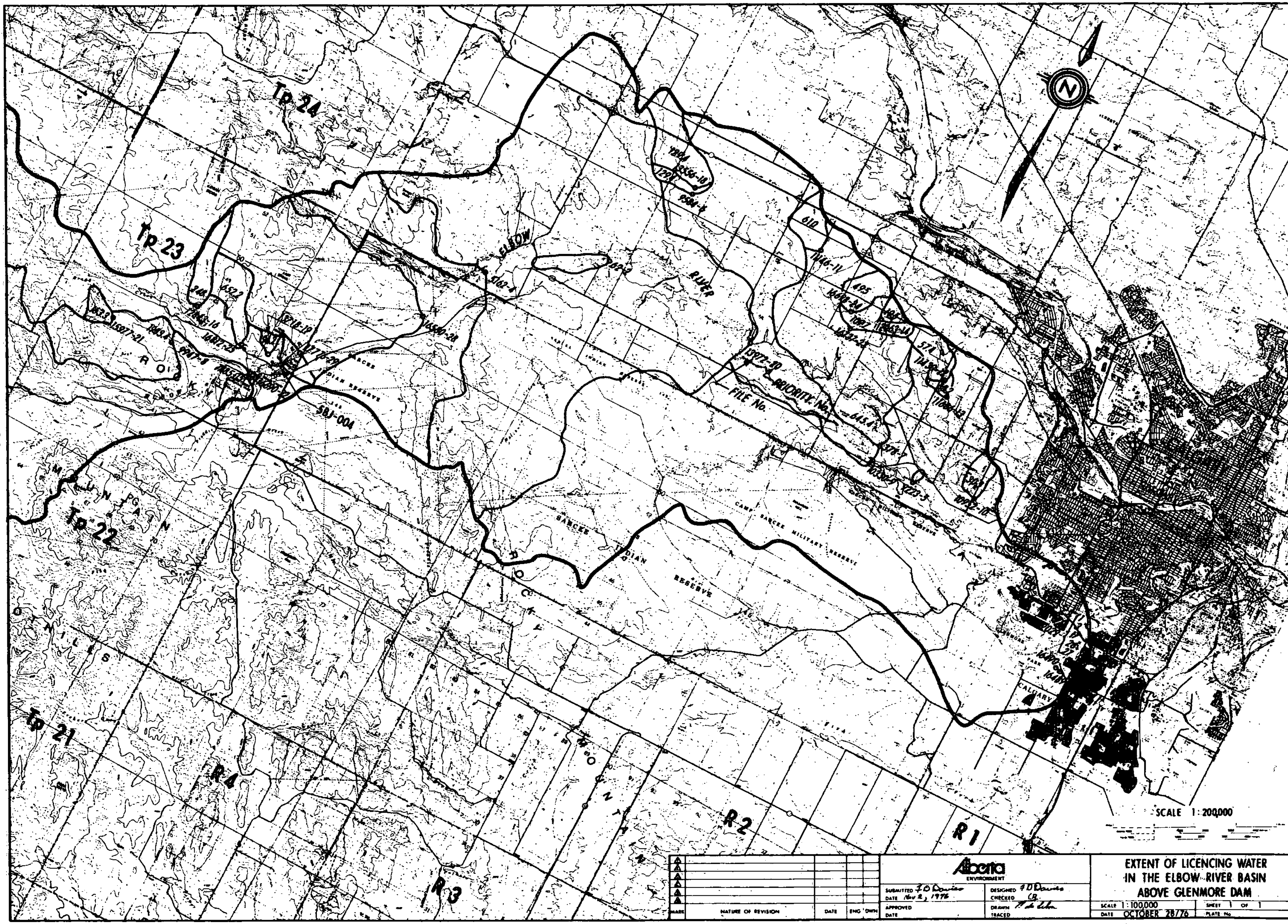
CRITERIA	MEDIAN 1:2 YEAR RETURN PERIOD	1:5 YEAR RETURN PERIOD	1:10 YEAR RETURN PERIOD
Estimated annual runoff (ac.ft.)	275	174	129
Volume requested by licencee	522	522	522
Amount allocated to licences above this reference point	275	174	129
Riparian flow @ this reference point	0	0	0
Total assigned water	275	174	129
Balance left for future licencing	0	0	0

TABLE 5

EXTENT OF WATER LICENCING IN ELBOW RIVER BASIN

FOR THE MEDIAN 1:2 YEAR RETURN PERIOD DROUGHT

PRIORITY NO.	FILE NO.	LOCATION	VOLUME REQUESTED	VOLUME AVAILABLE	VOLUME GRANTED	VOLUME REMAINING	UPSTREAM ALLOCATIONS	CONTROL LICENCE
1	2029	SW-32-23-01-5	50665.00	235450.00	50665.00	93057.56	0.0	1
2	62	NE-12-24-04-5	720.00	92.80	92.80	0.0	0.0	2
3	2029	SE-32-23-01-5	54000.00	235450.00	54000.00	93057.56	92.80	1
4	5162	SW-03-24-04-5	1544.00	213061.94	1544.00	93057.56	0.0	27
5	9223	NE-04-24-02-5	10.00	9.60	9.60	0.0	0.0	5
6	9584	SE-30-24-03-5	3.00	379.20	3.00	352.20	0.0	6
7	378	NW-08-24-02-5	120.00	1904.00	120.00	1764.00	0.0	7
8	9947	SW-10-23-05-5	50.00	1926.40	50.00	1871.40	0.0	8
9	10330	NW-05-24-02-5	615.00	223753.94	615.00	93057.56	1689.80	27
10	10952	NW-02-24-02-5	4.00	83.20	4.00	79.20	0.0	10
11	11146	NE-27-24-03-5	5.00	160.00	5.00	155.00	0.0	11
12	11430	SE-21-24-02-5	4.00	148.80	4.00	144.80	0.0	12
13	11686	NW-16-24-02-5	3.00	182.40	3.00	175.40	4.00	13
14	12063	NW-19-24-02-5	1.00	49.60	1.00	48.60	0.0	14
15	7485	NW-12-23-05-5	5.00	199860.00	5.00	93057.56	50.00	28
16	12843	NW-15-23-05-5	25.00	258.00	25.00	233.00	0.0	16
17	2029	SE-32-23-01-5	34000.00	235450.00	34000.00	93057.56	2431.40	3
18	13556	NE-30-24-03-5	24.00	318.40	24.00	294.40	0.0	18
19	13718	SW-13-23-05-5	15.00	103.20	15.00	88.20	0.0	19
20	13972	NE-10-24-03-5	10.00	213503.94	10.00	93057.56	1691.80	27
21	15977	SE-08-23-05-5	5.00	159.10	5.00	154.10	0.0	21
22	16690	NE-12-23-05-5	70.00	199860.00	70.00	93057.56	60.00	28
23	16737	SW-24-24-03-5	10.00	302.40	10.00	287.40	1.00	23
24	16698	NW-24-24-03-5	4.00	129.60	4.00	125.60	0.0	24
25	16812	SE-14-23-05-5	3.00	619.20	3.00	616.20	0.0	25
26	16489	SE-29-23-01-5	21.00	235450.00	21.00	93057.56	2617.40	17
27	16490	NE-29-23-01-5	30.00	235450.00	30.00	93057.56	2617.40	26
28	16530	NW-28-23-04-5	1022.00	210906.00	1022.00	93057.56	174.00	27
29	17776	NW-25-23-05-5	32.00	208970.00	32.00	93057.56	173.00	28


Tp 24
Tp 23
Tp 22
Tp 21
R4
R3
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ELBOW
RIVER
FILE No.
PRIORITY No.
SARCEE INDIAN RESERVE
CAMP SARCEE MILITARY RESERVE
SCALE 1:200,000
Alberta
ENVIRONMENT
EXTENT OF LICENCING WATER
IN THE ELBOW RIVER BASIN
ABOVE GLENMORE DAM
SCALE 1:100,000
DATE OCTOBER 28/76
SHEET 1 OF 1
NATURE OF REVISION

FIG. 3

Table 3, Willow Creek at the mouth, indicates there is available water on an annual basis for use at the 1:10 year drought runoff conditions. It should be pointed out, however, that at this level of water supply some cooperation between users would be needed. Not everyone will be able to get his water in July or August when flows are at their lowest.

As a consequence of the total allocation at location NE-25-13-01-5 in the Willow Creek basin, five other applications have been rejected for water use below the median runoff level. If they do get water more often than median runoff conditions would warrant, it is because other users have not taken their total allocation.

Summary

There are available water supplies for future allocation at the mouth of both the Willow Creek and Elbow River systems, even during the 1:10 year drought conditions. However, some local areas have been licenced beyond the median runoff level. Although, in general, water is available on the annual basis in these two basins, users need to be aware of the distribution of the resource in time.

At present the existing water shortages in the Willow and Elbow Basins are primarily not due to the unavailability of the resource on an annual basis but rather due to the, from the point of view of the user, unfavorable distribution of the runoff in the span of a year.

To fully utilize the water supply in these basins, water management procedures would be needed during drought years. The basins' users need to cooperate with each other. Some form of water mastering would improve the effective use of the available supply.

The licencing mechanism needs to include procedures for allocation of waters in time frames other than on an annual basis. Future procedures may restrict water licences to specific time periods within a year rather than grant them on an annual basis.

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IRRIGATION DEMANDS ON EAST SLOPE WATER

*R. F. Smith, P. Eng.

DEVELOPMENT OF IRRIGATION

First of all, the title of this paper may be somewhat misleading as I intend to deal with irrigation on a broad scale - from its early history to the present development, and the actual demands of irrigation for east slope water may be just a small part of the presentation. However, the title does fit in with the general theme of the symposium, and I am grateful for this opportunity to present a brief on the story of irrigation in Southern Alberta.

I can't let this opportunity pass without reminding you that civilization as we know it today had its beginnings in environments requiring irrigation. The climates of countries such as Egypt, Persia, India and China, that harbored such great civilizations, were relatively dry, and required irrigation for satisfactory crop production. I would not be so bold as to suggest that the people of the irrigated areas of Southern Alberta fall into this category, but at least the requirement of arid lands is there.

In order to set the stage for you that you might better understand the present irrigation situation in Alberta, I would like to start out by presenting a brief story of the development of irrigation with reference to the needs, the political aspects to some extent, and the involvement of private enterprise and governments.

Southern Alberta, because of its harsh climate of long winters and short summers, and sparse vegetation was slow in attracting settlers, and many that were attracted were soon disillusioned and either returned to their homeland, or went on to greener pastures. Any agriculture that existed in the early and mid 1800's was merely supportive to the fur trade to supply the trading posts with vegetables and fodder for the stock. In the 1850's, Great Britian sent Captain John Palliser to head a team of scientists to study the area lying between the South Saskatchewan River and the U.S. border to record its physical features and to determine its suitability for agricultural development. The area involved, which also included a sizeable tract in Southern Saskatchewan became known as the Palliser Triangle. After three years of study, Palliser submitted a pessimistic report back to his superiors, indicating that the land generally lacked tree growth, had limited water supplies and shortgrass. He thought it mostly unsuitable for cropping as he evaluated the soils as generally worthless, except for here and there in small swamps. It must be admitted that Palliser did see the country during a period of recurring drought, but his pessimistic report was one of the factors that retarded settlement in this area for some time. Following Confederation, Canada

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took over most of the Hudson Bay territory in the west, and sent yet another scientist, a professor in fact, to re-examine the area. Macoun's report was quite optimistic, indicating only 5% of the soil was unfit for agriculture and the climatic conditions more suitable for the growing of grains than other moister sections of the country. It should be pointed out here that while Palliser's name is well known in Western Canada, and has been carried on by the naming of a huge CPR hotel in Calgary, and a distillery in Lethbridge, after him, the name Macoun is hardly known at all. The significance of this appears to be that pessimists are remembered long after optimists.

Be that as it may, agriculture began to flourish in the Province, particularly with the coming of the N.W.M.P. who started several small farms in conjunction with their early forts, and of course, the building of the railway through the west was a great incentive to grow crops to provide freight for the railway.

The first irrigation in Alberta is officially listed to have occurred near Calgary, when John Glen diverted enough water from Fish Creek to irrigate 20 acres in 1878. This was the beginning of many developments, not all successful, in the next few years. Irrigation districts were first authorized under an ordinance of the N.W. Territories of 1894, however only one district was set up under this territorial ordinance, the Springbank Irrigation District near Calgary, incorporated in 1898 to serve some 23,500 acres. The district borrowed $40,000 as a charge against the land, and unfortunately never delivered any water. The works fell into disrepair, but the debt remained, and in 1914, a special Act was passed for the relief of the Springhill Irrigation District. This was probably the first of many "bailings out" by the Provincial Government as development progressed.

It may be pertinent at this time to mention basic legislation as it applies to water rights in North America. The development of irrigation in the U.S. was hampered and distorted by legal difficulties. The common law, derived from England, was designed to give all landholders along the stream the right to use it, however the practise of the frontier, enforced by much local legislation, was to allow the appropriation not only of land and minerals as private property, but also running water as well. This conflicted with accepted interpretation of common law, and resulted in endless confusion and litigation. It has been stated that more money was spent on litigation in the early days of irrigation development in the western U.S. than on actual construction.

This situation never arose in Alberta due mainly to the farsightedness of a few civil servants such as Col. J. S. Dennis and W. Pearce in the adoption of an over-riding statute, the North West Irrigation Act of 1894. Although the Act has been superseded and re-written many times, the basic principles still remain, and may be summarized as follows:

1. The ownership of all surface waters is vested in the Crown, and these waters, or the right to their use, cannot become private property.

2. The use of water is regulated by license from the Crown, which is subject to cancellation for non-use or misuse.

These basic principles have been incorporated in all Federal and Provincial legislation pertaining to the jurisdiction of waters up to this time and as a result there have been very few problems as far as the legal jurisdiction of water in Canada has been concerned.

This then sets the stage for development of irrigation in Alberta. This has been mainly accomplished by what the Hanson Report refers to as three phases, namely

1. The Commerical Phase
2. The District or Co-operative Phase
3. The Government Phase

Considering Phase 1, the Commerical Phase, it must be remembered that during the negotiations for the construction of the railway through Western Canada, large land grants were given to the railways to provide finances for railway construction. The pioneer in this field was the Canadian Northwest Irrigation Company (C.N.I.) organized in 1892 by E. T. Galt of Lethbridge, and financed by British capital. This company took over large blocks of land, originally granted by the Dominion Government as subsidies for the construction by the Galt interests of railways between Lethbridge and Medicine Hat and between Lethbridge and Great Falls, Montana.

The C.N.I. paid the parent company $2.00 per acre, and re-sold a large tract near Magrath and Stirling to Mormon settlers for $3.00 per acre. The irrigation works were constructed largely by the labour of the settlers themselves whose wages were paid half in cash and half in land at the above evaluation. Subsequently, the railway and land interests were consolidated into the Alberta Railway and Irrigation Company (A.R. & I.), and controlling interests were purchased by the CPR in 1912, who operated the scheme until it was taken over by the Provincial Government in 1946. The works constructed in the late 1890's, comprised a diversion in the Belly River at Kimball, near the U.S. border, and a main canal that ran through to east of Lethbridge. Water was delivered to the Lethbridge area in 1900. In 1919 the Taber Irrigation District was formed under agreement with the CPR whereby the company constructed the works in exchange for debentures. The district purchased water from the A.R. & I. Co. at Chin Coulee and delivered it to the rest of the project.

A second large development occurred between 1903 and 1914, on two blocks of land owned by the CPR between Medicine Hat and Calgary, the two blocks being the West Block and the East Block. The West Block, with headquarters at Strathmore was run by the CPR until 1944, when an attempt was made to close the system down. After representation to Edmonton by a group of water users, negotiations were carried out with the CPR, and the project became an irrigation district operated by the farmers on a modified scale. Similarly the Eastern Block, with headquarters at Brooks, became an irrigation district in 1935, with the assets being turned over to the farmers by the CPR, along with a lump sum of money to assist in operating the scheme.

The third commercial venture in this era was that of the Canada Land and Irrigation Company, whose one incentive was profit on their investment. Work started in 1909 on the diversion on the Bow River at Carseland and the main canal and distribution system, but it was not until 1920 that the first land was irrigated in the Vauxhall area. This project struggled along until 1950, when the project was purchased by the Federal Governemnt.

This then brings us to the second phase of development, the "District Phase". This has already been covered to some extent in the previous discussion, but generally began with the passing of the Irrigation Districts Act, 1915. This Act gave irrigation districts quasi-municipal powers, which in effect allowed them to issue debentures. The first three districts formed under this Act were Taber (1919), Magrath (1924) and Raymond (1925). Thus up until the next phase there were four differently governed areas receiving water from the old A. R. & I construction, namely,

(a)	The A. R. & I Project (Lethbridge-Coaldale) (operated by CPR as a private venture)	84,000
(b)	Taber Irrigation District (operated by the farmers)	21,500
(c)	Raymond Irrigation District (operated by the farmers)	15,100
(d)	Magrath Irrigation District (operated by the farmers)	7,000
	TOTAL	127,600 acres

In 1919 the Lethbridge Northern Irrigation District was formed, financed by a bond issued guaranteed by the Alberta Government, and was the only district to operate as a district from its inception. The headworks,completed in 1923, for the Lethbridge Northern were expensive, and consisted of a diversion weir on the Oldman River west of MacLeod, a 40 mile long supply canal which crossed the river on an elevated flume and required two long wooden siphons to cross coulees, and the reservoirs and distribution systems just north of Lethbridge. It might be noted that in 1924 the first water rates were $5.25 per acre, however out of the total levy of $500,000, only $13,000 was collected. By comparision in 1977, the rate is $6.50 per acre. In the 1930's the Provincial Government assumed a large portion of the bonded debt and appointed a trustee to manage the affairs of the district. This continued until 1968 when the district once again took over the managment of its own affairs.

It was previously mentioned that in 1935 and 1944 respectively, the Eastern and Western Irrigation Districts were formed. Four other small districts were also set up during the inter-war period, namely, the United Irrigation District at Glenwood; the Mountain View Irrigation District; the Leavitt Irrigation District, and the Aetna Irrigation District. The Mountain View and Leavitt Irrigation Districts were constructed by water-user labor, and this accounts for their fierce independence even today. The United Irrigation District attempted to be independent and self-financing, but in accordance with the Ewing Report of 1941, the Alberta Governemnt assumed responsibility for the debentures, and appointed a trustee to run their affairs.

It was quite apparent by this time, (early 1940's) that only small schemes with easy access to water could operate with only a little government help, and that large schemes such as those in the CPR block, or the Lethbridge Northern had to have assistance from either the Federal or Provincial Government to survive.

Thus we come to the Third Phase, the Government Phase.

In the Meek Report of 1942, it was noted that there was some urgency to build the St. Mary Milk River Project in order to establish rights to the Canadian share of the International waters, and also to take care of the impending return of the war veterans. The SMRD was really an extension of the old A. R. & I Project and replaced the old Kimball diversion with large dams and reservoirs on the St. Mary and Waterton Rivers, and a diversion on the Belly. This was a joint Federal-Provincial undertaking, and involved a potential development of about 500,000 acres including those already in the A. R. & I, Magrath, Raymond and Taber. The CPR agreed to transfer the A. R. & I to the Provincial Government in 1946, thus ending the CPR involvement in irrigation in Alberta. A Crown corporation was formed to administer all those lands not now administered by the Taber, Magrath and Raymond districts. Thus by 1955, all irrigation in Alberta was either administered as irrigation districts or Crown corporations administered by the Province, with one notable exception, the Canda Land Project at Vauxhall which had been taken over by the Federal Government. It should be pointed out at this time that the Western Block of ,the Canada Land development at Lomond and Enchant was constructed during the middle 1950's by the Province of Alberta and was operated as a Crown corporation as well, and known as the Bow River Development (West Block).

This brings us to the present era in irrigation, which I suppose could be termed a combined government-district phase. In 1963, the Alberta Government initiated a series of studies under the Agricultural Rehabilitation and Development Act (A.R.D.A.), of the irrigation districts, in order to determine the need for rehabilitation of the districts, and also to determine the benefits accruing to the various segments of the country in order to justify a cost sharing policy based on benefits received, and the study also was to establish recommendations regarding the administration and legislation aspects, as well as a policy for future development.

The studies were completed in 1967, and as a result of their recommendations, the Irrigation Act, 1968, was passed. This replaced seven existing Acts pertaining to irrigation, legislated the two Crown Corporations into irrigation districts, established boards of directors for the two districts which were being administered by official trustees and brought all irrigation projects in Alberta under one Act with the exception of the Bow River East Block which was still owned and operated by the Federal Government. The studies also indicated that benefits accrued from irrigation as follows:

Canada (as a whole)	35%
Alberta	32%
Local Municipalities (Urban & rural)	22%
Local Farmer or water user	11%

These were later modified to eliminate the Local Municipalities; their share being prorated to give the following:

Canada	45%
Alberta	41%
Local Farmers	14%

Subsequent negotiations between the Federal and Provincial Governments resulted in the Federal-Provincial Agreement on Irrigation in 1973, the terms of which included a guarantee by the Federal Government to rehabilitate certain named major structures on the Western, Eastern and Bow River Irrigation District, at an estimated cost of 16.5M, the transfer of Federal Government interests in the St. Mary's River Irrigation Project and the Bow River Irrigation Project to the Alberta Government along with specified amounts of money to cover take-over costs. This agreement thus led to the amalgamation of the former Federally operated East Block of the Bow River Development with the B.R.I.D. in 1974, thus finally placing all irrigation districts in Alberta under one legislation, namely the Irrigation Act (1968).

IRRIGATION IN ALBERTA TODAY

At the present time in Alberta there are thirteen active irrigation districts. These are run as separate enities with their own managers in the case of the larger districts or secretary-managers in the case of the smaller districts, and all have boards of directors elected by the ratepayers of the district. An association called "The Alberta Irrigation Projects Association" has been formed to represent the districts, and to give them an opportunity to present a common voice to the government and to the public on matters common to them all. The districts operate within the legislative authority of the Irrigation Act, which was passed in 1968. The Act, as now amended provides for an Irrigation Council, administered by the Irrigation Secretariat. The Irrigation Council is composed of six farmer members and two civil servants, and has, in addition to certain duties and powers laid down in the Act, the responsibility of advising and making recommendations to the government on matters pertaining to irrigation in Alberta. In 1972, an Irrigation Division was established within the Alberta Department of Agriculture. The Division, located in Lethbridge, is charged with expanding and improving services to farmers, and plays a significant role in long range planning and co-ordination.

The attached chart shows some of the pertinent details relative to the thirteen irrigation districts. The assessed acres on the rolls of the districts now total about 940,000 acres, with approxmately another 100,000 acres irrigated in private schemes throughout the Province, including a scheme of about 10,000 acres on the Blood Indian Reserve near Glenwood.

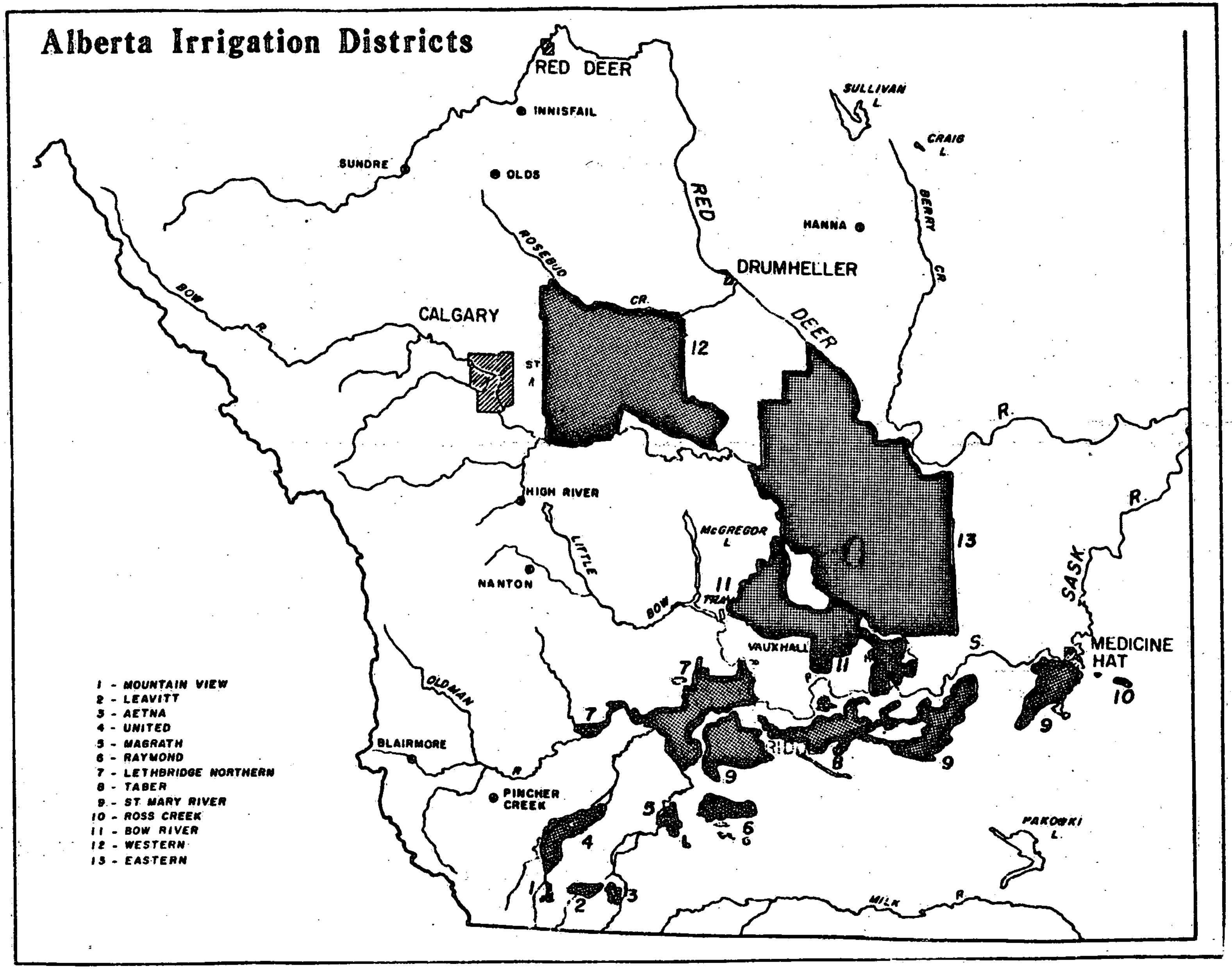
The irrigation districts have the right to levy an annual water rate, which is imposed on the assessed acres of the district. This is to cover annual operation and maintenance expenses, with some allowance for

CHART #1

IRRIGATION DISTRICT DATA

Irrigation District	Assessed Acres	Water Rates 1976	H.Q.'s Location	Water Source	Storage On-stream	(Ac.-ft.) Offstream
Aetna	3,081	$1.25	Cardston	Belly River	Nil	*7,000
Bow River	139,665	$3.50	Vauxhall	Bow River	Nil	332,000
Eastern	219,405	$3.85	Brooks	Bow River	Nil	203,000
Leavitt	4,430	$2.25	Cardston	Belly River	Nil	7,000
Lethbridge Northern	109,629	$6.00	Lethbridge	Oldman River	Nil	43,000
Magrath	9,069	$3.50	Magrath	*St. Mary River	See SMRID	Nil
Mountain View	3,720	$1.25	Mountain View	Belly River	Nil	7,000
Raymond	28,350	$3.25	Raymond	*St. Mary River	See SMRID	Nil
Ross Creek	2,069	$2.50	Irvine	Ross Creek	Nil	5,000
St. Mary River	262,231	$4.50	Lethbridge	*St. Mary River	383,000	347,000
Taber	66,423	$4.80	Taber	*St. Mary River	See SMRID	7,000
United	33,358	$2.00	Glenwood	Belly River	Nil	1,500
Western	52,190	$2.20	Strathmore	Bow River	Nil	5,000

Note: (1) St. Mary River includes Waterton River
(2) Storage on SMRID is common to Taber, Magrath, Raymond and St. Mary River Irrigation Districts (Storage shown for districts other than SMRID is within that district only)
(3) Storage is common for Aetna, Leavitt, Mountain View Irrigation Districts


Alberta Irrigation Districts
RED DEER
INNISFAIL
SUNDRE
OLDS
SULLIVAN L.
CRAIG L.
RED DEER R.
HANNA
BERRY CR.
DRUMHELLER
ROSEBUD CR.
BOW R.
CALGARY
12
13
HIGH RIVER
McGREGOR L.
LITTLE BOW
NANTON
SASK. R.
S.
MEDICINE HAT
VAUXHALL
OLDMAN R.
BLAIRMORE
PINCHER CREEK
PAKOWKI L.
MILK R.
1 - MOUNTAIN VIEW
2 - LEAVITT
3 - AETNA
4 - UNITED
5 - MAGRATH
6 - RAYMOND
7 - LETHBRIDGE NORTHERN
8 - TABER
9 - ST MARY RIVER
10 - ROSS CREEK
11 - BOW RIVER
12 - WESTERN
13 - EASTERN

a reserve. No government assistance is given in the operation and maintenance costs of the districts, however a cost-sharing program has been put into effect by the Province to rehabilitated the capital works of the districts, and to provide for some expansion. To expand on this a bit further, the ARDA studies of 1967 indicated, in summary that benefits of irrigation (modified) were as follows:

Canada	45%
Alberta	41%
Local Farmers	14%

Inasmuch as Canada had opted out of any further participation in irrigation in Alberta with the signing of the Federal-Provincial Agreement in 1973, Alberta decided to proceed with the rehabilitation program on its own. The Alberta Government committed $2,000,000 per year for 10 years for irrigation rehabilitation in 1973, and in 1975, committed 90 million dollars for irrigation rehabilitation over a 10 year period to be administered by the Department of Agriculture, with an additional 110 million dollars to be spent on headworks, administered by the Department of the Environment, the total 200 million dollars to come out of the Alberta Heritage Trust Savings Fund.

It should be noted particularly here that both the funds administered by the Department of Agriculture, namely the $2,000,000 per year appropriation, and the $90,000,000 from the Heritage Fund, are distributed to the districts in the form of a cost-sharing fund, the districts being required to contribute 14% of the aggregate fund, in accordance with the findings of the ARDA studies. The districts are responsible for the engineering and planning of the projects, and the cost sharing programs are administered by Irrigation Council.

The Government of Alberta also indicated, that inasmuch as the underlying principle on the water management of headworks in Alberta is that they should be managed to provide water for multi-purpose use, that they are committed to take over all major headworks, and thereby to assume all responsibility for rehabilitation, and operation and maintenance costs, as well as development of new on-stream storage facilities. This commitment is now being undertaken, with agreements signed in some cases and under negotiation in others. A fairly liberal definition has been used in the definition of headworks in the drawing up of the agreements.

Some idea of the water requirements for irrigation from the east slopes of the Rockies particularly from the Bow River Basin, and the Oldman River Basin, may be derived from the total diversion for irrigation in those basins for a particular year. For example in 1974, the diversions out of the Bow River and the Oldman River were 908,420 acre-feet and 729,330 acre -feet, respectively, however the return flow, which augments Alberta's commitment under the Prairie Provinces Water Board Agreement for flows to Saskatchewan was 259,410 acre-feet to the Bow River and the Red Deer River, and 111,700 acre-feet to the Oldman River. The average annual diversion for the years 1957 to 1975 was 1,298,550 acre-feet for both the Bow River and the Oldman River basins, and out of this an average of 383,170 acre-feet was returned, the return flow average being based on the years 1972 to 1975. The return flows of course include natural run-off from storms falling on the districts, and in fact, the Western Irrigation District indicated to me that one year they had a larger return flow than their total diversion.

It may be interesting to note that the gross value of production on the 940,000 acres of irrigation in the districts was $175,000,000 in 1976. The estimated value of production, had those acres not been irrigated but farmed as dry-land was estimated to be $30,000,000. This yieldsa gross return per acre of $188 for irrigated land, and $32.00 per acre for equivalent dry land.

A look at some of the present day trends in irrigation may be of interest at this point. Due to the high costs of labour, and the difficulties in obtaining adequate labour, there has been a definite trend for irrigators to subsitute capital for labour, mainly in the form of sprinkler systems. This of course has also opened up many new areas for irrigation that could not be reached before, particularly on the high sides of the district canals, and has led to an increased demand for irrigation water. The costs of the sprinkler units run from approximately $80,000 for a sophisticated central pivot unit with special equipment for irrigating the square corners, to $25,000 for a lateral wheel move, and down to $8,000 for a hand-set type. The latter are rarely used, except for small plots. Land levelling is still being done to some extent, although the advent of sprinklers may have reduced the amount done now, compared to that done in previous years.

The irrigation districts have also become much more sophisticated, and in an effort to reduce seepage problems, and also long range maintenance costs, have gone to concrete and other linings, and to a more minor degree, pipe installations where practicable. The Taber Irrigation District, for example, the district with the highest cash crops and the most intensely irrigated, has committed itself to have all its laterals in concrete lining. The T.I.D. is approximately 80% to 90% sprinkled at this time. The other districts all have some sprinklers, but to a lesser degree. It is estimated that approximately 40% of the land being irrigated in the districts today is sprinkled.

THE OUTLOOK FOR IRRIGATION ON THE EAST SLOPES

Irrigation in Alberta over the past decade has reached an age of maturity. By that, I don't mean that irrigation is stagnant, or standing still but merely that the benefits of irrigation are being realized more fully by the water users, and they are now more skilled in irrigation techniques, and willing to invest more capital on the basis of long range returns. This trend is evidenced by the tremendous investment made by the individual water users, and also by the large number of new applicants for irrigated acres in nearly every district. In fact most districts have now declared a moratorium on new applicants until the results of special studies now under way are completed.

One of these studies, and probably the most important in view of the long-range effects on irrigation in Alberta, is the Oldman River

Flow Regulation Studies, now underway, and expected to be completed in 1978 with recommendations to be forthcoming in early 1979. While ostensibly to study regulation of the Oldman River, the study also includes such items as irrigation potentials, and priorities, water requirements, environmental impacts, water-supply alternatives, and many other aspects. The study is being undertaken by a management committee, is overseen by the Department of the Environment, and involves several consulting firms for the various aspects.

The St. Mary River Irrigation District, as a result of the heavy demand for new irrigated areas, particularly in the east end of their project, recently completed a preliminary study of their own on additional internal storage within the project, which also involves main canal capacities, and priorities of development. This study is now being enlarged upon to take in a much broader scope.

A study by the Department of the Environment is now underway on the Eastern Irrigation District on potential on-stream storage, and alternate off-stream storage facilities. At the present time, the Federal Government have committed themselves to rehabilitation of the Bassano Dam which has no storage, and the district as well as the Alberta Department of the Environment, are interested in determining whether alternate investments in other facilities providing on-stream storage, or off-stream storage are feasible and practical.

In general it is apparent the potential irrigable land in Southern Alberta far exceeds the potential supply of water, and that the demands for water for irrigation from the east slopes is going to increase considerably in the next few years. It is estimated that, without any additional on-stream storage developments, and with some minor increase in off-stream storage, that the irrigated acreage will increase from its present 940,000 acres to approximately 1,200,000 acres by 1985. This is considered to be about the maximum acreage that can be developed with a tolerable degree of water shortage, with the present river diversion. This would increase the average demand, assuming that similar conditions prevail for the next period of years as they have for the previous period, by about 30%, or to an average of approximately 1,700,000 acre-feet annually. The construction of additional major storage facilities, both on-stream and off-stream would change this picture considerably. This increased water demand, while now only affecting the Bow River and the Oldman River basin, may ultimately affect the other basins on the East Slopes. The water distribution in Alberta is such that 89% of the flow is northward to the Arctic. The remaining 11% which flows throuth the southern populated areas of the Province must serve 85% of the population. In order to solve this problem of distribution, it may be necessary to reconsider the P.R.I.M.E. concept of inter-basin diversion, which was put forth by the Water Resources Division of the Department of Agriculture in the late 1960's.

This Gentlemen, concludes my presentation on the demands for east slope water for irrigation in Alberta. I sincerely hope that the abbreviated history, description of present day irrigation, and brief look into the future will be of some assistance in helping you to understand and evaluate the importance of irrigation to the overall economy of Alberta.

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REVIEW
OF THE
ST. MARY IRRIGATION SUPPLY SYSTEM
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For Presentation to:

ALBERTA WATERSHED RESEARCH SYMPOSIUM
AUGUST 31, 1977
Edmonton

ABSTRACT

The demands for more irrigation water being experienced on the St. Mary Irrigation System and the problems of supplying the present 375,000 acreage have prompted an overall review of project potential and main supply facilities.

Water and land resources are sufficient for a project of from 500,000 to 550,000 acres within the present districts.

A mathematical model of the supply system played a significant role in the study. This was used in conjunction with 56 years of hydrometric data to determine the optimum combination of canal, reservoir and land resources.

INTRODUCTION

One of the tools used in a recent review of the St. Mary River Irrigation District (SMRID) Main Canal System was that of modelling the project and simulating its operation under recorded runoff and weather conditions.

The purpose of the study was to chart a course of rehabilitation and improvements to the St. Mary River Irrigation District Main Canal System.

The demand for irrigable land has increased sharply in recent years. Total assessed acres served by the St. Mary Canal System has risen from 230,000 in 1960 to 375,000 in 1977.

Problems have developed in meeting this demand particularly in the eastern part of the project. A moratorium restricting new development is presently in effect in most of the east block of the St. Mary River Irrigation District. The moratorium is necessitated by the canal system below Chin Reservoir being inadequate to supply the increasing demands during peak summer use.

Information available included preliminary proposals for storage at Forty Mile Coulee and for increasing the capacity of Stafford Reservoir outlet, a preliminary classification of irrigable land by Alberta Agriculture, historic hydrometric records and water supply review by Department of Regional Economic Expansion, P.F.R.A. Hydrology Division, and canal and reservoir operating records provided by Alberta Environment and the District.

ST. MARY WATER SUPPLY SYSTEM

The St. Mary System consists of major on-stream reservoirs on the Waterton and St. Mary Rivers, a diversion weir on the Belly River, two major off-stream reservoirs and some 250 miles of main canal connecting all of these.

It is the largest irrigation system in Canada, serving some 2,000 individual farm units and numerous towns and villages with water.

Live storage on the reservoirs totals 650,000 acre-feet. Canal capacities range from 3,200 c.f.s. at St. Mary Reservoir near Cardston to 200 c.f.s. at Murray Reservoir near Medicine Hat.

These works were constructed by the Prairie Farm Rehabilitation Administration (P.F.R.A.) under an agreement between the Federal and Provincial Governments in the 1950's and 1960's. They replaced individual diversion and supply works built in the early part of the century to serve projects in the Magrath, Raymond, Lethbridge, Taber areas, and also provided water to the Bow Island, Medicine Hat areas for the first time.

The works in the Waterton to Ridge Reservoir reach have since been taken over and operated by Alberta Environment and works from Ridge Reservoir through to the lower end of the system by the St. Mary River Irrigation District.

WATER RESOURCES

The water supply available from the Waterton, Belly and St. Mary Rivers is estimated to be adequate to serve a 500,000 acre project with a risk of water shortages of from 10 to 20 percent occurring on a return frequency of about 10 years. This is equivalent to running out of water in late August or September once in 10 years.

Major assumptions used in arriving at this conclusion are:

1. The U.S.A. will use their share of the St. Mary flow.

2. Upstream uses by United, Aetna, Mountain View and Leavitt Irrigation Districts will remain near their present level.

3. Downstream releases required on a regular basis in each of the three rivers will be in the order of 30 c.f.s. continuous flow.

4. Total annual project water use per acre irrigated will be about 15 percent greater than that recorded in the years 1959 to 1973, and will be dependent mainly on the amounts of spring and summer precipitation in accordance with the formula developed by the Saskatchewan-Nelson Basin Board (SNBB).[1]

5. Acres irrigated annually will be 90 percent of assessed acres.

6. The flow data and weather patterns as recorded and/or reconstructed in the recent SNBB Study for the years 1912 to 1967 are representative of those which will occur in the future.

7. Forty Mile Coulee or equivalent major storage reservoir will be constructed within the project and canal capacities as recommended herein will be provided.

8. The season for running water is normally May 1st to October 15th and can be extended to include part of April whenever internal project reservoirs are less than 75 percent full.

9. Water is moved into internal project reservoirs at the earliest possible time.

Of the above conditions the most critical is the one concerning releases to downstream uses. The arrangement made in the early 1970's for continuous releases totalling 475 to 675 c.f.s., if continued, would have the effect of drastically reducing the acreage that could be adequately irrigated. Under these conditions and with no additional storage constructed, the project would be limited to its present 375,000 acres. These large releases were in fact only maintained for about two years. Present operating practice is usually to match outflow to natural inflow during winter months. These flows average 370 c.f.s.

The assumption of water use per acre irrigated being approximately 15 percent greater than that of the period 1959 to 1973 is somewhat arbitrary at this time. The main reason for this is to avoid the possibility of over-estimating the potential for development.

The U.S.A. legal share of the St. Mary flows varies between a low of 128,000 acre-feet and a high of 448,000 acre-feet annually and averages about 275,000 acre-feet.

1 Water Supply for the Saskatchewan-Nelson Basin, Appendix 4 Volume 1- Hydrology

The estimated use by the U.S.A. on the basis of 1970 level of development would be about 185,000 acre-feet. This means that if no further demands for St. Mary water developed in the U.S.A. annual inflows to the St. Mary reservoir would average about 90,000 acre-feet greater than those assumed in this study, with variations from 27,000 to 150,000.

It is recommended that monitoring of water use throughout the basin be continued and intensified, and when the project approaches full development by the above criteria a review of latest trends should indicate whether further development can be planned.

The only other close source of water for the St. Mary Project area would be that in the Oldman-South Saskatchewan River System. The recently completed preliminary study of the Oldman River identifies the potential water supply. A preliminary look was taken of two possible pump sites for future consideration.

LAND RESOURCES

Irrigable land within reach of existing works totals 550,000 acres. An additional 250,000 acres in the general project area are considered irrigable. Preliminary land classification of potential irrigable lands indicates that, in addition to the present 375,000 acres, within one mile of existing works an estimated 190,000 acres are suitable for irrigation development.

In addition to these there are several blocks of land within the St. Mary District totalling 40,000 acres which could be served by systems of greater than one mile length.

There are several areas outside the present Districts which have been or are being considered for development. These include the Highline Canal proposal, Standoff, New Dayton, and Verdigris Coulee areas. The total acreage in these areas is in excess of 200,000. All of these would require extensive new works.

It is recognized that the land classification is of a preliminary nature and that the rate and location of development will be determined largely by the individual land owners initiative and the main supply facilities made available.

The effect of the moratorium in the eastern block can be readily seen in the sharp reduction of rate of growth in that area in 1975-1976. Even with the moratorium, the District has applications totalling several thousand acres waiting to be considered. A deluge of applications is expected when the moratorium is lifted.

It should be noted that with the same growth over the next 16 years the 500,000 acre level would be reached.

OPTIMIZATION OF LAND AND WATER RESOURCES

There are two basic factors of water supply to an irrigation project. One is the total volume of water available in a season, the other is the capability of the supply system to meet the peak rate of demand in mid-season.

The first relates mainly to the yield of the water shed and the total volume of reservoir storage capacity. The second relates mainly to canal capacities and the location of internal storage sites for supplementing canal flows.

The general technique used was that of (1) modelling the existing project conditions, (2) gradually adding irrigable acreages in various configurations which might occur in the future, and (3) modifying works to meet the demands thereby created. This procedure was carried to the point where the water supply became the limiting factor and seasonal water shortages became significant.

The Waterton, Belly and St. Mary Rivers are the major sources of water for the St. Mary project. The recent SNBB Studies included a tabulation of hydrometric records in the basin and a reconstruction of monthly flows which would have occurred at specified points in the years 1912 to 1967 assuming a 1970 level of project development.

A project water use parameter, related to spring and summer rainfall, and reservoir evaporation data were also available from the SNBB work.

A summary of total annual runoff over the 56 years and a look at what the lowest probable runoff volume might be over a much longer period was presented in graphic form. This was arrived at by the development of a mathematical model of the project.

Each major reservoir and each block of land is treated as a node and each section of main canal or river is the link between these in the model. A node can have the property of any or all of storage, evaporation and consumptive use. The only node having all three properties in this model is that representing the Taber-Grassy Lake block where both land and reservoirs are combined. A link has the property of uni-directional flow.

It was not necessary to use a branching system to model the project even though there are minor branches. The four small reservoirs in the Taber area can be assumed to be "on-stream" without distorting project operation.

The separation of gravity and pumped water and the calculation of pumping costs at Forty Mile Reservoir is done by using a sub-routine based on the excess of outflow over inflow at the reservoir. Sauder Reservoir is not included in the model. Its capacity is too small to affect overall water supply requirements.

Project operating rules used in the model were:

1. The season for running water is normally May to October inclusive, except when project reservoirs are below the 75 percent level in April the season starts on April 15.

2. Priorities for water use are designated riparian flow, evaporation, consumptive use, storage and spillage in the order given.

3. Water available for storage is distributed first to 100 percent capacity of project reservoirs and 10 percent of St. Mary reservoir. If water is insufficient for this, it is distributed on a prorated capacity basis. Water in excess of the above is stored in St. Mary and then Waterton Reservoir.

4. Water which cannot be distributed because of canal capacity restriction is stored in the closest upstream reservoir.

The 500,000 acre model representing the recommended project development target was operated through the 1912 to 1967 record period.

CONCLUSIONS

Modelling the project and operating through a lengthy period provides insight into the interaction of canals, reservoirs, and water demands under a variety of conditions. This could not be easily gained in any other way.

Some of the factors which the model helped to evaluate were:

1. The addition of the Forty Mile Coulee Reservoir has the effect of substantially increasing the capacity of the system to meet peak demands without increasing the capacity of the main supply to the project.

2. Energy costs for pumping at Forty Mile Reservoir could vary from zero to $120,000 and average about $34,000 per annum.

3. Water management and in particular the practice of moving water into the internal project reservoirs at the earliest possible date becomes increasingly important with the growth of the project acreage.

In general the long term planning, consideration of alternatives in development and scheduling of project improvements can be done with considerably greater confidence with modelling results available.

ACKNOWLEDGEMENTS

To Alberta Agriculture, Irrigation Division for Preliminary Land Classification information, for information on previously proposed canal rehabilitation work and for information on other potential development.

To Prairie Farm Rehabilitation Administration Hydrology Division, Regina, Saskatchewan for provision of hydrology data, for details of previous water supply study and suggestions for more detailed study.

To Alberta Environment for provision of plans and information on existing works.

To St. Mary River Irrigation District staff for information and suggestions throughout the study.

RED DEER RIVER: USES, FUTURE DEMANDS AND MANAGEMENT REQUIREMENTS

W.G.A. SHAW[1]

INTRODUCTION

Perhaps more than any other river in Alberta in the last ten years, and certainly in the previous five, the Red Deer River has received the most attention due to well-publicized examinations of river management strategies. In October of 1973 the provincial Minister of Environment requested that a study of the Red Deer River be undertaken to determine the feasibility of regulating the river, to estimate the costs, and to specify the effects of regulation on year round flows and on the environment. The study was related to the government's policy for decentralization of industry from Edmonton and Calgary and the stimulation of regional economic growth throughout the Province. It was to assess the Red Deer River as an independent system, unlike some investigations which preceded it. In the old, and apparently scrapped, PRIME scheme[2] a portion of the Red Deer River was considered as an integral part of a series of diversion works to reroute water from water-rich basins to the drier southern areas of the Province of Alberta. The Red Deer River was similarily considered as part of a broader scheme under the Saskatchewan-Nelson Basin Board studies as late as 1972.[3]

Soon after the independent study was called for by the Minister of Environment in the fall, 1973, the water and land use issues in the basin, and particularly the upper portion, crystallized as the interests of various groups were drawn into the study. Nearly four, full long years later, the Provincial Cabinet in July of 1977 announced its decision to regulate the Red Deer River by means of a dam on the river seventeen miles upstream from the Town of Innisfail and 35 miles upstream from the City of Red Deer. This

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[1] W.G.A. Shaw is a Senior Associate Planner for the Red Deer Regional Planning Commission, heading the Regional Planning and Research Section.

[2] PRIME stand for the Prairie Rivers: Improvement, Management and Evaluation, a strategy advanced by the Water Resources Division of the Alberta Department of Agriculture in the 1960s.

[3] Saskatchewan-Nelson Basin Board, Water Supply for the Saskatchewan-Nelson Basin, Queens Printer, Ottawa, 1972.

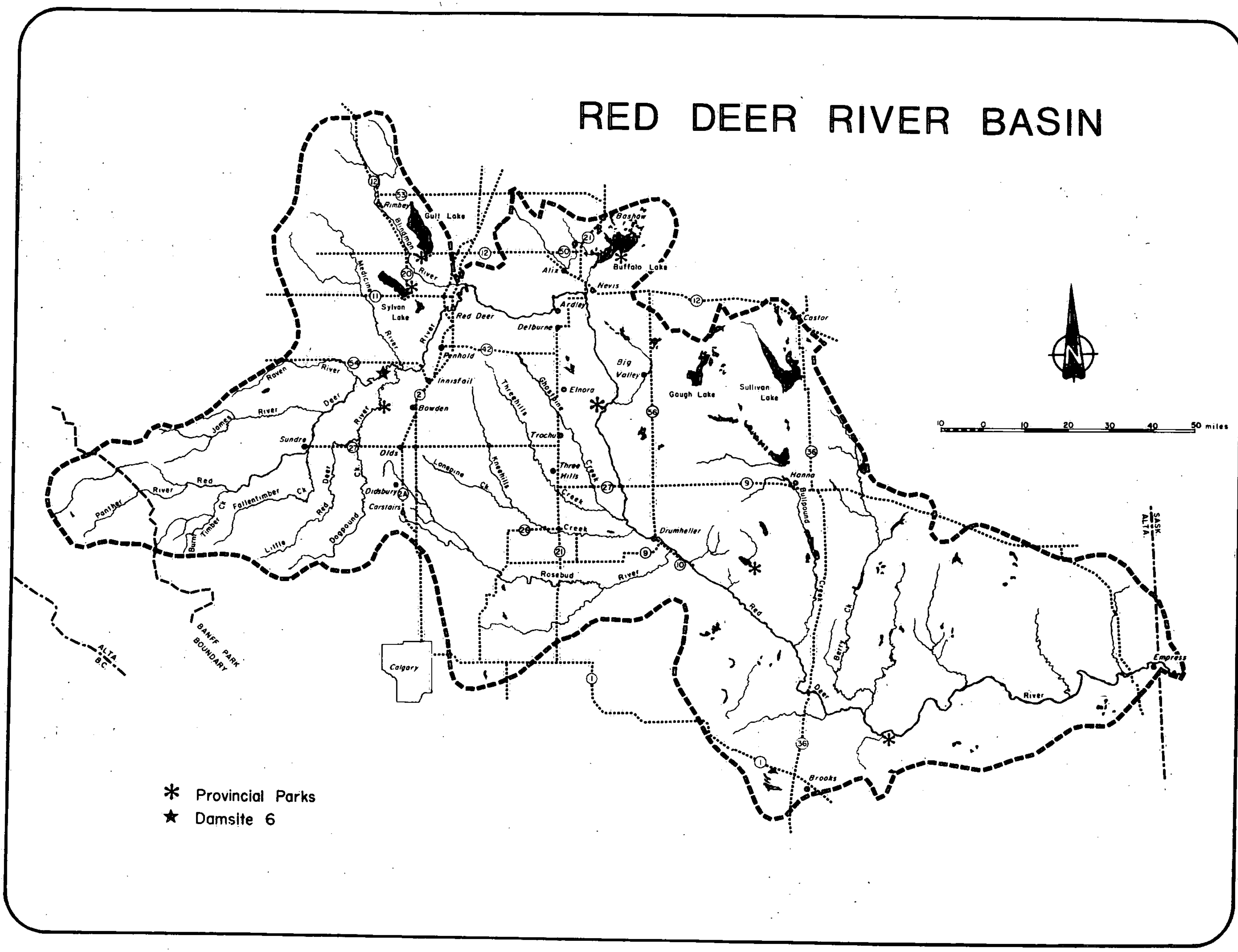
site was bitterly contested by opponents throughout the study process. However, the purpose of this paper is not to question the wisdom of the decision to regulate the river by the chosen means, but to provide an introduction to the Red Deer River, its importance to activity in the basin, and the management requirements needed to maintain the river as a vital link in the life of the basin.

The Red Deer River Basin

The Red Deer River Basin lies in the central portion of the settled area of Alberta (see map). With its headwaters in the Rocky Mountains of Banff National Park, the river first flows in a northeasterly direction through the mountains and foothills and onto the Western Alberta Plain until it reaches the City of Red Deer, where it turns east and then southeast through the Eastern Alberta Plain. Rising in the Rocky Mountains the river's source is at elevations in excess of 10,000 feet. Its mouth forms a tributary of the South Saskatchewan River at an elevation of approximately 1,900 feet just within the Province of Saskatchewan. In all, the basin occupies around 18,000 square miles, stretching 120 miles north-south and about 270 miles east-west and encompasses a variety of landforms including sharply folded mountains, rugged foothills, incised badlands, and rolling and flat prairies.

The population of the basin is approaching 140,000 people, or approximately seven per cent of Alberta's total. About one-quarter of the population lives in the City of Red Deer and nearly two-thirds, or 87,000, in the rural and urban municipalities along the Edmonton-Calgary transportation corridor. Like the City of Red Deer, the City of Drumheller, being the basin's second largest urban community, is located along the Red Deer River. The Town of Sundre is the only other center over 1000 in population adjacent to the river.

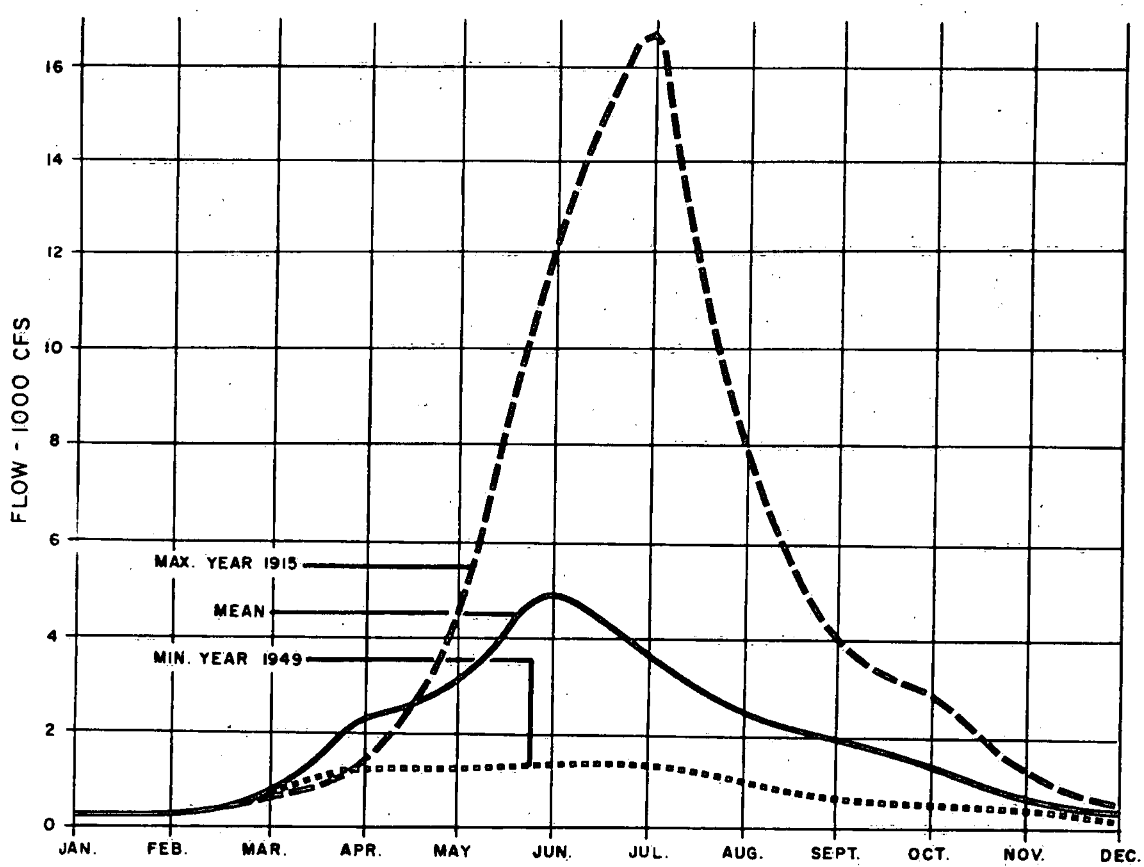
The Red Deer River Basin has a relatively diversified economy, although mainly dependent on agriculture and service industries. Overall, nearly one vocation in three is a farm job, while over one-half of the manufacturing occupations are related to processing food and beverages. In terms of value produced, oil and gas activities are also important. Coal extraction activities occur in the eastern part of the basin, while timber harvesting is widespread throughout the western high plain and foothill areas.


RED DEER RIVER BASIN
Provincial Parks
Damsite 6
Rimbey
Gull Lake
Blindman River
Medicine River
Sylvan Lake
Red Deer
Red Deer River
Alix
Bashaw
Buffalo Lake
Nevis
Ardley
Delburne
Castor
Penhold
Innisfail
Big Valley
Elnora
Gough Lake
Sullivan Lake
Bowden
Raven River
James River
Sundre
Olds
Trochu
Three Hills
Threehills Creek
Ghostpine Creek
Kneehills Creek
Lonepine Ck
Olds
Didsbury
Carstairs
Panther River
Red River
Fallentimber Ck
Burnt Timber Ck
Little Red Deer
Dogpound Ck
Rosebud River
Drumheller
Hanna
Bullpound Creek
Berry Ck
Calgary
Brooks
Empress
River
Banff Park Boundary
ALTA. B.C.
SASK. ALTA.
10 0 10 20 30 40 50 miles
N

The source of the Red Deer River lies east of the Continental Divide, and consequently not in the high mountain glaciers which spawn the larger Bow and North Saskatchewan Rivers. Therefore, the Red Deer River largely depends on snow melt and seasonal rains for its flow. Its major tributaries rise in lower mountain areas (Panther, Fallentimber and James Rivers), the foothills (Little Red Deer and Raven) and the high western plain (Medicine, Blindman), all of which enter the mainstream upstream from the City of Red Deer with the exception of the Blindman.

The flow of the river is highly variable. Daily flows as high as 56,000 cfs are documented, while the record low is 64 cfs. A record mean monthly high discharge of 16,700 cfs has been recorded in July, while the mean low for December has been known to drop to 96 cfs. The June average is about 5000 cfs and the average winter monthly low is less than 300 cfs. The following graph illustrates the flow variability of the Red Deer River.

RED DEER RIVER HYDROGRAPH (AT RED DEER)



SOURCE : ALBERTA ENVIRONMENT

Problems with the River

The Red Deer River has a number of problems which have been a continuous, and growing source of concern to inhabitants of the basin, the municipalities and industries therein, and provincial government officials responsible for water use and control. These relate to quantity, quality, erosion and flooding, as well as recreation considerations.

Described above is the variability in the flow of the Red Deer River. Because current demands appear to be around 16 cfs, while in most instances in excess of 300 cfs of water is available, it may be questioned why quantity is considered a problem. Basically, it is regarded as problematic because of the fear, subconscious or other, that during an unusual combination of circumstances for a period of a day or a number of days, insufficient water may be flowing in the river for existing municipal and industrial intake systems to function, thereby isolating a substantial number of people and businesses from a basic commodity. Bigger yet is the problem, or as many environmental extremists and non-growth advocates would describe as a phobia, that an unregulated Red Deer River leaves the basin in the unenviable position, as the growth advocates would suggest, of not having a guaranteed year round source of water, which thereby discourages industrial development and retards the general advancement of economic prosperity.

In the case of the Red Deer River, quantity is also a problem in that it is related to water quality. Provincial water quality criteria stipulate that the minimum acceptable dissolved oxygen content is 5 mg/l. Values below this level have been observed through tests on numerous occasions, being as low as 0.4 mg/l at Empress in January, 1972 and 0.6 mg/l at Drumheller in February, 1972. The Pollution Control Division of Alberta Environment has calculated that to maintain minimum oxygen levels in the river a minimum flow of 540 cfs would be required from a flow regulation dam upstream from Red Deer if the chosen location was Site 6. This flow, of course, exceeds most winter flows and therefore quantity can be associated with the quality problem.

Two other problems, flooding and erosion, are intertwined since the most significant erosion occurs during flood peaks. Floods along the Red

Deer River occur during the early spring break-up usually by backwater effects from ice jams, and in early to midsummer when heavy rains in the Eastern Slopes, combined with snow meltwaters, raise the river to peak flows. Sundre and Drumheller are particularly vulnerable to floods. It has been estimated that damages from a 1:100 year flood at Sundre would amount to nearly $900,000 and at Drumheller to $5.8 million.[4] Sundre is also susceptible to flooding from the tributary Bearberry Creek, which on a 100 year return, would cause damage in excess of one-half million dollars. Although the City of Red Deer is also situated along the Red Ded River, within the urban limits the flood plain is restricted by the river's banks. Only $50,000 damage could be expected from a 1:100 year flood. Throughout the river valley floods also create problems for agricultural lands through the deposition of silt and by burying or washing away of early seeded crops. Along the river, erosion is problematic from just below the foothill reach upstream from Sundre to the area of Dinosaur Provincial Park near Brooks. Major erosion problems, however, are concentrated between Sundre and Innisfail. In the period 1950 to 1974, between the foothills and the City of Red Deer ice scouring, high waters and resultant slumping eroded an estimated 2,200 acres of land worth some $500,000.[5]

Satisfying the growing demands for water-based recreation is an increasing challenge for Alberta's recreation planners. The Red Deer River basin, particularly north of Calgary, is highly susceptible to these demands because of its central location between two major urban complexes having a combined population approaching one million people. Good, high quality recreation lakes are not plentiful in this zone and, therefore, river shoreland recreation will become of greater importance. The Red Deer River valley is an obvious attraction because of its proximity to densely settled areas and its diverse and widespread scenic landscapes.

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[4] Alberta Environment, An Assessment of Alternatives to a Dam on the Red Deer River, Edmonton, December 1976, p. vii.

[5] Alberta Environment, An Assessment of Alternatives, pp. 56-57.

WATER USES

Provincial legislation distinguishes the following purposes for water: domestic, municipal, industrial, irrigation, water power and other. A study of municipal and industrial water demands, prepared as part of the Red Deer River flow regulation studies, provides data on these uses for the Red Deer River.[6]

During the early 1970's maximum municipal water withdrawal from the Red Deer River was just under 7 cfs. The four municipalities which rely on the Red Deer, either by surface withdrawal or infiltration wells, for their withdrawals are: Red Deer - 5.3 cfs, Drumheller - 0.3 cfs, Innisfail - 0.4 cfs and Sundre - 0.2 cfs. Consumptive municipal uses are estimated at no more than 20 per cent of water intake and, therefore, nearly 5.5 cfs are returned to the river by the municipalities. Of Red Deer's uses, about 20 per cent is for municipal industrial purposes. Other municipalities in the basin use an aggregate of about 2 cfs, mostly from groundwater sources and, therefore, their use has minimal effects on the Red Deer River.

While there are significant commitments at present for industrial water from the Red Deer River, only portions of these are exercised. Licenses for well injections total nearly 13 cfs from the Red Deer and 2.6 cfs from its tributaries, but it is estimated that only 8 cfs are used. Private industrial water withdrawals for industrial plants (non-urban municipal) take 1.3 cfs from the river annually. Only about ten per cent of these private withdrawals are consumed.

In total, then, municipal and industrial users withdraw around 16 cfs from the Red Deer River, with at most only 20 per cent being consumed. Domestic uses are not known, but are considered to be negligible. Stock watering and small irrigation activities occur and while data is not available for these, again they are considered negligible.

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[6] Seifried, A. and R. Lefrancois, "Municipal and Industrial Water Demands," Volume II Red Deer River Flow Regulation Planning Studies, Alberta Environment, Edmonton, 1975, pp. 1-40.

FUTURE WATER DEMANDS

When comparing the present use of 16 cfs with the mean winter lows of approximately 300 cfs, or even the daily record low of 64 cfs, one might question why water quantity is thought to be a problem with the Red Deer River. Obviously at present it is not. However, it must be remembered that in announcing the flow regulation study in 1973, the Provincial Government stated that one of the reasons for the investigation is that water quantity should not be a limiting factor to economic growth in the basin. It must be asked, then, what forms of growth, and how much, are anticipated?

It is expected that in the future the greatest growth in water demand will originate from the industrial sector. By the turn of the century, while oil and gas activity is not expected to grow, the coal industry will expand throughout the basin and a core of petrochemical plants is also anticipated. One or two coal gasification plants are projected, while one to four major coal-fired thermal electric generating plants could be developed within the basin. These would require related coal mining and coal washing plants for the supply of fuel, all greatly adding to demands for Red Deer River water. Also, another petrochemical plant in addition to the new ethylene installation near Red Deer is anticipated. Projections for up to twelve new petrochemical plants in the basin by 2004 have been made, but this prediction is likely exceedingly high. Based on these alternatives, industrial water demands are projected to range between 137.5 cfs and 292 cfs shortly after the turn of the century.

Municipal water demands will depend on the amount of economic growth in the basin through the resultant increases in population. By 2004, the current population of 140,000 in the basin could grow as high as 220,000 with maximum industrial development.[7] If most of this growth occurs in centers which rely on the Red Deer River as its water source, then it is expected that municipal water demands will reach 20.8 cfs. In addition, the newly completed Red Deer Regional Water Pipeline, which serves Innisfail, Bowden, Olds, Didsbury, Carstairs and Crossfield can supply a maximum of 13 cfs to these municipalities.

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[7] Seifried and Lefrancois, op. cit., p. 33.

In projecting water demands for agriculture it was felt that irrigation and livestock watering needs would be minimal. While irrigation does occur in the basin, the water source is the Bow River. Although irrigable land in the basin is more than the total being irrigated in the province at present,[8] the chance of extensive irrigation using Red Deer River water being commenced was felt to be unlikely given the current profitability of dry land farming and the high capital costs of introducing irrigated farming.

In summary, with maximum industrial expansion it is projected that by the year 2004 municipal and industrial water demands from the Red Deer River could total 325.8 cfs, which exceeds the historic mean monthly low flows. Assuming some industrial expansion, but much less than the projected maximum, water demands could total 161.2 cfs, or in excess of ten times current demands. Since mean monthly flows during the winter have been known to drop below 200 cfs, with the absolute daily minimum recorded at 64 cfs, should this amount of industrial development occur, the need for flow regulation is apparent. Meeting the required flow of 540 cfs at the Site 6 dam for water quality purposes would also fill industrial and municipal demands as long as consumptive uses were not excessive. Also, riding above all these demands is the need to guarantee that one-half of the Red Deer River flow is passed through to Saskatchewan as part of the prairie provinces' interprovincial agreement on water sharing in the Saskatchewan-Nelson basin.

RIVER BASIN MANAGEMENT

The Red Deer Regional Planning Commission and the individual communities of which it is composed recognize the critical importance of the Red Deer River, and consequently wish steps to be taken to assure the wise use and managment of the river. This would of course not only benefit the Commission area, but the whole basin as well as the recipient basins in the downstream portions of Saskatchewan and Manitoba. To this end the forms of importance of the river must be recognized, as should the key objectives in its management and the tasks required for these objectives to be realized.

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[8] Karkanis, P.G., Red Deer River Preliminary Irrigation Report, Alberta Agriculture, 1974.

Importance

While discussed earlier, it is useful to summarize the important uses of the Red Deer River, including its tributaries. Major and growing in importance are municipal water supply and industrial water supply. A greatly increased role will be for the development and production of electrical energy. Domestic and agricultural uses are basically of minor importance, but localized stock watering and irrigation activities could become significant in the future. Of course, the river is important as a fish habitat and this will continue, but moreover, increasing recreation demands will need to be met in the future. These diverse, but essentially interrelated demands require improvement in the management of the river and its basin on a coordinated basis.

Key Objectives

Numerous objectives for the management of the Red Deer River basin could be listed, but for the purposes of this paper these will be limited to nine key objectives. These are:

1. Water supply must be assured for all future demands.
2. Water quality should be improved and maintained above minimum provincial standards.
3. Minimize potential hazards from flooding and erosion in the flood plain.
4. Protect investments in the flood plain.
5. Improve year-round flow distribution.
6. Improve knowledge of all water resources in the basin and integrate the management of these; i.e. rivers, lakes, groundwater.
7. Integrate water management with the management of other resources.
8. Establish an effective, integrated management system.
9. Establish an education program for watershed and water conservation and management.

Essentially, these objectives state that our water resources need to be understood in terms of supply, demand, and their interrelationships. Also the effective management of water is dependent upon its integrated management with other resources through an effective co-ordinating agency which, among other things, would be required to implement regulatory measures on its own or through related jurisdictional authorities, to prevent and minimize flood and erosion losses, to improve watershed and water management, to assure water quality and guarantee water supplies for all future users within the basin, and to maintain downstream commitments.

Required Tasks

To meet the preceeding key objectives, a series of interrelated tasks must be undertaken. These tasks are as follows:

One: Develop, adopt and implement a long-range, integrated management plan for the Red Deer River basin based on extensive studies of water sources, supplies, uses, demands, land use (present and future), water quality, and so on.

Two: Establish an integrating agency in the form of a management board which manages the use of water within the basin and helps coordinate the activities of the numerous jurisdictional authorities already operative within the basin.

Three: Take protective action to sustain the role and quality of the headwater areas of the basin.

Four: Regulate environmental disturbances to minimize the impairment of water quality and promote improved year-round water yields.

Five: Administer pollution control measures and land use regulations to correct polluting activities.

Six: Undertake flow regulation of the Red Deer River for water supply, quality, flood control, erosion abatement and recreation purposes.

Seven: Prepare detailed flood plain maps and through the appropriate municipalities and agencies adopt and implement regulatory devices to restrict development in the flood plain.

Eight: Develop flow control structures to prevent flooding in existing developed areas.

Nine: Undertake the construction of erosion abatement structures in critical areas, if it is known that such structures will not subsequently transfer the eroding forces to the river to a limited number of concentrated points, thereby only creating new problems, but instead will spread these powers along a major reach of the river.

Ten: Encourage the wise use of lands in the river valley concentrating upon its values for agriculture, wildlife and recreation.

Eleven: Mount a public education campaign which informs individuals, groups and corporations of the value of water resources, its conservation and their roles in the wise use and protection of this vital commodity.

Twelve: Establish effective public involvement programs which allow basin residents to express their views on water and related land management and to assist in identifying planning objectives for the basin.

None of these thoughts or ideas are new or unique to water resource management in Canada. Many, in fact, parallel recommendations made by the Environment Conservation Authority to the Government of Alberta for the flow regulation of the Red Deer River.[9] However, the collection of these objectives and tasks as a result of recent studies and hearings on the Red Deer River represents a considerable advancement of consolidated thinking for this river and basin by its constituent municipalities and people, which five years ago were hardly thought of, let alone advocated.

SUMMARY

The Red Deer River is without question a key resource in the current activities of its basin. It does have recognized problems which deserve attentive action so the river in the future will be able to fulfill its growing role as the lifeblood of the basin. To this end, key objectives in managing the river and basin must be recognized with resultant action to be taken if the river is to successfully perform as a critical element in the prosperity and lifestyle of the basin. Similarily, individuals, municipalities and corporations must understand the value of our resources, and in their everyday activities be prepared to wisely use and conserve our water to assure its availability and quality for future generations.

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9 Environment Conservation Authority, Flow Regulation of the Red Deer River: Report and Recommendations, Edmonton, June 1977.

SASKATCHEWAN USES OF THE SASKATCHEWAN RIVER SYSTEM

ABSTRACT

The largest river system in Southern Saskatchewan is the Saskatchewan River System which rises in Alberta on the eastern slopes of the continental divide. The uses that Saskatchewan makes of this very important water resource are described. Saskatchewan's need for adequate hydrologic understanding of this water resource for forecasting, operation planning and long range water use planning are emphasized.

R. S. Pentland, P. Eng.,
Head,
Operation Planning Division,
Hydrology Branch
Environment Saskatchewan

CHAPTER I

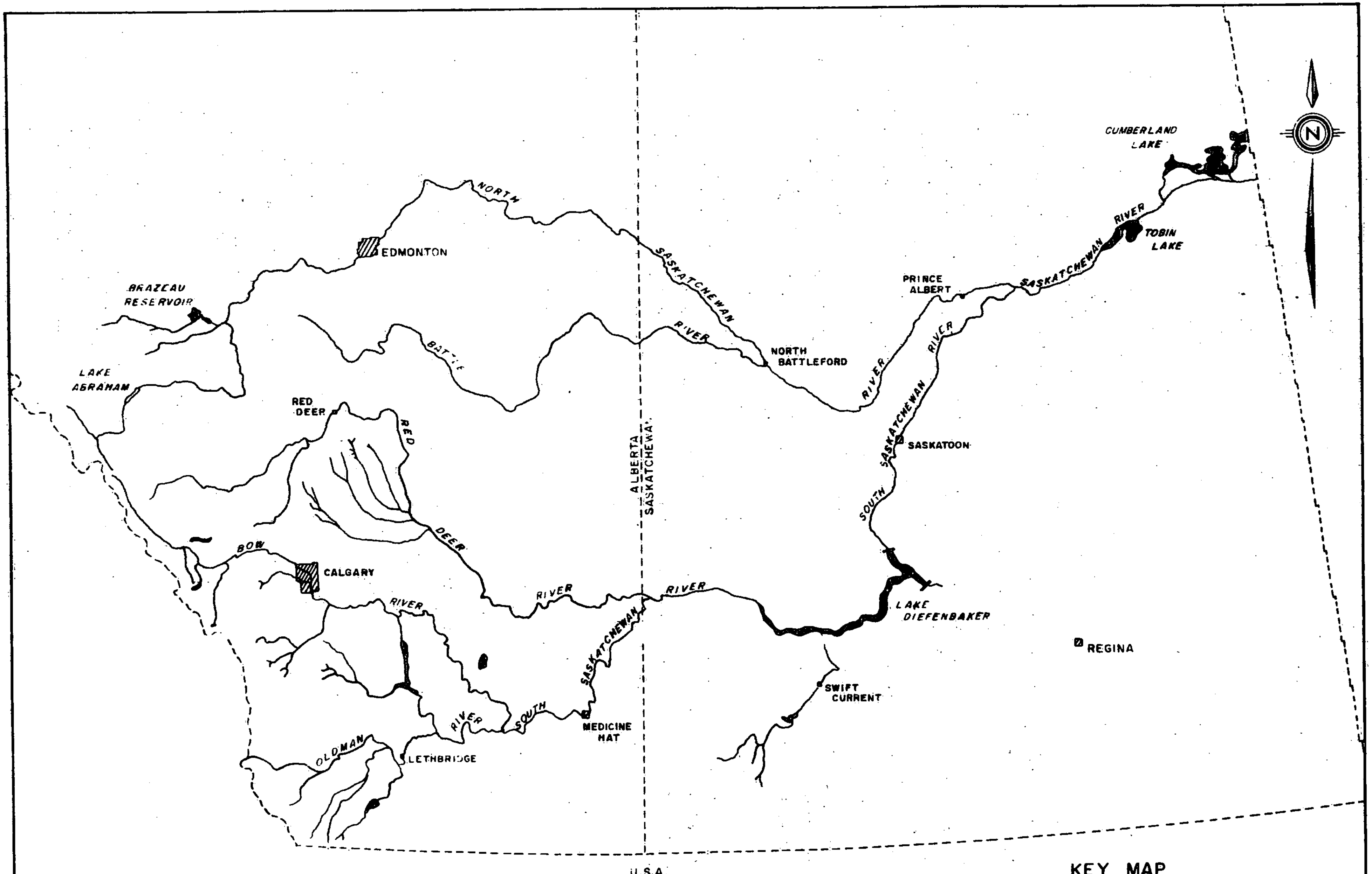
INTRODUCTION

Southern Saskatchewan is a relatively arid area where local streams and rivers provide an ephemeral water supply. Development of economic activities based on such water resources is very difficult.

The Eastern Rockies drainage water that is carried by the North and South Saskatchewan Rivers from Alberta through Saskatchewan's populated regions provides a much larger and more reliable source of water than the local rivers. Figure 1 shows these two large rivers.

A large segment of the population of Saskatchewan relies on this water for domestic, municipal, industrial, irrigation, recreation and energy generation uses. This paper provides a brief description of these uses.

In order for Saskatchewan to manage this very important resource it is necessary to look beyond provincial boundaries and understand the nature of the source of this water. Therefore Saskatchewan water managers are very interested in both physical and research developments that will provide insight into the source of this water resource in the Eastern Rockies.



KEY MAP
OF THE
SASKATCHEWAN RIVER SYSTEM
FIGURE I

CHAPTER II

APPORTIONMENT

Since the availability of water for Saskatchewan's use is limited by the Prairie Provinces Apportionment Agreement a brief outline of this agreement may be useful.

Prior to 1969 there was considerable uncertainty about the rights of the three Prairie Provinces to the use of water from the Saskatchewan River system. It was not clear how much of the flow the upstream provinces could consume and how much the downstream provinces could depend on receiving. Rational long range planning in all three Prairie Provinces was not possible.

In 1969 the Prairie Provinces and Canada solved this problem by signing the Apportionment Agreement. This agreement recognizes the right of an upstream jurisdiction to use waters that arise in their area and also the right of a downstream jurisdiction to enjoy continued use of these rivers. The flow is divided equally between the upstream and downstream province. Alberta can consume up to 50% of the natural flow of rivers that flow east into Saskatchewan. Saskatchewan can depend on receiving 50% of the natural flow but Saskatchewan must pass one-half of the water it receives from Alberta plus one-half of the flow arising in Saskatchewan to Manitoba. The agreement provides for a minimum diversion in Alberta to protect uses that existed before 1969 and minimum flow criteria are also identified.

The Prairie Provinces Water Board was created by these agreements to oversee apportionment and to assist Canada and the Prairie Provinces in co-operative management of this water resource. Through the Prairie Provinces Water Board a major level of liaison and co-ordination on interprovincial water matters has been possible.

Besides creating a board which is made up at a policy and senior administration level various technical subcommittees have been formed. The Committee on Hydrology co-ordinates water quantity studies on forecasting, natural flow and apportionment. The Committee on Water Quality co-ordinates water quality monitoring and establishment of criteria. The Committee on Interjurisdictional Agreements considers some of the problems peculiar to southeastern Alberta and southwest Saskatchewan where international as well as interprovincial problems exist.

CHAPTER III

WATER USES

A. General

The purpose of this chapter is to briefly outline the developments in Saskatchewan on the Saskatchewan River system and to summarize the water uses.

B. Lake Diefenbaker Development

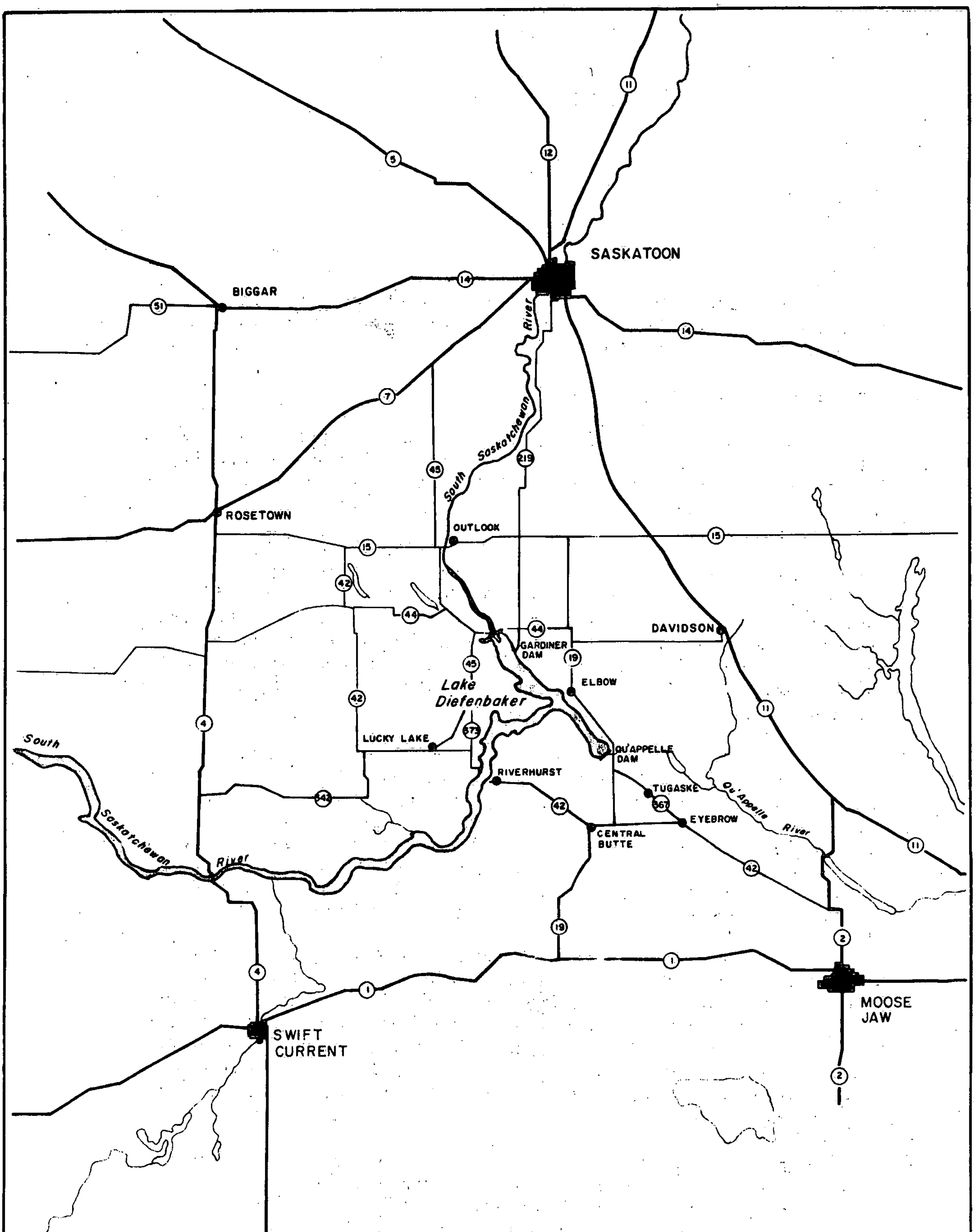
In the period from 1958 to 1967, Canada, through PFRA, and Saskatchewan jointly constructed the Gardiner Dam and Qu'Appelle Valley Dam, creating Lake Diefenbaker. Figure 2 shows the two dams and Lake Diefenbaker.

The cost of this project was about $120,000,000. Under a cost-sharing agreement, Saskatchewan financed $25,000,000 and Canada financed the remaining $95,000,000. Canada supervised construction of the works and provided all engineering. The cost of the Coteau Creek generating station at Gardiner Dam was not shared and represents an investment by Saskatchewan through the Saskatchewan Power Corporation of about $40,000,000. Figure 3 shows the general layout of Gardiner Dam.

Saskatchewan has also invested in works to utilize the water of Lake Diefenbaker for irrigation and for municipal and industrial water supply through the east side pump plant and the Saskatoon-Southeast Water Supply System and through improvements to the Qu'Appelle River to better utilize Lake Diefenbaker water. Additional works are contemplated. The consumptive uses of water from Lake Diefenbaker are very important, but in total they utilize a small fraction of the total flow of the South Saskatchewan River.

Part of the flow of the South Saskatchewan River was stored between 1965 and 1969 and the reservoir was filled slowly. The lake, covering 106,000 acres and containing 7.6 million acre-feet of water, was created. About 76,000 acres are permanently flooded by 4.4 million acre-feet of permanent storage, while the remaining 3.2 million acre-feet of volume is available for flow regulation. Curves showing the storage volume and surface area versus surface elevation are shown on Figure 4.

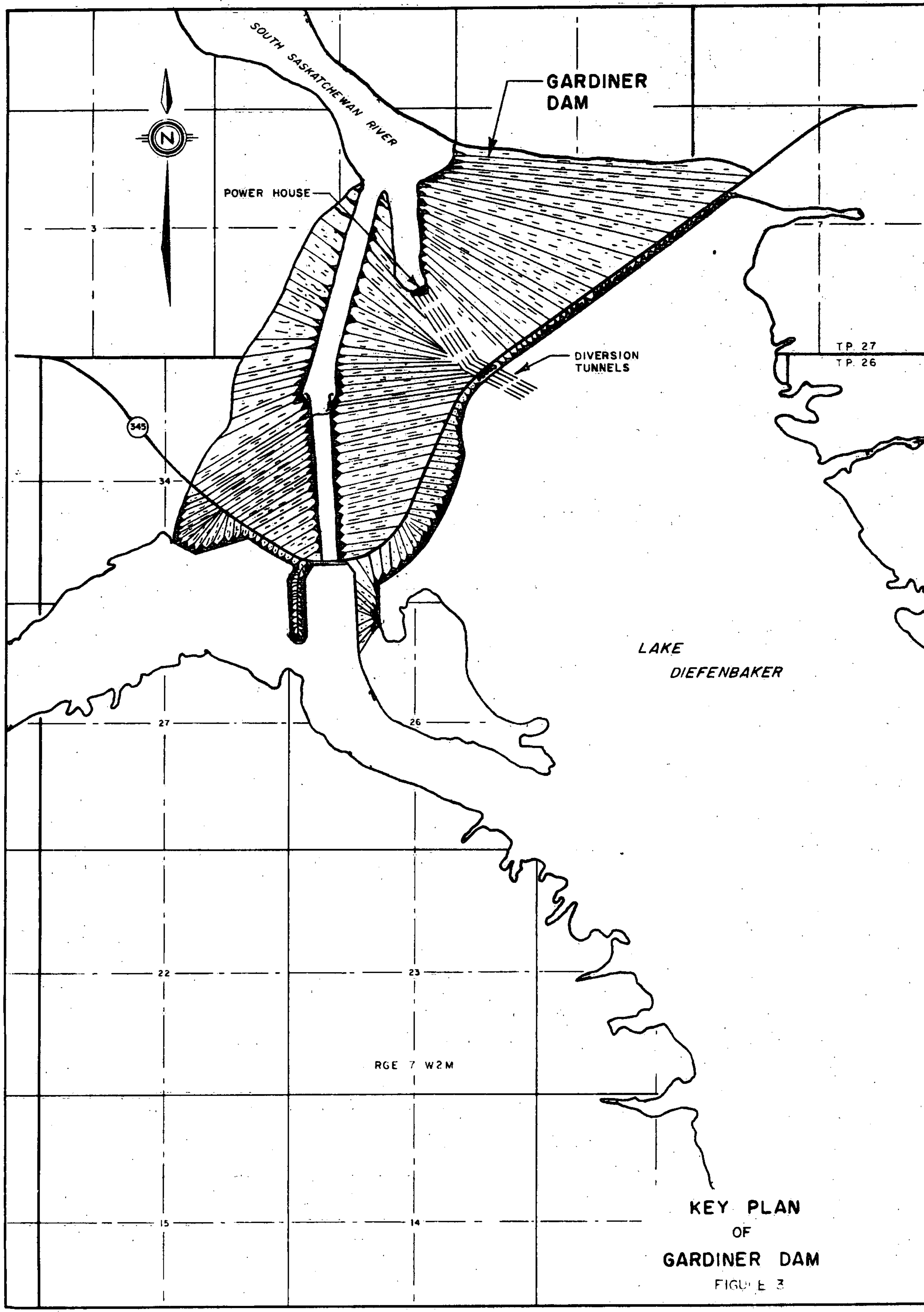
During the period of filling, flow in the South Saskatchewan River was maintained by releasing water through the diversion tunnels. From September of 1968, these releases were used for power generation at Coteau Creek Generating Station. The three



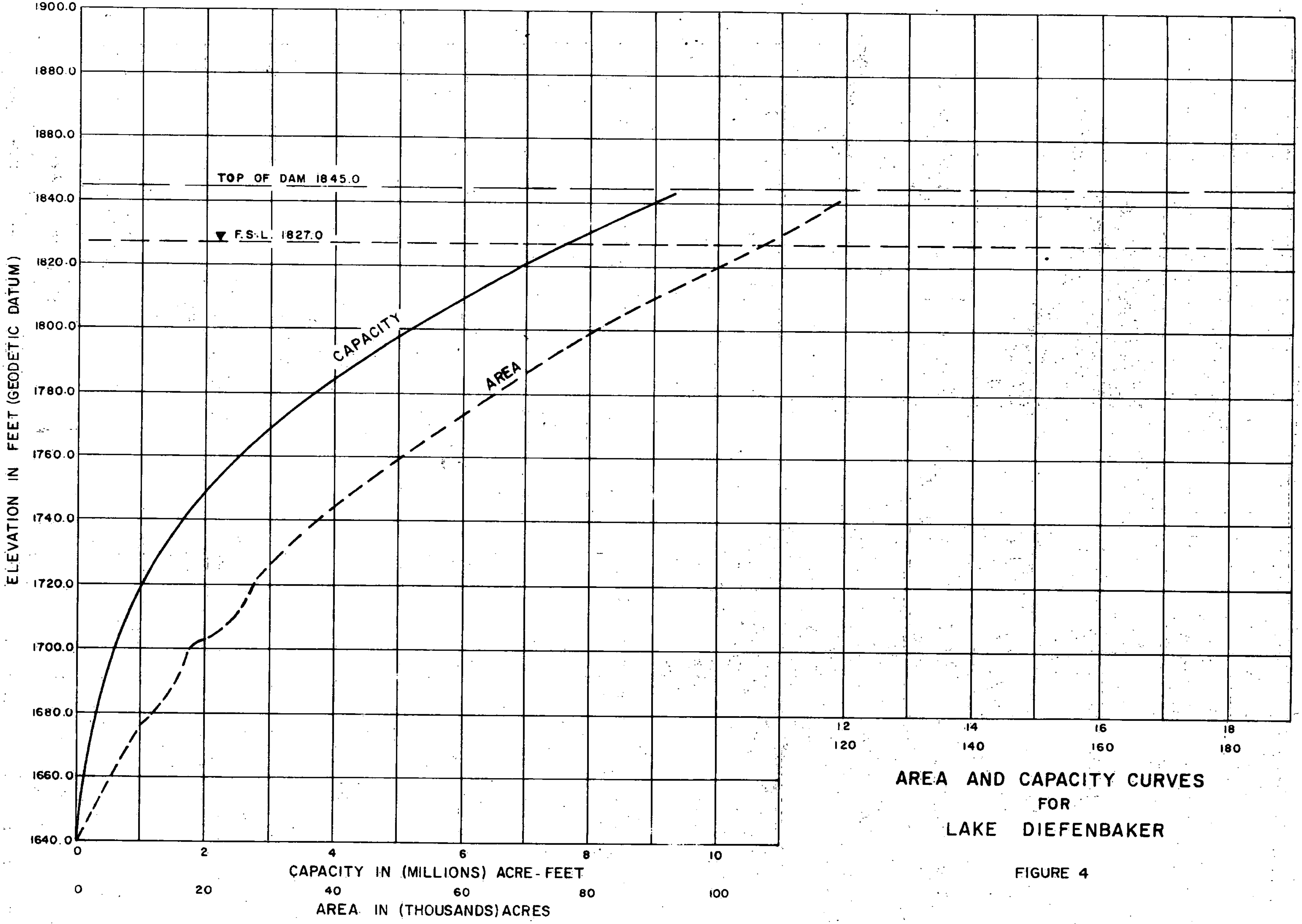
SASKATCHEWAN
DEPARTMENT OF THE ENVIRONMENT
HYDROLOGY BRANCH

DRN.	DATE
CK'D	PLAN NO.

FIGURE 2



KEY PLAN
OF
GARDINER DAM
FIGURE 3



AREA AND CAPACITY CURVES
FOR
LAKE DIEFENBAKER

FIGURE 4

diversion tunnels that have been harnessed for power generation can provide total releases up to 15,000 cubic feet per second (cfs) and the turbines generate 187,500 kilowatts at peak capacity. When necessary, outflows in excess of the power plant capacity are released through the gated spillway.

Besides the power production, irrigation, municipal and industrial water supply and the Qu'Appelle River water supply benefits, Lake Diefenbaker has become an important recreation center and sport fishing area. The large lake also provides flood control and, with careful planning and integrated operation, it has greatly increased the economic value of the Squaw Rapids Generating Station.

B. Squaw Rapids Development

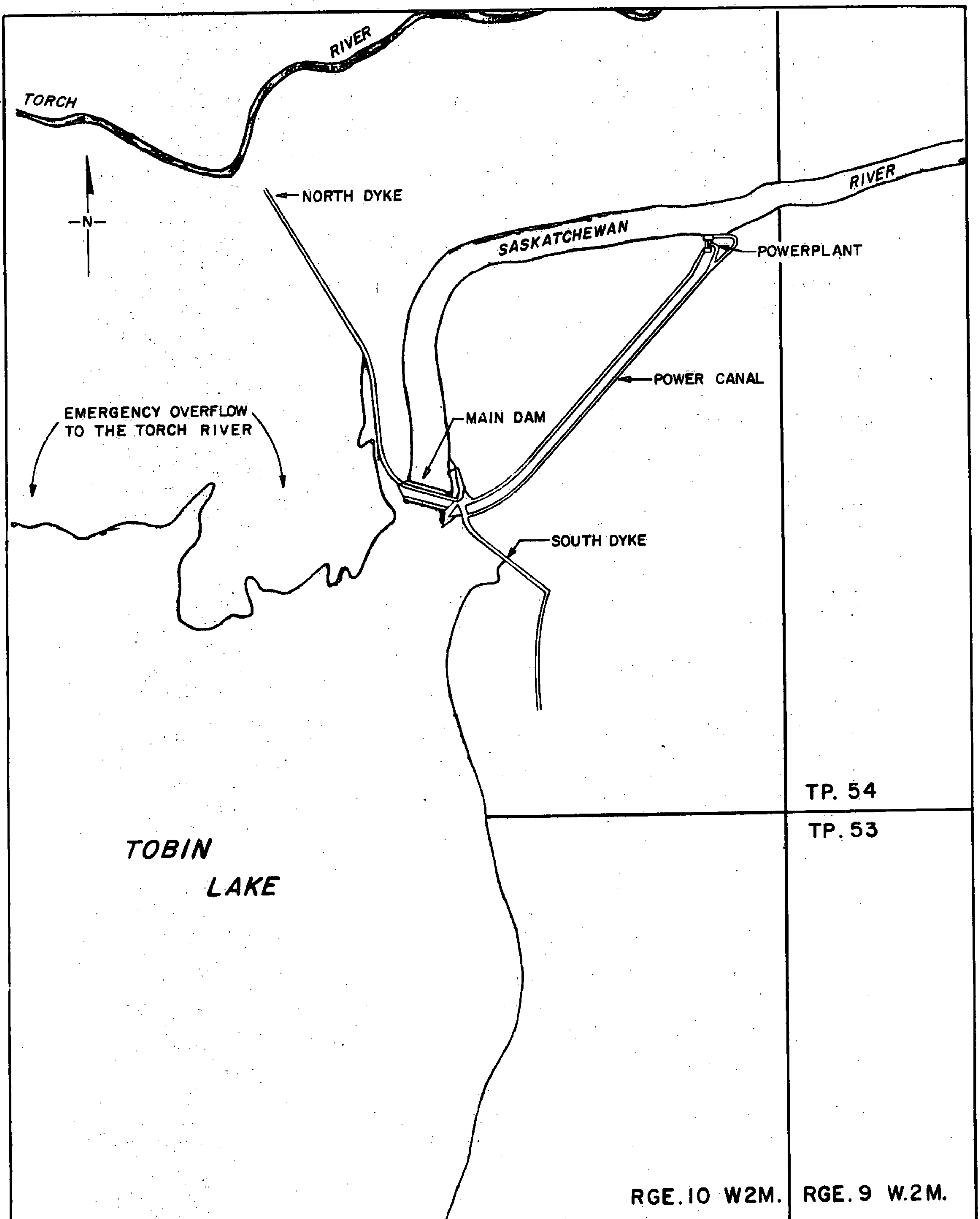
The Squaw Rapids development was completed by the Saskatchewan Power Corporation on the Saskatchewan River a short distance downstream of Nipawin in 1964. Figure 5 shows the general configuration of the development.

This project receives the combined flow of the North and South Saskatchewan Rivers. The reservoir, Tobin Lake, covers 75,000 acres and has a usable storage capacity of 505,000 acre-feet. Considering that the volume of the water flowing at this location is about twice that received at Lake Diefenbaker and the reservoir is substantially smaller, there is a much smaller effect on the seasonal flow patterns caused by this project than by Lake Diefenbaker. This power development is operated on essentially a "run of the river" concept with the storage capacity used to provide short-term flexibility. Use of this storage is planned on a week-to-week or at most a month-to-month basis rather than on a seasonal or annual basis as at Lake Diefenbaker. Area and storage capacity curves are shown on Figure 6 for Tobin Lake.

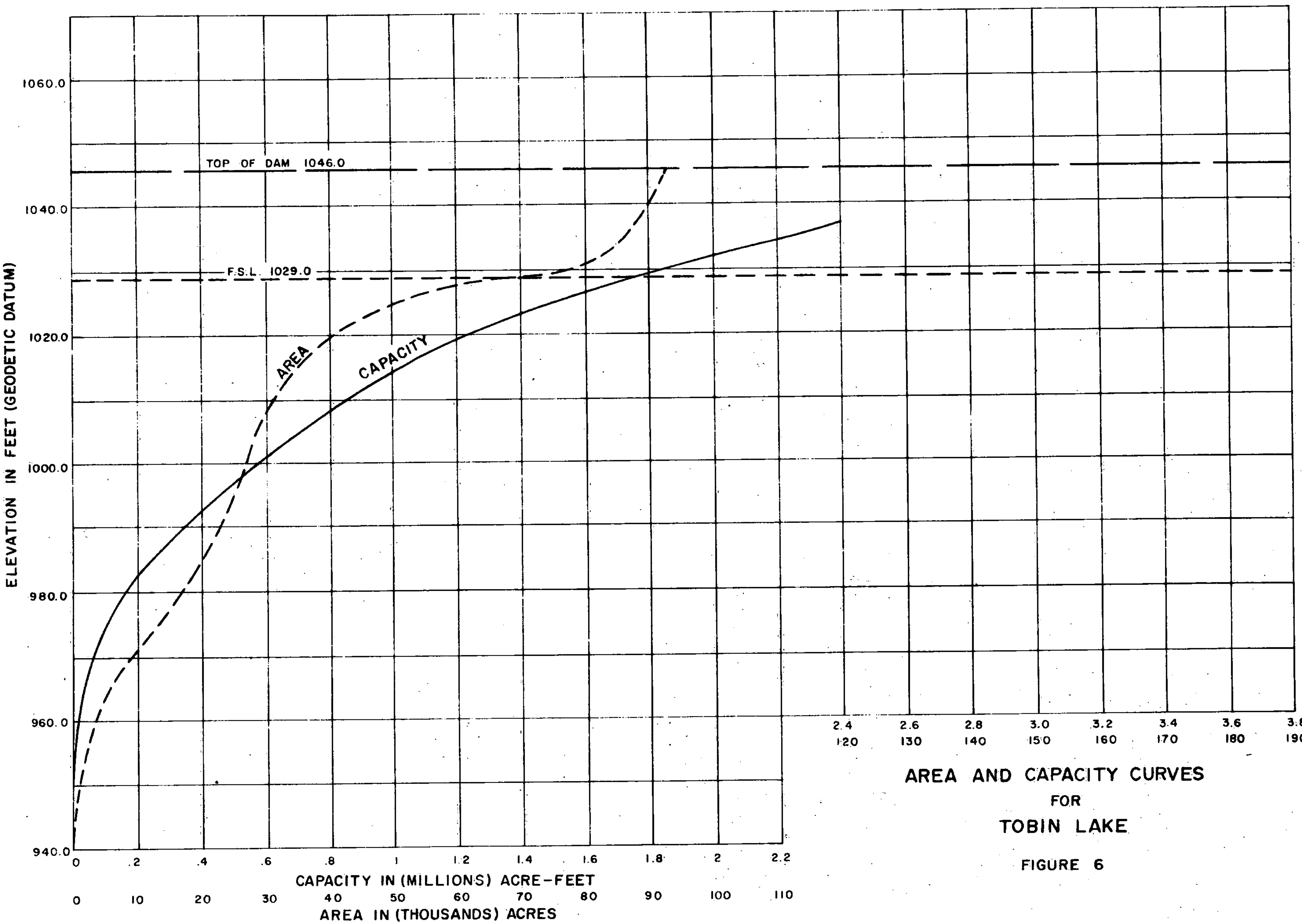
Regulated flows on the South Saskatchewan River as a result of Lake Diefenbaker greatly enhance the economic importance of Squaw Rapids Generating Station for power generation.

Two power Reservoirs in Alberta, Brazeau Reservoir and Lake Abraham, have improved flow patterns of the North Saskatchewan River for power generation in Saskatchewan. Brazeau Reservoir was first operated in 1961 and the Big Horn Dam forming Lake Abraham was completed in 1972. These Alberta reservoirs control only a portion of the headwaters of the North Saskatchewan River, but they have greatly increased the winter flows and thereby added to the usefulness of Squaw Rapids for meeting peak winter power demands.

Squaw Rapids has eight generating units that can pass up to a total of 40,000 cfs and produce 281,000 kilowatts at peak capacity.



KEY MAP
OF
SQUAW RAPIDS PROJECT
FIGURE 5



AREA AND CAPACITY CURVES
FOR
TOBIN LAKE

FIGURE 6

The spillway is used to pass flows in excess of 40,000 cfs when necessary.

Since water that is used at Coteau Creek Generating Station flows to Squaw Rapids, it is available for a second use a few days after leaving Lake Diefenbaker. Planning of operation at Coteau Creek must, therefore, take into account this second use and operations of the two generating stations must be closely co-ordinated.

Although it was built as a reservoir for a hydroelectric generation station, Tobin Lake has developed into a recreation area and also provides some flood control to the Cumberland Lake area and areas downstream in Manitoba.

C. Water Use

Virtually all the water that flows through Lake Diefenbaker and Tobin Lake is used. A portion is diverted down the Qu'Appelle River for the cities of Regina and Moose Jaw, irrigation, stock-water, recreation and waterfowl. A portion is diverted to irrigation projects east of the South Saskatchewan River. A portion goes to towns and potash mines southeast of Saskatoon. The remaining water is used to generate electricity.

On the average about 100,000 acre-feet of water is diverted for consumptive uses from Lake Diefenbaker each year. This quantity is growing as more uses develop.

About 50,000 acre-feet are diverted to the Qu'Appelle River for uses at Regina and Moose Jaw, potash mining near Belle Plaine, irrigation of about 1,000 acres of market gardens near Regina and several thousand acres of forage crops, and for maintenance of water levels for recreation uses of eight lakes.

About 50,000 acre-feet are diverted into the Saskatoon South-east Water Supply system to provide for irrigation of 20,000 acres of farmland, municipal water supplies, potash mine water supplies and recreation and wildlife projects.

About 600,000 acre-feet of water is lost to evaporation or augments groundwater resources in the vicinity of the reservoir. The remaining flow is used to generate electric energy. The average flow of the South Saskatchewan River is about 8,000,000 acre-feet.

At Tobin Lake the combined flow of the North and South Saskatchewan Rivers is used to generate electricity.

The two power generation projects produce an average of two million megawatt hours of energy per year which is about 25% of the electrical energy required for the Province of Saskatchewan.

Beside the uses at these major reservoirs the Cities of Saskatoon, Prince Albert and many smaller communities use the Saskatchewan River system for drinking water. Many private irrigation schemes use these rivers and various water based recreation uses exist along the rivers.

In total over half the population of Saskatchewan relies on this river system for municipal water supplies. Close to half the irrigation acreage in the province is served from this system and the area under irrigation is expanding. Many of the most heavily used recreation lakes in the province are maintained by water from these rivers. Power generated by hydroelectric stations reduces fuel costs by over fifty million dollars in an average year and conserves nonrenewable fossil fuels.

CHAPTER IV

IMPACT OF ALBERTA DEVELOPMENTS

A. General

With the large dependence on the Saskatchewan River system water managers in Saskatchewan must keep fully informed on Alberta plans of development on the eastern slopes of the Rockies.

B. Hydro Development

When Alberta develops storage for hydro development such as the Brazeau and Bighorn Reservoirs in the North Saskatchewan River Basin we receive some benefits and some disbenefits. Since summer flows are stored in such reservoirs we lose the use of the water in the summer, we lose the flushing impact of the spring and summer floods. We gain a degree of flood control and higher minimum flows in winter when our power demands are highest. The high winter flows improve the oxygen levels in the water as well as permitting improved use of hydroelectric generation. The winter flows of the North Saskatchewan average about three times their natural state counterparts.

C. Irrigation Development

When Alberta expands irrigation the net flow arriving in Saskatchewan is reduced and because a larger percentage is returned flow the quality deteriorates.

D. Municipal and Industrial Development

Municipal and industrial uses of water do not usually deplete the supply significantly but the quality of the water inevitably deteriorates.

E. Research Developments

Research that reveals information about the watershed upstream of Saskatchewan is of vital interest. Planning of water use in the short and long term relies on understanding the physical source of this water. The better we understand the water resource, the better it can be used by all the users.

CHAPTER V

SUMMARY

The North and South Saskatchewan Rivers are the largest and most reliable water resource in southern Saskatchewan.

About half the urban population of Saskatchewan relies on this river system for municipal water supply. The largest irrigation system in the province relies on this source. One-quarter of the electric energy consumed in the province is generated by hydroelectric stations on this river system. Fish, wildlife and recreation uses of this water are extensive.

Saskatchewan is very interested in all physical and research developments that may help improve this water resource or the management of the resource.

EAST SLOPES WATER DEMANDS--REAL OR IMAGINARY?

Dr. Marshall Gysie

ABSTRACT

There is much publicity about the demands of today's world for resources. It seems to be taken by many as an axiom that these demands will always grow exponentially, at least for the near future.

This paper will deal with three water resources projects, two proposed and one on-going, for the Alberta Rockies Eastern Slopes. One is an irrigation project, one a flow regulation project, and one an urban water supply project. Although each of these projects has been expounded as being in the "public-needs" category, it will be argued that there is strong evidence to indicate that they are in the "imagined-demands" category.

EAST SLOPES WATER DEMANDS - REAL OR IMAGINARY?

- by Marshall Gysi[(i)]

INTRODUCTION

The word demand has a rather unpleasant connotation when used in our everyday language. A polite person requests something; one less polite demands it. Webster's Dictionary defines a demand as "an authoritative claim; a peremptory request; the state of being much sought after".

Alberta, like most of Western North America, must feel the first of these definitions is best since it uses "appropriative law" in the allocation of waters. The person or group with the previous "license" has priority in use over a later (in time) licensee.

In the wetter (usually) eastern part of North America, "riparian doctrine" is more popular. The owners of land adjacent to surface waters have the right to take water for use on their land. These areas must accept the middle definition above for water demand. The water beside them is theirs, with no discussion necessary. To a certain extent, Alberta must partially believe this definition, as people bordering streams are allowed to use the water for "domestic use", where domestic implies them (people) and their livestock. A good interpretation for cow-country.

However, we surely all agree with last definition given above. A water demand must be at least "the state of being much sought after". In today's world, water certainly joins the long list of resources that are in demand by a still growing population.

Alberta has been blessed by many natural resources, water being only one of them. We are probably more famous for our petroleum resources, and with the present energy crisis, that makes us a "boom" province. Partly as a result of this boom, and its attendant population growth, there has

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been a boom in proposed water resources projects for the province. This paper will discuss three proposed Alberta water projects, one actually being the continuous expansion of an ongoing urban water supply system, in an attempt to show that we can often put a demand on our water resources that is unnecessary, and often in fact extremely uneconomic. One of the projects, the Three Rivers Dam, will be dealt with in more detail, to indicate how incorrect counting of benefits can inflate the benefit/cost ratio. A fourth Alberta water project will be commented on to indicate how a poorly conceived project can be non-wasteful in its primary product (water), but extremely wasteful in other resources (construction materials and pumping energy).

CALGARY'S URBAN WATER SUPPLY (AN ONGOING PROJECT)

In a recent paper(1) by Gysi and Lamb, the artificially high demand being placed on the Bow and Elbow Rivers by the Calgary water distribution system was discussed. Over eighty percent of Calgary's residential water customers are unmetered, and the percentage creeps up slowly every year. It appears that new house construction customers opt for non-metering since they anticipate large amounts of new-lawn watering. Yet, this freedom to choose metering or non-metering, the result of a 1966 plebiscite, is placing a long-term strain, and short-term potentially dangerous load on the supply system.

There are about 100,000 residential customers in Calgary who presently are non-metered. In the cold months they use about 10,000 gallons/month compared to 4-5,000 gallons/month for the 20,000 metered customers. In the summer months, their peak consumptions can reach 23,000 gallons, compared to 8,000 gallons for the metered customers. This "freedom-of-choice" policy regarding metering, which is in fact a "freedom-to-waste" policy, results in about 40-45 cfs extra present total city demand on a continuous average-annual basis. Of course, demand is never continuous or uniform, so this figure converts to much greater peaking capacity "requirements".

Potential short term shortages are always aggravated by the fact that periods of short supply (dry periods) coincide with periods of highest demand. Add to that 100,000 customers whose only constraint on watering is their community conscience, and you reach the situation that Calgary had in late April and early May of 1977. Glenmore Reservoir on the Elbow River was ten feet below crest, and dropping 0.1 feet per day, with extreme low spring runoffs predicted. Water supply personnel were investigating the possibility of installing emergency pumping capacity on the new Bearspaw Reservoir facilities on the Bow River. Daily consumptions from 110 MG (million gallons) to 150 MG continued, in spite of calls on the community for conservation, when the previous record daily consumption for April had been 70 MG.

A study by Hanke and Boland(2) showed that the long term per customer consumption in Boulder, Colorado residences dropped from about 10,000 U.S. gallons/month to about 6,000 U.S. gallons/month after a program of metering. There can be little doubt that Calgary is wasting water through their "freedom from metering" program.

The rapidly growing demands of the Calgary urban water supply system is just one example of partially artificial demands being placed on the Eastern Slopes water by a wasteful "pricing" mechanism.

THREE RIVERS DAM (PROPOSED IRRIGATION PROJECT)

Studies(3) of the Oldman River Basin in Southern Alberta by Alberta Environment report rapidly increasing "requirements" for water (quotation marks mine).

Conclusion number (3) of the Summary Report projects a threefold increase of 1975 water requirements by 1985 and a sixfold increase by 2005. The use of the word "requirements" gives a sense of impartial urgency to the conclusion, but any thoughtful reader will recognize the error of its use. Depending on the price of its sale, the demand for irrigation water could increase many times, with a strong correlation between the price and demand. There is little doubt that if irrigation water is sold at a subsidized (low) rate that the demand for it will be higher than if it were sold at the rate required to recover the capital cost of construction of supply and transmission works.

In a Science Advisory Council (S.A.C.) report[4] to the Alberta Environment Conservation Authority, conclusion seven of the above Summary Report is seriously challenged. Conclusion seven gives the Three Rivers Project, the most economically attractive of the several projects investigated, a benefit-cost ratio of 1.59, within a possible range of 0.89 to 2.29. The S.A.C. report debates several of the "benefits" used in the original economic analysis, and concludes that the actual benefit-cost ratio using available data is less than 1.0.

In an attempt to indicate the actual numbers involved, the review (and debate) of the original Alberta Environment economic analysis as outlined in the S.A.C. report will be repeated here.

Review of The Economic Analysis of the Three Rivers Dam

This analysis is founded on a report by J. Thiessen of SMIRD titled "A Comparison of Irrigated Crop Production to Dryland Farming in Southeren Alberta." The report was based on actual crop yields and market prices for the region, so that the irrigation benefits in the economic analysis start from a firm foundation. Two major assumptions regarding the benefits of the project follow, which give some instability to this firm start.

Initial minor criticisms can be made, for example debating the assumption of 75 percent and 50 percent cost reductions for municipal and industrial water treatment after the dam construction, but these assumptions have so little effect on the final benefit/cost ratio that it seems not worth arguing the point. However, the major criticisms involve assumptions that have a major effect on the B/C ratio.

Criticism 1

The use of primary and secondary employment wages on the dam construction as a benefit of the dam is improper procedure. An illustrative example will be given below to demonstrate this point. Use of construction employment wages as a benefit of a project cannot be considered, unless major unemployment exists in the region, and unless those unemployed are unable to obtain employment elsewhere. Even under such conditions of regional economic depression, one must argue carefully about the comparitive benefit of employment wages in the depressed region, versus the economic cost (tax payments) from other regions. In any case, Southern Alberta does not suffer from the degree of unemployment that would allow anyone to begin to argue philosphically about such relative benefits and costs.

As an illustrative example of the impropriety of using construction employment wages as benefits of a project let us consider a hypothetical project for Southern Alberta; that of digging a large hole, and then filling it. Only laborers with their own shovels (or strong fingernails) are hired. The total cost of digging the hole is estimated as $1,000,000, all labor wages, as is the cost of filling it. If one utilizes the same procedure used in Vol. 5 of the planning studies, where 75% of the labour costs were treated as disposible income, and 75% of disposible income was assumed spent in the region and hence counted as primary employment benefits, and where every dollar of primary employment benefits resulted in one and a half dollars of secondary employment benefits, the following analysis would result.

Total Cost of Project = $1,000,000 + $1,000,000 = (all costs are due to wages)	$2,000,000
Benefits Flood control, pollution abatement, aesthetics, etc.	$ 0
Primary employment benefits = 0.75 X 0.75 X 2,000,000	=$1,125,000
Secondary employment benefits = 1,5 X 1,125,000	=$1.687.500
Total Benefits	=$2,812,500
Benefit/Cost Ratio = $\frac{2,812,500}{2,000,000}$	= 1.41

According to this analysis, which uses the same assumptions regarding employment benefits as those used the the Three Rivers economic analysis, the Alberta government should consider digging and filling this hole because of the favourable benefit/cost ratio.

Few people would really consider this project as an economically viable project, in spite of the analysis.

In Table 19, page 116 of Vol. 5, the only benefits accruing to the Three Rivers project in the first five years (1975-1979) are the so called primary and secondary employment benefits. These discounted benefits total to $16,549,900.00, and should immediately be deducted from the total discounted benefits stream of $140,468,500.00 to give a new total of $123,918,600.00.

Criticism 2

The use of a multiplier of 1.5 times the primary irrigation benefits to obtain secondary benefits is not correct, if one is trying to determine provincial benefits. There will be some secondary benefits that will apply to the region (stemming-from benefits and induced-by benefits), but even if they were as high as 1.5 times the primary irrigation benefits, provincially or nationally they would be at least partially affected by the loss of not making the investment of the dam elsewhere in the economy. The Soil Conservation Service of the United States Government estimates secondary benefits of water resources projects as 10 percent of direct benefits, assuming those projects to have more economic linkages than other investments.

Discounted indirect benefits (domestic, municipal and industrial water treatment savings, pollution abatement and flood control) on table 17, page 114 of Volume 5 total to about six million dollars. If this is momentarily deducted from the revised total of $124,000,000 determined in Criticism 1 above, the total discounted primary (direct) and secondary irrigation benefits would amount to $118,000,000. This figure is 2.5 times the direct irrigation benefits (direct plus 1.5 X direct). Therefore, discounted direct benefits are about (118,000,000 ÷ 2.5) = $47,200,000. Adding the ten percent mentioned above as net secondary benefits that would be surplus to the province compared to other investments they could make of the same magnitude (except for another water project), one would arrive at (47,200,000 + 4,720,000) = $52,000,000 for discounted direct and secondary irrigation benefits. Adding back in the $6,000,000 of other indirect benefits that was momentarily deducted above, one would arrive at total discounted benefits of $58,000,000.

The above analysis which lowers the total discounted benefit stream of over $140,000,000 for the Three Rivers Project, determined in Volume 5 of planning studies, to about $58,000,000, is not a frivolous sleight of hand designed to make an apparent financially viable project look uneconomic. It is the same analysis that would be used by any water resources economist in any provincial or federal agency that was making a comparison of investment projects. Construction employment benefits and secondary (linkage) benefits have little bearing on such comparisons as these benefits would accrue to all projects of equal magnitudes. What must be compared are the direct benefits and costs of the projects, plus any indirect and secondary benefits that are unique to the project, and then only the excess secondary benefits that might accrue because one type of project exceeds the average project in efficiency of primary-secondary linkages.

Minor Criticisms

If one looks now at the revised total for discounted benefits ($58,000,000), some of the previously mentioned minor criticisms, become less minor. The domestic, municipal and industrial water treatment savings that were assumed to range from $365,000/year in 1980 through $594,000/year in 2005, would total to about $3,000,000 as a discounted benefit lump sum. This amount is about 5 percent of the revised $58,000,000 benefit total. These benefit calculations were seriously challenged in the main report by Department of the Environment personnel, but the benefits were still included in the economic analysis on the basis that they had little effect (less than 2 percent) on the benefit cost rates.

The pollution abatement benefit can also be challanged. On page 49 of the main report it is stated that the correlation between dissolved oxygen concentration and river flow below Taber is not good. Thus, the assumption of reduced waste treatment requirements because of augmented flows appears suspect.

If one then halved the assumed "water and waste treatment benefits" of about $6,000,000, the revised $58,000,000 would be lowered by $3,000,000 to about $55,000,000.

Another comment that might be made regarding irrigation benefits and costs is their timing. The analysis assumes that benefits and costs of increased irrigation acreage occur in the same year. If one assumed that costs preceded benefits by one year, then total irrigation benefits should be further discounted by one year, or 10 percent. This would lower the total discounted benefit stream to about $50,000,000.

The typical reader may now suffer from the apprehension that if this analysis were to proceed much further, the benefit stream might evaporate altogether under its harsh glare. Such is not the case. The $50,000,000 revised total probably represents a fairly firm, and much more realistic economic benefit that the province (especially the farmers in the LNID) might expect from the construction of the Three Rivers Project.

Based on this benefit total, and assuming that the cost data used in the report is correct, the benefit/cost (B/C) ratio for Three Rivers shrinks to 0.57. This does not imply that the project should be summarily discarded, but that a very careful and detailed economic analysis should precede any further decision making on its viability. This same statement of course applies to any project with a preliminary estimated B/C ratio near 1, including one as high as 1.59.

General Comments

Use of existing yields and market prices in the comparison of dryland versus irrigation farming benefits is good practice. One can argue that increased production could lead to market price reduction, or to the fact that farmers have asked for price supports for crops such as potatoes, or point out the past subsidization of the sugar industry, to suggest that the present market prices artificially inflate the true economic benefits of irrigation. However, others can argue that increased world populations, reducing agricultural lands due to creeping urbanization, or even cooling weather trends, should lead to increasing market prices for food. Both points of view could be argued at length without either side reaching agreement. The best approach is to use present prices, keeping in mind the possibilities of future changes.

One can also point out that other irrigation projects, such as the Diefenbaker Lake project in Saskatchewan, have not led to as rapid a conversion to irrigation farming from dryland farming as had been hoped. Whether similar resistance to change in Southern Alberta might take place, is a point of valid concern. This possibility should be investigated carefully, in order to as accurately as possible predict growth of irrigation benefits.

One last remark on the irrigation benefits per acre used from the Thiessen Report. In that analysis, the total costs per acre of dryland farming were virtually identical to the total revenues. This gives the impression to the reader that dryland farms make zero profits. The typical dryland farmer will no doubt argue to the Internal Revenue Department that such is the case, but many would feel that is part of the analysis should be carefully re-checked.

Summary of Remarks on the Economic Analysis

The above comments, as well as the original analysis, dwell mainly on the Three Rivers Project. This project is by far the most financially attractive of all the sites investigated in the Preliminary Planning Studies. From the analysis it is obvious that Three River (or any other reservoir in the Oldman River Basin) must sink or swim on its irrigation benefits merit. All other benefits are orders of magnitude smaller. The benefit/cost ratio in the analysis (1.59/1) seems artificially inflated by so-called construction employment benefits and high secondary benefits. There is a strong likelihood that the project is marginal from an economic standpoint, and a very thorough and careful economic re-analysis is recommended.

This S.A.C. review would tend to indicate that the Three Rivers project is on shaky economic ground. However, the real issue of debate should be the necessity of the provincial government to undertake (or investigate) irrigation projects. If these projects are economically and financially feasible, then a corporation of the benefiting farmers should be able to construct and operate them, perhaps with repayable financial assistance from the government. The danger of governments constructing and operating irrigation schemes is the possibility of uneconomic projects being built, and then the water being sold for only short run operating costs (or less).

As we have noted before, improper pricing (pricing too low) can lead to artificially high demands for a product. Should the Three Rivers Dam project be constructed by the Alberta Government, there would not be sufficient benefit at present to repay the capital and operating costs. In such circumstances, it is probable that water would be sold at below its true long run costs, and an extra artificial demand would be placed on Eastern Slopes water.

RED DEER RIVER DAM (PROPOSED FLOW REGULATION PROJECT)

Another project that has been debated at some length is a flow regulation dam on the Red Deer River. Main beneficiaries of the project would be industries and towns that would draw on a more dependable winter regulated flows. Thus the principal benefits from the dam would be the reduced costs of dependable water supplies for these facilities. The original benefit-cost study(5) assumed the primary benefits of the dam to be construction and operation employment benefits of new industries in the Red Deer Basin, including a plant that has been started without the dam being built, plus employment benefits from secondary industries that were 1.5 times as large as the primary benefits. These benefits were based on a rather optimistic scenario of large scale plants being built in the basin in the near future.

Debating the accuracy of the assumed scenario is futile, because no matter what number or timing of plant construction, any benefits of their construction would accrue to the province no matter where they were built in Alberta. The benefit gained by one community must be potential benefit lost by the competing communities that didn't get the plants. Relating all the employment benefits of these plants, (plus 1.5 times these benefits), to the Red Deer River Dam would require proof that these plants would not be built in Alberta without the dam. It would also require proof that all the people employed in the primary and secondary industries were on Alberta unemployment roles before the plants were constructed.

Once again, we have a case of project being promoted as having an attractive benefit-cost ratio when in fact the economic analysis was based on incorrect assumptions. If a correct analysis of benefits of the dam, mainly water supply benefits, shows that there are more benefits than costs, then the project will be economically feasible. Otherwise, there is the danger of an expensive dam being built, and then the additional demands being placed on Eastern Slopes water. In addition to increased evaporative losses from the reservoir surface, there is the danger of towns and industries carelessly consuming the "freely-available" water. Remember that like any other commodity, the lower the price that one pays for water, the more of it that tends to be consumed. If it comes free, there tends to be a lot of waste.

INNISFAIL REGIONAL WATER SUPPLY PLANT (A RECENTLY COMPLETED PROJECT)

The fourth Alberta project that will be briefly mentioned is the recently completed Innisfail water supply plant on the Red Deer River. This project is not too wasteful of Eastern Slopes water, except to the extent that the water will probably be sold below the long-run costs, thus raising demands higher than they would be if the water was not subsidized. However, it is wasteful in other areas.

This regional plant takes water from the Red Deer River, warms, softens and treats it, and then pumps it uphill over 600 feet in elevation to Crossfield, as well as to Carstairs, Didsbury, Olds and Bowden in between. With the rather small pipelines used for supply, this will require a head at the plant of about 2,000 feet (about 900 psi) for the year 2000 peak flows, as estimated in the engineering preliminary study.(6)

No benefit-cost analysis is available for this project, so it is not known what value of energy costs were used in any economic analysis. It may be possible that the project was built without being analyized for economic efficiency. However, without analysis, it would appear that supply of these towns from the south, using the free force of gravity to compensate for friction losses would be much more efficient.

The Bow River has average discharges much greater than the Red Deer River, and the Bearspaw Reservoir has new large, and easily expanded treatment facilities available. Any fourth year Civil Engineering student who chose an "Innisfail pumping-station plant" in preference to a "mainly gravity-fed Bearspaw plant" in a project design water supply course would surely expect an F in the course. It is very possible that we have in the Innisfail Regional Water Supply Plant another example of unnecessary demands on our resources of the Eastern Slopes, if not water demands, then certainly long term pumping energy demands.

CONCLUSION

This paper may appear to be overly pessimistic, as it seems to "pick on" several available water resource projects in Alberta's Eastern Slopes. There is probably a bit of truth in that impression, as the paper is intended to take a partial devil's advocate position. We do have valuable water resources projects in Alberta, and will no doubt continue to build water resources projects in the future that are necessary and valuable for the province. However, we must be always on the alert for projects that are economically inefficient, and that might end up putting unnecessary demands on our province's water (and other) resources.

It is important that Alberta adopt proper standards for the economic analysis of public works projects. If such standards were used, it is probable that much of the angry debate about uneconomic major projects would be avoided. We could then also be more assured that constructed projects really benefit the province, and make efficient use of our resources.

ACKNOWLEDGEMENTS

Research leading to some of the conclusions of this paper was supported through Grant No. A8933 from the National Research Council. The author thanks the Council for this support.

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SNOW ACCUMULATION AND MELT PATTERN
IN TREE LINE STANDS OF MARMOT CREEK BASIN

by Z. Fisera

ABSTRACT

Current studies of large snowdrift formations at Marmot Creek Basin in the area near timberline indicate that tree cover as well as topography has a decisive influence on location, size, and stability of snowdrifts. Both factors are extremely important in alpine areas because high wind velocity and duration cause almost continuous redistribution. Shading value of the trees increases with the advance of the warmer weather in May and June. Exposure to sun-rays changes with degree of the slope as well as aspect.

It is apparent from the study that an ideal snow trap near tree line is created by an L-shaped strip of trees or group of shrubs west and south of a depression in the terrain. Such traps could be created by cutting portions of existing stands to such shape or by planting trees to complete the L-shape. Limited success was recorded in planting of alpine fir (*Abies lasiocarpa*).

SNOW ACCUMULATION AND MELT PATTERN IN TREE LINE STANDS OF MARMOT CREEK BASIN

by Z. Fisera'

INTRODUCTION

Marmot Creek Basin is an experimental watershed located in the Kananaskis River valley about 80 km west of Calgary. The basin was selected for study in August 1962 and is described by Jeffrey (1965). Total area of the watershed was estimated as 9.40 km^2. Cabin Fork boundary traverse in 1971 indicated that the Basin area is 9.58 km^2. Kirby and Ogilvie (1969), describing alpine habitat types of Marmot Creek watershed, classified 110 ha as rock and talus and 331 ha as nine other alpine habitat types. This includes avalanche types that extend into the forest zone, as well as timberline types occurring where the forest breaks up into tree islands and krummholz colonies. At least an additional 100 ha of alpine fir, alpine larch, and stunted Engelmann spruce have little if any merchantable timber and could be considered as alpine forest. Thus no less than 56.4% of the area of Marmot Creek watershed is alpine in character.

Snow accumulation patterns vary greatly according to elevation, aspect, slope, roughness of the terrain, and presence of forest cover. The windswept ridges and steep slopes are bare most of the winter. There is often as much as 50 cm of fresh snow deposited by a storm in those areas; however, strong winds between snowfalls (Storr 1973) move this snow to more protected locations. In April and May, when density of the snowpack increases and sun crust occurs, snow on exposed slopes and ridges may last for several days, even weeks, but it is seldom greater than 50 cm in depth. Wind-driven snow will fill all gullies and crevices in rocks and sometimes form spectacular snowdrifts on the lee side of the boulders, ridges, tree clumps and krummholz communities. Much of the snow will end up in the alpine forest. Although redistribution from forest back to open slopes was observed, it does not occur frequently; significantly greater amounts of snow are deposited in the tree line stands than taken out.

Martinelli (1959) reported that selected alpine snowfields of the Front Ranges of Colorado released on average, 58 mm water per day to summer streamflow in July and August 1955 and 1956. Several

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methods of manipulating alpine snowpack were pointed by Martinelli (1960). He stated that:

1. a 5 cm layer of sawdust decreased melt by about 50%

2. induced avalanching several times each winter would cause snow to be piled into a small area at the toe of the slope and that rate of melt in such deep snow accumulations would be slower than in the relatively shallow snow on the steep slopes

3. enlargement and reshaping of natural snow storage areas by dirt-moving equipment offers a direct and fairly simple way to trap snow

Martinelli (1964, 1965a, 1965b, 1972) adequately demonstrated great potential for alpine snowmelt retardation in order to increase summer streamflow by snow-fencing methods. For several years 2.5 m tall fences at carefully selected sites have added approximately 1200 m^3 of water for each 30-38 m of fence length, measured on July 1. None of these methods has been tested to date on Marmot Creek Basin, although the option exists, particularly in snow-fencing.

Two additional methods were studied on Marmot Creek watershed

1. establishment of vegetative snow-fencing in areas of tree islands above tree line by reforestation

2. manipulation of tree line stands for maximum snowtrapping effect

It was observed that a large snowdrift at elevation 2280 m was formed each year in a depression east of a low ridge which runs on bearing N 50° W and is covered with two dense clumps of alpine fir and alpine larch approximately 3 m tall. In 1968 a 10-point snow course (21) was set up to monitor this drift. Table 1 indicates mean water content of the snow course 21 over the period of 9 years as well as water content of snow courses 19 and 14 for the corresponding period. Snow course 19 is at an average elevation of 2360 m in the open, above any vegetative cover. Snow course 14 is at an average elevation of 2140 m in the forest. The water content of snow course 14 in the critical month of May (1969-1977) was only 28.2% of the water content of snow course 21; snow course 19 was only 19.3% of snow course 21 for the same period. Year 1972 was excluded from the calculation because of incomplete results due to ice in the snowpack. It was therefore desirable to investigate if conditions at snow course 21 could be duplicated elsewhere in the basin by transplanting or otherwise propagating trees on a similar ridge in the vicinity.

The idea of reforestation above tree line is not new in Europe, particularly in Austria and Czechoslovakia. Records indicate that reforestation in the Giant Mountains of Bohemia started in approximately 1870 (Lokvenc 1958, 1962). Other authors describing reforestation projects above tree line in Czechoslovakia are Janousek (1957), Piskun (1963) and Simkovic (1963). In Austria, Stauder (1963a, 1963b) describes successfull reforestation in the Tyrol. Extensive reforestation also took place in Vorarlberg, Austria.

TABLE 1 MEAN WATER CONTENT OF SNOW COURSE 21, 19, and 14 (centimetres)

S.C.	Year	Feb.	March	April	May	June	July
21	1969	87	92	102	122	74	24
	1970	62	91	109	117	80	n.a.
	1971	105	110	+	122	108	27
	1972	98	+	145	+	105	20
	1973	30	50	80	116	117	16
	1974	93	103	80	120	113	55
	1975	83	86	100	94	99	n.a.
	1976	n.a.	114	+	132	120	34
	1977	47	63	85	80	42	n.a.
19	1969	7	15	13	13	nil.	nil
	1970	8	12	19	23	nil.	nil
	1971	19	22	24	26	8	nil
	1972	26	29	41	39	7	nil
	1973	11	10	24	24	9	nil
	1974	19	21	21	35	29	nil
	1975	12	13	17	22	5	nil
	1976	n.a.	33	27	26	12	nil
	1977	4	8	9	5	nil.	nil
14	1969	21	23	24	31	nil.	nil
	1970	15	17	26	31	nil.	nil
	1971	28	31	44	41	13	nil
	1972	38	51	59	54	7	nil
	1973	18	23	31	35	22	nil
	1974	27	34	36	43	39	nil
	1975	20	21	25	33	8	nil
	1976	n.a.	30	26	30	10	nil
	1977	11	16	21	11	nil	nil

\+ - denotes ice in the snowpack - some points not measured
n.a.- denotes readings not available
nil - denotes no snow at the time of readings

OBJECTIVES

The objective of the experiment was to evaluate the possibilities of manipulation of alpine snowpack by silvicultural methods in order to prolong snowmelt to summer months when demands for water increase. Alpine snowpack contributes to summer streamflow for several weeks after snow cover has disappeared from other areas. It is therefore desirable to retard the melt of alpine pack to the greatest possible extent.

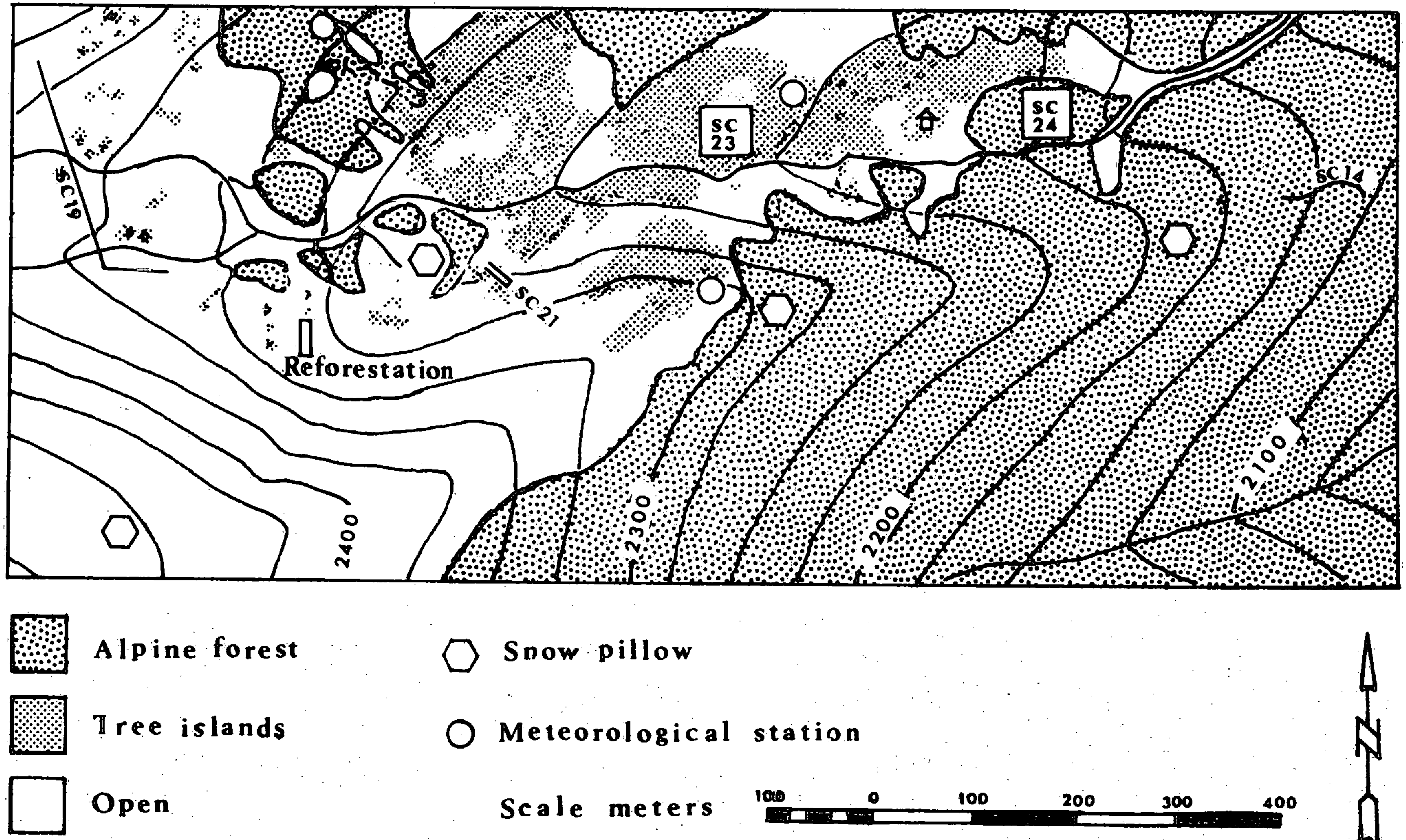
PROCEDURES

A plot 7.6 x 36.6 m was established on the edge of a depression 200 m WSW of snow course 21 at 2310 m elevation (Fig. 1). The location is described by Kirby and Ogilvie (1969) as Phyllodoce habitat type associated with podzolic soils on moist northerly exposures. The following transplantings and seedings were made in the plot:

July 18, 1969 -	10 alpine fir (Abies lasiocarpa) 50-79 cm in height and 2 alpine larch (Larix lyallii Parl.) 86 cm and 137 cm were transplanted from a reproduction 75 m NNE of the planting site. Rocks were placed west of each plant.
Sept. 22, 1971 -	10 alpine fir stem cuttings and 20 branch cuttings 15 cm were placed in the soil to test their rooting potential.
Oct. 9, 1971 -	30 alpine fir twig cuttings 12-20 cm with lower needles removed and the lower 2.5 cm treated with Seradix 3 were planted to test the rooting agent. 10 similar cuttings were planted without rooting agent. 10 transplants 4-10 cm with root system without soil (washed) were planted (5 with Seradix 3 treatment, 5 without). Plant material originated in the natural reproduction site 100 m NE.
Oct. 21, 1971 -	Alpine fir seed, collected mainly along north rim road in Cabin subbasin (elevation 1890 m and up), was seeded at various depths, some with peatmoss.
Sept. 24, 1974 -	Direct seeding of alpine fir, alpine larch and Engelmann spruce (Picea engelmanni Parry) seed originating from several locations within 750 m of the site. Seeded at various depths with and without peatmoss.

In order to gain a better understanding of snow drifting patterns and to examine the possibilities of manipulating the existing tree cover near timberline, two plots each 50 x 50 m were laid out in 1972. The first plot (S.C. 23) is located in an alpine meadow with tree islands covering approximately 30% of the area. The 11% slope is as gentle as could be found

Fig. 1 Marmot Creek Middle Fork near tree-line



in the mountainous area. Highest point is the NW corner at 2240 m and lowest is the SE corner at 2230 m. Tree islands consist of dense alpine fir, 90 years old, 6-7.5 m high. Diameter at breast heigth (Dbh) ranges from 5 to 20 cm. The second plot (S.C. 24) is laid out 300 m east of S.C. 23 in a stand of alpine fir 70% and alpine larch 30% (a few spruce trees are also present). Height of the fir ranges from 7.5 to 10 m, larch from 10 to 13 m. Dbh varies from 5 to 25 cm in fir and 30 to 52 cm in larch. Ages in fir are up to 150 years, although most of the stems are around 90 years. Most of the larch is 280 years; one 52 cm veteran was measured at 360 years. The slope is 19%, highest elevation being 2206 m along the west boundary and lowest 2194 m near the NE corner. Although the stand appears to be well stocked in comparison with other tree-line stands, only 45% of the area is under tree cover.

Both plots were marked with 10 stakes along the west and east boundaries, spaced 5 m apart. Snow samples at 5-m intervals were taken along the lines connecting opposing stakes with Mount Rose sampler (Figs. 2 and 3). Thus 100 points were sampled on each plot, twice a year, for a period of 4 years. First sampling was taken approximately at the time of greatest snow accumulation (May 24/73, May 5/74, May 27/75, and May 13/76). Second sampling was done within 7 days of peak flow (maximum instantaneous discharge) on Main Marmot weir. Dates of second sampling were June 27/73, June 13/74, June 16/75 and June 3/76. A profile along each line was ploted indicating terrain, forest cover, and snow water content totals for each point along the line from the June surveys. Profiles along line E on both plots are shown in Fig. 4. Values for each point are also shown in Figs. 2 and 3.

RESULTS AND DISCUSSION

Efforts to propagate alpine fir by transplanting from natural reproduction met with limited success. Of 10 trees transplanted on July 18/69, 7 are surviving. However, the tops of all trees are dry and only the lower branches were green in June 1977. A naturally reproduced alpine fir 12 m NW appears to be in similar condition and it is therefore possible that the site selected is too extreme for the experiment. The fact that some transplants are surviving after nearly 8 years indicates that there is some room for optimism. Direct seeding and stem and branch cuttings failed to produce any plants. Alpine fir in the tree islands above timberline propagates mostly by shoots, and the layering method

Fig. 2 Plot S.C. 23

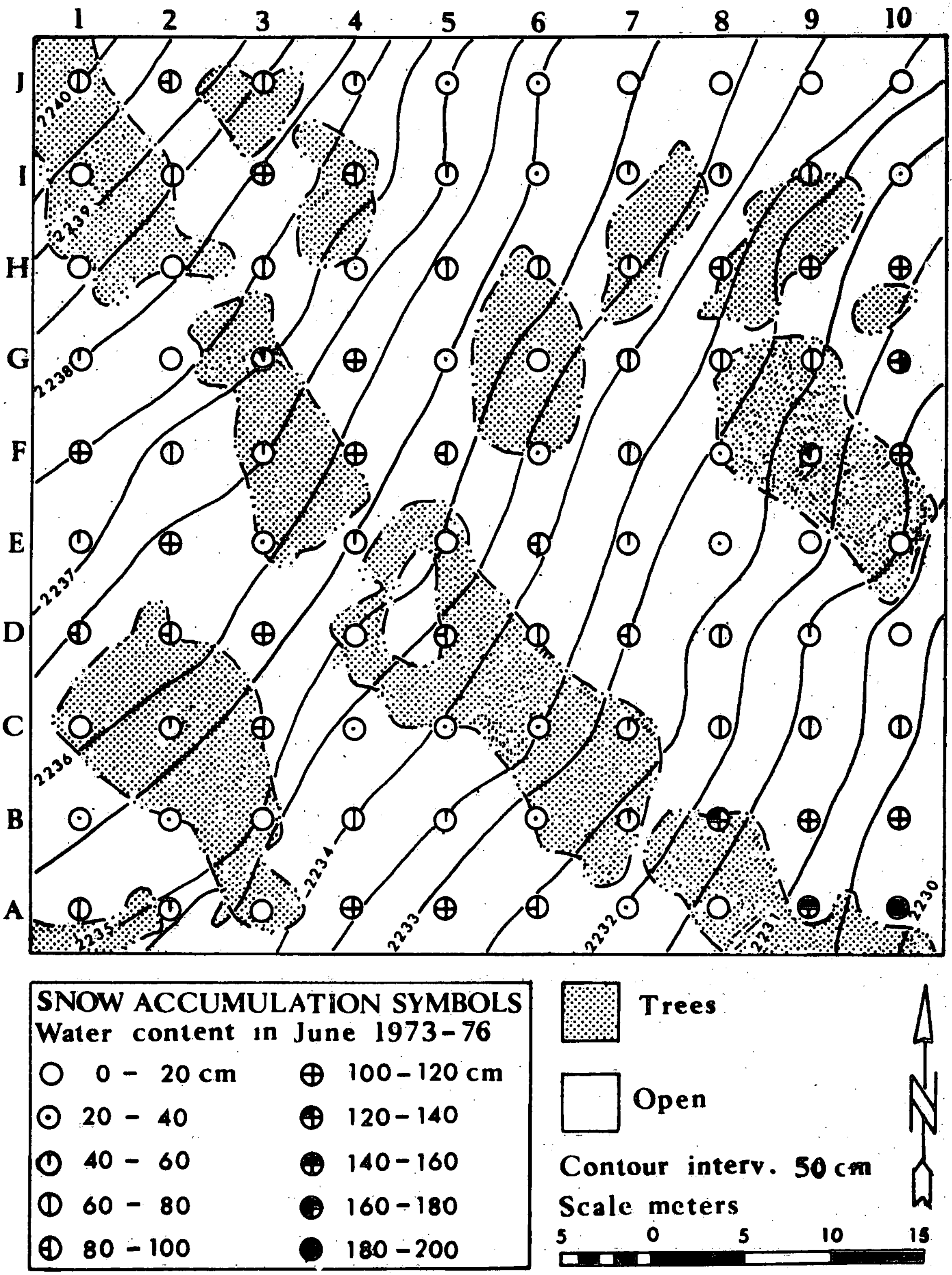


Fig. 3   *Plot S.C. 24*

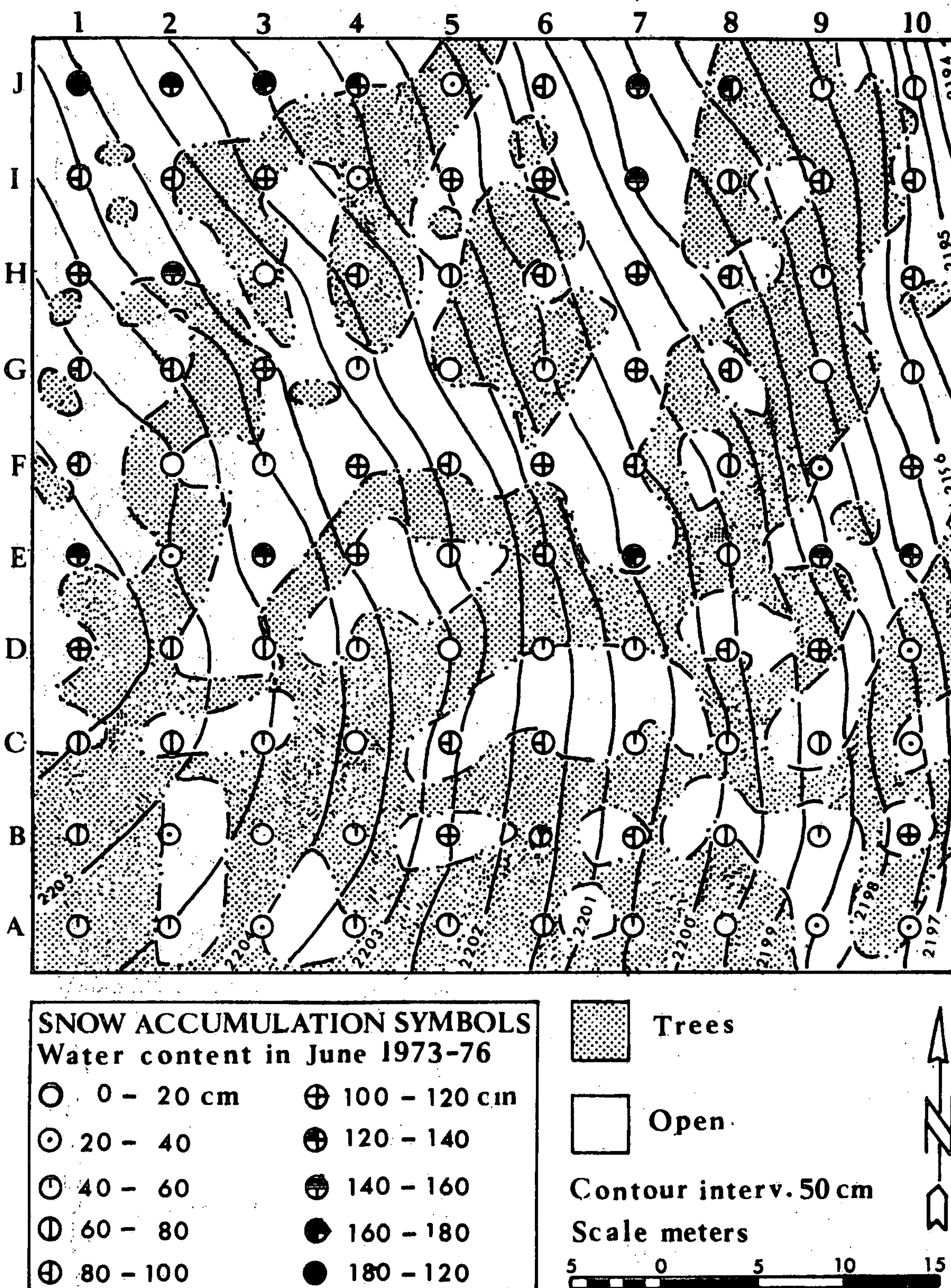
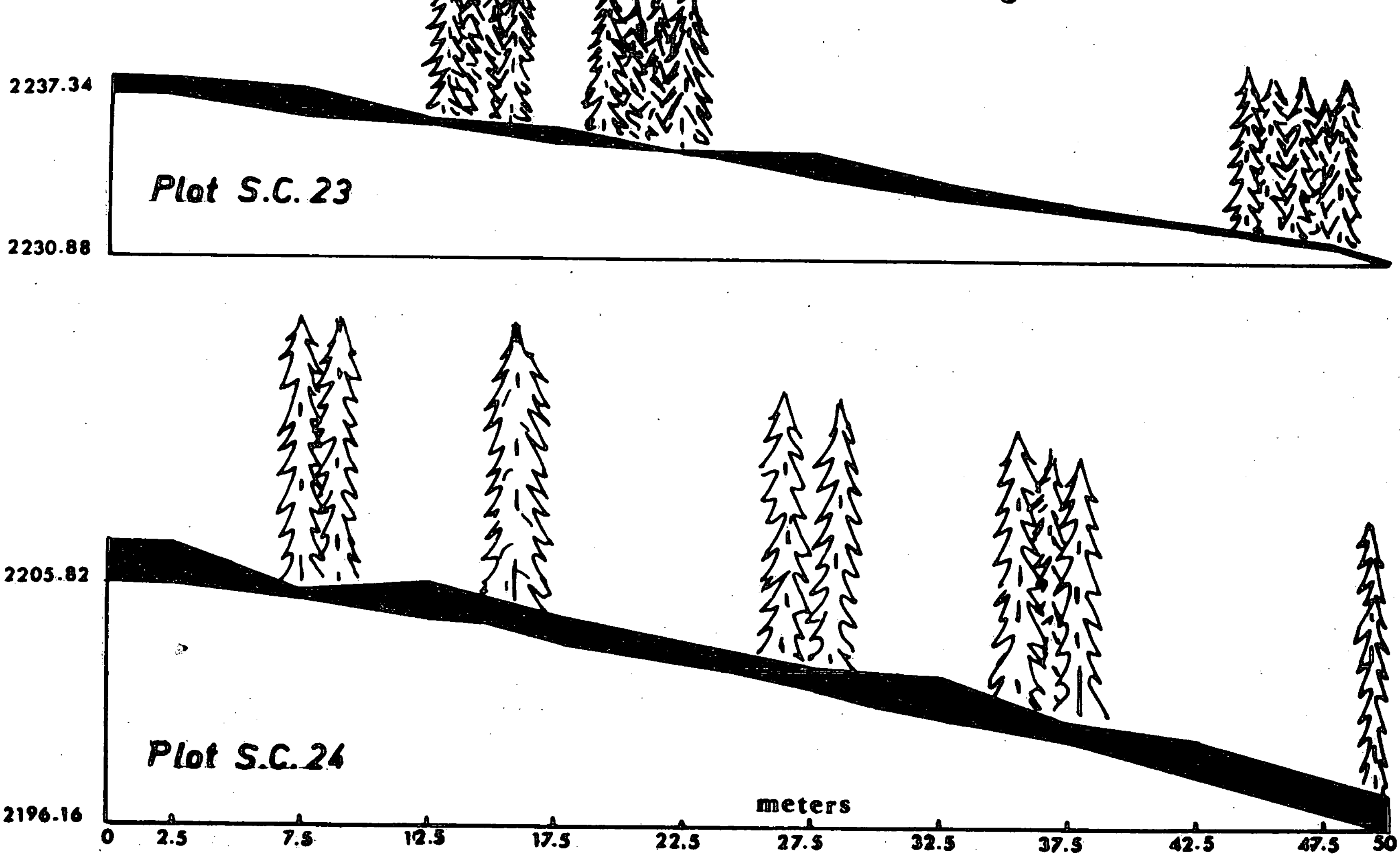


Fig. 4 **Profiles along line E**



should be thoroughly investigated. Also rooting of cuttings in greenhouse which was described by MacGillivray (1969), using balsam fir (Abies balsamea L.) and container planting offer additional possibilities. Alpine fir is not considered a desirable commercial species, and for this reason not much effort has been expended on propagation. Future experiments of this kind should be conducted under the guidance of a team of experts in soil science, silviculture, physiology and related fields. Even if it may prove to be impossible to propagate trees above krummholz colonies, the possibility of improving existing tree islands by planting trees in selected locations to complement their snow-fencing and shading qualities should be thoroughly investigated. Results from such a study could be applied in fields other than hydrology, particularly avalanche and erosion control.

Prior to establishment of plots S.C. 23 and S.C. 24, it was assumed that plot S.C. 23 (tree islands) would accumulate and preserve more snow than plot S.C. 24, which is relatively well stocked. This assumption proved to be wrong. Although the tree islands on the plot are generally elongated in SE-NW direction, they do not provide adequate shelter from sun and wind. On all surveys plot S.C. 24 had more snow than plot S.C. 23. Most snow on plot S.C. 23 was preserved at sampling points A9, A10, and B8, which have trees on the west and south sides. Most of the points with better-than-average water content have some trees on the west and south sides, although this is not always apparent from Fig. 2 if trees are outside the plot. Point E2 is in a slight depression, which accounts for increased accumulation. As expected, points within tree islands had little if any snow; points located on the south and west sides of tree islands lost their snow rapidly, presumably by reflected radiation. Points 7-10 on line J are on the edge of a meadow. There are no trees west of them and they do not accumulate sufficient amounts of snow to last till June.

Similar observations were made on plot S.C. 24. A slight change in aspect in the NW portion of the plot resulted in increased water content. Although in a regular air photograph the plot appears to be relatively well stocked, close field examination revealed numerous small openings in the canopy that permitted snow to accumulate. Also alpine larch, which represents 30% of the plot's tree cover, does not intercept snow to the same extent as fir does. Relatively more snow reaches the ground under larch than under fir. Small cuts in the cover could increase snow accumulation at the following points without reducing it elsewhere on the plot: A1, A8, B1, B4, C4, C6, C7, F8, G8, G9, I8 and I9.

The area of cut on plot S.C. 24 proposed for 1977 is 135 m^2, or 12% of the area under tree cover, just over 5% of the area of the plot. It is assumed that a greater tree removal will probably reduce the snow storage capacities of the plot. Should the same plot be located on a north-facing slope, the storage capacities would not be seriously endangered by increasing the area of the cut. This is indicated by the increase in water content at sampling points J1 and J2, which have NE exposure. Additional evidence is provided by S.C. 21, which is at the bottom of a 50% north-facing slope where relatively little shading is provided by tree clumps SW of the course. Here some snow is normally preserved until August. The reverse situation could be expected on a south-facing slope. Exposure to sun rays changes with degree of the slope as well as aspect. An opening on a 30% south-facing slope should therefore be smaller than an opening on a 5% slope where surrounding tree cover filters some of the solar radiation. It is extremely difficult to use a simple rule when treating alpine forest for maximum snow accumulating and storing capacity. Existence of numerous small openings in tree cover and great variations in terrain every few metres result in vast differences in the snowpack.

Peak flows on Marmot Creek occurred as early as May 27 (1976) and as late as June 30 (1963). There does not appear to be any relationship between the timing and the volume of runoff. However, it could be said that any snow that remains in the basin after that event is a valuable component of summer streamflow. Great caution should be exercised in preserving and improving the snow storage capacities of alpine forest and vegetative cover above the tree line.

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THE SEASONAL AND DIURNAL REGIME OF A GLACIER-FED STREAM, PEYTO GLACIER, ALBERTA

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A B S T R A C T

The main features of the discharge record for the period 1967-1974 are summarized for the small (22.8 km^2) Peyto Glacier Basin. The basin, situated on the east slope of the continental divide between 1900 and 3200 m above sea level, is 61% glacier-covered.

Approximately 90% of total annual flow usually occurs in the months June-September, but the distribution of flow within this period is variable from year to year. There is, however, an overall regulatory effect of the glacier on streamflow - in years of low snowfall the contribution of melting glacier ice to streamflow increases. The quantities of water derived from ice melt and from snowmelt are calculated throughout the summer season.

Diurnal regimes of flow vary considerably from early to late summer, the range in diurnal flow increasing markedly as the summer progresses.

Relationships between discharge curves and basin and meteorological characteristics are complex. Simple linkages are sought in terms of the distribution of terrain types within the basin, the quantity and distribution of snow at the end of winter, and the meteorological conditions during the summer.

At attempt is made to view the Peyto Glacier watershed in the context of the much broader East Slopes watershed. The eight year time frame of the present study is also viewed in the context of changing climatic conditions in the twentieth century so that a better perspective of the influence of glaciers on streamflow might be gained.

THE SEASONAL AND DIURNAL REGIME OF A GLACIER-FED STREAM, PEYTO GLACIER, ALBERTA

G. J. Young*

INTRODUCTION

Within any watershed it may be stated that there is an annual hydrological balance when precipitation inputs to the basin equal the sum of outflows plus losses due to evapotranspiration. During the year there may be seasonal imbalances due to lags in the system as when lakes are filling, when groundwater recharge is taking place or when snowpacks retain precipitation to be released later in the year when melting takes place. Snowpacks are particularly important in high mountain catchments where their effect is to greatly reduce runoff during winter and to release meltwater during spring and summer.

Glaciers have important regulatory effects both seasonally and over larger time periods. Seasonally, they tend to act like exaggerated snowpacks delaying flows until later in the summer. Over periods of decades or centuries, glaciers grow in size in times of cooler summers or when winters are particularly snowy and they release water from storage in warm or snow-free periods. Thus, in glacier-covered catchments, there will only be balance between basin inputs and outputs over long time periods.

It is important to realize that in the Rocky Mountains the twentieth century has been characterised by quite extensive glacier retreat (Henoch, 1971). Glacier volumes have diminished markedly, water has been released from storage and discharges on glacier fed streams have been higher than might be expected from precipitation inputs. This situation cannot continue indefinitely. If the climate of the region remains unchanged, then the glaciers will retreat further, but their contributions to streamflow will diminish as the ice remnants will be found in progressively higher or more sheltered localities. If summers become cooler and precipitation totals remain constant, the contribution to flow of glacier melt will decrease and total flows will decrease. Alternatively, if winter snowfalls increase, the glaciers may gain in mass: they will retain water rather than release it and while streamflows may increase because of the increased snowmelt, the outflows from the basin will be lower than precipitation inputs.

The purpose of this paper is firstly to examine the mechanisms by which water is released from glacier storage by reference to one well documented example. Secondly, the detailed example will be put into the

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context of a larger geographical area and into the context of a longer time frame.

THE PEYTO GLACIER CATCHMENT

(i) Location

This basin was one of a number of glacierized basins in Western Canada chosen for detailed hydrological study during the International Hydrological Decade (IHD), 1965/74. Its location is longitude 116°33'W, latitude 51°40'N on the eastern flank of the Rocky Mountains in Alberta. It is in the headwaters of the Mistaya River, a tributary of the North Saskatchewan River. The total basin area (above the stream gauging station) is 22.8 km^2 of which about 61% is glacier covered. The topographic map (Figure 1) further illustrates the characteristics of the basin.

(ii) The Measurement Program

During the IHD intensive hydrometeorological studies have been conducted within the Peyto catchment. They have been described in detail by Østrem (1966); techniques have been described by Østrem and Stanley (1969). The program consisted of three parts:

a) Monitoring the buildup of the winter snowpack on the glacier and the melting of the seasonal snowpack and glacier ice. From these measurements the changes in glacier volume have been calculated and the timing of the various melt components derived.

b) Monitoring basic meteorological variables including air temperature and precipitation during the summer ablation period at the base camp on rock near the snout of the glacier.

c) Monitoring discharge on Peyto Creek at the basin outlet (Water Survey of Canada Station 05DA008).

All the monitoring techniques were subject to considerable errors, but general trends are clearly discernible and it has been possible to determine important linkages between the various hydrometeorological components.

(iii) Previous Hydrological Studies in the Basin

A comprehensive review of work conducted in the Peyto basin has been given by Young and Stanley (1976). The most significant contributions to understanding basin runoff have been by Derikx (1973, 1975), Derikx and Loijens (1971), Foehn (1973), Goodison (1972), Loijens (1974) and Munro (1975).

TERRAIN TYPES

Within a glacierized basin, several different terrain types can be recognized. Their differences are important hydrologically

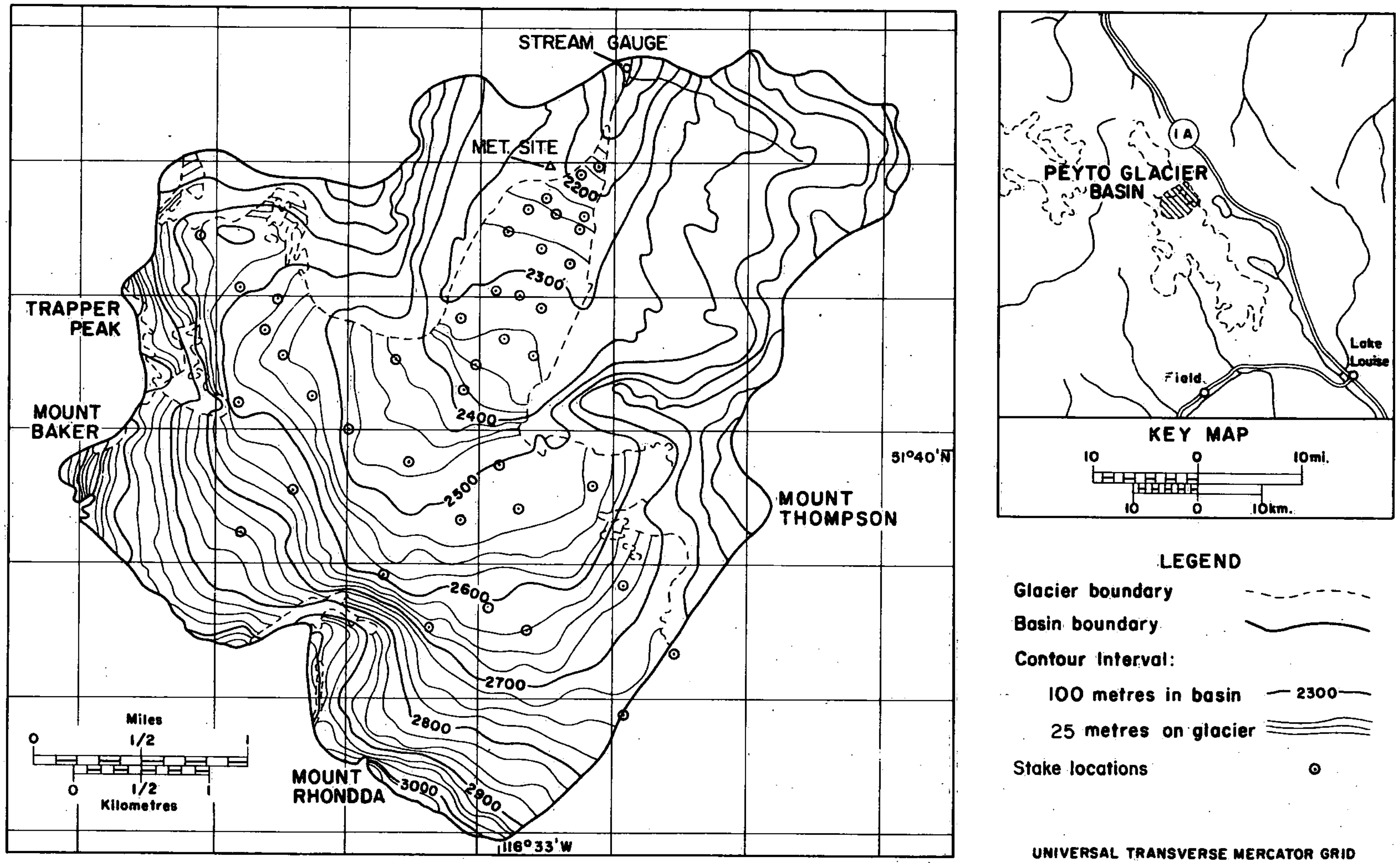

STREAM GAUGE
MET. SITE
2200
2300
2400
2500
2600
2700
2800
2900
3000
TRAPPER PEAK
MOUNT BAKER
MOUNT THOMPSON
MOUNT RHONDDA
51°40'N
116°33'W
Miles
0
1/2
1
0
1/2
1
Kilometres
1A
PEYTO GLACIER BASIN
Lake Louise
Field
KEY MAP
10
0
10mi.
10
0
10km.
LEGEND
Glacier boundary
Basin boundary
Contour interval:
100 metres in basin
2300
25 metres on glacier
Stake locations
UNIVERSAL TRANSVERSE MERCATOR GRID

Figure 1

partly because variations in micro relief and thermal properties greatly affect processes of snow accumulation and melting and partly because some of the terrain types contain ice in various forms which have different melt properties. Five different terrain types have been recognized within the Peyto catchment. They have been mapped, as shown in Figure 2. During the IHD, snow patches and glacier ice have diminished in size while the rock and ice-cored moraine areas have grown larger. Clearly, the proportions and the spatial distributions of the terrain types within a basin are unique to that basin. The Peyto basin is, however, probably fairly representative of many alpine glaicerized mountain basins. The terrain types and a description of their important characteristics are given below.

(i) *Rock.* Bare rock outcrops can usually be found at all elevations in the basin. Ridges, spurs and gullies are often separated by cliffs or steep slopes. The local relief is commonly rough, the rock surface being broken into areas of loose boulders and stones, the detail of local relief being determined largely by the underlying geology.

(ii) *Snow patches.* Many semi-permanent snow patches can be found on the rock areas, mostly at relatively high elevations. Most of these patches are small, occurring in gullies and hollows. They can change their geometry, size and areal distribution over the years - during the 20th century many alpine snow patches have been shrinking. The snow patches present much smoother local relief than the surrounding rocks.

(iii) *Glacier firn.* The upper parts of the glaciers present large, continuous expanses of gently undulating firn. These are the smoothest and most continuous surfaces within the whole catchment. There are locally steep and crevassed portions within the firn areas, but for the most part the firn areas are smooth.

(iv) *Glacier ice.* In the lower sections of the glacier, large expanses of bare, dirty ice become snow free during the summer months. In this area there is a component of flow from the depths of the glacier towards the surface - thus englacial debris is brought to the surface to form in some places a considerable thickness of dirt over the glacier ice. The glacier ice is in general smoother than the surrounding rock surface, but locally it can be dissected by the numerous small surface streams, local melt features, crevasses and moulins. The area of glacier ice slowly changes through time when the glacier is out of equilibrium with the climate.

(v) *Ice-cored moraines.* Evidence of glacier shrinkage is seen in the extensive areas of ice-cored moraines surrounding the glacier ice areas in the lower elevation zones of the catchment. The ice within the moraines is usually hidden under a blanket of jumbled boulders and dirt. The surface is extremely rough, irregular and unstable during the summer, when the underlying ice is slowly melting.

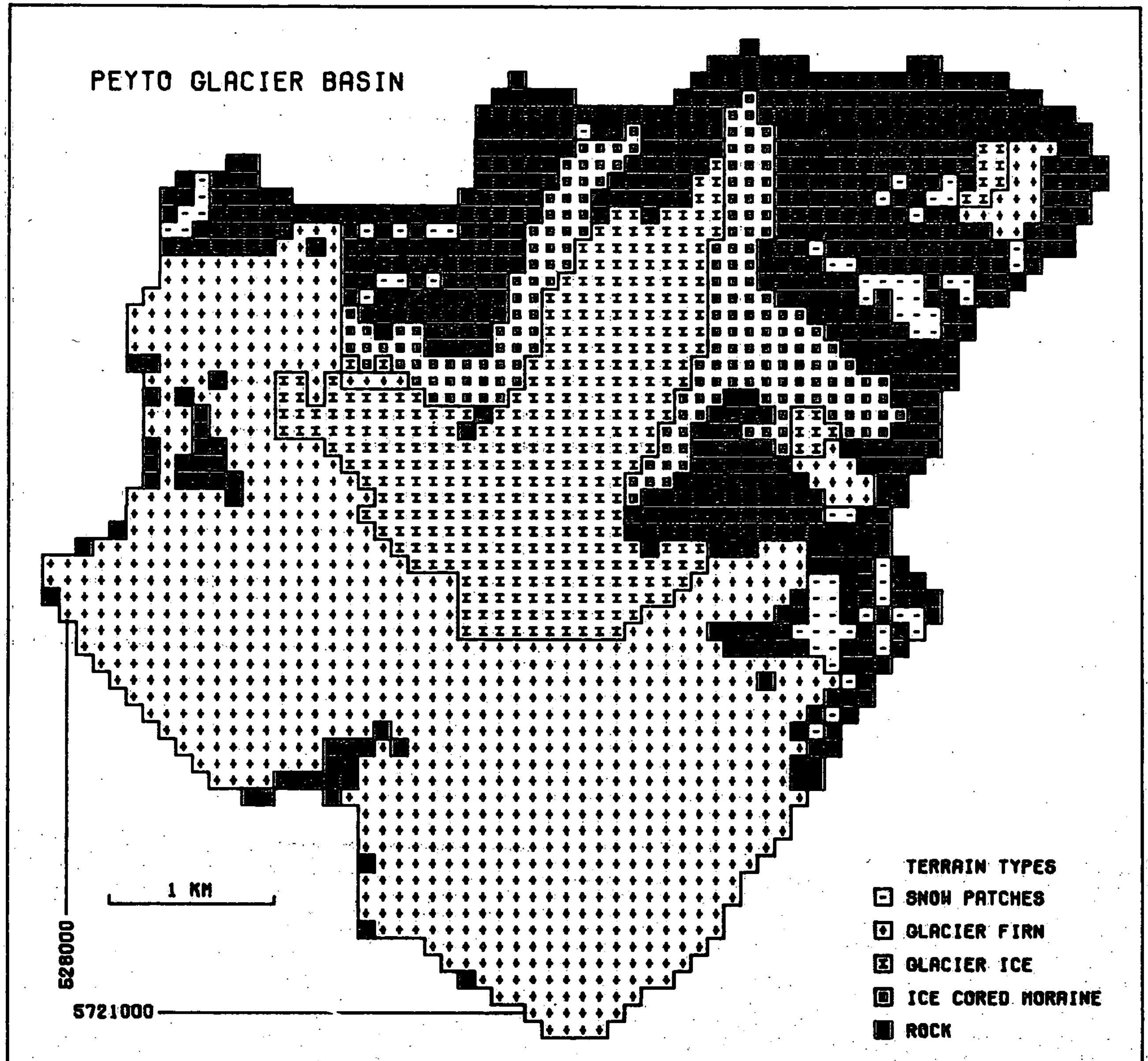

PEYTO GLACIER BASIN
1 KM
528000
5721000
TERRAIN TYPES
SNOW PATCHES
GLACIER FIRN
GLACIER ICE
ICE CORED MORAINE
ROCK

Figure 2

THE NATURE OF HYDROMETEOROLOGICAL LINKAGES WITHIN THE PEYTO BASIN

(i) Description of Hydrographs

Figure 3 shows the hydrographs for Peyto Creek 1967-74; they are expressed in volumes rather than rates of flow. The stream is only gauged in the months May-September, a period which on average accounts for some 95% of total annual flow. There are several years in which the hydrograph is missing or incomplete in September; however, flow is normally rapidly declining during that month. While daily discharges are available for all years, hourly discharges are available for only 1970-1974. For most discharges, measured values are probably within 5% to 10% of true values. Accuracy is probably considerably lower at very high flows.

The most striking fact about the hydrographs is their great variability from year to year. In some years, for example 1968 and 1969, peak flows occur early in the summer, while for example 1967 and 1971, peak flows occur much later. In 1970 there are several periods of equally high flows at intervals throughout the summer. Table 1 further illustrates the breakdown of flows into monthly components.

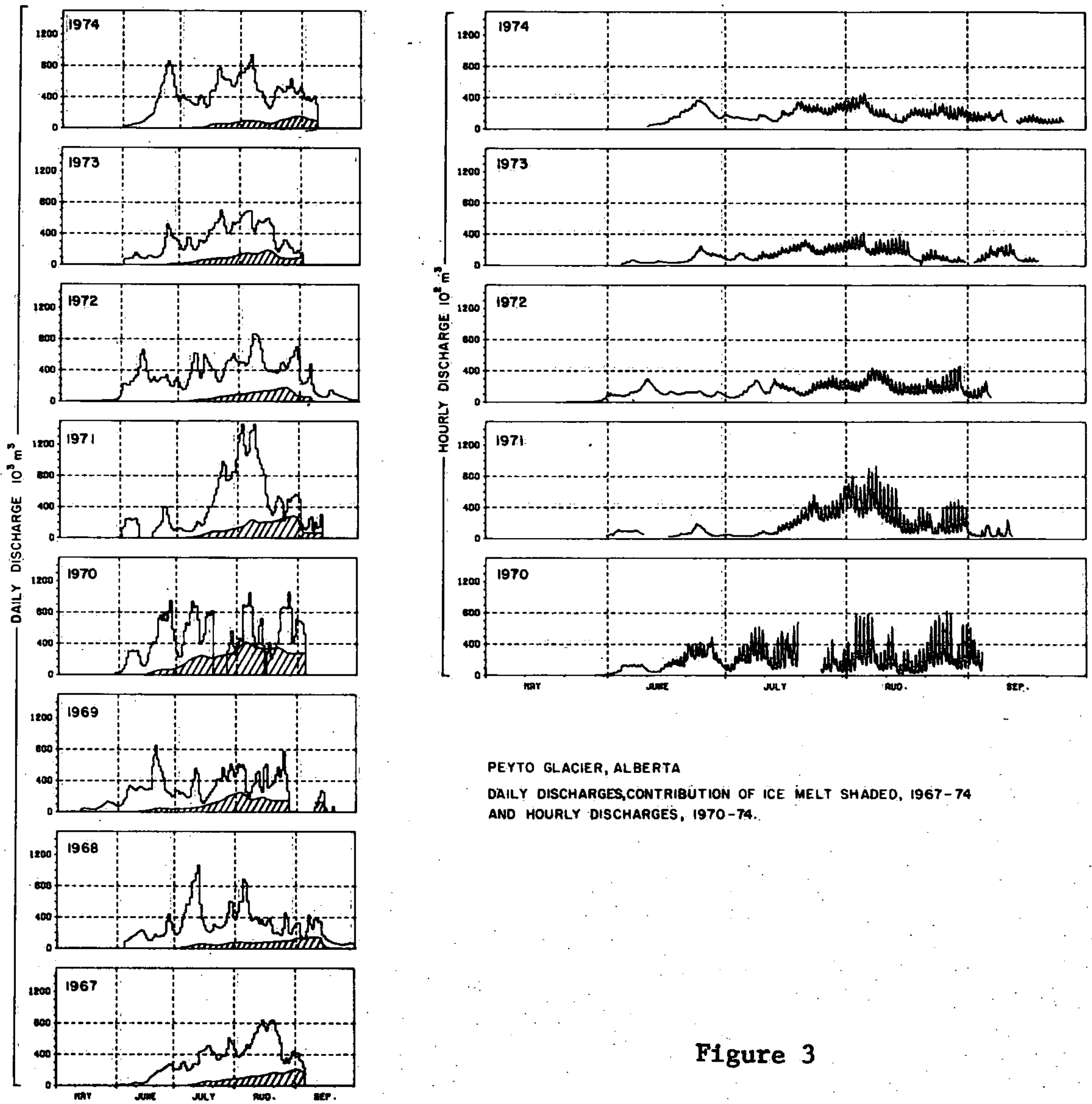
Diurnal flows have some characteristics which are common from one year to another and in some ways there are important differences between years. In early summer there is little diurnal range in flow. Usually during July a diurnal range in flow becomes evident and often becomes more pronounced as the summer progresses. In some years (1970 and 1971) the diurnal range is very great, daily high flows being four times as large as daily low flows. If the hydrograph could be examined in more detail, it would be found that the time of peak diurnal discharge would be about 1800 MST in May or June, changing to 1500 MST in late August.

(ii) Explanation of the Shape of the Hydrograph

The shape of the hydrograph is intimately linked to the interaction of a number of variables. To illustrate in a simple way what is in fact a very complex set of interrelationships, data from three years, 1967, 1970 and 1974, have been shown in Figure 4.

The amount and distribution of snow at the end of winter is of great importance. While snow-melt from rocks and moraines may proceed rapidly even in heavy snow years, deep snow packs on the glacier greatly retard melting of glacier ice, for in years of heavy snow accumulation the snowline retreats up-glacier slowly. Thus in 1967, a heavy snow year, melting was greatly retarded in contrast to 1970, a year of light winter accumulation. As a result of rapid snowline movement in 1970, there were large losses of ice and firn through melting.

The temperature throughout the summer influences melt rates immediately. Indeed, the rises and falls in the temperature curve are to



PEYTO GLACIER, ALBERTA

DAILY DISCHARGES, CONTRIBUTION OF ICE MELT SHADED, 1967-74 AND HOURLY DISCHARGES, 1970-74.

Figure 3

	Discharge $10^6 m^3$	MAY	JUNE	JULY	AUGUST	SEPT
1967	Qt	0.27E	3.09	11.44	17.33	9.51E
	Qi	0.0	0.0	1.34 (11.7)	4.49 (25.9)	2.38E(25.0)
1968	Qt	0.29E	5.22	13.62	11.63	4.85
	Qi	0.0	0.0	1.40 (10.3)	2.74 (23.6)	1.21E(25.0)
1969	Qt	0.40E	10.20	10.60	12.09	4.77E
	Qi	0.0	0.65 (6.4)	3.38 (31.9)	5.23 (43.3)	1.19E(25.0)
1970	Qt	0.19E	11.76	18.48	18.82	4.15E
	Qi	0.0	0.90 (7.7)	6.84 (37.0)	10.42 (55.4)	1.04 (25.0)
1971	Qt	0.43E	5.19	14.44	23.31	2.90
	Qi	0.0	0.01 (0.2)	1.86 (12.9)	6.85 (29.4)	0.73E(25.0)
1972	Qt	0.43	9.27	12.86	16.49	3.34
	Qi	0.0	0.0	1.29 (10.0)	3.98 (24.1)	0.84E(25.0)
1973	Qt	0.37E	5.25	12.60	12.49	6.14
	Qi	0.0	0.08 (1.5)	2.14 (17.0)	3.88 (31.1)	1.54E(25.0)
1974	Qt	0.21E	9.17	15.17	16.24	8.81
	Qi	0.0	0.0	1.10 (7.3)	3.15 (19.4)	2.20E(25.0)
Mean 67/74	Qt	0.32E	7.41	13.53	16.06	5.57
	Qi	0.0	0.21 (2.8)	2.42 (17.9)	5.09 (31.7)	1.39E(25.0)

Qt = total monthly discharge

Qi = total monthly discharge from melting glacier ice and firn

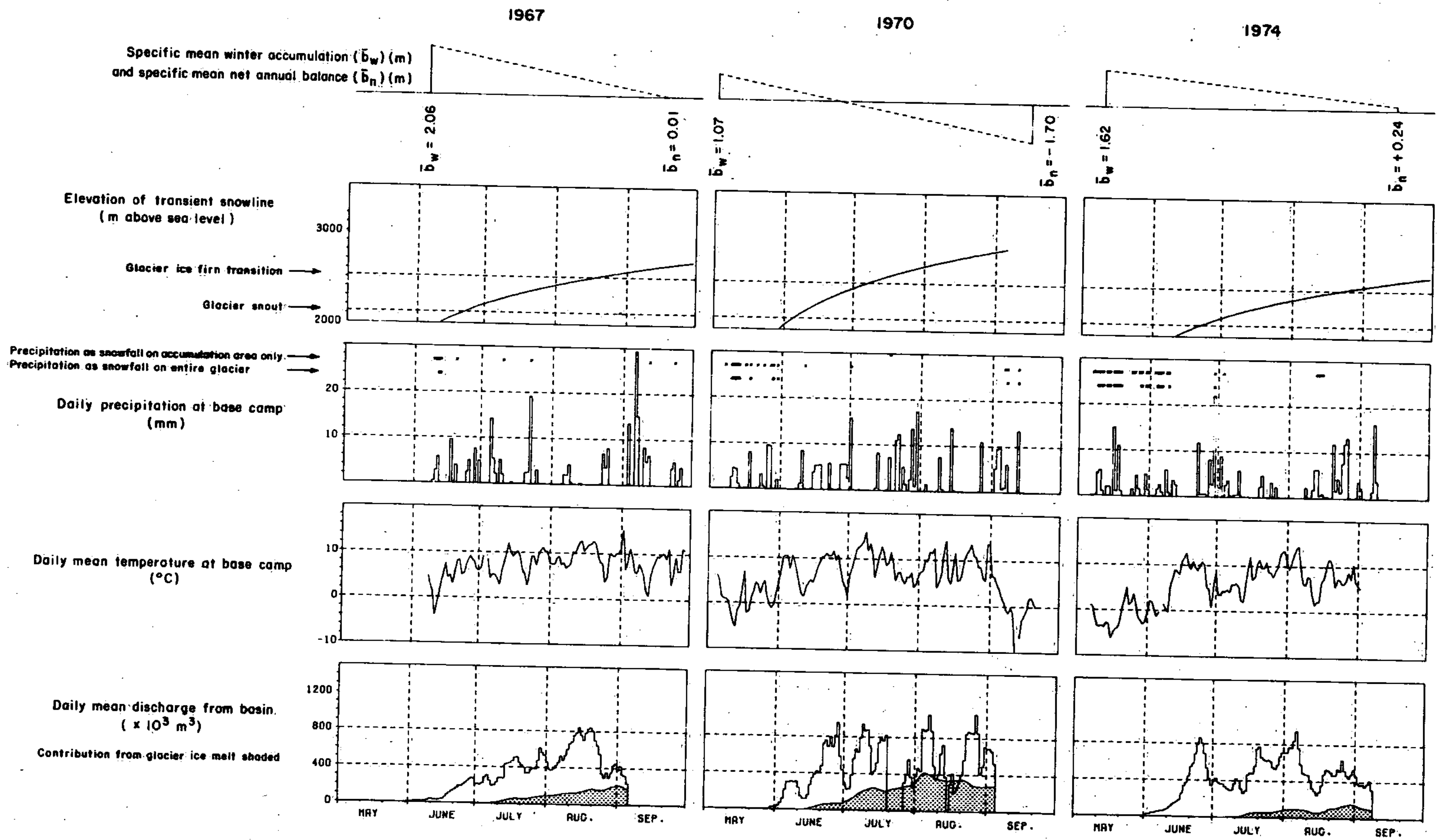
(1.5) = Qi as % of Qt

E = Estimated

September flows estimated from partial records.

Peyto Glacier, Alberta; breakdown of annual flows

TABLE 1



SUMMARY GRAPHS RELATING MASS – BALANCE TO METEOROLOGY AND DISCHARGE FOR 1967, 1970 AND 1974

Figure 4

a large extent paralleled by the hydrograph. However, the normal effect that a temperature drop has in decreasing melt is greatly reinforced when accompanied by snowfall. A heavy snowfall on 29 June 1974 was very significant in reducing discharge for many days.

The total amount of melting from glacier ice and firn is closely linked to the rise of the snowline which in turn is governed by the amount and distribution of snow at the end of winter and the temperature and precipitation record during the summer.

The diurnal discharge regime has these same controls. There is little diurnal range in discharge before glacier ice becomes bare of seasonal snow. As more ice becomes bare so the diurnal range increases. As the summer progresses, channels within the ice become more open and the time lag between melting of the ice and the meltwater reaching the gauge is diminished; timing of peak daily discharge therefore changes towards the time of maximum melting. Greatest ranges in diurnal discharge occur when there are large areas of bare ice and when skies are clear; i.e., at times of high energy input during the day and cooling during the nights.

(iii) Derivation of stream flow

A partial breakdown of the derivation of stream flow is given in Table 2. Ideally, it would be desirable to give a complete breakdown in terms of how much water is derived from each terrain type, the lengths of travel time from the various parts of the basin to the stream gauge and how these quantities change throughout the year. Unfortunately, the data for this are notavailable. However, from the mass-balance measurements, it is possible to estimate for the glacier surface quantities of meltwater derived from the winter snowpack, from glacier ice and from firn.

From Table 2 it can be seen that an average of some 30% of total annual flow is derived from the winter snowpack on the glacier, 15% from melting glacier ice and 7% from melting firn. The residual, some 48% of total flow, is accounted for by melting winter snowpack not on the glacier, summer rainfall not incorporated into the snowpack and the melting of ice-cored moraines, perennial snow patches and glacierets. There is considerable variation from year to year in the contributions from the various terrain types. This is most especially so in the contribution from melting firn. In years when the snowline remains low, the contribution from melting firn is negligible, whereas when the snowline retreats rapidly to high elevations, the contribution from melting firn can be even greater than the contribution from melting glacier ice. During the four years of negative mass balance, some 37 x $10^6 m^3$ of water came out of storage. This represented 20% of total stream flows in those four years. In the four years of positive balance, the glacier gained 13.8 x $10^6 m^3$ of water; this amount did not show in the streamflow record but represents the amount by which precipitation exceeded

YEAR	Annual Discharge $10^6 m^3$ (a)	Melt from Glacier Ice $10^6 m^3$ (b)	Melt from Glacier Firn $10^6 m^3$ (c)	Melt from Ice & Firn $10^6 m^3$ (d)	Melt from Seasonal Glacier Snow $10^6 m^3$ (e)	(d) as % of (a)	(e) as % of (a)	Volume Change in Total Glacier Mass $10^6 m^3$	Residual* (a)-(d)-(e)
1967	43.89	7.96	1.99	9.95	17.40	22.7	39.6	+0.13	16.54
1968	37.84	5.34	0.81	6.15	11.14	16.3	29.4	+4.69	20.55
1969	40.33	7.34	3.11	10.45	14.08	25.9	34.9	-5.36	15.80
1970	55.67	10.17	12.72	22.89	14.23	41.1	25.6	-22.78	18.55
1971	48.51	6.98	3.13	10.11	12.91	20.8	26.6	-5.49	25.49
1972	44.67	5.95	2.27	8.22	17.55	18.4	39.3	-3.35	18.90
1973	39.14	6.17	0.87	7.04	10.23	18.0	26.1	+5.76	21.87
1974	51.96	4.99	0.92	5.91	12.62	11.4	24.3	+3.22	33.43
Total	362.01	54.90	25.82	80.72	110.16	22.3	30.4	-23.18	

* Residual accounted for by
(i) Seasonal snowpack not on glacier
(ii) Rainfall over whole basin not incorporated into the snowpack
(iii) Melting from ice cored moraines, perennial snow patches and small glacierets

Peyto Glacier, Alberta, 1967/1974; Derivation of Streamflow

TABLE 2

outflow from the basin in those years.

THE PEYTO BASIN WITHIN THE NORTH SASKATCHEWAN BASIN

(i) Previous Studies

Besides the studies already cited for the Peyto Basin, there have been several other pertinent studies within the North Saskatchewan Basin. Articles by Collier (1958) and Heusser (1954, 1956) dealt in part with this area. The article by Davis and Coulson (1967) showed how difficult it is to draw conclusions in an area of sparse data. More recently, Loijens (1974) and Prantl and Loijens (1975) treated Mistaya Valley data for a short period of record. Henoch (1971) dealt with the period 1948-66 in the North Saskatchewan Basin. There have been many articles on the Saskatchewan Glacier; of particular interest are those by Campbell et al. (1969), Reid (1972) and Reid and Charbonneau (1972). A series of internal reports by the Water Survey of Canada, 1950 to the present, are of value for the whole eastern Rocky Mountain Watershed. The Athabasca Glacier just outside the North Saskatchewan Basin has been intensively studied and perhaps the most relevant articles as far as this paper is concerned are those by Mathews (1964) and Kite and Reid (1977).

(ii) Stream Regimes and Glacier Cover

Within the past 10 years, several new gauging stations have been established within the North Saskatchewan Basin: these have included Peyto Creek (05DA008) 1967, the North Saskatchewan at Whirlpool Point (05DA009) 1970, and Silverhorn Creek (15DA010) 1971. These, together with the Mistaya (05DA007) allow a comparison of regimes within the overall watershed. Table 3 summarizes the results and while these should be treated with caution (as the periods of record are slightly different and basin sizes and elevation ranges are substantially different), certain facts become apparent. Firstly, as the percentage of the basin covered by glacier increases, so the timing of maximum monthly discharge moves towards the end of the summer. Secondly, the yield per unit area increases with increasing glacier coverage. The most striking contrast is provided by Peyto and Silverhorn Creek, basins with approximately the same area and similar elevation ranges but with completely different glacier coverage.

(iii) Volumetric Change in Glacier Storage

This subject has been most comprehensively treated by Henoch (1971) and what is added by this paper is simply a recalculation of water quantities derived from glacier recession in the light of recently available data. Henoch relied heavily on the 1965-68 records of mass change for Peyto and Ram River glaciers in calculating an average annual contribution of 4% of streamflow deriving from glacier melt. On the basis of a further 6 years of IHD data now available, this figure would be raised to 8% if the same calculations were performed. In addition, it

Basin name	Basin number	Area km^2	Elevation range m above sea level	% glacier covered	Period of record	Mean annual discharge $10^6 m^3$	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
							% of annual flow											
N. Saskatchewan at Whirlpool pt.	05DA009	1911	1400-3490	15	1970-74	1690	0.8	0.7	0.7	1.1	7.3	22.9	24.6	25.8	9.7	3.6	1.6	1.1
Mistaya	05DA007	244	1630-3290	13	1967-74	206	1.0	0.8	0.9	1.3	7.4	23.9	25.0	22.2	10.3	4.0	2.1	1.3
Peyto Creek	05DA008	22.1	1950-3185	61	1967-74	45	0.4	0.4	0.4	0.4	0.7	16.4	30.0	35.6	12.3	2.0	1.0	0.4
Silverhorn Creek	05DA010	20.1	1700-3050	4	1971-74	15	1.0	0.6	0.6	0.9	14.0	27.3	26.8	16.0	7.5	2.8	1.5	1.0

A comparison of discharge regimes for basins within the N. Saskatchewan headwaters

TABLE 3

is thought that melt rates on large glaciers such as Saskatchewan and Freshfield extending to lower elevations than Peyto or Ram would be significantly higher and that the 8% figure would thus be conservative. It is, therefore, quite possible that some 8-10% of annual flow in the North Saskatchewan River at Saskatchewan Crossing is derived from change in glacier volume. This is a considerable contribution at present and one which, in the long term, must diminish.

(iv) Future Studies

The data base from which to make calculations of glacier melt contributions to streamflow has been inadequate because of the short record. From currently available maps and photos, it is difficult to estimate the proportion of basins covered by glaciers. Streamflow records for the most part have been short. This situation should improve in the future and it is hoped that more work will soon be done on the problem of assessing the contribution of glacier melt to streamflow.

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A CONCEPTUAL MODEL FOR ORGANIC WATER QUALITY IN FOREST STREAMS OF THE MARMOT BASIN

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For presentation to the
Alberta Watershed Research Program Symposium,
Edmonton, Alberta
August 30 - September 2, 1977

ABSTRACT

A model of the stream based primarily on an analogy with a chemical process reactor is proposed for the Marmot Creek basin water quality study. The model deals particularly with the process aspect of streams, presenting an integration of all input-output factors and process reactions. Input to the process model includes variable loads of key indicator organic compounds: the refractory compounds, tannins-lignins and humic-fulvic acids and the labile organic compounds such as hydrocarbons, phenols, carbohydrates, fatty acids and amino acids. Evaluation of the model for processes in the reactor revealed that refractory organic compounds humic and fulvic acids were unaffected by processes in the reactor. Tannins-lignins on the other hand, were degraded and generated in the reaction chamber, the rate of reaction being a function of temperature and microbial biomass. An increased load of refractory organic compounds after clearcutting indicated vegetation and soil as major source inputs to the reactor. Labile organic compounds such as phenols, carbohydrates, fatty acids and amino acids appear to undergo processes of degradation, conversion, deposition, evaporation and microbial utilization in the reaction chamber. Hydrocarbons and certain amino acids were generated in the reaction by microorganisms. In analogy with the behavior of stable isotopes, pairs of amino acids in the Marmot Creek waters exhibited marked depletion, with depletion factors ranging from 0.7 to 7.0.

INTRODUCTION

Water quality studies on organic compounds in surface waters of the Marmot Creek drainage basin form a part of numerous research projects being carried out in the basin in the study of forest management practices (Jeffrey, 1965). The present study started in 1974 with the objective of determining the effect of forest clearcutting on the occurrence and distribution of organic compounds in surface waters of the Marmot Creek drainage basin. Effects of forest clearcutting on organic compounds in surface waters were determined by studying refractory and labile organic compounds (Telang et al., 1976). Refractory compounds were tannins and lignins, and humic and fulvic acids. Labile compounds included amino acids, phenols, hydrocarbons, fatty acids and carbohydrates. A conceptual forest-stream ecosystem model was developed in 1975 as a vehicle to present results of the first years of study. The model accounted mainly for origin, sources and transfer of organic constituents in surface waters of the basin, and to a lesser degree for various chemical and biological processes taking place in the stream. The model was therefore elaborated to account for various processes taking place in the stream with the ultimate objective of developing a predictive model for water quality management and to define diagnostic chemical and biological parameters.

A variety of stream models have been developed for stream systems ranging from management to microprocessing (Biswas, 1976; Boling et al., 1975; Brebbia, 1976; Cummins, 1974; Hodgson et al., 1977; Hynes, 1970; Likens, 1970; Telang et al., 1976; and Williamson et al., 1976). For the present discussion a model of the stream introduced by Hodgson et al.(1977) based primarily on an analogy with a chemical process reactor is employed. With particular reference to stream processing, the stream water is pictured as flowing through a piece of pipe or a reaction chamber with a reactive catalytic inside surface on which most, but not all, of the conversion processes may take place. The reaction chamber is characterized by certain conditions of temperature, pH and redox. The reactive catalytic surface for the stream is pictured as a biologically active surface, which frequently is comprised of a layer of sessile and planktonic bacteria on the stream bed over which the reactants are carried by the stream flow.

Process Reactor Model

An elaboration of a stream process reactor model results in input, output and reactor function. Input to the process model includes variable loads of refractory and labile organic compounds. The significance of output lies in that the difference between aggregated input and output indicates the extent of conversion within the reactor. Thus, within the reactor model, water quality may be defined in terms of the state of the stream as a process reactor, that is, an integration of all input and output factors. The dominant processes are processes of degradation (for example, aromatic hydrocarbons to keto acids, generation of amino acids, carbohydrates and hydrocarbons) elaboration (for example, side chain oxidation, reduction, etc.) and processes of conversion (for example, fatty acids to hydrocarbons, humics to phenols).

Stream System

The study area, the Marmot Creek research basin, is in the Kananaskis range of the eastern Rocky Mountains, Alberta, Canada (Figure 1). The basin, totalling about 9.0 square kilometers in area, was set aside as a research area in 1962 by the Canadian Forestry Service to study water management practices (Jeffrey, 1965). It consists of three sub-basins--Twin Fork, Middle Fork, and Cabin Creek--each containing a major stream combining to form a single larger stream (Main Marmot) draining the basin. The basin is situated at longitude 115°09'15"W, latitude 50°56'57"N and is at an altitude of 1585 to 2805 m.

The climate is characterized by short, cool summers and long cold winters. The mean annual precipitation is 1080 mm, of which about three-quarters is snow (Singh and Kalra, 1972). Rain occurs during the June-September period. Frequent thawing periods occur in all winter months due to the chinook winds (Kirby and Ogilvie, 1969).

The vegetation is made up of sub-alpine spruce-fir *(Picea abies)*, shrubs, grasses and mosses and is described in detail by Telang et al. (1976). Clearcutting occurred at the Cabin Creek sub-basin in August, 1974, at six selected sites, each about 10 ha.

Analyses of Organic Compounds

Tannins-lignins, phenols, carbohydrates, biochemical oxygen demand and chemical oxygen demand in the sample stream waters were determined by the standard A.S.T.M. methods. Amino acids, fatty acids and hydrocarbons in the sampled stream waters were determined by conventional gas chromatographic methods (Telang et al., 1976). Humic and fulvic acids were determined in the form of total organic carbon by using a Beckman Model 915 carbon analyzer.

RESULTS AND DISCUSSION

The stream waters of the basin were examined at four points in a reach of 2.2 km. The points were the weirs of Twin Fork, Middle Fork, Cabin Creek and Main Marmot. Figure 1 shows the general location of the streams and Table 1 indicates several qualitative aspects of the stream system.

Samples of stream waters were collected on the 18th of each month. During the winter and early spring period, November-April, the stream remained covered with ice. Access to the flowing water was gained by drilling holes through the ice (100 cm thick) using an auger.

The general condition of the streams was that they were saturated with oxygen throughout the year.

The analytical data generated for evaluation of the reactor model for both the refractory and labile organic compounds in waters are summarized in Table 2. These organic constituents amounted roughly to

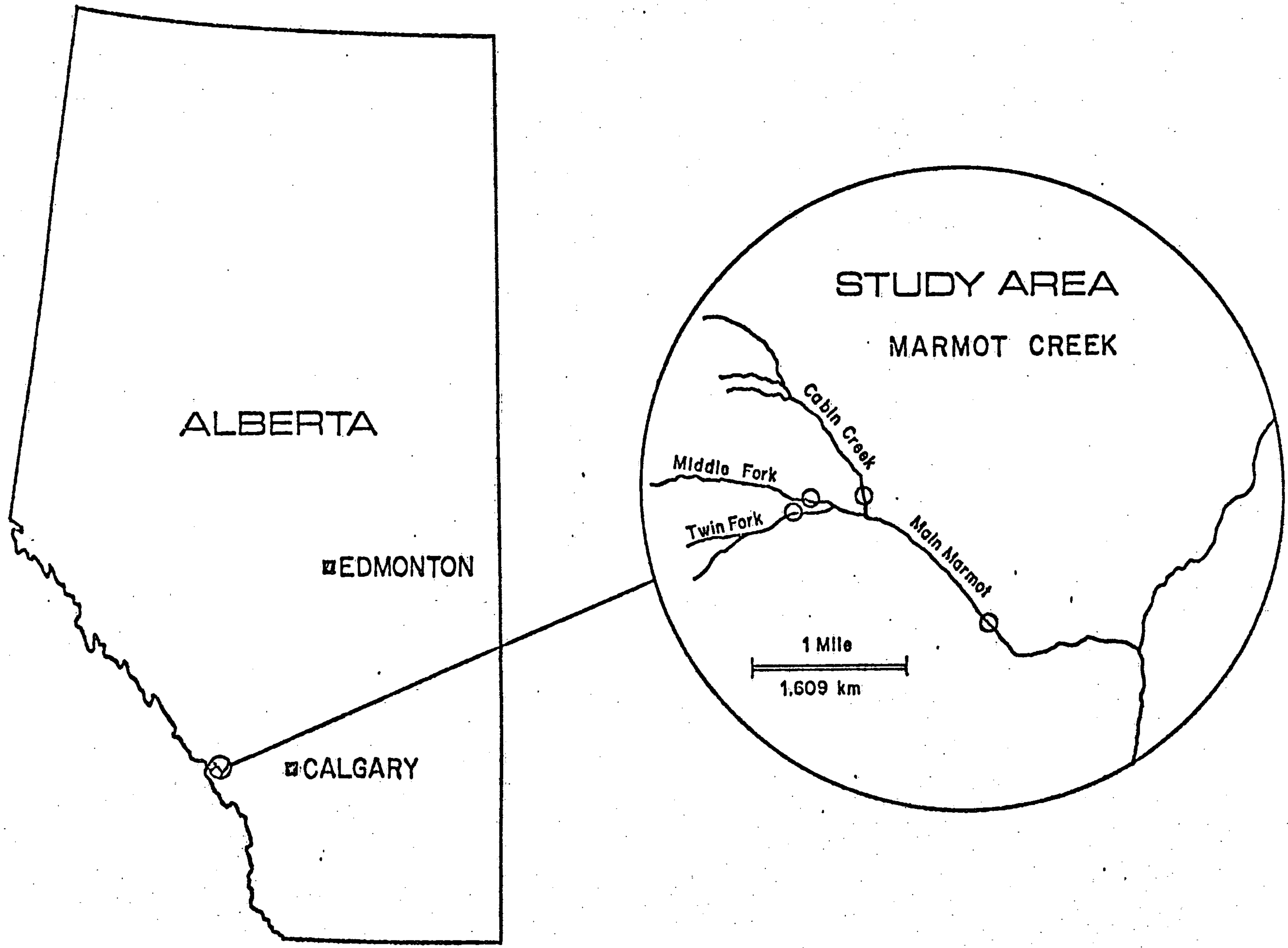
ALBERTA
EDMONTON
CALGARY
STUDY AREA
MARMOT CREEK
Cabin Creek
Middle Fork
Twin Fork
Main Marmot
1 Mile
1.609 km

Figure 1.

Table 1. SUMMARY OF DATA FOR REFRACTORY AND LABILE ORGANIC COMPOUNDS IN STREAM WATERS OF THE MARMOT BASIN IN μg/ℓ

	Twin Fork	Middle Fork	Cabin Creek	Main Marmot
Tannins-Lignins	87.0	95.0	550.0	205.0
Humic-Fulvic Acids	766.0	704.0	900.0	780.0
Hydrocarbons	0.022	0.055	0.06	0.05
Amino Acids				
Free	1.5	3.0	2.0	2.10
Combined	5.5	4.5	4.05	4.75
Fatty Acids	2.5	3.2	1.5	2.7
Phenols	6.0	2.9	4.2	2.75
Carbohydrates	84.0	70.0	53.0	50.0
Dissolved Oxygen	10920	10980	10900	11000
Biochemical Oxygen Demand	1990	2100	1890	2000
Chemical Oxygen Demand	3480	3810	4520	5380
Total Organic Carbon	3830	3250	4100	5000
FLOW RATE ℓ/day (mean of average)	2.65×10^6	2.8×10^6	1.5×10^6	8.3×10^6

Data are for monthly analyses during 1975.

Table 2. SUMMARY OF ORGANIC COMPOUNDS IN THE STREAM WATERS OF THE MARMOT BASIN IN kg/day

Organic Compound	Twin Fork	Middle Fork	Cabin Creek	Main Marmot
Tannin-Lignin	210.0	90.0	760.0	880.0
Humic-Fulvic Acids	2370.0	2000.0	1540.0	6000.0
Hydrocarbons	0.0003	0.0006	0.0004	0.0018
Phenols	14.0	11.0	12.0	29.0
Carbohydrates	800.0	420.0	180.0	900.0
Fatty Acids	4.0	4.5	4.7	7.4
Amino Acids (Total)	0.025	0.017	0.010	0.055
Chemical Oxygen Demand	17.0	16.0	11.0	63.0
Total Organic Carbon	14.0	14.0	7.0	60.0

Table 3. RELATIVE RATIO OF SELECTED PAIRS OF AMINO ACIDS

Stream	Serine/ Glycine	Threonine/ Glycine	Aspartic/Glutamic Acid Acid
Twin Fork	0.06	0.10	0.67
Middle Fork	0.07	0.13	0.82
Cabin Creek	0.12	0.16	0.67
Main Marmot	0.11	0.24	0.80

25 per cent of the total organic carbon present in the surface waters of the basin.

Reactor Model

The stream system of the Marmot Creek drainage basin with its four sampling points (Figure 1) can be conveniently treated as a simple "reactor" model. The model features Twin Fork, Middle Fork and Cabin Creek as the direct input units and Main Marmot as the output unit, and the processes involved being inferred from the differences between output and input in the stream.

Mass flow of the organic constituents in the stream systems forms the basic concept of the model. Organic constituents enter the model section by:

1. being present in the inflowing waters of the Twin Fork, Middle Fork and Cabin Creek streams;

2. being present in the surface runoff and tributary water entering the Main Marmot stream between the sampling input-output points (local input);

3. being generated *in situ* in the model section by stream biota; and

4. being leached from allocthonous substances (leaves, etc.) in the stream.

Similarly, organic constituents leave the section by:

1. being carried out by the Main Marmot stream flow;

2. being carried out by water seeping from the stream into the stream bed recharging subsurface aquifers;

3. being altered (degraded) in the stream (for example, oxidation, reduction, etc.); and

4. being deposited on the stream bed (for example, on sedimenting particles).

The analytical data of the study were treated in terms of the model to reach an understanding of the processes occurring in the Marmot basin waters. The reactor model was evaluated for the mass flow of several gross organic constituents (for example, tannins-lignins, phenols, etc.) and of individual constituents (for example, amino acids). The input of organic compounds was calculated from input concentrations and water flow rates (Water Survey of Canada, Calgary). The output was similarly calculated. The local input of organic compounds was calculated in keeping with the abundance of organic compounds in the main stream input (Hodgson et al., 1977).

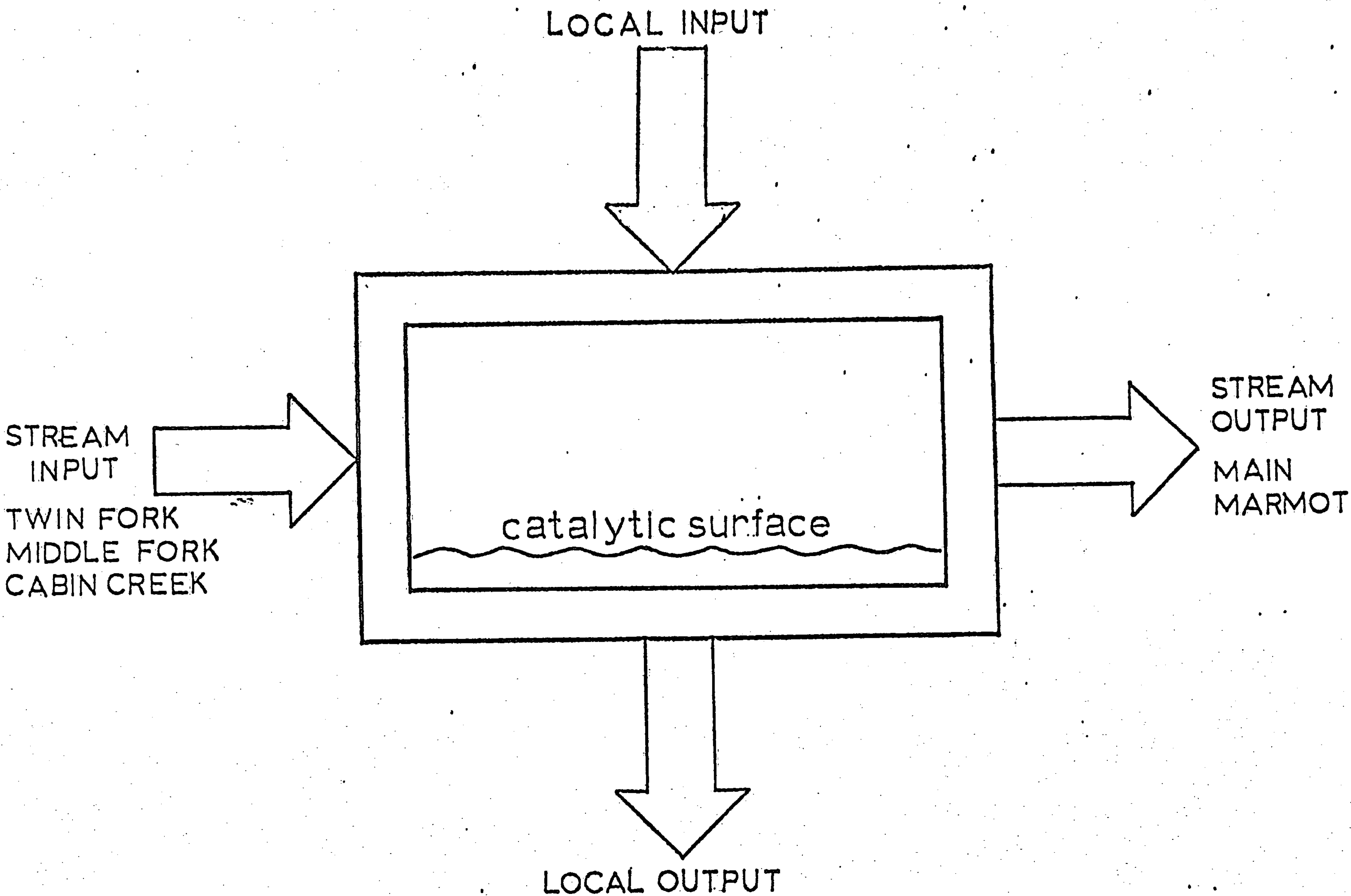

Figure 2. A PROCESS REACTOR MODEL FOR THE MARMOT CREEK DRAINAGE BASIN STREAM WATERS

Refractory Organic Compounds

Tannins-lignins and humic-fulvic acids being polymeric organic compounds undergo conversion and degradation very slowly compared to labile organic compounds.

Table 1 gives the average abundance of tannins and lignins, and humic and fulvic acid in the stream water of Twin Fork, Middle Fork, Cabin Creek and Main Marmot. The higher content of these compounds in the Cabin Creek waters was attributed to the clearcut vegetation and to land disturbance during the clearcutting operation (Telang et al., 1976).

The reactor model was evaluated for the mass flow of tannins and lignins. The first years of study identified the source of these polymers as vegetation and possibly soil structures. These polymers were transported to the stream waters by surface or sub-surface runoff or by direct lead fall (Telang et al., 1976). To understand the processes taking place in the reactor the data for tannins-lignins were normalized to 100 units per day mass flow of tannins-lignins. The significant findings in the evaluation of the model were (1) that roughly one-half of the tannins-lignins entering the stream reactor were lost in the reactor during the summer months, May to September (input 110 units includes local input, output 50 units), and (2) that during the winter months, December to April, roughly one-fourth of the tannins-lignins leaving the stream waters were generated in the reactor (input 100 units, output 125 units).

Examination of the normalized data revealed that on an average over a period of one year roughly one-third of the tannins-lignins entering the stream reactor were lost in the reactor. The input of tannins-lignins averaged yearly to about 1200 g/day (Table 2) of which Twin Fork contributed about 210 g/day, Middle Fork about 90 g/day and Cabin Creek about 760 g/day. The local input was calculated to be 200 g/day in keeping with the abundance of tannins-lignins in the main stream input. The output of tannins-lignins averaged yearly about 900 g/day, indicating the yearly loss of 300 g/day to the reactor.

A close examination of the monthly data of tannins-lignins revealed that in the Marmot Creek waters two processes were taking place depending on the season. During the months of May to September the input of tannins-lignins from the above three streams and local input averaged 2800 g/day, while the output for that period measured about 1400 g/day. The loss of 1400 g/day in the reactor could thus be due to the processes of conversion, degradation, deposition and of microbial utilization.

The biochemical oxygen demand, which is a rough measure of biological activity in the stream, was high in the waters of the Marmot basin during the months of June to September, averaging 20,000 g/day compared to 3000 g/day for the other months. Thus, it can be postulated that the observed loss of tannins-lignins during the months of May to September in the reactor may be partly due to biological degradation of tannins-lignins.

During the winter months, December to April, the load of tannins-lignins leaving the reactor increased to about 25 per cent over the total input. The input averaged about 520 g/day whereas the output averaged about 690 g/day. This increase could be due to a process of leaching of allochthonous material (leaves, twigs) or a direct result of the low volume of water flow. Polymerization of simple organic molecules (for example, aromatic acids and phenols to generated tannins and lignins in the stream waters) was possible.

Humic and fulvic acids in the stream waters of the Marmot basin were less subject to chemical and biological processes in the reactor compared to tannins-lignins. The input of humic-fulvic acids over a period of one year from Twin Fork averaged 2375 g/day, from Middle Fork 2100 g/day and Cabin Creek 1530 g/day, yielding combined input of 6000 g/day. Based on stream flow data, the local input was found to be very minor, at 800 g/day. The measured output in the stream waters of the Main Marmot averaged about 6000 g/day. Thus, the aggregation of input and output data revealed that the humic-fulvic acids entering the reactor were only slightly altered by the processes occurring in the reactor.

Labile Organic Compounds

Labile organic compounds being low molecular weight compounds undergo conversion, degradation and generation rapidly compared to polymeric refractory compounds. In the stream waters of the Marmot basin labile organic compounds were indicative of both source input and the processes taking place in the reactor.

Hydrocarbons

Hydrocarbons entering and leaving the reactor chamber of the reactor model averaged 0.0013 and 0.0018 kg/day respectively (Table 2). Normalization of the data to 100 units per day mass inflow of hydrocarbons revealed that hydrocarbons were generated in the reactor model. One hundred and fifteen units of hydrocarbon were entering the reactor from the three input streams and the local input unit, whereas 140 units of hydrocarbon were leaving the reactor, an increase of 25 units. Aquatic organisms were suggested to be largely responsible for the generation of hydrocarbons.

The conclusion indicating generation of hydrocarbons in the stream waters of the Marmot basin was independently supported by the carbon preference index (CPI) (Telang et al., 1976) which expresses the relative abundance of normal alkanes having odd carbon to those having even carbon numbers (Cooper and Bray, 1963). The CPI values of land and soil origin differ considerably from those of aquatic organisms. Many land plants and soil have a CPI greater than 4, whereas aquatic organisms have a CPI between 0.4 and 1.5 The carbon preference index of 1.2 to 2.0 in the waters of the Marmot Creek drainage basin indicated that a substantial part of hydrocarbons was generated by aquatic organisms (Telang et al., 1976).

Branched and cyclic hydrocarbons were also detected but were less abundant. It is recognized that n-alkanes are preferred carbon sources for most soil organisms over the corresponding cyclic and branched compounds. But the abundance of n-alkanes compared to cyclic and branched hydrocarbons suggests that n-alkanes experience little or no microbial attack in the reactor model. Thus, evaluation of the model suggests two processes occurring in the model--generation of hydrocarbons and minimal microbial attack.

<u>Phenols</u>

Input and output data indicate that phenols undergo chemical and/or biological processes in the reactor. The input of phenols to the reactor averaged 40 g/day of which Twin Fork contributed 14 g/day, Middle Fork 11 g/day and Cabin Creek 12 g/day. The local input was calculated to be 4.1 g/day. The output from the reactor averaged 28 g/day. Thus, roughly one-third of the phenols entering the stream reactor were lost to the reactor. The loss of phenols in the reactor could be attributed to the process of degradation (e.g., catechol to p-oxadipic acid) to the process of conversion resulting in polymerization to high molecular weight compounds (tannins-lignins, humic-fulvic acids) and to deposition.

Loss of low molecular weight phenols due to the process of evaporation is also possible. Due to the toxic properties of phenols, the loss of phenols due to biological processes appears to be less likely.

The data have been obtained so far for the total phenols and not for individual phenols. As a result, a phenol preference index (PPI), in order to understand detail processes in the reactor, needs to be developed.

<u>Carbohydrates</u>

The data for carbohydrates, like phenols, are for the total carbohydrates (Table 2). Evaluation of the model indicates that roughly half of the carbohydrates entering the reactor were lost in the reactor. Examination of the normalized data revealed that, on an average, 110 units of carbohydrates were entering the reactor and 60 units of carbohydrates were leaving the reactor. Carbohydrates being an important nutrient, the majority of the loss in the reactor could be attributed to biological processes occurring in the reactor; for example, utilization of carbohydrates by microorganisms to build their own cell mass. Carbohydrates degrade to simple sugars under acidic conditions. As the pH of the Marmot basin water is above 7.0, carbohydrates of the Marmot basin waters will not undergo the process of degradation in the reactor. Loss due to evaporation is considered to be negligible. Carbohydrate loss due to the process of conversion involving the incorporation of carbohydrates into humic-fulvic acid moieties and glycosydic compounds is however possible. Thus, the loss of carbohydrates in the reactor could be due to biological processes and/or other conversion processes.

Fatty Acids

Fatty acids occur in nature in both free and combined states. Very low concentrations of free fatty acids in the waters of the Marmot basin made individual determinations very difficult. Therefore, total fatty acid determinations were carried out on the water samples. The normalized data revealed massive destruction of fatty acids in the reactor. Like phenols and carbohydrates, roughly half of the fatty acids entering the reactor were lost in the reactor. Biological processes and the processes of conversion, degradation and deposition could account for fatty acid losses.

The normalized data on C_{16} and C_{18} saturated and unsaturated fatty acids showed similar behavior, except that C_{18} unsaturated fatty acids were less degraded in the reactor.

In the Marmot Creek basin waters the ratio of C_{16} saturated to unsaturated fatty acid was between 0.76 to 2.0 and for C_{18} between 0.74 to 1.28. These ratios indicate several sources of input such as phytoplankton, bacteria, leaves, algae, etc. Many plants and primitive organisms (Eglinton, 1969; Swain, 1965) have C_{16} saturated to unsaturated ratios of 1.4 to 2.5 and for C_{18} fatty acids between 0.32 to 0.92. The ratios of C_{16} and C_{18} saturated to unsaturated fatty acids to reveal sources of fatty acid input in the stream waters were found to be less satisfactory compared to the carbon preference index of hydrocarbons. This is because these ratios fall between a narrow range.

Amino Acids

The significant findings of the amino acid data were that mass flow of several amino acids varied considerably, that stream waters of the Marmot basin had one major source of amino acids and that amino acids were subjected to processes of degradation and generation.

The reactor model was evaluated for the mass flow of several individual amino acids. Thus, for example, the input of combined glutamic acid was found to be 9.0 g/day and of free glutamic acid to be 1.6 g/day. The measured outputs of combined and free glutamic acid were 10.8 and 1.1 g/day respectively. The input of combined and free serine, on the other hand, was far less--0.7 and 0.9 g/day respectively. The corresponding output of combined serine was 0.7 g/day and of free serine 0.6 g/day. The observed differences in concentrations of glutamic, serine and other amino acids may be due to their instability in the environment.

Analyses of amino acid data revealed one major source of amino acids in the waters of the Marmot basin waters. Amino acids occur both in free and combined forms in the environment. In the combined form they exist for the most part as polypeptide chains and in this way individual amino acids survive environmental strains much more readily than free amino acids. Survival of a polypeptide chain from the biotic source to the stream water should display the original relative abundance of individual amino acids when they are released by the laboratory hydrolysis method. Accordingly, a single source of combined amino acids would result in the same relative abundance of component amino acids in the combined acids of the surface waters of local streams. If, however, the relative abundance of one amino acid to another in the combined form varied from stream to stream this finding would indicate more than one source of amino acids in the stream waters. The ratios of three pairs were examined to test this hypothesis. In the combined form, the ratios of serine to glycine, threonine to glycine and aspartic acid to glutamic acid for the four streams ranged from 0.06 to 0.11, 0.1 to 0.25 and 0.7 to 0.8 respectively. The narrow range of ratios (Table 3) for individual pairs of amino acids suggest one major source of amino acids for the four streams of the Marmot basin.

The processes occurring in the reactor of the model were studied by normalizing the data of individual amino acids (Table 4) to 100 units per day mass inflow of combined acids. The amino acids involved were glycine, threonine, serine, phenylalanine, aspartic acids and glutamic acid. The significant findings in the evaluation of this model were (1) that roughly one-third of the "combined" acids, glycine and serine entering the stream reactor disappeared in the reactor (2) that roughly one-tenth of the "combined" amino acids alanine, phenylalanine, aspartic acid and glutamic acid were generated in the stream reactor unit and (3) that roughly one-third of the free amino acids disappeared in the reactor.

Loss in the reactor of individual amino acids, glycine, and serine in the combined form indicates that these amino acids were released from a peptide chain into the stream waters at a slightly faster rate than other amino acids, and were undergoing biological or chemical degradation faster than other amino acids. Generation of certain amino acids in the combined form in the reactor unit would indicate incorporation of certain free amino acids in the polypeptide chain by a process of polymerization. The observed differences in the abundances of free and combined amino acids fit the above observations. Based on these observations, if two amino acids, for example, glutamic acid and glycine, were subjected to processes in the reactor model, glycine is expected to be consumed faster than glutamic acid. A heterotrophic potential study with labelled glutamic acid showed that the rate of glutamic acid uptake by planktonic microorganisms was indeed slow, 3.0 ng/ℓ/h (Telang et al., 1976).

Further examination of the normalized data revealed that the main stream output of the individual acids in the combined form was generally dependent on the generation or degradation of individual amino acids in the reactor relative to the input. In the case of amino acids in the combined form disappearing in the reactor, the output mass flow varied relative to the input, ranging from 60 to 105 units for the average of 85 units. For amino acids generated in the reactor the output mass flow was reasonably constant ranging from 120 to 140 units for an average of 135 units. On the other hand, the variability in mass flow of free amino acids entering and leaving the reactor was extremely large. For free amino acids entering the reactor

Table 4. NORMALIZED MASS BALANCE FOR SELECTED AMINO ACIDS

Amino Acid	Free Amino Acid Input	Free Amino Acid Output	Combined Amino Acid Input	Combined Amino Acid Output
Alanine	30	20	120	125
Glycine	30	20	120	70
Threonine	35	40	120	150
Serine	180	80	120	105
Phenylalanine	75	50	120	140
Aspartic Acid	30	15	120	135
Glutamic Acid	20	10	120	125

Table 5. DEPLETION FACTORS FOR SELECTED PAIRS OF AMINO ACIDS FOR THE STREAM WATERS OF THE MAIN MARMOT

Acid Pair	Depletion Factor
Serine/Glutamic Acid	7.0
Serine/Alanine	3.2
Phenylalanine/Glutamic Acid	2.8
Serine/Threonine	1.8
Phenylalanine/Aspartic Acid	1.5
Serine/Glycine	1.1
Isoleucine/Leucine	0.6
Valine/Glycine	0.6
Serine/Valine	0.6

it ranged from 15 to 180 units with an average of 60 units. For amino acids leaving the reactor it ranged from 10 to 80 units for an average of 30 units. These variabilities in individual amino acids in combined and free form indicate different rates of polymerization, rates of hydrolysis and rates of degradation biological utilization. Examination of the normalized data indicated that serine was by far the most abundant free amino acid entering the Marmot basin reactor model, 180 units. And, also, it was the most degraded amino acid in the reactor, 80 units. The next was phenylalanine with 75 and 50 units respectively. The values of other amino acids entering and leaving the reactor averaged 30 and 20 units. Normalization of input and output units of free amino acids revealed the stability of amino acids in the Main Marmot waters. Most stable amino acid was found to be isoleucine, followed by leucine, alanine, glycine, phenylalanine, glutamic and, proline, aspartic acid and serine. The ranking so developed corresponds generally with that developed by Abelson (1959), Hare-Mitteren (1969), Khan and Sowden (1971) and Vallentyne (1969).

Recently, Hodgson et al. (1977) used the abundance of amino acids in the waters of the Medicine river, Alberta to monitor environmental stress. Based on the stability of amino acids found in the Medicine river waters, they examined a variety of pairs of amino acids for evaluation of depletion factors, which were typically measured as:

$$DF_{Glycine/Serine} = \frac{(Gly/Ser)\ free - (Gly/Ser)\ combined}{(Gly/Ser)\ combined}$$

A similar approach to the Marmot basin waters showed small but real depletion, e.g. valine/glycine (DF = 0.6) while others showed profound changes serine/glutamic acid (DF = 7.0) and phenylalanine/glutamic acid (DF = 2.8) (Table 5).

Chemical Oxygen Demand and Total Organic Carbon

Evaluation of the carbon flow in the reactor model of the Marmot basin indicated that substantial quantities of carbon were generated in the reactor model. The chemical oxygen demand studies indicated the mass flow input of carbon as 44 kg/day, local input as 8 kg/day and output as 64 kg/day, with the net generation of 12 kg/day of carbon in the reactor. The total organic carbon study indicated the carbon input as 35 kg/day, local input as 7 kg/day and output as 60 kg/day, with the net generation of 18 kg/day of carbon in the reactor. Both these independently carried out studies indicate an average generation of 15 kg/day of carbon. This indicates large amounts of organic carbon are generated in the reactor by microorganisms, phytoplankton, zooplankton, and by stream bed sediment.

The foregoing data in general are demonstrative of the stream processes in the Marmot basin waters.

CONCLUSION

The Marmot basin reactor model indicated that refractory organic compounds, humic and fulvic acids remained unchanged by the processes in the reactor. Tannins and lignins on the other hand were affected by the processes in the reactor, the rate of reaction being a function of temperature and aquatic biomass. Of the labile organic compounds, hydrocarbons and some amino acids were generated in the reactor. The carbon preference index of hydrocarbons indicated the source input of hydrocarbons to be aquatic organisms. Other labile compounds such as phenols, carbohydrates, fatty acids and amino acids, glycine and serine, were altered in the reactor unit by the biological and chemical processes of conversion, degradation, generation and deposition.

ACKNOWLEDGEMENTS

The authors acknowledge the technical assistance of Jenny Wong, Walter Binder and Anita Serres, the field assistance of Denny Fisera, Canadian Forestry Service and typing assistance of Sandi Hvizdos and Della Patton. This work was supported by the office of Research Subventions, Inland Water Directorate, Environment Canada, Ottawa, Ontario, and Environmental Planning and Research Service, Alberta Environment, Edmonton, Alberta.

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MUSKEG LEACHING AS A POTENTIAL THREAT TO WATER QUALITY IN THE RED DEER RIVER

B.L. Baker, S.A. Telang and G.W. Hodgson

ABSTRACT

Organic substances were leached in the laboratory from samples of organic soil from muskeg in the Red Deer drainage basin and compounds were identified and measured. Natural leachate obtained in the sample area was also tested and its organic content was found to be similar to the laboratory-leached samples. Data on occurrences and levels of several organic substances were compared with similar data obtained from waters of the Red Deer river and the Medicine river. Chemical oxygen demand of the leachates was eight times greater than median levels of C.O.D. in the Red Deer river (85 mg/ℓ compared with 10 mg/ℓ); tannins and lignins in the leachates exceeded river water levels more than four times (3 mg/ℓ and 0.8 mg/ℓ); and amino acids were an order of magnitude higher in the leachates (0.33 mg/ℓ and 0.02 mg/ℓ). Unstable free amino acids were significantly lower in the river water than in the muskeg. In the leachates combined amino acids and free amino acids were nearly equal in abundance whereas in the river waters they were fifteen times more abundant. The relative abundance of an unstable free amino acid (serine) to a more stable one (glycine) was similarly higher in the natural leachate than in the river water (from almost twice as much in the leachate to only half in the river water). The high levels of organic substances in leachates and the differences observed between the river water samples and the leachate suggest that muskeg leaching is a source of organic compounds to river waters and may pose a threat to water quality in the Red Deer river.

MUSKEG LEACHING AS A POTENTIAL THREAT TO WATER QUALITY IN THE RED DEER RIVER

B.L. Baker, S.A. Telang and G.W. Hodgson*

The purity of water in a natural watercourse is affected both by natural causes and the activities of man. Through natural cycles many natural compounds migrate through sediments, water and the atmosphere in a never ending process. During the cycle both inorganic and organic chemicals are deposited and accumulated. Man influences the natural cycles through his activities. He alters the landscape, builds industrial plants, municipalities and cities, removes substances from the earth and replaces them with altered materials. All these activities bring about changes in the soil, water and atmosphere.

The natural watercourses of the earth are particularly affected by these activities because water is an excellent solvent and can accommodate a broad range of compounds either in solution or in suspension. Downstream from large cities and industrial plants the altered condition of water due to man's activities is very evident. However, alterations in the condition of water can also occur from natural processes.

Mountain streams are normally thought of as being crystal clear, bubbling over rocks and containing pure, fresh water. This is not true in all cases. Some of the rivers and streams of the foothills area of Alberta, with no direct input from man's activities, contain water that is stagnant, full of sediment, highly colored and aesthetically undesirable. The pollution of the river is due strictly to natural causes.

Many natural processes influence water quality by contributing either directly or indirectly to the organic load of a stream. If a stream flows through arid countryside, it accumulates very little organic material; however, if growing and decaying vegetation occurs close to the banks of the stream, the likelihood of organic contribution to the water is considerably greater. A study of a relatively pristine river system, with tributaries flowing through heavily vegetated areas but itself passing through little vegetation, should show the differences in the load of organic substances entering the waters from each type of environment and also provide for study of some prime source of organic compounds.

The Red Deer river drainage basin in central Alberta (Figure 1) is a system that comprises the necessary conditions for such an investigation. Above the city of Red Deer the Red Deer river has only limited direct contact with vegetation along its shores. In contrast, one of its tributaries--the Medicine river is in close contact with vegetation in the area. In addition, throughout the area drained by the Medicine river are extensive areas of muskeg.

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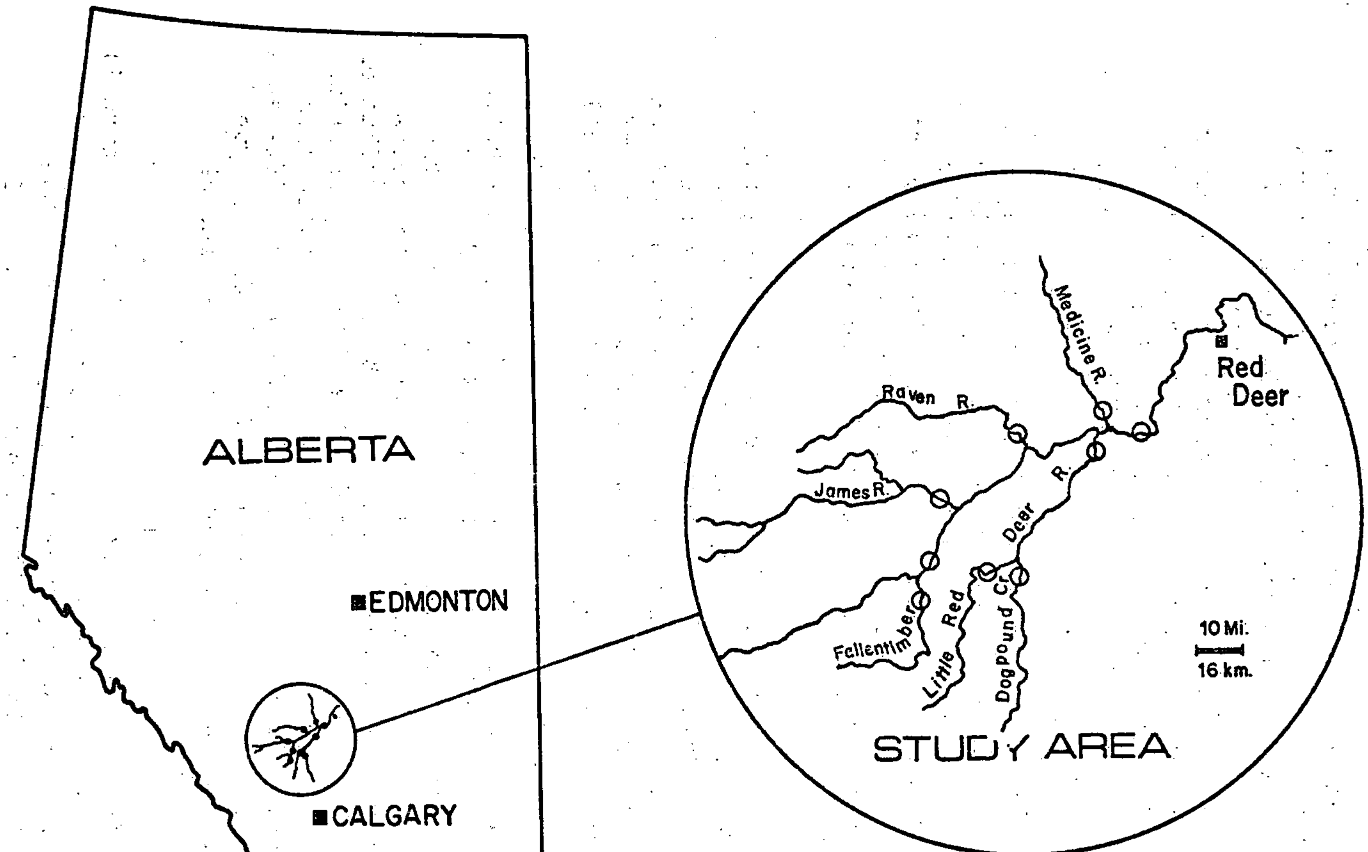

Figure 1. Water Quality Study Area

The chemical content of running water varies from region to region and depends to a large measure on local geography and climate. Though water includes both inorganic and organic constituents, the chemical content of water is generally reported in terms of dissolved inorganic elements and suspended particulate matter. Organic constituents are seldom considered adequately because inorganic elements in water are more easily detected and quantitatively measured than the organic elements. In terms of water quality, interest in organic constituents of water stems from the contribution of these compounds to taste, color and odor, but the ultimate concern is with overall water management. All living processes--plant and animal--contribute organic compounds to watercourses and these are more difficult to manage than industrial processes contributing specific waste substances to water supplies.

In recent years, new analytical procedures have been developed that measure several classes of organic compounds. Studies of the occurrence of these compounds in the river system can assist in determining sources of specific organic compounds found in the water and can also provide for an evaluation of environmental stress in drainage basins. The latter study is more simple in a basin such as the Red Deer, where only limited effects of man's activities occur and where interrelationships of organic compounds may be readily assessed.

Organic compounds and their effect on water quality in a particular river must be compared with some standard of water quality before the organic water quality of that river can be determined. The most readily identified and best understood water quality parameter is the level of dissolved oxygen. This level is dependent to a considerable extent on the number of oxygen-consuming organic compounds, which will depress the level of dissolved oxygen if present in the water in sufficient quantity. Depletion of the oxygen in the water will create eutrophic and reducing conditions, and make the water unsuitable for consumption.

Other parameters, related to the levels of available oxygen, are chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Chemical oxygen demand is the amount of oxygen needed to oxidize all the easily oxidizable organic and inorganic material in the water, and biochemical oxygen demand is the amount of oxygen necessary for the oxidation of water-borne-oxidizable compounds by microorganisms. Two other parameters which are used to define organic content of water, and for which standard determination methods are available, are phenols, and tannins and lignins. In general, these compounds are hydroxylated aromatic compounds that have deleterious effects on dissolved oxygen and toxic influences on fish.

Newly developed analytical techniques exemplify the significance of less well known organic compounds in aqueous systems. Some of the organic compounds that are now being analyzed are humic and fulvic acids, amino acids, fatty acids and hydrocarbons. Of these more characterizing organic compounds, humic and fulvic acids provide the best general measure of total organic compounds because they account for over 60 per cent of all organic compounds in water (Schnitzer and Skinner, 1974). The level and distribution of amino acids is a good measure of growth potential in the water and of interacting systems that may affect water quality. Fatty acids, active precursor compounds in the natural environment, are eventually changed to hydrocarbon material in protopetroleum source rocks. Since these acids occur in plants and are water soluble, their presence and levels can be studied, as can the hydrocarbon content, as a supplementary measure of geochemical diagenesis and environmental stress.

Within the Red Deer drainage basin are extensive areas of muskeg. This material has defied definition over the years although many attempts have been made to explain its existence, its constitution and its influences on man's activities. It is identified by a number of names--muskeg, bog, fen, swamp, marsh (Terasmae, 1973). More specifically it has been termed "organic terrain" by Radforth (1969), the outstanding expert on muskeg in Canada, who, when trying to define it, stated that

> "The range of meaning ascribed to it is so broad that the word has questionable value when used as a precise reference term. Primarily the idea of organic constitution is inferred. There is also the suggestion that a high precentage of water influences the character of the organic medium" (Radforth, 1952).

Organic deposits such as coals, lignite, oil and submerged peat beds are excluded (Radforth, 1952).

Muskeg areas cover at least 500,000 square miles in Canada--probably the largest occurrence in the world (Terasmae, 1973). In the Red Deer river drainage basin considerable areas of muskeg are observed. These areas are not extensive in that large units of muskeg exist in single occurrences--rather each area tends to cover not more than a single square mile; but the drainage basin contains a significant number of these muskeg occurrences and tributary rivers that flow through this type of area are characterized by highly colored water. In a recently published report on organic water quality in the Red Deer drainage basin, disturbingly low levels of dissolved oxygen were reported during the winter months in some of these streams (Baker et al., 1976). It was believed that these unacceptably low levels were directly due to the introduction from muskeg of organic matter with a high chemical oxygen demand.

The present study was undertaken to determine the occurrence and distribution of organic compounds in one of Canada's remaining pristine river systems and to examine the potential introduction of organic compounds into that river system by muskeg leaching.

METHODS

Water samples were obtained from the Red Deer river and the Medicine river. They were examined for the occurrence and levels of several parameters indicative of the organic constituency of the samples. Muskeg samples were dug from a typical muskeg-type terrain adjacent to the Medicine river. The grass growing on the organic layer was removed and a sample of the organic material was taken.

Although the thickness of the organic layer was not determined, it exceeded the sampling depth of about one foot. These samples were subjected to controlled leaching with reoxygenated double distilled water. As a reference to this leaching study, a sample of natural leachate in the immediate vicinity of the muskeg sampling location was obtained and subjected to the same analyses as both the river water samples and the experimentally obtained leachate.

River Samples

All samples were collected in glass containers and capped with aluminum foil-wrapped stoppers. The aluminum foil had been previously washed with double-distilled water. All sample containers were rinsed with the water to be sampled before collection of the sample.

Standard water quality analysis methods were followed for the measurement of dissolved oxygen, chemical oxygen demand, biochemical oxygen demand, phenols, and tannins and lignins (American Public Health Association, 1971). Analytical procedures for the determination of hydrocarbons, amino acids, fatty acids, and humic and fulvic acids, were adapted or developed from other studies (Baker et al., 1976).

Experimental Muskeg Leaching

Experimental leaching of the muskeg sample was conducted by mixing 10 kg of muskeg sample with 15 litres of reoxygenated double-distilled water. The mixture was stirred vigorously for five minutes, then allowed to stand for eight days in a closed glass container under purified nitrogen. At the end of the leaching period the leachate was separated from the leached muskeg sample by filtration through a #1 Whatman filter paper.

RESULTS AND DISCUSSION

Organic water quality data reported here for the Red Deer river and the Medicine river (Table 1) show median values obtained from a continuing study on the water quality of the Red Deer river over the past three years (Baker et al., 1976). Seasonal variations occurred in these levels and in some parameters the levels varied considerably. For example, though chemical oxygen demand varied from 0.3 to 72 mg/ℓ throughout the drainage basin in the three-year period, it has a median value of 10.5 in the Red Deer river and 33.2 mg/ℓ in the Medicine river. On the average, levels of organic constituents were higher in the Medicine river than in the Red Deer. This difference undoubtedly reflects the differing level of contact between indigenous vegetation and the river water in those two rivers. Dissolved oxygen in the Red Deer is higher than in the Medicine. It should be noted here that during the winter months under complete ice cover, Medicine river water had D.O. levels near 2.0 mg/ℓ whereas the Red Deer was characterized by levels near 8.0 mg/ℓ. This observation undoubtedly reflects the influence of organic substances present in the water. Chemical oxygen demand is three times as high in the Medicine river as in the Red Deer river; tannins and lignins are twice as high in the Medicine, amino acids four times as high, hydrocarbons three times as high, humic and

TABLE 1

LEVELS OF ORGANIC CONSTITUENTS IN RIVER WATERS

Parameter	Red Deer River	Medicine River
Dissolved oxygen, mg/ℓ	10.2	8.4
Chemical oxygen demand, mg/ℓ	10.5	33.2
Biochemical oxygen demand, mg/ℓ	2.2	2.2
Phenolics, mg/ℓ	0.005	0.005
Tannins and lignins, mg/ℓ	0.495	0.895
Amino acids, mg/ℓ	0.020	0.079
Fatty acids, mg/ℓ	0.009	0.006
Hydrocarbons, mg/ℓ	0.0001	0.0003
Humic acids, mg/ℓ	0.1	0.8
Fulvic acids, mg/ℓ	0.9	8.8

fulvic acids one order of magnitude higher. With the lower average flow of water in the Medicine river as compared with the Red Deer river (270 cfs and 1820 cfs respectively in 1974) these higher levels of organic compounds and the concomitant higher oxygen demand results in even poorer water quality in the Medicine river. Interestingly, the biochemical oxygen demand in both river waters is very nearly the same.

One possible source of organic compounds in the Medicine river may be the extensive muskeg occurrences in the Medicine river drainage basin. Both natural leachate and an experimental leachate were analyzed to determine whether organic compounds are leached from muskeg. The results of those tests are reported in Table 2. Both leachates contained organic compounds; in some cases levels were considerably higher than those observed in the river waters. Dissolved oxygen in the natural leachate was at an acceptable level, (8.3 mg/ℓ) whereas in the experimental leachate it was only 3.8 mg/ℓ--below the minimum acceptable level for water quality and representing a reduction of 4.9 mg/ℓ from the level in the original leaching water. The difference between the two leachates may partially be due to the fact that the natural leachate was in constant contact with the atmosphere, thereby permitting uptake of oxygen, whereas the simulated leachate was generated in a closed glass container under an atmosphere of purified nitrogen. Despite this difference, the experimental leachate picked up organic material in greater amounts than the natural leachate, though there was no difference in biochemical oxygen demand. This observation reflects a low transfer of microorganisms from the muskeg sample into the leaching water as compared with the presumably equilibrated system that the natural leachate represents. Chemical oxygen demand reached 85 mg/ℓ in the experimental leachate, whereas the natural leachate contained only 21 mg/ℓ (still a high average for pristine river waters). Tannins and lignins reached 3.1 mg/ℓ in the experimental leachate; the natural leachate contained 0.7 mg/ℓ. Phenolics were apparently not efficiently released to either the experimental leachate or the natural leachate. Amino acids in both leachates exceeded levels observed in both river waters studied.

The abundance of amino acids in waters has been used to monitor environmental stress (Hodgson et al., 1977). In the present study amino acids were measured in the Medicine river, the natural leachate and in the experimental leachate, and levels of the individual amino acids in each sample are reported in Table 3. Total amino acids in the Medicine river were 0.076 mg/ℓ, the natural leachate, 0.184 mg/ℓ and the experimental leachate, 0.333 mg/ℓ. From these data there appears to be sufficient amino acids in either leachate to account for any amino acids observed in the Medicine river. Clearly, levels of total amino acids are not, by themselves, adequate parameters for determining whether muskeg is a potential source of organic compounds.

Amino acids occur in the environment either as free amino acids or as polypeptide polymers (proteins) with repeating sequences of amino acids in extensive chains. In such form, the individual amino acids will survive environmental stresses much more capably than amino acids in the free amino acid state. If such a polypeptide

TABLE 2

ORGANIC CONSTITUENTS IN MUSKEG LEACHATES

	Natural Leachate	Experimental Leachate
Dissolved oxygen, mg/ℓ	8.3	3.8
Chemical oxygen demand, mg/ℓ	21	85
Biochemical oxygen demand, mg/ℓ	5.3	3.6
Tannins and lignins, mg/ℓ	0.67	3.1
Phenolics, mg/ℓ	0.001	0.004
Amino acids, mg/ℓ	0.18	0.33
Alkane hydrocarbons, mg/ℓ	not determined	0.007

TABLE 3

AMINO ACIDS IN MEDICINE RIVER, NATURAL LEACHATE AND EXPERIMENTAL LEACHATE, mg/ℓ

	Medicine River		Natural Leachate		Experimental Leachate	
	Free	Combined	Free	Combined	Free	Combined
Alanine	0.001	0.007	0.010	0.015	0.013	0.024
Valine	<0.001	0.001	0.006	0.005	0.002	0.007
Glycine	0.002	0.015	0.007	0.019	0.022	0.024
Isoleucine	<0.001	0.001	0.004	0.002	0.004	0.003
Leucine	<0.001	0.0C2	0.007	0.004	0.005	0.008
Proline	0.001	0.005	<0.001	0.012	nd	0.014
Threonine	0.001	0.005	0.004	0.008	0.003	0.008
Serine	0.001	0.004	0.012	0.010	0.003	0.002
Methionine	<0.001	0.001	nd	nd	nd	0.001
4-OH-Proline	<0.001	0.001	0.002	<0.001	0.002	0.002
Phenylalanine	<0.001	0.001	nd	nd	0.002	0.002
Aspartic acid	0.001	0.013	0.009	<0.001	0.015	0.005
Glutamic acid	<0.001	0.009	0.005	0.002	0.045	0.020
Tyrosine	<0.001	nd	0.004	0.016	0.075	0.021
Ornithine	0.001	<0.001	<0.001	0.020	<0.001	<0.001
Lysine	<0.001	0.001	0.001	<0.001	0.001	<0.001
Total	0.010	0.066	0.071	0.113	0.192	0.141

nd = not detected

survives as such from the biotic source to the stream water, it should still display the same relative abundance of individual amino acids when they are finally released by analytical (hydrochloric) acid hydrolysis. Accordingly, a single source of combined amino acids (peptides) would result in the same relative abundance of component acids in the surface waters of local streams. If, however, the relative abundance of one amino acid to another in the stream waters varies from the ratio observed in suspected source materials, this finding indicates more than one source of amino acids as observed in the stream waters. The ratios of one pair of amino acids were studied to test this hyopthesis and are reported for the relative amounts of serine and glycine in Table 4. In the combined form, the ratio of serine to glycine in the Medicine river waters is 0.27 whereas in natural leachate it is 0.53. If the natural leachate were the only source of amino acids these ratios would be identical. Since they are not, other sources of environmental stresses must contribute--either sources with a different serine to glycine ratio or environmental stresses that alter the ratio by selectively reducing the amount of serine observed in the combined amino acids. In the experimental leachate, the relative abundance between serine and glycine was only 0.09 indicating that the conditions under which the experimental leachings were conducted did not exactly duplicate natural leaching thus reflecting "environmental stress." This extra unnatural leaching can be considered as a stress that alters the levels of individual amino acids in such a manner that distortion of the original ratio occurs and an altered ratio is displayed. There is insufficient data available to assess which force operates to alter the ratio of these two amino acids in combined form as seen in the differences in the stream waters and in the natural leachate.

Amino acids also occur as free individual amino acids. In this form they are much more susceptible to outside stresses. Among the individual acids observed in studies of amino acids, a wide range of stabilities is observed among the acids. Some are quite stable, others less stable while others are very unstable. The amino acid data appear to indicate the nature of processes taking place in the surface waters. Simplistically, free amino acids are released when the polypeptides are hydrolyzed in the waters. The relative abundance of the released acids will then be the same as in the combined acids from which they were derived unless (a) the acids have different stabilities on release and are degraded at different rates, or (b) additional free acids arise through other processes. The data for a labile acid (serine) and a refractory acid (glycine) were compared, in the expectation that serine would be depleted relative to glycine. Table 4 shows that this indeed is true, with serine decreasing relative to glycine in the free acid form as observed in Medicine river waters when compared with the similar data for natural leachate (0.50 as compared with 1.70). Once again the occurrence of unnatural conditions was observed in the experimental leaching in which the ratio between serine and glycine was reduced from 1.70 to 0.14. This effect demands an explanation in terms of other processes or transformations apparently involving other sources than muskeg leachate in which the ratios of individual amino acids are different than those in the muskeg leachate, or processes occurring that either reduce the levels

TABLE 4

RATIOS BETWEEN INDIVIDUAL AMINO ACIDS IN MEDICINE RIVER WATER, NATURAL LEACHATE AND EXPERIMENTAL LEACHATE

	Serine/Glycine
Medicine River	
Free amino acids	0.50
Combined amino acids	0.27
Total amino acids	0.31
Natural Leachate	
Free amino acids	1.70
Combined amino acids	0.53
Total amino acids	0.85
Experimental Leachate	
Free amino acids	0.14
Combined amino acids	0.09
Total amino acids	0.11

of serine in the water system or generate glycine in the free amino acid form. A possible mechanism for this is the generation and release of free amino acids rich in glycine by contemporary organisms in the soil and surface waters. The data for serine and glycine in this regard are supported by corresponding data involving alanine, isoleucine, aspartic acid and glutamic acid.

SUMMARY AND CONCLUSIONS

Naturally occurring waters in direct contact with muskeg contain significantly greater amounts of organic substances than those waters not in contact. The amounts measured were capable of reducing water quality. Experimental leaching of muskeg samples taken from the Red Deer river drainage basin supported the thesis that the extra organic material is contributed by the muskeg. Dissolved oxygen levels in the muskeg leachates were below the acceptable minimum of 5 mg/ℓ for pure water. Levels of chemical oxygen demand observed in the leachates exceeded median levels in the Red Deer river basin up to eightfold (85 mg/ℓ as compared with 10 mg/ℓ). Tannins and lignins reached 3 mg/ℓ, whereas in the river water levels seldom exceeded 0.8 mg/ℓ. Biochemical oxygen demand in the leachates occurred at the maximum levels observed in the river waters. Phenolics were released to the leachates in quantities substantially lower than those seen in the rivers, which may only reflect an inadequate standard procedure for measuring phenolic compounds. Amino acids were readily leached from the muskeg samples, reaching levels more than an order of magnitude higher than those seen in Red Deer river waters (0.33 compared with 0.02 mg/ℓ). The ratio of free amino acids to combined amino acids in the river waters was 1:6, whereas in the leachates that ratio was close to 1:1. A preferential loss of the more unstable free amino acids may occur in transit from the muskeg to the river. A similar environmental stress effect was observed in the ratio between serine (an unstable amino acid) and glycine (a stable amino acid) in which the serine to glycine ratio of 1:1.7 in the natural leachate was altered to 1:0.5 in the river water.

Muskeg is probably a significant source of organic substances to waters of rivers or streams draining areas containing appreciable amounts of muskeg. The high oxygen demands of these substances represent a potential threat to the water quality of such river waters.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of the Inland Waters Directorate of Environment Canada and the Research Secretariat of Alberta Environment who provided funding for this project; and to Jenny Wong and Walter Binder for technical assistance.

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SOME PRELIMINARY WATER BALANCES OF MARMOT CREEK SUB-BASINS

by

D. Storr [1]

INTRODUCTION

Water balances of various complexity and for various time periods have been presented for Marmot Creek as a whole by Storr and Ferguson (1972), Storr and Golding (1973), Storr (1974a, 1974b) and Storr and den Hartog (1975). These whole basin balances describe the hydrologic regime but because of the smoothing effect of the larger area, sub-basin balances would be of greater value in assessing the effects of forest harvesting.

This study of the sub-basin balances therefore attempts to provide base-line relationships between precipitation, streamflow, evapotranspiration, and sub-surface storage changes against which the effect of the logging operations in the sub-basins can be judged. These balances also test the reliability of the component data on the smaller scale of the sub-basin, and the methods and principles used in the whole-basin studies.

Marmot Creek watershed has been described in detail in many references so this will not be repeated here. Stevenson (1974) concluded that the basin as a whole is relatively water-tight with little or no sub-surface inflow or outflow. He did not, however, rule out the possibility of sub-surface leakage between sub-basins.

Details of the hydrometeorologic and hydrometric instrumentation are found in the following sections on component analysis. The networks and sub-basin boundaries are shown in Figure 1.

HYDROLOGIC COMPONENT ANALYSIS

Precipitation

The accuracy of areal estimates of precipitation is dependent on two factors - the accuracy of the point measurements, and the representativeness of those points.

It is well recognized (Rodda, 1970) that almost all raingauges have a built-in undercatch factor which is proportional to the degree of turbulence the gauge causes in the wind flow. The standard MSC raingauge used at Marmot Creek is low and small in area compared to most

1 Consulting hydrometeorologist, RR2, Ganges, B.C. This study was performed under contract #OSZ-0484 with Atmospheric Environment Service.

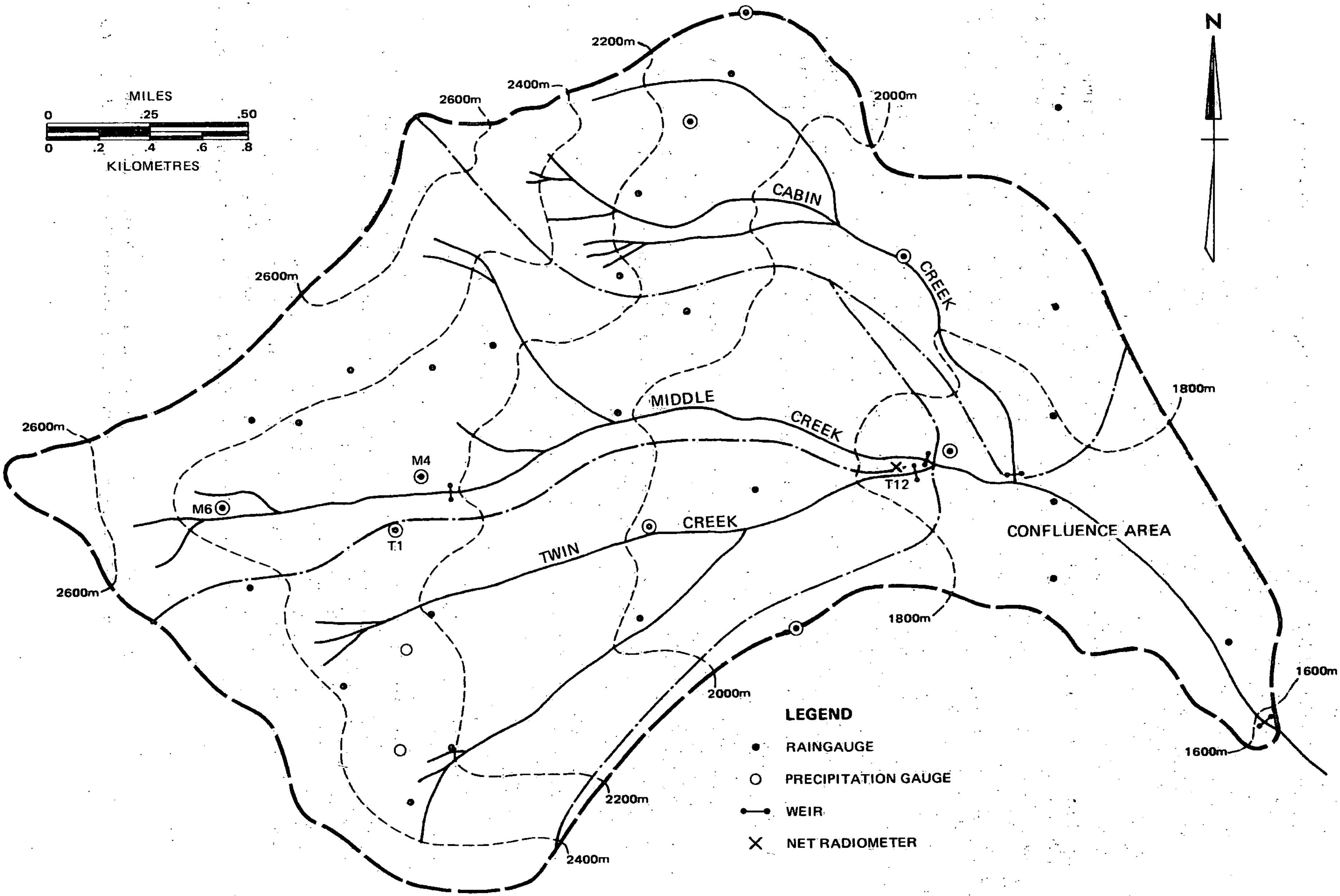

Fig. 1. MARMOT CREEK INSTRUMENTATION

gauges, so the obstruction to the wind and therefore the undercatch factor is also small. To reduce the wind factor further, the gauges are located in small clearings in the forest or in scrub vegetation in the alpine zone.

A dense network of 33 raingauges has been used in Marmot Creek, of which combinations of 13 provide sub-basin estimates for Cabin sub-basin, 16 for Middle sub-basin, and 12 for Twin sub-basin. It has been shown (Ferguson and Storr, 1974) that the percentage error in estimating areal rainfall increases with the deviation of the gauge-elevation curve (showing the percentage of gauges below indicated elevations) from the area-elevation curve. The curves of elevation vs area, raingauges and storage gauges for each sub-basin are shown in Figures 2, 3 and 4. Comparing the raingauge-elevation and area-elevation curves, it is noted that the deviations for both Cabin and Twin sub-basins are reasonably small although the Cabin raingauge curve terminates at 2255 m, leaving approximately 15% of the area ungauged. It can be seen from the slope of the area-elevation curve that this upper zone is very steep (like the similar zones in Middle and Twin) and no suitable gauging sites could be found. In Middle sub-basin, the deviation between the area-elevation and raingauge-elevation curves is rather large above 2285 m but is very small below that level so for the area as a whole the deviation is not extreme. With these dense networks of raingauges, areal estimates by either Thiessen polygons or the isohyetal method give very similar results and there is little room for error. Considering both the factors of point accuracy and representativeness, it is felt (rather subjectively) that the error in sub-basin estimates of rainfall is probably less than 7%.

For the measurement of annual precipitation, about 75% of which is snow, a network of 11 storage and recording gauges has been used at Marmot Creek with combinations of 4 of these used to give estimates of Cabin Creek precipitation, and 7 each for Middle and Twin sub-basins. The gauges are installed on open platforms with the gauge orifice at lease 90 cm above the deepest expected snowpack. This practice introduces an unavoidable and variable error. If the snowpack builds up close to orifice level, drifting snow will enter the gauge and be measured as snowfall. Just before the gauge is covered completely, the orifice is like a hole on a golf green, trapping every drifting particle and creating a large overcatch. When the gauge is covered, no snow can enter until the snowpack melts off with an unknown fraction dropping into the gauge. As will be discussed later, this happened on at least two occasions at Marmot Creek. The gauges were not installed on extremely high platforms to escape this problem because of the greater wind speeds at higher levels causing a general decrease in accuracy.

Now comparing the area-elevation and storage gauge-elevation curves in Figures 2, 3 and 4, it is seen that the deviations are much larger and so greater errors in sub-basin estimates would be expected. Because it is mainly the alpine areas which are undergauged (because of lack of suitably sheltered sites), the errors will be negative, i.e. the estimates will be lower than the true values. This factor, however, is offset by the tendency for more snow to fall in small clearings (because of the lower turbulence) than over the forest in general. The percentage error of the storage gauge data will therefore vary from year to year

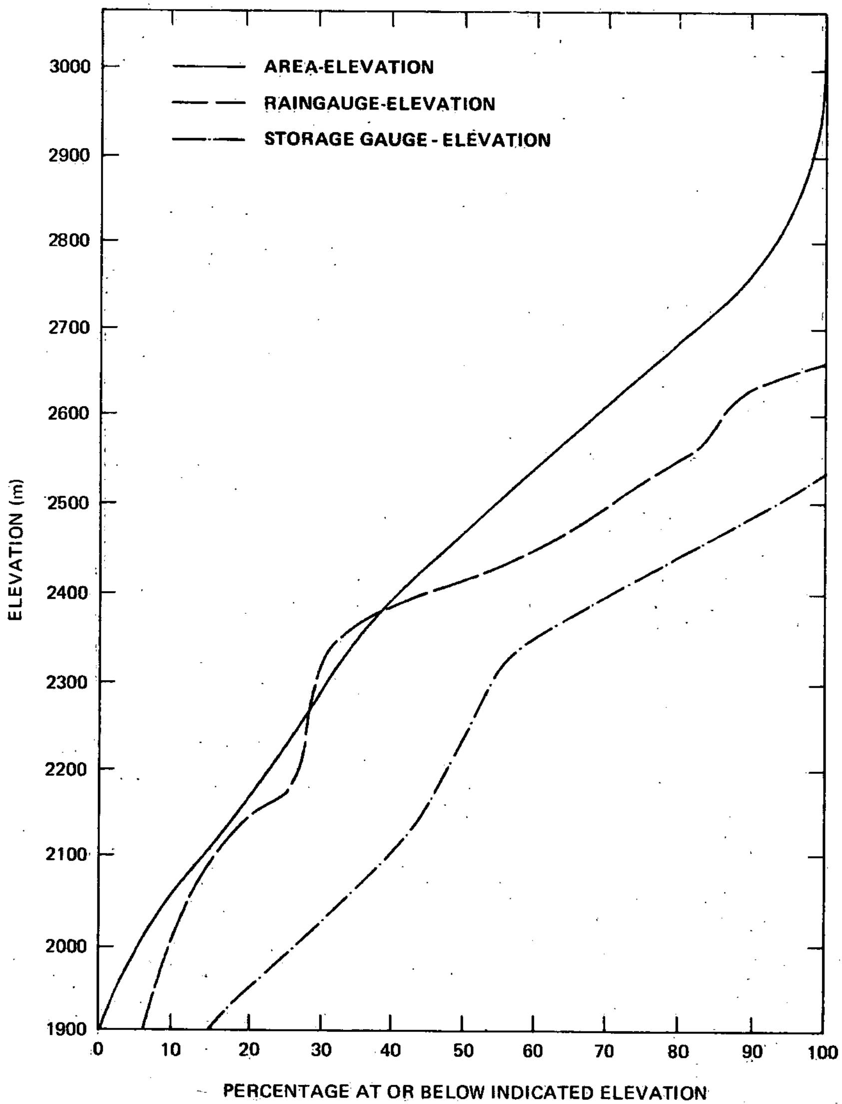

Fig. 2. AREA-ELEVATION AND PRECIPITATION GAUGE-ELEVATION CURVES FOR CABIN SUB-BASIN

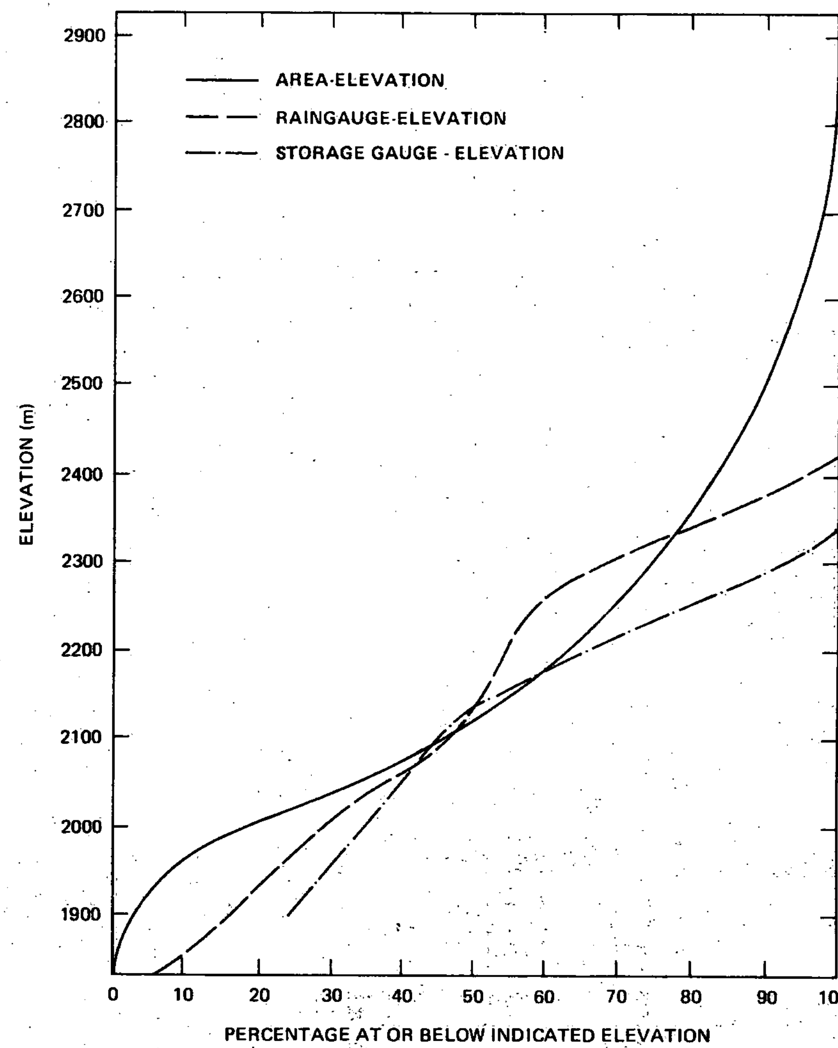

Fig. 3. AREA-ELEVATION AND PRECIPITATION GAUGE-ELEVATION CURVES FOR MIDDLE SUB-BASIN

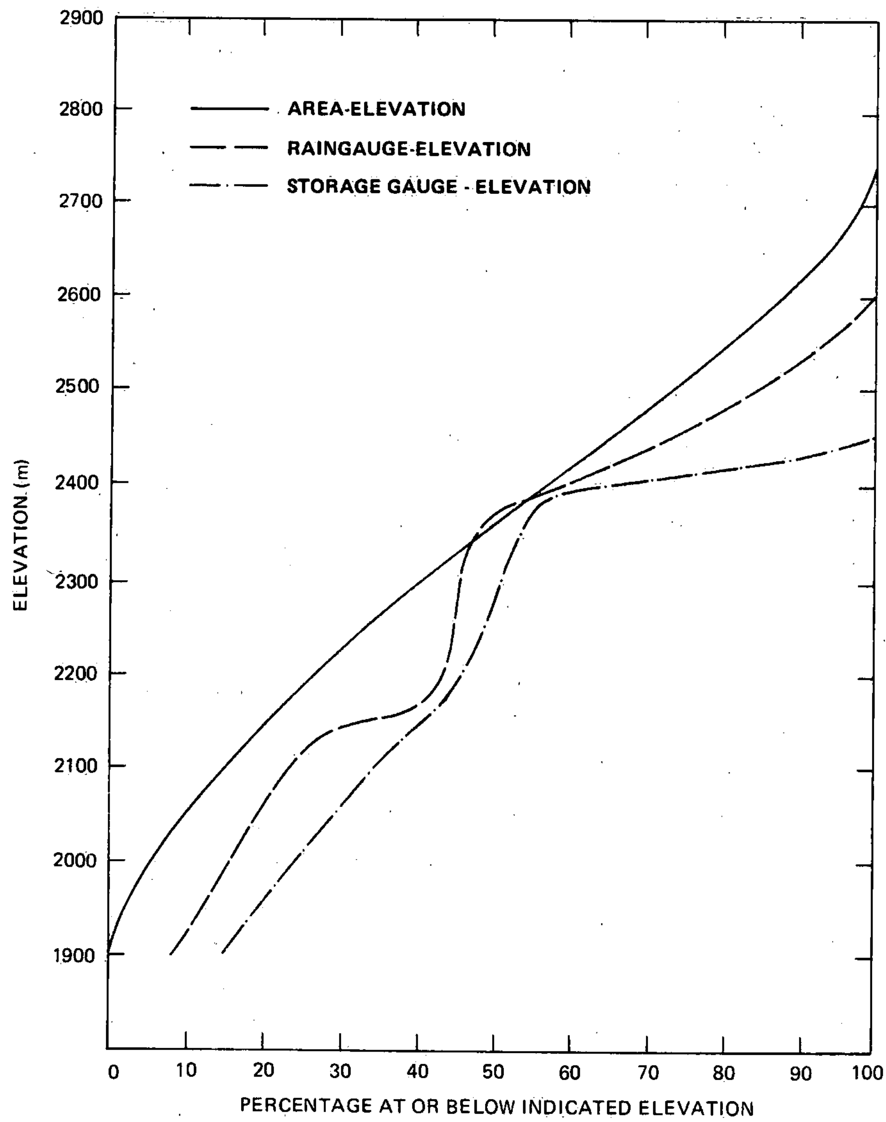

Fig. 4. AREA-ELEVATION AND PRECIPITATION GAUGE-ELEVATION CURVES FOR TWIN SUB-BASIN

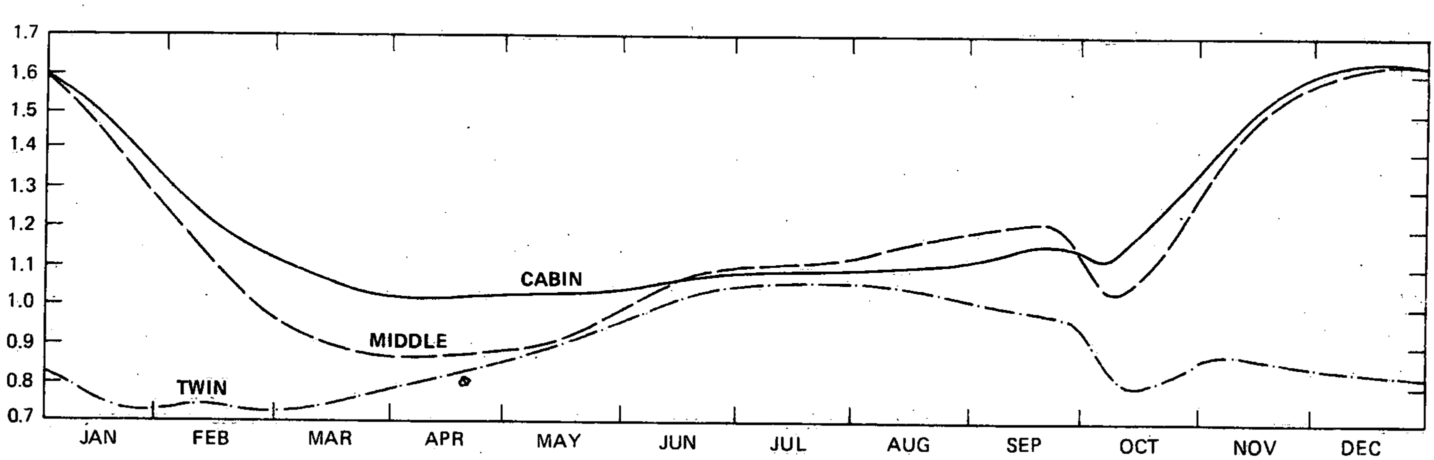

Fig. 5. FACTOR TO CONVERT MEASURED POSITIVE NET RADIATION AT THE TOWER TO SUB-BASIN AVERAGE OF EFFECTIVE POSITIVE NET RADIATION

with the amount of snowfall and with wind conditions during snowfall. This error is discussed further when the results of the sub-basin water balances are presented.

Because of the objectivity of the technique, all estimates of sub-basin precipitation in this study have been made by the Thiessen polygon method. The weighting factors for the various gauges are given in Table 1.

Table 1. Thiessen weighting factors (%) for Marmot Creek sub-basins.

Annual Precipitation

Cabin Sub-basin

Site	Factor
Cabin 5	7.23
Cabin 2	42.50
Cabin 9	33.09
Con 5	17.18

Middle Sub-basin

Site	Factor
Middle 4	37.00
Middle 6	28.84
Twin 1	3.72
Twin 11	14.35
Cabin 2	5.42
Cabin 9	5.93
Con 5	4.74

Twin Sub-basin

Site	Factor
Twin 1	6.12
Twin 2	28.51
Twin 3	32.28
Twin 9	1.01
Twin 11	28.39
Middle 4	1.80
Con 5	1.89

Summer Rainfall

Cabin Sub-basin

Site	Factor
Cabin 1	10.29
Cabin 2	11.97
Cabin 3	4.30
Cabin 4	18.80
Cabin 5	3.06
Cabin 7	0.88
Cabin 8	11.49
Cabin 9	22.31
Middle 2	4.44
Middle 3	0.27
Con 3	9.09
Con 4	0.44
Con 5	2.66

Middle Sub-basin

Site	Factor
Middle 1	8.13
Middle 2	8.60
Middle 3	12.68
Middle 4	6.31
Middle 5	5.90
Middle 6	14.10
Middle 7	5.26
Middle 8	11.13
Middle 9	6.41
Cabin 3	1.38
Cabin 4	1.52
Cabin 9	1.55
Twin 1	3.04
Twin 8	6.17
Twin 10	5.46
Con 5	2.36

Twin Sub-basin

Site	Factor
Twin 1	4.09
Twin 2	12.94
Twin 3	13.07
Twin 4	12.48
Twin 6	12.74
Twin 7	12.86
Twin 8	8.06
Twin 10	8.06
Middle 1	2.76
Middle 4	0.96
Twin 11	10.73
Con 5	1.25

It can be seen that erroneous data from one or even two sites will have little effect on the accuracy of the areal estimate of summer rainfall for any of the sub-basins, but poor data from Cabin 2, Middle 4 or 6, or Twin 3 would have very serious results on the accuracy of the estimate of annual precipitation. From a security viewpoint, a good case could be made for increasing the number of storage gauges in each sub-basin.

Streamflow

Streamflow was measured on Middle and Twin Creeks by identical concrete, 90-degrees, sharp-crested, V-notch weirs. Their capacity was increased in August 1971 from a head of 762 mm to 1067 mm after overtopping was suspected for a few days during the peak spring run-off of that year. The pools are log-lined with a concrete baffle at the upper end to spread the inflow and dissipate energy. Bentonite mud was mixed with backfill on the pool sides and bottom to prevent seepage. Heat lamps keep the notches ice-free in winter.

Because of the greater sediment load from Cabin Creek, its flow was measured by an H-type flume. Its capacity was increased from 762 to 1067 mm in May, 1970.

The three stream gauges have been rated both volumetrically and by current meter and conform closely to the theoretical rating. Streamflow data are considered to be the most accurate of the components of the water balance at Marmot Creek. The responsible hydrologists estimate maximum errors on an annual basis of approximately 3%.

Evapotranspiration

The energy budget method proved satisfactory in estimating evapotranspiration for Marmot Creek as a whole (Storr, 1974a), so it has been used again in this study of the sub-basin balances. In brief, this involved: (a) adjusting the measured net radiation at the 45 m tower in the lower part of Twin sub-basin for the average slope, aspect, and vegetative cover of each sub-basin to obtain averages of the available energy each month (Storr, 1972); (b) budgeting appropriate amounts for photosynthesis (Denmead, 1964), the energy flux into or out of the ground and forest (Baumgartner, 1956; Rauner, 1958), and that used to melt the snowpack; and (c) separating the remaining fluxes of latent and sensible heat by the use of the Bowen ratio.

The results of (a) are shown in Figure 5, the ratios between average effective positive net radiation in each sub-basin and the measured positive net radiation. It can be seen that for all months except July and August, the energy available for Cabin Creek is appreciably higher than that in Middle Creek, which in turn is markedly higher than Twin Creek. This is due to the progressively lower percentage of south-facing slopes in the three areas. The dip in each curve in late September or early October is due to the onset of permanent snowpack with its resulting higher albedo.

To obtain estimates of the negative portion of the daily net radiation cycle in each sub-basin, the Stefan-Boltzman law and the average air temperature in the sub-basins was used. The measured negative net radiation is representative of Cabin sub-basin throughout the year, and of Twin and Middle for all months except June, July and August when they are cooler than the air at the tower. For these months, the negative net radiation was estimated at 97% of that measured at the tower.

Applying the work of Denmead (1964), it was assumed that photosynthesis became significant in May as the snowpack melted, reached its peak in June and July and then tapered off. For each sub-basin it has been therefore estimated that photosynthesis utilized 2% of the positive net radiation in May, 3% in June and July, 2% in August and

0% in September. Ignoring photosynthesis would have caused very little effect on the estimation of evapotranspiration and the water balances, but it was included in this study in an attempt to account as much as possible for all the fluxes of energy.

The energy fluxes into or out of the ground (Q_G) and forest (Q_F) in the sub-basins has been estimated using the same pattern (Figure 6) as that for the whole of Marmot Creek (Storr, 1974a), which is similar to that found by Vowinkel and Orvig (1973) for a coniferous forest in Quebec. The annual cycle begins in May when heating of the forest and bare slopes more than counterbalances the loss from the soil through the snow, and reaches a maximum in July when all the snow is gone, the sun is high, and the soil on the alpine slopes is drying. The energy stored each summer is released the following winter, with maximum output in the fall when the temperature gradient between soil and air is greatest and before the snowpack reaches its critical insulating depth. A gradual decrease in output is then postulated through the winter and spring months.

Estimating the energy used for melting the snowfall (Q_M) also followed a similar reasoning to that used for Marmot Creek as a whole, but the pattern was adjusted for the different rates of melt in each sub-basin due to the differences in aspect and snowpack accumulation. This resulted in the following estimates for Q_M:

	March	April	May	June	July	August
Cabin sub-basin	0	3S	37S	37S	3S	0
Middle sub-basin	0	2S	40S	32S	6S	0
Twin sub-basin	0	1S	34S	40S	5S	0

where S is the winter's snowfall (cm water equivalent). The shape of the average hydrograph for each sub-basin was used as a guide for the above.

Estimating a mean monthly Bowen ratio (B) for each sub-basin was one of the mos t critical phases of the process for computing evapotranspiration. Because the water balances of Marmot Creek as a whole gave consistently good results (Storr, 1974b, Storr and den Hartog, 1975), the estimates of B for the whole basin were used as a guide for the estimates of B for the sub-basins, modified only where justified by the differences in snow melt rates and soil drying rates. The estimates of L (1+B) finally adopted for each sub-basin are presented in Figure 7.

This technique for estimating evapotranspiration was performed for each of the sub-basins for each month from August 1963 to December 1974. The 1975 data were not available at the time of development of the model so will be used later to test the results. An example of the evapotranspiration calculations can be seen in Table 1 of Storr (1974a).

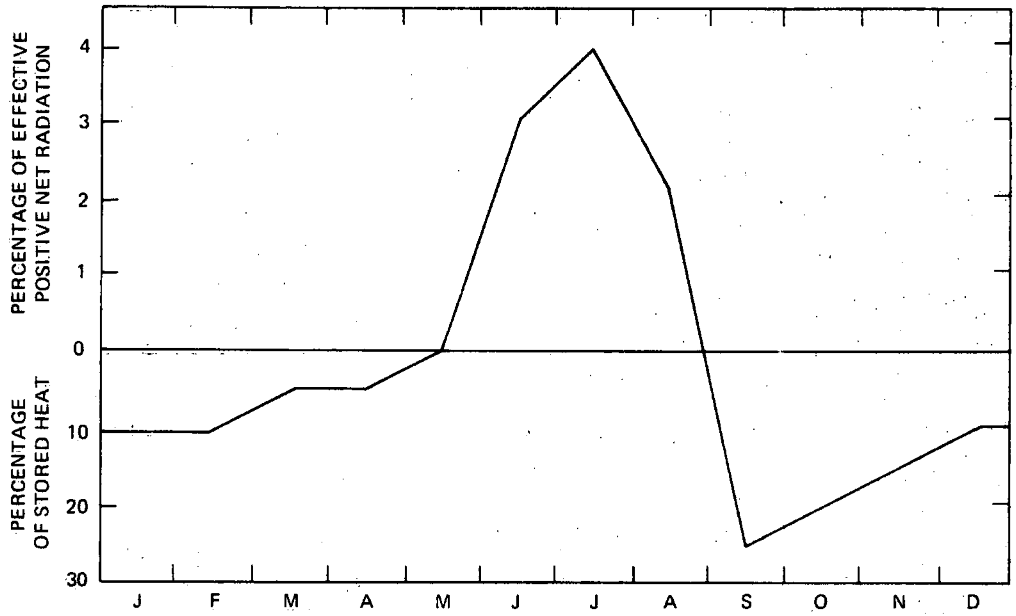

Fig. 6. ESTIMATED AVERAGE ANNUAL CYCLE OF $Q_G + Q_F$ AS PERCENTAGE OF EFFECTIVE POSITIVE NET RADIATION AND OF STORED HEAT

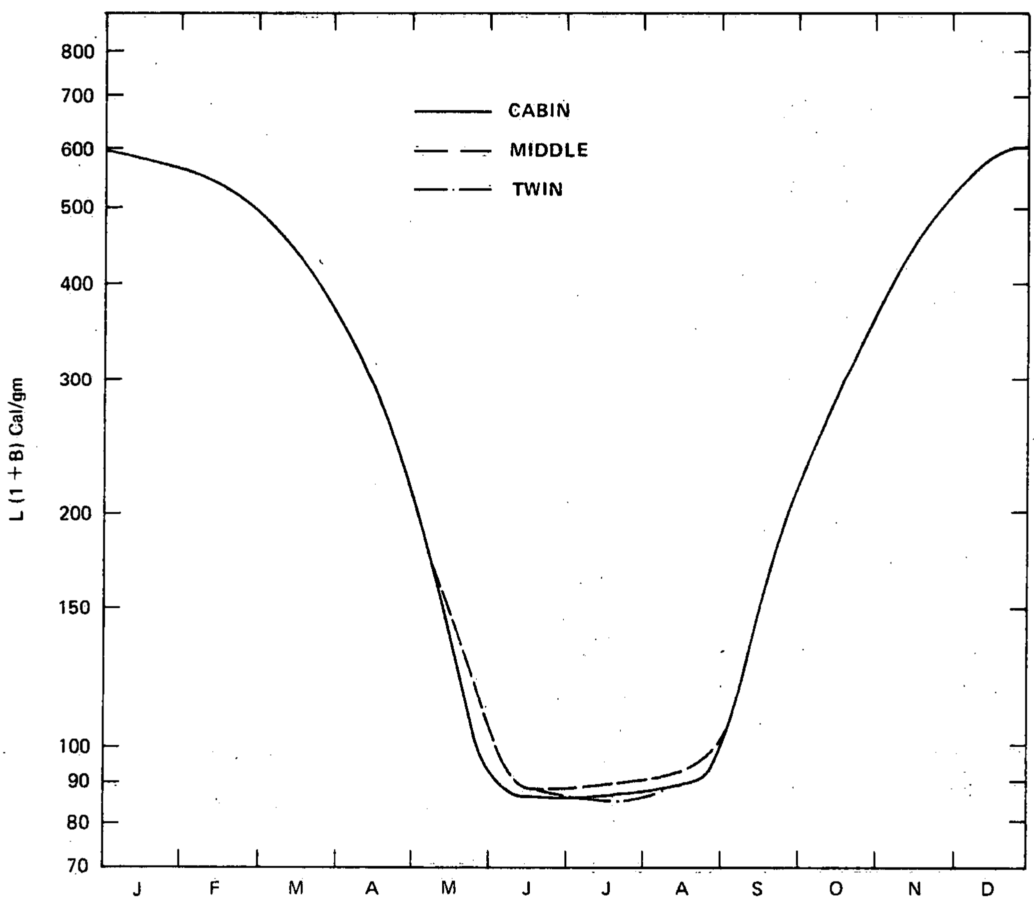

Fig. 7. ESTIMATED ANNUAL RADIATION OF MEAN MONTHLY L(1+B) FOR EACH SUB-BASIN

Change in Sub-Surface Storage (ΔW)

The process used to calculate the change in storage for Marmot Creek as a whole (Storr, 1974b) was repeated for each sub-basin. In brief, because there are no lakes or glaciers in the basin, for periods when there is no direct surface flow into the stream, the amount of flow ($\bar{N}$) is a direct function of the amount of water in the sub-surface reservoir, so the change in storage (ΔW) is a direct function of the change in streamflow (ΔN). Because the sub-surface reservoir is not a rectilinear box, ΔW is also a function of streamflow itself. For Marmot Creek as a whole, the relationship between ΔW, ΔN, and $\bar{N}$ was developed from 68 recession periods over nine years when firm data on streamflow and rainfall were available, snowmelt was finished, and evapotranspiration could be calculated from net radiation with the least risk of error. ΔW was then obtained as a residual for each period.

This process was repeated for the sub-basins, using 28 periods for Cabin, and 27 for Middle and Twin. The following relationships were derived by computer processing by Mr. B. Goodison of AES, Downsview:

Cabin sub-basin: $\ln(\Delta W/\Delta N) = 4.8085 - 1.2644\,(\ln \bar{N}),\ r^2 = 0.986$

Middle sub-basin: $\ln(\Delta W/\Delta N) = 4.777 - 1.1419\,(\ln \bar{N}),\ r^2 = 0.968$

Twin sub-basin: $\ln(\Delta W/\Delta N) = 5.0438 - 1.1380\,(\ln \bar{N}).\ r^2 = 0.960$

The relationships between ΔW, ΔN, and $\bar{N}$ for each sub-basin differ slightly because of the differences in the geomorphic characteristics of the sub-basins.

RESULTS

Four-variable water balances, derived by the methods described, for 11 water-years, 11 July's and 11 August's (1964-74 inclusive) for the three sub-basins are presented in Tables 2, 3 and 4.

Table 2a

Annual Water Balances for Cabin Sub-Basin (mm)

Water-year	Precip-itation	Stream-flow	Evapotrans-piration	Storage Change	Net Error
15.10.63-30.9.64	897	404	448	+78	-33
30.9.64-2.10.65	972	465*	504	+119	-116
2.10.65-3.10.66	745	376	449	-172	+92
3.10.66-3.10.67	761	339	508	-27	-59
3.10.67-10.9.68	797	241	432	+101	+23
10.9.68-9.9.69	821	450	401	-39	+9
9.9.69-8.9.70	718	265	441	-36	+48
8.9,70-7.9.71	852	345	469	0	+38
7.9.71-5.9.72	955	374	450	+89	+42
5.9.72-6.9.73	809	332	429	-9	+57
6.9.73-30.8.74	900	401	465	+31	+3
Total:	9227	3992	4996	+135	+104
Mean	838.8	362.9	454.2		+9.4

* - Sept 1/64 - Apr 30/65 estimated by correlation with Middle weir.

Table 2b

July water balances for Cabin sub-basin (mm)

Year	Snowmelt	Rainfall	Streamflow	Evapotranspiration	Storage Change	Net Error
1964	28	50.3	58.1	130	-130	+20.2
1965	25	61.5	94.8	149	-130	-27.3
1966	21	65.9	52.7	122	-87	-0.8
1967	24	25.5	47.5	144	-146	+4.0
1968	21	73.0	47.1	137	-100	+9.9
1969	21	72.1	129.7	106	-128	-14.6
1970	16	44.2	50.0	119	-126	+17.2
1971	28	39.0	37.8	127	-126	+28.2
1972	28	91.4	62.9	121	-73	+8.5
1973	24	44.3	51.7	130	-124	+10.6
1974	28	31.1	63.3	136	-125	-15.2
Total:	264	598.3	695.6	1421	-1295	+40.7
Mean	24	54.4	63.2	129.2	-117.7	+3.7

Table 2c

August water balances for Cabin sub-basin (mm)

Year	Rainfall	Streamflow	Evapotranspiration	Storage Change	Net Error
1964	25.5	16.5	108	-95	-4.0
1965	130.4	45.3	117	-14	-17.9
1966	64.8	19.0	92	-80	+33.8
1967	53.3	15.7	115	-86	+8.6
1968	79.0	23.7	76	-60	+39.3
1969	21.7	23.0	104	-115	+9.7
1970	17.1	15.8	96	-106	+11.3
1971	22.9	14.3	105	-93	-3.4
1972	45.8	26.3	109	-120	+30.5
1973	46.5	17.4	86	-35	-21.9
1974	87.2	25.7	87	-46	+20.5
Total:	594.2	242.7	1095	-850	+106.5
Mean	54.0	22.1	99.5	-77.3	+9.7

Table 3a

Annual water balances for Middle sub-basin (mm)

Water-year	Precip-itation	Stream-flow	Evapotrans-piration	Storage change	Net error
15.10.63 - 30.9.64	1116	576	419	+150	-29
30.9.64 - 2.10.65	1106	650	489	+23	-56
2.10.65 - 3.10.66	896	558	426	-154	+66
3.10.66 - 3.10.67	863	517	487	-39	-102
3.10.67 - 10.9.68	906	458	400	+144	-96
10.9.68 - 9.9.69	897	595	388	-123	+37
9.9.69 - 8.9.70	817	388	420	-6	+15
8.9.70 - 7.9.71	996	493	451	+3	+49
7.9.71 - 5.9.72	1076	553	411	+61	+51
5.9.72 - 4.9.73	922	481	405	+60	-24
4.9.73 - 30.8.74	1008	544*	443	-9	+30
Total:	10603	5813	4739	+111	-59.0
Mean	963.9	528.5	430.8		-5.4

* - April and May 1974 largely estimated from spot measurements

Table 3b

July water balances for Middle sub-basin (mm)

Year	Snowmelt	Rainfall	Streamflow	Evapotrans-piration	Storage change	Net Error
1964	74	69.4	120.7	127	-134	+29.7
65	53	94.0	164.4	149	-118	-48.4
66	50	78.5	98.5	120	-105	+15.0
67	57	37.6	110.3	142	-125	-32.7
68	51	80.4	109.2	136	-71	-42.8
69	48	86.9	154.0	105	-135	+13.9
70	37	55.8	63.9	118	-128	+38.9
71	68	41.1	78.2	124	-91	-2.1
72	72	98.3	117.2	118	-66	+1.1
73	57	48.2	86.2	128	-129	+20.0
74	64	36.5	105.1	133	-112	+25.6
Total:	631	726.7	1207.7	1400	-1217	-33.0
Mean	57.4	66.1	109.8	127.3	-110.6	-3.0

Table 3c

August water balances for Middle sub-basin (mm)

Year	Rainfall	Streamflow	Evapotrans-piration	Storage change	Net error
1964	36.2	21.8	114	-96	-3.6
65	139.6	63.7	123	-39	-8.1
66	75.6	33.9	97	-24	-31.3
67	53.8	29.8	121	-115	+18.0
68	99.8	50.7	80	-43	+12.1
69	24.5	24.3	109	-106	-2.8
70	20.0	17.7	102	-97	-2.7
71	21.8	23.8	110	-118	+6.0
72	48.9	44.9	115	-131	+20.0
73	42.9	24.1	91	-68	-4.2
74	97.0	40.8	91	-56	+21.2
Total:	660.1	375.5	1153	-893	+24.6
Mean	60.0	34.1	104.8	-81.2	+2.2

Table 4a

Annual water balances for Twin sub-basin (mm)

Water-year		Precip-itation	Stream-flow	Evapotrans-piration	Storage change	Net error
15.10.63	- 30.9.64	1183	634	393	+155	+1
30.9.64	- 2.10.65	1145	695	444	-15	+21
2.10.65	- 3.10.66	974	652	385	-135	+72
3.10.66	- 3.10.67	1127*	594	423	-49	+159
3.10.67	- 10.9.68	939	510	365	+170	-106
10.9.68	- 9.9.69	926	682	349	-125	+20
9.9.69	- 8.9.70	796	431	378	-23	+10
8.9.70	- 7.9.71	1029	596	377	+9	+47
7.9.71	- 5.9.72	1214*	667	375	+68	+104
5.9.72	- 4.9.73	927	538	377	+15	-3
4.9.73	- 30.8.74	1040	614	398	+53	-25
Total:		11300	6613	4264	+123	+300
Mean		1027.3	601.2	387.6		+27.3

* - gauges Twin 2 and Twin 3 suspect data due possible overtopping

Table 4b

July Water balances for Twin sub-basin (mm)

Year	Snowmelt	Rainfall	Streamflow	Evapotrans -piration	Storage change	Net error
1964	49	66.2	129.1	126	-174	+34.1
65	46	72.7	184.7	146	-161	-51.0
66	42	76.9	124.4	118	-156	+32.5
67	61	36.4	136.0	139	-179	+1.4
68	44	78.4	117.0	134	-118	-10.6
69	41	83.4	160.5	103	-179	+39.9
70	34	53.5	68.5	116	-162	+65.1
71	58	40.5	99.2	114	-131	+16.3
72	63	95.6	151.5	117	-120	+10.1
73	48	46.3	118.4	126	-171	+20.9
74	55	34.7	142.5	131	-166	-17.8
Total:	541	684.6	1431.7	1370	-1717	+140.9
Mean	49.2	62.2	130.2	124.5	-156.1	+12.8

Table 4c

August water balances for Twin sub-basin (mm)

Year	Rainfall	Streamflow	Evapotrans -piration	Storage change	Net error
1964	36.7	27.6	102	-95	+2.1
65	120.1	75.4	111	-57	-9.3
66	76.2	35.9	87	-36	-10.7
67	52.7	32.5	108	-125	+37.2
68	87.7	47.1	72	-68	+36.6
69	24.5	33.2	98	-109	+3.3
70	19.1	23.2	91	-109	+13.9
71	22.6	30.2	98	-138	+32.4
72	47.1	50.7	103	-152	+45.4
73	46.7	31.7	81	-90	+24.0
74	99.6	50.9	81	-36	+3.7
Total:	633.0	438.4	1032	-1015	+178.6
Mean	57.5	39.9	93.8	-92.3	+16.2

DISCUSSION

Unlike the balances for the whole of Marmot Creek (Storr and den Hartog,1975), in which the errors were almost equally divided between positive and negative and largely self-cancelling, indicating a water-tight basin and no obvious bias in the estimates of the components, the errors in the balances of Twin and Cabin sub-basins are consistently positive while the balances of Middle are close to neutral but have a slight tendency towards negative errors.

A biased sampling of precipitation favoring areas of heavy precipitation in Twin and Cabin and slightly low precipitation areas in Middle would be one possible cause of these biases, but as discussed in the precipitation section of component analysis, there is little room for this. Similarly, an under-estimate of evapotranspiration in Twin and Cabin and an over-estimate in Middle would produce the same result, but the estimates for all three sub-basins are based on the common measurement of net radiation at the Twin 12 tower and use a similar process to estimate evapotranspiration, so this is unlikely. Leakage under the weir on Twin Creek and the H-flume on Cabin would account for the same excesses in the balances for these creeks but is difficult to prove or disprove. Another possibility is sub-surface flow out of Twin and Cabin sub-basins. Because Middle has a slight negative bias, this might imply that some of the leakage from Twin and Cabin went into Middle, but because of the amounts, most of the excesses must go into the confluence area. It would then be measured as it passed over the main stream weir. All four possible causes may contribute to the biases in varying degrees at various times, but it would appear that sub-surface leakage is the major factor.

Contrary to the statement (Storr, 1974a) that the snow storage problem is eliminated by the choice of the water-year periods, the interpretation of the data for some of the water-years before 1968 is made difficult by this factor. This is because any snow which may have fallen in September was measured and included as part of one year's precipitation, but melted and was measured as streamflow in the following year. It is impossible to quantify how much of this occurred in any one year, but the heavy snowfall of September, 1965 is one known case affecting the second and third water-years in Tables 2a, 3a, and 4a. In the annual balances of Cabin and Middle sub-basins, it is reflected in large negative errors in 1964-5, and large positive errors in 1965-6. The problem was finally overcome by advancing the water-year end (as recorded by the reading dates of the storage gauges) to early September.

To illustrate the improvement resulting from this change, the mean absolute error in Cabin annual balances dropped from 65 mm for the 6 water-years before 1968 to 33 mm for the next six water-years. For Middle, the mean error dropped from 70 to 34, and for Twin from 72 to 35. The over-all net errors from this factor are of course self-cancelling, but studies of the errors in individual years should probably be confined to the years after 1968.

The mean absolute errors of the sub-basin water balances are compared with those of the whole basin in Table 5 with the error as a percentage of input in brackets.

Table 5

Mean absolute (mm) and percentage errors of the water balances

	July		August		Annual	
Cabin sub-basin	14.2	(7.2%)	18.3	(13.9%)	47.3	(5.6%)
Middle sub-basin	24.6	(10.5%)	11.8	(8.49%)	50.4	(5.2%)
Twin sub-basin	27.2	(10.2%)	19.9	(13.3%)	51.6	(5.0%)
Marmot basin			11.7	(10.0%)	14.1	(2.0%)

It can be seen that both the mean absolute error and the percentage errors for the sub-basins are 2 - 3 times the whole-basin errors for annual balances, but average only slightly larger in August. If sub-surface leakage is the major cause of the water balance errors, this suggests that the leakage is most serious during periods of high flow and relatively minor during the low flows and low storage levels of August.

The effect of aspect and topographic shading on streamflow/ precipitation ratios can be seen in Table 6.

Table 6

Average annual streamflow/precipitation ratios for Marmot Creek and sub-basins

Marmot Creek	Cabin Creek	Middle Creek	Twin Creek
0.503	0.433	0.548	0.585

For the whole basin, streamflow is about half of precipitation, i.e., streamflow and evapotranspiration are about equal, but this average hides a rather wide range within the basin. In Cabin Creek with its higher percentage of south-facing slopes, the N/P ratio drops to 0.433, while Twin with its large percentage of north-facing slopes has a ratio of 0.585. This illustrates one important factor in land management for water production: shading, either natural or man-made, will reduce evapotranspiration and increase water production.

TEST OF MODEL ON 1975 DATA

As stated earlier, the 1975 data were not available when the balance models were developed, so are used here as a test of its applicability. The methods described in the "Components Analysis" section were therefore applied to the 1975 data with the following provisos.

Because of a reduction in AES staff in 1975, the raingauge network was reduced from 33 to 24 gauges. This would cause only a slight decrease in the accuracy of the estimate of basin mean rainfall (Ferguson and Storr, 1974), but its effect on sub-basin averages has not been calculated. The precipitation at formerly measured sites was therefore estimated from inter-gauge relationships.

The streamflow data were missing for Twin Creek for the months of March,April and May, and for Middle Creek for February, March and April. Correlations between monthly discharges from these creeks and the main weir were very poor, so the missing data were approximated from the scatter diagrams. It is fortunate that with the exception of May, these months have very low flows, so the error introduced by the estimates is probably less than 2% of the true annual discharge.

The estimated effective net radiation on Cabin was not adjusted for the effect of the 1974 logging as this would require adjusting the weighted mean albedo of the area. The albedo of the logged areas is higher than that of the forest which was removed, so the net radiation and the evapotranspiration should be less than before logging. Also, changes in the snowmelt pattern would have a slight effect on the evapotranspiration estimate but were not considered at this time. These changes will show indirectly in the water balances.

The water balances for the 1974-5 water-year and for July and August 1975 are presented in Table 7 for the three sub-basins.

Table 7

Sub-basin balances (mm) for 1974-5 water-year and July and August 1975.

	Precip-itation	Stream flow	Evapotran-spiration	Storage change	Net error	% error	11 year mean error %
Cabin							
1974-5	740	265	360	+37	+78	10.5	5.6
July 1975	90.4	49.1	97	-68	+12.3	7.7	7.2
August 1975	87.1	28.2	66	-46	+38.9	29.0	13.9
Middle							
1974-5	864	417	341	+56	+50	5.8	5.2
July 1975	104.4	94.5	95	-76	-9.1	5.0	10.5
August 1975	101.2	49.0	69	+6	-22.8	21.3	8.4
Twin sub-basin							
1974-5	881	475	307	+52	+47	5.3	5.0
July 1975	100.9	123.9	93	-111	-4.4	2.0	10.2
August 1975	90.2	51.1	62	-8	-14.9	15.2	13.3

Comparing the percentage error for 1975 with the mean percentage error for the previous 11 years, it can be seen that Cabin sub-basin error is close to the 11 year average for July, but is almost double the average error for the annual and August balances. Because the annual error is positive, this suggests that evapotranspiration has been reduced approximately 20 - 35 mm/year by the logging.

A similar comparison for Middle and Twin sub-basins shows the percentage error is close to the 11 year average for all 6 periods with the exception of the August balance for Middle and it is well within the range of errors in the previous years. The negative errors in Twin sub-basin in July and August do not fit the 11 year pattern: was a leaking weir repaired? Was it a random fluke or was the attempt to estimate the missing rainfall data inaccurate? Both possibilities are now being studied.

CONCLUSIONS

Models have been developed for calculating the water balance components of each sub-basin.

Sub-surface leakage is suspected as the most probable cause of the consistent positive errors in the Cabin and Twin sub-basin balances. The errors are greatest and the leakage most serious in times of high streamflow.

The test of the model with the 1975 data illustrates the ability of the process to detect and quantify the effect of a change in land management on water production.

The importance of complete data from all the hydrologic components is emphasized.

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ESTIMATION OF AVERAGE ANNUAL PRECIPITATION IN THE MOUNTAIN PARKS

by

B. Janz [1]

Hydrologists and climatologists familiar with the watersheds of western Alberta realize that the precipitation patterns in the Rocky Mountains are quite complex. This complexity and the paucity of data in mountainous areas have been a major deterrent to a clear understanding of the precipitation regimes in these areas.

A comprehensive analysis of annual precipitation in the mountain areas has been attempted by Janz and Storr (1977). The approach taken in arriving at this analysis and its limitations are reviewed in this paper.

PRECIPITATION PRODUCING MECHANISMS

A brief review of the precipitation mechanisms operative in the parks may be helpful in better understanding the precipitation patterns found in the mountains.

Reinelt (1970) suggests that it is an article of meteorological faith that the production of significant amounts of precipitation requires the presence of moist rising air. This statement identifies the two essential components necessary for precipitation: a moisture supply and a lifting mechanism.

Large-Scale Weather Systems (Fig. 1A)

Both the moisture supply and lifting mechanism have their origin outside the parks and are not related to topography. Such systems are related to the seasonal storm tracks. The moisture source may be an ocean many kilometres distant from the parks, and the lifting of the air is caused primarily by dynamic conditions within the atmosphere. General rains or widespread snowstorms affecting the parks are associated with such systems. However, although the main lifting mechanism is independent of topography, the distribution of precipitation in the mountains can be strongly influenced by topography. Examples of such systems are upper air troughs, frontal lows, warm and cold fronts, and cold lows.

Orographic Precipitation (Figs. 1B and 1C)

The moisture supply has its origin well outside the parks area but the mountains provide the lifting mechanism. The classic concept of moist westerly winds being robbed of their moisture when they encounter the

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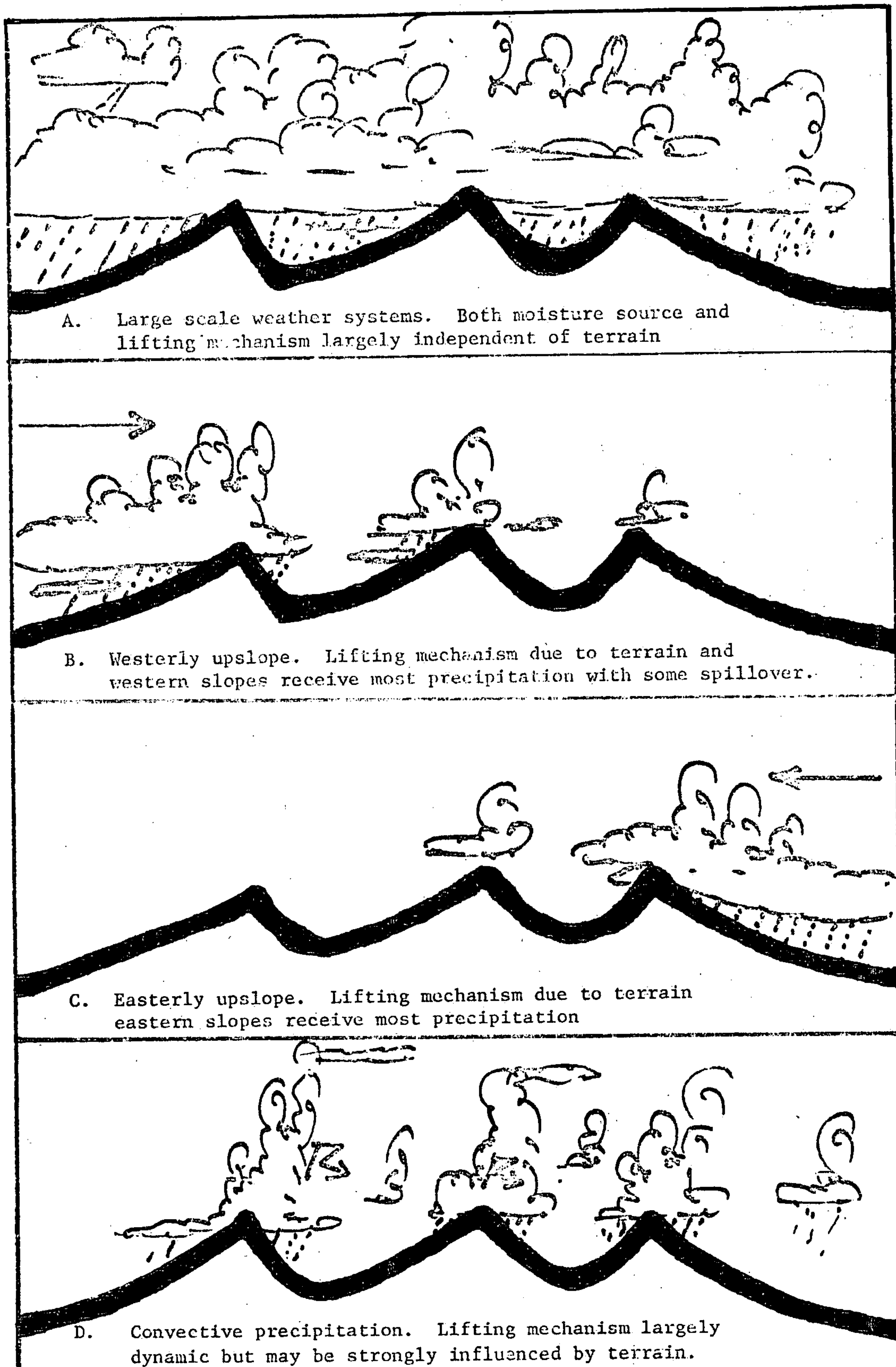

Figure 1. Illustrations of precipitation producing mechanisms

western slopes of mountains is generally familiar. However, easterly winds bearing moisture from Hudson Bay or the southern United States undergo the same treatment when they reach the foothills and mountains of western Alberta. In such cases most of the moisture is deposited along the eastern slopes of the mountains, but often some rain or snow spreads into Banff and Jasper parks. The early autumn or late spring storms which deposit extensive snow along the foot-hills but seem to miss the parks are essentially associated with easterly upslope.

Convective Precipitation (Fig. 1D)

Many thunderstorms in the parks have their origins outside the park borders. However, topography may make a major contribution to the lifting mechanism required to realize the instability. The mountain ranges also channel the individual storm cells.

PRECIPITATION VARIATIONS WITH ELEVATION

The principle that (other factors being equal) precipitation increases with increasing elevation is generally accepted, and it has been suspected for some time that it also holds true for the Rocky Mountain areas.

Banff and Jasper parks and the adjacent areas to the east have a number of storage gauges located at elevations ranging from under 1200 to over 2700 m (Fig. 2 and 3). However, a major problem is that some of the gauges, especially those within the parks, have been in operation only a few years. Thus, the records are of varying duration ranging from only 3 years to about 20. Also, it is unlikely that the exposures at the different sites are comparable. One would expect the best results from a network of stations having comparable exposures and a common period of record. However, this is not available at this time and an analysis to identify general principles was attempted.

The average annual precipitation based on the period of record from about 30 storage gauges was plotted against elevation (Fig. 4). A glance at the plot leaves little doubt that precipitation increases with elevation. The question is whether a quantitative relationship can be developed. When the data are sorted out two facts emerge: there is a set of stations that are dry, (e.g. Willow Creek, Topaz Lake, Kootenay Plains etc.,) and there is another set that appears to be excessively wet (e.g. the Marmot Creek stations, Miette, Smokey River etc.). This leaves a fair number in-between (e.g. Sunwapta, Temple, Howse River Cabin etc.). The data from the first (dry) and last (in-between) were analyzed to obtain approximate regression equations. The respective equations, obtained by the method of least squares, are shown in Fig. 4. Data from the Marmot Creek stations, Amethyst, Fatigue Pass, Waterfowl, Smokey River, and Miette were not included in the analysis for these regressions.

The dry stations (i.e. below the dashed line) have the following parameters in common:

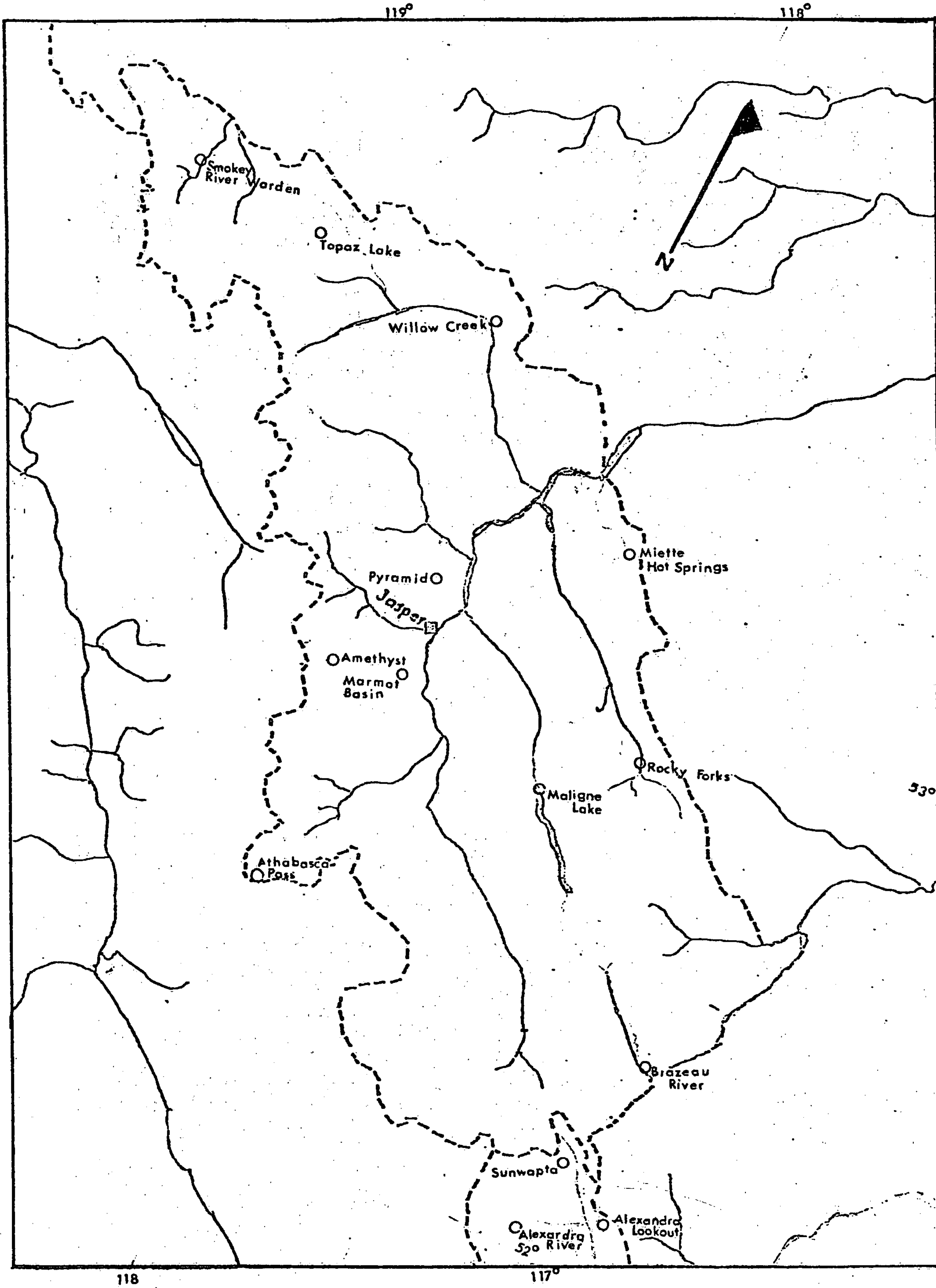

Figure 2. Location map -- storage gauges (Sacramento) in Jasper National Park

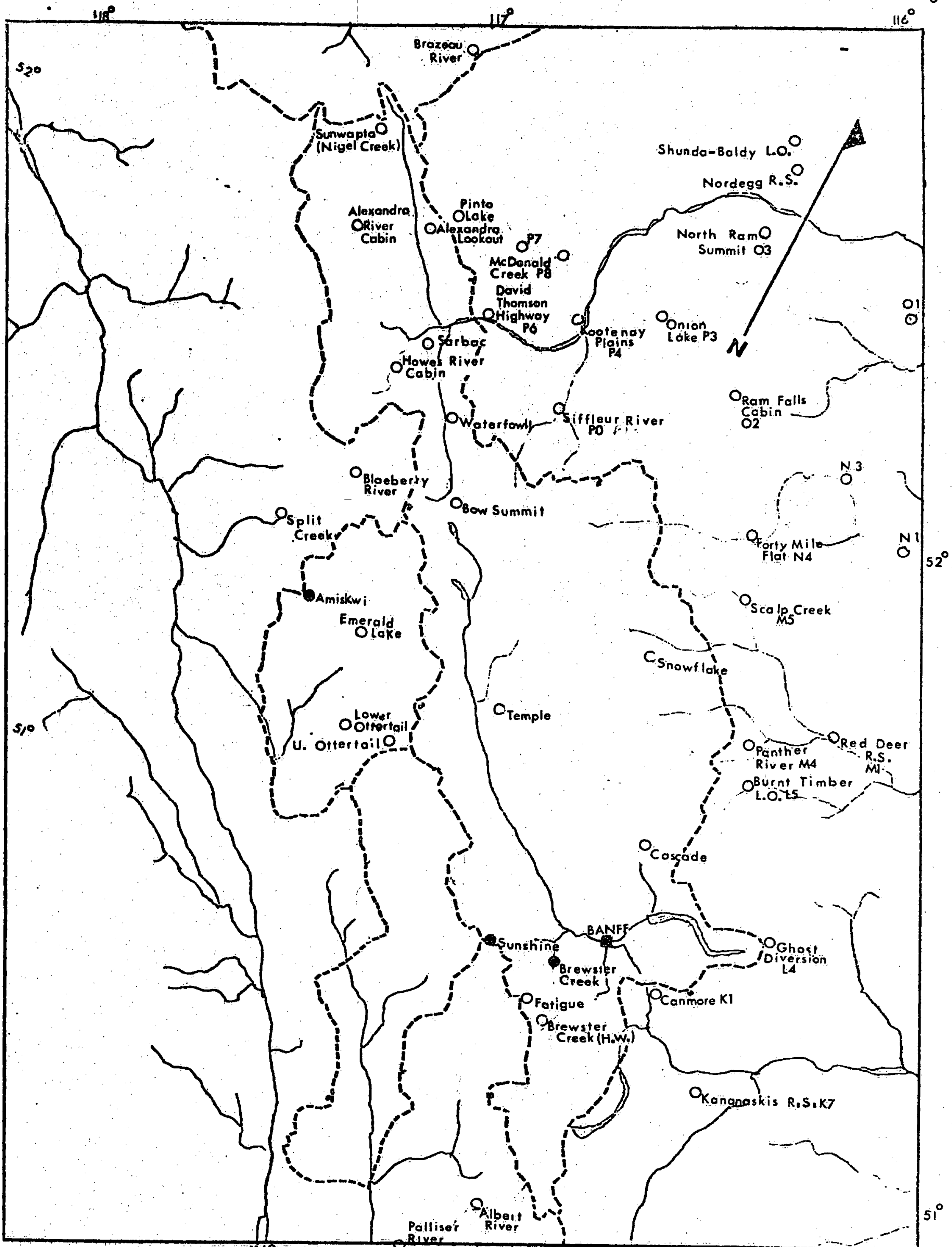

Figure 3. Location map -- storage gauges (Sacramento ○ and Fischer-Porter ●) in Banff and Yoho National Parks

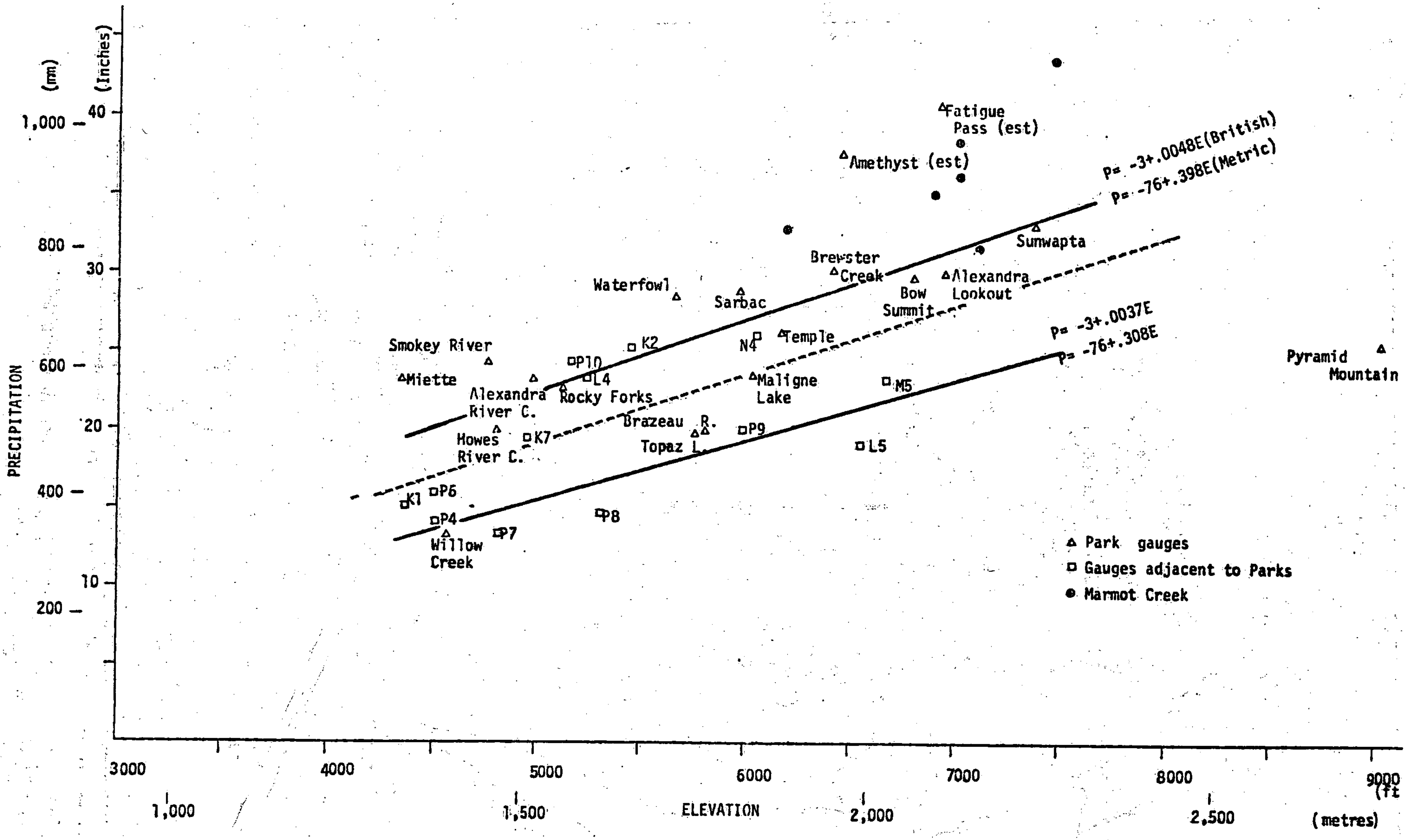

Figure 4. Average annual precipitation - elevation relationship for storage gauges in and adjacent to Banff and Jasper National Parks

(1) They are situated in fairly flat valleys with barriers to both east and west. In other words, they are protected from both easterly and westerly upslope conditions.

(2) Most of them are in the first or second valley inside the eastern boundary of the parks. Those outside the parks, such as Kootenay Plains and McDonald Creek, are well inside the easternmost range of mountains.

The middle category of stations does not have an area grouping such as the first. However, the following observations were made:

(1) They are situated in the first valley east of the continental divide, or

(2) they are located east of the park and are subject to easterly upslope conditions.

The third category (i.e. the very wet) was not analyzed, partly because data had to be estimated or only limited data were available. Storr and Ferguson (1972) analyzed Marmot Creek data with several more stations than shown and arrived at the following regression:

$P = -415.9 + .636E$ where P is the average annual precipitation in millimetres and E is elevation in metres.

AVERAGE ANNUAL PRECIPITATION MAP

The precipitation-elevation relationships described provided the basic tool for the preparation of a map depicting average annual precipitation in the mountain parks. All available precipitation data from storage gauges, recording gauges, and climatic stations were incorporated. Adjustments were made to allow for known precipitation anomalies, and where possible, aspect was taken into account. The Warden Service and the Inland Water Directorate offered suggestions and comments which resulted in modifications of certain areas. Amounts at the higher summits were qualitatively estimated. Since few quantitative precipitation data are available from elevations above about 2,300 m, a great deal of personal judgement was involved in estimating values at higher elevations. It has been shown in previous paragraphs that precipitation increases with elevation. However, it is known that at some elevations above the level of quantitative observations the trend reverses. In other words, at some high elevations precipitation decreases with increasing elevation. This level has not been determined for the Rocky Mountains, although a few ideas have been advanced.

Several things should be remembered in connection with the map:

(1) The map is a first approximation of the distribution of average annual precipitation in the parks.

(2) One of its most useful features is that it delineates the dry and wet areas of the parks.

(3) The parks have essentially a continental climate. Hence departures from average precipitation as shown on the map may be up to 50% higher or lower than the values shown in certain years.

(4) No adjustment was made for systematic gauge undercatch or overcatch. The question is probably academic as other errors probably outweigh these.

CONCLUSIONS

The average annual precipitation regime in the mountain parks can be estimated using storage gauge data to establish a precipitation - elevation relationship. This relationship can then be applied in the preparation of a map of average annual precipitation. Although this may be a crude approach the quantitative values are useful in portraying the relative orders of magnitude of total precipitation within the different areas of the parks.

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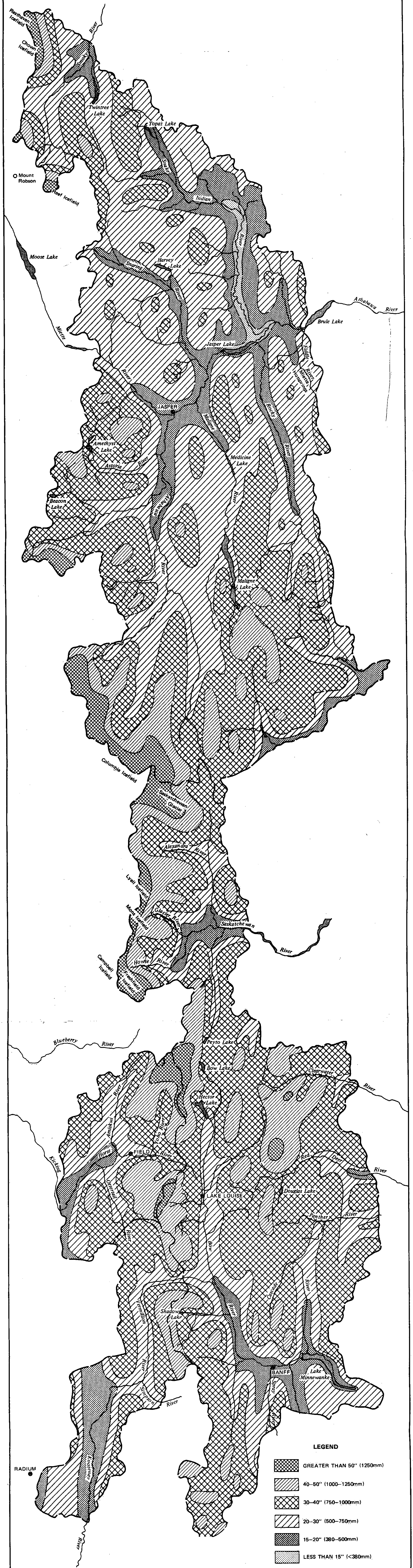

AVERAGE ANNUAL PRECIPITATION

PRECIPITATION CLIMATOLOGY OF THE EASTERN SLOPES AREA OF ALBERTA

by

J.M. Powell

ABSTRACT

The precipitation climatology of the mountains and foothills of west and southwestern Alberta is discussed using all available published precipitation data for the area, including that from storage gauges. Maps are presented of average annual, winter (October-April), and summer (May-September) precipitation for the area. Other aspects of the precipitation climatology are described, including months of greatest and least precipitation, rainfall and snowfall amounts and percentage occurring as rain, number of days with measurable precipitation, greatest amount of precipitation in a 24-hour period, the role of orography, and frequency of convective precipitation as expressed by thunderstorm days. Finally, suggestions are made for improving or augmenting the precipitation data base.

PRECIPITATION CLIMATOLOGY OF THE EASTERN SLOPES AREA OF ALBERTA

by

J.M. Powell[1]

In an address to the Canadian Association of Geographers at Regina on "Precipitation mapping in the Prairies", Arleigh Laycock (1977) stressed the growing user demand for better precipitation maps. These maps should recognize topographic effects and include precipitation data from a large number of sources, not just those using data from official meteorological stations, which tends to be the case for many maps published by the Atmospheric Environment Service. In his presentation he listed the many potenial sources of precipitation data. In this paper I have attempted to bring together most of the published climatological records to produce preliminary precipitation maps for the Eastern Slopes. However, I have not used the hydrological data available, or those to be found in unpublished theses. Maps are presented of the average annual, winter (October-April), and summer (May-September) precipitation for the area. Information is also given to describe other aspects of the precipitation climatology, such as periods of greatest and least precipitation, percentage occurring as rain or snow, number of days with measurable precipitation, greatest amount of precipitation in a 24-hour period, and frequency of thunderstorm days.

EARLIER PRECIPITATION MAPS OF THE EASTERN SLOPES

Many maps have been published showing the annual precipitation of Alberta including the Eastern Slopes. Most of these maps have been based only on the long-term records of climatological stations published by the Atmospheric Environment Service or its predecessor. Examples of such maps are those to be found in the various Atlases of Canada (Canada Department of Mines and Technical Surveys 1957; Canada Department of Energy, Mines and Resources 1973), Atlas of Alberta (Government of Alberta and University of Alberta 1969) or papers by McKay (1961a), Longley (1972), and others. Several of these maps are based on only a sparse number of stations, sometimes only on the first order meteorological stations, and often no attempt is made to cover the mountainous terrain of the Eastern Slopes (Government of Alberta and University of Alberta 1969; McKay 1961a). Even the recent map by Longley (1972) gives only spot totals for selected sites within the mountain area, with no attempt to give isohyetal patterns (Fig. 1). The lack of coverage for the Rocky Mountains is due to the paucity of stations; for example, only Banff, Jasper, and Lake Louise are long-term stations, which are also only in valley bottom situations and therefore not representative of the mountain topography. Drawing of large-scale isohyetal maps can only be schematic because of the great natural variation of topography

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Fig. 1. Mean annual precipitation (inches) for Alberta based on data for 1941-1970 period (after Longley 1972).

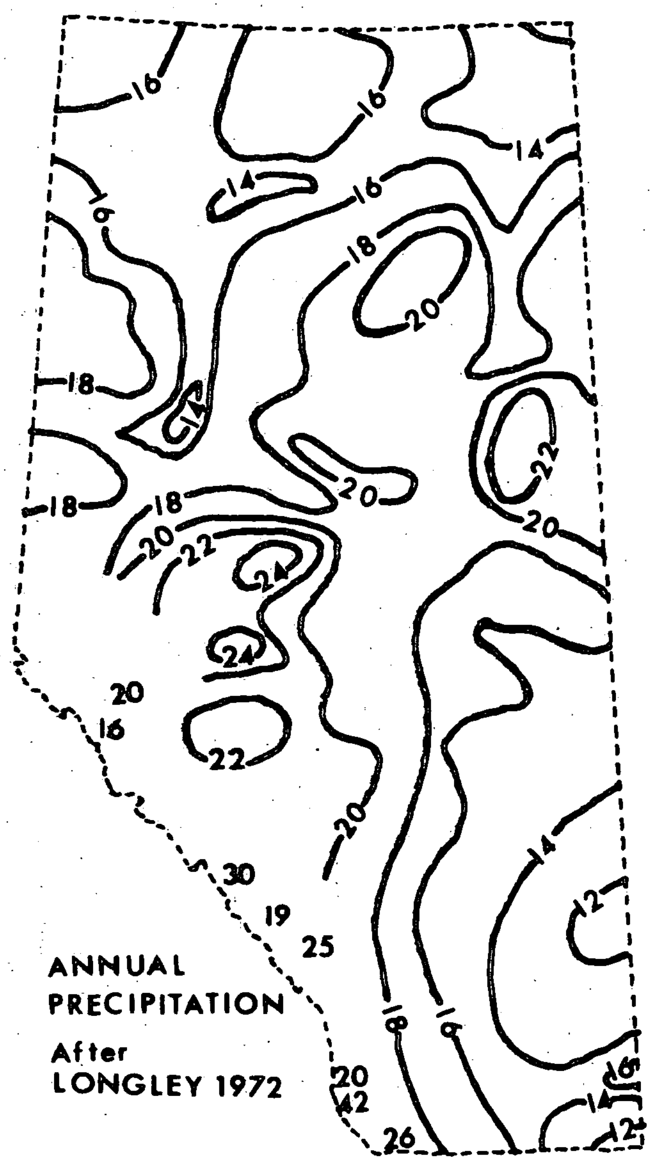
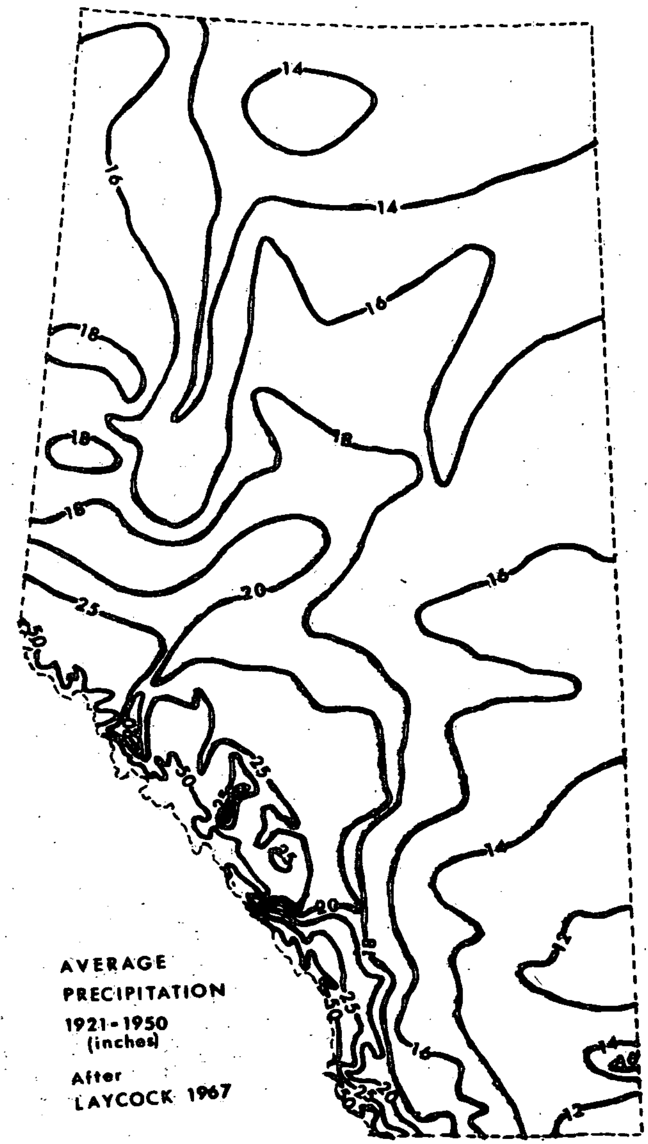


Fig. 2. Average annual precipitation (inches) for Alberta based on data for the 1921-1950 period with allowance for topographic variations (after Laycock 1967).



and precipitation. A few authors have attempted to give isohyets for the mountainous area. Laycock (1967) made allowance for topographic variations in his map based on all available precipitation data for the 1921-1950 period (Fig. 2). Muttitt (1961), in his discussion of spring and summer rainfall patterns in Alberta, used 1955-1960 data from 34 forestry stations to augment the records from the regular climatological stations and showed that certain areas received much heavier precipitation than had been shown previously. Powell and MacIver (1976) published a map of summer precipitation for the Hinton-Edson portion of the Eastern Slopes based on 1961-1970 data from 21 stations. A first estimation of average annual precipitation for Banff and Jasper National Parks was provided today by Janz (1977) and recorded earlier in a report (Janz and Storr 1977).

In addition to the increased employment of forestry fire-weather stations in Alberta as regular summer climatological stations, the establishment of Sacramento-type storage gauges in the Eastern Rockies Forest Conservation Board (ERFCB) area was a big step forward in learning more about the seasonal and annual totals of precipitation in the Eastern Slopes area. The first of these gauges was installed in the fall of 1952; in 1963 a total of 98 were in use (Poliquin and Hanson 1973). Two reports by the ERFCB summarizing the precipitation data from this area have been published (Poliquin 1968; Poliquin and Hanson 1973); one, covering the period 1952 to 1957, assigns each station to one of four regions, as suggested by McKay (1961b), and the other covers the period 1952 to October 1972, giving for several stations averages for 20 years of data. This latter publication gives maps in considerable detail for the mean winter (October 15-May 14) and summer (May 15-October 14) precipitation as well as annual precipitation for the area of the Eastern Slopes south of the Brazeau River. Ferguson and Storr (1969) used data from the ERFCB storage gauge network to produce a map of average annual precipitation over southwestern Alberta, which indicated an area of high precipitation (over 1650 mm) in the western portion of Waterton Lakes National Park. Earlier, Curry and Mann (1965) used precipitation-elevation relationships to prepare preliminary isohyetal maps for much of the ERFCB Reserve area south of the Bow River based on a decade of storage gauge data and compared their results against annual streamflow records.

SOME FEATURES OF THE PRECIPITATION CLIMATOLOGY

Orography

It has often been stated that Alberta lies in the rain shadow of the Rockies (Kendrew 1938; Muttitt 1961), the implication being that, but for the Rockies, the province would have a much wetter climate. Reinelt (1968, 1970) has indicated that "actually, it would be better to say that Alberta is in the rain-shadow of the Coast Range, and that the Rockies increase rather than decrease Alberta's share of precipitation.... In winter, Alberta is in the precipitation shadow of the Rocky Mountains, but in the warmer months there is no evident effect. The eastern slopes of the Rockies provide orographic lift for air masses with north-easterly circulation components" (Reinelt 1970). This effect is most important during

May and June close to the mountains. Reinelt estimates that the orographic component is conservatively estimated to be of the order of 37% of the total precipitation in the mountainous regions, and not less than 13% of the total for the entire province.

Topography has long been recognized to play a role in influencing the distribution of precipitation; examples from our area have been given by Ferguson and Storr (1969), Storr and Ferguson (1972), Storr and Golding (1976), Storr (1967a), Reinelt (1968), and Poliquin and Hanson (1973). Storr and Ferguson (1972), in their study of the Marmot Creek basin, showed an annual variation of precipitation from less than 600 mm to 1184 mm with an elevational change of only 800 m. Poliquin and Hanson (1973), using some of the same stations in the Kananaskis Valley, showed a mean annual increase of 198 mm per 304.8 m, with similar increases elsewhere, although east of the front range and north and south of the Crowsnest Pass increases of only 76-114 mm per 304.8 m were calculated. Janz (1976) also points out the role that location and topography play when moist air flows upward over rising terrain in comparing the major effects that could be expected at Waterton Park and Lake Louise. In the Waterton Lakes area there is a lack of "protective" ranges or foothills, which permits greater easterly upslope lift over short distances, resulting in very heavy snow and rainstorms, especially in early autumn and late spring. This area has recorded the highest average annual snowfall (572.5 cm, Environment Canada 1975) of any Canadian station east of the Rocky Mountains (with exception of Cape Dyer, NWT) and the highest 24-hour snowfall (87.4 cm.) between the Rocky Mountains and the Niagara Peninsula of Ontario (Janz 1976, Reinelt 1968). The highest annual rainfall in the Prairie Provinces has also been recorded in this area (561 mm). Pollock (1975) has provided an index for the heavy rainfalls (generally over 100 mm) that have occurred in the area. A rainfall of 251 mm occurred at Waterton Lakes River Cabin in two days in June 1964 (see Janz 1976). Storms of over 200 mm have also been recorded at Cardston (1908), Campsie (1957), Pekisko (1969), and Nose Mountain Lookout (1972).

Convective Precipitation

Convective precipitation contributes considerably to summer precipitation. In Alberta there appear to be preferred areas for storm development and therefore areas with a higher frequency of thunderstorms. Kendall and Petrie (1962), in their study of thunderstorm days, employed data from 12 stations in the study area. Calgary, Claresholm, Edmonton, Penhold, and Rocky Mountain House all had frequencies above 20 days a year, whereas Banff, Beaverlodge, and Jasper had a frequency of <10 days a year. The highest frequency occurred in July at nine of the stations. They also noted that there are probably more thunderstorms at higher elevations in the mountains than represented by the lower elevation stations such as Banff and Jasper. Lawford (1970) studied 19,000 storm reports from the Alberta Forest Service stations and synoptic stations in the area from 1962 to 1968. He gives such data as mean time of occurrence, duration, probability by months, and the frequency of storm approach angles. McLean (1968) gives thunderstorm occurrence maps, based on Alberta Forest Service data, for 2-week periods and for the 6 months April 16 to October 15. The peak frequency (>35 days) in the 6-month period occurred in the area between the Smoky and Athabasca Rivers near Tony Lookout. Much of the northern foothills and Swan Hills area had frequencies above 20, as did the area in the Clearwater Rocky Forest west of Red Deer. Frequencies below 10 days a year occurred around Jasper and adjacent foothills. The area south of the Red Deer River in the foothills to the International border generally had 13-17 days of thunderstorms a year. Maps for 1972 and 1973 (Stashko n.d.) give number of days with lightning and show the highest incidence near Red Deer (>50), with other cells with 25 to 35 days in the Swan Hills, and the area east of Edson. The Rocky Mountains generally fall in a zone with <15 days a year, except 15-30 days occurred in the Crowsnest and Waterton Lakes area in 1972 and 25 days near Fort Macleod in 1973.

The Alberta hail studies are well known. Wojtiw (1975) has summarized the hailfall in central Alberta from 1957 to 1973. These studies just touch the Eastern Slopes in the area of Rocky Mountain House. Over the 17-year study period (15 May to 15 September) hail has been reported on 61.3 days per season, with the greatest number in 1957 (77 days) and the smallest in 1961 (37 days). About 50% of the hail occurs in July, when the probability of a hailstorm is at a maximum. Many of these hailstorms originate along the Eastern Slopes, and Wojtiw indicated two pockets of high hail frequency, one just east of Rocky Mountain House, the other near Sundre. There was also a marked reduction in the hail frequency from west to east across his study area.

METHODS AND MATERIALS

For the present study the Eastern Slopes is taken to include that area considered by the Alberta Environment Conservation Authority (1972) in its "Public Hearings into Land Use and Resource Development in the Eastern Slopes" and the adjacent parts of the Rocky Mountains found in the national parks. For the plotting of precipitation patterns stations in the plains to the east and north of the Eastern Slopes area were included to more accurately place the isohyets.

The official method of measuring precipitation in Canada has changed little since 1878. Rainfall is caught in a gauge with an orifice area of 64.5 cm^2 and a capacity of 115 mm, standing 30.5 cm above ground level and measured in a graduated cylinder. Until 1961 it was standard procedure at all stations to take daily depth measurements of freshly fallen snow with a ruler, assuming a density of 0.1 to convert to water equivalent values. Since 1961 Nipher-shielded snow gauges have been used at synoptic stations and a few other stations. The efficiency of the catch and the accuracy of the methods of measuring precipitation have often been questioned (e.g., Peck 1972; Potter 1965; Rodda 1971; Stashko 1976). Sacramento or similar storage gauges have also been employed, and these are generally considered to undercatch compared to the daily methods of measurements with the standard rain gauge (Poliquin and Hanson 1973; Curry and Mann 1965). There is usually a greater undercatch with an increased exposure to wind at higher altitudes. The Sacramento gauge has a capacity of 2540 mm, an orifice area of 324.5 cm^2, and is installed with the orifice at about 2.5 m above ground to avoid overtopping in areas of high snow accumulation. Other recording gauges include the Fischer and Porter, Leupold and Stevens, and the Universal Weighing type gauges. The ERFCB storage network employed a modification of the Sacramento gauge with an 20.32-cm orifice and a 254-cm capacity (Poliquin and Hanson 1973).

Precipitation data for the Eastern Slopes and adjacent areas in Alberta were taken from the Canadian Normals 1941-1970 (Environment Canada 1975). Stations included in earlier publications of precipitation normals but not in the most recent edition were also included (Canada Department of Transport 1967; Connor 1920). Records for a few stations were obtained from McKay et al. (1963). In addition precipitation totals were extracted from the publication "Supplementary Precipitation Data", volumes 1 to 8 (Canada Department of Transport 1969-), for all recording precipitation gauges and storage gauges in the area. The records were used if there were 3 or more years of data. The precipitation normals given by Poliquin and Hanson (1973) up to October 1972 for the storage gauges in the ERFCB Reserve area were added up to October 1976, and new normals calculated for each station. Also, values for the discontinued storage gauges listed in Table VII of McKay et al. (1963) were included to give a denser network of stations for some areas. Precipitation records for a few new climatological stations were extracted from the "Monthly Record" for the period 1966 to 1976 in order to provide more data in areas generally having sparse coverage. Summer precipitation values for several forestry stations not included in the Canadian Normals were also included from a study by Powell and MacIver (1976, 1977) covering the period 1961-1970.

In the estimation of seasonal averages for the climatological stations the summer period was considered to be May to September inclusive, and the winter period October to April. No adjustment was made for the storage gauges; their summer period of recording was generally from mid-May to mid-October, and the winter period mid-October to mid-May.

It is recognized that the records from the various stations employed in the study do not always have comparable data because of the different length of record or time period coverage. However, this is not considered to be critical, and no attempt was made to adjust the records for a uniform time period or possible undercatch in the case of the storage gauges. The maps are to be considered preliminary; it was thought better to use all readily available data and not take time for adjustment computations which may not have merit for such a study. Some of the values used are probably anomalous and will be corrected with a longer period of record; other anomalous values may result from exposure problems in remote areas which give unrepresentative catches and may warrant field checking.

RESULTS AND DISCUSSION

Annual Precipitation

The average annual precipitation in the Eastern Slopes area ranges from near 300 mm to over 1460 mm (Fig. 3). The lowest amount occurs in the Kootenay Plains area of the North Saskatchewan River where several storage gauges have an average of <400 mm. Other areas with <500 mm occur around Jasper, in the Banff-Canmore area, the upper Clearwater River, and in the area north of Cowley. Generally, most of the Foothills area from the Porcupine Hills north to the Smoky River receives between 500 and 700 mm. The highest precipitation zone (>1000 mm) occurs in the western portion of the Waterton Lakes National Park and the mountains west and south of Castle Ranger Station. Another zone with precipitation above 1000 mm occurs along the British Columbia-Alberta boundary north of Coleman. The limited amount of sampling along the Great Divide and adjacent mountains indicates that average annual precipitation ranges from 800 to 1000 mm; however, these totals are probably conservative. Near the upper levels of Marmot Creek basin, which is not on the Great Divide, the average annual precipitation is over 1000 mm, while in the valley to the east annual precipitation is in the 500 to 650 mm range. The map has not been drawn to allow for all the topographic variation in the mountains and foothills. If precipitation-elevation relationships and aspect had been considered a much finer pattern of isohyetal lines would have resulted.

Winter Precipitation

Average winter precipitation, October to April inclusive, is shown in Fig. 4. The station data base for this map was similar to that used for the annual precipitation map. Winter precipitation ranges from around 150 mm in the Lower Foothills to over 850 mm south of Castle Ranger Station. Most of the Upper Foothills zone receives between 200 and 300 mm. The same areas that receive the highest annual precipitation also receive the most winter precipitation. Similarly, Jasper, the Kootenay Plains-Nordegg, the upper Clearwater River, and Canmore areas in the mountains receive the lowest (<200 mm). In the south the stations in the Crownest Pass area receive more winter precipitation (>300 mm), although the Foothills north of Pincher Creek to the Porcupine Hills receive only between 200 and 250 mm.

Snowfall

The map of average snowfall is not completely comparable with that of winter precipitation because some heavy falls of snow can occur in September and May; in fact, several stations in the area have recorded snow also in the months of June, July, and August.

The map of average snowfall shows high water equivalent amounts in the Waterton Lakes area (over 500 mm) and at Lake Louise (482 mm). The zone receiving over 200 mm is restricted to a narrow band in and adjacent to the mountains from south of Jasper to Clearwater and Red Deer Ranger Stations, Banff, Cochrane (but not including Calgary), Turner Valley, Cowley to near Cardston. This may not be accurate in the northern area because of the paucity of stations regularly reporting snowfalls, although Grande Prairie

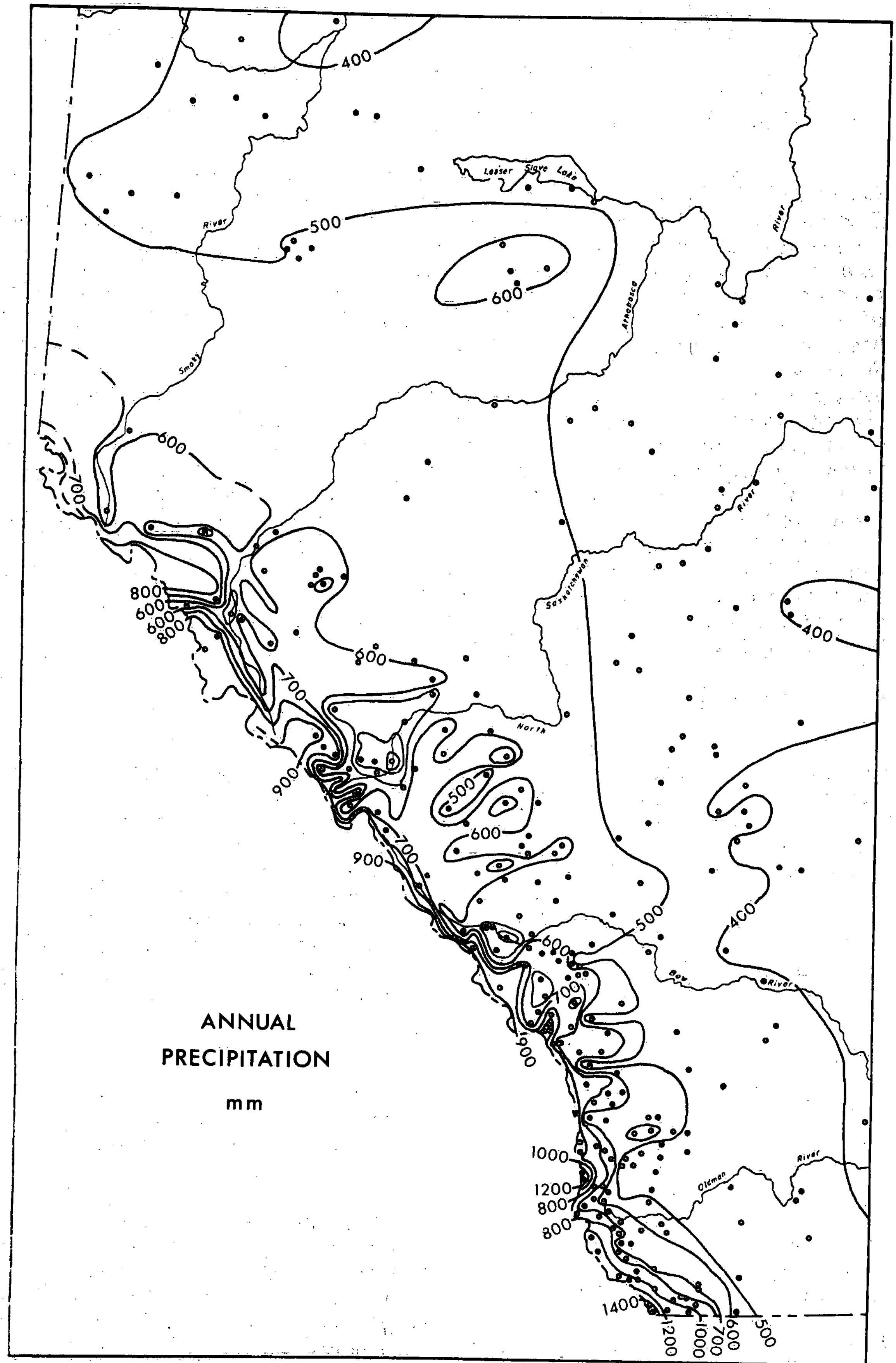


Fig. 3. Average annual precipitation (millimetres) for the Eastern Slopes and adjacent areas of Alberta based mainly on climatic normals and precipitation storage gauge data.

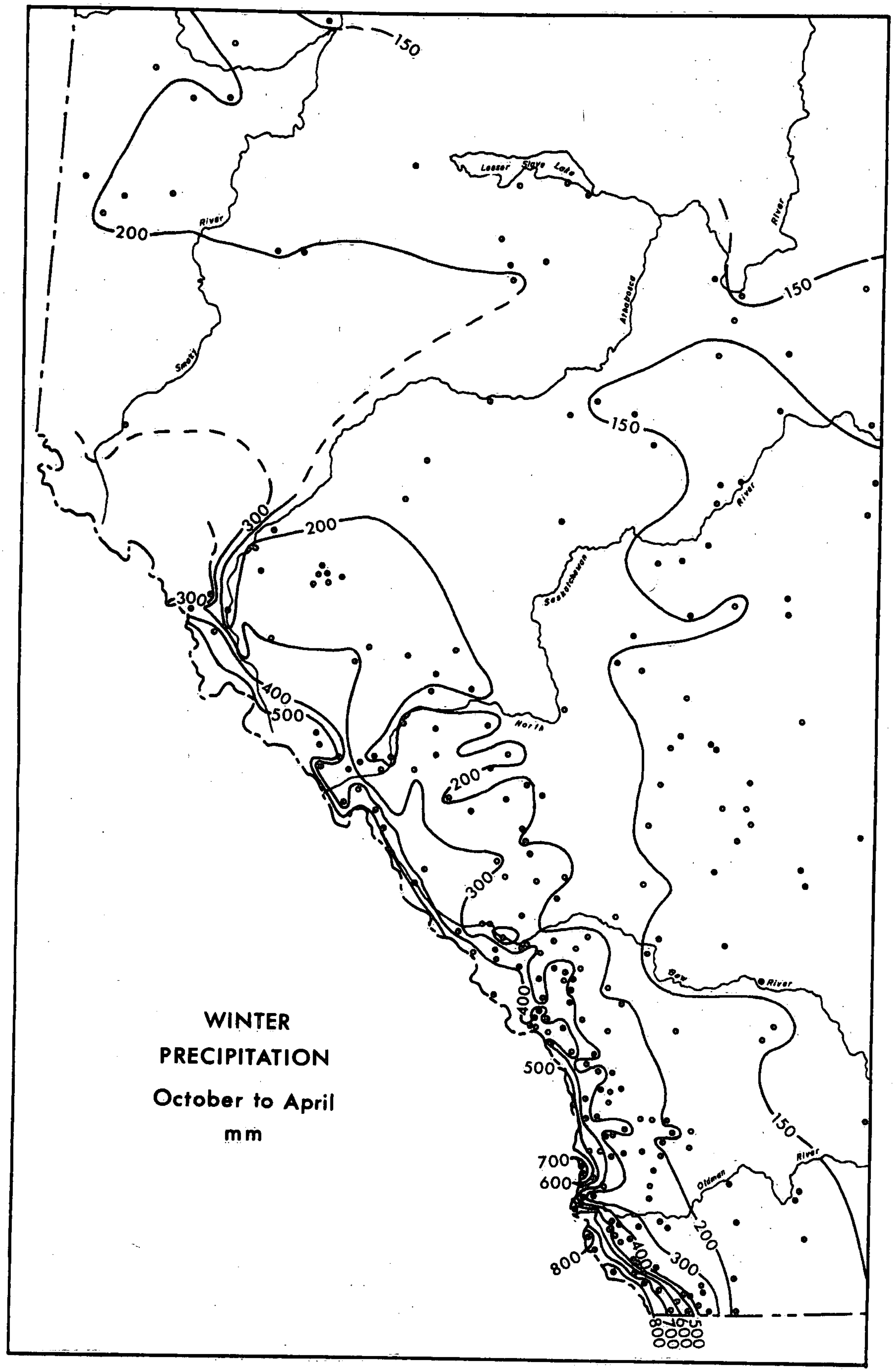


Fig. 4. Average winter (October-April) precipitation (millimetres) for the Eastern Slopes and adjacent areas of Alberta based mainly on climatic normals and precipitation storage gauge data.

(176 mm), Entrance (161), Whitecourt (169), Edson (168) and Rocky Mountain House (177) all have averages well below 200 mm. The winter precipitation map (Fig. 4) suggests that some of the areas where storage gauges have been maintained may receive more than this amount.

Summer Precipitation

Average summer precipitation, May to September, is shown in Fig. 5. The station data base for this map is more extensive than for annual and winter precipitation, as data from many of the forestry lookout stations have been included. This gives a much denser network of stations north of the Bow River and especially to the north of the Athabasca River. The lowest summer precipitation occurs in the Kootenay Plains area (<200 mm). Other low amounts (<250 mm) occur around Jasper, in the Banff-Canmore corridor, Kananaskis valley, and Coleman-Cowley area. The extreme southwest portion of Alberta is among the areas with the highest summer precipitation (>400 mm). Other areas receiving >400 mm include the higher areas of the Foothills, where several of the lookouts have an average of over 450 mm.

Rainfall

The map of total rainfall is somewhat similar to the map of summer precipitation (Fig. 5), as would be expected, although as with snowfall, rain can occur in any month of the year, especially at lower elevation stations. The highest rainfall occurs in the western portion of Waterton Lakes National Park (>500 mm). Other centers of high rainfall occur in the Swan Hills (>450 mm), and areas in the Foothills centered on the Lovett-Wolf-Clearwater area and near Elbow Ranger Station south of the Bow River. Lowest amounts of rainfall, based on the stations given in the Climatic Normals, occur in the Bow River and Oldman River corridors and around Jasper (<300 mm).

In the area to the east of a line from Athabasca, to Whitecourt, Edson, Rocky Mountain House, Crossfield and Vauxhall, over 70% of the precipitation falls in the form of rain. In the extreme southwest of the province, centered on Waterton Lakes National Park and the Castle River area, less than 50% falls as rain. At Lake Louise only 37% occurs as rain, the lowest percentage recorded in the area. Jasper and Entrance, on the other hand, have 68% of their precipitation in the form of rain. Banff, Kananaskis, and a band of stations to the south, including Pekisko, Coleman, Cowley, Pincher Creek, and Carway, have from 50 to 60% of their precipitation as rain.

Month of Greatest Precipitation

The month of greatest precipitation is June in the southern portion of the area. This area includes Jasper-Hinton and the area south of a line from Nordegg to Rimbey and north of Stettler. Lake Louise is an exception in this area in recording the greatest precipitation in December, followed by November. This southern area can be further subdivided when the month of next highest precipitation is considered. The area south of a line from Banff to Okotoks and Vauxhall all has the second highest precipitation month in May, or in the extreme southwest several stations have April

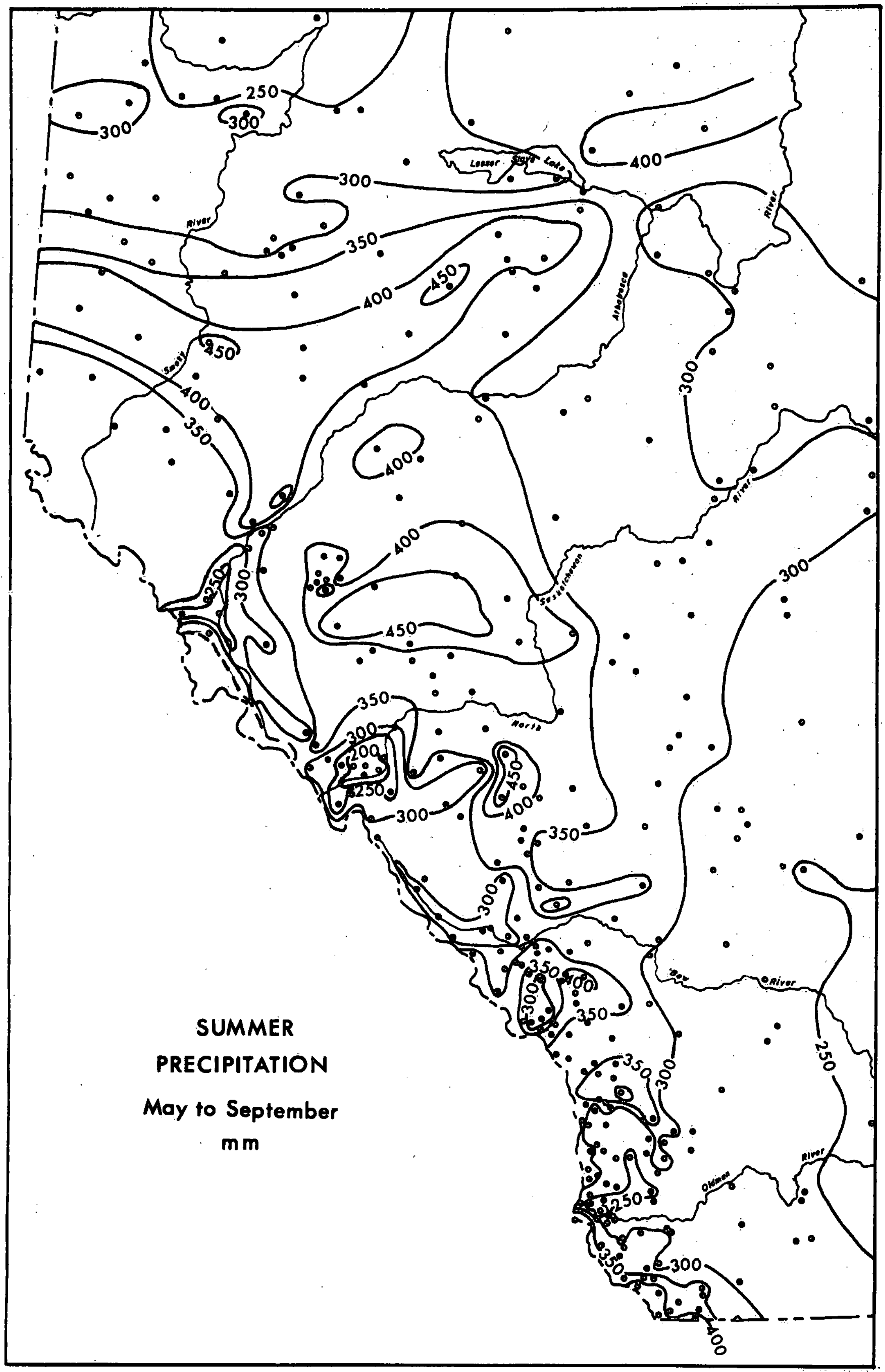


Fig. 5. Average summer (May-September) precipitation (millimetres) for the Eastern Slopes and adjacent areas of Alberta based on climatic normals, storage gauge, and other precipitation source data.

as the second highest month. The rest of the area to the north of the line has the second highest month in July and a few stations in August. In the area north of about 52° 30' N most stations have July as the month of greatest precipitation, with June the next highest. There are exceptions, in that stations in the Peace River area, and part of the Swan Hills and the area to the east, have the highest monthly precipitation in June. The lookout stations of Kakwa, Huckleberry, and Snuff Mountain and the stations of Radway, Lac La Biche A, and Vilna have their highest amount in August. Stashko (1971) showed the summer month trends for the forestry station using 1963-1970 data. This indicated that most of the northern stations showed a peak in July, with some in August, and all the southern stations a peak in June with the exception of Sundre and Burnstick, which continued the peak through July.

This feature of the peak precipitation pattern moving northward in July is well known and was recently investigated by Chakravarti (1972). He showed that it was related to the unusual extension of the Pacific High Pressure cell towards the northeast and a northward displacement of jet streams, frontal zones, and cyclonic tracks.

Month of Least Precipitation

A marked feature of the period of lowest precipitation is that the extreme southwestern portion of the province, including Beaver Mines, Castle Ranger Station, and the area round Waterton Lakes, has a minimum in July, the month immediately following the period of greatest precipitation. Four of the stations in Waterton Lakes area have the second lowest month in August, and the other stations with a minimum in July have a secondary minimum in October. All other stations in the study area have the month of least precipitation in the winter, and there is much variation as to which month this occurs. Many stations show very little range in the totals for the winter months. A large group of stations in an area which includes Wetaskiwin, Rocky Mountain House, Clearwater Ranger Station, Calgary, Fort Macleod, and Lethbridge has a minimum in the months October to December. Entrance, and the stations of Calgary Glenmore Dam, Cowley Olin, Fort Macleod, Mountain View, and Carway all record a minimum in October, and at Cardston, October and January share the minimum. Stations in or near the mountains, such as Pincher Creek, Cowley A, Coleman, Banff, Lake Louise, and Jasper and a large area including Grande Prairie A, the Lesser Slave Lake area, Whitecourt, Edson, and Edmonton have a minimum in March. Several stations in the Peace River have a minimum in April. Stations in the Foothills south from Red Deer Ranger Station to Lundbreck and Claresholm have a minimum in January or February, and the old record at Coalspur indicated a minimum in February.

Greatest Amount of Precipitation in a 24-Hour Period

The greatest amount of precipitation recorded in a 24-hour period will vary depending on the period of record and the fact that precipitation can vary widely from place to place. The values recorded in the Canadian Normals were plotted on a map along with values from a few other selected stations known to have received high amounts. The highest rainfall totals have occurred at Lyndon (170 mm), Red Deer (154), Waterton Lakes Belly River (149), White Mountain Lookout (139), Jasper Park East Gate (131), Pekisko (129), Goose Mountain Lookout (126), Waterton Lakes Red Rock (121), and Willow Creek Ranger Station (120). Some of the long-term stations have recorded relatively low values, for example, Banff (53 mm) and Lake Louise (58), that for Lake Louise being a snowfall. The highest 24-hour snowfall occurred at Waterton Lake Red Rock (87 mm), while many other stations in southwestern Alberta have recorded totals >70 mm. Pollock and Gaye (1973) noted in their analysis of all records prior to 1972 that the heaviest 1-day extreme rainfalls occur along the foothills and that there is a rapid decrease westward from the foothills into the mountain valleys. They showed that in a 100-year return period 1-day rainfalls >150 mm can be expected at a few points, such as White Mountain Lookout, Tony Lookout, Grave Flats Lookout, Burnstick Lookout, Pekisko, and Willow Creek Ranger Station. Major portions of Banff and Jasper national parks and the area north of the Crowsnest Pass can expect <75 mm in 1 day. Maximum rainfall frequencies for periods of less than 1 day and for 1-3 days covering various return periods were published by Bruce (1959, 1968), and Storr (1963, 1976b).

Number of Days with Measurable Precipitation

Most of the Eastern Slopes area has at least 100 days with measurable precipitation, with the exception of a few stations in the valley corridors through the mountains, such as Entrance (89 days), Anthracite and Exshaw (91), and Coleman (89), and others in the southwest area. The highest number of days with precipitation for stations in the area were recorded at Lake Louise (136), Grande Prairie, Waterton Park HQ (130), Banff and Beaverlodge (129), Whitecourt, Castle Ranger Station (127), Jasper (126), Rocky Mountain House, and Waterton Lakes Red Rock (125).

CONCLUSIONS

This preliminary study has provided average annual, winter, and summer precipitation maps for the Eastern Slopes area of Alberta along with other precipitation data that can be mapped using the readily available published precipitation averages. Better maps could be produced for the area if smaller scale mapping was used that took into account precipitation-elevation relationships for various aspects and regions in the area. Better averages could now be developed for some of the short-term stations using all available data, especially for some of the stations in the northern half of the Eastern Slopes area. There is still a paucity of stations recording winter precipitation north of the Athabasca River. A few storage gauges have recently been placed in this area, but more are required to adequately develop precipitation patterns. More storage gauges should be placed along the Great Divide to adequately measure precipitation in this alpine zone. The estimates made by Janz and Storr (1977) for this zone in Banff and Jasper national parks now need to be checked at a number of other points. Finally, the other often short-term sources for precipitation data mentioned by Laycock (1977) need to be integrated into the overall picture. Water balance studies based on streamflow data should prove useful in indicating areas where precipitation data is inadequate or needs corrections. Maps of water surplus and deficiences using recent data will help in this regard, especially when based on individual drainage basins.

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RUNOFF SIMULATION MODELS FOR RESEARCH BASINS

by

Ted Cheng and Walter Nemanishen

ABSTRACT

During the 1964-74 International Hydrologic Decade, forty-three research basins representing various sets of physiographic and environmental conditions were instrumented to collect data relative to their hydrologic cycles. To evaluate the adequacy and usefulness of these historic hydrometeorological data, mathematical runoff simulation models have to be utilized.

In this paper, three of the well-known runoff simulation models, SSARR, Modified STANFORD and UBC, are described and applied to three research watersheds, Marmot, Davin and Tri Creek, which are located in the Saskatchewan River Basin. The simulation results of previous runoff seasons are presented with comments. Discussions are made on the possible use of simulation models along with the data collected on research basins for the efficient operation and proper planning of water related projects.

RUNOFF SIMULATION MODELS FOR RESEARCH BASINS

by Ted Cheng* and Walter Nemanishen**

INTRODUCTION

Large reservoirs, such as Lake Diefenbaker (on the South Saskatchewan River) are usually designed for multi-purpose uses. They are designed to simultaneously provide power production, recreation areas, flood control, and a good quality water supply for irrigation, industrial, and municipal demands. Long-range and short-range reservoir operating plans are required to minimize conflicts among the various uses. Flood control requires a reservoir to be kept at reasonably low levels in order to store flood water, while recreation uses require that a reservoir be kept at a reasonably high and constant level. Power production and the water supply to satisfy irrigation and municipal demands require a fairly constant release of water from a reservoir. The main objective of building a reservoir is to accept and store large quantities of runoff which is a variable at relatively constant intervals in time. Not until the development of runoff simulation models did Saskatchewan River basin forecasters have the ability to predict runoff with the accuracy needed for multi-purpose reservoir operation. The successful adaptation of these models is largely due to adequate hydrometeorological data from several well-instrumented research basins. This data was essential to develop mathematical relationships for various components of the mountain-foothills-plains hydrological cycles.

RUNOFF SIMULATION MODELS

Numerous hydrologic models have been developed during the last decade to simulate runoff by using hydrologic and climatological input data. The basis of all models is a logical mathematical representation of the various processes contributing to runoff. These physical processes are not specific to any particular geography, but are applicable to any hydrologic unit, including all sub-basins within a large river basin. Recorded streamflow and climatological data are used to establish coefficients and exponents in all the simulation and routing equations. Usually this is done by trial and error, although an experienced hydrologist can usually provide close starting approximations if he is familiar with specific basin characteristics.

Some realistic compromise is necessary between required forecasting accuracy and basin data input considerations. As recognized by

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Quick (1970):

> The more accurately it is desired to simulate the hydrologic phenomena the more complex the model must be. It is not difficult to construct a model of any degree of complexity; but the more sophisticated it is, the more difficult it is to find the best values for the parameters in the model with some degree of objectivity.

According to the investigation by Lawson (1974) on simulation techniques used in water resources planning and management, five types of deterministic watershed models are recognized:

1. Statistical models (API, Square Grid)
2. Analytical models (SSARR, USDAHL-70)
3. Water Balance models (STANFORD, Modified STANFORD, WALLINGFORD, MARMOT, WRB, SACRAMENTO, UBC)
4. Hydrodynamic models (MIT)
5. Mathematical physics models (FREEZE)

Three of the models used in Saskatchewan River basin forecasting are described next.

SSARR Watershed Model

Streamflow Synthesis and Reservoir Regulation Model (SSARR) and the associated computer programs are designed to simulate runoff in a river system in which the entire area is separated into homogeneous hydrologic units. The SSARR model was developed by systems analysis; therefore, maximum flexibility and modification are provided.

The SSARR model has been designed to perform streamflow synthesis for planning, study-type functions (i.e., design flood studies, reservoir regulation studies, extension of the periods of observed streamflow data), as well as for operational functions (i.e., daily operational forecasting, operational reservoir regulation).

This model is able to reconstruct the historical streamflow events from hydro-climatic data. Most of the essential information required by the model is of such a nature that an experienced hydrologist familiar with physiographic and hydrologic characteristics of the basin can estimate initial trial values for the necessary coefficients and establish basic relationships as well. Specific basin coefficients are subsequently optimized by trial and error. This procedure is called hydrograph reconstitution.

Simulation of the basin unit runoff is based on the determination of water excesses (which is the actual water available for runoff) from the relations between the rainfall or snowmelt moisture input and the soil moisture index which in turn is related to the evapotranspiration. Water excesses are then divided into base, sub-surface, and surface flow components which are routed separately through a predetermined number of single phases.

The SSARR model is designed to execute snowmelt computations in a basin unit either from air temperature indices or employing generalized snowmelt equations developed by the Corps of Engineers and presented in their manual, "Runoff from Snowmelt" (1960). The equations express the six physical parameters affecting the snowmelt:

1. Solar radiation
2. Terrestrial radiation
3. Convection heat transfer from the air
4. Latent heat of vaporization by condensation from the air
5. Rain-water heat content
6. Conduction of heat from the ground

Modified STANFORD Watershed Model IV

In 1971 the United States National Weather Services (NWS), which operates most of the River Forecast Centres in that country, had chosen the STANFORD Watershed Model IV (Crawford & Linsley, 1966) as the catchment model for its river forecast system. Subsequently, this model was modified by the NWS with new snowmelt computation and parameter optimization procedures and the whole computer program was rewritten in a higher level of computing language. These changes have been described in two technical reports published by the NWS (HYDRO14 and HYDRO17).

This simulation model consists of three major procedures: soil moisture accounting, runoff attenuation, and snow accumulation and ablation. A whole basin can be separated into several smaller areas, each of which is considered to be unique in physiographic characteristics. Each small area may be under different atmospheric influences and responsed distinctly.

Precipitation, temperature, and potential evapotranspiration are the major data inputs. Additional meteorologic data are used if snowfall is significant. Calculations begin from known or assumed moisture conditions and are continued until the input data is exhausted. Precipitation is stored in the snowpack and in three soil moisture storages.

The upper and lower zone storages, together with the groundwater storage, combine to represent variable soil moisture profiles and groundwater conditions. The upper and lower zone storages control overland flow, infiltration, interflow, and inflow to the groundwater storage. The upper zone simulates the initial watershed response to rainfall and is of major importance for smaller storms, and for the first few hours of larger storms. The lower zone controls watershed response to major storms by controlling longer-term infiltration rates. Groundwater storage supplies the base flow to stream channels. Evaporation and transpiration may occur from all of these storages.

Total channel inflow from overland flow, interflow, and groundwater enters channel system simulation and emerges as synthesized streamflow, a continuous hydrograph of outflow from the watershed.

UBC Watershed Model

The UBC model was originally developed for simulating Fraser River discharges (Quick, 1970). In the model, a watershed is subdivided into a series of homogeneous elevation bands. Some variable parameters are selected by the hydrologic studies to represent the elevation variation in the distribution of precipitation, evapotranspiration, soil moisture, and groundwater discharge. Fixed parameters are needed for the hydrologic linkages which synthesize a streamflow hydrograph from the total daily water excesses of all bands. The fixed parameters are related to the river basin's physiographic features. These can only be determined by trial and error calculations until the "best fit" is obtained between computed and recorded streamflow hydrographs.

The computer program for the UBC watershed model contains a series of elementary budgetary calculations that determine the daily water excess. Daily temperature and precipitation rates are the basic input data. A subroutine determines if the precipitation is rain or snow. Snowmelt and rainfall are added to obtain a daily total water input. Separate water excess calculations are maintained for each elevation band, as the water losses vary from one band to the next. Water loss calculations are handled as a sequential cause-effect problem. Each daily soil moisture deficit condition results from the deficit yesterday, and today's net change from snowmelt, rainfall, and evapotranspiration. For each elevation band, the net daily change in the soil deficit condition provides a new watershed state on the following day that continues to control the further capability of the watershed to generate runoff.

After all the daily losses are deleted, the remaining water is distributed to surface and sub-surface runoff by a function related to soil moisture. At this point the "water excess" calculations are completed. The next step is daily streamflow synthesis based on a unit hydrograph model developed by Nash. Separate unit hydrographs and calculations are maintained for the surface and sub-surface runoff components.

The surface runoff hydrograph is determined by applying the unit hydrograph ordinates to the corresponding portion of daily water excess. Meanwhile, the daily water excess to sub-surface runoff is routed through a temporary storage reservoir. It is released according to a specified functional relationship.

The water released on successive days is converted to streamflow by applying the ordinates of a separate unit hydrograph.

APPLICATIONS OF SIMULATION MODELS TO RESEARCH BASINS

During the course of studies for the Prairie Provinces Water Board (1971-1976), the applicabilities of various runoff simulation models had been assessed. The results indicated that SSARR and UBC models were best to be used on mountainous regions, and the Modified STANFORD model on plains. Therefore, these three models were used to analyze the data collected on the four research basins. Three of these basins are described next to illustrate the potential of the models for watershed and water resource management.

Marmot Creek Basin Simulation

The 3.63 square miles of Marmot Watershed is located at the Bow River headwaters area in the eastern slopes of the Rocky Mountains within Alberta, and ranges in elevation from 5,400 feet MSL to 9,200 feet MSL. The slope of land surface is generally steep and heavily covered by trees, where evapotranspiration and interception losses are dominant. About one-third of the total area is above 7,500 feet MSL and free of vegetation.

Marmot Creek Watershed offers data that is useful for illustrating the capability of a watershed budget model. Sample data were abstracted for the active runoff periods from 1963 to 1970. The meteorological and snowpack water-equivalent data were limited to the lower elevation range of the watershed. The Con 5 meteorological data site is located at 5,750 feet elevation, and the snow course data from sites Marmot 1, Marmot 8, and Marmot 19 provided water equivalent indices at elevations of 5,350, 6,010, and 7,060 feet. A map of this basin is given in Figure 1.

More data has been collected throughout the full range of elevation, but this additional data was not used for this study because it was intended to illustrate the use of moderately sparse data. Monthly pan evaporation data required for the analysis were abstracted from measurements at Calgary.

Figure 2 shows the computed depletion and reaccumulation of the snowpack throughout the elevation ranges compared with the measured values for 1967. These computed values are derived purely from the initial snowpack on March 1 and subsequent temperature and precipitation data. Hydrographs generated by the UBC and SSARR models are illustrated in Figures 3 and 4.

Davin Watershed Simulation

The Davin Watershed is at the headwaters of Fahlman Creek and is approximately 18 miles southeast of Regina. The drainage area of the watershed is 6.8 square miles. The basin is outlined in Figure 5.

Runoff in Fahlman Creek usually begins in late March when the air temperature is moderate and snowmelt starts. Snowmelt contributes over 90 percent of the annual runoff volume even though the amount of snowfall is only about half of the rainfall amount. Heavy rain may cause

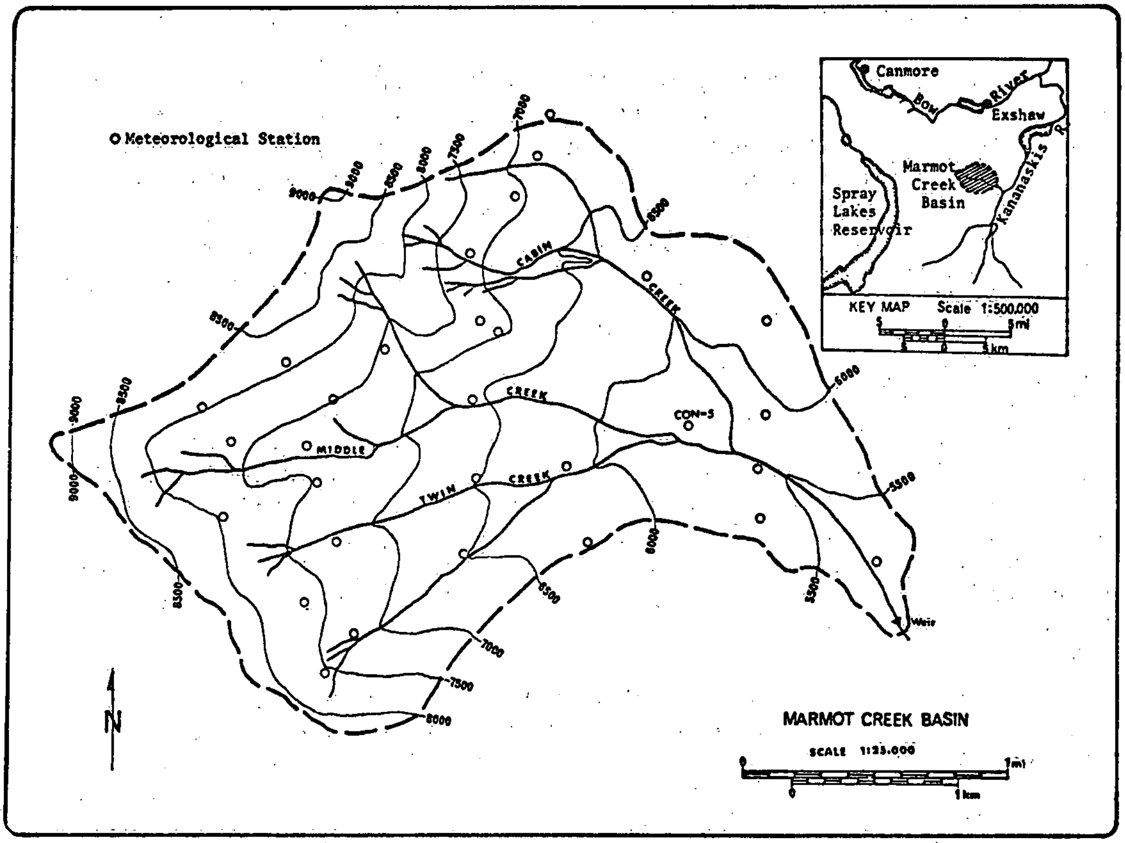

FIGURE 1: MARMOT CREEK BASIN

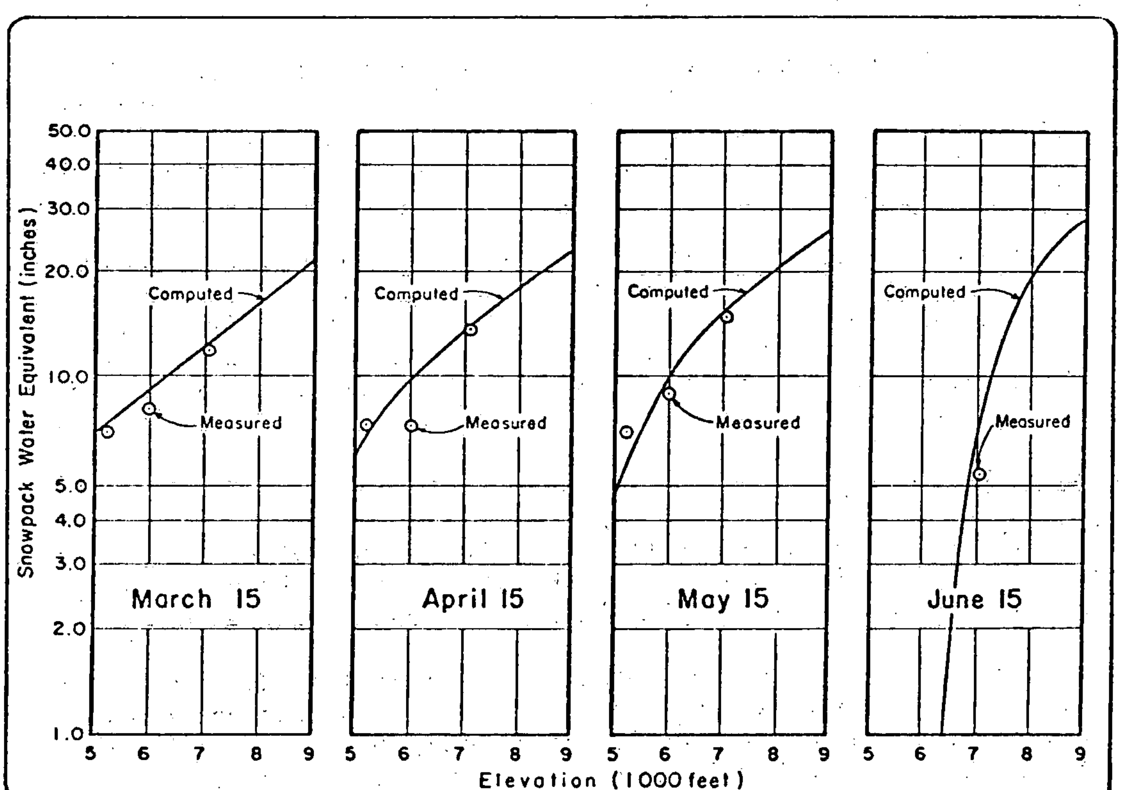

FIGURE 2: MEASURED AND COMPUTED WATER EQUIVALENT AT VARIOUS ELEVATIONS

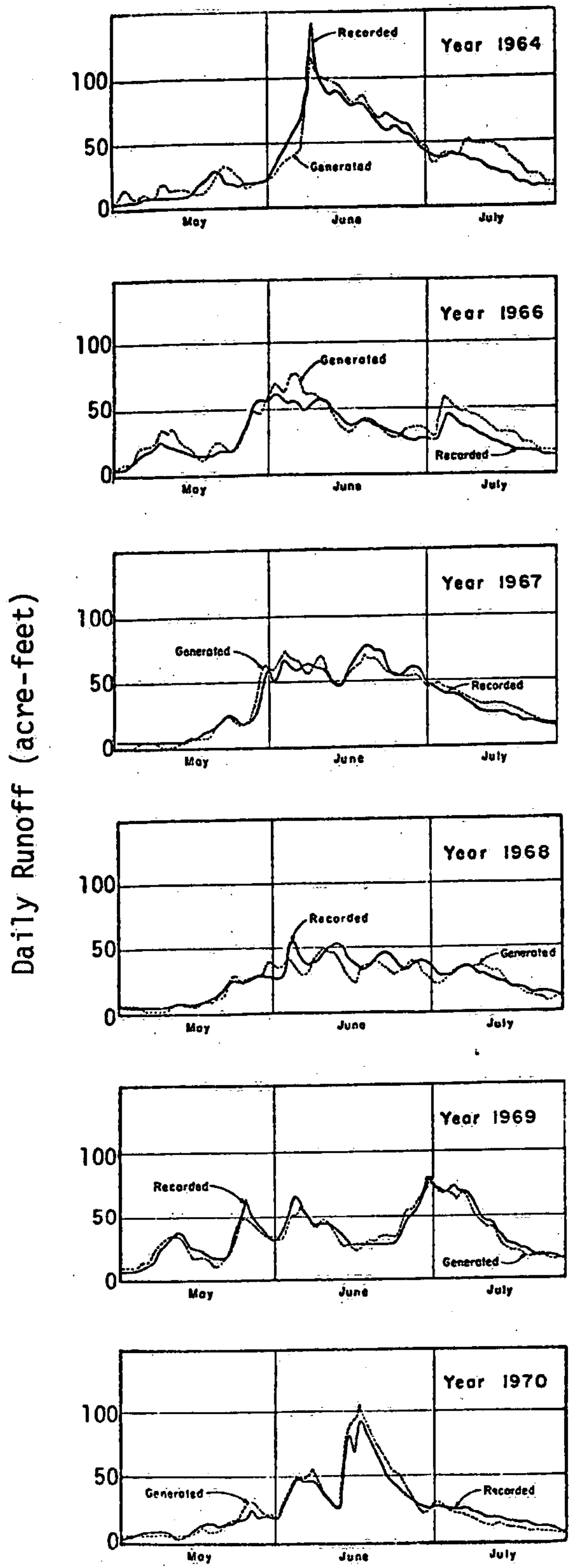

Figure 3: Seasonal Runoff Hydrographs For Marmot Creek Main Stem (Using UBC Watershed Model).

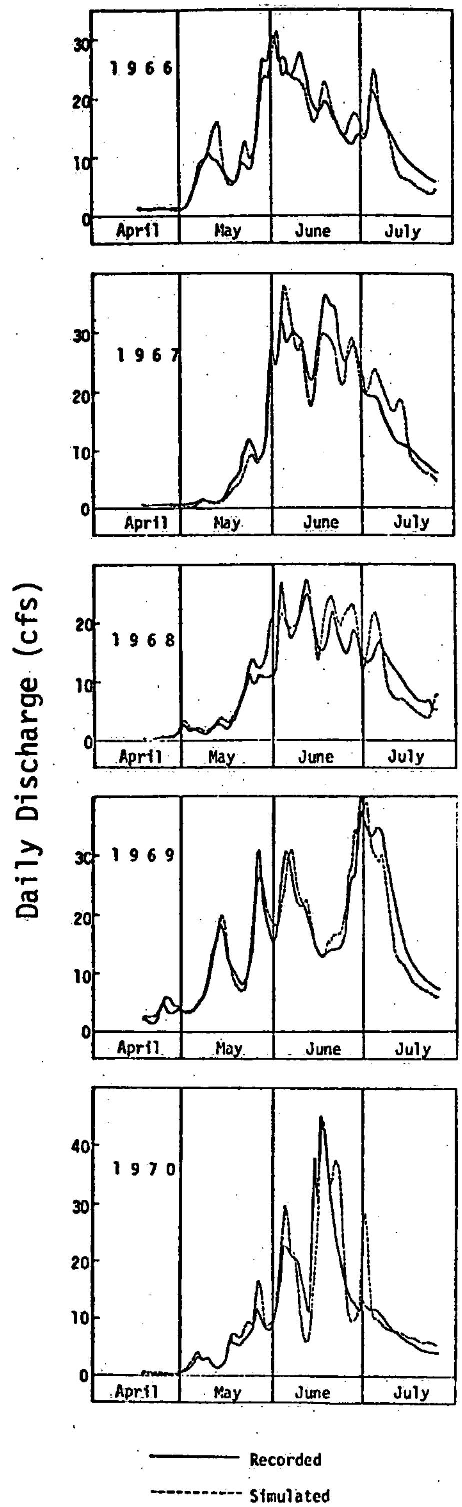

Figure 4: Seasonal Runoff Hydrographs For Marmot Creek Main Stem (Using SSARR Model).

significant but brief runoff peaks during the summer.

The Fahlman Creek near Davin hydrometric station has records since 1951; however, only daily mean flows are available. There are six climatological stations within the area but they only record summer precipitation. There is a synoptic station in the township of Davin, just outside the watershed, and temperature and precipitation records are available from this station. Class A pan evaporation and soil moisture data are available only during the summer months. Snow courses, with observations from February to April, were started in 1970.

Six seasonal runoffs (1967-1971 and 1974) of Fahlman Creek have been simulated by the modified STANFORD model and their resultant hydrographs are shown in Figure 6. Since the 1974 runoff was very high as compared to the others, the plot scale was different.

During the reconstitution of the Davin Watershed, the following points had been observed; the model user should consider them carefully and search for additional information to confine the uncertainties and improve the accuracy of future simulations:

> The interceptional storage feature in the model was used to account for the large depressional storage on the plains. The initial storage level has a significant effect on both seasonal runoff volume and the timing of flows. An experiment was undertaken to select suitable initial values in order to obtain optimal results. After this had been done, the initial values were plotted against the soil moisture deficits which were generated by the Hydrologic Soil Moisture Budget on the same date, March 1. A curve, Figure 7, was drawn to fit the points. This curve can be used to establish the initial storage value if the soil moisture deficit reading or estimate is available.

Tri Creek Basin Simulation

As the name indicates, there are three small streams in the Tri Creek basin (see Figure 8). Their names are Wampus, Deerlick, and Eunice Creeks, all having similar topography, with elevations ranging from 4,150 to 5,500 feet above MSL. The total area is 22.2 square miles and is located in the Rocky Mountain foothills of north-central Alberta. Land slopes are gentle and range from 4 percent to 10 percent. The whole basin is moderately occupied by stands of native poplars and white spruces with alternating jack pines.

The drainage patterns are pretty well developed with the main stems running northward and intercepting the McLeod River at the mouths of the three streams. Snowmelt runoffs are normally active during the month of May. Sizeable peaks can be produced with large snow packs accumulated during the winter months. Heavy summer rain storms coupled with saturated soil may generate annual runoff peaks.

The U.S. Corps of Engineers' procedure, the SSARR Model, is employed to compute the runoffs from the Tri Creek basin. For the

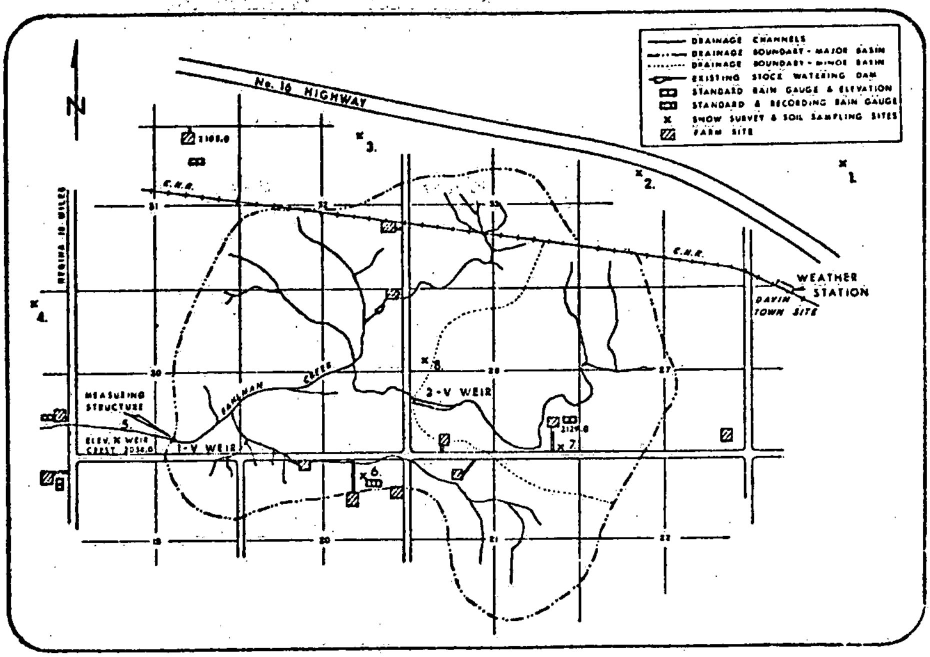

Figure 5: Davin Research Watershed.

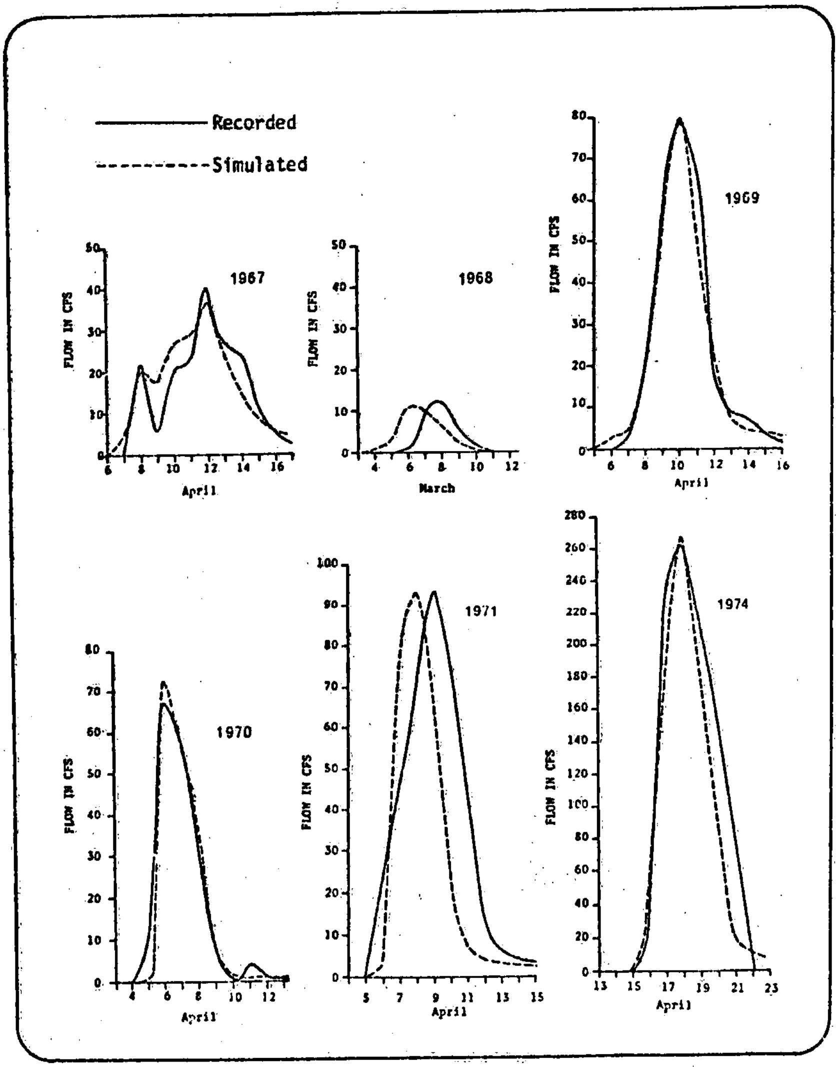

Figure 6: Seasonal Runoff Hydrographs For Fahlman Creek Near Davin.

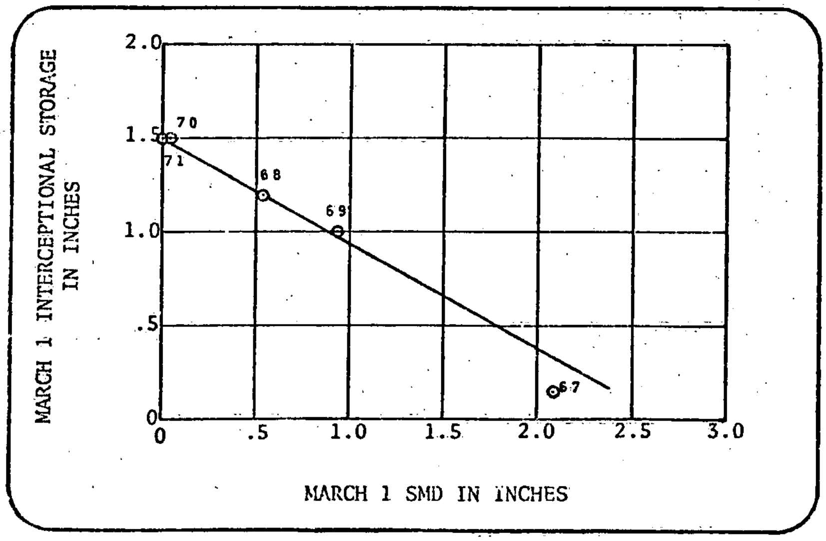

Figure 7: Initial Interceptional Storage for Davin Watershed.

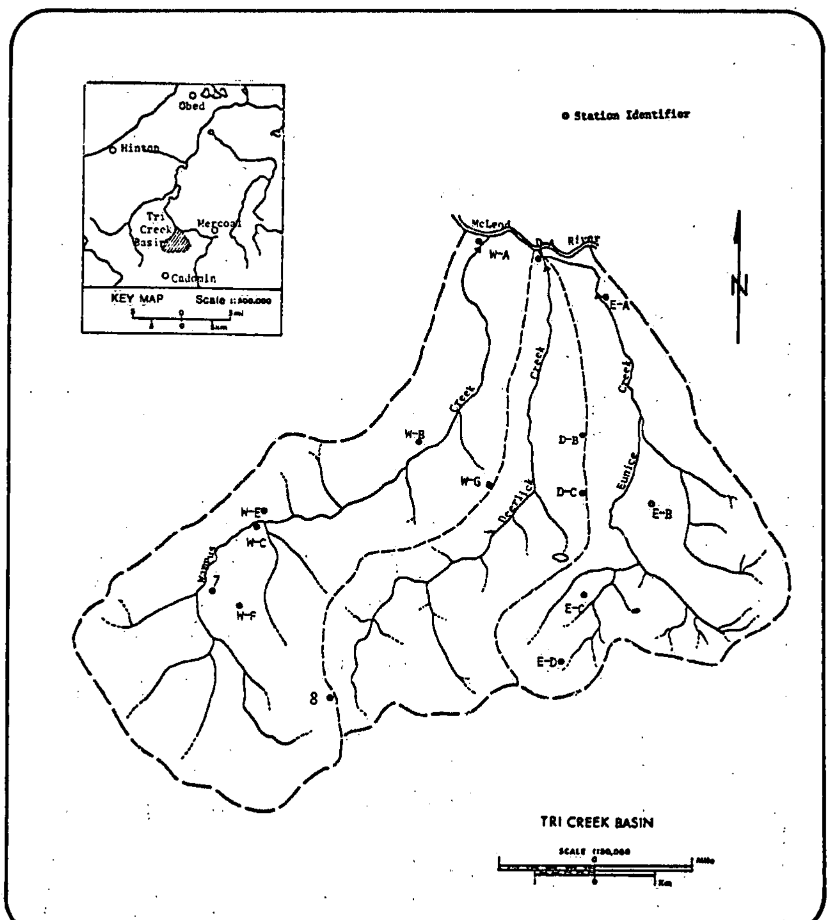

Figure 8: Tri Creek Basin

snowmelt calculations, the temperature index and snowband options were selected. The generalized snowmelt equation option is available but there is not enough data. Other methods such as snowcover depletion, snowcover and snowfree split areas, and five elevation bands have been tried but the results are either the same or even worse than the ones obtained by using the snowband (one or two bands) method.

To find a set of optimal model parameter values, several recent seasonal runoff hydrographs have to be fitted. With the Tri Creek basin the previous five spring-summer runoff seasons, April to July 1971 to 1975, were used to derive a fixed set of physical parameters. The starting values of the variable parameters such as soil moisture and snowpack water equivalent for each season were different. The time dependent variables which describe the atmospheric changes are also different from season to season and from basin to basin.

The resulting reconstitution of historical seasons of runoffs was plotted in Figures 9, 10, and 11. The major difficulties in the reconstitution were the establishments of the initial soil moisture values and the melt rates. The amount of moisture in the soil regulates the runoffs from the ground to the channel and thus affects the outflow volume. The amount of water, calculated by using the specified melt rate and released by the snowpack during a warm period, alters the shapes of the outflow hydrographs in terms of magnitude and timing. These two initial parameters are influenced by the qualities of the temperature and snow survey data. That is to say, how well the records represent the whole basin or elevation band. The errors in selecting parameter values sometimes can offset the errors in the original time-dependent data. For instance, a high initial soil moisture value may be balanced by an under-measured snowpack water content; the selection of a lower melt rate may be compensated for by the use of maximum temperatures for the whole half day (12 hours) instead of only for the two-hour peak. Adversely, an error on one parameter may be cumulated with the errors on others, i.e., an under-catched snow or rain gauge couples with the over-estimated evapotranspiration.

USE OF MODELS AND RESEARCH BASINS FOR IMPROVING THE MANAGEMENT OF THE SASKATCHEWAN RIVER AND ITS WATERSHED

The comprehensive hydrological data bases available from the research basins have enabled streamflow forecasters to adapt existing runoff simulation models for forecasting runoff from the eastern slopes of the Rocky Mountains contributing to the Saskatchewan River system and the Qu'Appelle River basin. Real-time runoff forecasting accuracy is improved by using runoff data from these basins to determine areal runoff coefficients and rain-snow elevations for mountain streams. Recognizing the value of research basins such as Marmot Creek, Water Survey of Canada forecasters (engaged on the Prairie Provinces Water Board streamflow forecasting study) recommended that these basins be retained to provide runoff indices.

The benefit of runoff forecasts is substantial. Studies made by Blackwell (1967) showed that hydro power production from Lake Diefenbaker could be increased on the average by $62,000 per year, based on 1967 data, and could approach $650,000 for an unusual year.

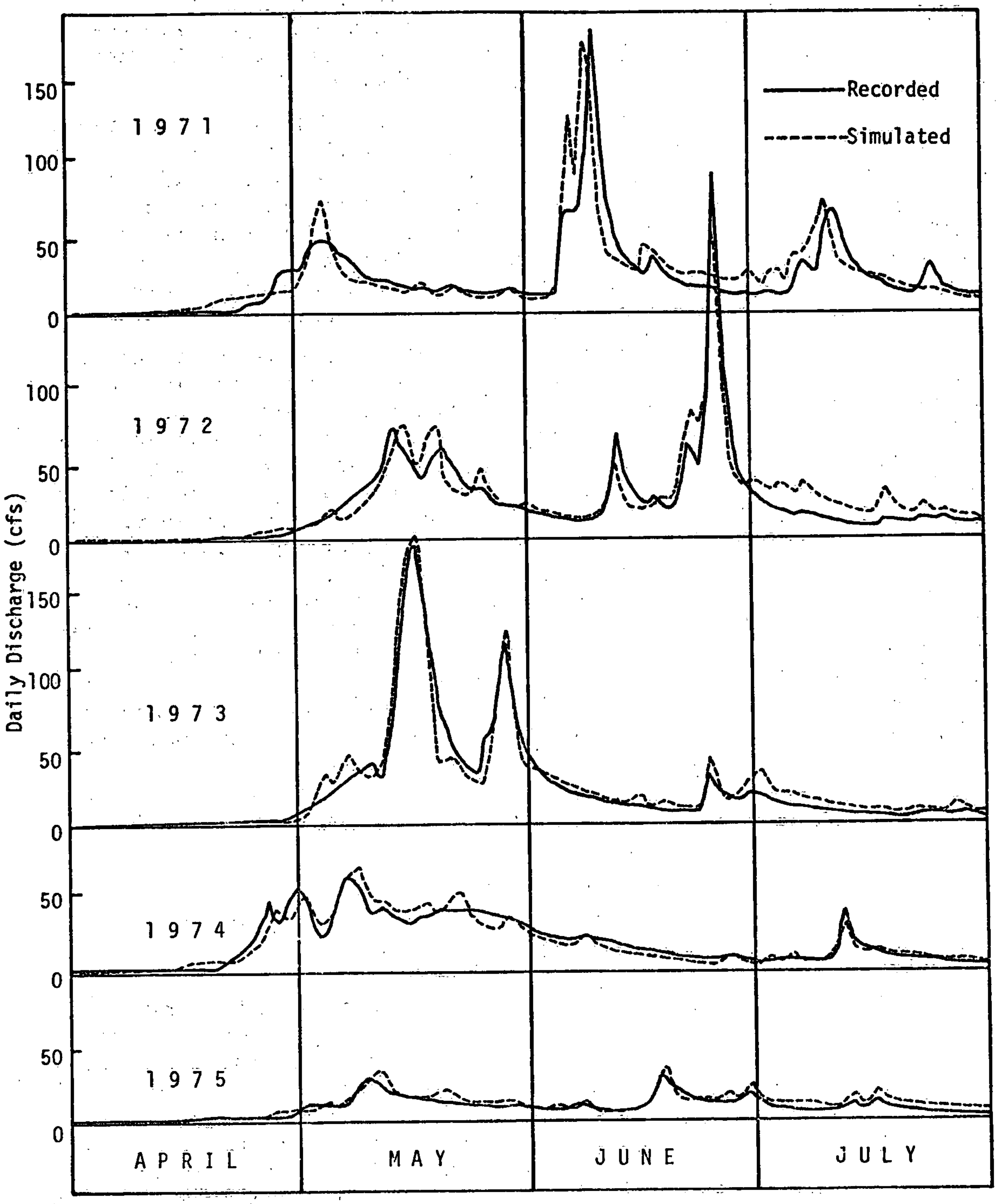

Figure 9: Seasonal Runoff Hydrographs for Wampus Creek near Hinton.

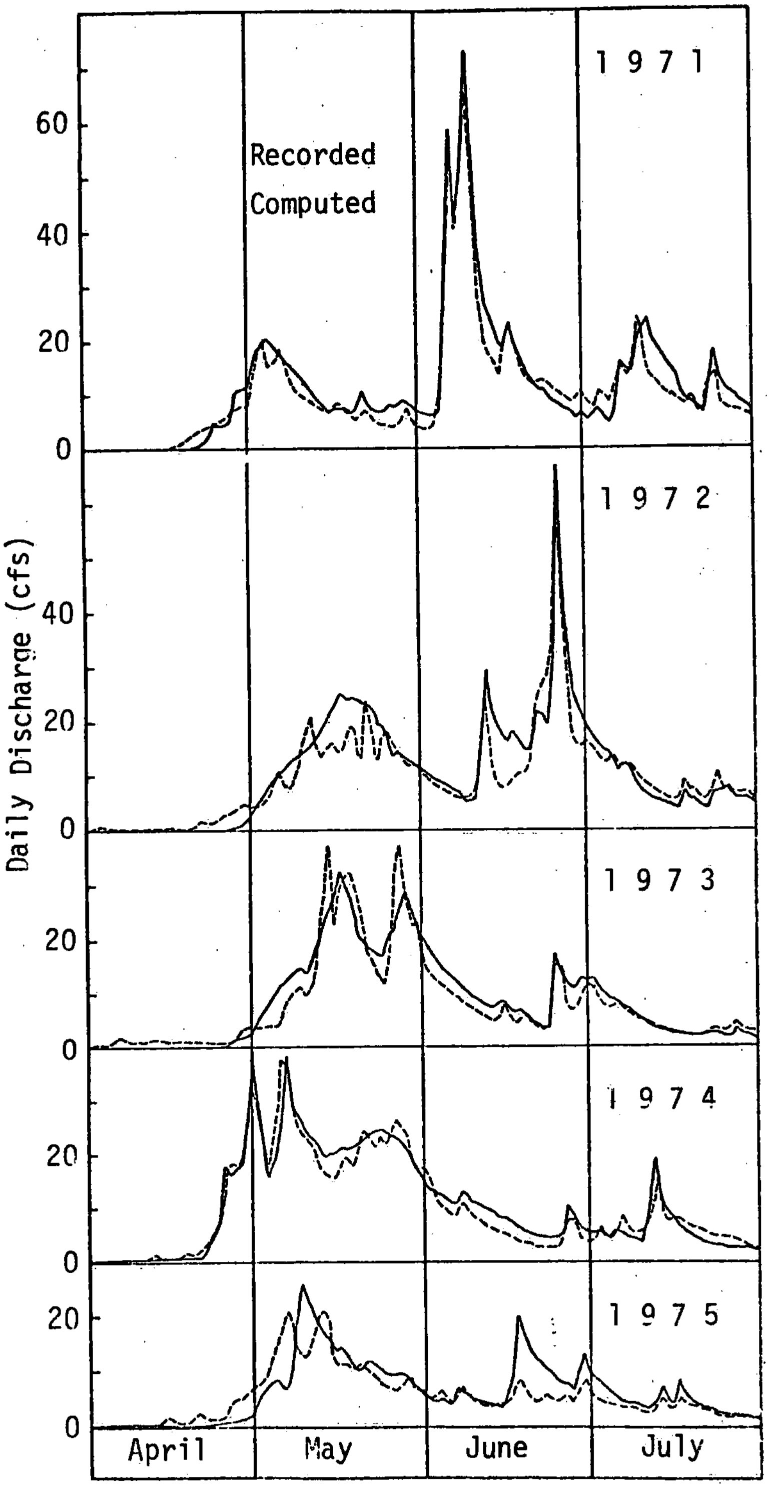

Figure 10:
Seasonal Runoff Hydrographs For
Deerlick Creek Near Hinton

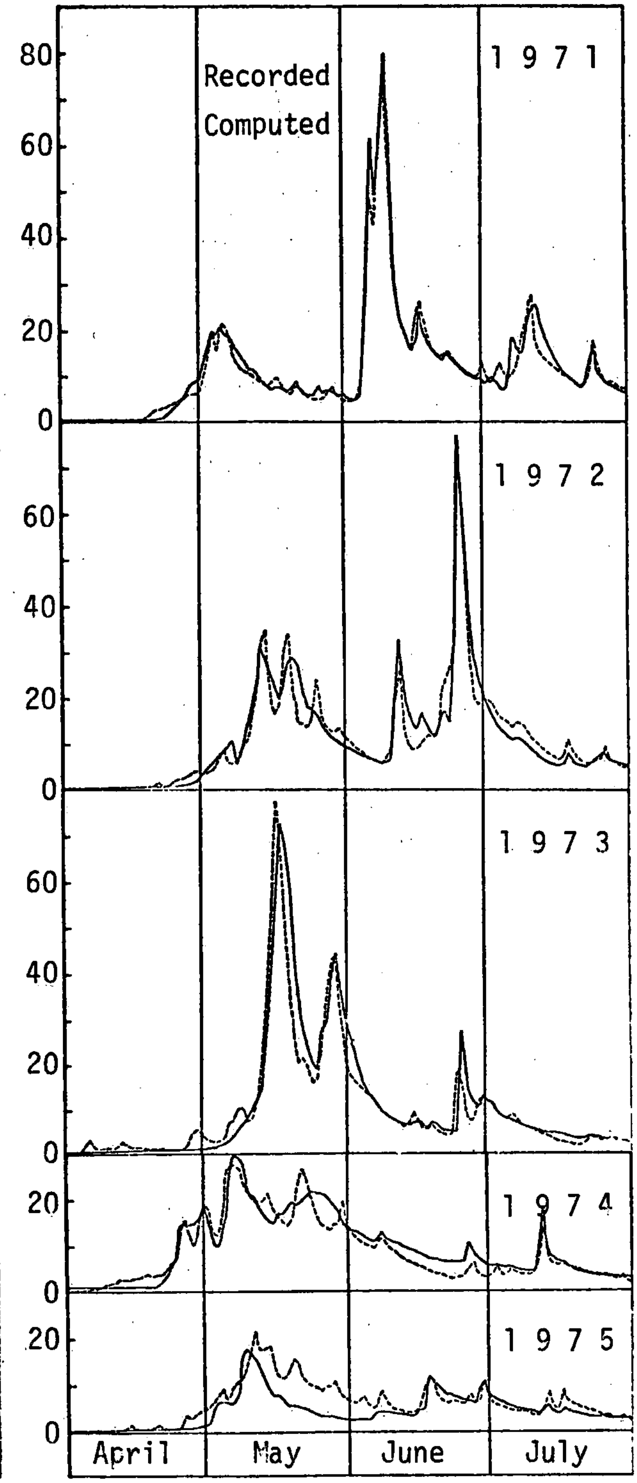

Figure 11:
Seasonal Runoff Hydrographs For
Eunice Creek Near Hinton

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A PRELIMINARY STUDY OF CHANGES IN WIND STRUCTURES PRODUCED BY A COMMERCIAL-APPEARING CUT IN MATURE FOREST

by

L. S. Meeres [1]

INTRODUCTION

Cabin Creek, a sub-basin of the Marmot Creek Experimental Watershed in the Kananaskis Valley in Southwestern Alberta, was selected for patch-block logging in 1974 to demonstrate the effects of a commercial-type harvest operation on a number of hydrological features, including snow accumulation and evapotranspiration, both of which are affected by wind. The Atmospheric Environment Service designed a project to measure the winds above and within the forest both prior to and following the logging operation in order to determine the mean wind patterns both vertically and in a quasi-horizontal plane parallel to the slope, and to show the effect of logging on these patterns.

Storr (1976) has reported on the wind patterns prior to logging. This report presents the results of a preliminary study of the wind patterns following the removal of patches of the forest and compares these patterns with those found by Storr. Effects of wind direction with respect to the boundary of the cut-block are also investigated. The behavior of stronger winds ($\geq$ 15 m.p.h.) is examined separately.

Finally, to assist in the interpretation of the effects on snow accumulation of the changes in wind structure, a brief study of the relationship between measured precipitation in the Marmot Creek basin and wind speed or wind direction was undertaken.

THE STUDY AREA

The average slope of the study area is 20 to 25%. The area is covered by a dense stand 60 to 70 feet tall consisting mainly of spruce and fir. Kirby and Ogilvie (1969) have given a more detailed description of the forests of Marmot Creek.

INSTRUMENTATION AND DATA

In September, 1972, four 100 foot towers were installed in two pairs for this study. The location of these towers is shown in Figure 1.

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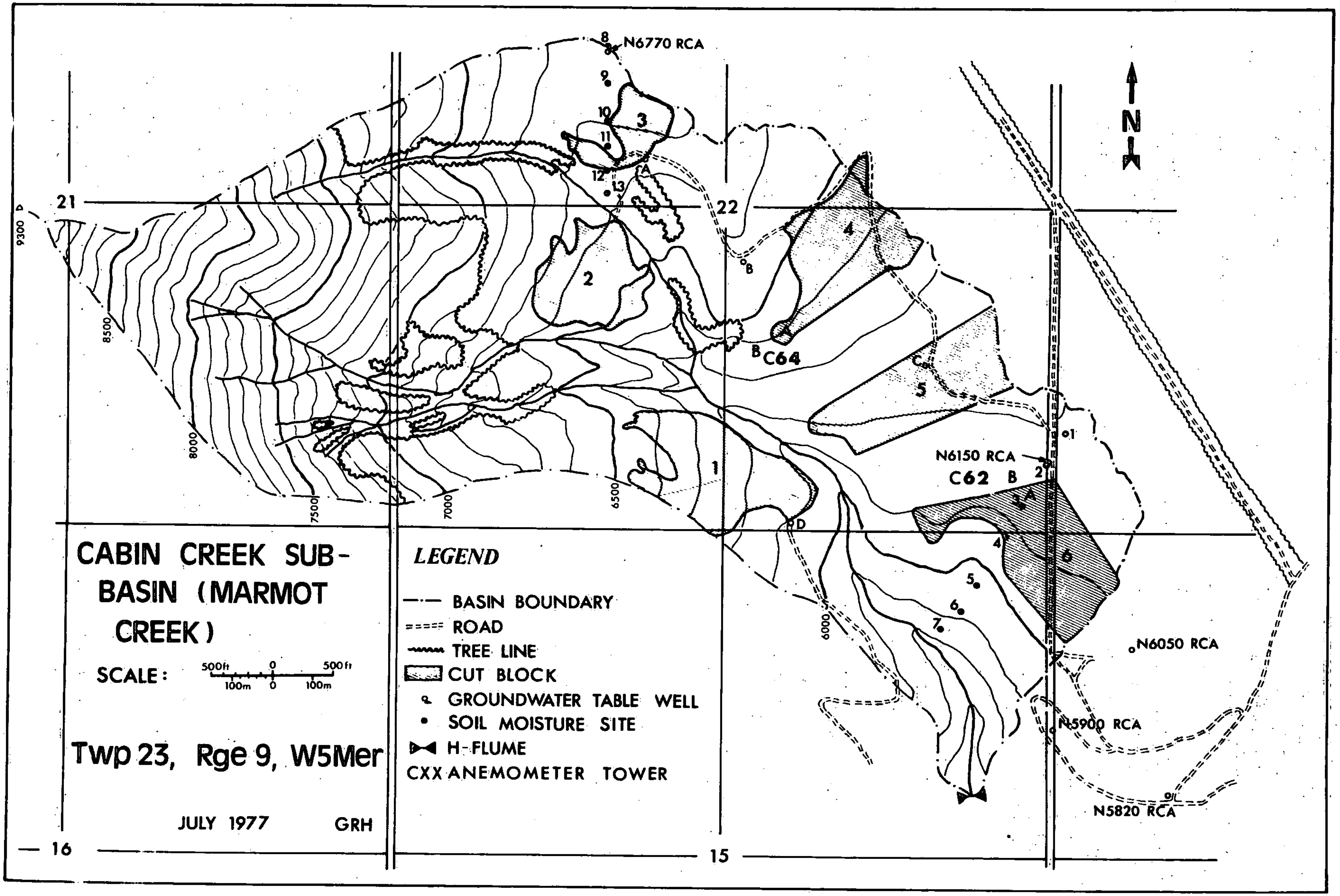

Figure 1. Marmot Creek, Cabin Fork sub-basin, showing cut blocks and location of Anemometer towers.

The first pair of towers was erected at an elevation of approximately 6,200 ft. ASL and carries the designations C62A and C62B. The slope in the immediate area is less than the basin average at about 10%. The second pair was erected at an elevation of approximately 6,400 ft. ASL and carries the designations C64A and C64B. The slope in the immediate area is about 25%. The A tower in each pair was located in an area that has subsequently been cut over while the B towers were located in the uncut forest. In erecting the towers initially, care was taken to remove as few trees as possible in order to maintain the forest environment as nearly as possible to its natural state. The towers in each pair were just under 100 yards apart, about equidistant from the boundary of the harvested area and on a line nearly normal to that boundary. The pair at C62 are on either side of a long straight cut boundary running west-southwest to east-northeast. At C64 the cut area forms a rounded-out V open to the northeast. Tower C64A is less than 100 feet from the trees.

Three anemometers were mounted on each tower. The top anemometer was a standard MSC (AES) type 45B located 103 feet above ground (at the tower base). This instrument records the wind run in whole miles and the wind direction to eight points of the compass. Two Casella totallizing anemometers, modified by the addition of a microswitch at one of the rotating gear wheels, recorded every second mile of wind run. These two instruments were mounted approximately at tree-top level and at 10 feet above ground at each tower. The actual heights of the "tree-top" counters were 66 ft. above ground at C62A and 70 ft. above ground at each of the other three towers. The lower and middle anemometers do not record direction. The vertical arrangement of anemometers is shown in Figure 2.

On October 31st, 1975, at approximately 5 p.m. the tower at C64A collapsed when a tree from the edge of the forest fell across one of the guy wires. This was at the beginning of an episode of very strong winds which caused extensive blowdown in surrounding areas of the eastern slopes. This tower has not been replaced.

Data from both types of anemometer are generated in the form of pulses which are recorded by Esterline-Angus multichannel pulse recorders with a chart duration of one month. Separate recorders, powered by 110 VAC, were used for each pair of towers.

Data

The charts were examined at the monthly visit by the technicians (more frequently in summer) in order to detect and correct any instrument or recorder malfunctions. The data was manually abstracted at some later date. Storr (op. cit.) has delineated the problems in obtaining adequate data, and the problems were no less severe during 1975 when the data for this study was collected. Only 15 days were found with usable data from all 12 anemometers, due mainly to persistent failure of the middle instrument at C62A. These data were used to correlate the wind speeds at the pairs of towers and between the two sets of towers at tower top and "tree top" levels. Monthly mean winds at tower top level for months with 20 or more days of data were also correlated. Correlations calculated in this study for the period after the harvest were lower than those found by

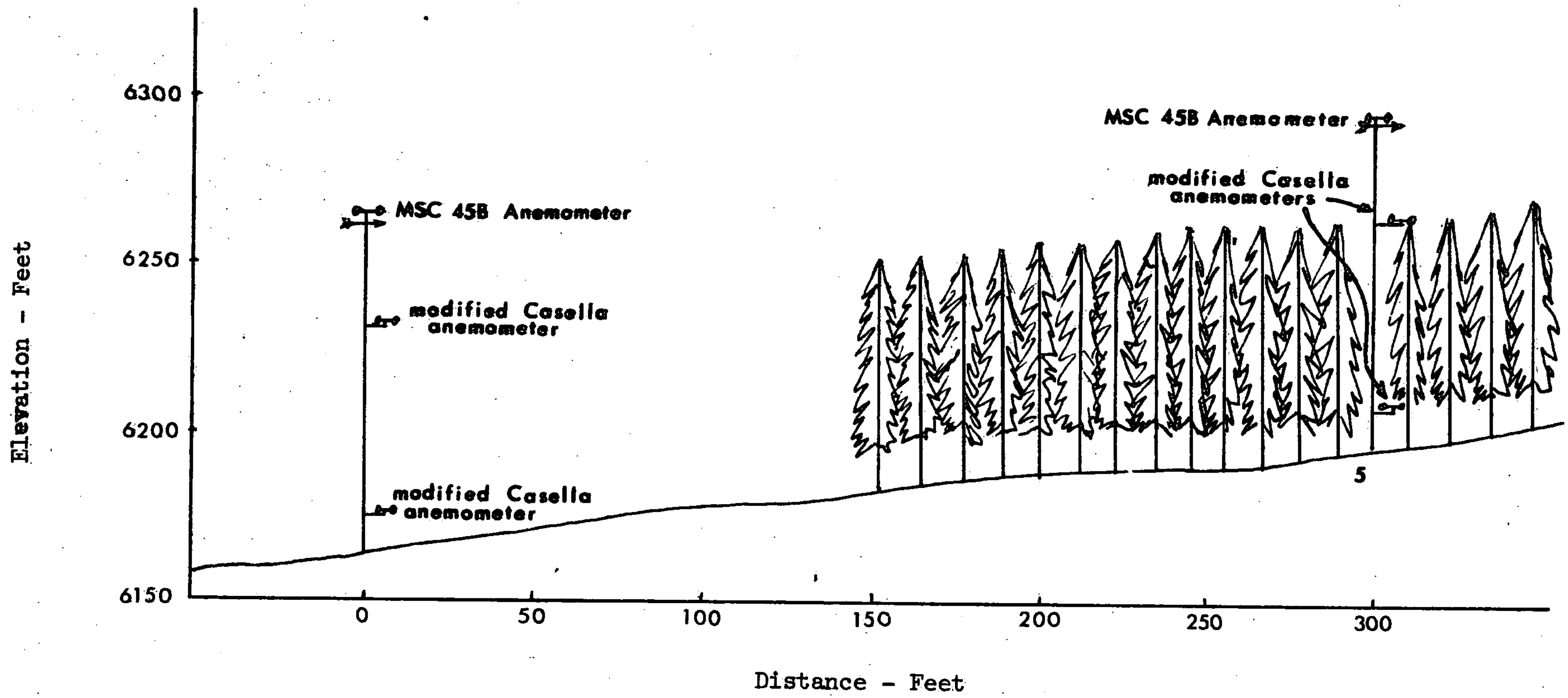

Figure 2. Tower configuration and instrumentation - C62 after cutting.

Storr for the pre-cut period. However, they indicated reasonable homogeneity in the data, so that analysis of the data was continued, treating each tower individually.

THEORETICAL CONSIDERATIONS

The variation of wind speed with height in the friction layer has been examined by a number of investigators. Munn (1966) shows that for laminar flows the vertical wind profile should follow a logarithmic curve near the ground but he concludes that, empirically, real wind profiles over a usefully thick layer tend to obey a power law so that:

$$\frac{V_1}{V_2} = \left(\frac{Z_1}{Z_2}\right)^P \qquad (1)$$

where V_1 is the wind speed at some reference level Z_1, V_2 is the wind speed at heigh Z_2, and p is an exponent dependent on surface roughness and lapse rate. In the case of winds over tall vegetation, Z must be replaced by (Z-d) where d is the effective height of the vegetation (Martin, 1971). Eq. 1 then becomes:

$$\frac{V_1}{V_2} = \left(\frac{Z_1 - d}{Z_2 - d}\right)^P \qquad (2)$$

Buckler (1969) in a study of winds at selected sites on the Canadian Prairies, concluded that the power law provided a close approximation to the observed monthly mean winds with the most probable value of p being 0.25 in summer and near 0.20 in winter. Davenport (1960) estimated values of p as high as 0.50 over large cities and as low as 0.14 for flat open terrain, the value depending on the roughness of the surface over which the wind is blowing.

In his study of the wind profiles at the Cabin sub-basin before the patch cut, Storr arrived at a most probable value for p of 0.20, based on four months data representative of winter, spring and summer conditions, using the data from the tower-top and tree-top level anemometers. Martin (1971), using multi-level data from a 61 m (200 ft.) tower at the Petawawa Forest, found values of .280 to .477 depending on the vertical temperature gradient, i.e. the stability.

In classical meteorological theory (Petterson, 1969) it is generally accepted that the friction effect extends to elevations of 2,000 to 3,000 feet above ground on the average.

RESULTS

Linear regression curves of monthly mean winds were developed by the method of least squares for the tower top levels at each pair of towers and for C62A vs. C64A. These are shown in Figures 3, 4 and 5, with the regression equations and correlation coefficients. Correlation coefficients ranged from .936 to .990 compared to Storr's values of .971 to .998. Wind speeds at the lower pair based at 6,200 ft. ASL were greater than at the higher pair located at 6,400 ft. ASL, as noted in the previous

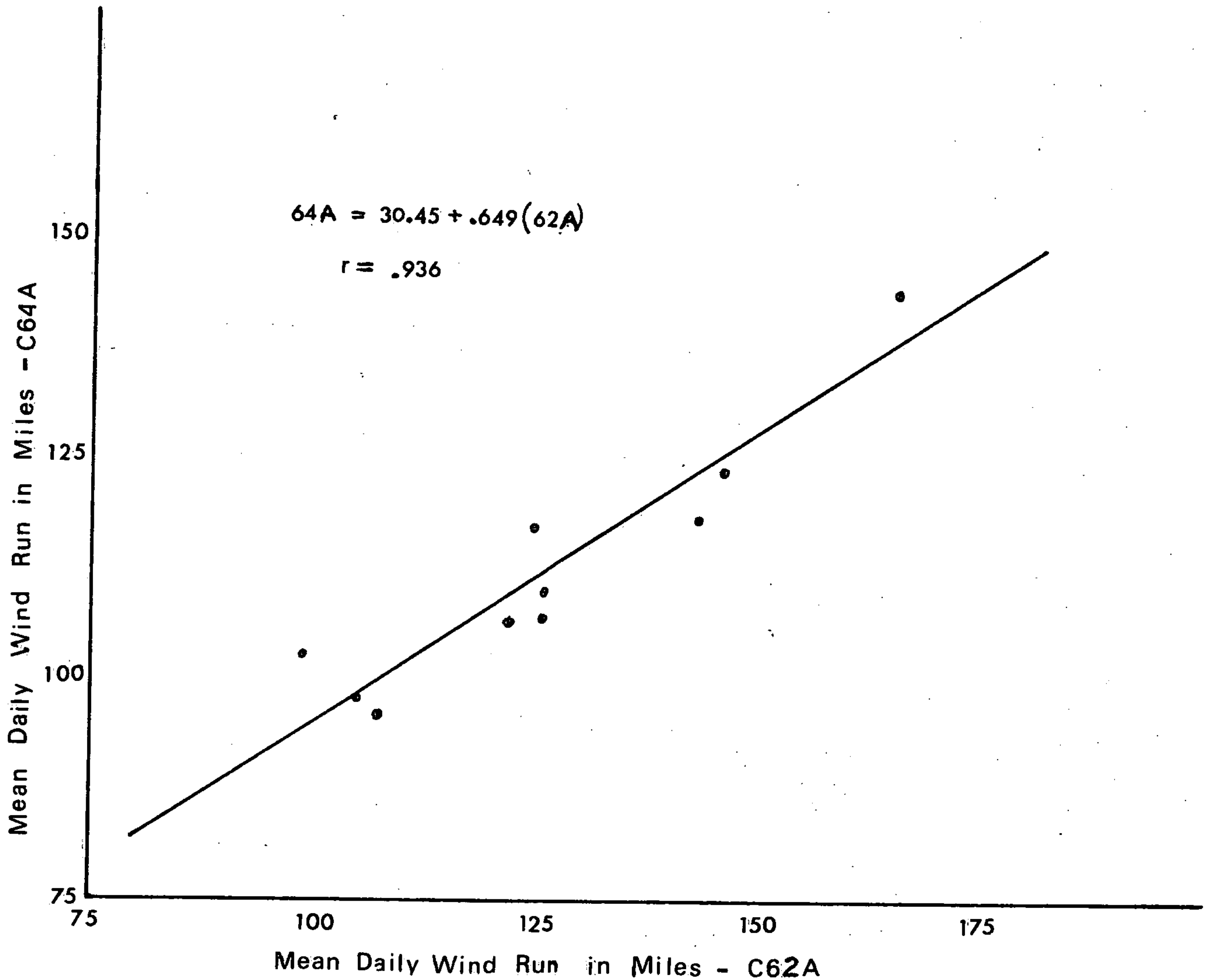

Figure 3. Comparison of tower-top winds at towers C62A and C62B.

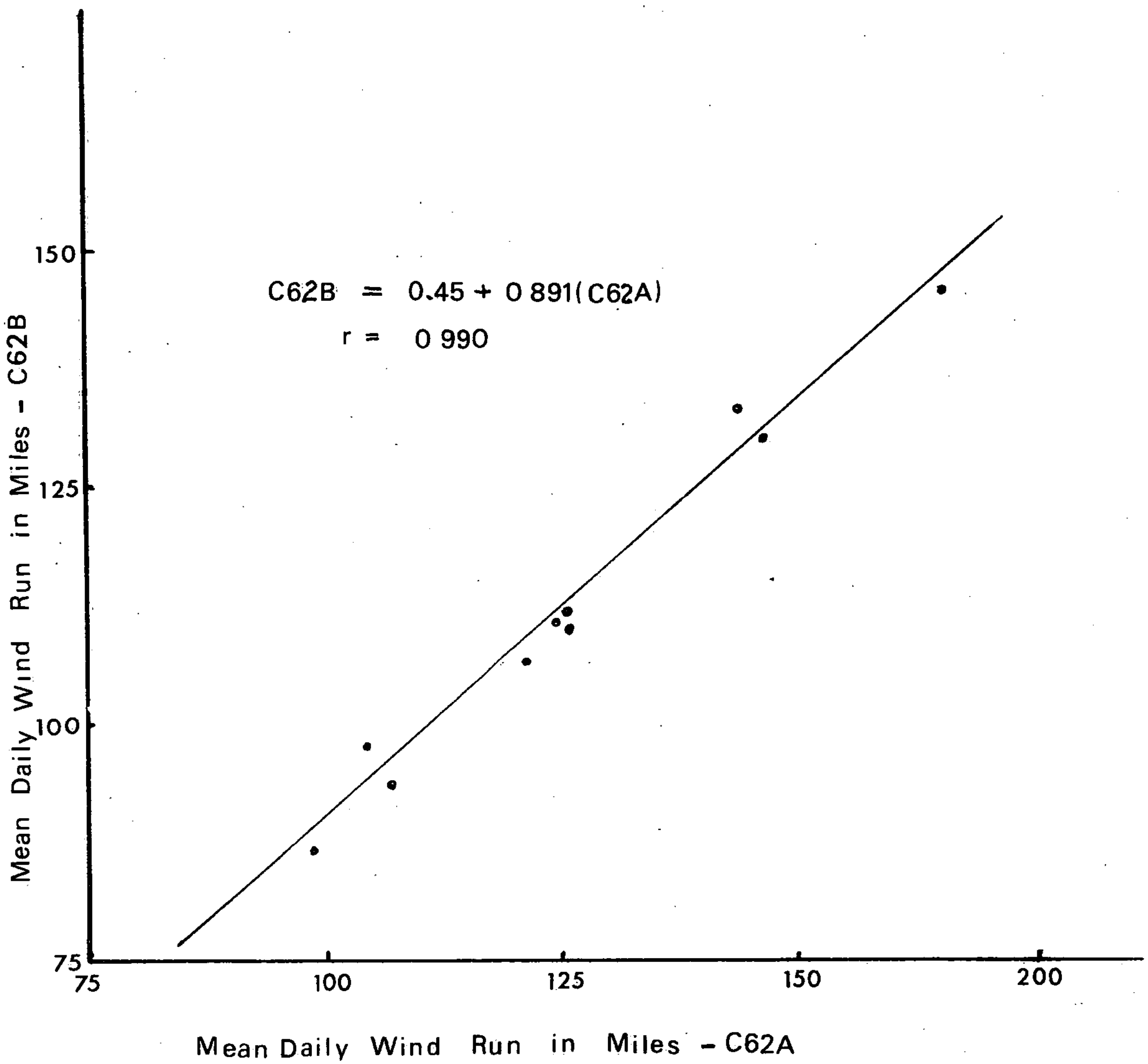

Figure 4. Comparison of tower-top winds at towers C62A and C62B.

Tower top winds

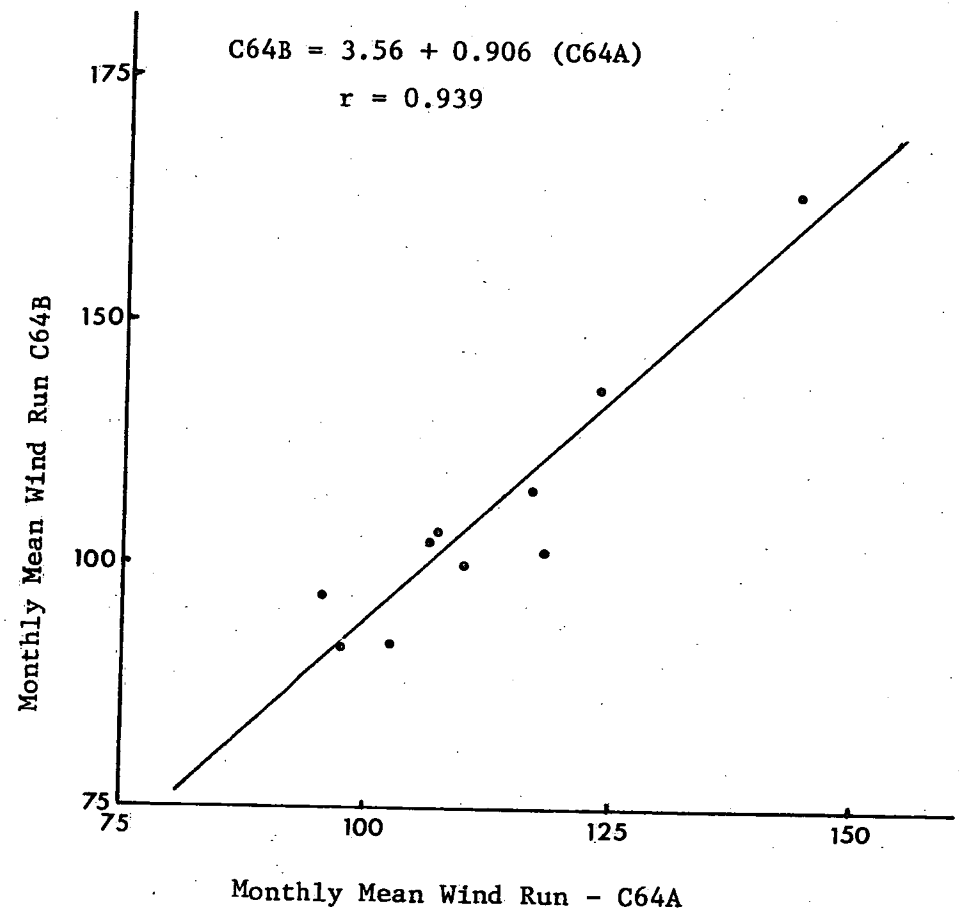

Figure 5. Comparison of tower-top winds at C64A and C64B.

study by Storr and contrary to the usually expected pattern. Figures 6, 7, 8, and 9 show the relationships between tower-top winds and the lower level winds for the fifteen days when all anemometers were operating.

The vertical profile of all winds in a 100 day sample at C64A in the cut-over areas fits the power law:

$$V_1 = V_2 \left(\frac{Z_1}{Z_2} \right)^P$$

with P = 0.469, while at C62A with only the top and bottom levels available, assuming a power law relationship, estimate of P = .30. The whole profile is lower in each case than Storr's predicted value, which might have been anticipated since the increased frictional effect due to greater roughness will affect the wind speed downwards from the gradient wind level at a height several times that of the towers. Vertical profiles of mean winds for a sample of 100 days are shown in Figures 10a and 10b. Only the tower-top and 10 foot levels are available for C62A.

Vertical profiles of stronger winds (tower top hourly winds $\geq$ 15 m.p.h. at either C62A or C64A) show considerable variation when these stronger winds are sorted by direction (as measured at the tower top) as shown in Table 1. Some significant differences show up at the 10 ft. level, especially at station C62A, where a marked sheltering effect is evident with north and northwest winds as compared to southwest and south winds. At C64A, the uncut forest extends around the northwest, west and south sides. Since strong winds from the northeast, east and southeast are so infrequent, no conclusive measure of the effect was possible at C64. The few occurrences of winds from these directions and from the west and northwest give very low or negative values of P. This suggests the possibility that stationary eddies are formed with these winds.

Table 1. Values of Exponent P at C62A and C64A for 8 Wind Directions.

Wind Direction	C62A				C64A			
	103' vs. 66'		103' vs. 10'		103' vs. 70'		103' vs. 10'	
	No. of Hours	P**	No. of Hours	P	No. of Hours	P	No. of Hours	P
N	0	-	0	-	7	.109	6	-.092*
NE	0	-	0	-	0	-	0	-
E	0	-	0	-	1	.398	1	.067*
SE	0	-	0	-	12	.492	12	.510
S	60	.396	66	.177	57	.530	56	.547
SW	184	.195	206	.135	132	.540	132	.511
W	0	-	2	.190*	1	1.450	1	-.058*
NW	11	1.097	28	.643	8	.041	8	-.081*

* Samples consisting of less than 10 hours may not be representative
** P is the exponent in the power law equation
Negative values of P indicate winds decreasing with height

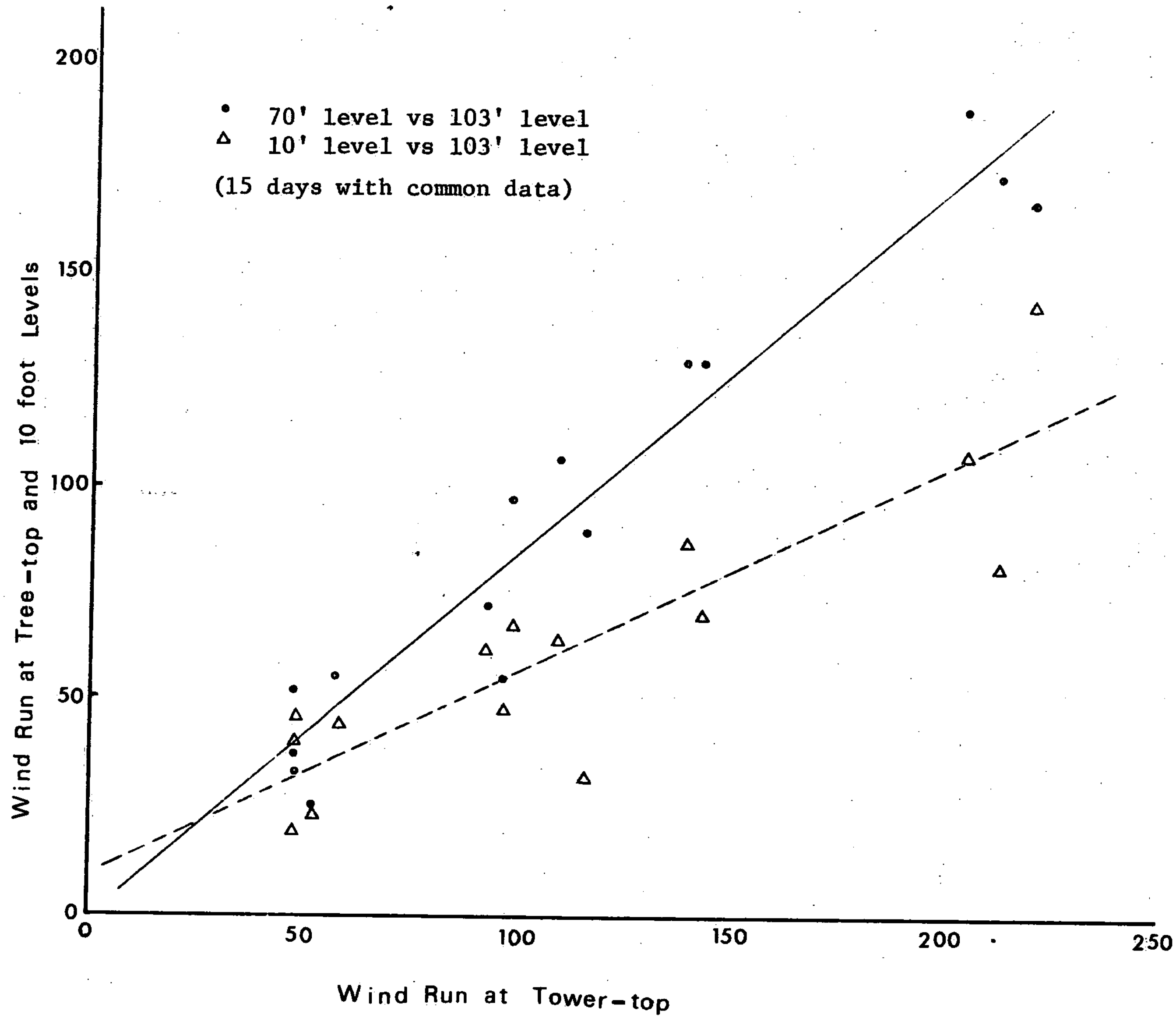

Figure 6. Comparison of winds at tree-top and 10 foot levels with tower-top winds - C62A.

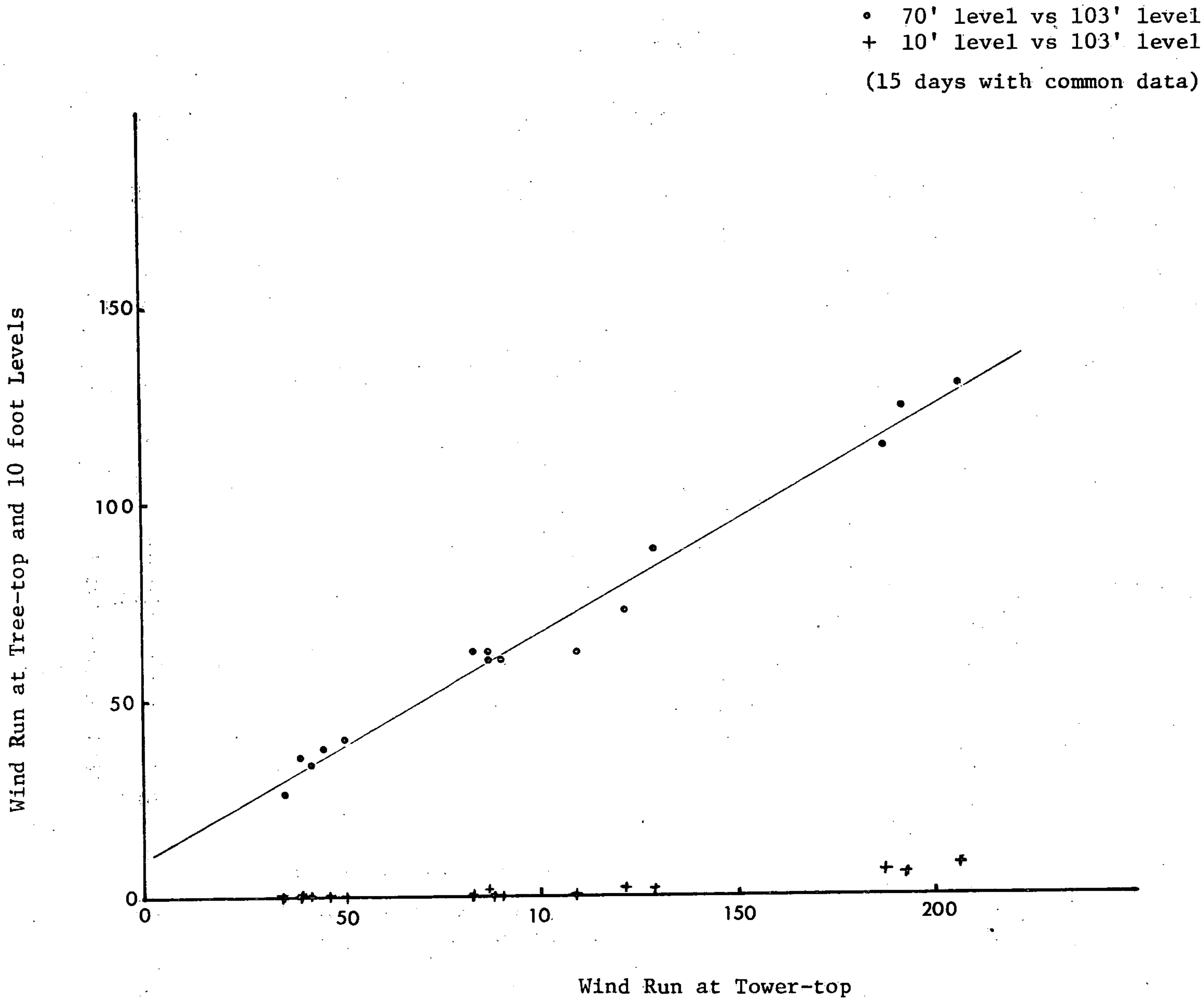

Figure 7. Comparison of winds at tree-top and 10 foot levels with tower-top winds at C62B.

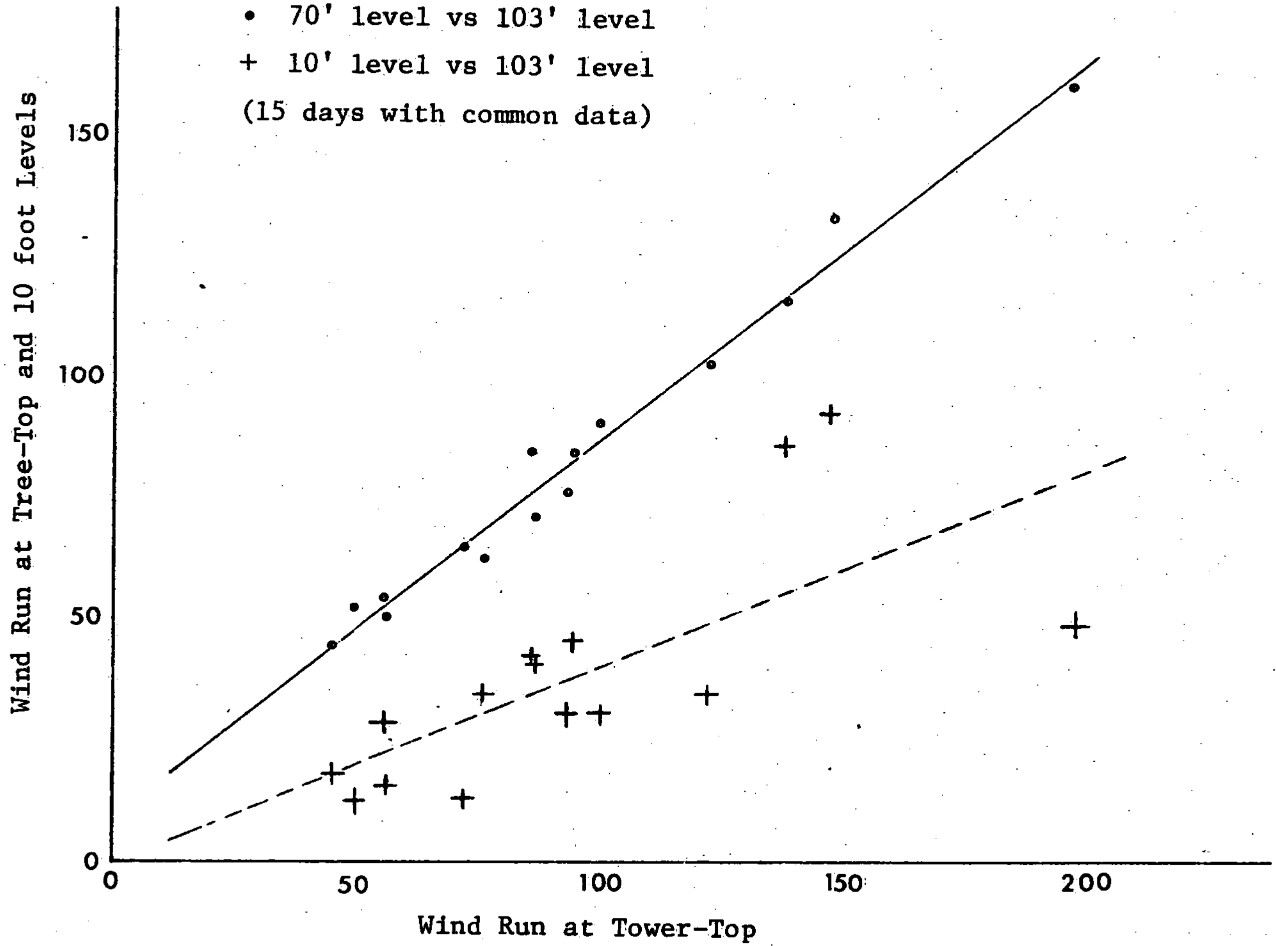

Figure 8. Comparison of winds at tree-top and 10 foot levels with tower-top winds at C64A.

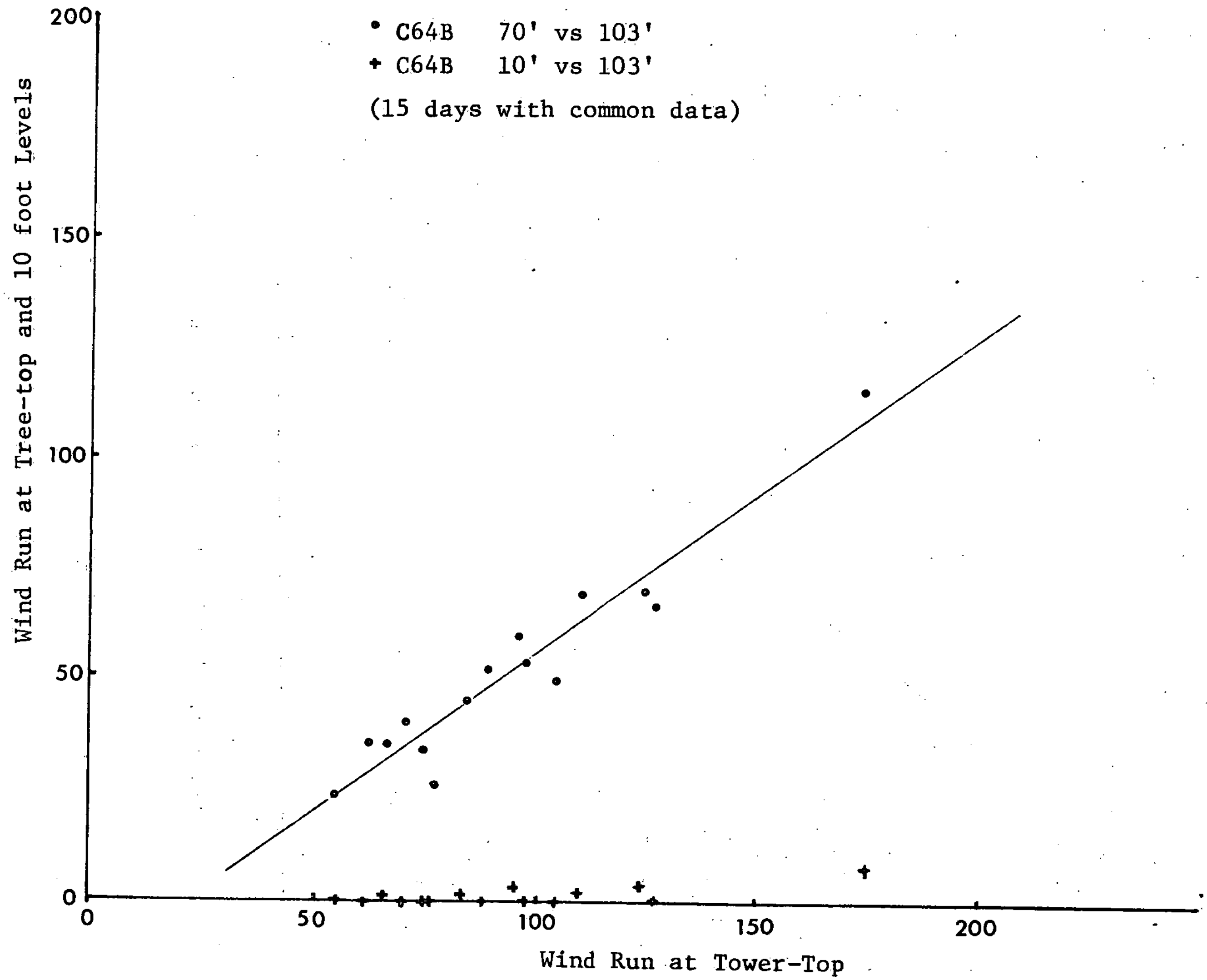

Figure 9. Comparison of winds at tree-top and 10 foot levels with tower-top winds at C64B.

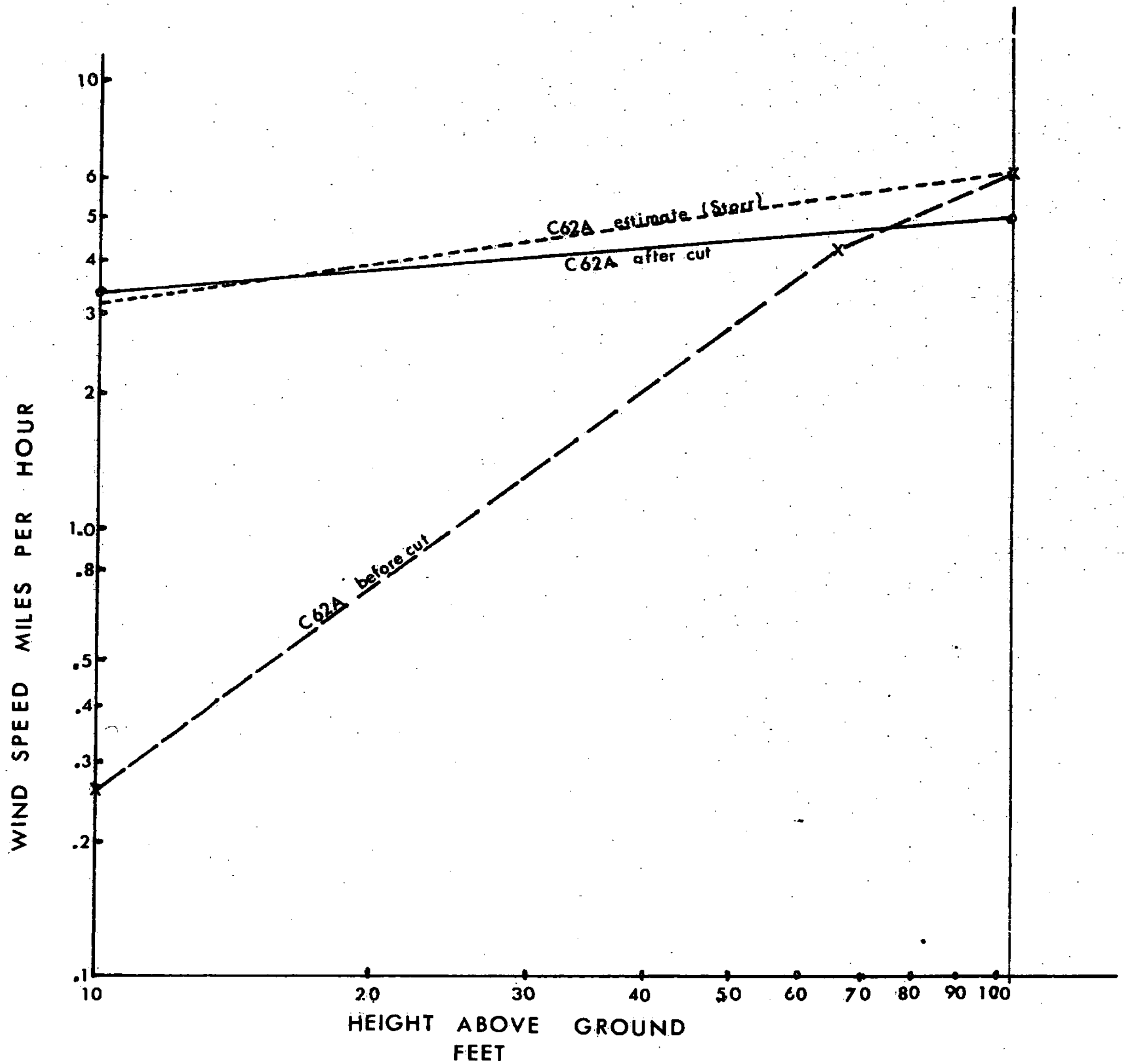

Figure 10a. Vertical wind profiles - C64A.

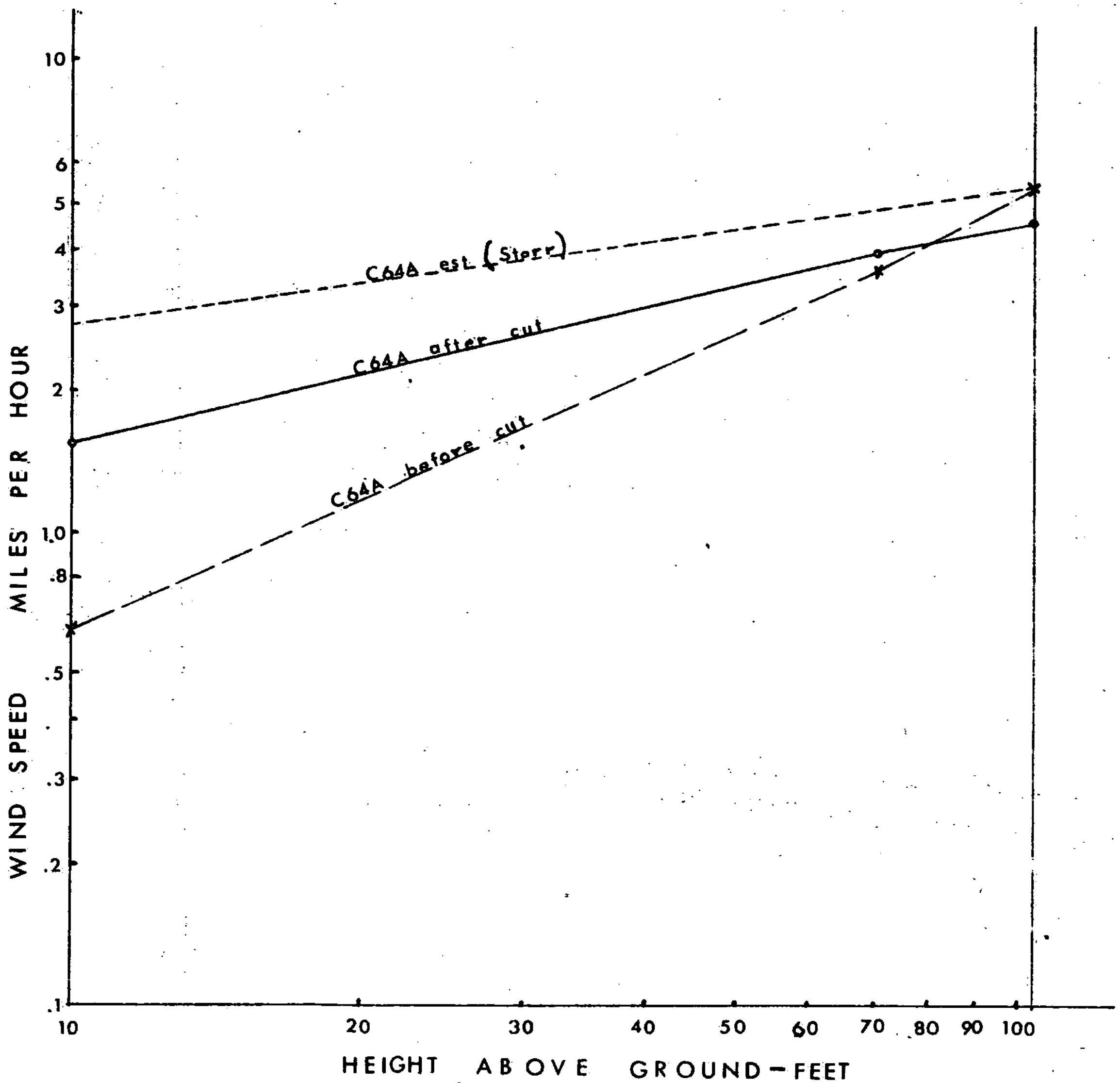

Figure 10b. Vertical wind profiles - C64B.

Winds and Precipitation

Winds recorded at the top of C62A were examined for all hours when precipitation at station Con 5 near the confluence of the branches of Marmot Creek was .03 in. or more. Table 2 shows the distribution of hourly precipitation amount vs hourly wind run, while Table 3 shows the distribution by wind direction. It is clearly evident that most of the precipitation falls with relatively light winds.

Table 2. Frequency of precipitation intensity by wind speed classes at C62A.

One hour precipitation	Wind speed class 0-3	4-9	10-18	>18	All winds
.03-.05	49	52	20	1	122
.10	23	12	8		43
.15	2	3	1		6
.20	1	2			3
.25	1				1
	76	69	29	1	175

Table 3. Frequency of precipitation intensity by wind direction at C62A.

One hour precipitation	Prevailing wind direction								
	NW	W	SW	S	SE	E	NE	N	C
.03-.05	6	6	15	36	19	10	8	14	8
.10	10		3	8	4	5	5	6	2
.15				2	1	3			
.20			1	1					1
.25		1							
	16	7	19	47	24	18	13	20	11

CONCLUSIONS

1. It appears likely that the roughness parameter for the whole test area has been increased by clearcutting blocks. This will cause a slight reduction of the wind speeds at and above tree top level over much of the sub-basin and into adjacent areas.

2. The average wind speed profile in large cut areas approximates a power law relationship above the 10 foot level.

3. The test cutting has introduced increased variability in the wind speeds at "tree top" level and tower top level.

4. Wind speeds at the 10 foot level in the cut-blocks show a marked variability with wind direction. Where the stand is dense and 60 to 70 feet tall, the sheltering effect in moderate to strong winds extends downwind for at least 150 feet.

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WATERSHED TREATMENT TO ALTER SNOW ACCUMULATION AND MELT RATES

by

Douglas L. Golding

ABSTRACT

The James River study in Alberta has shown that snow accumulation and melt rates can be greatly influenced by the size of opening cut in the forest. With the uncut forest as control and circular openings of 1/4-6 tree heights (H) in diameter, 1-3H openings accumulated the greatest depth of snow, and 3/4-1H openings had the slowest melt rates.

The results of the James River study were applied to West subbasin of Streeter basin to accumulate snow in areas cleared for grazing by domestic cattle and big game animals. First-year results showed that more snow was held in small cut patches than in larger natural openings or in treed areas.

Cut blocks on Cabin subbasin of Marmot Creek accumulated significantly more snow than would have been the case had there been no cutting, even though the cut was designed to simulate commercial harvest, not to increase snowpack. Treatment of Twin subbasin was designed on the basis of results from the James River study to concentrate snow in openings and to decrease the overall melt rate. The objective is to prolong snowmelt recession flow and to delay the time of peak runoff. Treatment consists of clearing 40% of the forest in 2500 circular openings of 3/4-1 1/4 tree heights in diameter.

WATERSHED TREATMENT TO ALTER SNOW ACCUMULATION AND MELT RATES

by

Douglas L. Golding[1]

INTRODUCTION

Regulation of stream flow through watershed management in Alberta and large parts of North America is dependent on snowpack management. Timber harvesting changes wind patterns (hence snow accumulation) and energy input (hence snowmelt rates). Review of the literature reveals many studies relating forest-opening size or shape to snow accumulation, e.g., Kittredge (1953), Anderson (1956), Anderson, Rice and West (1958), Hoover and Shaw (1962), Stanton (1966), Swanson and Stevenson (1972), and Meiman and Dietrich (1975). The problem is that many of these studies had no replication, used irregularly shaped natural openings, or were in unique topographic situations. Results were sometimes apparently in conflict and extrapolation was difficult.

This paper reports on:

(1) a study of snow accumulation and melt in a replicated number of various-sized openings carried out on level terrain 130 km NW of Calgary (the James River study area)
(2) the application of the results of the James River study to the treatment of Streeter basin experimental watershed, and first-year results
(3) snow accumulation in clear-cut blocks on Cabin subbasin of Marmot Creek experimental watershed
(4) the application of the James River study results to the treatment of Twin subbasin of Marmot Creek.

SNOW ACCUMULATION IN SMALL FOREST OPENINGS-JAMES RIVER STUDY

Objective

The objective of this study was to determine snow accumulation and ablation in circular forest openings of 1/4 tree height (H) to 6H in diameter. From the literature it was recognized that the potential for snowpack management dropped off rapidly at 6H and larger. Circular

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openings were used so that the opening offered the same width to winds of all directions.

Method

The study area (Fig. 1) is very flat, supporting a homogeneous stand of lodgepole pine of approximately 20m average height. The foothills of the Rocky Mountains begin to rise about 11 km to the west. Nine opening sizes (1/4, 1/2, 3/4, 1, 2, 3, 4, 5, and 6H) plus uncut control were located in random order along each of 10 transects 200 m apart. Distance between opening centers was a minimum of 200 m (sometimes greater to avoid proximity to seismic exploration lines crossing the area).

Beginning in 1969, openings were laid out on the ground, trees were felled, and slash was burned. For all openings, for the control, and for the forest surrounding the openings, snow measurements were made on the four cardinal directions radiating from the opening center. For openings greater than 1/2H, measurements were also made on lines radiating out from the center in NE, SE, SW, and NW directions. Each opening greater than 1/2H was divided into equi-area rings within which, on the directional lines noted above, measurement points were located at random distances from the ring edge. Measurement points were not located at random distances in the surrounding forest but at fixed distances beginning at 1.8m from the edge and going out as far as 40.2 m in the case of the largest opening (Fig. 2).

Snow water equivalent (w.e.) and depth were recorded using a Mt. Rose snow sampler. Measurements were taken each year at maximum accumulation, midway through the melt season, and near the end of the melt season, 1973-1976.

In 1976, 14 openings of 1H were cleared to determine the effect of close spacing on snow accumulation. The openings were located on four lines so that their edges were 20.1 m apart (Fig. 3). Measurements were made on these plots and on 1H openings and control plots of the main study at maximum accumulation, midway through the melt season, and near the end of the melt season, 1977.

Results

At annual maximum snowpack, least accumulation was in the uncut forest control, rising steadily to a maximum in the 2H (except for 1974 when it was in the 3H), then dropping off gradually to 6H (Fig. 4). Averaged over the 4 years, 3/4H and 6H accumulated 34% and 32% more w.e. respectively than did the control; the intervening sizes registered an even greater increase, to a maximum of 45% more in the 2H (Table 1). The last measurment of the season, averaged for the 4 years, indicates that when there is no snow left in the forest there is still 3.68 cm w.e. in the 2H and even more, 4.11 cm,

Table 1. Mean snow accumulation and ablation by forest-opening size, 1973-76

Opening	Mean snow w.e. at Maximum pack, 1973-76		Mean ablation rate, 1973-76
(H)	(cm)	(% of OH)	(% of 1H)
Control	8.18	100	131
1/4	9.35	114	118
1/2	9.86	120	108
3/4	11.00	134	103
1	11.25	138	100
2	11.86	145	115
3	11.73	143	131
4	10.97	134	132
5	10.95	134	138
6	10.82	132	135

Table 2. Snow accumulation in closely-spaced 1H openings by location and compared to main study 1H and OH openings, 1977

Location	Snow w.e. 1977, in centimetres		
	March 14	April 5	April 13
Closely spaced 1H openings	8.5	8.6	2.0
Perimeter	8.7	8.6	2.3
Center	8.3	8.4	1.3
North side	8.6	8.8	2.5
East side	8.4	8.8	2.0
South side	8.4	8.9	2.3
West side	8.6	8.5	2.3
Main study 1H openings	8.6	8.9	1.8
Main study OH openings	5.6	5.8	0.0

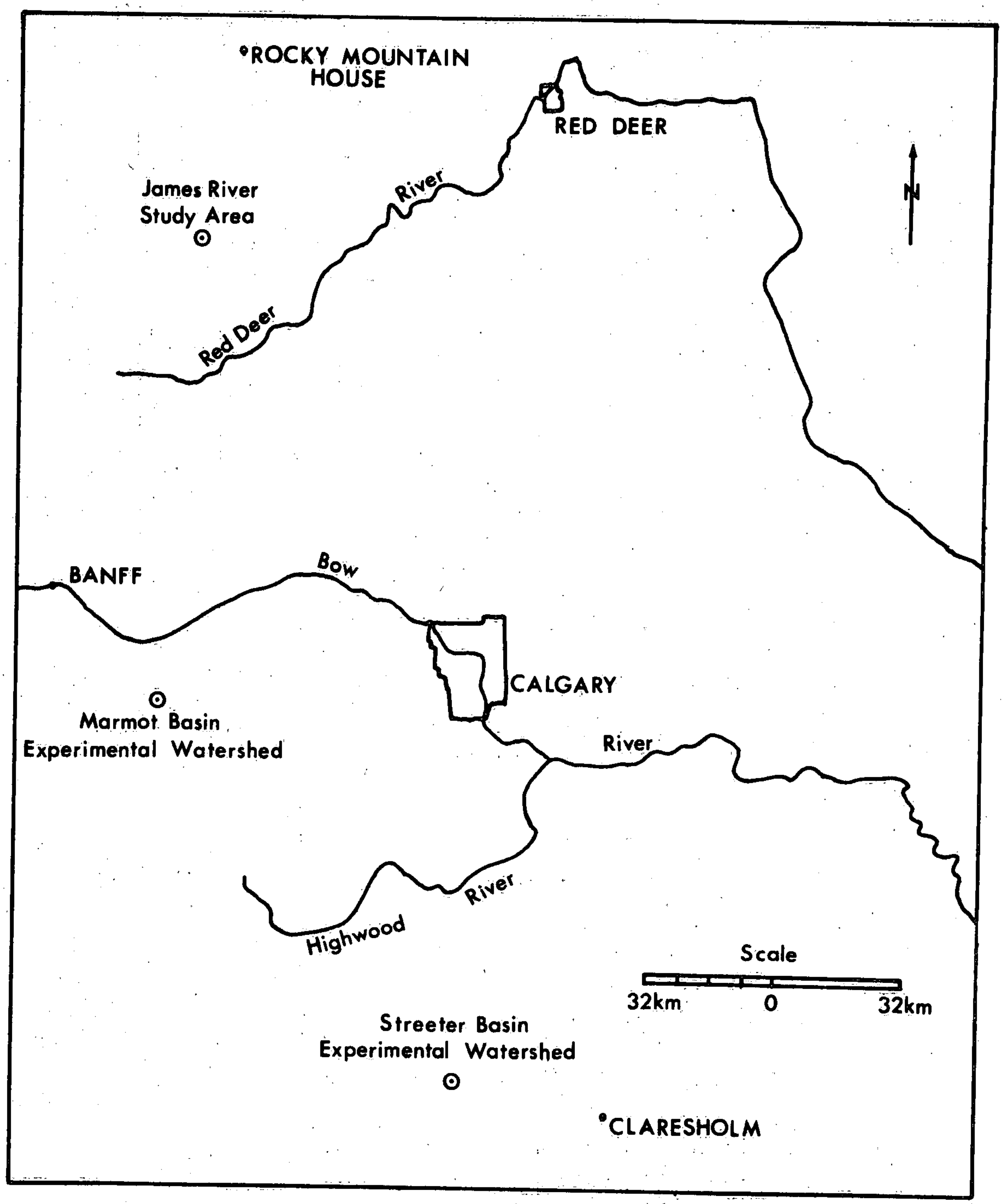

Fig.1. Map of western Alberta showing study locations.

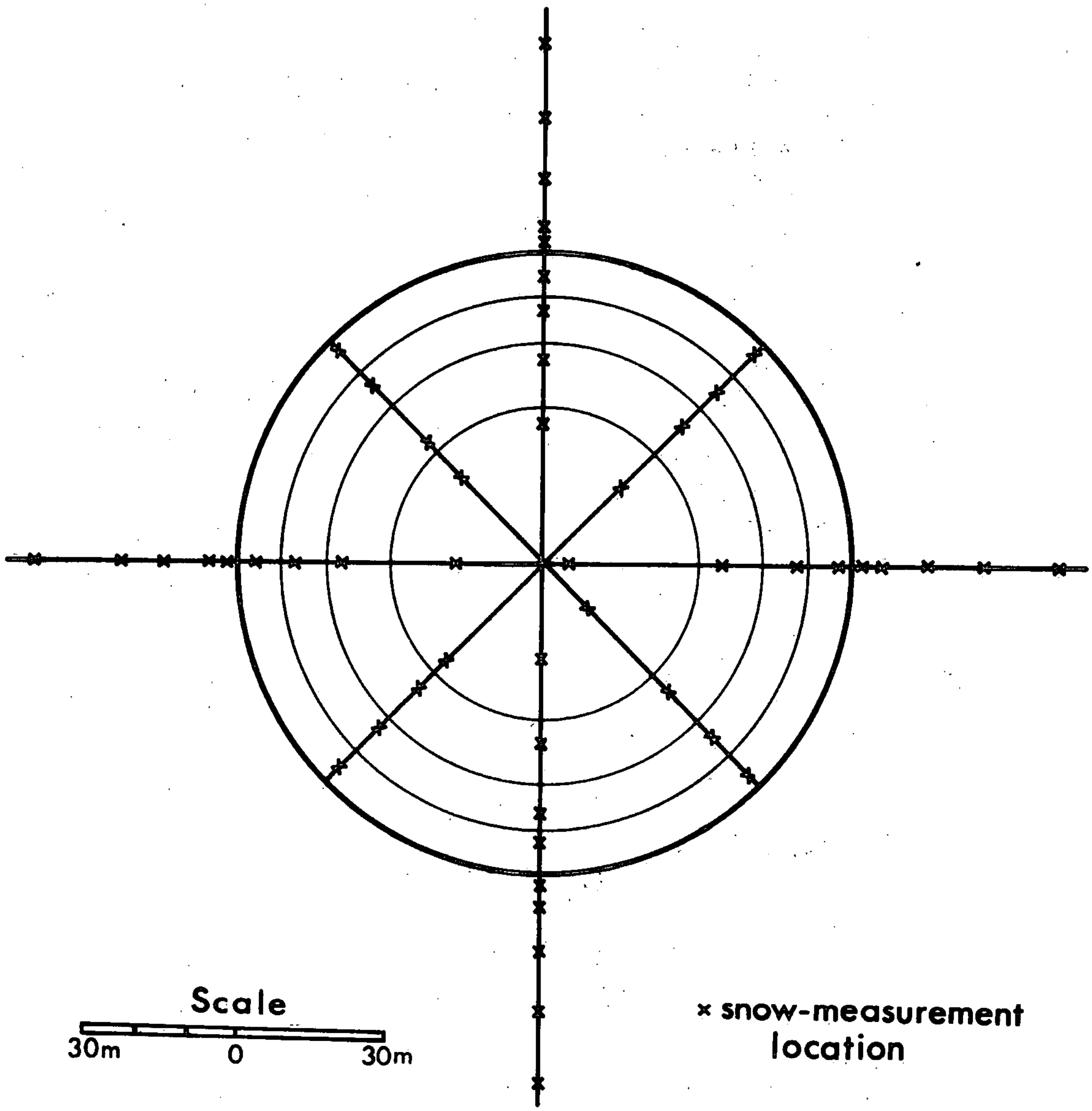

Fig. 2. Snow-measurement locations in a 6H opening.

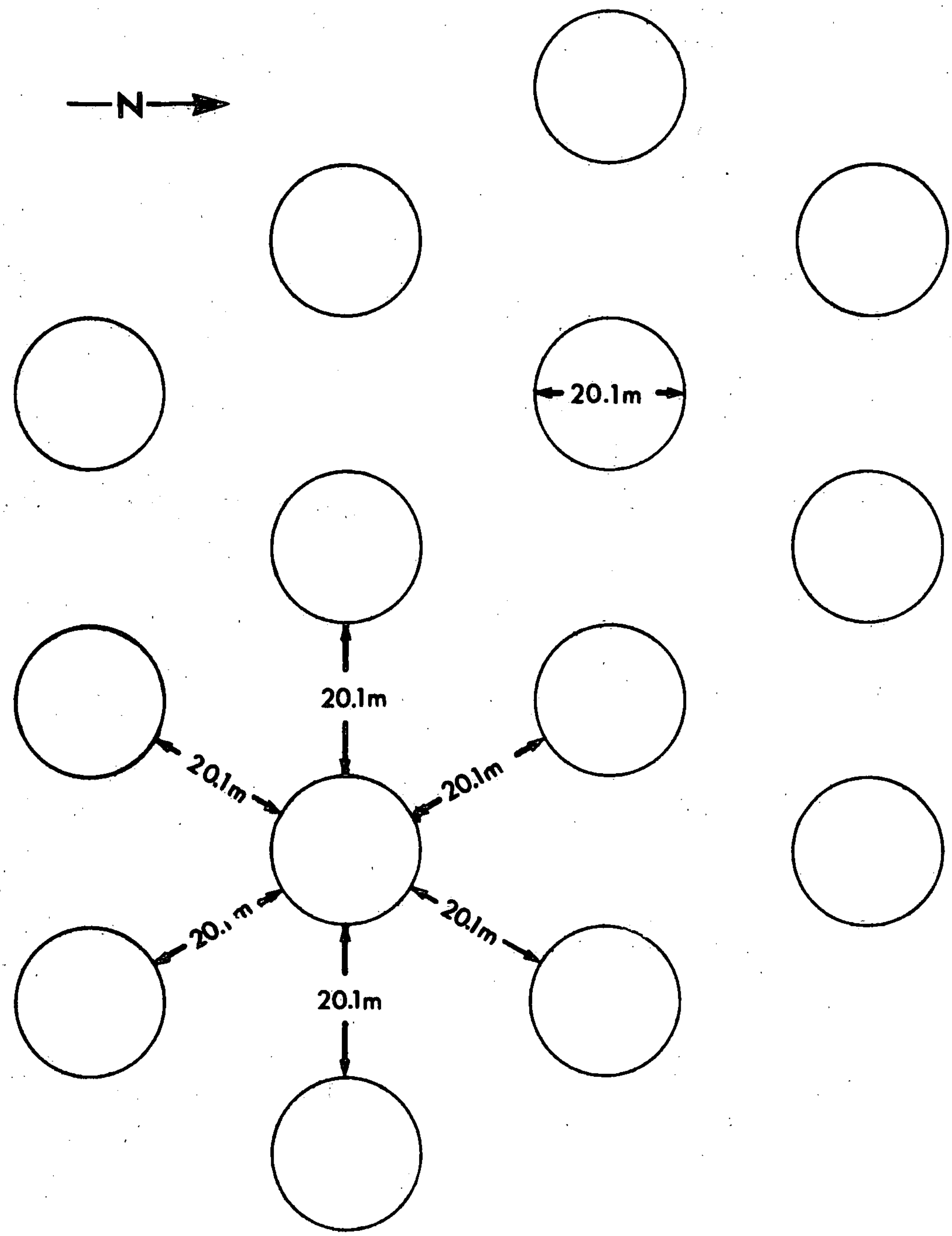

Fig. 3. Closely-spaced 1H openings at James River study area.

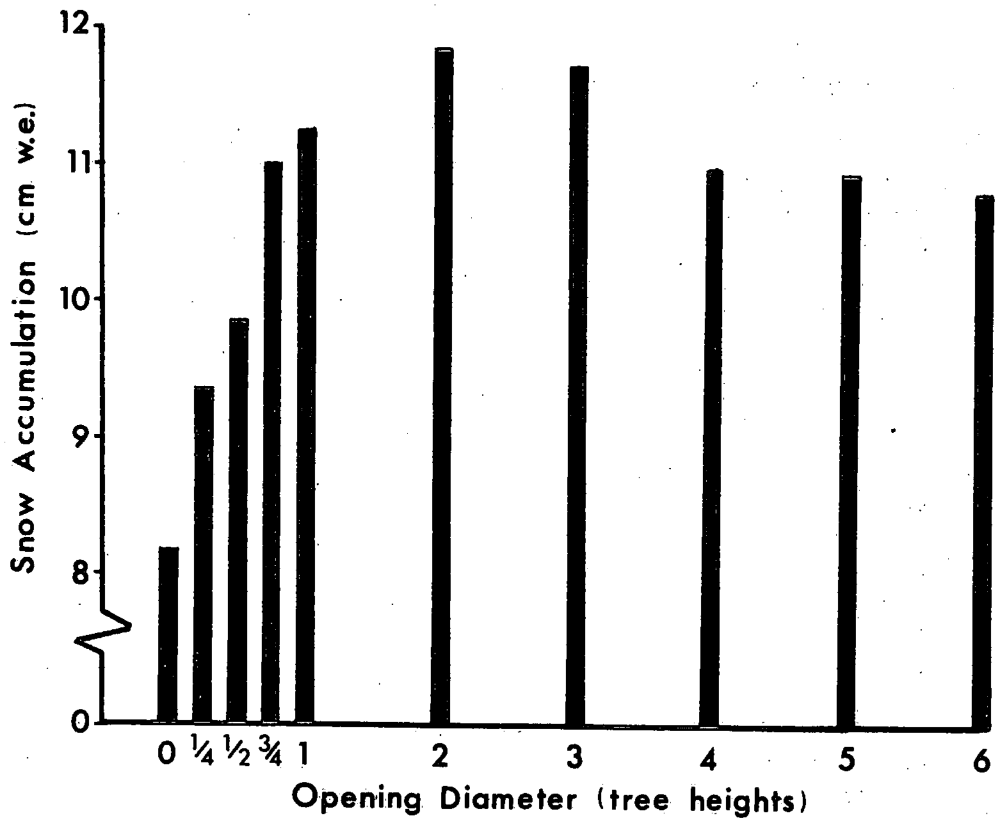

Fig. 4. Mean maximum snow accumulation, 1973-1976, in forest openings at James River.

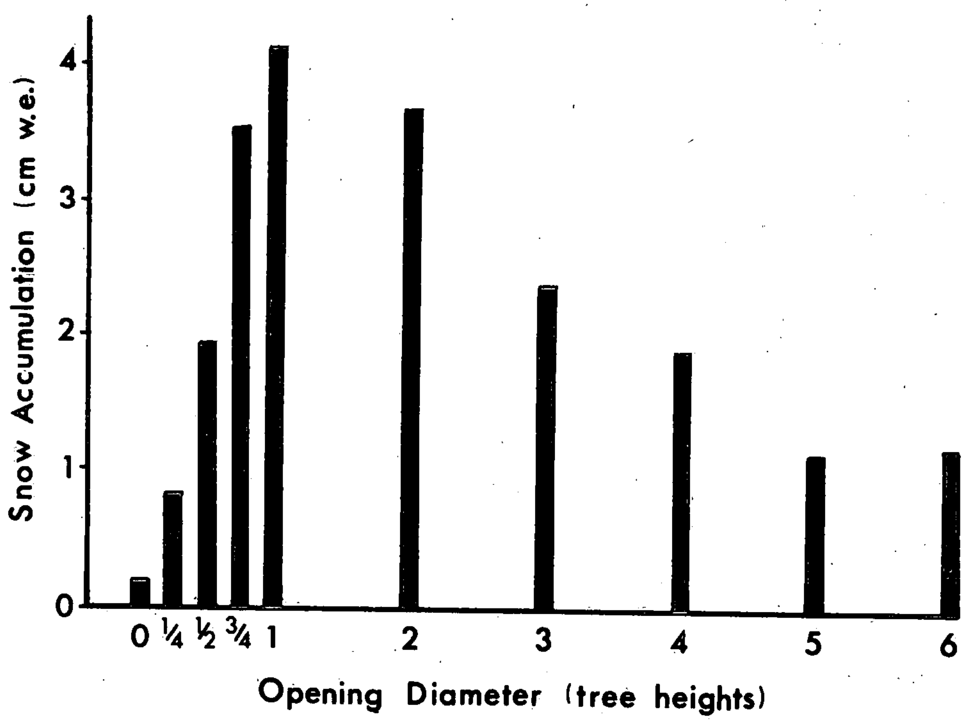

Fig. 5. Mean snow accumulation at last measurement of the season, 1973-1976, in forest openings at James River.

in the 1H opening (Fig. 5).

Daily ablation rates followed the same trend from year to year, but different melt-season weather resulted in variation in level from year to year. Highest ablation rates were in the control and 3-6H openings (Table 1). In the control, the ablation rate was 31% greater than in the 1H, the opening with the lowest rate. The rate dropped gradually from 1/4-1H and rose rapidly to 2H (15% greater than 1H) and 3H (31% greater than 1H) to a maximum of 38% greater in the 5H. In terms of absolute values, the greatest melt rate was in the 3H in 1974, 0.76 cm/day.

There was less snow in the forest surrounding each opening than in the opening itself. Minimum accumulation occurred in the north quadrant of the surrounding forest, maximum accumulation in the south quadrant. At the time of maximum accumulation there was more snow in the control than in the forest surrounding the openings except in the 1H opening. However, when the snow has completely melted in the control, there is usually snow remaining in the forest surrounding the openings.

For the 14 closely spaced 1H openings, location within the group did not affect snow w.e. at maximum pack (April 5). The 10 openings around the perimeter of the group accumulated 8.6 cm w.e. compared with 8.4 cm w.e. for the four openings inside the perimeter (Table 2). Openings on the south side averaged 8.9 cm w.e., those on the north and east sides 8.8 cm, and on the west side 8.5 cm. The mean for the 14 openings, 8.6 cm w.e., is essentially the same as the 8.9 cm w.e. accumulated in the more widely spaced 1H openings of the main study area. However, by April 13, when melt had progressed substantially, differences were apparent. The four openings in the center of the group contained only 1.3 cm w.e. compared to 2.3 cm w.e. in the 10 openings along the perimeter. The average for the 14 openings was 2.0 cm w.e. By this time, the uncut controls have lost all of their snow, whereas there is still 1.8 cm w.e. remaining in the widely-spaced 1H openings of the main study. Of particular interest here is the comparison between the four center openings and the 10 perimeter openings. Center openings accumulated as much snow as perimeter openings, but melt rates were faster at the center This may be caused by insufficient shading from the openings to the south. If this were the case, the north-side openings should also exhibit a faster melt rate, which they did not. Further elucidation of this awaits measurement of the 1978 snowpack.

TREATMENT OF STREETER BASIN EXPERIMENTAL WATERSHED

Introduction

Streeter basin was established as an experimental watershed in 1963 to consider the problems of water supply on areas cleared for forage production (Jeffrey 1965). The vegetation is representative of the montane-aspen transition between mixed prairie and coniferous subalpine forest. The main tree species are aspen and black poplar, which attain heights of 20m on lower slopes but on windswept ridges reach only 4.5-7.5 m. Shrub stands range from 1.5-4.5 m. Forest and shrub stands are interspersed with grasslands.

The basin, located in the Procupine Hills 100 km SSW of Calgary (Fig. 1), is 598 ha in area. Of the three subbasins, West was designated for treatment aimed at improving range condition for cattle and wildlife while maintaining or prolonging summer streamflow. The hydrologic goal was to be met by manipulating vegetation in such a way as to (a) concentrate snow in given areas to retard sublimation and melt, and (b) enhance infiltration of snowmelt by reducing snow accumulation in groundwater discharge areas and increasing it in recharge areas. The range goals included rejuvenating shrub stands to improve existing browse and herbage production in small patches for maximum wildlife use.

Treatment

Treatment was based on the results of the James River study and consisted of cutting patches in the poplar stands of 1 1/2-2H width by 60-180 m in length (Fig. 6). The long axis was oriented normal to the direction of high-velocity winds that are responsible for the redistribution of fallen snow. Strips of approximately equal width were left uncut between openings, and trails were cut between patches to facilitate movement by cattle and big game. In shrub stands, strips of 3-5 m width were cleared. Stems were sheared off at ground level by tractor blade to promote suckering. Slash was piled and burned in the patches but was left on the ground in the strips.

As part of the program to assess the effect of the treatment, snow courses were established running through cut and uncut patches on the treated (West) subbasin and through treed and natural openings on East subbasin, both on east-facing slopes at the same elevation (Fig. 6). Natural openings on East subbasin are approximately 60 m wide by 200 m long. Only one snow survey was made in 1977, on March 3.

Results

The snowpack on Streeter basin is usually ephemeral, appearing and disappearing throughout the season, at least in the lower parts of the basin. This year (1977) it was even more so, with much less than average pack. However, the results of the one snow survey indicated that the treatment did accomplish what was intended for snow accumulation: snow was trapped in the openings and held for the snowmelt period.

On West subbasin, cut openings accumulated 5.8 cm snow w.e., or 135% of the 4.3 cm w.e. in the uncut area (Table 3). On East subbasin, natural openings accumulated 2.0 cm, or 53% of the 3.8 cm w.e. in the treed area. The large natural openings on the East subbasin did not hold snow as well as the treed area, and had only 35% of that in the cut patches of West subbasin. The treed areas on East and West subbasins held similar amounts of snow, 3.8 and 4.3 cm w.e. respectively.

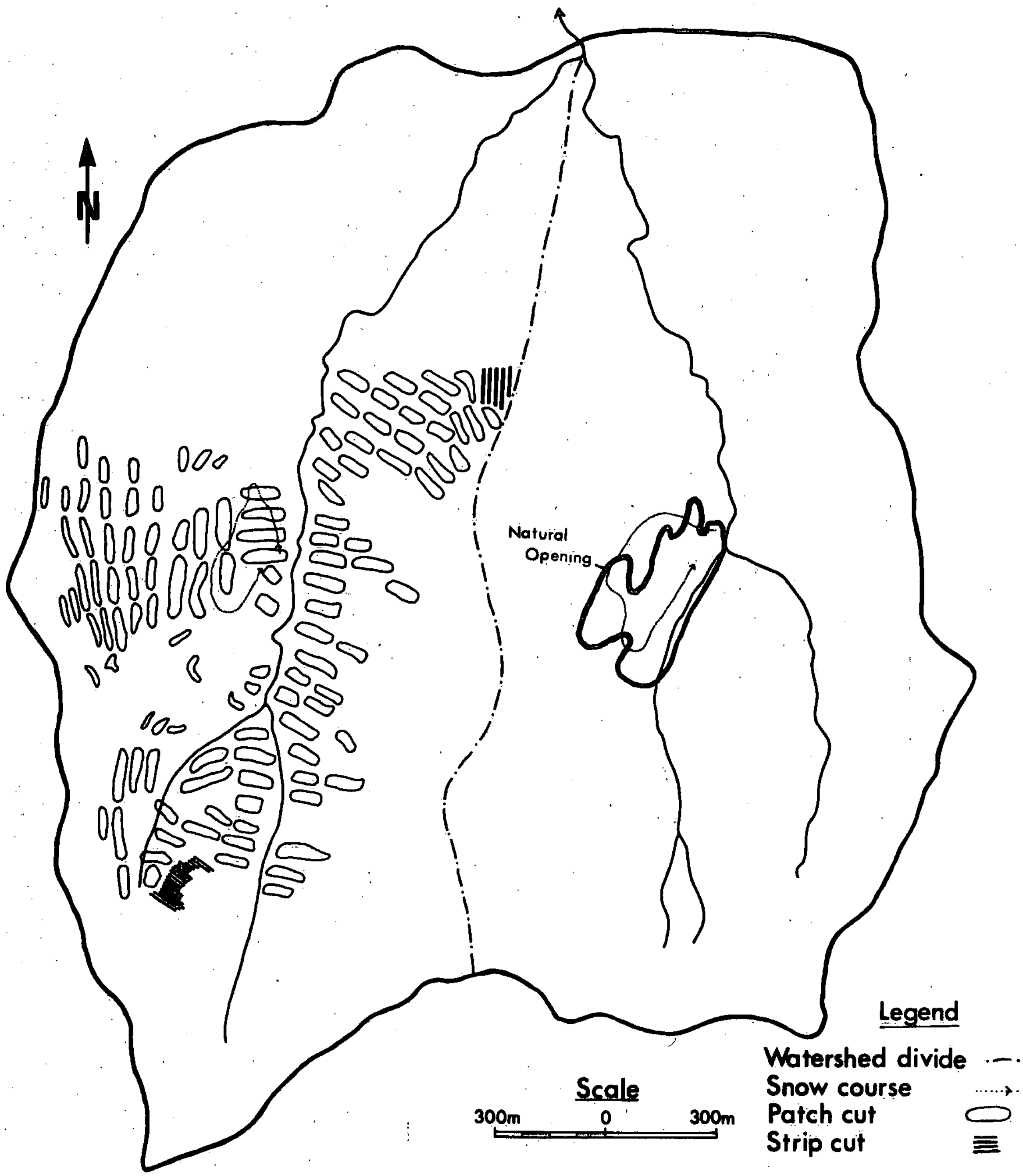

Fig.6. Streeter basin experimental watershed showing treatment.
(Twp 13 Rge 1 W 5)

Table 3. Snow accumulation in openings and treed areas of East and West Streeter subbasins, March 3, 1977

Location	Number of Samples	Snow-water equivalent
		(cm)
West subbasin		
Cut openings	17	5.8
Treed areas	20	4.3
East subbasin		
Natural openings	32	2.0
Treed areas	13	3.8

SNOW ACCUMULATION IN CUT BLOCKS ON CABIN SUBBASIN OF MARMOT CREEK BASIN

Marmot Creek experimental watershed was established in 1962 to study the hydrology of subalpine spruce-fir forests (Jeffrey 1965). It is located about 40 km SE of Banff, Alberta (Fig. 1) and is composed of three subbasins, each about 260 ha in area.

Treatment

In 1974, treatment was applied to Cabin subbasin to simulate a commercial harvest. Six blocks totalling 55 ha were were clear cut (Fig. 7), ranging in size from 3 to 13 ha. Blocks were 150-275 m wide and 200-450 m long.

Method

In 1969, an intensive snow survey was begun in order to study the patterns of snow accumulation as they relate to topography and stand density and to treatment. Samples were taken on a 20-m (east-west) X 200-m (north-south) grid within the forested part of the basin in the third week of March each year. In 1972, in anticipation of the commercial harvest of Cabin subbasin, sampling intensity was increased in those areas designated for logging by changing the north-south sampling interval from 200 m to 100 m.

Snow w.e. was calibrated, using Middle subbasin mean snow w.e. as control, for each of five of the cut blocks, for the five cut blocks combined, for the adjacent area (within 60 m of the cut blocks), for the uncut part of Cabin basin, and for Cabin basin as a whole (cut and uncut areas). Calibration consisted of constructing a regression describing the relation between snow w.e. on the area of interest and on the control area for the period of pretreatment record.

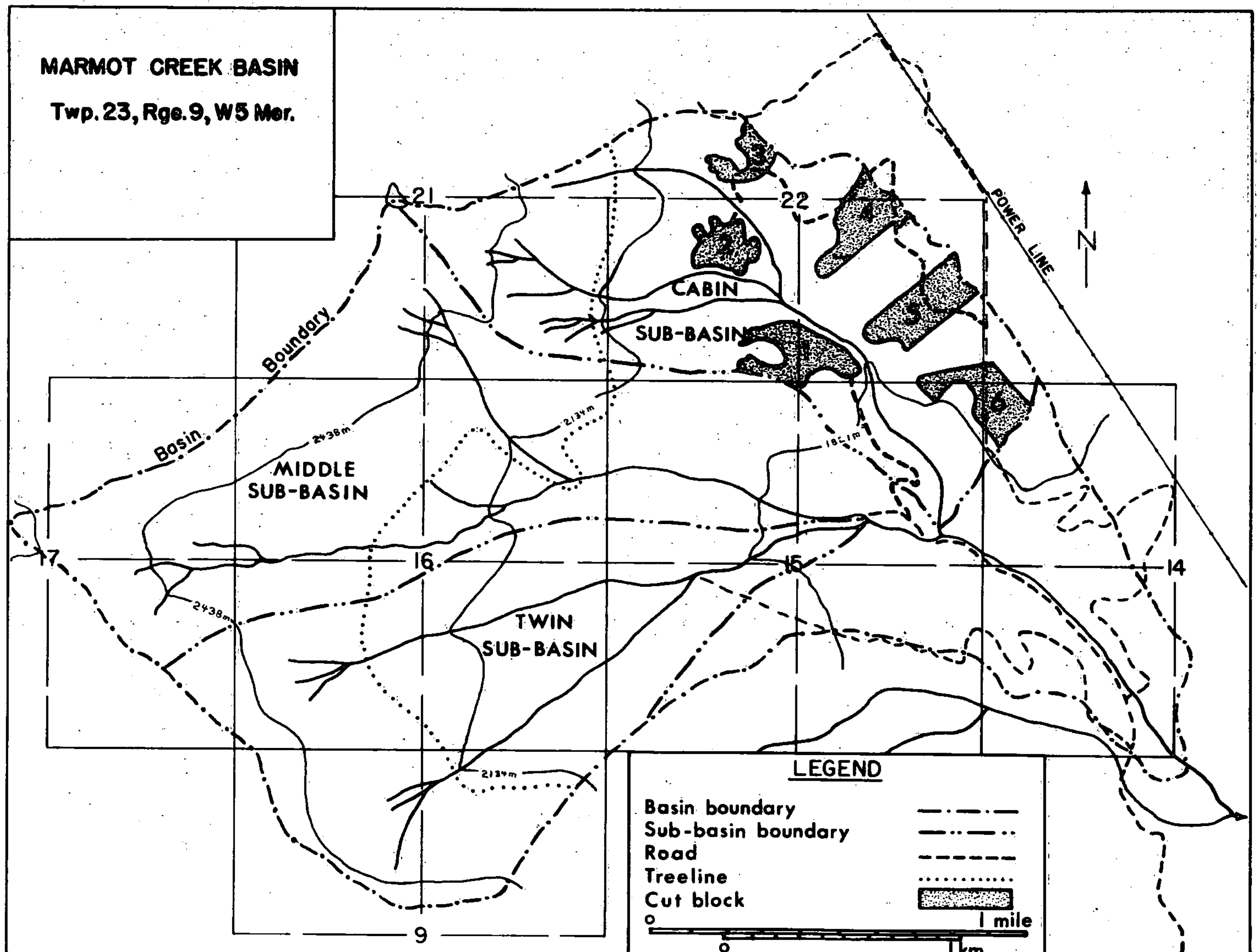

Fig. 7. Marmot Creek basin showing cut blocks on Cabin sub-basin.

After treatment the regression was used to predict the w.e. for the treated areas as if the pretreatment relation still held. The difference bewteen the predicted and the observed was tested statistically to determine if the change were significant at the chosen level of probability, and therefore attributable to the treatment. The 90% level of probability was chosen for this study. The longer the period of record, both pre- and posttreatment, the smaller the difference that may be statistically significant. For most of the measurement points on Cabin subbasin there is a 6-year pretreatment record (1969-1974). However, for those points added to intensify sampling in the areas designated for cutting there is only a 3-year pretreatment record (1972-1974).

Results

Of the five cut blocks, all but one (No. 5) accumulated significantly more snow than predicted for no treatment, and though that one had more snow, the increase was not significant (Table 4). All cut blocks combined had significantly more snow than predicted. Where did the additional snow come from? Of the five areas adjacent to the cut blocks (i.e., within 60 m of the cut) none had significantly different snow accumulation than predicted, two having slightly more and three slightly less. The mean observed accumulation for the five adjacent areas exactly equalled the predicted. So the additional snow in the cut blocks was not at the expense of snow adjacent to the cuts. The total uncut part of Cabin subbasin had slightly (but non-significantly) less snow than predicted, but Cabin subbasin as a whole had a significant increase over predicted.

Twin subbasin had slightly less snow (0.28 cm w.e.) than predicted. Middle subbasin was used as control in the snowpack calibration except in determining a predicted snow w.e. for itself, in which case it was calibrated on Twin subbasin. It had slightly more snow (0.33 cm w.e.) than predicted. In neither Twin nor Middle were the differences between observed and predicted snowpack significant.

The evidence indicates that the additional snow in the cut blocks cannot be attributed to redistribution from adjacent areas. Is it due to snow that would have been intercepted by tree crowns and ultimately would have evaporated? Large losses have been attributed to this process. In lodgepole pine in the Colorado Rockies, 32% of seasonal snowfall was attributed to interception loss (Wilm and Dunford 1948). Miner and Trappe (1957) reported that 24% of snowfall was intercepted in lodgepole pine in eastern Oregon. Others, however, have reported much lower interception losses, e.g., 5% in Douglas-fir and white pine in Northern Idaho (Satterlund and Haupt 1970), and 10% in the Central Sierra Nevada (Anderson 1967). Hoover and Leaf (1967) attributed the increase in snow accumulation in cut blocks at the Fraser Experimental Forest in Colorado to redistribution,

Table 4. Observed and predicted snow w.e. on Cabin subbasin for 1975-1977

Area	Mean w.e. 1975-1977		Difference (cm)
	Observed (cm)	Predicted (cm)	
Block 1			
Cut	19.0	14.7	4.3*
Adjacent	15.5	14.7	0.8
Block 2			
Cut	18.8	15.2	3.6*
Adjacent	15.2	15.7	-0.5
Block 3			
Cut	21.1	16.3	4.8*
Adjacent	20.1	18.3	1.8
Block 5			
Cut	16.5	15.2	1.3
Adjacent	15.0	15.2	-0.2
Block 6			
Cut	15.2	13.0	2.2*
Adjacent	13.0	14.0	-1.0
All cut blocks	18.0	14.7	3.3*
All adjacent areas	15.7	15.7	0.0
Cabin basin uncut	15.0	15.5	-0.5
All Cabin basin	16.3	15.2	1.1*

*Significant at the 90% level of probability based on 3-year posttreatment record.

not to interception loss.

On Marmot Creek it is unlikely that a significant amount of evaporation from the snowpack on the ground could occur during winter months due to radiation (Storr 1968). However, Satterlund and Eschner (1965) suggested that the differences in the energy and vapor balances between snow in tree crowns and on the ground are sufficient to account for considerably greater losses from intercepted snow. Evaporation from snowpack on the East Slopes during chinooks can exceed 12 cm w.e. over the winter (Golding 1977), several times the amount of the increase in the cut blocks on Cabin subbasin. However, seldom does intercepted snow remain in the tree canopy on Marmot Creek for more than a day (except in a few isolated sheltered locations) because the wind blows it off and redistributes it. Also, when snow is in the crowns at the onslaught of a chinook, it quickly warms up and slides off the branches to the ground.

It is difficult to accept that interception loss is responsible for all of the 22% increase of observed over predicted snow accumulation in the cut blocks, even though calibration results indicate it is not due to redistribution from the adjacent forest.

TWIN SUBBASIN TREATMENT

The forest manager is presently limited to harvesting practices that are known to speed up snowmelt and to increase flow on the rising limb of the spring hydrograph. These practices can be used to augment total flow or to desynchronize flow from several catchments entering a single river. Desynchronization can lengthen the time span of the spring freshet by producing more water prior to the aggregate peak flow from the several catchments. In many instances it would be desirable to augment flow after the peak.

The treatment of Twin subbasin of Marmot Creek has been designed to prolong recession flow from snowmelt and to delay the time of peak runoff. This is to be done by creating a microenvironment conducive to concentration of snow and reduction of its overall melt rate. The treatment, which will be applied during 1977-1978, consists of cutting the trees from approximately 40% of the forested area of the subbasin in 2500 circular openings. The openings will be 12.2 and 18.3 m in diameter (depending on whether the height of the stand is less than or greater than 15.2 m respectively). In terms of tree heights, the opening diameters will range from about 3/4 - 1 1/2 H. Results from the James River study indicate that this size range should allow the objectives of the treatment to be attained.

SUMMARY

The James River study in Alberta has shown that snow accumulation and melt rates can be greatly influenced by the size of opening cut in the forest. For the uncut forest control and circular openings of 1/4-6 tree heights (H) in diameter, 1-3H openings accumulate the greatest depth of snow, and 3/4-1H openings have the slowest melt rates.

The results of the James River study were applied to West subbasin of Streeter basin to accumulate snow in areas cleared for grazing by domestic cattle and big game animals. First-year results show that more snow was held in cut patches than in natural openings or in treed areas.

Cut blocks on Cabin subbasin of Marmot Creek accumulated significantly more snow than would have been the case had there been no cutting, even though the cut was designed to simulate commercial harvest, not to increase snowpack. Treatment of Twin subbasin was designed on the basis of results from the James River study to concentrate snow in openings and to decrease the overall melt rate. The objective is to prolong snowmelt recession flow and to delay the time of peak runoff.

ACKNOWLEDGEMENTS

I wish to acknowledge the help of W.C. Cumberland, L. Fisera, L.A. Lafleur, and B.E. Robson for field measurements and office compilation.

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EFFECT OF LARGE-SCALE CLEAR-CUTTING ON WATER YIELD IN WESTERN ALBERTA

by

R.H. Swanson and G.R. Hillman

ABSTRACT

The streamflow from nine partially clear-cut and nine uncut control catchments on the North Western Pulp and Power Company's lease near Hinton, Alberta, was measured during 1974. The water yield from the clear-cut catchments was 187 mm compared to 147 mm from the controls, a difference that was statistically significant at the 80% confidence level if all data are lumped, or at the 95% level if data are stratified by locality. This 27% difference in water yield compares favorably with the average increase noted on similarly harvested experimental catchments in the U.S. and Africa of 29%.

This increase, from a 135-km^2 sample of 900 km^2 of clear-cutting since 1954, is similar in magnitude to that obtained after massive tree death following a bark beetle attack on the 1882-km^2 White River Watershed in Colorado. Results of both studies lend some support to the extrapolation of small experimental catchment results to large drainage basins.

EFFECT OF LARGE-SCALE CLEAR-CUTTING ON WATER YIELD IN WESTERN ALBERTA

by

R.H. Swanson and G.R. Hillman[1]

INTRODUCTION

Clear-cut harvesting of forests is an established silvicultural practice throughout much of Canada. Several forested experimental watersheds in the United States and elsewhere have been harvested in various clear-cutting configurations to determine the effect of this practice on water yield. The average annual yield increase noted on 10 experimental watershed studies given in Table 1 is 29%. This result should be indicative of the effect that one can expect from clear-cutting elsewhere.

Clear-cutting has been the harvest method on the Northwestern Pulp and Power Company Limited (NWPP) lease near Hinton, Alberta since 1954. By 1974, approximately 90 000 ha had been clear-cut in a patchwork pattern dispersed over 7800 km^2. We were able to delineate over 100 catchments on the lease that had been partially clear-cut. The existence of so many treated watersheds concentrated in a reasonably homogenous vegetation and climatic zone presented an opportunity that we felt was unique in North America to verify, on a much larger areal scale than could ever be achieved using classical experimental research, the increase that forest clear-cutting causes in water yield.

The objective of the study reported here was to verify that anticipated water yield increases of 20-30% following clear-cut harvesting actually occurred. This was accomplished by gauging the streamflow from a number of logged and nonlogged control catchments and by comparing their yield difference using the "t" statistic. In this paper we describe the lease area, sampling program, and the results of this study. A more complete account is given by Swanson and Hillman (1977).

GENERAL DESCRIPTION OF THE FOREST MANAGEMENT AREA

Pulp Lease and Operation

The NWPP lease area is located east of the Rocky Mountains near Jasper National Park between latitudes 53 and 54°N, and longitudes 116 and 118°W (Fig. 1). It supports spruce-lodgepole pine forest typical of the Lower Foothills (B.19a) and Upper Foothills (B.19c) sections of the Boreal Forest Region (Rowe 1972). Growing stock over the lease by areal percent-

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Table 1. Percentage area harvested and annual streamflow as percentage of annual percipitation for 10 experimental watersheds (adapted from Hibbert 1967)

Watershed	Area ha	Location	Area clear-cut %	% precipitation as streamflow not harvested (NH)	harvested (H)	ratio H/NH
Coweeta 13	16.1	North Carolina USA	100	43	64	1.49
Coweeta 3	9.2	North Carolina USA	100	33	40	1.21
Coweeta 22	34.4	North Carolina USA	50	62	71	1.15
Fernow 1	29.9	W. Virginia USA	85	38	47	1.24
Fernow 2	15.4	W. Virginia USA	36	44	48	1.09
Fernow 7	24.2	W. Virginia USA	50	54	60	1.11
Wagon Wheel Gap	81.1	Colorado USA	100	29	36	1.24
Fool Creek	289.0	Colorado USA	40	37	48	1.30
Kamakia	35.2	East Africa	100	28	51	1.82
Kenya	688.0	East Africa	34	22	27	1.23
			69.50	39.00	49.20	1.29

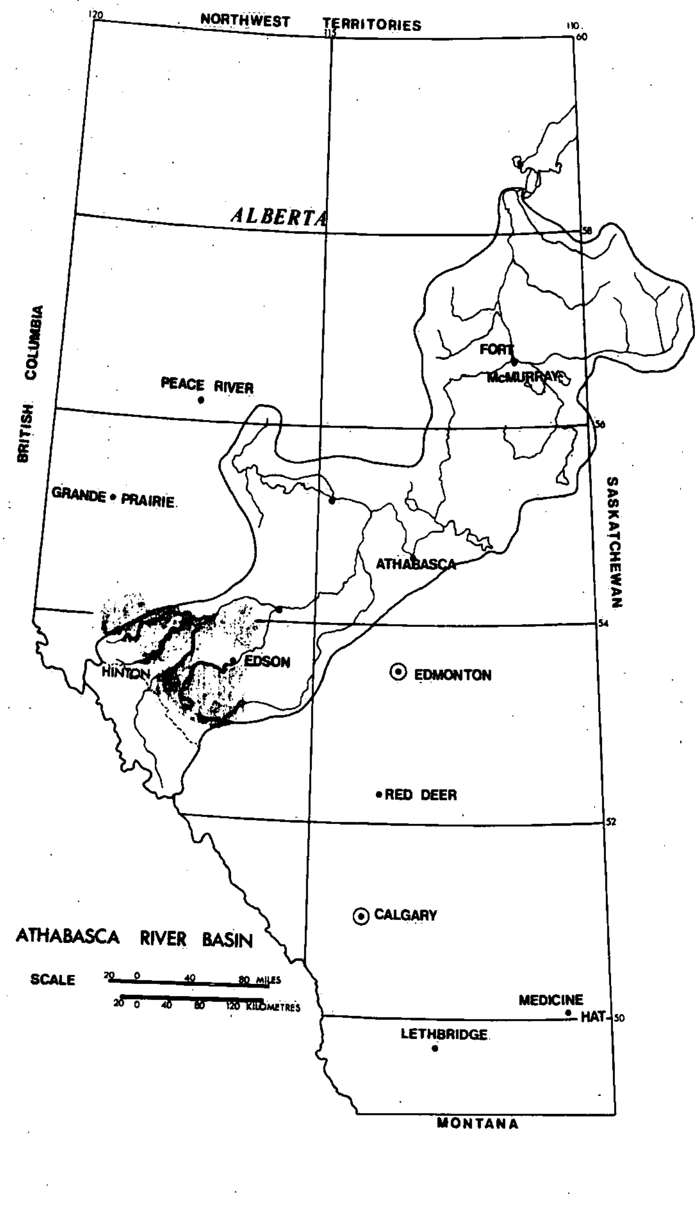

Fig. 1. Location of the North Western Pulp and Power Company Ltd. lease in the Athabasca River Basin. The shaded area includes both the current management portion (7773 km^2) and an additional 7800 km^2 provisionally allocated to the company.

age is 53% lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.), 19% white spruce (Picea glauca (Moench) Voss.), 8% black spruce (P. mariana (Mill.) B.S.P.), 5% alpine fir (Abies lasiocarpa (Hook.) Nutt.), 9% Populus spp., and 6% standing dead trees (MacArthur 1968).

The lease is divided into five working circles (Fig. 2). A working circle is further divided into a number of compartments, each containing an estimated timber volume at harvest time of 12 500 000 m^3. The company extracts an annual harvest of 900 000 m^3 (the timber on approximately 4500 ha) from one or more compartments each year (Crossley 1972; MacArthur 1968). The boundaries of these compartments generally coincide with historical fires that created a large number of even-aged stands. At maturity these stands appear remakably uniform in height and density. The trees are from 17 to 20 m tall, 1000 to 1500 stems/ha.

The initial harvest in each compartment took roughly 50% of the area in alternate 16- to 25-ha clear-cut strips or blocks (Fig. 3). The leave strips or blocks are being removed in a second cut. In 1974, near the end of the first 20-year cutting cycle, large clear-cut blocks up to 1400 ha existed, but not all timber had been removed from most areas. The company must leave a buffer strip adjacent to both sides of designated streams and other designated water bodies. Also, some of the timber, mainly the Populus species, is undesirable under current milling practices and is not harvested. Nor is timber removed from slopes too steep for extraction without severe damage to the soil. Therefore, even when clear-cutting is completed, timber may remain on about 5-40% of the surface area.

Climate

The climate is continental with long, cold winters and short, cool summers. Annual precipitation averages between 500 and 550 mm, of which about 30% occurs as snow between October and April (Alberta Environment 1974). Mean annual and mean summer temperatures are 2-3 and 8-12^{o}C respectively.

Hydrology

Summer precipitation and hydrographs for 1974 from three different-sized watersheds covering the major elevation zones of the lease are given in Fig. 4. (These rivers and streams are not gauged from freeze-up through breakup, roughly November through April.) The Wampus Creek and McLeod River hydrographs show that approximately one-half of the total seasonal streamflow arises from snowmelt (snow on the ground at the end of April 1974 was 158 mm, water equivalent) and from mixed rain and snow during May. All three hydrographs are from watersheds relatively free of harvest influence in 1974, as none had occurred in the 27.2-km^2 Wampus catchment or in the 966-km^2 Wildhay watershed, and less than 10% of the 2610-km^2 McLeod watershed had been harvested.

The hydrograph from the Wildhay River has been included to illustrate the differing runoff pattern that this predominately alpine watershed produced compared to those patterns of the lower elevation forested areas

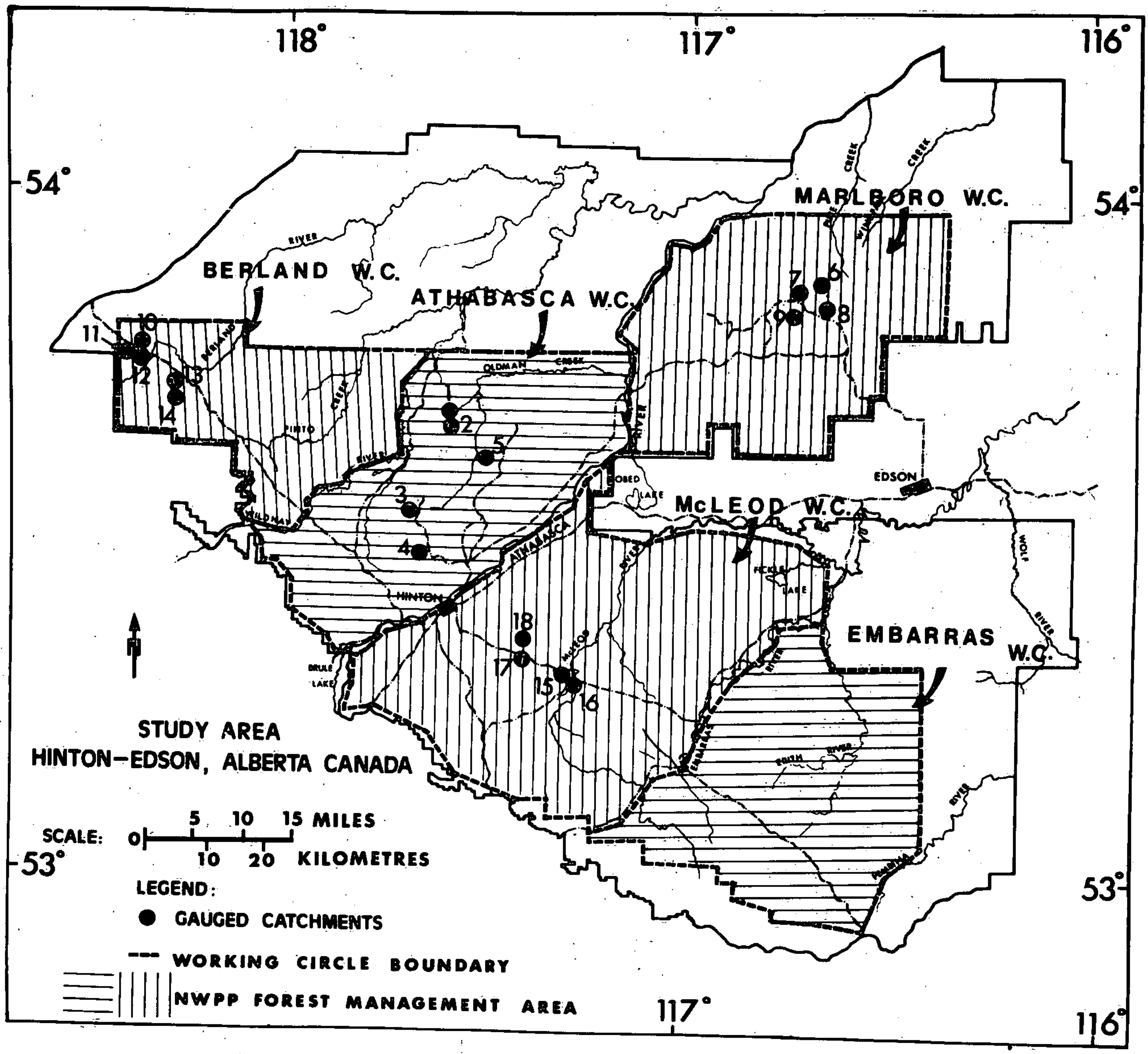

Fig. 2. Working circle boundaries and gauged catchment locations, NWPP lease area. The crosshatched portion is currently under lease agreement with the Province of Alberta; the remainder is subject to negotiation.

Fig. 3. A sample of the cutting pattern on the Athabasca working circle that exists midway through and at the end of a cutting cycle. The strip in the foreground was clear-cut in the first half of the cutting cycle; the leave area between strips is to be clear-cut in the second half of the cycle. The end result at the conclusion of all harvest during a cutting cycle is shown in the left background. All but a few isolated patches of trees have been removed. In terms of hydrologic alteration, the end result is a complete clear-cut, even though new trees are well established on the initial clear-cut areas. (Photo taken 11 March 1976).

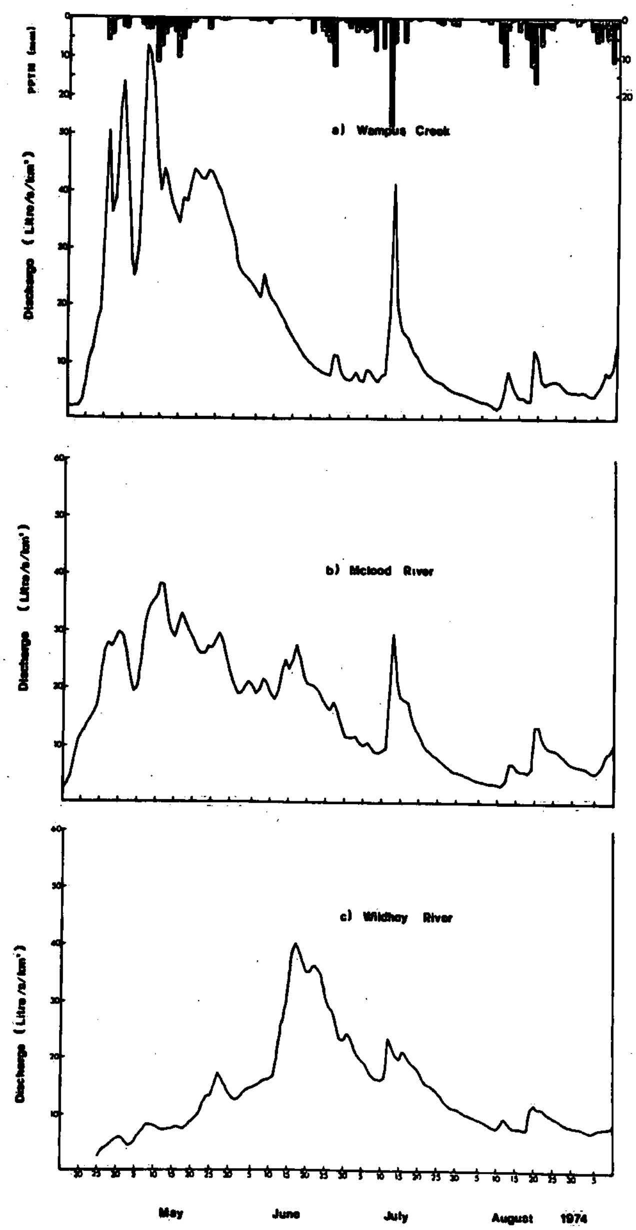

Fig. 4. Summer precipitation over the lease--hydrographs from Wampus Creek and the McLeod River, which originate within the forested portion of the lease. The Wildhay River hydrograph has been included to illustrate the flow distribution in time from an alpine watershed versus that of the two mid- to low-elevation watersheds. (Streamflow data courtesy Water Survey of Canada.)

represented by Wampus Creek (which is part of the McLeod basin), and the McLeod River itself. The water yield from a small alpine portion in the McLeod watershed tends to keep this watershed's runoff at a higher level during the summer than the totally forested Wampus catchment.

The only precipitation other than that occurring during snowmelt that causes appreciable response in the large river hydrographs is that associated with cold low or frontal storms. The marked peak occurring in July and the smaller one in August (Fig. 4) are from such storms. Isolated convective storms are common throughout the lease. These do cause local runoff, but their effect is generally masked when it is combined in the major river hydrographs.

VERIFICATION OF WATER YIELD CHANGE

Method

The method we chose to verify the expected results was to determine the water yield from the existing clear-cut and nonharvested areas of the NWPP lease. This was done by gauging a number of harvested and nonharvested (control) catchments and comparing the difference in water yield for the major runoff season, mid-April through mid-September. One or two years' data was thought sufficient, as our goal was to evaluate the change in water yield due to this harvest and not to document long-term hydrologic characteristics.

Our sampling criterion was to determine a 25% change in water yield at the 80% confidence level. We felt that a one-in-five chance of error was acceptable for this evaluation test and for later use in making land-management decisions affecting water.

The entire 7800-km^2 lease was considered a single population from which we could select a number of catchments for gauging, although poor access and a lack of harvested catchments precluded samples in the Embarras working circle. Also, we could not be certain that the clear-cut catchments chosen were free of hydrologic bias because the decision as to which areas to harvest first was made quite apart from this study and was based on oldest tree age. Obviously, the oldest trees are found in areas that have been free from fires for the longest time, which might mean that these sites were (and may still be) wetter than those surrounding. This is a source of bias that we could not remove. However, wherever possible we selected control catchments as near physically to their harvested counterparts so that present climatic conditions were similar. In general, this precaution ensures that the timber age on a control catchment is within 20 years of its clear-cut counterpart.

There have not been any similar statistical evaluations reported that could guide us in our sampling intensities. Therefore, we estimated the number of catchments necessary to detect a 25% increase in water yield with 80% confidence as nine each logged and control from equation (1) (Freese 1967).

$$n = (2t^2s^2)/D^2 \qquad (1)$$

where: n = number of samples (catchments) of each type
D = difference in streamflow we wished detected
s^2 = estimate of population variance
t = students "t" value at desired probability

(An estimate of the variance during the high runoff months of May and June was obtained using streamflow data from the three contiguous basins on the 57-km^2 Tri Creeks experimental watershed located in the southern portion of the McLeod working circle. We assumed that the variance in these data would be less than that over the entire lease and doubled the value obtained to estimate the number of sample catchments needed as nine.)

Selection criteria were: (1) control catchments could not have more than 10% of their timber removed, (2) logged catchments must be clear-cut over 30% or more of the total area, (3) the area of either type had to be between 7 and 26 km^2, and (4) there had to be reasonable access and a stable stream section for gauging.

Establishment

Sixteen catchments were selected in 1972 (two pairs of logged controls in each of the four circles) and gauged periodically during May through September of 1973. Two additional catchments were added during 1973 and all 18 were gauged in 1974 from the last week in April through mid-September. These are described in Table 2, and their locations are shown on Fig. 2.

All stream gauging controls were natural. A water level recorder was installed in a stilling well at each control section, which was rated three to five times a week in 1973, less frequently in 1974 with a cup-type current meter to obtain a stage-discharge relation for use with recorded stage.

An Atmospheric Environment Service of Canada MSC type "A" precipitation gauge was installed near each control section and serviced at least once each week. Six U.S. Weather Bureau type Belfort and three Fischer-Porter weighing rain and snow gauges were located at strategic positions throughout the lease. Two snow courses in each working circle were measured in April to ascertain snow on the ground when snowmelt commenced. In addition, snow course and precipitation data from an intensive climatic study being conducted in the same area were made available to us (J.M. Powell, personal communication).

Data Presentation and Analysis

Daily streamflow was calculated in litres per second and compiled for each catchment. All analyses were conducted on data converted to water yield in litres per second per square kilometre or millimetre to allow for

Table 2. Gauged catchments on NWPP lease, Hinton, Alberta

Catchment		Location		Dominant	Drainage		Harvest History		Edge/Area	Elevation
No.	Drainage	Latitude (N)	Longitude (W)	Forest Cover[1]	Area (km^2)	Category[2]	Average Age Years[3]	Percent Cut (1974)	Ratio (m/ha)	(m above msl)
Athabasca Working Circle										
1	Oldman Ck.	53°41'53"	117°33'48"	PL, SW	17.0	C	-	Nil	-	1190-1400
2	Oldman Ck.	53°41'03"	117°33'48"	PL	14.9	C	-	Nil	-	1220-1400
3	Oldman Ck.	53°31'31"	117°40'51"	SW	16.4	L	7.9	84	58	1450-1520
4	Fish Ck.	53°28'50"	117°38'54"	SW	11.6	L	10.6	76	31	1210-1520
5	Oldman Ck.	53°37'18"	117°31'25"	SW, PL	19.7	L	10.2	35	38	1280-1580
Marlboro Working Circle										
6	Pine Ck.	53°54'55"	116°43'20"	PL	23.9	C	-	8	-	1190-1450
7	Pine Ck.	53°54'22"	116°45'44"	PL	22.1	L	6.7	38	148	1190-1370
8	Edson R.	53°50'00"	116°40'54"	PL, SW	7.0	L	7.7	37	88	1140-1450
9	Edson R.	53°48'43"	116°44'52"	PL, SW	23.1	C	-	9	-	1110-1400
Berland Working Circle										
10	Hendrickson Ck.	53°46'37"	118°22'03"	PL	22.0	C	-	Nil	-	1420-1620
11	Vogel Ck.	53°46'58"	118°27'07"	PL, SW	11.1	C	-	Nil	-	1480-1650
12	Cabin Ck.	53°45'51"	118°21'55"	PL, SW	12.6	C	-	Nil	-	1400-1770
13	Fox Ck.	53°43'07'	118°16'11"	PL	18.2	L	8.9	57	39	1370-1520
14	Fox Ck.	53°42'15"	118°16'47"	PL, SW	12.3	L	9.0	60	20	1370-1740
McLeod Working Circle										
15	Anderson Ck.	53°18'19"	117°18'04"	PL, SW	19.7	C	-	6	-	1190-1680
16	Ck. (not named)	53°18'32"	117°17'04"	PL, SW	8.8	C	-	21[4]	-	1190-1460
17	Anderson Ck.	53°19'16"	117°22'43"	PL, SW	10.7	L	11.5	56	90	1280-1620
18	Quigley Ck.	53°20'30"	117°23'17"	PL, SW	16.8	L	11.3	46	114	1280-1430

[1] PL = lodgepole pine SW = white spruce

[2] C = control catchment L = logged catchment

[3] Average age = Σ[(Area cut in year) x (1974-year cut)]/ΣArea

[4] Catchment 16 is logged in excess of our criterion for a control. Eleven percent was logged prior to 1973, but the extra 1% above our criterion was not considered sufficient to exclude this otherwise desirable catchment. However, an additional 10% of the timber was logged during July-August 1973, bringing the total to 21% at the start of the 1974 runoff season and greatly exceeding our control catchment criteria.

We still used catchment 16 as a control during 1974 because: (1) all of the harvest is near or on the catchment divide, and harvest in this area is generally considered to have the least effect on streamflow, and (2) the cutting was done relatively late in the growing season so that the effect of full forest transpiration during 1973 on carry-over soil moisture to 1974 would already be present. We could not have used this catchment as a control in 1975, if the study had been continued, because (2) above would only be true the first year following late summer harvest.

differences in area between catchments. Precipitation from nonrecording gauges was generally read daily, but if not, weighted over the days-of-occurrence interval indicated by the traces from the recording precipitation gauges. These water yield and precipitation values for the lease were displayed graphically to select time intervals for further analysis.

The "t" statistic was used to test the significance of water yield differences noted. Sixteen degrees of freedom were available for the unpaired mean difference comparisons and 7 degrees of freedom for the paired differences. In the results and discussion below, "significant" means at the 80% level, except where a higher confidence value is noted.

RESULTS

The composite hydrograph for 1974 is shown in Fig. 5. Shaded portions indicate time periods when water yield from the logged exceeded that from the control catchments. Table 3 is a summary of the water yield and statistical tests for 1974.

The major runoff-season yield, April 25 to September 15, from logged catchments was 186.6 mm compared to 147,4 mm from the unlogged controls. This difference of 27% is very close to the 29% difference between logged and unlogged experimental catchments results (Table 1). Logged catchments yielded significantly more water during all but the recession from the snowmelt period.

Both paired and unpaired comparisons of water yield are given in Table 3. In the unpaired comparisons, data from all logged catchments and all control catchments are compared. This is the most stringent statistical test of the two, as there has been no attempt to limit the natural variation that results from differing precipitation volumes over the lease area. However, in the paired tests, a form of stratification by local climate and topography occurs, as in general the logged and control catchment in a particular area are in close proximity, if not adjacent to each other. Therefore, the paired tests generally result in significance at a higher confidence level, but the difference in water yield is essentially the same as for the unpaired comparisons.

DISCUSSION

These results are significant in more than just the statistical sense. This is a 135-km^2 sample from 900 km^2 of clear-cutting, and the individual sample catchments themselves are all at least six times larger in area than the average of the experimental catchments in Table 1. Our findings imply that the results from small catchments can be extrapolated to at least somewhat larger ones. Whether one can make the jump to entire river basins may still be open to some question, but in our opinion, one probably can.

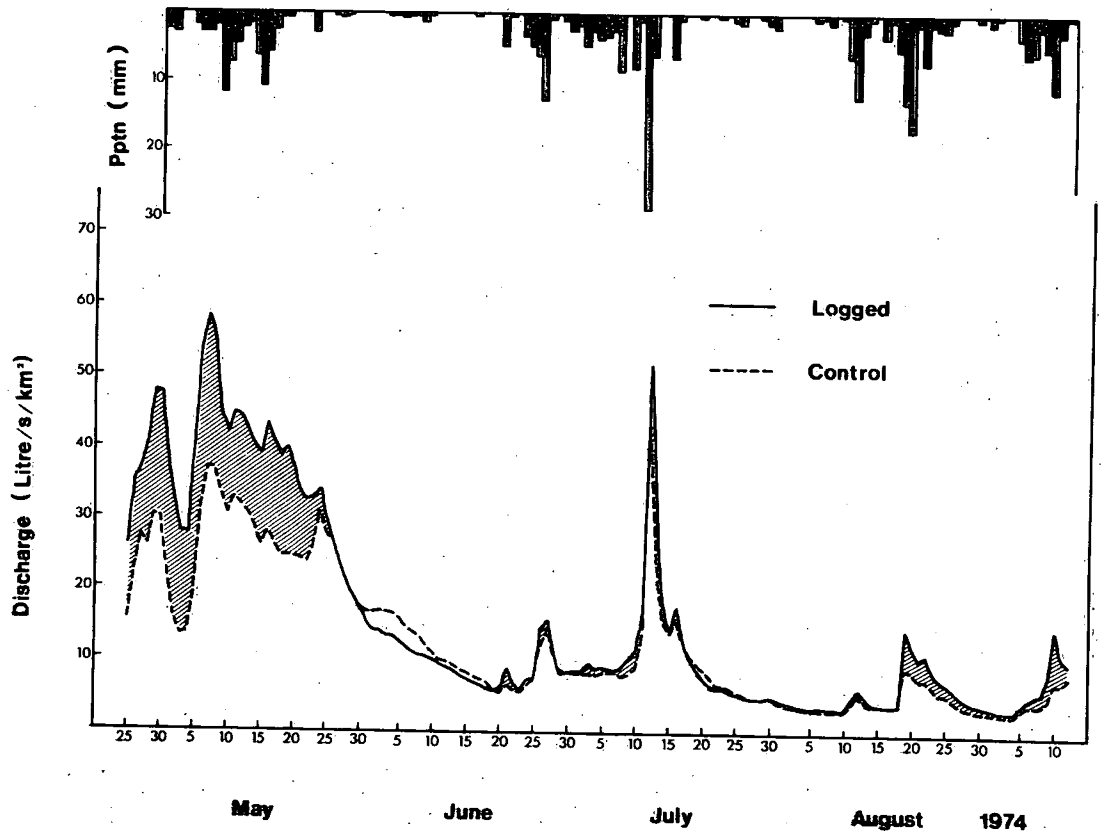

Fig. 5 Composite hydrographs for 1974 from nine logged and nine control catchments on the study area. Shaded portions indicate times when logged yield exceeded control.

Table 3. Comparative statistics of composite runoff from logged and control catchments for 1974

			Runoff (mm)						
			Unpaired comparison df=16				Paired comparison df=7		
Runoff period	Event	Precipitation input (mm)	Logged	Control	"t"	Confidence level (%)	Difference	"t"	Confidence level (%)
Apr. 25–May 23	Snowmelt and rain	[1]278	98.9	62.3	1.907	90	34.2	2.958	95
June 1–8	Recession	4	8.8	10.9	-0.954	[2]n.s.	-0.4	-0.372	n.s.
July 9–14	Recession	43	11.9	10.0	0.749	n.s.	2.2	2.519	95
Aug. 19–28	Rainstorm	43	7.8	5.8	1.630	80	2.1	2.424	95
Sept. 7–10	Rainstorm	34	3.0	1.9	3.027	99	1.2	3.070	98
Apr. 25–Sept. 15	Mixed	513	186.6	147.4	1.47	80	42.4	2.455	95

[1] Snowpack April 11, 1974 and rain and snow to May 23.

[2] n.s. = not significant at 80% confidence level.

There have been no other evaluations of clear-cutting of the scale presented here, but a somewhat similar situation exists in western Colorado, where a large portion of the trees on the White River watershed were killed by bark beetles. Love (1955) reported a 22% increase in water yield for the first 5 years after the beetle attack affected 585 km^2 of the 1974-km^2 watershed. Bethlamy (1975) re-examined data for the same period as Love and for an additional 15-year period and concluded that the average increase for the 20 years since the beetle attack was 15.7%.

Approximately one-third of the White River watershed was affected by the bark beetle attack, and the increased yield was marginally detectable in the main river draining the area. In our case, if streamflow were measured near Whitecourt on the Athabasca River, because the clear-cut area on the watershed upstream is only 900 km^2 of a total area of 17,265 km^2, the increase in flow of approximately 1% would not be detectable here under the best gauging circumstances.

SUMMARY

1. We obtained streamflow from nine clear-cut and nine control catchments on the North Western Pulp and Power Co. Ltd. lease near Hinton, Alberta.

2. The water yield from the clear-cut catchments was 187 mm compared to 146 from the controls. This difference in water yield is statistically significant at the 80% level if all data are lumped, or at the 95% level if the data are stratified by local climate and topography.

3. This result, a 27% increase in water yield, compared favorably with the 29% that one obtains by averaging the results from clear-cut experimental catchments in the U.S. and Africa.

4. Our results, coupled with those from a bark beetle epidemic on the White River watershed in western Colorado, suggest that the effects of clear-cutting noted on streamflow from small catchments will also be present on large drainage basins.

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IMPACT OF PULPWOOD CLEARCUTTING ON STREAM

WATER QUALITY IN WEST CENTRAL ALBERTA

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ABSTRACT

Water quality samples collected from logged catchments in the North Western Pulp and Power Company lease area showed increased concentrations and yields of most of the inorganic constituents. The samples were collected during the spring snowmelt and early summer period (May 21 to August 7, 1975) when high flows in streams result in maximum export of nutrients. The constituents determined were Ca, Mg, Na, K, HCO_3, SO_4-S, Cl, NH_4-N, NO_3- and NO_2-N, and PO_4-P.

The increased concentrations of many constituents in the logged catchments are noteworthy, especially since dilution resulting from increased streamflow from the clearcuts should have lowered the concentrations. Higher export of nutrients from the clearcuts as a result of increased solute yields in stream waters has management implications for sites where soil mantle is thin.

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INTRODUCTION

Water is a major carrier of chemical constituents in the forest ecosystem. Although the concentration of nutrients in the stream waters originating from such areas may be low (Cooper 1969, Singh 1976), the total amounts carried downstream are large.

The materials transported by natural waters are characteristic of the soils and rocks of the catchments. Collection of water quality information enables us to establish benchmark conditions for assessing the effects of natural and cultural changes (Toebes and Ouryvaev 1970).

The addition of nutrients derived from forest ecosystems could be beneficial if the receiving water bodies are oligotrophic. However, even minimal additions of nutrients could be harmful to eutrophic waters. Since forestry practices regulate nutrient outflow from forested areas, the accelerated export of dissolved constituents should be monitored carefully for polluted aquatic environment.

The objective of this study was to establish benchmark conditions of nutrients in the stream waters of undisturbed catchments and to assess changes due to extensive clearcutting.

MATERIALS AND METHODS

Materials

The study was conducted on undisturbed and clearcut catchments forming part of the lease area of the North Western Pulp and Power Ltd., Hinton. These catchments are part of the Berland and the McLeod Working Circles. The leasehold covers 7970 km^2 and extends from 52° 56' to 53° 59' N and from 116° 23' to 118° 27' W (Fig. 1). The company harvests 44.5 km^2 per year, composed of 60% lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), 30% white spruce [*Picea glauca* (Moench) Voss] and 10% black spruce [*Picea mariana* (Mill.) B.S.P.] and sub-alpine fir [*Abies lasiocarpa* (Hook.) Nutt.]. Further details on company operations are given by MacArthur (1968) and Crossley (1975).

The details about surficial geology, soils, and climate of the area have been provided by Roed (1968, 1970), Dumanski *et al.* (1972), and Powell and MacIver (1976) respectively.

A total of eight catchments of varying sizes was selected, four in each working circle. Out of these four, two were unlogged (U) and other two had been logged (L) in the previous years. Details of catchments in terms of dominant forest cover, drainage area, percentage clearcut, elevation, dominant soils, surficial deposits, and bedrock geology have been reported by Singh *et al.* (1974).

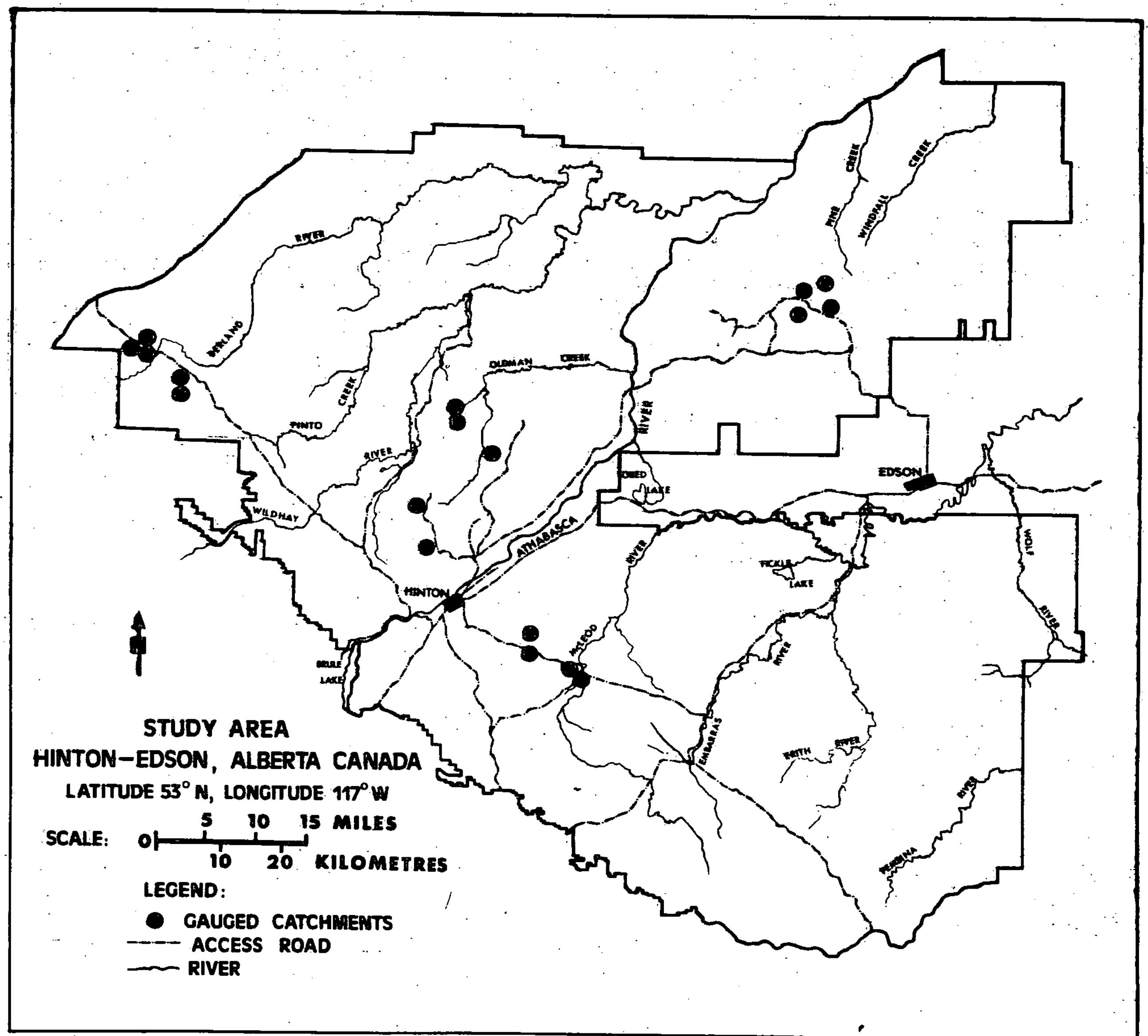

Figure 1. Forest lease area of the North Western Pulp and Power Limited, Hinton, Alberta

Methods

Water samples (1 ℓ) were collected from the gauged stations on a weekly basis during May 21 to August 7, 1975. Discharge measurements were taken concurrently at the time of sampling.

The samples were filtered using Whatman grade GF/A filter papers. Analyses were completed as soon as possible after collection. Calcium, Mg, Na, and K were determined by atomic absorption spectroscopy using Perkin-Elmer model 303 equipped with a three-slot burner head and a digital concentration readout (Perkin-Elmer Corp. 1973). For the determination of HCO_3, potentiometric technique using a two-endpoint titration (pH 4.5 and 4.2) was employed on a Radiometer automatic titration system (Lively *et al.* 1974). Sulfate-S was determined by a turbidimetric method using $BaCl_2$. Chloride was determined potentiometrically with an Ag-AgCl electrode (APHA 1971). For NH_4-N, absorbancy of the color developed by Nessler reagent (APHA 1971) was read on a double beam spectrophotometer (Coleman 124D). Nitrate- and NO_2-N and PO_4-P were determined by Technicon auto-analyzer (Technicon Corp. 1971, 1973), using scale expansion where necessary.

RESULTS

Concentration of Dissolved Constituents

The mean concentrations (mg/ℓ) of the analyzed nutrients are given in Table 1 for the Berland Working Circle and in Table 2 for the McLeod Working Circle.

In the Berland Working Circle, the lower and the upper limits of the range of concentration of Ca, Mg, HCO_3, Cl and NO_3- and NO_2-N showed increases due to clearcutting. The lower limit of Ca in the control catchments (U) was 17.0, compared to 32.9 for the clearcuts (L). The corresponding values for the lower limits of the other constituents were: Mg 2.7 (U), 6.0 (L); HCO_3 84.8 (U), 145.3 (L); Cl 0.7 (U),1.0 (L) and NO_3- and NO_2-N 0.005 (U), 0.035 (L). The upper limit of Ca in the control catchments was 42.9, compared to 51.8 for the clearcuts. The corresponding values for the upper limits of the other constituents were: Mg 7.2 (U), 8.8 (L); HCO_3 196.8 (U), 214.6 (L); Cl 1.1 (U), 1.2 (L), and NO_3- and NO_2-N 0.011 (U), 0.058 (L). However, Na, K, SO_4-S, NH_4-N and PO_4-P did not show any conspicuous changes, possibly due to dilution effects caused by increased streamflow from clearcuts. Similarly, in the McLeod Working Circle no obvious changes could be noticed for any of the constituents.

Yield of Dissolved Constituents

The mean yields (kg/km^2/day) of dissolved constituents in the Berland and McLeod Working Circles are given in Table 3 and 4 respectively.

Table 1. Concentration (mg/ℓ) of dissolved constituents in the stream waters of Berland Working Circle.

Constituents	Control				Clearcut			
	BE0131		BE0133		BE0334		BE0335	
	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Calcium	42.9	1.7	17.0	0.8	51.8	1.5	32.9	1.1
Magnesium	7.2	0.6	2.7	0.2	8.8	0.2	6.0	0.2
Sodium	4.9	0.8	5.0	0.8	3.9	0.6	3.8	0.7
Potassium	0.74	0.03	0.52	0.03	0.66	0.04	0.70	0.04
Bicarbonate	196.8	11.2	84.8	4.3	214.6	17.6	145.3	8.5
Sulphate-sulphur	1.2	0.1	1.2	0.2	0.8	0.1	1.5	0.2
Chloride	1.1	0.1	0.7	0.1	1.2	0.1	1.0	0.1
Ammonia-nitrogen	0.12	0.04	0.12	0.03	0.09	0.03	0.21	0.04
Nitrate and nitrite nitrogen	0.011	0.002	0.005	0.001	0.058	0.009	0.035	0.006
Phosphate-phosphorus	0.011	0.001	0.015	0.001	0.014	0.001	0.013	0.001

Table 2. Concentration (mg/ℓ) of dissolved constituents in the stream waters of McLeod Working Circle.

Constituent	Control				Clearcut			
	MC0731		MC0732		MC0933		MC0934	
	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Calcium	57.6	2.5	54.3	2.6	57.2	2.3	48.5	2.0
Magnesium	10.2	0.4	8.7	0.4	9.6	0.4	7.2	0.3
Sodium	4.4	0.8	4.6	0.8	4.4	0.8	5.3	1.0
Potassium	0.76	0.01	0.79	0.04	0.70	0.04	0.56	0.04
Bicarbonate	263.8	9.6	236.8	15.3	255.8	15.8	230.2	19.8
Sulphate-sulphur	1.7	0.1	1.1	0.1	1.3	0.1	1.0	0.1
Chloride	1.2	0.1	1.1	0.1	1.1	0.1	1.1	0.1
Ammonia-nitrogen	0.10	0.01	0.21	0.01	0.20	0.02	0.24	0.01
Nitrate and nitrite nitrogen	0.022	0.003	0.006	0.001	0.008	0.001	0.013	0.003
Phosphate-phosphorus	0.017	0.002	0.017	0.001	0.016	0.001	0.021	0.010

Table 3. Yield ($kg/km^2/day$) of dissolved constituents in the stream waters of Berland Working Circle.

Constituent	Control				Clearcut			
	BE0131		BE0133		BE0334		BE0335	
	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Calcium	32.2	5.1	9.4	1.7	21.7	1.9	27.8	5.0
Magnesium	4.9	0.6	1.7	0.6	3.7	0.3	5.5	1.5
Sodium	3.6	0.6	2.8	0.6	1.6	0.2	3.0	0.5
Potassium	0.53	0.08	0.29	0.06	0.28	0.03	0.59	0.13
Bicarbonate	149.0	26.4	48.6	9.2	91.0	12.2	124.3	25.0
Sulphate-sulphur	0.9	0.3	0.9	0.4	0.4	0.1	1.7	0.8
Chloride	0.7	0.1	0.3	0.04	0.5	0.04	0.8	0.1
Ammonia-nitrogen	0.09	0.03	0.09	0.04	0.04	0.02	0.24	0.13
Nitrate and nitrite nitrogen	0.009	0.002	0.003	0.001	0.023	0.003	0.025	0.003
Phosphate-phosphorus	0.009	0.002	0.009	0.002	0.006	0.001	0.011	0.003

Table 4. Yield (kg/km^2/day) of dissolved constituents in the stream waters of McLeod Working Circle.

Constituent	Control				Clearcut			
	MC0731		MC0732		MC0933		MC0934	
	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Calcium	17.2	1.3	8.8	0.7	27.7	1.9	23.0	2.4
Magnesium	3.1	0.2	1.4	0.1	4.7	0.3	3.4	0.3
Sodium	1.3	0.2	0.8	0.2	1.9	0.3	2.3	0.4
Potassium	0.23	0.01	0.14	0.02	0.36	0.05	0.29	0.05
Bicarbonate	78.9	6.0	37.7	2.8	122.2	8.0	105.8	9.9
Sulphate-sulphur	0.5	0.1	0.2	0.03	0.7	0.1	0.5	0.1
Chloride	0.3	0.03	0.2	0.03	0.6	0.1	0.5	0.1
Ammonia-nitrogen	0.03	0.01	0.03	0.01	0.10	0.02	0.11	0.01
Nitrate and nitrite nitrogen	0.006	0.001	0.001	0.0001	0.004	0.001	0.005	0.001
Phosphate-phosphorus	0.005	0.001	0.003	0.0004	0.008	0.001	0.009	0.003

Although the drainage areas of the catchments differed in size, the yields reported in the tables are on an equal-area basis. The calculation of yields in this manner serves two purposes: (1) it allows a valid comparison between controls and clearcuts on a unit area basis, and (2) it takes into account the dilution effects due to increased streamflow noticed on the clearcuts.

The yield totals from the two controls and the two clearcuts for the Berland Working Circle were as follows: Ca 41.6 (U), 49.5 (L); Mg 6.6 (U), 9.2 (L); Na 6.4 (U), 4.6 (L); K 0.82 (U), 0.87 (L); HCO_3 197.6 (U), 215.3 (L); SO_4-S 1.8 (U), 2.1 (L); Cl 1.0 (U), 1.3 (L); NH_4-N 0.18 (U), 0.28 (L); NO_3- and NO_2-N 0.012 (U), 0.048 (L) and PO_4-P 0.018 (U), 0.017 (L). Thus, all the constituents, with the exception of Na and PO_4-P, showed higher yields in the clearcuts. Similar yield totals for the McLeod Working Circle were Ca 26.0 (U), 50.7 (L); Mg 4.5 (U), 8.1 (L); Na 2.1 (U), 4.2 (L); K 0.37 (U), 0.65 (L); HCO_3 116.6 (U), 228.0 (L); SO_4-S 0.7 (U), 1.2 (L); Cl 0.5 (U), 1.1 (L); NH_4-N 0.06 (U), 0.21 (L); NO_3- and NO_2-N 0.007 (U), 0.009 (L) and PO_4-P 0.008 (U), 0.017 (L). All the constituents in the McLeod Working Circle showed higher total yields from the clearcuts.

As the yield data are on comparable basis, an overall perspective for the areas represented by the catchments for the two working circles can be obtained from the summary provided in Table 5. Yields of all constituents increased as a result of clearcutting.

DISCUSSION

The results of this study show the same general pattern reported earlier (Singh and Kalra 1975, Singh *et al.* 1974). Clearcutting accelerates the export of many nutrients.

The study shows important implications for the management of the leasehold area. Most of these clearcuts have been harvested over a period of many years. However, they are still showing an increased outflow of nutrients in the stream waters. If these sites are not revegetated quickly with desirable species, the nutrients released as a result of harvesting will be lost from the site, decreasing forest productivity. The addition of nutrients to the streams could increase productivity of aquatic organisms under oligotrophic conditions. It would however, constitute undesirable influence on eutrophic water bodies (Beeton 1969, Biggar and Corey 1969, U.S. Environmental Protection Agency 1973a).

The effects of increased outflow of nutrients from the clearcuts can thus be viewed in terms of site productivity (forest production), stream productivity (microbial, invertebrate, and fish populations), and downstream users (human populations, agricultural and industrial uses). The storage of water in a downstream dam or reservoir can act as a trap for deposition of nutrients (Hynes 1970). The specific effects

Table 5. Summary of mean data on yield (kg/km^2/day) of dissolved constituents in the stream waters of Berland and McLeod Working Circles.

Constituent	Control			Clearcut		
	Total Catchments	Mean	Standard Error	Total Catchments	Mean	Standard Error
Calcium	4	16.9	5.4	4	25.0	1.6
Magnesium	4	2.8	0.4	4	4.3	0.5
Sodium	4	2.1	0.6	4	2.3	0.3
Potassium	4	0.30	0.08	4	0.38	0.07
Bicarbonate	4	78.6	25.0	4	110.8	7.8
Sulphate-sulphur	4	0.6	0.2	4	0.8	0.3
Chloride	4	0.4	0.1	4	0.6	0.1
Ammonia-nitrogen	4	0.06	0.02	4	0.13	0.04
Nitrate and nitrite nitrogen	4	0.005	0.002	4	0.014	0.006
Phosphate-phosphorus	4	0.006	0.001	4	0.009	0.001

of the accelerated loss of nutrients from the clearcuts on all of these factors remain largely unexplored in west-central Alberta.

As recommended by the Panel on Freshwater Aquatic Life and Wildlife (U.S. Environmental Protection Agency 1973b), total dissolved materials should not be changed to the extent that the biological communities characteristic of particular habitats are significantly changed. Further, prior to any physical alterations of a watershed, a thorough investigation should be conducted to determine the expected balance between benefits and adverse environmental effects. Only preliminary work has so far been done on assessing the effects of suspended and settleable solids on fish and invertebrates (Rothwell 1975).

Forestry practices that encourage rapid growth of vegetation on clearcuts should be continuously sought. Practices that reduce soil disturbance by logging or slash burning favour vegetation regrowth (Fredriksen 1971-72). Reduction in the size of the clearcuts, interspersed with uncut strips, also creates a more favourable habitat. The effects of different-sized clearcuts on nutrient flow from the site and on other related factors mentioned above need to be researched further.

Light partial cutting, minimum soil disturbance, quick revegetation, and adoption of practices to avoid flushing of nutrients to the streams would help to lessen the impact of logging on nutrient release.

ACKNOWLEDGEMENTS

We would like to express our thanks to W. C. Cumberland for collecting water samples and discharge data, F. G. Radford for laboratory analysis, and B. E. Robson for statistical computations.

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ABSTRACT

ROTHWELL, R.L. 1977. SUSPENDED SEDIMENT AND SOIL DISTURBANCE IN A SMALL MOUNTAIN WATERSHED AFTER ROAD CONSTRUCTION AND LOGGING. PROCEEDINGS ALBERTA WATERSHED RESEARCH PROGRAM (AWRP) SYMPOSIUM, AUGUST 31-SEPTEMBER 2, 1977, NORTHERN FOREST RESEARCH CENTRE, EDMONTON, ALBERTA.

The effects of road construction and logging on water quality in Marmot Creek Experimental Watershed were studied in terms of suspended sediment and soil disturbance. The objective of the study was to demonstrate that water quality deterioration associated with forest harvesting can be prevented by careful planning of road construction and logging. Roads were constructed in Cabin sub-basin 2 years before logging. Logging was done by clear-cut blocks, with logs skidded by rubber-tired skidders and crawler tractors. Suspended sediment record was obtained on a daily basis during the summer flow season, 4 years before roads and logging and 3 years afterwards. Soil disturbance and erosion caused by roads and logging were evaluated by mapping and reconnaissance of disturbed areas.

Soil exposure from roads and logging affected 25% of the total area of Cabin sub-basin. Soil exposure on cut blocks averaged 32%, with most of it caused by skidroads. Mapping and reconnaissances of disturbed areas showed very little erosion and no sediment transport towards streams. Analysis of sediment data showed no increases in sediment concentrations or discharges that could be associated with roads or logging.

SUSPENDED SEDIMENT AND SOIL DISTURBANCE IN A SMALL MOUNTAIN WATERSHED AFTER ROAD CONSTRUCTION AND LOGGING

by

R. L. ROTHWELL[1]

INTRODUCTION

This paper describes the impact of road construction and logging on water quality in a small watershed. The purpose of the study is to demonstrate that water quality deterioration usually associated with forest harvesting can be prevented or minimized by careful planning of road construction and logging.

BACKGROUND

The most frequent causes of water quality deterioration in forest areas are road construction and logging (Fredricksen, 1965, 1970; Meeghan, 1972, Packer, 1965; Reinhart et al., 1963). Water quality deterioration usually appears as large increases in suspended sediment concentrations, which result from the erosion of mineral soils exposed and disturbed by road construction and logging. Such damage is usually greatest during and shortly after road construction and logging, when soils are exposed and unprotected from the erosive forces of rainfall and flowing water. Fredricksen (1965) observed in a small watershed, increased suspended sediment loads 250 times normal levels during road construction. Sediment concentrations such as these however, usually return to normal in a 1-3 year period with the revegetation and stabilization of exposed soils.

The magnitude of erosion and sediment caused by forest harvesting to a large degree is determined by the severity and extent of soil disturbance, which varies with logging and road construction methods, and topography. In logging it is not the cutting of trees that causes problems, but their removal from the forest. Hoover (1951) demonstrated this at the Coweeta Experimental Forest, where no increases in erosion or sediment were observed when trees were cut and left on the ground. It is the removal or skidding of logs from the forest that can cause excessive soil disturbance.

Logging methods that cause the greatest soil disturabance and exposure are those where logs are skidded (i.e dragged) from the forest by tractors or wheeled vehicles. Tractors can be used to log large areas and to skid logs for long distances. The networks of skidroads required cause more soil

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disturbance than other logging methods. Soil disturbance, as a per cent of logged area, averages 35% for tractor logging compared to 17% for cable methods (Dyrness, 1965; Garrison and Rummel 1951; Haupt, 1960; Smith and Wass, 1976; Wooldridge, 1960). These differences are greater on steeper slopes, where tractors are forced to maneuver straight up and down slopes, or to establish roads by cut and fill excavation. Garrison and Rummel (1951) observed soil disturbance from tractor logging on slopes greater than 40%, to be 2.8 times that caused by cable methods. Furthermore, tractor logging leaves a pattern of skidroads that converge in a downslope direction, which can act to concentrate overland flow on road surfaces, increasing the potential for erosion and sediment transport.

The impact of forest harvesting on water quality can be very large. A comparison of different studies shows sediment loads from logged watersheds to be 4-400 times greater than those of unlogged or undisturbed watersheds (Fredricksen, 1970; Leaf, 1965; Meeghan, 1970). Suspended sediment concentrations from undisturbed forests are usually very low, averaging less than 10 parts per million (ppm). Comparison of sediment concentrations for 3 months showed average values of 4 and 94 ppm, with maximums of 80 and 3500 ppm for an uncut and a cut watershed respectively (Dils, 1957). In another watershed study, measured sediment varied from 1.79-3.43 ft^3/acre for three years after logging compared to a long term average of 0.28 ft^3/acre (Leaf 1966, 1975).

Roads and road construction are identified in most studies as the largest sources of erosion and sediment affecting water quality (Fredricksen, 1970; Meeghan, 1972; Reinhart _et al._, 1963). Logging or skidding can cause significant soil disturbance, but it is usually less in comparison to roads. Roads expose larger areas of mineral soil and make more direct contacts with stream channels than logged areas. The net effects of roads on water quality however, are poorly documented. Despite the universal use of roads in logging operations, and that roads are generally built for access prior to logging, very few measurements have been made of the unconfounded effects of roads on water quality (Packer, 1965). The data available however, are sufficient to show roads as serious sources of erosion and sediment.

Fredricksen in Oregon (1970) observed maximum turbidities, 6 years prior to road construction, never to exceed 200 ppm. Immediately following construction and with the first storm however, suspended sediment concentrations increased to 1728 ppm, while in a nearby control watershed concentrations were 22 ppm. Meeghan (1975) reports soil losses of 78 and 3520 lbs/acre/year for undisturbed and disturbed watersheds respectively. Separation of soil loss in the disturbed watershed gave rates of 125 lbs/acre/year for cutting and skidding, and 17,180 lbs/acre/year for roads.

A large amount of the damage caused by roads and logging can be prevented or minimized by careful planning of operations and/or application of improved methods. Haussman (1960) reports poorly planned skidroad networks in the Northeastern U.S. occupy 20% of a cut block, while a well planned network needs only 10% of the same area. Trimble and Wietzman (1953) measured soil losses of 52 lbs/acre on high order skidroads with water bars and grades less than 10%. In comparison, soil losses on poor skidroads with no drainage structures or grade limits were 433 lbs/acre. The value of careful planning is best illustrated by a West Virginia study (Reinhart et al., 1963) comparing the effects of commercial clearcut, diameter limit, extensive selection and intensive selection on water quality. In the clear-cut watershed with unplanned skidroads and no provisions for road drainage, maximum water turbidity was 56,000 ppm. In contrast, maximum water turbidity for the intensive selection cut with planned skidroads was 25 ppm, slightly higher than on an uncut (control) watershed with water turbidity of 15 ppm. Analysis indicated that the differences were caused primarily by skidroad location and construction.

OBJECTIVES

The primary objective of this study is to demonstrate that water quality deterioration, normally associated with forest harvesting, can be prevented by careful planning of road construction and logging. Furthermore, it is to demonstrate that the implementation of existing forest harvesting guidelines, as set down by the Alberta Forest Service, are sufficient to protect and maintain water quality.

The study is a test and demonstration of existing harvesting methods and regulations applied to a given geographic site in Western Alberta. Government guidelines pertinent to water quality protection are listed below (Alberta, 1971):

1. No debris from road construction and maintenance, and logging shall be allowed to enter any water course.
2. Roads shall be located and constructed so as to cause a minimum of soil erosion and sediment deposition in streams, and no road shall restrict the natural flow of a stream.
3. Abandoned skidroads and trails shall have adequate drainage to prevent erosion.
4. No green timber shall be cut within 100 feet of the high water mark of any water course.
5. Logging methods (i.e. skidding) shall be confined to the use of horses, rubber tired skidders or crawler tractors.

STUDY AREA

The site of this study is Marmot Creek Experimental Watershed, which is in the Rocky Mountains, 80 km west of Calgary, Alberta. Marmot watershed lies between the elevations of 1737-2743 m and has three sub-basins: Cabin, Middle and Twin. Forest harvesting was done in Cabin sub-basin, which is

2.36 km^2 in area and has slopes ranging from very steep (60%+) to gentle (2-5%). Approximately 75% of the sub-basin is forested with a mixture of white spruce (*Picea glauca* (Moench.) Voss), alpine fir (*Abies lasiocarpa* (Hook) Nutt.), and small areas of alpine larch (*Larix lyallii* Parl.). The upper 25% of the sub-basin is unforested and consists of alpine meadows and bare rock.

Streamflow from Cabin is dominated by spring snowmelt. Spring runoff usually starts in early May and peaks in early June. Maximum and minimum flow for 1969-1975 varied from 577-3 liters/sec (l/sec). Mean annual flow for Cabin is 23 l/sec with a range of 0.85-28.3 l/sec (Marmot Creek Basin, 1969-1975).

The climate of the area is characterized by long, cold winters and wet cool summers. Mean monthly temperatures range from lows of -6°C in January to highs of 13°C in July. Annual precipitation for 1969-1975 averaged 838 mm with 40-45% occuring during the months of May-September (Marmot, 1969-75).

The soils of Marmot and its sub-basins are poorly developed mountain soils. A soil survey of the watershed has identified soil types of Bisequa Grey Wooded, Podzol, Alpine Black, Regosol, Rock and Organic (Jeffrey, 1966). The soils are coarse textured, with high gravel and calicum carbonate contents and are well drained. The soils of the basin are stable and low in erodibility.

STUDY METHODS

The study was divided into two parts: (1) road construction and (2) logging. Roads were constructed in Cabin sub-basin in the fall of 1971, two years in advance of logging to allow an unconfounded analysis of road effects on water quality. Logging was done in July-September 1974. The effects of logging and roads on water quality were evaluated in terms of suspended sediment concentrations on a before and after basis. The extent and severity of soil exposure on roads and cut blocks were also measured. Analytical methods employed are: comparison of means, frequency analyses of sediment concentrations, and regression.

To insure minimum disturbance and no change in water quality, road location and construction and cut block layout were carefully planned. The primary concerns in road work were to minimize road-stream crossings, maintain a protective strip of undisturbed vegetation between roads and streams, minimize cut and fill excavation and avoid steep gradients. Road locations were marked in the field by a crew of three men using an abney, topographic chain, and hand compass. Preliminary road locations were done in the spring, prior to road construction, to allow site evaluations when runoff and soil water were at maximum levels. Road construction however, was done in the fall, when runoff and the frequency of rainstorms are low, to minimize the potential for erosion and sediment transport from freshly disturbed soils. Furthermore, all road construction was supervised by professional foresters to insure proper application of harvesting guidelines and to minimize soil disturbance.

Roads were constructed in the fall of 1971, with 2.89 km of new access road built in Cabin and 4.04 km of existing roads in and out of Cabin upgraded. The average distance between access road and Cabin Creek is 326 km with maximum and minimum values of 581 and 0 m respectively. The minimum value represents the only road-stream crossing in Cabin, which is located in the upper part of the basin between cut blocks 2 and 3 (Figure 1). The stream at this point is intermittent, with flow only in the spring runoff period. The average gradient for all roads, new and improved is 10%, with maximum values of up to 20% for short distances. Cut and fill excavations on both old and new roads vary between 1-1.2 m in depth and have slope ratios of 1 1/2:1. The widths of road right-of-away and travel surafce are 20 and 4.25 m respectively. The total area used or disturbed by roads in Cabin is 8.9 ha or 3.4% of total watershed area.

Logging was done in July to September 1974. The primary criteria used for cut block layout were to locate cut areas on the upper and mid-slope positions away from stream channels and to avoid steep slopes and cut blocks shapes requiring long skidding distances and excessive soil disturbance. The harvesting method was clear-cut blocks with the logs skidded downslope to landings by rubber-tired skidders and crawler tractors. Six clear-cut blocks, ranging in size from 8-13 ha were established in Cabin (Figure 1). The average distance between stream channels and the lower edges of the cut blocks is 107 m with maximum and minimum values of 630 and 78 m. Approximately 20% of total watershed area, or 50% of the spruce-fir forested area was harvested.

Total skidroad and access road constructed during logging was 20 km, with 90% of it in skidroads. Average skidroad and access road distances per cut block were 3.7 and 0.3 km respectively. Skidroads gradients varied from 5-40%, with steeper gradients of 15-40% on steep slopes where skidroads intersected and on approaches to landings. Average skidding distance was 321 m with maximum and minimum values of 507 and 89 m. The skidroads follow a pattern of converging on the landings downslope, which can concentrate overland flow on road surfaces. This effect was mitigated to a large degree by the construction of skidroads parallel to ground contours and the construction of cross drains on skidroads at intervals of 30 m apart on grades of 10% or less, and 15 m apart on grades in excess of 20%. The cut blocks and their slope positions are individually described in Table 1 and Figure 2.

Sediment measurements were started by Water Survey of Canada in 1969, 3 years prior to road construction and continued on a regular basis to the present. Initial sampling was done with a U.S.G.S. DH48A sediment sampler or by grab samples at the H-flume notch at Cabin outlet. Sampling each year was started in early spring with the advent of snowmelt, and continued to freeze-up in late September or early October. Normally 1-2 samples were obtained daily during peak flows and snowmelt runoff; and 1-2 samples per week during low flows in late summer and fall. Concurrent measurements of stream discharge were obtained with each sediment sample. In 1971, sampling was intensified by the installation of an automatic sediment sampler at Cabin Outlet. Sampling frequency for the automatic sampler is controlled by variation in stream discharge. During high flows discrete samples are obtained every 4-6 hours, and during low flows, samples are obtained once per day.

Table 1. Soil exposure on cut blocks: determined from maps of cut blocks. Cabin sub-basin, Marmot Creek Experimental Watershed, 1975.

Block No.	Total Area: ha	Per Cent Total Area in: Skidroads	Access Roads	Landings	Mileage in kilometers of: Skidroads	Access Roads	Skidroad Lengths in meters: Average	Max.	Min.	Average Slope Steepness: %
1	10.95	19.1	2.5	9.2	4.18	.14	324	426	91	23
2	7.80	16.1	8.9	3.6	2.51	.35	266	368	114	24
4	10.39	17.1	16.2	6.7	3.54	.34	313	355	292	19
5	10.84	18.44	4.5	8.3	3.81	.24	273	507	89	10
6	12.70	18.1	6.5	2.0	4.60	.42	428	558	266	16
Total	52.68	18.22%	7.5%	5.9%	18.64	1.49				

Table 2. Sediment concentrations, seasonal sediment discharges for April-September, and annual peak discharges for Cabin sub-basin, Marmot Creek Experimental Watershed, 1969-1975

YEAR	SEDIMENT CONCENTRATIONS ppm mean	maximum	SEDIMENT YIELD kg	kg/ha	ANNUAL PEAK D DISCHARGES 1/sec
1969	4	49	9750	41	325
1970	12	53	9250	39	322
1971	6	239	8700	37	577
1972	3	24	8450	36	289
1973	2	47	3750	16	170
1974	5	85	7939	34	458
1975	2	24	1437	6	144
MEANS	5	74	7040	30	326

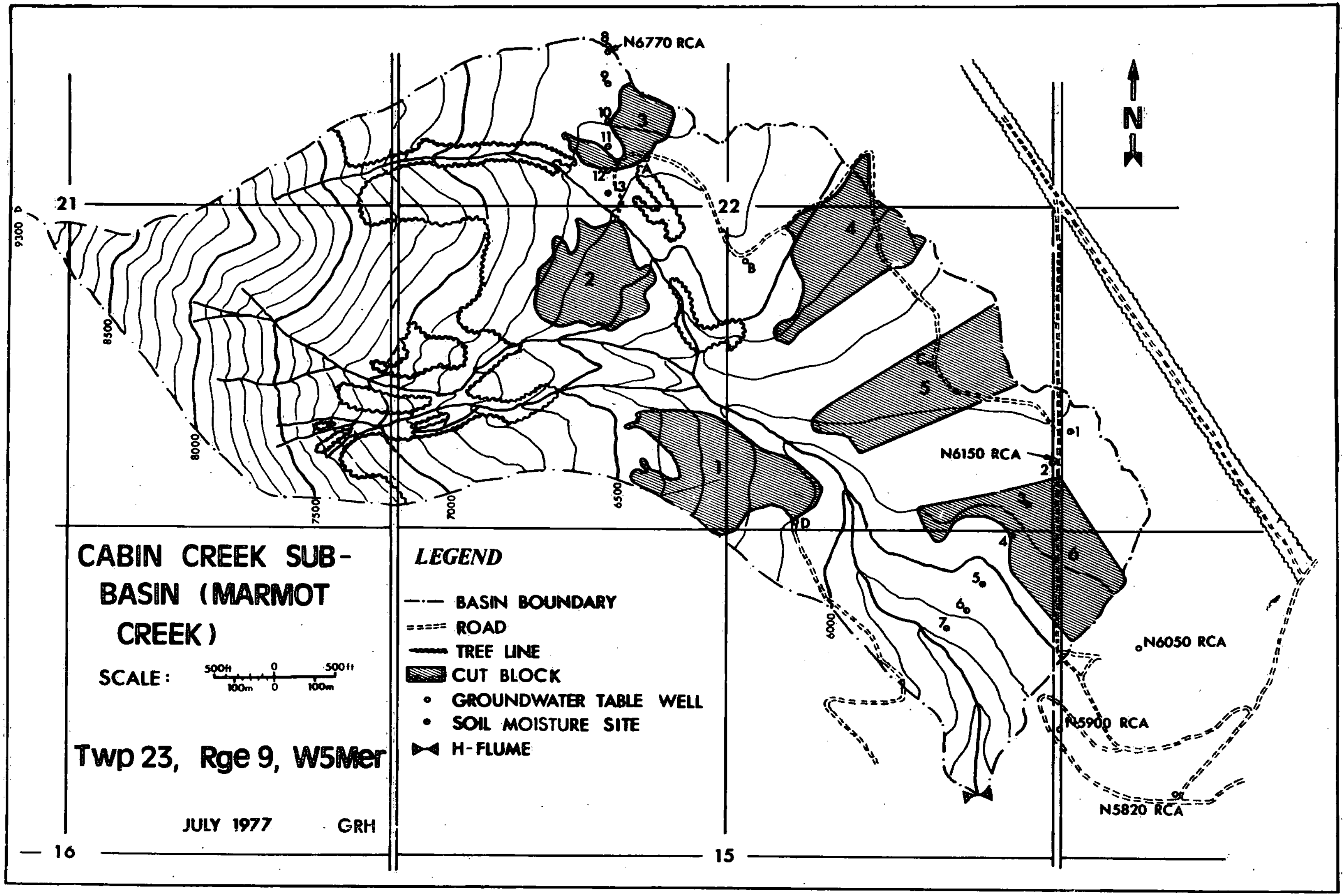


FIGURE 1 Cabin Creek Sub-Basin

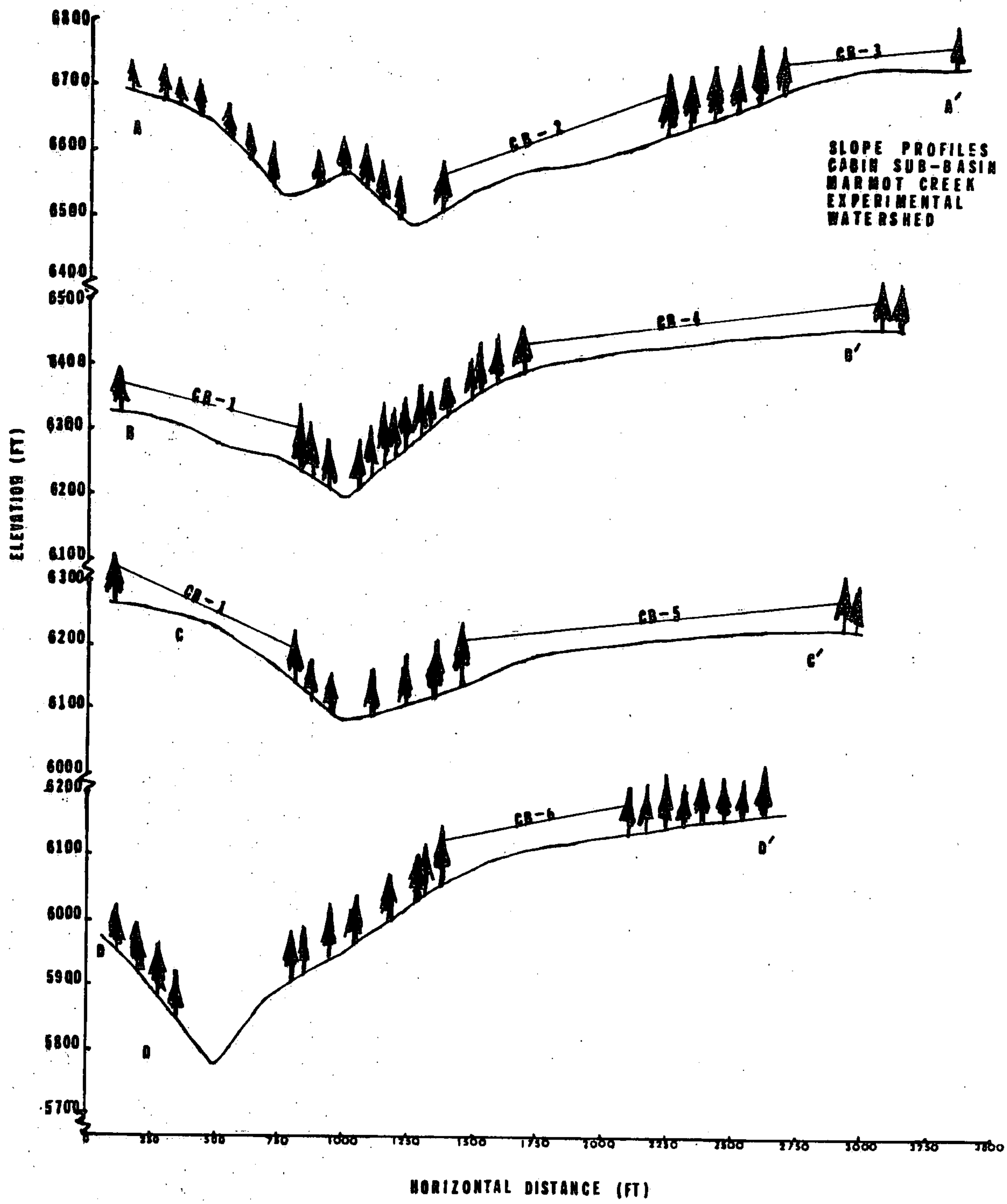


FIGURE 2 Slope positions of cut blocks (CB) 1-6 in Cabin Creek Sub-Basin.

In the spring of 1975, following logging, a network of 8 automatic, composite sediment samplers was established along the main stem channel of Cabin. The samplers were located upstream and downstream of each cut block. The purpose of the network was to identify specific cut blocks as sources of sediment. It was assumed that large differences between upstream and downstream samples are indexes of sediment input (Gilmour, 1972). Samples were collected on a weekly basis and analyzed by filtration techniques (American Public Health Association, 1965).

The extent and occurrence of soil exposure, erosion and sediment transport from roads and cut blocks were evaluated by mapping of cut blocks and frequent on-site reconnaissances of roads and cut blocks. Mapping included the identification of cut block boundaries and the location and pattern of skidroads, landings and access roads in each cut block. On-site reconnaissances were done during road construction and logging, and during spring runoff and rainstorms when erosion and sediment movement would be most apparent. On each reconnaissance, signs of erosion were searched for by walking all main skidroads, access roads, landings and the downslope edges of cut blocks and roads. The extent of soil exposure was measured by using a systematic grid of milacre plots (0.404 m^2) spaced at 20 m intervals on transect lines, which were 40 m apart running straight up and down the slope. On each plot the area of mineral soil exposure and occurence of erosion were visually estimated and noted. These data were then grouped in soil disturbance classes of: High (61-100% exposure); Moderate (46-60%); Low (16-45%) and Nil (0-15%).

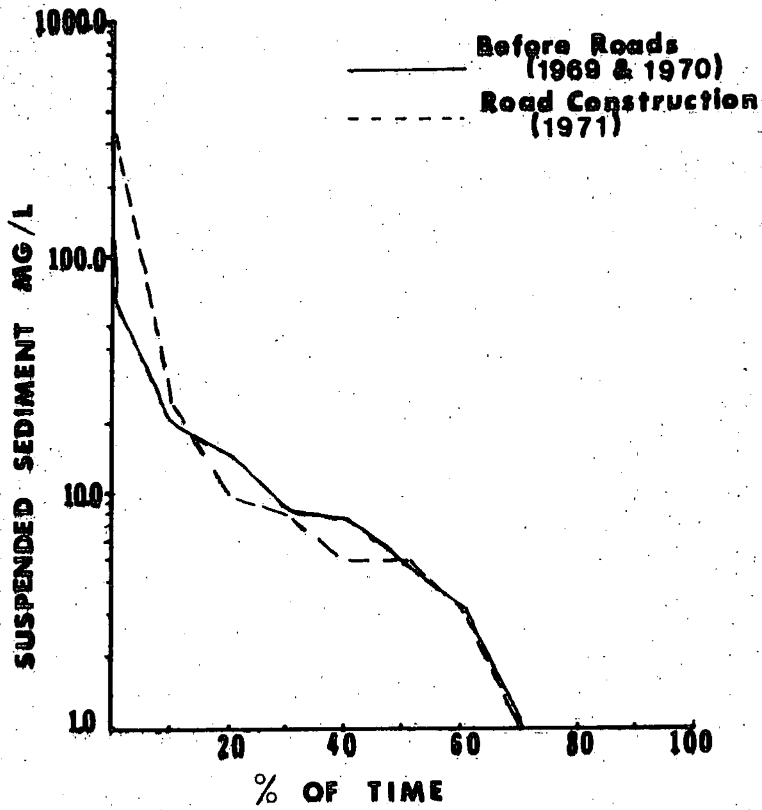
RESULTS

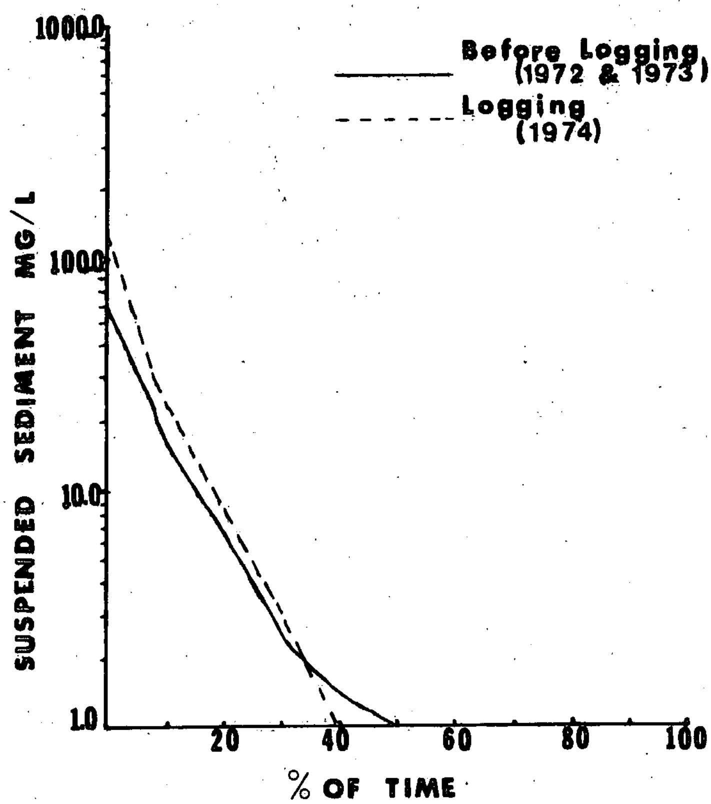
Road Construction

Soil exposure on roads and road right-of-ways was 100%. No post-construction revegetation of roads was done, and natural revegetation has been slow. The roads, 6 years after construction are effectively bare of vegetation, except for a few grasses, herbs and small tree seedlings. On-site reconnaissances of the roads each spring and summer since construction have not detected any serious erosion or sediment transport. The erosion that has occured is small and minor, consisting of shallow rills, 20-25 mm deep, on cut and fill slopes and road surfaces. Roadside ditches have downcut to depths of 75-100 mm in some places, with eroded materials trapped by logging debris along the road or by adjacent undisturbed vegetation. The inspection of downslope edges of roads showed no sediment movement towards Cabin Creek.

Examination of suspended sediment data show sediment production in Cabin Creek is low. Mean daily sediment concentrations prior to road construction (1969-1970) varied from 0-4 parts per million (ppm). The highest sediment concentration observed in Cabin to date is 239 ppm, which coincided with a peak flow of 481 l/sec. Frequency analyses of sediment concentrations for 1969 and 1970 show that 80-90% of the time (April-September) concentrations are less than 10 ppm (Figure 3A).

Measurement of sediment during and after road construction did not show any large or unusual increases in sediment concentrations. Mean daily suspended sediment in Cabin during construction, August 31-September 27, 1971, was 6 ppm with a maximum value of 24 ppm. Sediment levels in the spring of 1972 and 1973,





FIGURES 3A, 3B Frequency curves of suspended sediment concentrations in Cabin Sub-Basin following construction, also were very low. Daily mean concentrations from early May to mid June for both years varied from 0-38 ppm, with maximums of 62 (1972) and 191 (1973) ppm. A comparison of sediment frequency curves (Figure 3A), before and after road construction shows no large and/or consistent changes in the magnitude or time distribution of sediment concentrations. A calculation of seasonal sediment yields (Table 2) also shows no large inputs of sediments into streams during or after road construction.

Logging

Soil exposure in the cut blocks ranged from nil to high. Surveys in the spring and summer of 1975 showed that 20-30% of all milacre plots sampled were rated high in soil exposure, 5-8% as moderate, and the remaining 60-75% as low or nil. High soil exposure occurred where skidding and truck traffic completely removed the litter-duff layer. Areas of low soil exposure occurred off skid-roads, where traffic was light and the litter-duff layer left undisturbed or worked into the upper soil horizons. The mapping of the cut blocks gave results similar to the surveys for soil exposure. The average area exposed per cut block was 3.36 ha, or 32% of average cut block area (Table 1). Skid roads were the largest cause of soil disturbance accounting for 58% of total disturbance, followed by access roads at 24% and landings at 18%.

On-site reconnaissances of cut blocks during and after logging did not detect any serious erosion. The erosion and soil movement observed were minor and consisted of small rills, 20-30 mm deep, on back and fill slopes and road surfaces. Eroded soil was transported short distances of 2-3 m, before being deposited and trapped by logging debris. No evidence of sediment movement off cut blocks was observed.

Suspended sediment data during and after logging in Cabin show no large increases in sediment. Suspended sediment samples during 1974 and 1975 averaged 5 and 2 ppm, with maximum values of 85 and 24 ppm respectively. Frequency analyses of sediment concentrations also indicate no changes in the magnitude or time distribution of sediment from previous years (Figure 3B).

The data obtained from the network of composite samplers along Cabin Creek show similar results. Station to station comparisons of these data did not show any large differences or high sediment levels that could be associated with any particular cut block. Concentrations were low, averaging no more than 3-4 ppm per day. Examination of the sediments sampled suggests that most of the sediment load originates from channel erosion. Particulate material caught on filter papers in analyses were unweathered, fractured bits of lime-stone, similar to local bedrock. The fragments were flat and platy and 1-2 mm in size.

Seasonal sediment discharges for 1974 and 1975 also confirm no effect of logging on water quality (Table 2). Total suspended loads for 1974 and 1975 were 7939 and 1437 kg respectively. Sediment in 1974 was greatly increased over that in 1973 and 1975, but cannot be attributed to logging as most of the increase occured in June with spring runoff, prior to logging.

The fluctuations in seasonal sediment discharges for Cabin are considered normal and a function of storm size, storm frequency and streamflow response. Stratification of sediment data for the period 1969-1975 identified 13 storms that produced marked increases in sediment concentrations. These storms ranged in size from 9-168 mm of rainfall and generated streamflow responses of 2.83-370 l/sec (12-1600% of mean annual flow). A multiple regression analysis of these data shows that 90% of the variation in sediment data can be explained by storm size and streamflow response. (Sediment Concentration $= b_0 + b_1$Streamflow response + b_2Storm Size; $n = 13$; $R = 0.95^{**}$; $SE_e = 15$ ppm).

SUMMARY AND CONCLUSIONS

The results of this study show water quality in Cabin sub-basin did not change during or after road construction and logging. No large increases in sediment and/or high concentrations occurred during the study that could be associated with forest harvesting. Suspended sediment concentrations before and after forest harvesting were very low. Mean suspended sediment concentrations for 1969-1975 ranged from 2-12 ppm with maximum values varying from 24-239 ppm. Seasonal sediment discharges for April-September also were very low, averaging 7040 kg, with a range of 1437-9750 kg. Variation of seasonal sediment was attributed to fluctuations in storm size and storm frequency and streamflow response.

The road construction, logging and government regulations employed in Cabin sub-basin are representative of logging operations in the spruce-fir forests of southern Alberta. Soil disturbance caused by tractor logging in Cabin was 32%. This level of disturbance is considered normal for the method and topography involved, and falls within the range of values (21-39%) reported by others (Dyrness, 1965; Garrison and Rummel, 1951; Haupt, 1960; Smith and Wass, 1976). Approximately 60% of the soil disturbance in the cut blocks was caused by skidroads. Most of this soil exposure, and that on roads outside of the cutblocks consisted of the complete removal of the litter-duff layer and 100% exposure of mineral soil.

Soil erosion on roads and cut blocks was very low, considering the extent of soil exposure and lack of rapid revegetation. Erosion observed during surveys and reconnaissances of cut blocks and roads consisted of shallow rills, 25-30 mm deep on cut and fill slopes and on road surfaces. In some places, roadside ditches were downcut to depths of 75-100 mm, with eroded material carried downslope short distances before being trapped by logging debris or undisturbed vegetation. Seasonal sediment discharges on an areal basis average 30 kg/ha (26 lbs/ac) which is low, compared to soil loss values of 140-19250 kg/ha (125-17180 lbs/ac) reported by others (Fredricksen, 1970; Leaf, 1966; Meeghan, 1972).

The protection of water quality during road construction and logging in Cabin sub-basin is attributed to the following factors. (1) The avoidance of excessive soil disturbance by careful planning of roads and logging. Specifically, the location of roads and cut blocks away from stream channels, the avoidance of steep road gradients, and minimizing the number of road-stream crossings. Furthermore, logging and road construction were done at the time of year when runoff, soil moisture and rainfall are at minimum levels. (2) The provision of trained supervisors to insure that road and logging prescriptions were implemented as planned. This avoided mistakes and made field crews aware of the environmental impacts of forest harvesting on water quality. (3) The soils of Cabin are very stable and low in erodibility. The coarse textures and high carbonate contents of the soils make them very resistant to erosion and sediment transport.

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IMPACT ON WILDLIFE OF LAND MANAGEMENT ALTERNATIVES
FOR THE ALBERTA EAST SLOPES

BY

E.S. TELFER

ABSTRACT

Wildlife discussed includes big game mammals, furbearers, small mammals, forest grouse and non-game birds. Emphasis is on comparison of the impact of five forest management alternatives on wildlife in the coniferous forests of the East Slopes of the Rocky Mountains in Alberta. Optimum management for water yield would create an interspersion of mature forest with permanently maintained openings which would have a width equal to the stand height and would comprise about 40 percent of the area. Conditions for big game, furbearers and birds should improve somewhat. Two-stage removal of old stands benefits most species at first but logging of residual stands removes needed habitat elements. Continuous clearcutting has the same effect. The optimum cutting pattern for wildlife would provide forest edge valuable to many species of birds and furbearers as well as big game and would produce greater bird species diversity by adding edge and early-successional habitat to mature forest. Animals that prefer mature forests, such as caribou *(Rangifer tarandus)* and cavity-nesting birds would suffer some loss of critical habitat but would not be eliminated by the snowpack management and wildlife management alternatives. The tentative nature of the hypotheses regarding animal reactions to forest conditions is stressed and study of individual species requirements urged. Scale of land treatment is regarded as a key factor determining the impact of the treatment.

IMPACT ON WILDLIFE OF LAND MANAGEMENT ALTERNATIVES FOR THE ALBERTA EAST SLOPES

BY

E.S. TELFER[1]

INTRODUCTION

Some people will no doubt be surprised to see a paper on wildlife appearing on the program at a symposium on watershed management. However, most are becoming rather familiar with the ecological principle that "everything affects everything else" so will readily appreciate that any scheme of land management will profoundly change the animal communities present.

So what? Why does it matter if our planned changes in the landscape should affect animals? Surely only those who have lived as hermits for the past decade can be unaware of the great public concern for the welfare of all wildlife. Not only hunters and fishermen but a greater number of birdwatchers and amateur naturalists take a deep personal interest in the wildlife resource. There is also a general acceptance of the principle that we humans have a moral responsibility to see to it that our activities do not exterminate other species sharing this planet, and do not irreversibly degrade our human environment.

The purpose of this paper is to predict the impact on wildlife of structural changes likely to occur in the vegetation of the forests of the Alberta East Slopes as a result of five forest management alternatives. Since "Wildlife exists as a byproduct of vegetation" (Thomas *et al.* 1977) we can expect substantial changes in species present and numbers of individual animals when management alters vegetation over extensive areas.

I will attempt to model conditions that would follow from the five alternatives. The conclusions resulting from the exercise are supported by minimal field data from the Alberta East Slopes themselves. They should therefore be treated as hypotheses for further testing rather than definitive statements.

This paper deals with the East Slopes and Foothills of the Rocky Mountains in the Province of Alberta. The region begins at the American border and extends northwesterly, including the outlying Porcupine Hills, to drainage of the Smoky River where the Rocky Mountains bend westward into British Columbia, a distance of approximately 700 km. The region extends from the continental divide

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at elevations reaching 4000 m, north-easterly to the Great Plains Physiographic Region at elevations of 700-800 m. The belt of mountains and foothills varies from 20 to over 100 km in width, excluding the closely similar Swan Hills. However, many of the comments contained in this paper also apply generally to the Swan Hills.

The vegetation of the East Slopes is dominated by coniferous forests which extend south along the cordillera between the alpine tundra on the west and the prairie and boreal mixed wood forest of the Great Plains on the east. Rowe (1972) classified the forest into three belts with the Lower Foothills Section of the Boreal Region at lower elevations, succeeded by the Upper Foothills Section which in turn blends into the East Slope Rockies Section of the Subalpine Region.

Smaller areas were classified as the Douglas-Fir and Lodgepole Pine Section of the Montane Region.

Dominant tree species are logepole pine *(Pinus contorta)*, White spruce *(Picea glauca)*, Engelmann spruce *(P. Engelmanni)*, Alpine fir *(Abies lasiocarpa)*, Trembling aspen *(Populus tremuloides)*, and Balsam poplar *(P. balsamifera)*.

Lodgepole pine and the poplar habitually invade burned areas although poplars are largely restricted to the eastern, lower foothills and valleys. Lodgepole pine is eventually replaced by white spruce in the Boreal Region (and Engelmann spruce in the Subalpine) and is in turn invaded by alpine fir (Day 1972). Because of large fires in the 1800's much of the East Slopes support mature lodgepole pine stands.

The East Slopes possess diverse and relatively dense wildlife populations, described below in greater detail. The variety and high densities of game species and proximity to large human population centres, coupled with the treaty right of Indians to hunt without restriction, has led to heavy hunting pressure on Alberta-owned Crown lands. About one-third of the East Slopes are in national parks which draw visitors from all over the world, placing a premium on additional non-consumptive use.

The term "wildlife" is usually applied to vertebrate animals that live on land -- birds, mammals, reptiles and amphibians. For the purposes of this paper I will deal mainly with economically or ecologically important groupings of birds and mammals, with more general comments on other vertebrate groups. This approach necessarily oversimplifies the intricate ecological relationships in East Slopes forest.

The position of the East Slopes, juxtaposition with prairie, alpine tundra, aspen parkland and northern boreal forests, with large areas of Columbian Montane Forest to the west of the mountains, means that many animal species are available to invade suitable habitat in the East Slopes forest. This fact is reflected in the 140 species of birds selected for consideration in the present review. Most of the species are extremely rare on the East Slopes. In most forest structural classes it is normal to observe 20 to 25 species on a plot of several ha or on 1 km-long transect. Of the species recorded, several might be expected to be common while the others would be rare.

Mammals are divided into categories that are functional (insectivores) and economic. Large carnivores like grizzles *(Ursus arctos)* are included with the "furbearers". One economically important furbearer, the red squirrel *(Tamiasciurus hudsonicus)* is also an important small mammal herbivore and is included in the small mammal category.

LAND MANAGEMENT ALTERNATIVES

Much of the East Slopes forest area is as yet only lightly disturbed by man. High grading for sawlogs, fire suppression and seismic exploration have been major impacts. Locally, pulpwood harvesting, oil and coal extraction, livestock grazing and recreation are beginning to have a concentrated impact. However, many options remain open. The five alternatives for management of the forest described below are worthy of consideration in the light of present social and economic needs in Canada.

Alternative No. 1 - Uncut Virgin Forest

The simplest management alternative is to do nothing. Much of the East Slopes forest is presently managed in this way with the very important exception that wildfire is efficiently suppressed. The assumptions that I have made for this alternative include continued fire suppression, leading to increasing maturity and a shift from lodgepole pine toward greater dominance by spruce and alpine fir.

Structurally the virgin forest becomes more patchy with maturity (Telfer, unpublished). Steep southerly exposures often remain treeless. Decay and windthrow create other open patches of a tree height or less wide which are invaded by shrubs and by fir seedlings. Stable, brushy borders exist along streams and in boggy, lower slope openings. Old stands range from 15 m tall at high elevations to 25-30 m on better sites. Within the closed stands large accumulations of undecomposed windfall and other litter are common. Dead trees and snags (stubs of tree trunks with few remaining limbs and often lacking bark) form a significant portion of the stand.

Alternative No. 2 - Optimum Snowpack Management (Snow Mgmt.)

Treatment of forests under this alternative is schematically presented in Fig. 1, based on research results of the Alberta Watershed Research Program (R. Swanson, pers. comm.). Forty percent

ALTERNATIVE FOR OPTIMUM SNOWPACK MANAGEMENT
(SNOW MGMT.)

YEAR	TREATMENT BY PERCENTAGE OF AREA	
	40 %	60 %
0	Cut small openings about 1 tree height wide, spaced mechanically and shaped to conform to landforms and visual quality constraints	Cut individual high-quality stems between openings.
30	Cut down vegetation in openings	Light selection cut between openings
60	Cut down vegetation in openings	Light selection cut between openings
90	Cut down vegetation in openings	Light selection cut between openings
120	Cut down vegetation in openings	Light selection cut between openings

Fig. 1. Description and scheduling of vegetation treatments tentatively proposed for forests on the Alberta East Slopes under a management alternative for optimum snow accumulation and meltrate.

ALTERNATIVE FOR TIMBER MANAGEMENT
BY 2-STAGE STAND REMOVAL (TM.2-STAGE)

YEAR	TREATMENT BY PERCENTAGE OF AREA	
	60-95 %	5-40%
0 30	Approximately half the merchantable stands cut in blocks or strips during 1st ten years. Removal of residual blocks follows regeneration of initially cut areas. Snags and other unmerchantable stems are bull-dozed. Scarification is followed by artificial seeding and planting as required.	Reserved strips along waterbodies, cull or low-volume stands. Uncut except for individual high-quality stems.
60 90		
120	Second two-stage removal of merchantable stands.	Reserved strips largely untouched. Some originally uncut stands may now be merchantable.

Fig. 2. Description and scheduling of logging and regeneration in forests of the Alberta East Slopes under the two-stage stand removal timber management alternative currently widely used.

of the area (less any natural openings) would be cut in small patches approximately one tree height wide. The remainder of the area would be cut through selectively to remove commercially valuable stems. However, snags and cull trees would remain. Logging would not be expected to pay but merchantable wood removed would help defray costs. The goal would be to accumulate snow in the openings, thereby slowing meltrate and sublimation while increasing total runoff and lengthening the period of elevated runoff into the summer.

At approximately 30-year intervals it would be necessary to chop the regeneration growing in the openings. Since access would have to be gained to the area for brush cutting further selective harvesting of merchantable trees in the forested patches could be feasible.

Alternative No. 3 - Two-Stage Stand Removal (T.M. 2 - Stage)

This management system is actually in use in tree harvesting operations on the East Slopes. Approximately 50 percent of the merchantable stand area on treated forest compartments is cut in blocks roughly 16 ha in area, or in strips 100-200 m wide. Once satisfactory regeneration is established in the cut areas (usually 10 to 20 years after cutting) the residual blocks or strips are clearcut. Regeneration is aided by extensive scarification or blading of surface debris followed by planting or seeding. The sequence of operations is outlined in Fig. 2, assuming a 120-year rotation which seems not unreasonable as an average for higher elevation forests, expecially for production of spruce-fir.

Alternative No. 4 - Continuous Clearcutting (T.M.C.C.)

This alternative is under study on a pilot project on the East Slopes. Once a management compartment is entered for harvest, cutting would proceed by swaths followed within a few years by scarification and regeneration (Fig. 3). Scarification removes all snags and cull trees. As harvesting and regeneration operations move across the compartment all but main access roads are levelled and planted. Harvesting and regeneration are thus completed on a compartment almost simultaneously.

Successional Stages following Clear-cutting

All alternatives require preservation of buffer strips adjacent to water bodies; also all compartments contain some unmerchantable stands due to small size, low volume or inaccessibility -- muskeg for example. Many East Slopes Foothills management compartments have more than 70 percent of their area clothed by merchantable stands but the average on those considered operable is probably somewhat less (J. Wright, pers. comm.).

ALTERNATIVE FOR TIMBER MANAGEMENT BY CONTINUOUS CLEARCUTTING (T.M.C.C.)

YEAR	TREATMENT BY PERCENT OF AREA	
	60-95%	5-40%
0 30	Clearcut entire management compartment within ten years followed by scarification, bulldozing snags and other unmerchantable stems. Artificial seeding and planting as necessary several years after completion of cut.	Reserved strips along waterbodies, cull or low-volume, or otherwise unmerchantable stands. Uncut except for scattered selection of better stems.
60 90		
120	Second continous clearcut of all merchantable stands.	Reserved strips largely untouched. Some originally uncut stands may now be merchantable.

Fig. 3. Alternative for timber management by continuous, or progressive, clearcutting. A proposed system for managing the Alberta East Slopes Forest.

ALTERNATIVE FOR OPTIMUM WILDLIFE MANAGEMENT (WILDL.)

YEAR	TREATMENT BY PERCENT OF AREA				
	15-24%	15-24%	15-24%	15-24%	5-40%
0	Clearcut in strips or patches <200m. wide. Leave 15 snags per ha.				Reserved strips along waterways and unmerchantable stands. Individual high-quality stems will be removed at each re-entry to block, while some stands will move into the merchantable category.
30	Regenerate by scarification with artificial seeding & planting as required.	Clearcut in strips or patches <200m. wide. Leave 15 snags per ha.			
60		Regenerate by scarification with artificial seeding & planting as required.	Clearcut in strips or patches <200m. wide. Leave 15 snags per ha.		
90			Regenerate by scarification with artificial seeding & planting as required.	Clearcut in strips or patches <200m. wide. Leave 15 snags per ha.	
120	Clearcut in strips or patches <200m. wide. Leave 15 snags per ha.			Regenerate by scarification with artificial seeding & planting as required.	

Fig. 4. A land management alternative for optimum wildife management, describing the nature and scheduling of proposed treatments, on the Alberta East Slopes.

During the period 30 to 60 years after initial felling in a compartment, regrowth is expected to pass through a stage when some taller patches provide shelter for ungulates and increased crown space for nesting and foraging birds while more open patches provide browse and low cover. I have predicted the use likely to be made of that stage by various animal forms. However, complete coverage of logged acreage by regeneration of commercial conifers uniform in age will guarantee that the mid-successional stage will be short.

A similar assessment has been made for conditions near the end of the first rotation where a dense, uniformly spaced stand of trees of pole and small sawlog size will occupy the compartments. The model of stand development does not consider thinning or fertilization to speed growth. Thinning is now being tried experimentally and may gradually be applied to increasing areas of regenerated stands.

Alternative No. 5 - Optimum Cutting for Wildlife (Wildl.)

The final alternative discussed is one that I hypothesize would be reasonably near to optimum for most wildlife species but still a technically practical harvesting system. Stages in treatment are outlined in Fig. 4. Leave strips for protection of water bodies are reserved as in alternatives T.M.2 - stage and T.M.C.C. The model calls for reentry at roughly 30-year intervals to clearcut approximately one quarter of the merchantable stands in strips or patches less than 200 m (10 chains) wide. A reasonable number of snags and dead trees would be left in the cut area. Otherwise, cut areas would be regenerated as in the other timber management schemes.

METHODS

Where land management activities yield commercial wood products fairly conventional economic analyses can be used to evaluate management alternatives. Increases in economic activity related to increased water runoff, or to changed flow regime, permit attachment of money values to the water management potential of a management alternative. However, many benefits flowing from forests defy definition in money terms, although certain dimensions of their value can be quantified by economists. What is a ruffed grouse really "worth"? What value do we put on a warbler's song? Can we evaluate the worth of a woodpecker eating a bark beetle? How much does a healthy, functioning ecosystem, covering a large region, contribute to the national net worth? While such aspects of our environment have a generally recognized value we cannot exhaust their meaning by affixing a dollar sign. Many of them fall into the category of things for the enjoyment of which we earn money!

The nebulous nature of wildlife values give a different dimension to evaluation of land management alternatives as they relate to wildlife production. Certain assumptions must be made (all of which are debatable) which are listed below:

a) It is desirable to have relatively dense populations of "game" and furbearing mammals, game birds and fish, and of economically valuable insect eaters and predators.

b) No species should be exterminated from a region by adverse land management practices.

c) Within any locality, the greatest number of species should be maintained reasonably consistent with human activities.

With these assumptions as a basis it is possible to assess the impact of the above-described management alternatives on wildlife. The approach chosen is that described by Brown (1976) for a similar study of a small watershed in Arizona. Brown and his colleagues expressed the value of habitat produced by various management alternatives on a scale from 0 (no good, local extinction) to 5 (excellent habitat) for a series of species groups. Average ratings were then calculated and compared to each other for a qualitative assessment of the alternatives.

For this review I have evaluated habitat requirements of 140 bird and 47 mammal species that have been reported from the East Slopes. Many of the species are of rare occurrence. Since the East Slopes forest forms a narrow belt adjoined by other biotic regions, chances are good for invasion by species more characteristic of other regions if suitable habitat is created. Fortunately, species rare on the East Slopes have their main centre of population density elsewhere.

Ratings of the value of habitats to various species are based on inferences about habitat requirements from descriptions in standard references; Godfrey (1966), Salt and Salt (1976), Harrison (1975), Powell *et al.* (1975), Weins (1975), Thomas *et al.* (1975), and Myers and Meredith (1975) were used for birds while Soper (1964), Banfield (1974), Burt and Grossenheider (1976), Wallmo (1969), Stelfox and Taber (1969), and Stelfox *et al.* (1976), Patton (1974), Radvanyi (1970), and Canadian Wildlife Service unpublished data, were used for mammals.

It is likely that many of the rankings would be disputed by other biologists. Rank assignments are tentative and I hope further work will refine them. However, although the value of various habitats for individual species might be rated higher or lower by others, it is unlikely that mean ranks for the treatment alternatives would be greatly altered.

The impact of vegetation manipulations occurs not only immediately after treatment but extends in variable ways into the indefinite future. In my analysis I have hypothesized the value of habitats at varying stages of post-treatment development, illustrated by schematic diagrams (Figs. 5-8) a technique applied to wildlife in

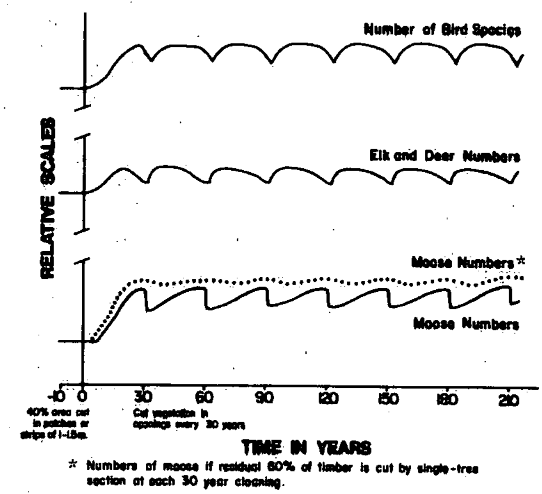

Fig. 5. Graphic models of the hypothesized response of birds and big game mammals to the proposed land management alternative for optimum snowpack management on the Alberta East Slopes.

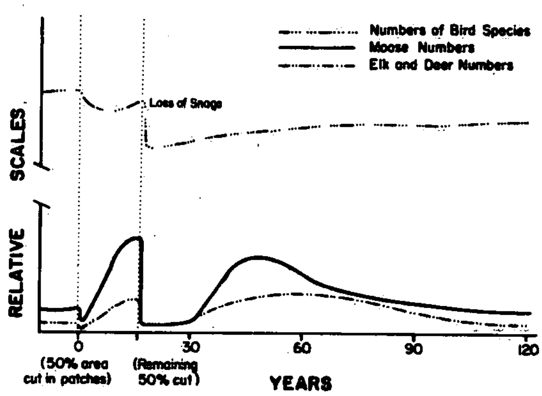

Fig. 6. Graphic models of the hypothesized response of birds and big game mammals to the present practice of two-stage forest stand removal on the Alberta East Slopes.

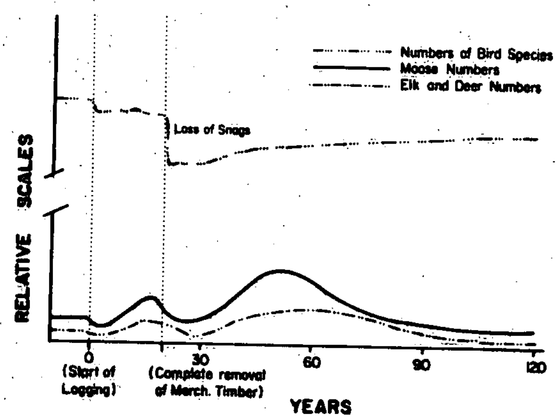

Fig. 7. Graphic models of the hypothesized response of birds and big game mammals to proposed "continuous" or "progressive" clearcutting alternative for forest management on the Alberta East Slopes.

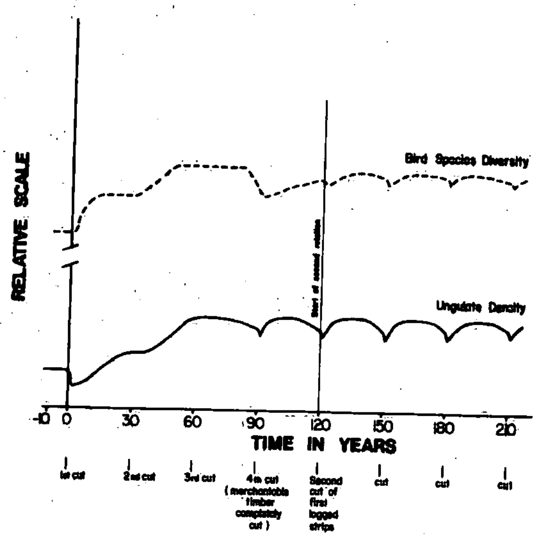

Fig. 8. Graphic model of the hypothesized response of birds and big game ungulates to a land management alternative considered to be optimum for wildlife on the Alberta East Slopes.

the Pacific coastal forests by Bunnell and Eastman (1976). In the case of the "snow mgmt." treatment I have theorized that habitat conditions will remain relatively unchanged following initial treatment. Both T.M. 2 - stage stand removal and T.M.C.C. will create similar habitats for wildlife by mid-way through the rotation, providing a mixture of cover with some food patches, and also late in the rotation when stands mature. Ratings are estimated for those points in time as well as immediately after completion of cutting. The "optimum wildlife" alternative has been rated on conditions existing after the fourth reentry when all old growth has been removed. Conditions should thereafter remain relatively constant except for periodic variations due to climate and to other environmental factors.

RESULTS

Mean ranking of habitat quality for several groupings of birds and mammal species (Table 1) have been compared for various management alternatives (Table 2). The groupings are arbitrary. Some groupings are taxanomic (finches), some economic ("furbearer"), while one ("hole nesters") relates to a specific habitat requirement. The number and percentage of species for which each alternative was ranked as "good habitat" (ranks 4 and 5) are presented in Table 3.

Analysis of ranking suggest that:

a) Cutting for optimum snowpack management should provide habitat roughly equivalent to unmanaged old growth for most groups.

b) Both types of commercial logging may create rather serious deterioration in habitat quality for most groups. However, impact should vary markedly between logging compartments depending on percent of area treated. Low quality of habitat ratings later in the rotation stem from loss of snags, dense uniform stands and reduction in openings due to planting - a "green desert".

c) The "optimum for wildlife" option shows a marked advantage over the others. Am I being too generous to my own brainchild? Only adequate testing of the hypothesis can determine its validity.

An important factor contributing to the impact of any land treatment is the extent of area treated. Effects like those described above may not occur if areas treated are small relative to species' home range. If changes do occur with small treatments they may represent a local shift of activity into or out of favourable or unfavourable conditions rather than increase or decrease in regional populations. Peek *et al.* (1976) postulated that cuttings to provide extra browse would have to be established throughout a township area (93.6 km^2) to increase moose numbers. Creatures of smaller home range, like breeding songbirds, should respond to treatments of much smaller extent.

Table 1. Mean ranking of forest management alternatives for Alberta East Slopes forests of spruce-fir and pine on a scale of 0 to 5 for various groups of animal species

Animal Group	Management Alternatives						
			Commercial Logging				
	Unmanaged old growth	Optimum snowpack mgmt.	2-Stage stand removal	Continuous clearcut	Mid-succession after clearcut	End of 1st rotation	Optimum for wildlife
BIRDS							
Cavity nesters	3.6	3.7	0.9	0.6	1.5	0.9	3.9
Woodpeckers	3.5	4.3	1.1	0.5	1.9	0.8	4.3
Hawks & eagles	3.7	3.5	2.1	1.5	1.9	2.5	4.3
Owls	4.0	3.4	0.6	0.1	1.9	1.4	3.3
Blackbirds	1.2	1.9	2.3	2.0	1.6	0.8	2.9
Finches	2.8	2.6	2.6	0.8	2.0	2.3	4.1
Sparrows	1.5	2.4	3.4	3.2	2.1	0.9	3.0
Thrushes	3.0	4.8	1.5	0.5	2.3	1.3	4.5
Warblers & vireos	2.1	2.9	3.2	1.6	2.6	1.4	3.5
Flycatchers	1.7	2.6	3.2	0.9	2.8	1.1	3.3
Grouse	1.6	2.0	4.4	1.4	1.8	1.4	3.2
All Birds	2.4	2.9	2.3	1.5	1.9	1.5	3.5
MAMMALS							
Insectivores (Shrews & bats)	3.8	3.6	1.5	1.6	2.1	2.6	3.7
"Small mammals"	2.6	2.2	3.1	2.0	2.5	2.2	3.5
"Furbearers"	2.5	2.9	3.7	2.0	2.4	1.5	3.9
Ungulates	2.2	2.4	1.8	1.3	2.2	1.6	4.6
All Mammals	2.6	2.6	3.0	1.8	2.4	2.0	3.8

Table 2. Differences in mean ranking of habitat quality for wildlife on a scale of 0 to 5 for various forest treatment alternatives compared to unmanaged old growth forest on the Alberta East Slopes

Animal Group	Management Alternatives						
			Commercial Logging				
	Present unmanaged old growth	Optimum snowpack yield	2-Stage stand removal	Continuous clearcut	Mid-succession after clearcut	Near end of first rotation	Optimum for wildlife
BIRDS							
Cavity nesters	3.6	+0.1	−2.5	−3.0	−2.1	−2.7	+0.3
Woodpeckers	3.5	+0.8	−2.4	−3.0	−1.6	−2.7	+0.8
Hawks & eagles	3.7	−0.2	−1.6	−2.2	−1.8	−1.3	+0.6
Owls	4.0	−0.6	−3.4	−3.9	−2.1	−2.6	−0.7
Blackbirds	1.2	+0.7	+1.1	+0.8	+0.4	−0.4	+1.7
Finches	2.8	−0.2	−0.2	−2.0	−0.8	−0.5	+1.3
Sparrows	1.5	+0.9	+1.9	+1.7	+0.6	−0.6	+1.5
Thrushes	3.0	+1.8	−1.5	−2.5	−0.7	−1.7	+1.5
Warblers & vireos	2.1	+0.8	+1.1	−0.5	+0.5	−0.7	+1.4
Flycatchers	1.7	+0.9	+1.5	−0.8	+1.1	+0.6	+1.6
Grouse	1.6	+0.4	+2.8	−0.2	+0.2	−0.2	+1.6
All Birds	2.4	+0.5	−0.1	−0.9	−0.5	−0.9	+1.1
MAMMALS							
Insectivores	3.8	−0.2	−2.3	−2.2	−1.7	−1.2	−0.1
"Small mammals"	2.6	−0.4	−0.4	−0.6	−0.1	−0.4	+0.9
"Furbearers"	2.5	+0.4	+1.2	−0.5	−0.1	−1.0	+1.4
Ungulates	2.2	+0.2	−0.4	−0.9	0.0	−0.6	+2.4
All Mammals	2.6	0.0	+0.4	−0.8	−0.2	−0.6	+1.2

Table 3. Number and percent of vertebrate species for which the forest conditions under various management alternatives for the Alberta East Slopes forest are "good" (Ranked 4 or 5 on a scale of 0 to 5)

		Management Alternatives						
				Commercial Logging				
Animal Group	Total no. species	Uncut virgin forest	Optimum snowpack mgmt.	2-Stage stand removal	Continuous clearcut	Mis-Succession after clearcut	Near end of first rotation	Optimum for wildlife
Birds	140	41	49	41	21	23	21	76
Percent	100	29	35	29	15	16	15	54
Mammals	47	17	15	22	10	11	10	28
Percent	100	36	32	47	21	23	22	60

Hypothetical projections of changes in population parameters through time following treatment (Figs. 5-8) suggest increase for moose *(Alces alces)*, deer *(Odocoileus hemionus* and *O. virginianus)* and elk *(Cervus canadensis)* under the optimum snowpack alternative. Numbers would then fluctuate around a higher mean. Bird species diversity would increase somewhat as the small patches create new niches. Under the 2-stage stand removal alternative deer, moose and elk numbers would increase following removal of the first patches but would drop drastically with removal of residual blocks as cover was lost. Later, as regeneration in the blocks first cut reached pole size (10-35 cm diameter breast high) cover would again be available, along with browse, and for a couple of decades good moose densities and increased bird species diversity should occur.

While habitats were not ranked for other vertebrates such as fishes, reptiles and amphibians, some general comments may be made. Stebbins (1966) lists six amphibians and two reptiles as occurring on the East Slopes in Alberta. The long-toed salamander *(Ambystoma macrodactylum)* and western toad *(Bufo boreas)* are both noted to frequent a great variety of habitats while the frogs including the chorus frog *(Pseudocies triseriata)*, leopard frog *(Rana pipiens)*, wood frog *(R. sylvatica)* and spotted frog *(R. pretrosa)* are associated with water bodies and wetlands. Two varieties of garter snake, the red-sided *(Thamnophis sirtalis parietalis)* and the western terrestrial *(T. elegans)* occur on the East Slopes. Both should benefit from any kind of logging. Low vegetation provides them with cover and insect prey.

The impact of the management alternatives on aquatic ecosystems has been an important concern of the Alberta Watershed Research Program leading to continuing studies on the Marmot and Tri-Creeks experimental watersheds. It has been well established that removal of trees from a substantial percentage of forested watershed will cause a sizeable increase in run-off (Hibbert 1967). Large scale forest removal as called for by the commercial logging alternatives described above would cause increased runoff during at least the first third of the rotation.

Stream ecosystems are capable of withstanding periods of high runoff, and indeed can benefit from occasional severe floods that wash silt from gravels used as spawning beds by salmonid fishes such as trout, *(Salmo spp. and salvelinus spp.)* and create deeper pools. However, such floods may also displace fish and invertebrates downstream. Later in the season flows drop. The net result is decreased stability of the stream environment.

The unmanaged forest produces less water but its streams have a more stable regime. The optimum snowpack management alternative is designed to produce more water, including a greater peak flow, but to prolong the snowpack runoff and smooth out the hydrograph. The result is hypothesized to be a more stable system with a greater average volume of water supporting a greater population of organisms including fish.

It is assumed that riparian leave strips of uncut timber will be sufficient, in combination with properly located roads, to prevent sedimentation in streams and to maintain stable water temperatures.

The management alternative for "optimum wildlife" would be expected to produce flow peaks and discharge volumes intermediate between the other two pairs of alternatives, thus being somewhat better for fish production than the commercial logging option but perhaps poorer than the optimum snowpack option or the unmanaged forest.

CONCLUSIONS

Figures 5 to 8 provide crude models of the impact of four land management alternatives. Like all models they are the product of integration of data with hypotheses. Their purpose is to generate more comprehensive hypotheses for research planning. The present state of our knowledge suggests that current logging systems are less than optimum for production of wildlife given the previously stated assumptions relating to desirable wildlife conditions. Cutting patterns for optimum snowpack management would be considerably better and some improvement over conditions in old growth for most species. It is hypothesized that better patterns for wildlife can be created if desired. However, knowledge of habitat requirements for many species is limited and often difficult to interpret in terms that forest managers can apply.

There is thus a need for more extensive observational and experimental research before wildlife parameters can be included with certainty in forest management on the East Slopes.

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CONTROLLING THE WATER QUALITY IMPACT

OF

TIMBER HARVESTING OPERATIONS IN THE EASTERN SLOPES

by Ron C. Davis

ABSTRACT

The Alberta Forest Service attempts to minimize the water quality impact of timber harvesting in the eastern slopes region through the implementation of operational programs of watershed management. Watershed management considerations are integrated at the planning and operational stages of logging operations to minimize the impairment of water quality.

Inorganic sediment, when it is the product of accelerated erosion, is the main water pollutant associated with timber harvesting. The most frequent source of stream sedimentation from logging is the erosion of haul roads. Planning the location and design of roads to maximize their stability and to avoid the disturbance of stream channels and implementing effective erosion control measures during and shortly after construction will reduce the amount of stream sedimentation.

Protection of the small watercourses that are associated with the cut-blocks is essential to control sedimentation of larger streams having important fishery and recreation values. Therefore controls are placed on log-skidding and scarification operations to minimize the disturbance of intermittent and small permanent streams. Protection of the large streams involves the provision of buffer strips.

In order to control the accelerated erosion of stream channels, controls are placed on the area of a watershed that can be cut-over as well as on the location of cut-blocks.

CONTROLLING THE WATER QUALITY IMPACT OF TIMBER HARVESTING OPERATIONS IN THE EASTERN SLOPES

BY

Ron C. Davis*

BACKGROUND

With the establishment of the Eastern Rockies Forest Conservation Board in 1947, priority was given to 'protecting the watersheds' of the eastern slopes of the Rockies in Alberta, specifically those provincial lands comprising the headwaters of the Saskatchewan River. Protecting the watershed involved the control of wildfire; the control of renewable resource uses such as timber harvesting and livestock grazing; and the control of land surface disturbances such as roads, seismic lines, wellsites, pipelines, and coal mines.

Since that time, watershed protection, which we define as the control of soil erosion and the protection of streams, has been an established function of the Alberta Forest Service. This is reflected in existing regulations, ground rules, and management practices presently governing the use of forest lands in the province.

INTRODUCTION

The harvesting of timber as a renewable resource is a major economic activity in the eastern slopes region.** Because of the large acreages of land influenced, timber removal has a major impact on the quantity, timing, and quality of water that is delivered as streamflow from the watersheds of the eastern slopes.

A primary objective of watershed management is to control the hydrologic impact of timber harvesting operations in order to protect the quality of water for such beneficial uses as fisheries, recreation, and water supplies. Poorly planned and conducted logging operations can deteriorate the quality of water in small creek basins that have important fishery and recreation values. If destructive logging practices are allowed to persist in any watershed, the quality of water in the large river systems may also become impaired.

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** In this paper the eastern slopes region includes provincial lands comprising the headwaters of the Saskatchewan, Athabasca, and Smoky River systems.

The purpose of this paper is to indicate how watershed management considerations are integrated at the planning and operational stages of logging operations to minimize the impairment of water quality.

There are three main watershed management considerations associated with timber harvesting, and each warrants a separate discussion.

1. The control of land surface disturbance.
2. The protection of stream environments.
3. The control of accelerated stream channel erosion.

CONTROL OF LAND SURFACE DISTURBANCE

Inorganic sediment, when it is the product of accelerated erosion, is the main water pollutant associated with timber harvesting. It is a major pollutant in terms of the degree to which it impairs the suitability of water for fishery, recreation, and water supply uses. Therefore a major objective of watershed management is to control accelerated soil erosion and the subsequent deposition of sediment in stream channels.

Logging Haul Roads

The most frequent source of stream sedimentation from logging in the eastern slopes is the construction of haul roads and the subsequent erosion of their surfaces, ditches, and fill slopes. The main reasons for the problem are:

1. A lack of careful advance planning in road location and design; and
2. Ineffective erosion control practices, i.e. drainage and revegetation.

Much can be done at the planning stage of the logging operation to prevent the occurrence of severe erosion and sedimentation caused by poor road location and design.

From a watershed protection standpoint, the main objectives in road location are:

1. To avoid unstable slopes;
2. To avoid the constriction of stream channels; and
3. To minimize the number of contact points with streams (crossings, fill constrictions).

These objectives can often be attained through pre-planning. For a given set of design standards, alternative routes can be plotted on air photos or topographic maps after a consideration of information available on soils, geology, topography, and landforms. This process enables the identification of potential problem areas such as unstable slopes, slides and slumps, erosive soils, rock outcrops, and groundwater discharge areas. Adjustments in the location can be made after an examination of these areas in the field. Stream crossings can also be examined in the field in order to select locations that are stable, and where runoff from ditches can be diverted away from the channel. Design requirements for bridges and culverts can also be determined at this time.

The locations of all logging roads are included in each company's annual operating plan, and are thus subject to review by Alberta Forest Service personnel. This review process has become interdepartmental for the major haul roads.

The ground rules established under The Forests Act that govern logging operations in the province contain a clause stating that no road can be located within 5 chains of the high-water mark of a secondary stream. In practice the 5-chain requirement is used as a guideline only due to the variety of conditions encountered in the field. In many instances, it is preferable to construct roads within the 5-chain guideline in order to avoid excessive amounts of soil disturbance on valley slopes which are often steep and unstable. Where valley-bottom locations are necessary, the main objective is to minimize the number of actual contact points with the stream. Roads constructed on floodplains require approval and licensing by Alberta Environment, and are subject to special road design, construction, and erosion control measures.

Whether the road-builder is a private company or a government agency, there is often a tendency to lose sight of the purpose of a road and to create excessive amounts of soil disturbance in the process. This is the reason for the establishment of uniform road classes and minimum standards for logging roads in the province. As shown in Appendix I, elements of road design are specified in the ground rules for each class of road. Logging companies must specify the class of each road included in their annual operating plan.

The objective of the road standards is to ensure that design speeds, gradients, right-of-way widths, and cut and fill slopes are suited to the purpose of the road. This helps control unnecessary amounts of soil disturbance.

Despite significant improvements in the standard of road location and design, erosion of haul roads continues to be the main environmental problem associated with logging operations in Alberta. The industry needs to improve the effectiveness of its road drainage and revegetation practices.

In general, the road drainage measures specified in the ground rules are not being implemented effectively. The most common drainage problems include:

1. Excessive ditch erosion from insufficient cross-drainage;
2. Poor design (insufficient capacity and length) and installation of culverts; and
3. Lack of ditch diversions or sediment traps at stream crossings to reduce sedimentation.

A lack of prompt revegetation of exposed road surfaces is a major factor contributing to stream sedimentation, since most of the erosion occurs shortly after construction. The ground rules allow companies 1 year following the completion of skidding operations in a harvesting area to complete the revegetation of haul roads. This requirement needs to be more strictly enforced.

Stream sedimentation from the erosion of haul roads will continue to be a problem until erosion control becomes an integral part of road design and construction. Drainage and revegetation requirements for a given road should be determined in the planning stage of road location and design, and should be considered as normal construction procedures (and costs). Erosion control, i.e. effective drainage and revegetation, should take place during the actual construction or clean-up operation. Priority should be given to stream crossings and steep slopes.

Operations On The Cutblock

Little soil disturbance is caused by conventional tree-felling operations in Alberta. Under wet conditions, soil compaction may result from the use of mechanical feller-bunchers. However this type of equipment is used mainly in flat topography where the erosion hazard is low.

Fortunately in Alberta most log-skidding operations are conducted in the winter months on frozen ground. A minimum of soil disturbance is usually associated with winter logging. In the eastern slopes region, however, summer operations are frequently conducted and are of greater concern.

Under certain conditions, severe soil disturbance can result from skidding operations, whether by cat, rubber-tired skidder, or cable systems. Erosion of the compacted surfaces of skid-roads and landings can lead to stream sedimentation problems. The exposure of mineral soil by mechanical scarification for forest regeneration purposes is also of concern.

The main watershed protection objective is to minimize the amount of soil disturbance on the cut-block. By maintaining the high infiltration capacity of the forest floor following timber removal, precipitation or snowmelt will continue to reach stream channels as subsurface flow and not as overland flow from compacted or eroding soil surfaces. The following practices are recommended to achieve this purpose.

1. The area occupied by skid-roads and landings should be limited to less than 10 percent of the cut-block area.
2. Skid-roads should be located parallel to the contour to avoid the concentration of runoff over exposed soil surfaces.
3. The number of contact points with watercourses should be kept to a minimum. Small watercourses on the block should be used as skidding unit boundaries where possible. Landings can then be located between the watercourses, and logs skidded away from the stream channels.

4. Scarification should be done on the contour to avoid concentrating runoff in the furrows. Logging slash distributed evenly across the cut-block reduces the velocity of overland flow and traps sediment.

STREAM PROTECTION

A system of stream classification has been adopted to aid in the implementation of the ground rules with regard to stream protection. As shown in Appendix II, three types of streams are recognized: intermittent, secondary, and main. Guidelines for the protection of each class are specified in the ground rules.

Protection of the small intermittent watercourses that are often associated with the cut-blocks is a major objective of watershed management. The erosion of soil exposed by skidding or scarification operations in these small channels can lead to severe sedimentation downstream. Protection of these streams is essential to avoid water quality problems in the larger streams having important fishery and recreation values. There is no point in leaving buffer strips along the larger streams without an appropriate degree of upstream channel protection. Thus the present ground rules emphasize the protection of intermittent and small permanent streams, and are considered to be the most stringent in Canada in this regard.

Buffer strips are not required along intermittent streams except where the stream is designated as being important for fish spawning. The main operational guidelines for protecting intermittent streams are as follows:

1. Random skidding across watercourses is not permitted except during the winter months.
2. When summer operations are involved, skidding across watercourses must be done at designated (gentle slopes, stable bank and bed materials), and properly constructed crossings (log fill with a brush mat covered by a maximum of 1 foot of soil). The objective here is to impede the natural flow of water as little as possible and to minimize the amount of soil exposed in the channel. In some instances such crossings have to be removed after logging to allow the passage of fish.
3. Skidding of logs directly along watercourses is not permitted, irrespective of the season of operation.

The protection of permanent streams, i.e. secondary and main streams, involves the provision of reserve or buffer strips of vegetation on each side of the stream.

The buffer width requirements specified in the ground rules are intended to be used as guidelines only, since each situation encountered in the field has its own set of topographic, soil, and vegetation conditions. Expert judgement is required to achieve a degree of stream protection that is both effective and practical in a given field situation.

Controversy has persisted over the need for buffer strips along streams. Arguments against them are usually based on losses of merchantable timber. In addition, extensive blowdown of timber into streams creates debris jams which may promote channel instability (bank erosion and channel changes); as well as unaesthetic stream environments.

The counterargument is that buffer strips do not have to be permanently excluded from timber production. In most instances mature trees are not required. Young forest growth, riparian vegetation (willow, alder, birch), or undisturbed ground will often provide sufficient streambank protection. Companies are encouraged to remove mature or overmature timber near streams in situations where the timber can be removed without causing disturbance of the stream channel.

At the present time buffer strips are essentially mechanical barriers to keep logging equipment out of stream channels. However buffer strips can be justified for many other reasons.

1. Filter sediment and logging debris from roads and cut-blocks.
2. Control runoff (especially snowmelt rates) from important source areas of streamflow.
3. Regulate stream temperature.
4. Provide habitat for terrestrial insects important for fish food.
5. Provide areas of quality outdoor recreational opportunity, for example, an aesthetic environment for sport fishermen and hikers.
6. Provide escape cover and travel corridors for various species of wildlife.

Because of the variety of potential uses of buffer strips, a more sophisticated system of stream classification is presently under consideration. Conceptually the system would be based on:

1. Resource uses and values of the stream and its adjacent valley environment.
2. Forest management considerations such as timber merchantability and operability.
3. Stability of the stream channel and the lower valley slopes.

Such a classification system would permit the delineation of streamside management units. Silvicultural alternatives could then be identified that would protect streams and realize resource values within the management unit. This sytem would hopefully aid field staff in placing effective controls on timber and other industrial operations.

CONTROL OF STREAM CHANNEL EROSION

The removal of timber from watersheds increases the amount of water that is available for streamflow. The magnitude of the increase in streamflow is directly related to the percentage of the watershed area that is cutover. This is one of the reasons for the requirement in the ground rules that no more than 50 percent of the area of merchantable timber in a sub-watershed*** is to be harvested in any one cut.

The objective here is to ensure that streamflow increases within the sub-watershed can be safely accommodated by the stream channel, i.e. without the accelerated erosion of streambanks and the scouring of bed materials.

The 50-percent merchantable-area limitation is useful as a general guideline but it is often not appropriate in specific situations. This is because each sub-watershed is unique in terms of its:

1. Distribution of merchantable timber by elevation, slope, aspect, and proximity to stream channels.
2. Streamflow increase potential, i.e. mean annual runoff, soil depth, existing cutover and burned-over area (including the density and height of regeneration).
3. Stability and present condition of stream channels.

Proposed timber operations in the eastern slopes are evaluated to predict the expected increase in the quantity of streamflow. Based on an evaluation of the stability and present condition of the main stream channel, allowable increases in streamflow are determined for specific sub-watersheds. A recommendation is then made as to the maximum area of a sub-watershed that can be cut-over, based on the ability of the stream channel to safely accommodate the predicted increase in streamflow.

Besides placing limits on the area of a sub-watershed that is cut-over, other considerations are taken to minimize the magnitude of streamflow increases. For example, the location of cut-blocks parallel to the contour minimizes the concentration of runoff from the block to the stream channel.

The concentration of cut-blocks in valley-bottoms is avoided where possible because such locations are major source areas of streamflow. They remain saturated for a significant portion of the water year (April to October), and are the first areas to contribute to streamflow during snowmelt or rainstorms.

Where possible, attempts are made to avoid the concentration of cutting in the low-energy, i.e. delayed snowmelt, locations in the sub-watershed. Such locations include high elevations, north aspects, and in some instances, valley-bottoms. The concern here is that an earlier melt from these locations will shorten the length of the normal snowmelt period, thereby increasing the risk of increasing peak flows.

SUMMARY

1. A primary objective of watershed management in the eastern slopes region is to control the hydrologic impact of timber harvesting operations in order to protect the quality of water for beneficial uses such as fisheries, recreation, and water supplies.

*** In the eastern slopes, the sub-watershed is normally the area drained by a third or fourth order stream. Streams of this size will usually have important fishery and recreation values.

2. Inorganic sediment, when it is the product of accelerated erosion, is the major water pollutant associated with logging operations.
3. Erosion of logging haul roads is the most frequent source of stream sedimentation associated with timber harvesting. Despite better standards of road location and design, improvements are required in road drainage and revegetation practices.
4. Soil disturbance from summer log-skidding and scarification operations can result in stream sedimentation. Therefore present ground rules emphasize the protection of the small watercourses associated with the cut-blocks to avoid water quality problems in the larger streams.
5. Protection of secondary and main streams involves the provision of buffer strips. At the present time buffer strips are mainly barriers to keep logging equipment out of stream channels. A more sophisticated system of stream classification is being considered because of the variety of potential uses and values of buffer strips and streamside environments.
6. The removal of large volumes of timber from watersheds can cause increases in the quantity of streamflow. To control accelerated erosion of streambanks and beds, controls are placed on the area of a sub-watershed that can be cut-over as well as on the location of cut-blocks.

CONCLUSION

The impact of timber harvesting on water quality in the eastern slopes region is minimized by implementing operational programs of watershed management. Such programs consist of four basic components.

1. The development and use of inventory information to evaluate the impact of proposed logging operations.
2. The translation of impact assessment results into operational controls.
3. The effective implementation of operational controls in the field.
4. Follow-up and monitoring to determine the effectiveness of controls in protecting water quality.

Appendix I

UNIFORM ROAD CLASSES

AND MINIMUM STANDARDS

CLASS I (Primary)	Permanent main road, available year round.
CLASS II (Secondary)	Permanent branch road, generally available 10 months.
CLASS III (Tertiary)	Lateral access through cut-blocks, 10-year average term, limited access during wet periods.
CLASS IV (Temporary)	Temporary truck road within or between cut-blocks (2-year average life).
CLASS V (Temporary Access)	Temporary light truck road.

ITEM	ROAD CLASS I	II	III	IV	V
Safe Design Speed - mph	55	45	35	25	-
Sustained Speed - mph	40	30	20	10	-
Maximum Degree of Curvature	5	8	13	25	-
Sight Distance - ft.	600	450	300	-	-
Max. favorable Grades - %					
Sustained	6	7	8	10	12
Pitch	8	8	10	12	14
Max Adverse Grades - %					
Sustained	4	4	6	6	12
Pitch	5	6	8	8	14
Right of Way Width - ft.	132	100	80	66	33
Surface width - ft.	32	28	20	18	16
Maximum Bared Width - ft.	90	85	60	30	30
*Cutslopes - Cotan	1-1/2:1	1-1/2:1	1-1/2:1	1-1/2:1	1-1/2:1
*Fillslopes - Cotan	2:1	2:1	1-1/2:1	1-1/2:1	1-1/2:1
Bridge & Culvert Strength-tons	150	150	100	100	5
Engineering					
Plan	Detailed Design	Detailed Design	Rough Plot	Traverse Only	Traverse Only
Profile	Detailed Design	On cuts & fills over 5 ft	On steep grades only	On critical grades only	None
R/W Stakes or Flags	Both Edges	Both Edges	Center Only	Center Only	Center Only
Construction stakes	Cut, fill & Centerline complete	Centerline & all cuts & fills over 5 ft.	Only at critical areas	Only at critical areas	None

*Subject to soil erodibility at individual sites. On very sensitive terrain, cuts over 5 feet should be 2:1, fills over 5 feet should be 3:1

Appendix II

WATERCOURSE MANAGEMENT

Stream Course Identification

Stream course identification will be based on the physical description of the stream and preliminary planning will use an order system which is cross referenced to the physical description. The order system will also be used as a basis for operational planning whereas the actual application will be based on the physical description of the watercourse.

1. Intermittent Watercourse Physical Description

   a) Minor Intermittent: This watercourse will transport water from 20% to 50% of the May to October runoff period. The channel is visably definable but small (up to 2 feet in width), and usually vegetated. Bank development shows evidence of cutting by water action.

      These watercourses can be important from a fisheries standpoint. Fish seldom spawn up this far; however, the watercourses do develop small drift invertebrate populations in the pools and riffles.

      Disturbances of these watercourses will lead to sediment production during flow periods, and its subsequent deposition may damage fish and invertebrate habitats in the minor intermittent streams themselves, and in the higher order streams.

   b) Major Intermittent: These streams will carry greater volumes of flow than the minor intermittents, but may appear dry during periods of prolonged drought. The stream channel is well defined and except for dry season, the channel is free of vegetation. The channel width will vary, but will usually be wider than 2 feet.

      Spring spawning fish will often use intermittent watercourses providing there are no blockages. Aquatic insects develop in the pools and riffles, if gravel and rubble is present and no excessive siltation. Down stream water quality is greatly affected from sediment being introduced into intermittent watercourses.

2. Secondary Watercourse Physical Description

   a) Small Permanent: Water flows continuously during the May to October runoff period. Banks are well defined and valleys may be associated with these watercourses. Gravel and rubble will be present in the channel.

      Small permanent watercourses will normally provide suitable fish habitat. Significant populations of aquatic insects are usually present. Water quality and fish populations are sensitive to siltation.

b) Large Permanent: Water flows the entire year in a channel which will vary from 3 to 12 feet wide. The channel flow has gravel and rubble. Bank development is more extensive and often is in the form of benches. There streams support fish populations. Water quality and fish populations are sensitive to siltation in these streams.

3. Major Watercourse Physical Description

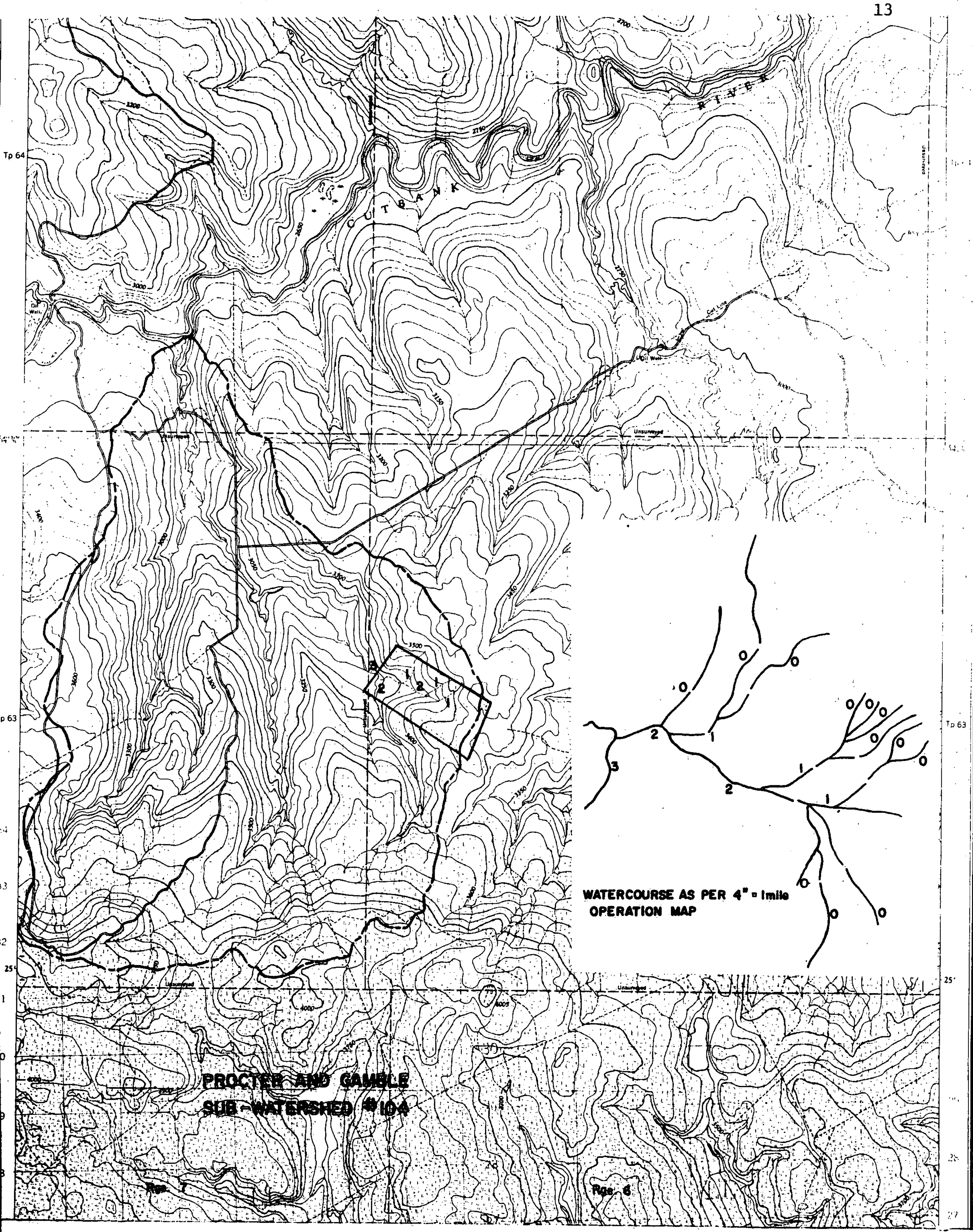
a) Major streams and Rivers: Water flows the entire year. The stream channel will vary in size from a minimum of 6 feet wide in channels to pools and riffle areas often exceeding 20 ft. wide. Usually bottom material has a significant amount of gravel and rubble content. These water courses support resident fish populations and forms the most important part of the fish habitat in the watershed. Valleys of variable width, ranging from 1/4 mile up to several miles, are associated with these streams.

Watercourse Classification

Each watercourse shall be classified into one of three categories: Main, Secondary and Intermittent. A method of stream order classification will be utilized which is based on a physical description of the structure of the stream.

Description

Map Classification	Physical Description	Operation Consideration
A. Intermittent Watercourse		
0 - order		Intermittent ground rules
	Minor Intermittent	to apply plus harvesting precautions and
1st - order		
	Major Intermittent	rules as defined
B. Secondary Watercourse		
2nd - order		Secondary watercourse
	Small Permanent	ground rules to apply
3rd - order		
	Large Permanent	
C. Main Watercourse		
4th order		
	Major Streams or	Main watercourse ground
5th - order	Small Rivers	rules to apply


Tp 64
CUTBANK
RIVER
Oil Well
Cut Line
Unsurveyed
Tp 63
WATERCOURSE AS PER 4" = 1mile
OPERATION MAP
PROCTER AND GAMBLE
SUB-WATERSHED #104
Rge. 7
Rge. 6

Watercourse Operating Ground Rules

1. Intermittent Watercourses

Intermittent watercourses generally definable only on the ground, and occasionally designated on the watercourse map. These watercourse descriptions include minor intermittent and major intermittent watercourses.

Operational requirements are:

a) Crossing: random skidding in and through will be permitted during frozen and dry soil conditions. Planned log crossings will be required during wet periods to prevent rutting and minimize bare soil. Upon abandonment these crossings do not need to be removed from minor intermittent streams.

b) Scarification can cross these courses during dry periods and only on the contour.

c) Roads shall not be constructed in the watercourses.

d) Fish spawning movements very likely occur in major intermittent watercourses and where such is indicated, special crossings must be provided and removed unless otherwise designated to be left by a Forest Officer. No debris or skidding will be allowed in this watercourse.

2. Secondary Watercourses

Small but permanent streams as designated on the watercourse map or as defined by classification.

Operational requirements are:

a) No roads, landings or bared areas within 5 chains of the high water mark without the written approval of the Forest Superintendent.

b) No disturbance of any kind, and no removal of forest cover within 1.5 chains of the high water mark except where specificially approved in writing following inspection by a Forest Officer.

c) Where removal of forest cover within 1.5 chains is approved in writing by a Forest Officer, no skidder, scarifier or other machine can operate within the 1 chain area. Winching or other means must be used so the machine will remain outside the 1 chain strip.

d) Any trees felled within the 1.5 chain area to be felled away from the watercourse unless otherwise approved in writing by a Forest Officer, and no debris or slash to enter the watercourse. Any debris or trees which accidently or inadvertly enter the watercourse shall be completely removed immediately.

3. Main Watercourses

Major streams and rivers as designated on the watercourse map or as defined by classification.

Operational requirements are:

a) No roads, landings or bared areas to be located within 5 chains of the high water mark without the written approval of the Forest Superintendent.

b) No disturbance of any kind and no removal of forest cover, within 3 chains of the high water mark except where specifically approved in writing following inspection by a Forest Officer.

c) Where removal of forest cover within 3 chains is approved, in writing by a Forest Officer, no skidder, scarifier or other machine can operate within the 1 chain area. Winching or other means must be used so the machine will remain outside the one chain strip.

d) Any trees felled within the 3 chain area are to be felled away from the watercourse, and no debris of any kind will be allowed to enter the watercourse. Any debris or trees which accidently or inadvertently enters the watercourse shall be completely removed immediately (using winches) without the machine entering the watercourse.

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