

MANAGING FOREST LANDS FOR WATER

PROCEEDINGS OF RESEARCH-MANAGEMENT
SEMINAR HELD AT EDMONTON, ALBERTA
JANUARY 13 & 14, 1970

EDITED BY D. L. GOLDING

NORTHERN FOREST RESEARCH CENTRE
INFORMATION REPORT NOR-X-13
JULY, 1974

CANADIAN FORESTRY SERVICE
DEPARTMENT OF THE ENVIRONMENT
5320 - 122 STREET
EDMONTON, ALBERTA, CANADA
T6H 3S5

TABLE OF CONTENTS

	PAGE
FOREWORD	1
LIST OF REGISTRANTS	2
WATER AND MULTIPLE USE - Robert H. Swanson	3
WATER AS A FOREST PRODUCT IN ALBERTA: Its Value in Quantity, Quality and Timing - R.D.S. MacDonald and W. Poliquin	5
LAND-MANAGEMENT PRACTICES THAT AFFECT WATER YIELD - Douglas L. Golding	13
FOREST-MANAGEMENT PRACTICES THAT INFLUENCE STREAMFLOW REGIME - Robert H. Swanson	33
LAND-MANAGEMENT PRACTICES THAT AFFECT PHYSICAL AND CHEMICAL WATER QUALITY - Teja Singh	49
WATERSHED-MANAGEMENT PRACTICES IN RELATION TO OTHER FOREST USES - Edward C. Wyldman	73

FOREWORD

Managing forest lands for water was the theme of the research-management seminar held in the Alberta Forest Service Depot in Edmonton, Alberta, January 13 and 14, 1970. The seminar was authorized by the Steering Committee of the Alberta Watershed Research Program. The goal of the seminar was to bring the results of research to bear on managing the forest for its varied products, particularly water, and to establish a forum for communication between those managing the forest resources of the province and those doing research in watershed management.

The 36 participants in the seminar were from the Forest Service, Fish and Wildlife Division, and the Water Resources Division of the province of Alberta, the Forest Technology School, the Eastern Rockies Forest Conservation Board, and the Canadian Forestry Service. The seminar was opened by Mr. R. H. Swanson, Research Coordinator for the Alberta Watershed Research Program. Greetings were extended by Mr. Gordon Smart representing the Alberta Forest Service.

The six papers that follow were presented as a basis for discussion. These deal with multiple use of the forest, water as a forest product, the relation of watershed management and other forest uses, and land management effects on water yield, regime, and quality.

D. L. Golding,
Editor

LIST OF REGISTRANTS

F. Bishop, Alberta Fish and Wildlife Division, Peace River
B. A. Coulcher, Alberta Forest Service, Edmonton
D. M. D'Amico, Alberta Forest Service, Edmonton
R. K. Deepprose, Alberta Water Resources Division, Edmonton
L. N. Donovan, Alberta Forest Service, Edmonton
F. Facco, Alberta Forest Service, Edmonton
Dr. D. L. Golding, Canadian Forestry Service, Calgary
R. T. Heywood, Alberta Water Resources Division, Edmonton
G. R. Holecek, Alberta Water Resources Division, Edmonton
C. W. Hunt, Alberta Fish and Wildlife Division, Red Deer
C. Jackson, Alberta Forest Service, Edmonton
C. B. Lane, Alberta Fish and Wildlife Division, Edson
D. R. Iyons, Alberta Forest Service, Edmonton
Dr. R. D. S. MacDonald, Canadian Forestry Service, Calgary
W. J. McLean, Alberta Forest Service, Edmonton
R. E. Miller, Alberta Forest Service, Edmonton
J. T. Nalbach, Alberta Land Use Assignment Section, Edmonton
E. Nyland, Alberta Land Use Assignment Section, Edmonton
P. Paetkau, Alberta Fish and Wildlife Division, Edmonton
R. J. Patterson, Alberta Fish and Wildlife Division, Edmonton
W. Poliquin, Eastern Rockies Forest Conservation Board, Calgary
C. L. Primus, Alberta Water Resources Division, Edmonton
M. J. Romaine, Alberta Forest Service, Edmonton
H. M. Ryhanen, Alberta Forest Service, Edmonton
C. D. Sawyer, Alberta Department of Lands and Forests, Edmonton
J. A. Schalkwyk, Alberta Land Use Assignment Section, Edmonton
F. J. Schulte, Alberta Water Resources Development Planning Branch, Edmonton
Dr. T. Singh, Canadian Forestry Service, Calgary
G. Smart, Alberta Forest Service, Edmonton
G. D. Stephen, Alberta Forest Service, Edmonton
R. H. Swanson, Canadian Forestry Service, Calgary
C. Van Waas, Alberta Land Use Assignment Section, Edmonton
H. O. Walker, Forest Technology School, Hinton
E. C. Wyldman, Alberta Forest Service, Edmonton

WATER AND MULTIPLE USE

by

Robert H. Swanson

Canadian Forestry Service

Edmonton, Alberta

INTRODUCTION

There are few things that we foresters do to land that do not affect the water that emanates from it. Clearing creates more water, regrowth produces less, road construction bares soil and dislodges sediment, scarification wreaks havoc with the soil surface - an important layer in the hydrologic cycle. And yet, the water is used by cities, people enjoy the benefits of water-based vacations, fish somehow manage to survive. Why?

Forests have a great deal of built in "forgivingness". Forbs, grass, shrubs, and later, trees reoccupy harvested areas. The soil surface is restored. The streams become clear and the process swings full circle. Most of the time.

It would appear then, that water production is reasonably compatible with extractive forestry practices. After all, things do get better with time. But what happens during the healing period? What about the water user - is he rightfully saddled with higher filtration costs to remove your sediment? Where are the fish to go; are there alternative streams for them? What does the person who lives downstream do with your extra water in the springtime? These are questions we have not had to face before.

Our job has been to get the wood out - as cheaply as possible. Besides, we have been improving things. Our roads are utilized by hunters, campers, and fishermen to reach otherwise inaccessible areas. Everyone knows we need more water, so creating more runoff is really an improvement. And besides, we're only changing things over a small area for a short time. Why, in five years everything is back to normal. Says who?

Do you know that the capability of one lodgepole pine-Engelman spruce watershed to "create" more water after harvest is now expected to last longer than 30 years and that almost all of the increase will occur during the spring runoff period when we need it least? Do you realize that a stream and its resident users make up a dynamic system into which it is extremely difficult to introduce some species of fish - or even to reintroduce the same species? Do you appreciate that a flood has to occur only for a few minutes to wipe out years of labor? Are you aware that users of forest land for other than wood production

are increasing in numbers at an ever increasing rate? Do you enjoy the forestry profession and want to continue in it? Then be aware that the activity of others is creating new demands on your profession. Your freedom to operate solely within economic or silvicultural constraints is being eroded. The "other" users are going to have their say. They are not "fading away".

The following was prepared to help you - the professional forester - do a better job of managing a forest (a watershed if you will, because all forest land is watershed) where the use or users of water must be considered. No one can establish rules for operating in a watershed because the users, not the land, must set the operational constraints. The user may be in the watershed - as a trout in a stream- or far removed - as a resident of The Pas, Manitoba, dependent upon the Saskatchewan River for drinking water. The users goals may not be compatible with economical forestry. They may not even be compatible with each other. But they can no longer be ignored. Your decisions as to how to operate in your watershed can be based on knowledge - knowledge of how the system works to produce the water product.

We in research do not know all of the answers, but where we can apply intuition and experience, we have. Our experience with and knowledge of forest-water systems can be useful to you, the manager. The results of a number of research experiments have been interpreted in the following pages for you. This is but one attempt to communicate.

WATER AS A FOREST PRODUCT IN ALBERTA: ITS VALUE IN
QUANTITY, QUALITY, AND TIMING

by

R.D.S. MacDonald

Department of Community and Social Development

Saint John's, Newfoundland

and

W. Poliquin

Forestry Consultant

Calgary, Alberta

INTRODUCTION

The Alberta Forest Reserve supplies most of the water flowing into the Saskatchewan - Nelson Basin¹, while other forested areas in the province affect the water in substantial parts of the Mackenzie Basin. The importance of these forest areas as prime watersheds was recognized in federal and provincial laws when, about twenty years ago, the dominant use of the Forest Reserve was proclaimed to be water production.

Ideally, the forest should be managed to produce not only water, but that combination of products that maximizes the value of the forest land. Today, political pressures from groups interested in the forest for other uses are building up, and it is essential to re-examine the possible uses. This involves placing a value, both for the present and the future, on the quantity, quality, and timing of the water supply to downstream users as well as to dwellers in the natural streambed and surrounding environment.

¹ For example about 90% of the mean annual flow of the South Saskatchewan River at Saskatoon comes from the 20% of the drainage area on the east slopes of the Rocky Mountains in southwestern Alberta (Munn and Storr 1967).

THE VALUATION PROBLEM

Value in Quantity

If streamflow is normal or average, what are the economic consequences of manipulating it? To answer this question we must have some idea of present and future values of water for each measurable unit, noting however, that the same quantity of water has to be viewed not as one commodity but as many, some of which are private goods and others public.

For instance, it might be thought that the simplest way of allocating water to various downstream uses is to sell water rights based on net consumption. What if we have a system such as shown in Fig. 1?

Suppose that the first downstream user is a person, A, who has an irrigation project to which he pipes $3/4$ of the streamflow. Of this diverted water, half is lost in evaporation, transpiration, and groundwater seepage. Let us also assume that the rest of diverted water re-enters the river at point B. What do users X and Y do in view of the lower water flow? If there was a system of water rights it would pay X and Y to bid up the price of water rights if they wished to have more than is available if A is unimpeded in his consumption. Since surplus runoff from A's irrigation project reaches the stream bed at B, streamflow between A and B is quite different than that between B and C, thus users on stretch AB would probably have to function as one purchaser of water rights in relation to users on stretch BC.

By setting up these water rights, our problem is apparently solved. We have a value attached to water in the stream. Of course, if there was more than enough water to go around there would be no need to establish water rights and their value would be zero.

Our water rights system is however geared to one set of users - namely, those who direct and consume water; it ignores all those other users who are not consumptive in their use, e.g., shipping interests, recreationists, fishermen, hunters, etc. Each of these groups demands mobility and space on a certain minimum quantity of water. A third set of demands upon the water in the natural stream bed consists of the collective demand for goods that are inevitably enjoyed by all, i.e., public goods such as landscape and amenity, certain ecological successions, etc. It would appear therefore that the water rights marketing system would have to work within constraints reflecting public and private demands for these other uses and intrinsic qualities. Such constraints would have to be set up largely via the political process. Not only would a tremendous amount of

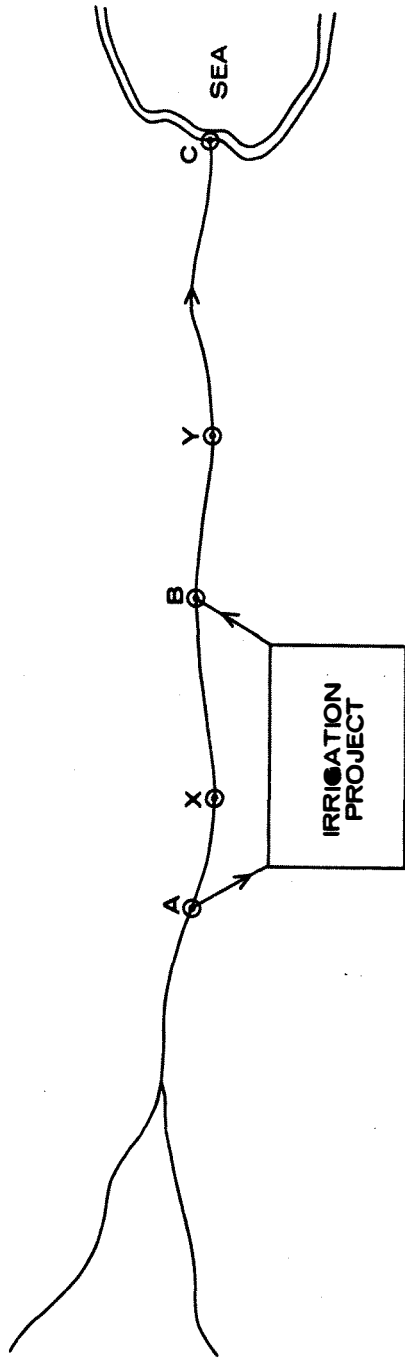


Fig. 1. Water system with several users.

information have to be fed into the decision-making scheme, but careful attention would have to be paid to the type of political or decision-making structure that existed in the watershed and river basin. One rough way of approaching this valuation would be to find the cost of an alternative water supply.¹ The trend in most countries has been towards political and administrative agencies that are responsible for water decisions in a whole river basin.

Value in Quality

So far we have assumed that water quality has been constant in our hypothetical river basin. Manipulation of a forested watershed is capable of affecting water quality quite drastically. Assuming that water quality is generally high for most downstream users as the stream flows from a natural forest, the watershed manager must be careful not to cause external diseconomies by reducing this quality. If such external diseconomies are caused by the watershed manager then the discounted social net returns to forest land are decreasing.

In the area of forest management, the most likely cause of external diseconomies is sedimentation which can increase downstream water treatment costs substantially - siltation of dams is probably the most visible example. Industrial and other water consumers also invest in the following range of water treatment, the cost of which may increase due to poor forest management: filtration, coagulation chlorination, ozonation, aeration and deaeration, slime and algae control, neutralization, and removal of silica, iron, manganese, alkali.

Determining the economic effects of watershed management on water quality is very difficult, largely because we do not know the cause and effect relationships between forest management and water quality. Downstream users rarely sue for damages either because their water treatment plant has a wide range of tolerance or excess capacity, or because it costs too much to find out who is causing the damage.

Some people such as fishermen and ecologists may be worried about the temperature effects on water of cutting forests in certain ways. Small changes in temperature can affect the life cycle and

¹ Although the total social cost of an alternative water supply is rarely established.

breeding capability of many species of fish, for instance. Again it is very costly to determine who is causing "what" and whether "what" is affecting the wildlife population and ecological balance, so it is quite possible that external diseconomies are often discovered too late, if at all.

Value in Timing

The timing of the water supply can also be very important economically. If one could be sure of a steady flow of water in a streambed all year round, the need for most dams would be lost. Since there appear to be no areas where the climate is consistent enough to assure a year-round stable flow, the main economic concern is with flood damage and drought. Unfortunately, the watershed manager is again faced with the problem of lack of knowledge about cause and effect relationships between forest manipulation and timing of flood crests and periods of low stream levels, although some of the effects are obvious. Long term weather patterns have to be established and the forest site has to be studied in detail. Fortunately, we already know from techniques employed elsewhere, that it is possible to obtain beneficial effects. For example, foresters in the United States have been able to delay snowmelt by two to three weeks, and there is no reason why their techniques could not be employed here.

THE PRESENT VALUE OF WATER IN ALBERTA

What about the present economic effects of manipulating Alberta's forest stands in relation to the water system?

Quantity

Present information leads one to believe that in the Prairie Region of Canada the water in the stream bed is still a free commodity as a private good--its market value is zero. As a public good however, its value to society is huge but unmeasurable. There is no doubt that farmers pay so much per acre foot of irrigation water, or that industries and domestic consumers pay so much per thousand gallons of water, but everything seems to point to the fact that these values reflect the distribution costs of the water supply rather than the value of water itself as a private good. We do not yet seem to have reached the point where there is competition for water rights although the Prairie Water Board Agreement would seem to indicate that this is not far away. No

attempt has been made to divert water into Alberta's water system. This along with the talk of exporting Canada's surplus water to the south, leads us to believe that water as a private good in the streambed has a zero value at the margin, at present.

Quality

At present there is little or no evidence to suggest that downstream users have benefitted or suffered from watershed use in Alberta. Power companies have expressed no interest in the costs of removing sediment from their dams, largely because it is no problem at present, presumably due to lack of forest use in the watersheds above these dams.

However, forest management in a watershed may include fertilization and insect and disease protection entailing use of toxic compounds which cause pollution problems. The Alberta Forest Service has to our knowledge never used these chemicals on a large scale in any watershed area, so the problem is of academic importance at present.

Timing

Timing is probably the most important aspect of water in this region at this time. Perhaps the most interesting possibility is that of flattening flood peaks by controlling snowmelt through judicious timber harvesting, so that the melt period is prolonged two or three weeks. Of more importance, it is possible to accelerate snowmelt to produce dangerously early flood volumes.

As far as we know, there are no data that relate stream regime or flooding to good or bad forest management in Alberta.

Indeed flood damage statistics are surprisingly few and tend to be "guesstimates". Flooding is in most cases not a regular event. Calgary, for instance, has not had any flooding since the 1930's. To give some up-to-date idea of the extent of the economic losses from flood damage one has only to look at the 1964 floods in the Lethbridge-Waterton National Park area, which caused an estimated \$1 million damage in Waterton Park alone. Even if sizeable floods occur once every fifty years the benefits to be had from delaying snowmelt are immense. If one considers that the cost of forest stand manipulation for this purpose can probably be covered by sale of stumpage, the benefit-cost ratio must be enormous.

Timing may also be important in relation to downstream users such as irrigation and hydro-electric companies who need certain

minimum and maximum flows for much of the year. In this sense the \$1.65 to \$3.00 per acre-foot that is paid by irrigation users may be partly a payment for a certain level of water during the dry months. At certain times of the year, water supply may indeed be exceeded by demand, actually causing pricing of the water itself.

THE FUTURE VALUE OF WATER IN ALBERTA

According to our ideal forest management scheme we wish to maximize discounted social net returns to forest land. In the case of forest manipulation for water production, this means that we should have some idea not only of the present market and social prices for water, but also of its future prices. If we know what the present and future prices of water are, all we have to do is decide upon an interest rate and discount to the present to obtain that portion of the soil rent that is attributable to water production. The decision about the correct rate of interest is difficult. There is much debate about whether there should be a social or a market rate of interest, and what the correct market interest rate should be. Such a decision is easy compared to that of establishing the future value of water which involves uncertainty and intangible values. It is more difficult to attach subjective probabilities to future values of water than for most other commodities, especially for an area such as the Prairie Region of Canada which has a complex watershed system, and being relatively under-developed is very likely to see changes in demand.

Peter Drucker (1969) in his book, "The Age of Discontinuity" claims that in the first half of the twentieth century, economic growth and industrial development followed relatively predictable trends despite two World Wars. However, because of underlying institutional and cultural changes, we can be less certain of what the future holds in the so called post-industrial society. Some people predict that a large megalopolitan area will develop behind the Rocky Mountains extending in a north-south line from Colorado to northern Alberta. At the other extreme there are people who advocate a zero rate of economic growth and suggest that the Prairie Region persuade other regions of Canada and other countries to compensate it for economic growth foregone in the interest of preservation of wilderness areas such as the boreal forest. Political decisions on these questions are unlikely to be explicit. Instead, the future will be determined by uncontrollable events such as the wheat glut of 1969. Did the wheat glut mean the beginning of the end of a Prairie Region economy based on agriculture, or was it just a temporary upset in the long run growth of world demand for this grain? Nobody knows the answer, which could be of fundamental importance to watershed planners in view of the high consumption of water by irrigation projects. If the Prairies cease to be the bread basket of the world due to changes in agriculture marketing patterns and the "Green Revolution", the objectives of all watershed research and management programs would have to be altered.

What we can be sure of in the future is increased use of the forest and increased downstream use, even if we do not know the patterns of this use. In view of the possibilities of recycling water by downstream users and the possible decline in the relative, if not absolute, importance of consumers dependent on irrigation¹ the value of water rights is likely to stay at a low level in the foreseeable future. However, in view of the increased intensity of use, both in the forested watershed and downstream, there are bound to be greater conflicts over water quality and timing. Diseconomies due to deterioration of water quality and timing are likely to increase rapidly unless the forest is manipulated with adequate controls. This has happened in many areas of the world where there is a long history of forest exploitation. There is no reason to believe that the Prairie Region is any different.

PRACTICAL IMPLICATIONS FOR MANAGEMENT

We have deliberately avoided quoting figures for the value of water because these are rarely quoted in the context of forest management, and there does not appear to be enough information on the subject; obviously more research is required on both the supply and demand sides, and above all, on the institutional basis for a water-marketing system. The forest manager should be interested in the value of water in the stream bed only, and these figures are hard to obtain in most countries. Water as a private good has been valued in the United States and a few other countries, but the Prairie Region does not yet appear to have reached such a state of high-water use. It is extremely doubtful that we should even attempt to measure the value of water as a public good. It is very likely to be misleading.

We believe that our discussion does provide some clue as to where we should be placing the most emphasis in watershed research and management. First, it seems clear that the payoffs from investing in forest management schemes which increase the rate of flow of runoff are so obscured by uncertainty as to constitute an excessively risky investment. On the other hand it seems clear that potential diseconomies from poor forest management are so enormous in terms of water quality and timing, that we must concentrate on these aspects of water supply in terms of forest research and management in the Prairie Region.

REFERENCES

- Drucker, Peter. 1969. The age of discontinuity: guidelines to our changing society. Harper and Row, New York. 402 p.
- Munn, R. E. and D. Storr. 1967. Meteorological Studies in the Marmot Creek Watershed, Alberta, Canada, in August 1965. Water Resources Res., 3 (3): 713-722.

¹ Of course if Canada exported water to the United States, the value of water in terms of quantity might be raised significantly--certainly it would not be zero. However, developments in the United States indicate that importation of water would only be a short term solution to many of their problems. Also, we cannot be sure whether it is in Canada's interests to export water in the first place.

LAND MANAGEMENT PRACTICES THAT AFFECT WATER YIELD

by

Douglas L. Golding

Canadian Forestry Service

Edmonton, Alberta

INTRODUCTION

This is the first of three topics dealing with the effect of land management on water; on its yield, regime, and quality. Quality is a distinct topic even though yield and regime exert an important influence on it, particularly with regard to dilution of pollutants. However, because yield and regime are closely related, we will distinguish between them by defining yield for the purpose of this paper.

Water Yield

Water yield is the total volume of flow over a given period such as a month, season, or year. However, we will deal mainly with annual flows. Shorter periods will be considered under "regime". In its narrowest sense, yield consists of streamflow. However, yield can be both surface and subsurface flow. Broken down into its components it becomes:

$$\text{YIELD} = \text{PRECIPITATION} - \text{EVAPOTRANSPIRATION} \pm \text{STORAGE CHANGES (surface, soil, groundwater)} - \text{INFLOW (surface and subsurface)}.$$

Evapotranspiration (hereafter called ET) is the total water loss to the atmosphere from water, soil, and plant surfaces. On a tight basin (i.e., where there is no groundwater inflow or outflow) and for periods long enough that storage changes are negligible (e.g., a year), the equation is essentially:

$$\text{YIELD} = \text{STREAMFLOW}$$

or

$$\text{YIELD} = \text{PRECIPITATION} - \text{ET}$$

Hydrologic Cycle

To influence water yield and regime by land management, we must alter some of the components of the hydrologic cycle. The hydrologic cycle is the circulation of water, as liquid, solid, or vapor, from the

atmosphere to the earth and back to the atmosphere, the cycle repeating continually.

We shall deal with the subject under four headings:

(1) Research results - a brief review of the results of water yield-land use studies carried out on experimental watersheds, (2) Factors affected by land management - that is, what hydrologic factors are affected by land use, (3) Land management for water yield, (4) A forest-management prescription for water-yield increase in Alberta.

I RESEARCH RESULTS

Following is a brief review of the results of studies carried out on experimental watersheds. The purpose is only to show that land use can alter streamflow, and to give some idea of the degree of change that may be realized. We will concern ourselves mainly with forest or wild land. Here the effects of change are usually most dramatic, and also, management agencies have a much greater degree of control over such land.

Table 1 (abstracted from Hibbert 1967) describes results from six watershed studies. The three Colorado study areas are similar to the East Slopes of the Rocky Mountains in vegetation, elevation and climate.

The fourth area, Coweeta, North Carolina, has a more humid climate and up to seven times more precipitation than the Colorado areas. The five-year average yield increase on Coweeta #17 was 4-10 times as great as on the Colorado watersheds; but, expressed as a percentage of pre-treatment yield, this is only $1\frac{1}{2}$ - 2 times as great. Most studies show increased yield after reduction of forest cover (Fig. 1). Two exceptions are shown in Table 1, Coweeta No. 40 and Workman Creek, Arizona. No increase in yield resulted from logging, but in both cases, selective logging rather than clearcutting was used.

Attention is drawn to the departure from a regularly decreasing water-yield increase after cutting as shown in the last column of Table 1. This may be related to annual variations in climatic variables, particularly precipitation, or to other factors. In Fig. 1, variation in yield increase with reduction in forest cover is due to differences between watersheds, in climatic variables, as well as other factors.

II FACTORS AFFECTED BY LAND MANAGEMENT

The logical question arising from watershed studies is, what factors in the system are responsible for the changes that do take place?

Table 1. Description and results of water-yield experiments (from Hibbert 1967)

Watershed	Vegetation	Mean annual precipitation	Mean annual streamflow	Description of treatment	Water-yield increases by years following treatment				
					1	2	3	4	5
		(inches)	(inches)		(inches)				
Fraser Colo. Fool Creek	Lodgepole pine and spruce-fir	30.0	11.1	40% of area clearcut in strips, regrowth	3.4	2.1	3.1	3.8	2.1
Wagon Wheel Gap, Colo.	84% forested (aspen & conifers)	21.1	6.2	100% clearcut, slash burned, regrowth	1.3	1.8	1.0	0.9	0.5
Meeker, Colo. White River	Spruce	10.4	missing	80% of timber on 30% of area killed by insects	2.3 (average for 5 years)				
Coweeta, N.C. #17	Mixed hardwoods	74.6	30.5	100% clearcut, regrowth cut in years 1 and 2	16.0	14.2	10.1	6.6	9.6
#40	Mixed hardwoods	76.6	41.4	27% of basal area cut by selective logging	nonsignificant				
Workman Creek, Arizona South Fork	Ponderosa pine	32.0	3.4	30% of basal area cut by selective logging	nonsignificant				

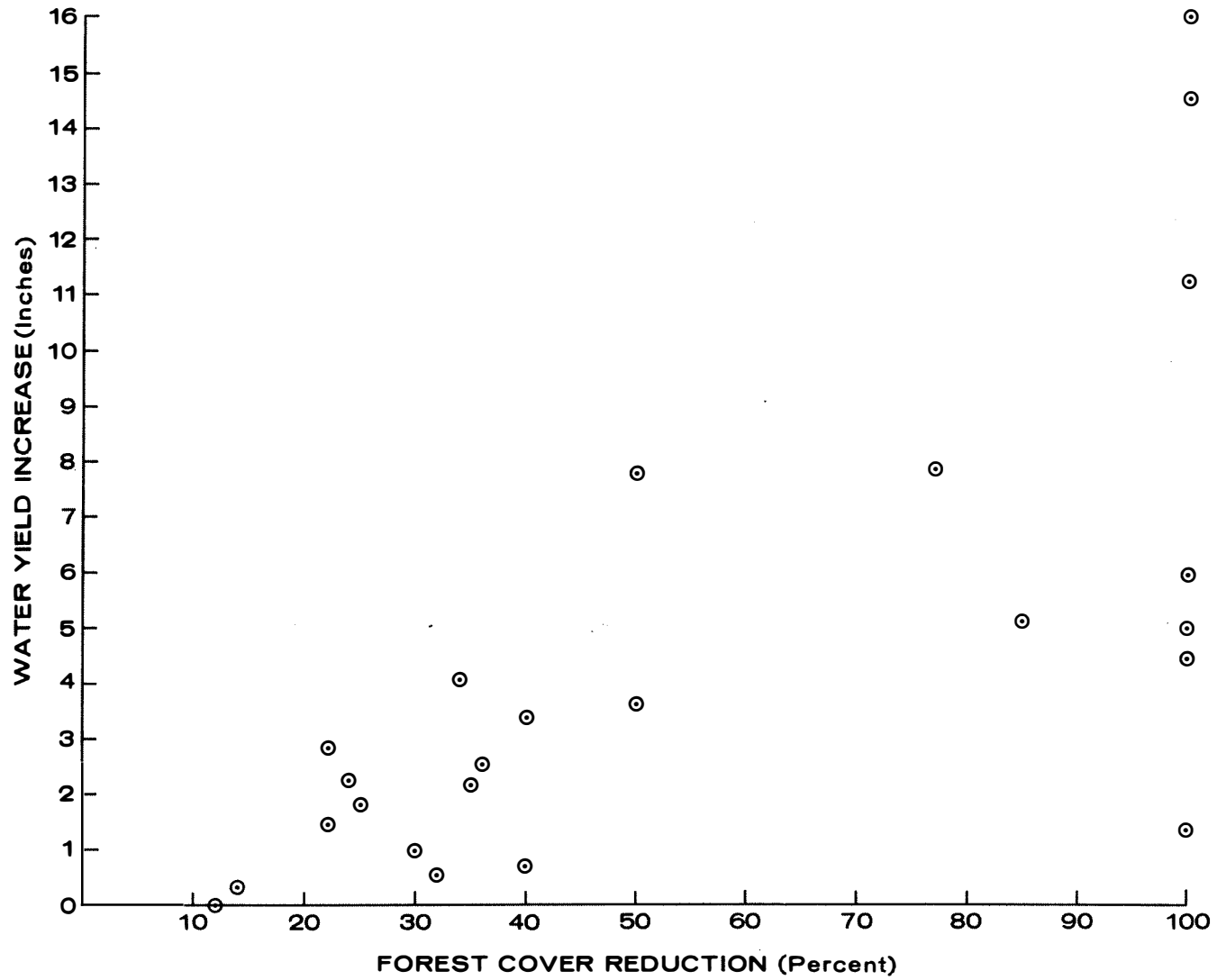


Fig.1. First year water-yield increases after forest-cover reduction.
 (from Hibbert 1967)

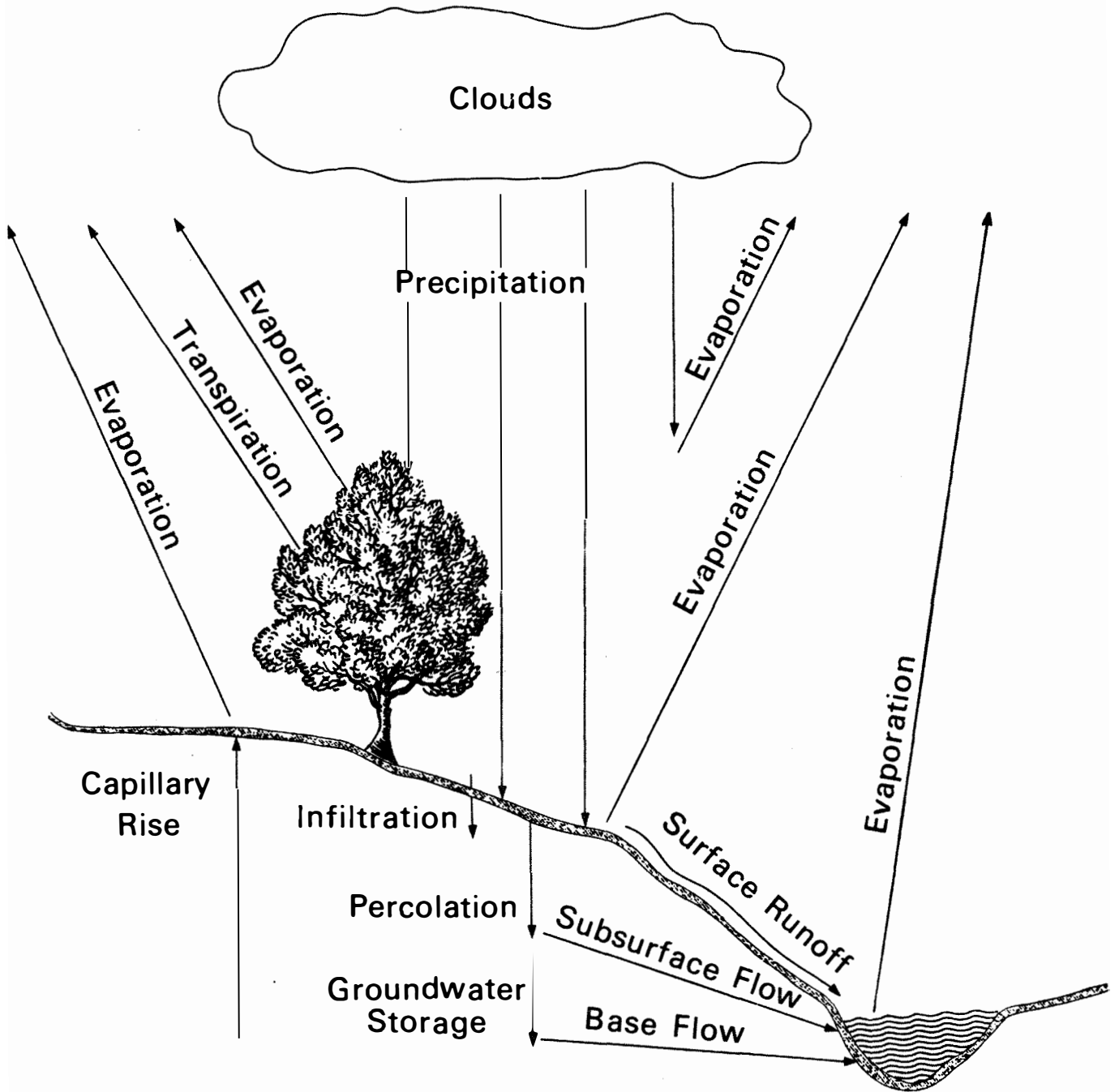


Fig. 2. The hydrologic cycle.

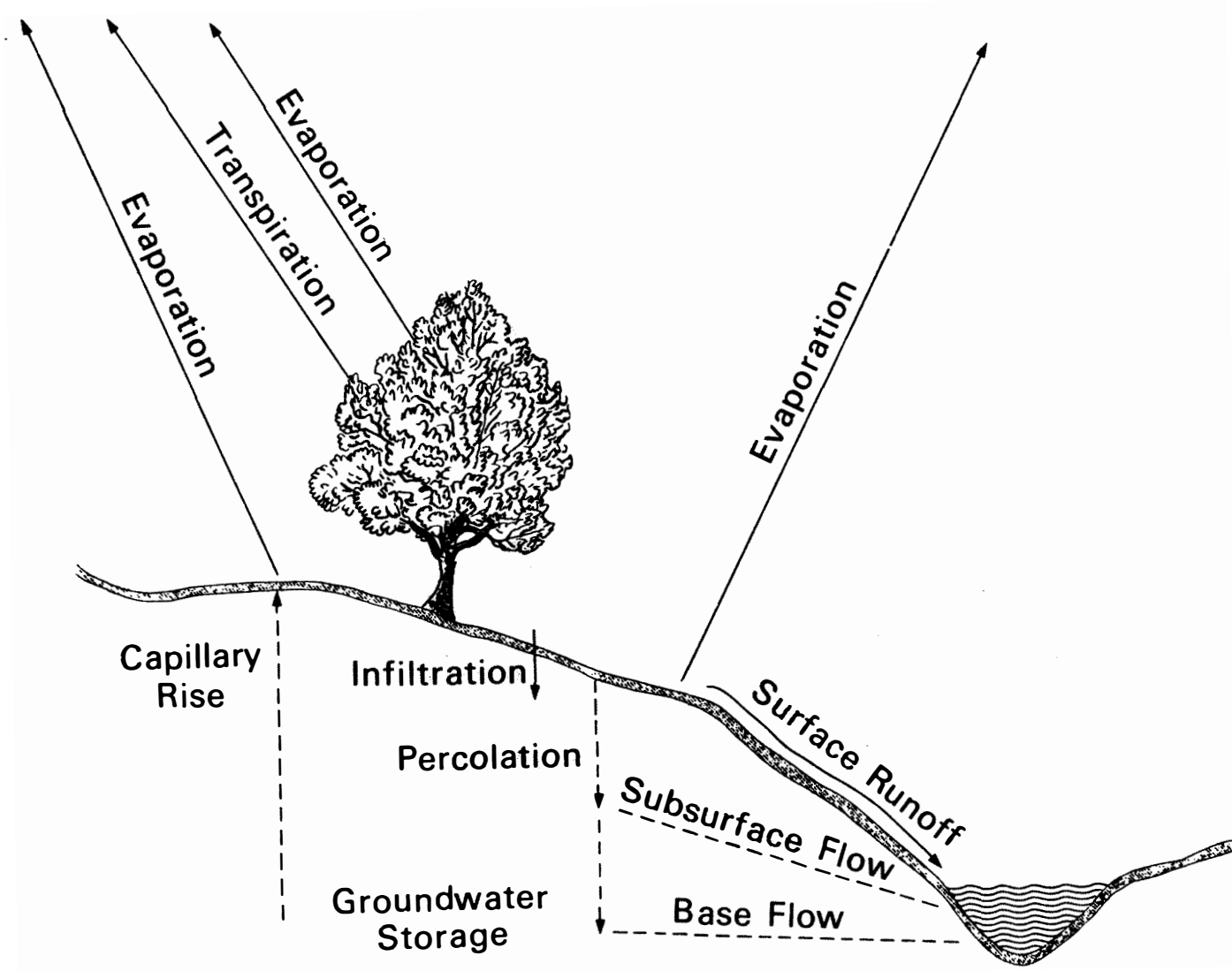


Fig.3. Components of the hydrologic cycle influenced by land management.

In other words, how has the hydrologic cycle been changed by forest-cover change? If we can answer this we are in a much better position to manage land to meet our water needs.

Let us look at the hydrologic cycle (Fig. 2). The input, precipitation, evaporates while falling, is intercepted by plant cover (and evaporated or redistributed beneath the canopy), or reaching the ground, runs off over the surface or infiltrates the soil. It then percolates through the soil profile reaching surface channels by subsurface flow or by base flow from groundwater storage. The cycle is maintained by the evaporation or transpiration of water at various stages in the cycle.

We can influence various components of the cycle, thus changing the disposition of water at different stages of the cycle. Fig. 3 illustrates those components that can be altered by land management. These are: interception, infiltration and overland flow, percolation and subsurface flow, evapotranspiration, the energy budget, and the disposition of precipitation.

Interception

Interception is precipitation that has been temporarily held by vegetation. Interception loss is that part of interception that is evaporated. This loss may vary from a very small percentage of heavy precipitation to 100 per cent of very light precipitation. Reducing forest cover will reduce interception loss from tree foliage. This will, however, increase the amount of rainfall reaching and hence intercepted by lower vegetation. There will be greater evaporation from lower vegetation after logging due to higher wind velocity and greater solar radiation at the lower level after cutting. Nevertheless, in most cases there will be a net decrease in interception loss after cutting.

Infiltration and Overland Flow

The rate at which water infiltrates the soil is greatly influenced by land-use practices. A reduction in infiltration rate tends to increase overland flow. This in turn reduces the loss to soil moisture and groundwater recharge, and increases yield. Infiltration rates may be reduced by:

- (1) Removing vegetation and litter. This increases the force of rain hitting soil surfaces. Rain drops impinging directly on soil surfaces cause fine particles of soil to be removed from aggregates and swept into soil pores, thus decreasing infiltration rate. Litter reduces overland flow by absorbing water and thus maintains infiltration rate.
- (2) Mechanically compacting soil surfaces. Skid roads account for much of the decrease in infiltration rates on cutovers. Tractor logging, for example, requires more road per acre logged than does a highlead or skyline system.

We must recognize, however, that a lower infiltration rate, and its corollary, greater overland flow, has serious effects on water quality and regime. Overland flow contributes greatly to flood and erosion problems. Table 2 illustrates the relation of runoff and sediment yield to land use in Mississippi. Data were averaged for three years on 16 watersheds where annual precipitation was about 52 inches. Annual runoff was 2-16 times greater from cultivated watersheds than from forested, but sediment production was 200 times greater.

Table 2. Mean annual runoff and sediment yield from 16 watersheds in northern Mississippi (Ursic and Dendy 1965)

Land use	Mean annual runoff (inches)	Sediment yield (tons/acre/year)
Cultivated land	16	21.75
Pasture	15	1.61
Abandoned field	7	0.13
Hardwood	5	0.10
Pine plantation	1	0.02

Percolation and Subsurface Flow

Land management has little direct influence on percolation and subsurface flow. Indirect influence results from changes in infiltration rates.

Evapotranspiration

Many studies have shown that ET, or consumptive use as it is often called, varies with land-use practices. The two factors governing amount of ET are (1) water supply, and (2) energy available to act on the water supply. Land use affects both of these. Trees have a greater supply of available water than do most agricultural crops because of the deeper root penetration of trees.

Forest stands maintain high infiltration rates through root and biological activity. The same activity promotes upward movement of water as well. Erosion on bare soils causes sediment-clogged pores. When the top layers of such soils dry out, upward as well as downward movement of water is restricted by a "self-mulching" effect. That is, land use affects water yield by influencing the supply of water available for both evaporation and transpiration.

Energy Budget

Solar radiation is the energy supply for ET. Part of the incoming solar radiation is reflected back into space; part is converted into energy that goes into heating the air, vegetation, and soil; part is re-radiated back into space; the remainder provides the energy for ET. Solar radiation is partitioned differently by different land uses. That is, the amount of energy available for ET is different for different land uses.

Differences in albedo are responsible for the greatest variation in energy balance from one land use to another. Albedo is the proportion of solar radiation reflected by a surface. For example, the albedo of a conifer forest is about 0.11; of grassland about 0.23 (Table 3). Twenty three per cent of incoming solar radiation is reflected by grassland, twice that of the forest. The forest, then, has more energy available for heating and ET. Table 3 shows the effect of albedo on potential ET for four land uses. By "potential" is meant the amount of ET if total solar radiation, less the amount reflected,

Table 3. Average annual values for albedo and potential ET based on solar minus reflected energy (from Baumgartner 1967)

Land	Albedo	Potential ET in inches based on solar minus reflected energy
Conifer Forest	0.11	54
Cultivated Land	0.20	49
Grass Land	0.23	47
Bare Soil	0.35	39

were completely used for ET. However, this amount of energy is not completely used for ET; some is lost due to long-wave radiation from the vegetation and soil. The remainder is net radiation. Table 4 gives potential ET based on net radiation for the same four land uses.

Note that the ranking of the land uses is the same as in Table 3, i.e., forest, cultivated land, grass land, and bare soil, but ET has been reduced by different amounts for each land use. The reason is that the emission of long-wave radiation is a function of the temperature of that body. The cooler the body, the less the radiation. Forest canopies radiate less than warmer bodies such as grass.

Table 4. Potential ET based on total net radiation
(from Baumgartner 1967)

Land use	Potential ET in inches based on total net radiation
Conifer Forest	39
Cultivated Land	37
Grass Land	30
Bare Soil	23

Fig. 4 illustrates the results of many studies of ET for various land uses (Baumgartner 1967). The range of values found is shown by the line, the average value by the circle. Most studies have shown greater ET from forest than from other land uses. It is mainly this difference that accounts for lower water yield from forested areas before cutting.

The question naturally follows as to the effect of species, density, and age of the forest on ET, and this on water yield. However, the difficulty of measuring ET from forests permits few detailed conclusions. It appears that coniferous forests use more water than deciduous, probably because they are in leaf all year. It seems also, that water use increases gradually until the peak of annual volume increment, usually around 60 years of age. The range of ET for most species is about 10-20 inches/year.

Disposition of Precipitation

Another factor that must be considered is the disposition of precipitation. This has particular relevance to snow. Accumulation patterns and melt rate can be influenced by land use, particularly by forest management. Changing the configuration of the forest canopy can change wind velocity and degree of turbulence. This in turn alters snow-accumulation patterns, and energy balance. The greatest effect of such change is on streamflow regime but some change in yield can be brought about if enough is known of the hydrology of the area. For example, if snow is induced to accumulate in drifts and the energy balance altered to increase melt rate, yield might increase for two reasons. First, if melt rate exceeds infiltration rate, there will be overland flow and increased yield. Secondly, melt water that enters the soil in excess of the amount needed to recharge soil moisture will reach stream channels via subsurface or base flow.

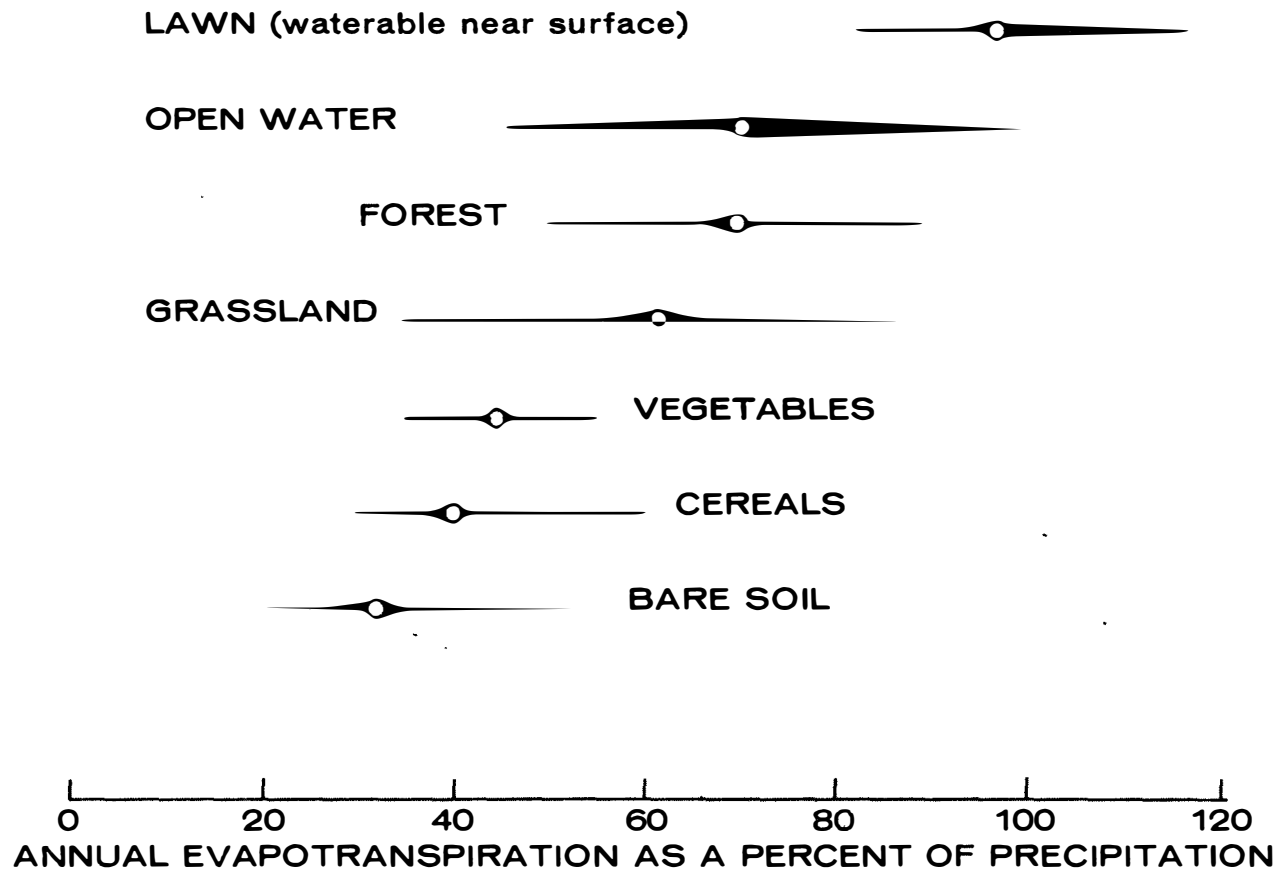


Fig. 4. Annual evapotranspiration as a per cent of precipitation (from Baumgartner 1967)

III LAND MANAGEMENT FOR WATER YIELD

The objective of land management for water yield may be to increase, to maintain, or to decrease yield. However, with the presumed shortage of water in western North America and in the context of management of Alberta's forested areas, water-yield increase will be the topic of this section. In general, a prescription for water-yield increase may be reversed to achieve the opposite goal.

Two components of the hydrologic cycle provide the greatest opportunity for yield increase in that they are amenable to man's influence and they have the greatest effect on water yield. These are ET and interception. A reduction in stand density results in a reduction in both ET and interception. If the reduction has been sufficiently large, this will cause an increase in yield. Fig. 1 shows that reducing forest cover increases yield and the greater the cover reduction, the the greater the yield increase. For this to happen, however, the water that would otherwise have been evaporated from the tree crowns or taken up by root systems and transpired, must reach stream channels. That is, water must not be intercepted by vegetation at a lower level or by the roots of adjacent trees. In this climate, the moisture content of the soil is usually below the level at which ET would be maximum. In other words, the amount of water available limits the amount of ET. Therefore, increasing the water available to those trees adjacent to clearcut openings will increase the transpiration of those trees.

At this point, we should distinguish between recharge and discharge areas. A recharge area is where water is absorbed and added to groundwater either directly into a geologic formation, or indirectly by way of another formation. A discharge area is where groundwater is channelled to surface layers of the soil, for example, springs and seeps. In the recharge area, some of the water infiltrating the soil quickly becomes unavailable to vegetation so there is little transpiration loss. On the other hand, water supply is unlimited on discharge areas so that water use by trees is much greater. On areas other than discharge areas, depletion of soil moisture may extend 2-3 tree heights into openings, in which case little of the expected saving from cutting is realized. However, in most cases, soil moisture depletion probably extends less than $\frac{1}{2}$ tree height into the opening.

The foregoing suggests that the greatest water-yield increases should result from (1) clearcutting, and (2) minimizing the ratio of border length to area cut. The larger the area cut, then, the smaller is this ratio, and the greater should be water-yield increase. However, the larger the clearcut, the greater the wind velocity at ground level and the greater the evaporative losses. Studies have shown that there is less water loss by interception, evaporation (either from ground or snow surfaces), and transpiration, from strip cuts than block cuts, and from block cuts than uncut forest.

Removal of riparian and phreatophytic vegetation will increase water yield. Phreatophytes grow with their roots below the water table. Riparian, or streamside, vegetation, while not necessarily phreatophytic, has an unlimited water supply for much of the growing season because of its location. Both riparian and phreatophytic vegetation transpire much more water than does other vegetation. Removal of these classes of vegetation along stream and discharge areas may result in savings much greater than cuts of similar size anywhere else on a watershed.

Finally, rotation age of the timber is an important factor. Annual increases in water yield will gradually decrease as cutovers regenerate and a new stand is established. It has been estimated that 35-50 years after cutting spruce, fir, and lodgepole pine stands in Colorado, water yield will have dropped to its pre-cutting rate (i.e., yield increase has dropped to zero) (Goodell 1964). Maximum increase occurs the first year after cutting and decreases in subsequent years until it becomes zero between 35 and 50 years. Let us assume a regrowth period for the East Slopes of 40 years. A cutover area will contribute to water yield increase if the new stand is less than 40 years old; the younger the stand, the greater the increase; and stands older than 40 years contribute zero increase. In a forest managed on a 100-year rotation, 1/100 of the area is 1-year old, 5/100 is five years or less, 40/100 is 40 years or younger. Because 40/100 of the area is 40 years or younger, 40 per cent of the area contributes to water yield increase. If the rotation age were reduced to 80 years, then 40/80 or 50 per cent of the area would contribute to increased yield. With a rotation of 40 years, 40/40 or 100 per cent of the area would contribute to yield increase.

Table 5 shows the effect on water yield of reducing rotation age of a spruce-fir and pine forest (Golding 1968). Data were extrapolated from the Fool Creek experimental watershed, Fraser, Colorado (Goodell 1958, 1964 and Love 1960) where climate, water yield, and forest types are similar to our conditions. The annual yield from the virgin forest is 15 inches. This is increased by 8 per cent by managing on a 120-year rotation (a common rotation in these forest types); by 12 per cent on a rotation based on maximum average annual increment; by 16 per cent on a financial rotation; and 24 per cent on a rotation dictated by the 40-year regrowth period.

IV FOREST-MANAGEMENT PRESCRIPTION FOR WATER-YIELD INCREASE

1. Log in 3- to 6- chain wide, east-west strips to provide shade on at least one margin of the cut area (Fig. 5).
2. Identify recharge and discharge areas on watersheds to be cut. Modify cutting patterns on both of these areas to make the best use of their character. On recharge areas, cutting strips should be 1-3 tree heights wide and at right angles to the prevailing wind to maximize snow accumulation and shade the pack. On discharge areas

Table 5. Yield increases related to rotation age for a forest of Engelmann spruce - alpine fir, and lodgepole pine^a (from Golding 1968)

Rotation	Yield (inches)	Yield increase/ unlogged yield (per cent)
None, unlogged	15.0	-
Spruce-fir - 120 years Lodgepole pine - 120 years	16.2	8
Spruce-fir - 120 years ^b Lodgepole pine - 50 years ^b	16.8	12
Spruce-fir - 80 years ^c Lodgepole pine - 50 years ^c	17.4	16
Spruce-fir - 40 years ^d Lodgepole pine - 40 years ^d	18.6	24

^a Types are assumed to be in the proportion of two parts spruce-fir to one part pine.

^b Based on the culmination of Mean Annual Increment, medium site, Interior British Columbia (Stanek 1966).

^c Based on financial rotation (i.e., maximizing present net worth of the site) using as guides, studies in British Columbia by Dobie (1966) and Smith and Haley (1964) and assuming a pulpwood economy.

^d Based on the regrowth period so that throughout the rotation each acre is contributing to yield increase.

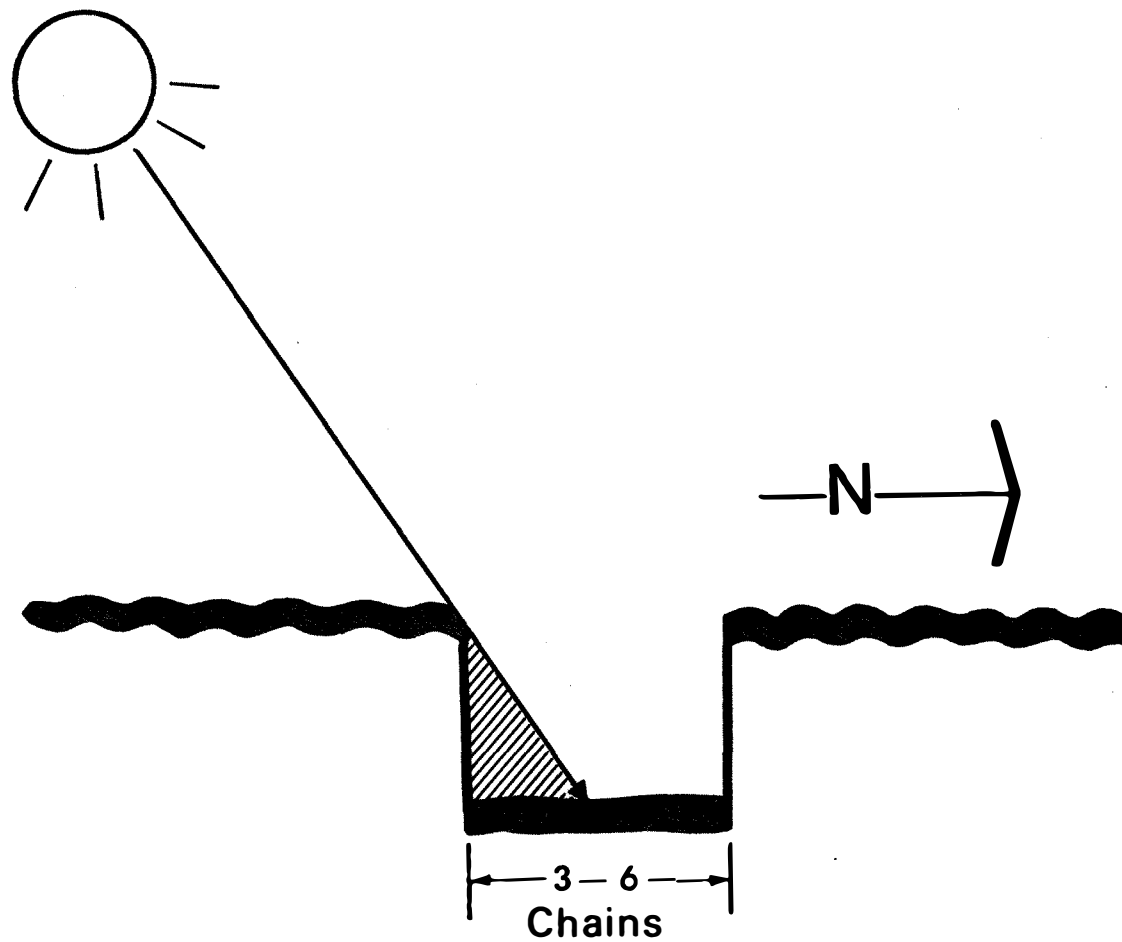


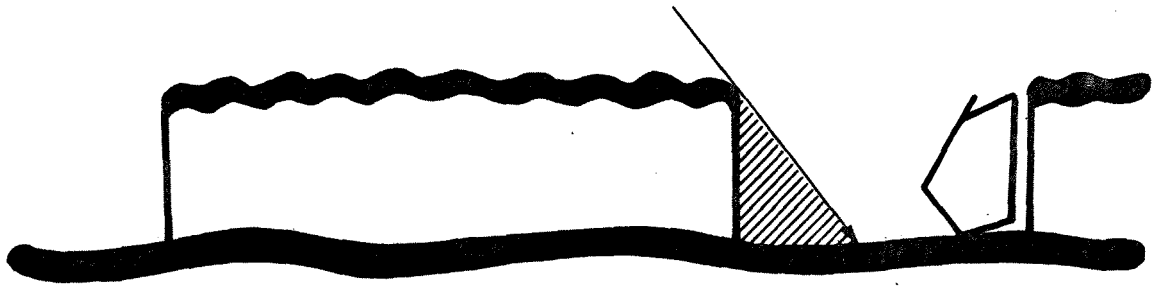
Fig. 5. East-West stripcuts to shade south edge of opening for snow management.

the ideal would be to maintain the area free of trees and shrubs. After the first cut, a periodic treatment to minimize regrowth would be of value, using for example, herbicides, hand tools, or self-propelled brush masticators.

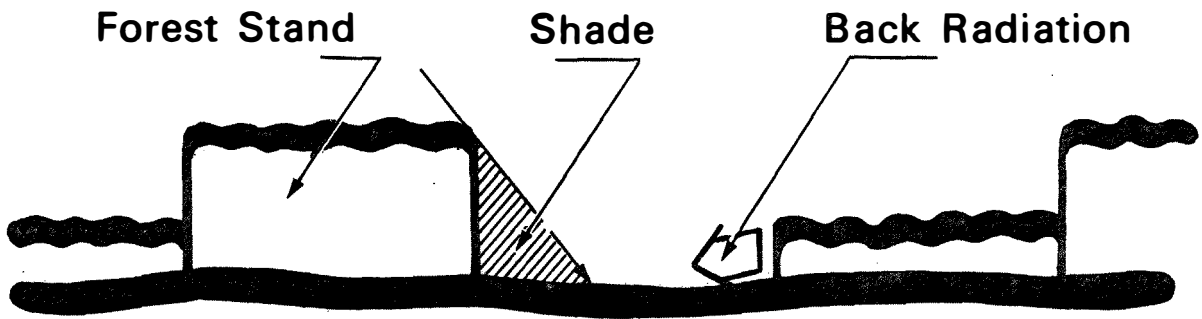
3. Progress southward in following cutting cycles with the second strip parallel to the first. In this way a wall of mature trees will shade the most recent cuts and back radiation from the north will be minimized (Fig. 6). (This prescription, as well as the following dealing with snow, is based on work by Anderson (1963, 1969).
4. On east-west slopes, strips run downhill. Cut a short strip perpendicular to the cut strip at its lower end. This lateral will entrap cold air flowing downslope and will reduce evaporation from the snowpack (Fig. 7).
5. Deal with slash by one of the following methods:
 - (a) Where the combination of steep slopes and highly-erodible soils constitute an erosion hazard, lop and scatter slash.
 - (b) Pile and burn slash. Slash left as it falls speeds melting of snow in spring and hence evaporation loss.
 - (c) Windrow slash along the downhill edge of stripcuts (except on wide strips on north slopes) to help pond cold air (Fig. 8). This will reduce evaporation both from the snowpack in winter and surface vegetation in summer.
6. Reduce rotation ages so that the ratio of regrowth period to rotation age is as large as practical. Rotations based on financial maturity are usually much shorter than those fixed by annual growth. This is especially true in a pulpwood economy where there is no premium for large size and length of clear bole.
7. Remove riparian vegetation along streams supplying areas of critical water shortage, and where there is a major loss to stream-side vegetation. Such areas are usually on alluvial plains outside the forest. Of course, consideration must be given to maintaining stable stream banks. This may require leaving all riparian vegetation or being selective in removal.

REFERENCES

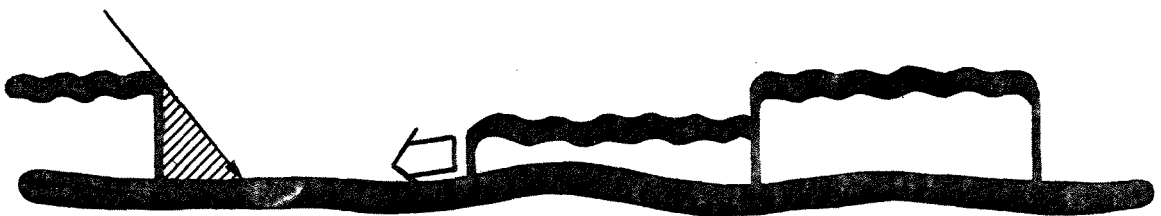
- Anderson, H. W. 1963. Managing California's snow lands for water. U.S. Forest Serv., Pacific SW Forest & Range Expt. Sta. Res. Pap. PSW-6.28 p.



FIRST CUTTING CYCLE



SECOND CUTTING CYCLE



THIRD CUTTING CYCLE

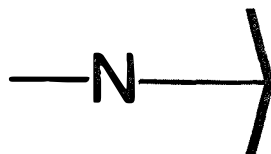


Fig. 6. Wall-and-step forest for snow management

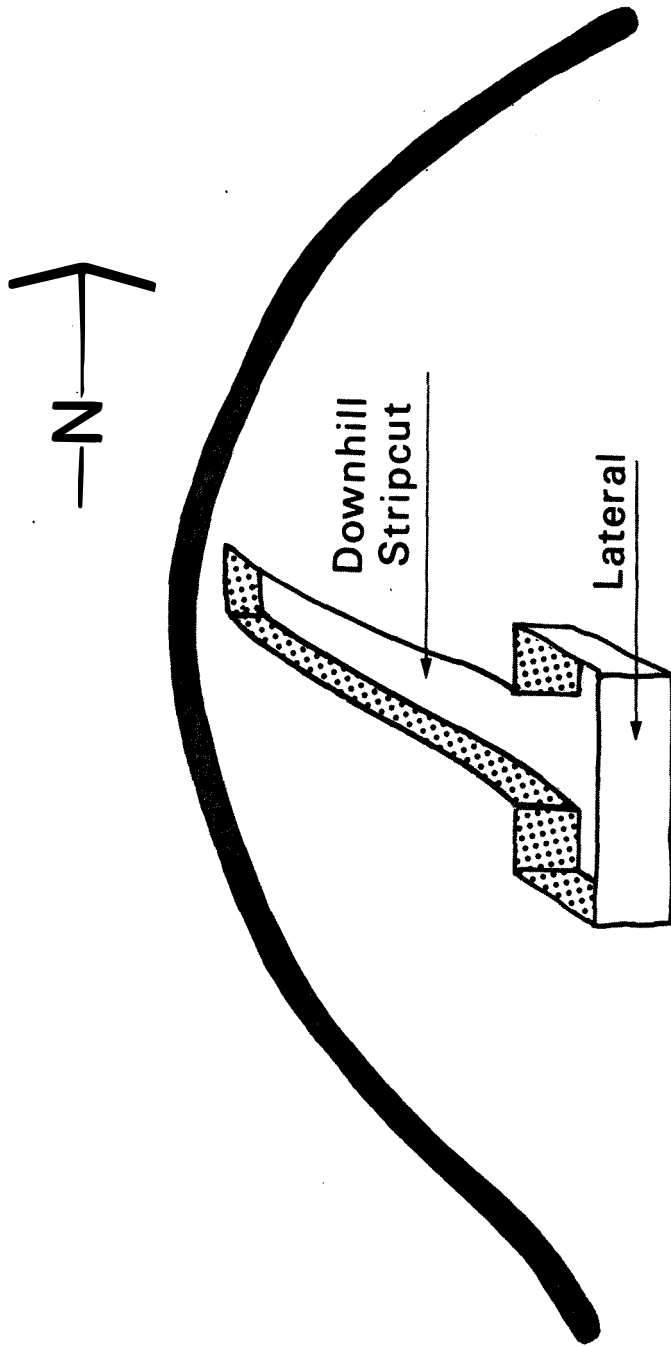


Fig. 7. Downhill stripcuts with lateral for cold air trapping

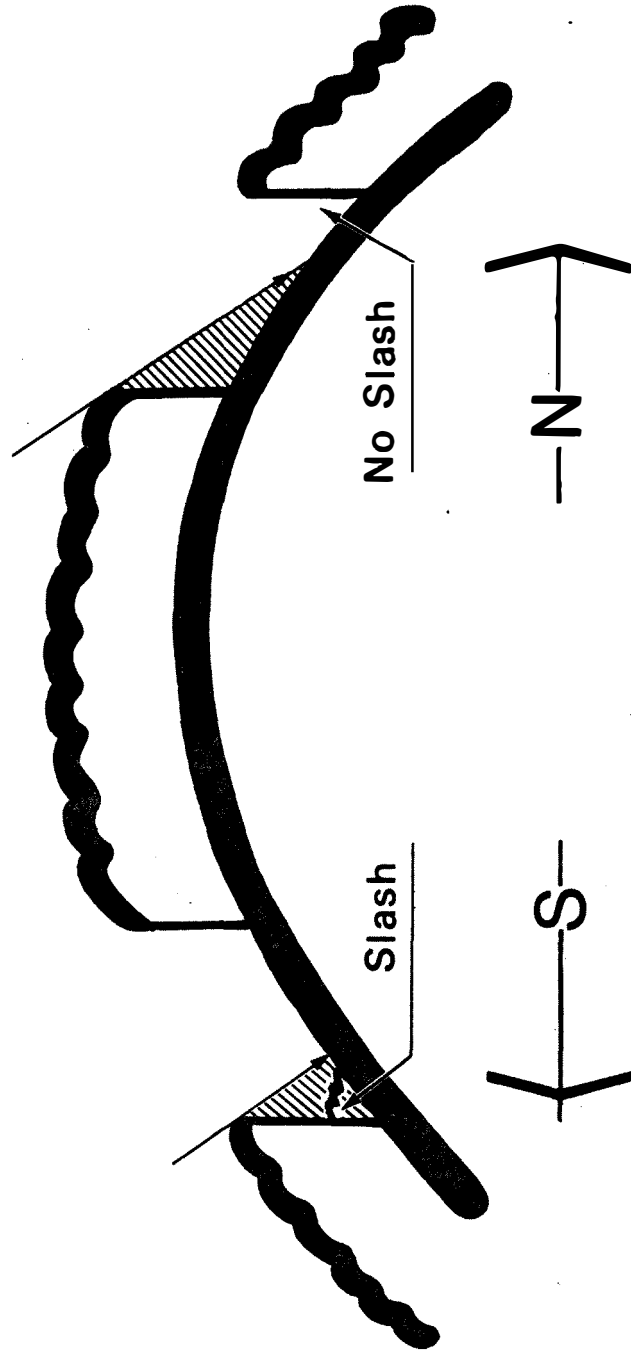


Fig. 8. Cold-air trapping with slash in stripcuts on north and south slopes

1969. Snowpack Management. In Snow. Oregon State Univ., Water Resources Inst., Seminar WR 011.69. p. 27-40.
- Baumgartner, A. 1967. Energetic bases for differential vaporization from forest and agricultural lands. Proc. Int. Symp. on Forest Hydrol., Penn State Univ. Pergamon Press. p. 381-389.
- Dobie, J. 1966. Product yield and value, financial rotations and biological relationships of good site Douglas fir. M.F. thesis, Faculty of Forestry, Univ. of B.C. 141 p.
- Golding, D.L. 1968. Regulation of water yield and quality in British Columbia through forest management. Ph. D. thesis, Faculty of Forestry, Univ. of B.C. 406 p.
- Goodell, B.C. 1958. A preliminary report on the first year's effects of timber harvesting on water yield from a Colorado watershed. U.S. Forest Serv., Rocky Mt. Forest Rge. Exp. Sta., Sta. Pap. No. 36. 12 p.
- Goodell, B.C. 1964. Water management in the lodgepole pine type. Proc. Soc. Amer. Forest. Annu. Meeting, Denver, Colo. p.117-119.
- Hibbert, A.R. 1967. Forest treatment effects on water yield. Proc. Int. Sump. on Forest Hydrol., Penn State Univ. Pergamon Press. p. 527-543.
- Love, L.D. 1960. The Fraser Experimental Forest....its work and aims. U.S. Forest Serv., Rocky Mt. Forest & Range. Expt. Sta., Pap. No. 8. 16 p.
- Smith, J.H.G. and D. Haley. 1964. Allowable cuts can be increased safely by use of financial rotation. Brit. Col. Lumberman 48(7): 26, 28.
- Stanek, W. 1966. Occurrence, growth, and relative value of lodgepole pine and Engelmann spruce in the Interior of British Columbia. Ph. D. thesis, Faculty of Forestry, Univ. of B.C. 252 p.
- Ursic, S.J. and F.E. Dendy. 1965. Sediment yields from small watersheds under various land uses and forest covers. Proc. Fed. Inter-agency Sedimentation Conf. 1963. U.S.D.A. Misc. Publ. No. 970. Pap. No. 6 p. 47-52.

FOREST MANAGEMENT PRACTICES THAT INFLUENCE STREAMFLOW REGIME

by

Robert H. Swanson

Canadian Forestry Service

Edmonton, Alberta

INTRODUCTION

Water is a transient forest product. That is, a forest does not generate water, but holds it in temporary custody on its way from precipitation to stream flow. It is during this brief custodianship that we as forest managers have an opportunity to influence how much, how dirty, and when water is delivered to a stream. How much and how dirty are subjects of separate papers in this proceedings. This paper will deal primarily with how quickly precipitation becomes stream flow.

A forest is not like a dam. The control is not complete. In fact control is limited to small shifts in the time and rate that events occur. The occurrence of events and the rate at which they happen, whether natural or modified by man, are the substance of stream regime. In this paper, I will discuss some aspects of timber management that are capable of influencing regime. I will also present some quantitative examples of the regime changes that have occurred following harvesting on forested experimental watersheds where conditions are similar to those found in the mountains and foothills of Alberta.

REGIME DEFINED

Regime is the time that events occur and the rate of change in the magnitude of an event both prior to and following it. An alteration in either time of event, rate of change, or both is a change in regime. These regime concepts are illustrated by Fig. 1.

Regime is a magnitude-with-time concept. As such, two parameters are needed to define it - both magnitude and time. Events can be large or small in a long or short time span. The choices of magnitude and duration are infinite. The time base on which we choose to display stream-flow is the factor limiting the complexities of regime description. In general, the smallest time base used is one hour, the longest a year. However, local situations may require even finer definition.

In most forested situations there are three runoff events of importance. The spring freshet that results from snow melt is easily handled on a day time-base. Changes in magnitude that occur from day to day are reasonably predictable. The second event is the flow from long-duration, low-intensity rain storms that occur over large areas. Stream-

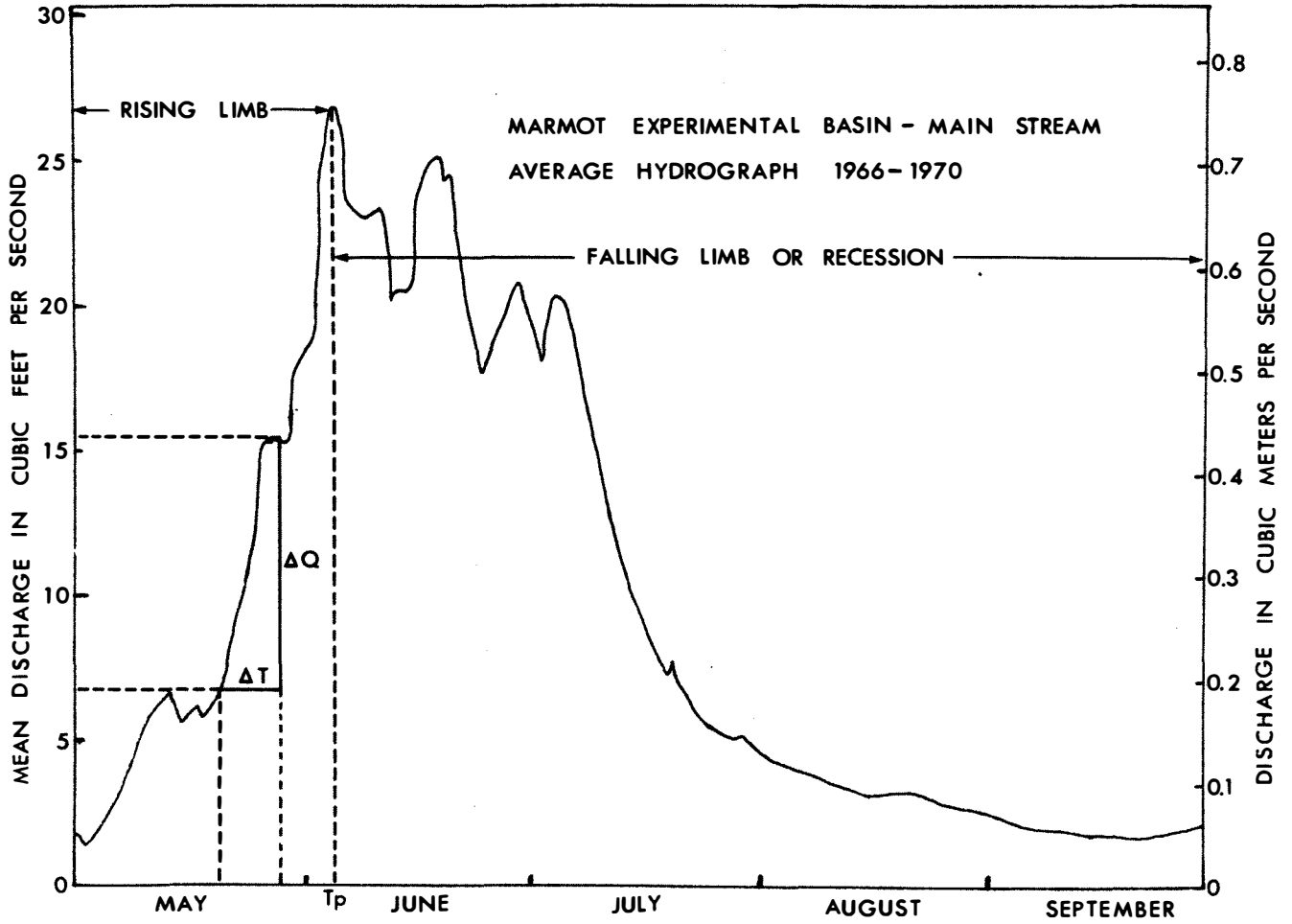


Fig. 1. Regime concepts illustrated using Marmot Experimental Basin main stream hydrograph. The snowmelt period dominates at Marmot. However, the same terms and concepts would apply to the hydrograph from an individual storm.

flow from these is more variable than that from snow melt. Consequently, a finer time-scale must be used to describe it. In this case 4-, 6-, or 12-hour intervals are often used. The third event is streamflow arising as a result of localized shower activity. Thunder storms are the most common of this type. This precipitation event can create high-volume streamflow in very short time-spans. The time-scale needed to describe shower activity is often one hour or less.

I should also point out that accompanying each change in time-base, there is a comparable change in the area from which streamflow must be measured to properly evaluate the event. Snow melt occurs uniformly over thousands of square miles. Uniform rain is common only over a few hundred square miles, while thunder storm activity may not be uniform over even one square mile. It is this combined complexity of variable time-base and areal uniformity that makes stream regime hard to characterize and even more difficult to precisely describe.

Forestry practices, when superimposed on an already complex regime picture, create even greater regime diversity. There is therefore a natural tendency to ignore these effects and to concentrate instead on gross annual alteration in streamflow. But we live in a "short-term" world. That is, we are not nearly as impressed by the fact that the average streamflow in a river is normally 100 cubic feet per second (cfs), as by the fact that we live in a house on the flood plain, the flow right now is 300 cfs, and the water is in our living room. A change this large, solely attributable to timber harvest, has occurred!

WHAT DETERMINES REGIME

The determinants of regime in any given stream-watershed system are precipitation intensity and duration, precipitation distribution, level and distribution of soil moisture, and topography (both surface and sub-surface). All interact to some degree.

Rain intensity and duration are not influenced by land management activities. Most flooding is a result of too much rain too fast. Flooding of this type cannot be stopped by any combination of either good or bad land management. However forestry practices can make bad floods worse, marginal floods no longer marginal. These aspects will be discussed under factors to consider in forest-management planning.

Snowmelt is affected by forest management. Snowmelt can be treated as precipitation occurring at the time of melt. The rate at which snow melts, i.e., the precipitation intensity, is primarily a function of thermal-energy input, either from wind, such as chinooks in Alberta, or from the sun. The major source in most cases is the sun, and the presence of trees influences the amount of both advected energy and solar radiation reaching the snow surface. The complete role of forest canopy in governing the speed of snow melt is beyond the scope of this paper. Suffice it to say that clearing generally speeds snow melt, and therefore in a sense alters precipitation intensity. This is an important alteration in energy

input and it will be discussed more fully under the examples given in the next section.

Precipitation distribution can be influenced by forest management but its effect on regime is less easily understood. Obviously, direct input of rain into that portion of a stream channel containing water produces an immediate effect: the amount of water in the channel increases in direct proportion to the rainfall intensity and channel area. However, the precipitation that falls on an area immediately adjacent to the stream channel can and usually does cause a similar immediate rise in stream flow. This latter is due either to surface flow or translatory flow. The combined total of all three components is known as quick flow.

Surface flow is rarely observed in forests. Thus the main mechanism for quick flow must be translatory flow. Such flow is best illustrated by considering a pipe completely full of marbles. If one marble is added at the input, one must be discharged at the output. The input and output marbles are not the same, but their volumes are equal.

Translatory flow takes place from an area immediately adjacent to a stream channel. Water added to the surface of this area upsets an equilibrium state and a like volume is discharged into the stream. The extent of the area from which translatory flow originates is variable. And it is this variability that makes predictions of the rate and volume of runoff that will result from a given storm size, most difficult. In the spring under a uniform snowpack, the entire watershed may act as quick-flow source area; in summer only the stream-channel area may be the quick-flow source.

Forest harvesting affects precipitation distribution by changing the aerodynamics of the surface topography and by reducing the interception losses. The redistribution of snow is readily apparent near the edge of an opening. There is more snow on the ground than under the surrounding timber. If the opening is quite large, the edge may also contain more snow than the opening even though the opening will have more snow than it would have had if it had remained timbered. Redistribution will continue as long as there is a surface discontinuity, either between new growth and residual stand, or in the second cut, between a newly cleared area and the previous cut's regrowth.

The effect on rain is not as marked. More rain reaches the ground in a clearing than under the timber because of reduced interception. An edge may also induce more rain near it. However this latter is more difficult to measure than with snow and consequently has not been proven.

With either rain or snow, clear harvesting of trees from source areas will cause greater quick-flow rates and volumes than prior to harvest. The magnitude of these flows is governed by the amount of harvesting done on source areas, and the moisture regime of such areas before and after harvest. This leads us to the third regime determinant, soil moisture.

Soil moisture is a major determinant of regime. It is highly influenced by forest harvesting. The removal of trees results in lessened transpiration demand on the soil moisture supply. If regrowth is slow, as it is in most of Alberta, then the effect on soil moisture may last for twenty or more years.

Soil moisture affects regime because precipitation can flow directly through a soil profile, be retained in the soil, displace water already in the soil, or flow over the surface - all dependent upon the moisture conditions that exist during the precipitation event. In forests, flow over the surface is more the rare than normal case. Obviously, under highly-intense rain storms, or for short distances, some surface flow occurs. Such flow is a result of saturated and/or impermeable underlying soil. However, the more common occurrence in forestry is translatory displacement of water from saturated soil. The effect of both surface runoff and translatory flow is similar, i.e., a rapid increase in stream flow. But, the mechanism is different and this difference is quite important from the standpoint of erosion and sediment production.

The location of saturated soil areas with respect to a stream channel is also important in regime determination. Highly moist areas physically continuous with the stream cause most of the precipitation that they receive to become quick flow. A similar-sized area of saturated soil physically separated from the stream channel may or may not contribute directly to quick flow. This latter depends upon the sub-surface linkage. Also, some surface flow may develop on such areas only to be absorbed by intervening dry areas before it reaches a stream course. A distribution pattern of alternate dry and wet areas is usually not conducive to quick flow.

Soil physical properties influence regime through their effect on hydraulic conductivity. Conductivity is related to particle size, particle-size distribution, degree of aggregation, pore space, pore arrangement, etc. This property (conductivity) is also influenced by temperature - an obvious effect is freezing - and by soil chemistry. In general, the hydraulic conductivity of most forest soils is adequate to transmit the amount of precipitation that they receive. The hydraulic conductivity of soil becomes a regime determinant at its extremes - that is if highly permeable or impermeable. Between these extremes it is generally adequate and regime is determined more by other than soil properties. However, soil physical properties are radically altered by such forestry practices as scarification and road building. The effect of these two practices on stream regime should definitely be considered in planning any timber harvesting operation.

The last determinant of regime to be discussed is topography - both that of the surface and that governing the rate and direction of ground water movement. Topography itself is not altered by timber harvesting. But often certain topographic situations exert major control on regime, and forestry operations on such an area will effect ensuing streamflow response.

Surface runoff occurs more readily on steep slopes. This is perhaps stating the obvious. But it bears emphasizing because of our inherent desire to harvest wood wherever it is found. Steep slopes are surface-runoff prone and therefore erosion prone. The vegetation on such slopes helps to delay runoff as well as control erosion. Any operation that removes established vegetation and/or compacts the soil will cause more rapid runoff. Once a new local runoff regime is established on a steep slope, it is often difficult if not impossible to restore natural conditions.

Drainage systems and density are functions of topographic relief. In flat or low relief terrain such as much of Alberta east of the mountains, the surface drainage system is not the principle path for precipitation to stream channel - especially on watersheds in the $\frac{1}{2}$ to $1\frac{1}{2}$ square-mile range. In watersheds of this size, most of the streamflow originates via highly localized subsurface-flow systems and the surface-drainage pattern functions only intermittently. Watersheds of this size are the primary source for streamflow in Alberta and they make up the majority of the land area.

These localized groundwater systems consist of recharge and discharge areas that in general conform to ridges and valleys respectively. However, a local system may not be complete within one topographic unit. That is, groundwater may be discharged from more than one recharge area.

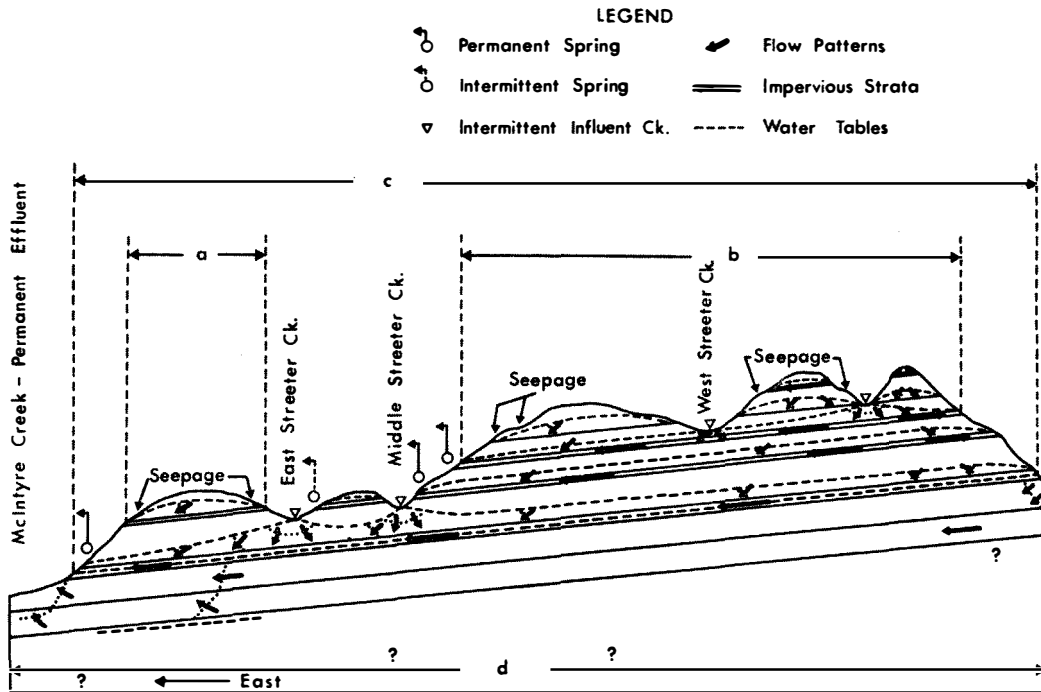
A good example of this is found in the Streeter basin experimental watershed in the Porcupine Hills of Southwestern Alberta. Here, three local groundwater systems are interconnected. The final disposition of precipitation falling on Streeter is not in the basin at all but one drainage removed to the east (Fig. 2). This type system is typical of the foothills.

The overall drainage from the groundwater system represented by Streeter is "reasonably fast". The soils and overlying material are porous so that subsurface flow proceeds quite rapidly. However, it could be made more rapid. Any practice that reduced snow retention on the ridges or upper slopes and at the same time increased the amount of snow accumulating in the stream course, would speed up the rate of stream discharge from Streeter.

The interaction between topography and regime is obvious only for surface flow. If no actual groundwater information is available, then the "best guess" as to what is happening is to assume that the groundwater drainage system is a subdued replica of the surface topography. This means that ridges would be considered recharge areas, valleys zones of discharge. To speed up flow, losses should be minimized on discharge zones. This is easily accomplished by timber harvest within them.

TYPE EXAMPLES OF REGIME ALTERATION

Flow alteration, either in quantity or in time, occurs whenever



Streeter Basin Alberta Hypothetical Hydrogeology Based On Bore Holes And Surface Geology

Fig. 2. Hydrogeological structure as it relates to streamflow generation from subsurface flow paths on Streeter Basin Experimental Watershed in Southern Alberta. The surface area of the catchments serving each of the three creeks is roughly the same. However the flow in East Streeter is 10 times that in Middle which is in turn 10 times that in West. The final disposition of precipitation falling on Streeter appears to be in McIntyre Creek which is not included in the topographic unit defined as Streeter Basin.

the hydrological system is changed. This alteration happens because the physical processes governing flow are modified. In a forest situation, much of the precipitation is lost to the atmosphere through evapotranspiration. Tree removal reduces this loss. The effect is more water in the surface-soil layers. The net effect of this water is always greater runoff. This qualitative physical fact is not dependent upon vegetation type, latitude, slope, etc. It will occur whenever forests grow and are harvested.

The fact that operation of a physical process is altered by forest removal makes possible the general qualitative extrapolation of the results of harvesting from one locale to another. There should be no doubt in the reader's mind that removing timber increases water yield. Every experiment conducted to date has verified this. The only real question remaining is how does this increase affect the downstream uses. This in turn depends upon when and how much increase occurs.

One of the earliest experiments to determine the effect of clear harvesting on streamflow occurred in Colorado between 1908-1926. The Wagon Wheel Gap experiment demonstrated that clear harvesting a 243-acre watershed increased its water yield and that most of the increase occurred in the snowmelt runoff period (Fig. 3). Wagon Wheel Gap experienced very few high intensity rainfall events. However, those that did occur after clearcutting produced higher and slightly earlier hydrograph peaks than before (Fig. 4).

The vegetation - climatic type sampled by Wagon Wheel Gap is similar to that found in the southern portion of the Alberta foothills. The spring runoff period starts earlier than on Marmot Experimental Basin in Alberta, and peaks at about the same time (Fig. 5). However the duration of the spring freshet is prolonged much longer in Alberta, probably because of a consistent rainy period in late May-June. The size of the Wagon Wheel Gap clearcut is about upper to mid-range of what is found as commercial practice in Alberta's foothills. The effect of clearcuts of this size on snowmelt runoff timing, and on the hydrograph from low intensity rain storms, should be similar.

At the opposite end of the clearcut-size spectrum is the Fool Creek Watershed experiment, also in Colorado. Here one half of the timbered area of a 714-acre watershed was clear harvested in a patchwork-pattern of 0.6 to 3.6-acre blocks (Fig. 6). Annual streamflow increased by 25% after harvesting; all of the increased volume occurred before spring runoff would have started in the before-harvest condition (Fig. 7). It is not precisely evident which size of cleared patch is most responsible for this increase in early snowmelt.

The 3.6-acre blocks are 6 x 6 chains square. These represent one half of the harvest area but only one quarter of the total number of patches. The effect of this size opening is increased snow within the cleared area and decreased deposition under the adjacent uncut strips. The difference between cleared and uncut snow accumulations is 6.7", roughly three times the difference noted between 2- or 3-chain wide cut-uncut areas of 2.0". Studies from other areas have indicated

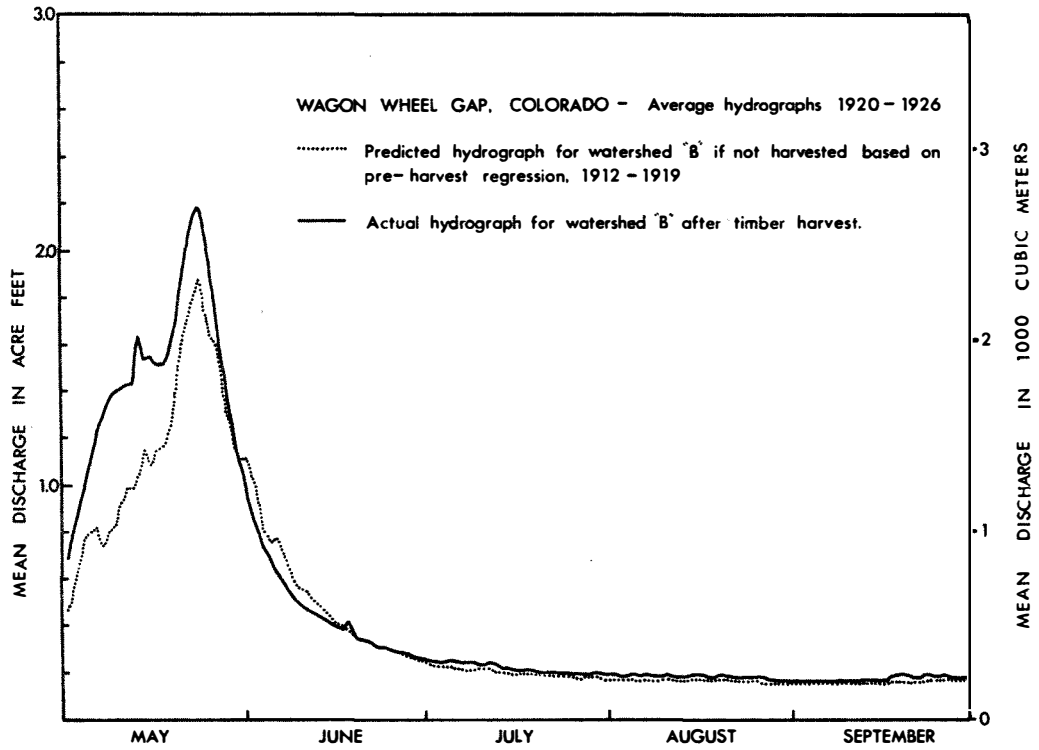


Fig. 3. Alteration to snowmelt and subsequent runoff regime as it occurred following clear harvesting of the 243-acre watershed "B" at Wagon Wheel Gap, Colorado. Plotting constructed from the data of Bates and Henry (1928).

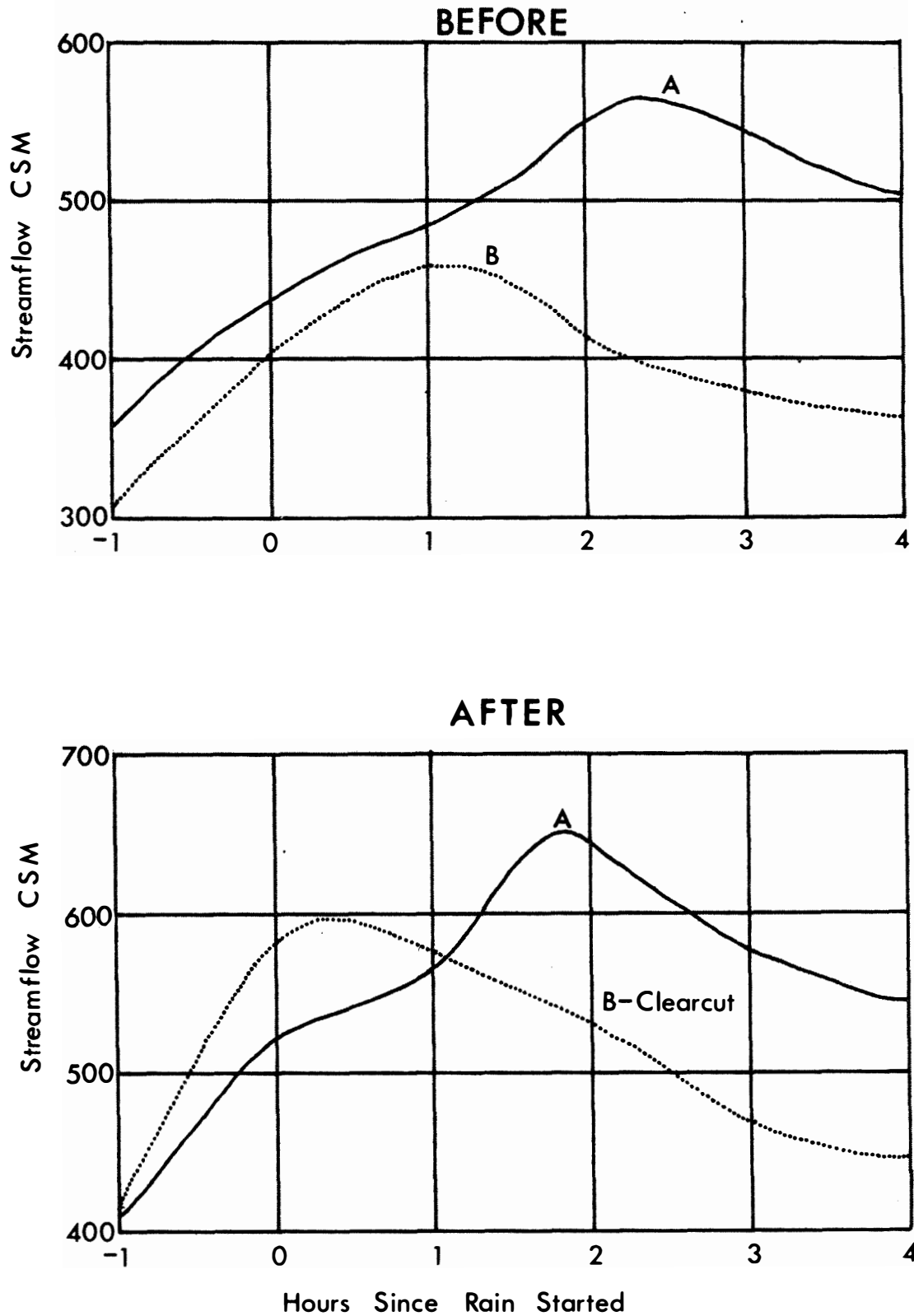


Fig. 4. Average flow pattern resulting from 14 isolated summer storms before and after clearcutting, Wagon Wheel Gap, Colorado. From Bates and Henry, 1928.

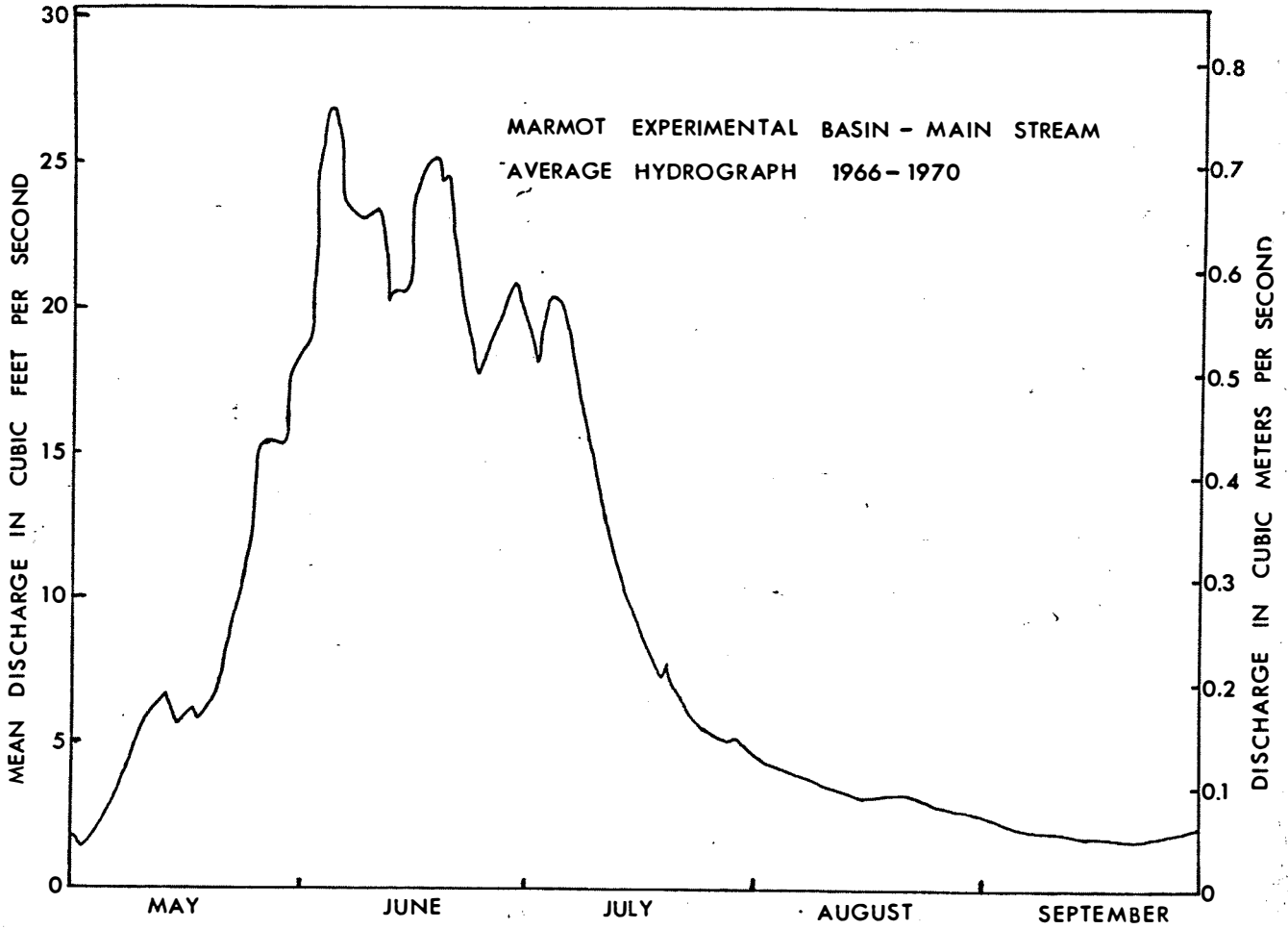


Fig. 5. The peak discharge from Wagon wheel Gap (Fig. 3) occurs at the end of May much as in Marmot as indicated above. The broader response of Marmot may be due to a slower snowmelt period, a greater volume of snow than Wagon Wheel Gap, or rain occurring in June. The general similarity of the Marmot hydrograph to those of Wagon Wheel Gap and Fool Creek (Fig. 7) suggests that timber harvest in Alberta would produce similar results to those from Colorado.



Fig. 6. Cutting pattern on Fool Creek watershed, Colorado. Vegetation is lodgepole pine and engelmann spruce. Most of the precipitation falls as snow.

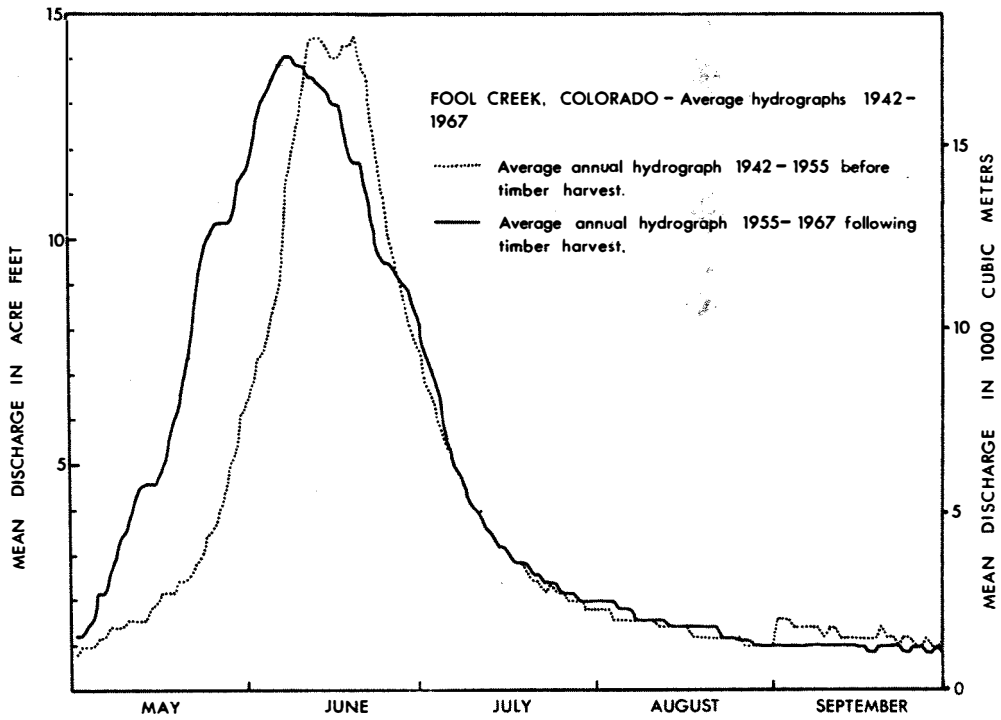


Fig. 7. More runoff earlier in the season is indicated in this hydrograph from Fool Creek Watershed after imposition of the harvest pattern of Fig. 6. Data from U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station.

little additional snow in openings with the small dimension greater than 5 chains. Thus it would appear that a combination of openings and uncut with average dimension between $2\frac{1}{2}$ and 6 chains would produce the maximum effect upon snow accumulation and subsequent early snowmelt runoff.

The Fool Creek watershed experiment cited here is the only test of this type in existence. Therefore, we should be very careful about specifying timber sales over vast acreages where the clear-harvested areas are small (less than 5 acres) until these effects are better understood. This size may well be the best configuration for increasing annual yields, but its effect on the early snowmelt hydrograph makes the increase of dubious value in Alberta except where sufficient short-term reservoir storage is available to retain it for future use.

One further point on snow accumulation-snowmelt runoff: the longevity of the effect. Measurable early flow resulting from the Fool Creek harvest is predicted to continue for at least 30 years. This is because the energy-exchange relationships and aerodynamics of the residual canopy will not return to "normal" until there remains no definite edge between the cleared-uncut areas. This means that the new growth must be approximately $\frac{2}{3}$ the height of its surroundings. In Alberta as in Colorado, regrowth is slow. Very little regeneration is evident 10 years after clear harvest. No one really knows how long it will take the trees that are being established on the areas now harvested to reach 40 ft. A good guess would be in excess of 40 years.

Timber leases in Alberta often make up a significant portion of a river's headwaters. Harvesting plans are such that from $\frac{1}{100}$ to $\frac{1}{80}$ of the area is harvested each year. A deceptively small increment of regime change can occur each year in response to this harvest. Full effects will not be noted for 30 or more years. Beyond 30 years the effect will remain fairly constant if the harvesting continues at the same pace. It is important therefore that timber sales and leases be considered in light of their full effect at 30+ years, rather than on the annual increment which may be too small to be significant in a sizeable drainage.

Rainfall events are quite important in Alberta. Much of the summer streamflow from the lodgepole pine and mixed-wood types originates as rain. Timber harvest affects runoff from this area too. The type of effect is as shown in Fig. 8.

Fig. 8 is a pair of before-after clear-harvesting storm hydrographs from the Fernow Experimental Forest in West Virginia. The only real change in regime is the very sharp initial peak in the after-harvest hydrograph from watershed No. 1. This peak does not remain for long, but could be damaging to downstream structures and water users. This type of runoff change can occur following any timber harvest. It was interpreted in the case above as a resultant caused by flow directed to the stream from roads and skid trails. It could also occur following extensive valley-floor harvest on a ground-water-discharge plain. The reduced transpiration loss caused by timber

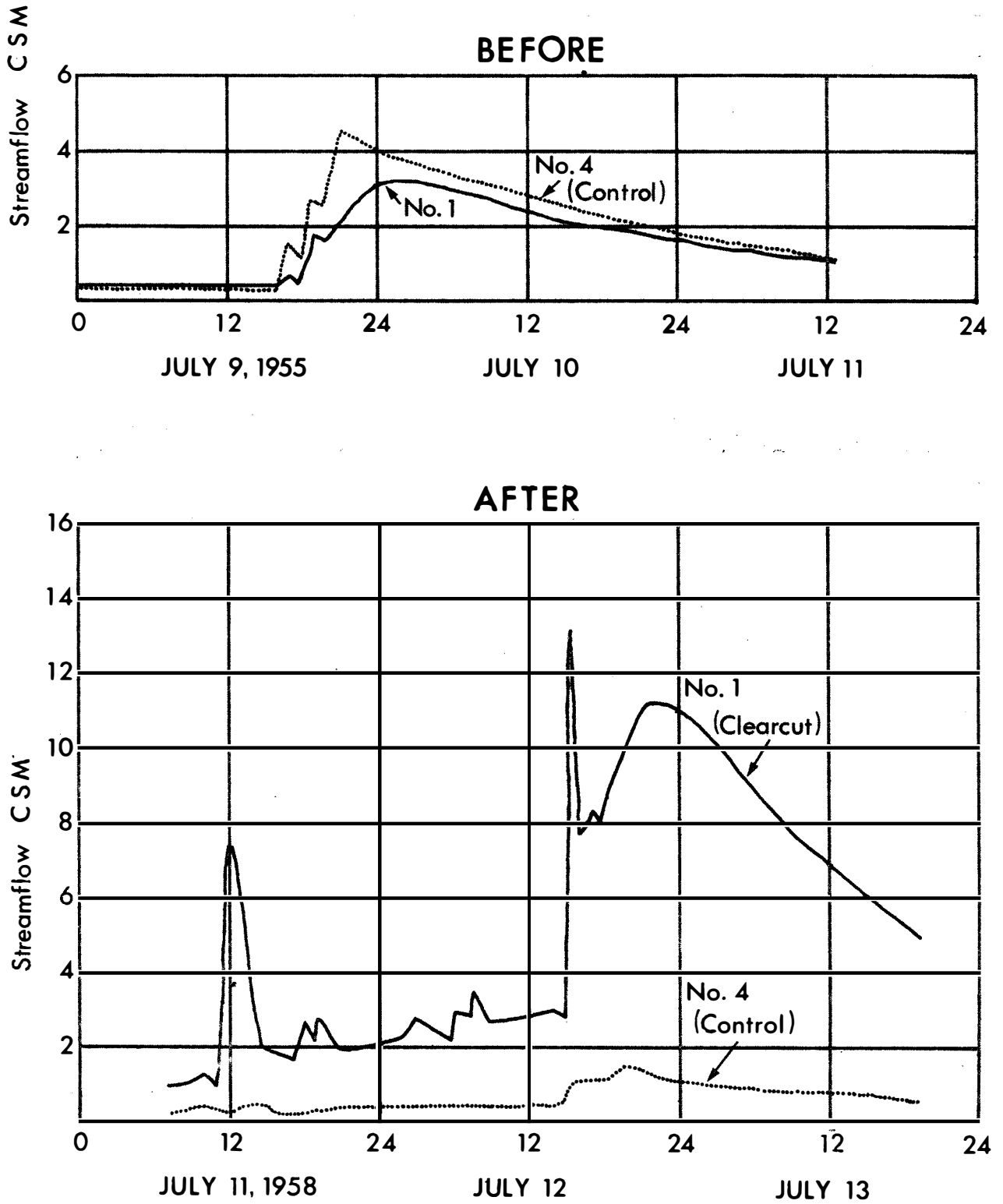


Fig. 8. Sample storm hydrographs before and after clearcutting, Fernow, West Virginia, From Reinhart and Eschner, 1962.

removal would result in a very wet area adjacent to the stream. Such an area would be quite susceptible to overland flow from a local stream.

MANAGEMENT OPTIONS TO REDUCE REGIME ALTERATION

The first and least acceptable option to reduce regime alteration is to stop harvesting altogether. The waste of valuable timber products precludes this alternative. It may however be desirable to postpone harvest in certain critical areas until either the market allows intensive silvicultural treatment for water, or a price is charged for water which is sufficient to defray any extra harvesting costs brought on by managing for water rather than timber alone.

A second option is to limit the rate of timber removal to insure only minimal hydrograph alteration. This could be accomplished by limiting the acreage cut in any one drainage to 10-20% in a 50-year period. This would have an added benefit in that management options for increased yield of water or timber would remain open for years to come. Obviously once an area has been totally clear-harvested, there are no opportunities for future development until the stand becomes reestablished in a commercial forest.

A third option is to shift to some silvicultural system other than clear harvest. Selection, group selection, and some form of shelterwood are possible alternatives. At the present time these are considered uneconomical. However, a consideration of all benefits, i.e., water, wildlife, livestock grazing, aesthetics, recreation, and timber, and some substantial monetary contribution from these other uses might change this. We, as foresters, should push for both technical and economic input from other forest uses to obtain a higher intensity of forest management than can be achieved through timber sales alone.

LAND MANAGEMENT PRACTICES THAT AFFECT
PHYSICAL AND CHEMICAL WATER QUALITY

by

Teja Singh

Canadian Forestry Service

Edmonton, Alberta

INTRODUCTION

Watersheds, as pointed out by Colman (1953), are the natural counterparts of reservoirs artificially created by man (Fig. 1). With capacity to store water (watershed storage capacity, consisting of detention storage and retention storage) and release it gradually, watersheds regulate the flow of mountain streams (Fig. 2). Vegetated watersheds provide opportunities for protection against floods and accelerated erosion by reducing surface runoff and diverting most of the precipitation to sub-surface flow, soil moisture storage and groundwater recharge.

A land management practice that causes soil disturbance and change in vegetation is likely to modify the water intake capacity of a watershed and have an important impact on the quantity of water delivered from such areas. Watershed practices also exercise considerable influence on water quality as such practices invariably affect the passageways through which water moves in mountain areas. A sand-filled bucket (Fig. 3) and the components of a streamflow hydrograph (Fig. 4) illustrate these concepts in a simple way.

Fig. 5 shows stream-flow hydrographs with component parts on a vegetated and a deforested watershed. The total discharge of a stream consists of (1) surface runoff, (2) subsurface flow, and (3) base flow. Surface flow is contributed by water running over the soil surface, and is usually a major component in areas devoid of vegetation cover. Sub-surface flow and base flow, in general, are more pronounced in the vegetated watersheds. Well-vegetated watersheds produce hardly any over-land flow.

The shape of the hydrograph for each component also shows its behaviour with respect to peak flows. Surface flows usually show wide fluctuations because the water moving over the ground surface is discharged more quickly into a stream channel than is subsurface water. The base flow is the slowest and usually more sustained and less variant of the three types of flow.

THE WATERSHED AND THE RESERVOIR

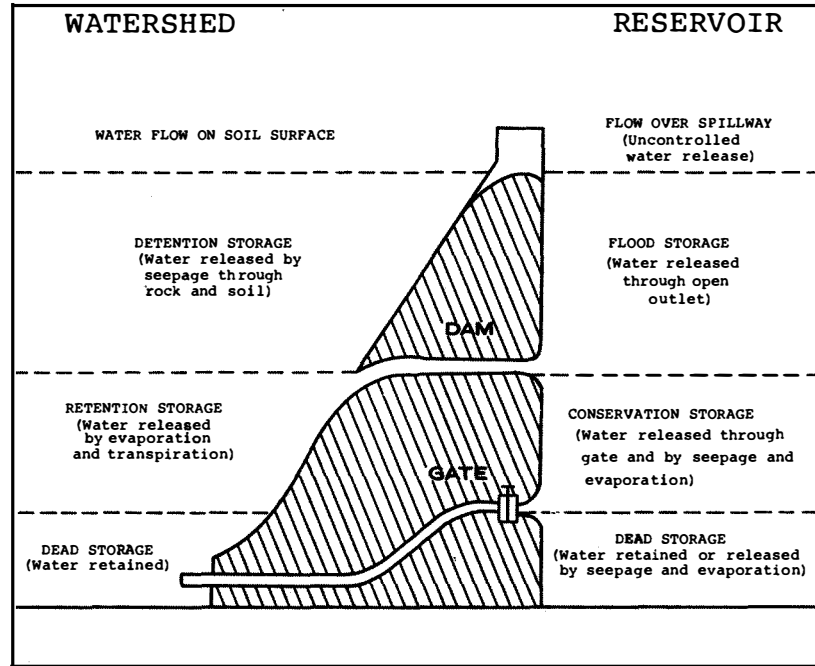


Fig. 1. Watersheds as natural counterparts of reservoirs (after Colman 1953)

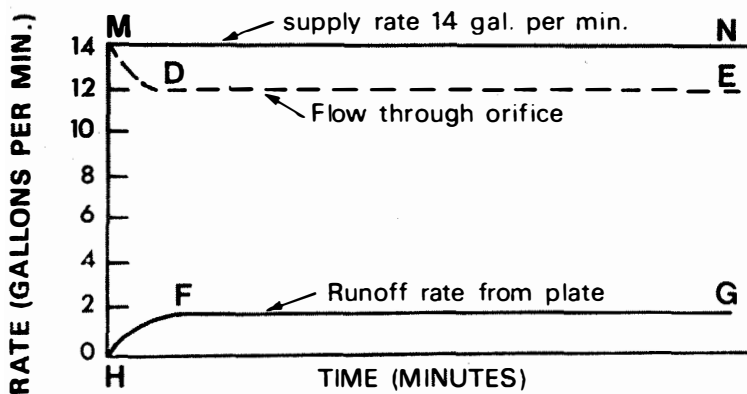
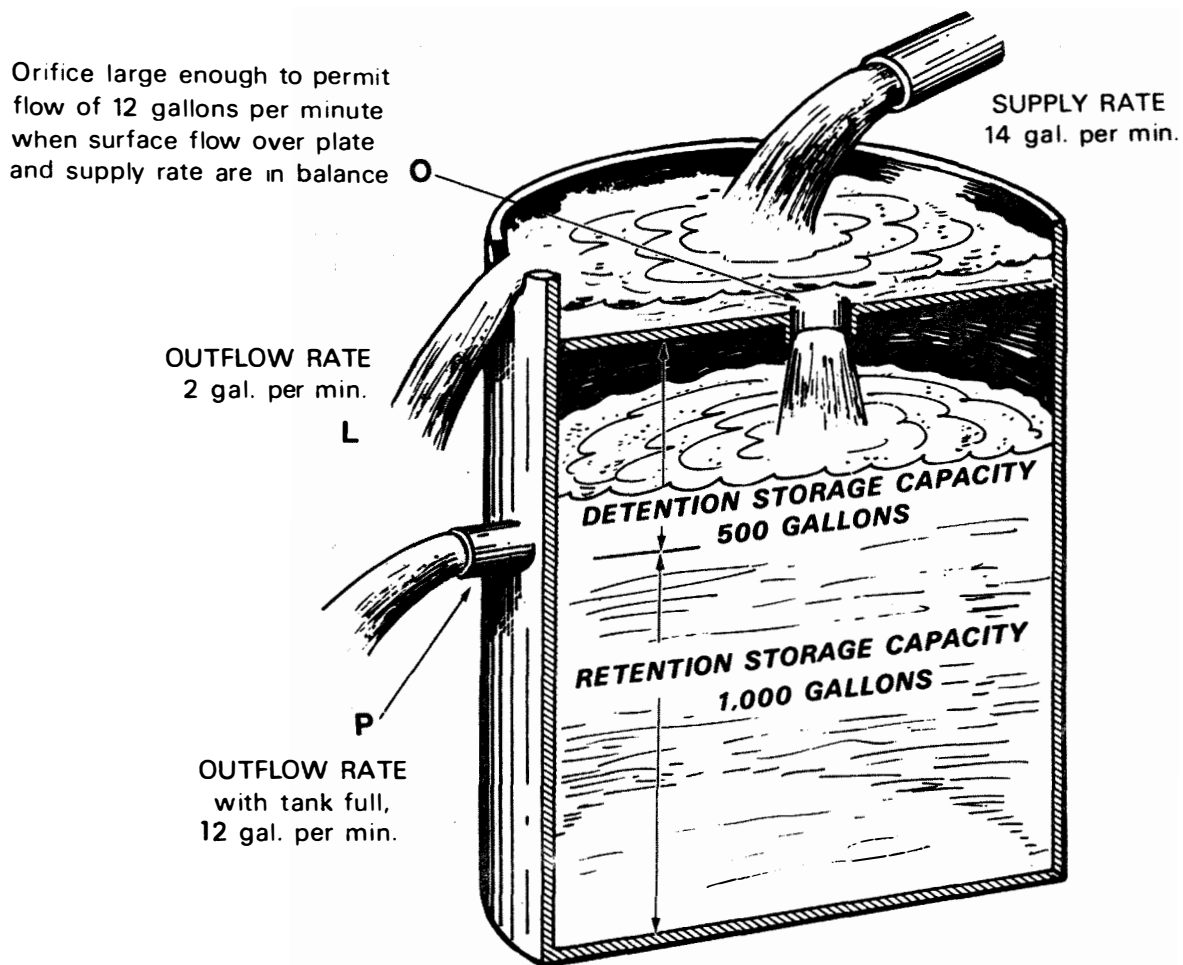
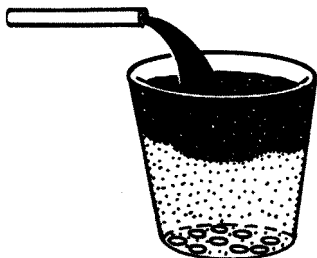


Fig. 2. A simplified mechanistic example of a watershed
(after Lassen et al. 1952)

THE SAND-FILLED BUCKET

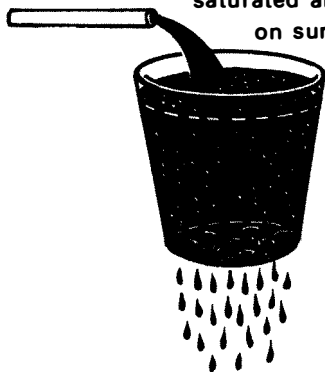
1 Water wets the dry sand



2 Drip starts after sand is wet to bottom



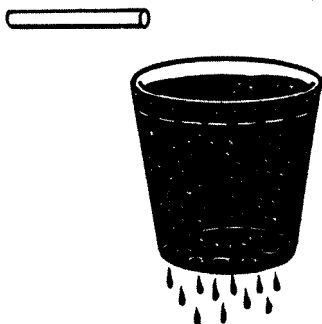
3 Drip rate reaches maximum when sand is saturated and water stands on surface. Drip rate equals rate of water application.



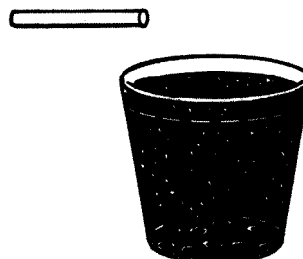
And



4 Water content of pierced bucket equals that of an unpierced bucket



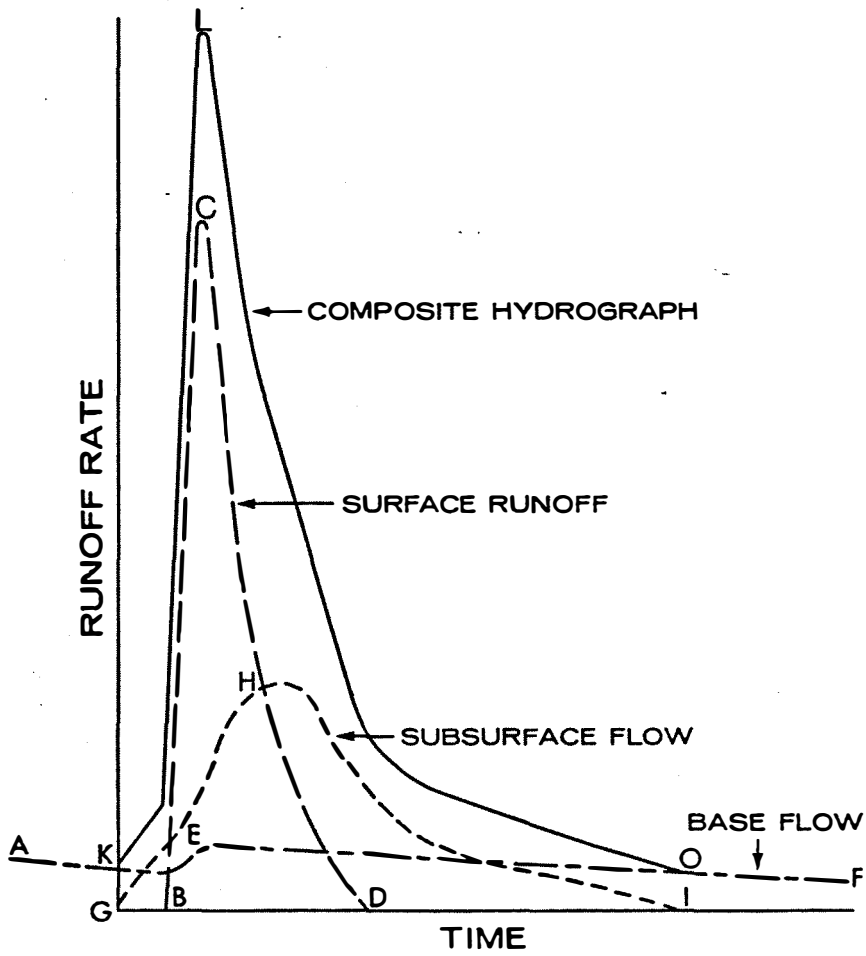
5 With water supply cut off, drip continues until....



6 The pierced bucket drains to its true storage capacity

"A pierced bucket of sand represents a watershed fairly well, if one imagines the sand as representing the layers of rock and soil that make up the body of the watershed."

Fig. 3. Illustrating the true storage capacity of a watershed (after Colman 1953)



A stream-flow hydrograph with component parts, reflecting the effects of a rain

Fig. 4. Components of a streamflow hydrograph

Distribution of rainfall on vegetated and bare areas into surface runoff, subsurface flow and base flow. Width of arrows indicates the relative amount of each component



Fig. 5. Well-vegetated watersheds produce hardly any surface runoff (after Lassen et al. 1968)

Infiltration capacity, or the maximum rate at which a soil in a given condition at a given time can absorb rain, is the prime factor in deciding the dominant component of the total stream-flow hydrograph. Vegetation, topography, and soil physical characteristics are the main modifying influences on infiltration rates and are, therefore, the factors deciding the nature of streamflow from a mountain watershed.

The water flowing over, in, and out of the soil system is affected in quality by interactions with materials with which it comes in contact. Sources of dissolved constituents in the water moving through the hydrologic cycle are shown in Fig. 6.

High runoff and the consequent high flows in streams are usually accompanied by dilution of the more mineralized groundwater. In terms of water quality, therefore, the high-flow stream waters are likely to be of low mineral content. The low-flows, on the other hand, are drawn mostly from base flows and usually have high concentrations of dissolved solids. The change in specific conductance (as an indicator of dissolved solids) resulting from varying amounts of stream flow and ground water discharge are shown in Fig. 7 taken from data collected at Marmot Creek Watershed.

Before proceeding further we need to specify what constitutes water quality. In a restricted use of the term, water quality refers to the sediment load carried by water (Colman 1953). This is also the traditional sense in which foresters have usually used the term, perhaps because the direct results of major forestry practices (e.g., timber harvestings, construction of logging roads) are more readily noticeable in terms of sediments delivered to streams than are the less obvious aspects of water quality which require elaborate laboratory analyses for assessment. However, the term is more comprehensive than that; e.g., Eschner and Larmoyeux (1963) have defined water quality as the sum of the measurable characteristics of water.

As the quality of water is inevitably related to the use that is to be made of it, the meaning adopted here is that of Bullard (1963) who defined water quality as the sum of characteristics of water that describes its usefulness for a specific purpose. This, then, leads us into consideration of water quality in the particular context of a given class or category of water use. As water quality requirements are different in each case (e.g., drinking water, industry, agriculture, recreation, propagation of fish and other aquatic life), watershed practices should therefore be examined in relation to their impact on each specific or pertinent water use. Also, quite often stream waters serve more than one purpose; in such cases the quality requirements need to be examined in the multiple-use context.

WATERSHEDS AS SOURCE OF PUBLIC WATER SUPPLIES

Of all uses, the quality requirements for supply of untreated drinking water are among the most demanding. According to Dortignac (1965),

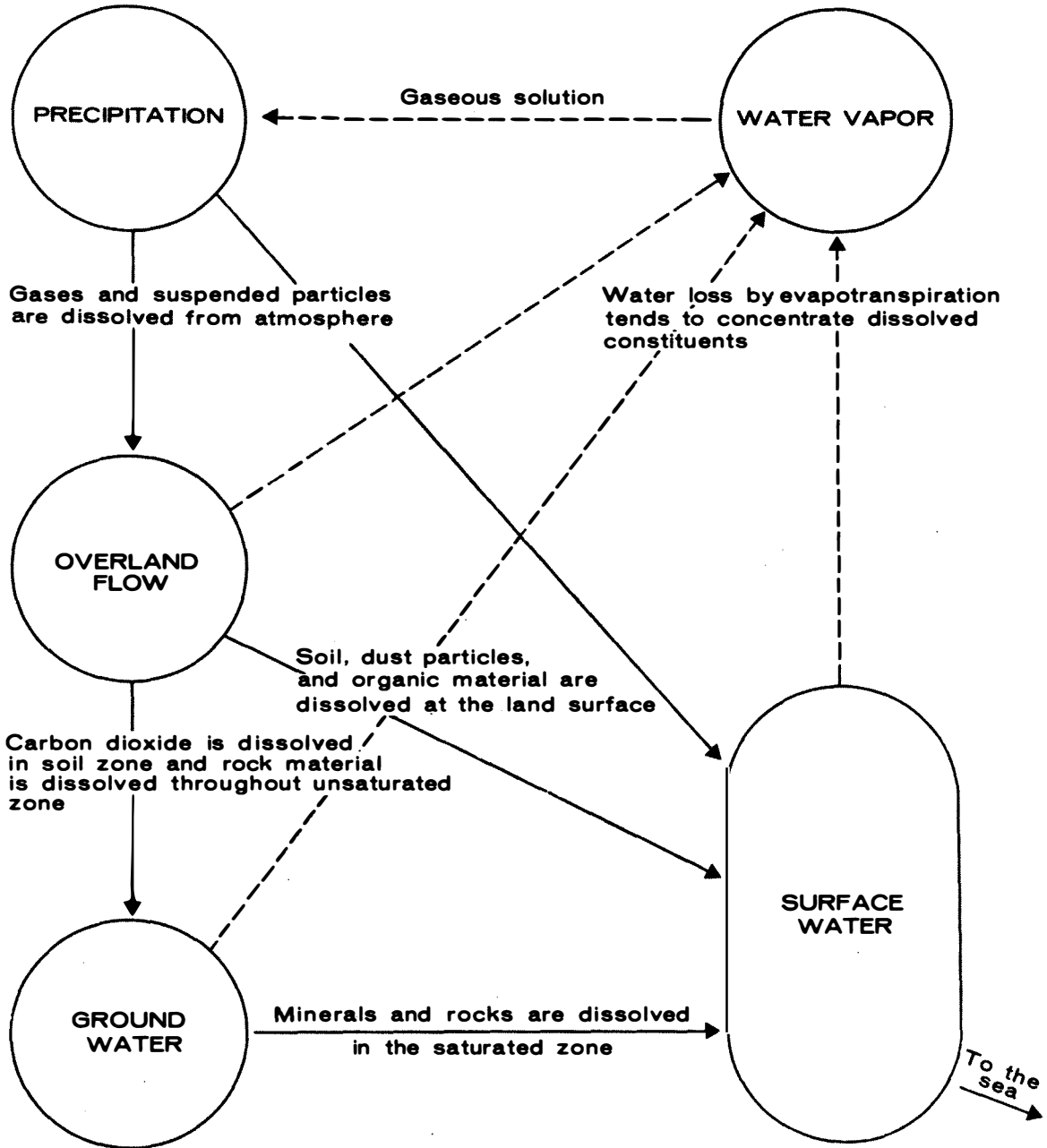


Fig. 6. Sources of dissolved constituents in water moving through the hydrologic cycle (after Archer et al. 1968)

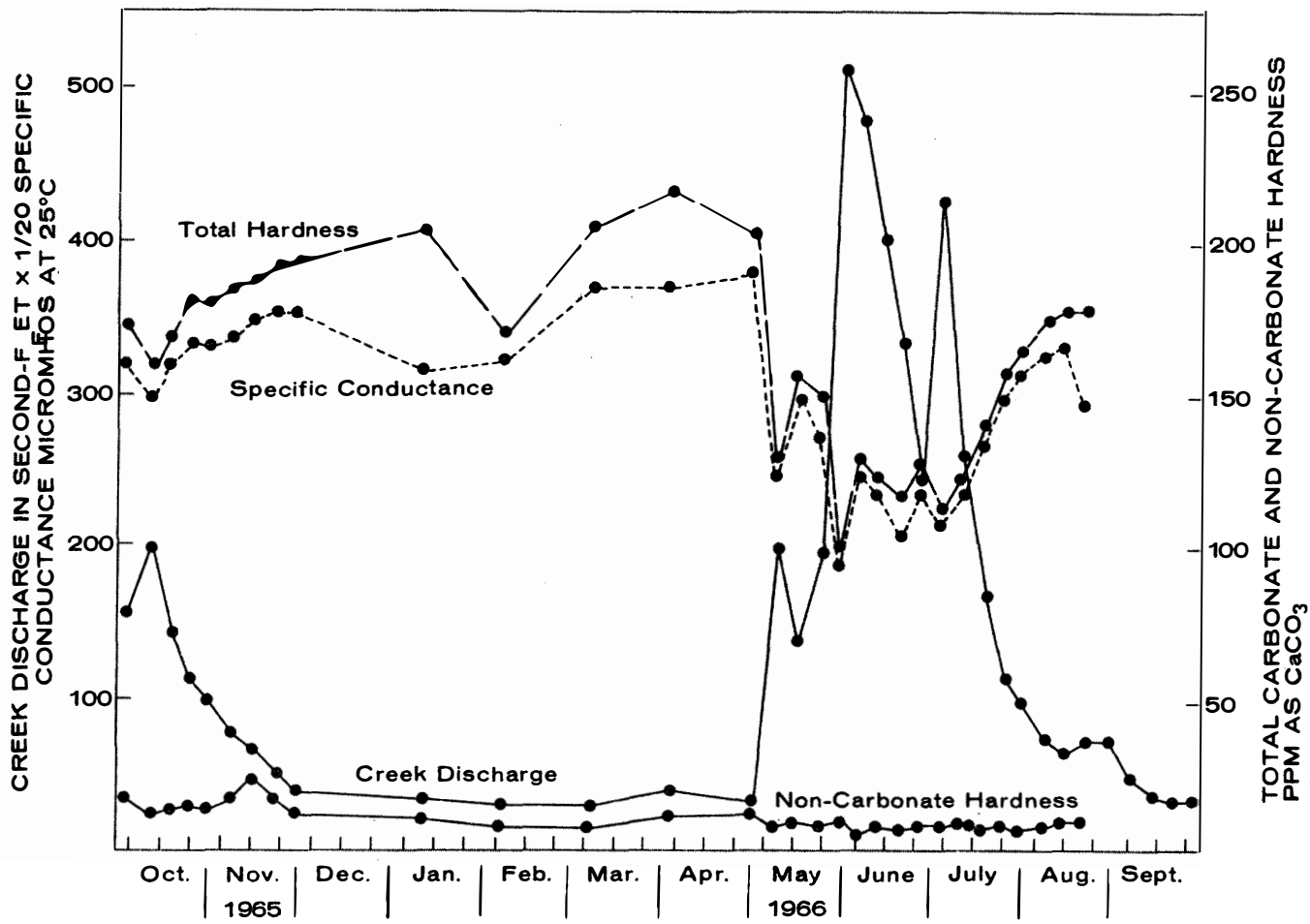


Fig. 7. The relationship between mineral content and streamflow. Marmot Creek at control weir, October 1965 - August 1966

surface water supplies are tapped by about 6,000 communities in the United States. Because of more area under forests in Canada the percentage of total population dependent on unprocessed water from forest watersheds would be considerably more than that in the United States. Another estimate, by Beattie (1963), suggests that about 40 million acres of the National Forest lands in United States provide unprocessed surface water to approximately 17 million people. In some cases, therefore, it would be incumbent on watershed managers to exercise sufficient restraint on their activities to ensure that the quality of water does not deteriorate beyond the prescribed drinking water standards. Water treatment facilities of the very minimal type are a practical feasibility in case of isolated small communities.

In cases where storage facilities and pre-processing are the essential pre-requisites of a municipal water supply system, the aim in general should be to reduce the cost of processing treatments and to insure the longevity of storage reservoirs by keeping sediment loads to a minimum. A reduction of 25-30% in suspended sediment, for example, can reduce the cost of processed water by about 10 dollars per million gallons (Dortignac 1965). As the per capita use in the United States, for example, is 44 thousand gallons per year, the savings in treatment costs and enhanced longevity of the available storage space could be substantial with proper land use practices in the source areas. A city with a population of 1 million requires 120 million gallons of water per day for domestic needs (Jones et al. 1967)

In terms of sediment production, if an inch of soil were scraped off a 390 square mile watershed, the sediment will displace 7 billion gallons of water, enough for domestic requirements of a city of 100,000 people for two years. Thus, however insignificant the impact of land use practices may appear to be, the accumulative amounts of sediment can be huge in the case of large catchments. Much of the consequent extra expenditure can be reduced or avoided by careful planning of routine forestry operations in the catchment areas especially where such watersheds are the source of city water supplies.

WATERSHEDS AS SOURCE OF WATER FOR INDUSTRY

The well accepted quote that "water, or the lack of it, sets limits to man's activities" is nowhere more evident than in the case of industrial development. Almost all large scale industrial plants require water in large quantities for steam generation and cooling purposes (Sewell et al. 1968).

Water quality requirements of special importance in steam generation are those relating to the scale-forming hardness in steam boilers. For hydro-electric power, the high sediment load in water can be a powerful abrasive, necessitating early replacement of expensive machine parts.

Of particular interest to foresters in Alberta is the paper and pulpwood industry which is presently undergoing expansion. Northwestern Pulp and Power Ltd., of Hinton is expected to double its current production to 1,100 tons per day by 1973. Three new paper mills (one each in the Whitecourt area, Grande Prairie, and Rocky Mountain House) are also expected to be set up soon. The pulpwood industry, on the whole, is an enormous consumer of fresh water supplies. A mill with a daily pulping capacity of 1,000 tons, for example, has total water needs (for steam, cooking, washing, drying and cooling) equivalent to that of a city with a population of approximately 1 million people (Southern Pulp and Paper Mill 1968). The water quality requirements are also quite demanding, some processes require water of a quality higher than that supplied by most municipal water plants. All of this can add to high cost as a result of poor watershed practices.

Water quality requirements differ widely in other industries such as textile, lumber, chemicals and allied products, petroleum, primary metal industries, food processing, leather tanning, and canning. Similar inevitable increases in the cost of treatment occur when water quality deteriorates as a result of high sediment load of streams because of mismanagement in the catchment areas.

WATERSHEDS AS SOURCE OF WATER FOR FISH AND WILDLIFE

Waters from mountain watersheds support a variety of fish and aquatic life. According to Shields (1968) the areas to which salmon return to spawn provide some of the richest acreage of the federal forests in Alaska. This is also true of salmon spawning areas of B.C. A relatively few acres of spawning riffles on streams along the Alaskan coast produced approximately 56 million salmon taken by fishermen in 1965 (Shields 1968) valued at over 116 million dollars. Each acre of gravel beds produced half a million youngsters normally, but the survival can be increased to over 2 million in clean gravel. The survival is directly related to the low sediment contents and free circulation of water to supply needed oxygen and to clear metabolic wastes.

The water quality criteria that have direct effect on the aquatic organisms are: dissolved materials, pH, temperature, DO (dissolved oxygen), carbon dioxide, oil scum, turbidity, settleable materials, floating materials, tainting substances, radioactive wastes, plant nutrients from waste products, and toxic substances (e.g., pesticides) (U.S. Dept. Interior 1968). Land use and forestry practices affect, primarily, erosion sediments, temperature, DO, color and transparency, tainting substances, and turbidity. Higher peak flows than those evidenced in uncut and undisturbed forestry areas involve channel scour, bank undercutting, and movement of stream-bed gravels.

Increased sediment loads and changes in stream temperature are directly related to forestry management and timber harvesting practices, particularly clear-cutting. Both are of considerable importance to areas that are the spawning and breeding habitat for fish (Meehan et al. 1969). Eschner and Larmoyeux (1963) have reported a decrease in the minimum winter stream temperatures of 3.5°F, and an increase in the summer water temperatures of 8°F as a result of vegetation removal. In another study, clearcutting increased temperatures of small streams by 14°F during August and September (Brown and Krygier 1967).

The greater diurnal fluctuation in water temperatures of small streams caused by extensive cuttings is of even greater concern than the seasonal variations mentioned above. Higher temperatures are accompanied by increased metabolic rates and, therefore, more oxygen consumption; for example Wiebe and Fuller (1934) found that at 25°C the oxygen consumption of large-mouth black bass was 282 percent of that at 15°C. Increased decomposition of organic materials can further affect the fish habitat adversely. Also, the increase in turbidity of stream waters could mean reduced light penetration, reduced plant photosynthesis and, consequently reduced bottom fauna.

As high water temperature is one of the most important factors limiting the distribution and survival of trout, no waste of high heat content should be discharged in trout streams. Land management practices, in general, should be conducive to maintenance of favourable water temperatures. The channel stability of streams should receive prime consideration, and timber harvesting practices and the accompanying logging-road construction should produce minimum erosion.

Increasing or decreasing water temperatures trigger spawning activities, metamorphosis, and migration in many wildlife species. Water temperature, when changed from the optimum, also affects the ability to compete with other organisms.

Fish is part of the diet of many wildlife species (e.g., pelicans, loons, ducks, herons, otters, raccoons, bears). Water quality standards applicable to fishery habitat are thus applicable to most wildlife in general; the two are inter-related. Forestry practices that influence fishery resources are therefore of equal concern to the survival and propagation of most wildlife that is water-dependent for food and breeding. In this connection special mention should be made of waterfowl, as much of Canada provides breeding habitat for migratory game birds.

WATERSHEDS AS SOURCE OF IRRIGATION WATER FOR AGRICULTURE

In Canada, irrigated acreage totals 1 million, almost all of which is in Alberta, Saskatchewan, and British Columbia. Most of the water used in agricultural irrigation is drawn from river flows. Because of low precipitation and high evaporation, the areas most likely to experience irrigation shortages are the southern parts of the western prairies.

Total dissolved solids present in irrigation water determine the osmotic potential of soil solutes and, therefore, its actual availability to the growing crop. Most of the soluble salts originate primarily from solutions of rock materials as water percolates to groundwater reservoirs and reaches open channels as interflow. Overland flow similarly picks up soluble salts from soil surface. Evapotranspiration further increases the concentration of salts as a result of evaporation and selective absorption by plants.

Much of the water required for irrigation is needed within the few months of the growing season. Adequate storage facilities are often essential for impounding part of the river flows during the non-growing period. Sedimentation of such reservoirs is usually a major concern whenever loss of storage capacity is likely to occur as a result of unwise forestry practices in the source areas.

The problem of storage depletion is more critical in small upland reservoirs on sloping mountain watersheds. According to a recent estimate, in the United States (Dendy 1968), 20 percent of all small reservoirs will be half-filled with sediment and their utility seriously impaired in about 30 years at present siltation rates.

Sediment considerations are important in water spreading also. Even coarse-grained porous media showed clogging at turbid water concentrations as low as 50 ppm (Behnke 1969). Such clogging can affect vital hydrological phenomena such as groundwater recharge.

WATERSHEDS AS SOURCE OF WATER FOR RECREATION

Forest watersheds are a prime source of outdoor recreation. Swimming, water-skiing, fishing, boating, and camping are examples of water-oriented recreation. Aesthetic values are considerably heightened by, and are directly related to good water quality. Clear, clean waters, as compared to muddy, turbid flows, always provide the more sought after and preferred sites for the above mentioned recreational uses.

Water-oriented recreation and its growing popularity will demand more attention from forest-watershed managers in future. In United States, outdoor recreation is already the form of leisure activity preferred by many, approximately 90% of whom like to have it associated with water (ORRRC 1962). The federal forests and grasslands of the United States were estimated to provide 153 million visitor-days of recreational use in 1968. (Freeman 1967).

Recreational pressures are expected to increase as more leisure time comes within the reach of all in the not too distant future. In addition to water recreation already mentioned, winter skiing is of particular interest in Canada.

Recreational use is also an important consideration in the design and location of many hydro-electric projects and water storage reservoirs in Canada. At times it has been considered the only use, e.g., in the metropolitan Toronto region where five reservoirs are being built for satisfying the single purpose of recreation.

Forestry practices in such cases need to be aimed at minimal soil disturbance. Excessive sedimentation and siltation of streams and lakes should be prevented. Proper care should be exercised to prevent deposition of logging debris in the stream channels; in other words, the land use should be strictly oriented towards enhancing, or at least maintaining the current water quality of recreational use areas. Remember, most of the outdoor recreational activities are directly dependent on the availability and abundance of good, clean water from our watersheds.

NAVIGATIONAL WATERS

Navigation by water is one of the oldest and cheapest modes of transportation. Navigational needs can, therefore, be one of the considerations along certain reaches of a river when a chain of multi-purpose reservoirs (e.g., those by the Tennessee Valley Authority along Tennessee River) are built. There is a need to maintain a specified minimum depth for navigation in such reaches.

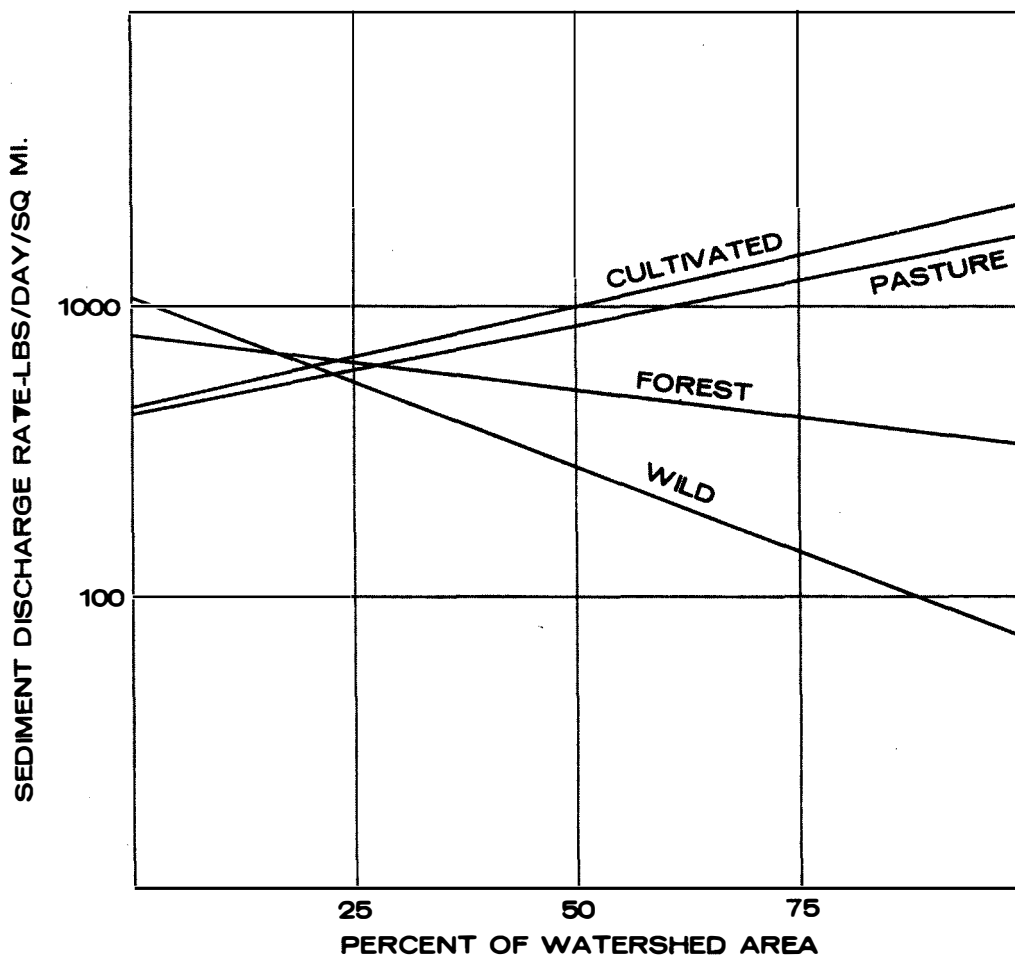
The suspended sediment carried in surface waters is likely to settle out when the velocity of flowing water is decreased on entering such reservoirs. This, in turn, can result in loss of available depth. Sediment source areas of streams entering such rivers should, therefore, be carefully managed with a view to avoiding undue increase in siltation.

TIMBER HARVESTING AND LAND USE PRACTICES INFLUENCING

WATER QUALITY

Watersheds in their natural state are the producers and custodians of undisputedly good quality water. Turbidity values for the untreated Marmot Creek Watershed, for example, are extremely low during non-storm periods and have rarely exceeded the drinking water standards even in the peak flows measured so far.

The intensity of soil disturbance invariably determines the total runoff and sediment produced from a watershed. The wildland watersheds, therefore, have a small discharge rate as compared to, say, cultivated areas. A comparison of stream sediment discharges according to the percentage of total watershed area devoted to a particular land use (Fig. 8) is provided by Striffler (1964).



○

Fig. 8. Relations between sediment discharge rates and land use (after Striffler 1964)

Mechanical clearing is in progress in many brush-invaded areas. In southern Alberta, for example, aspen and willow are "walked down" by bulldozer and are piled and burnt later (Johnston and Smoliak 1968). The surface soil disturbance in such cases is maximum, because the brush clearing treatments are usually applied over the entire area. Although sediment yield may be of no great consequence when the areas affected are level or slightly rolling, significant changes often occur in chemical water quality as reported by Gifford and Tew (1969) in their small plot infiltrometer studies in southwestern Utah where Pinyon-juniper vegetation was chained, windrowed, and seeded to grass.

Ground cover provided by litter and understory vegetation is an effective cushion against the direct impact of rain drops on the soil surface. Such cover is, therefore, directly related to rainstorm erosion and runoff. In their experiments on a sub-alpine watershed in the headwaters of Ephraim Creek in the Great Basin Experimental Area of Utah, Croft and Bailey (1964) showed conclusively the protective influence of ground cover on overland flow and erosion. They found that when the ground cover was 60-75% a very small portion (2%) of total rainfall formed overland flow and the soil loss was merely 0.25 ton per acre. With the destruction of ground cover the surface runoff and soil loss increase exponentially (Fig. 9). When only 10% of cover from understory vegetation and litter remained on the plot surface, as much as 73% of the rain formed surface runoff and soil erosion amounted to 5.5 tons per acre. The potential erodibility of a mountain watershed, though initially conditioned by soil and parent material, is thus effectively modified by the vegetation cover near the ground surface.

As estimated by Copeland (1969), approximately 90% of the total watershed damage in forest areas can be attributed to poor design, location, construction, and maintenance of logging roads. Those timber-harvesting systems which require an intensive lay-out of logging roads, are, therefore, the least desirable for good watershed management as regards water quality. This is amply demonstrated by the Zena Creek logging study, Payette National Forest, Idaho, which showed that the sediment produced from the jammer-logged area was 462 times that from the high-lead system (Craddock 1967).

High-lead logging systems have, therefore, found increased usage in the Western United States and also to some extent in Canada. Although the initial cost of equipment is high, such systems, nevertheless, provide the more versatile and preferred types of logging methods on steep watersheds.

Tractor logging, often done in conjunction with other less damaging timber harvesting methods, is still the most common method of timber removal in many parts of Canada. Because of soil compaction, and consequent reduction in infiltration capacities, logging when soil is wet should be particularly avoided. Tractors, moreover, should not be operated on areas so steep that it becomes necessary to excavate skid roads into

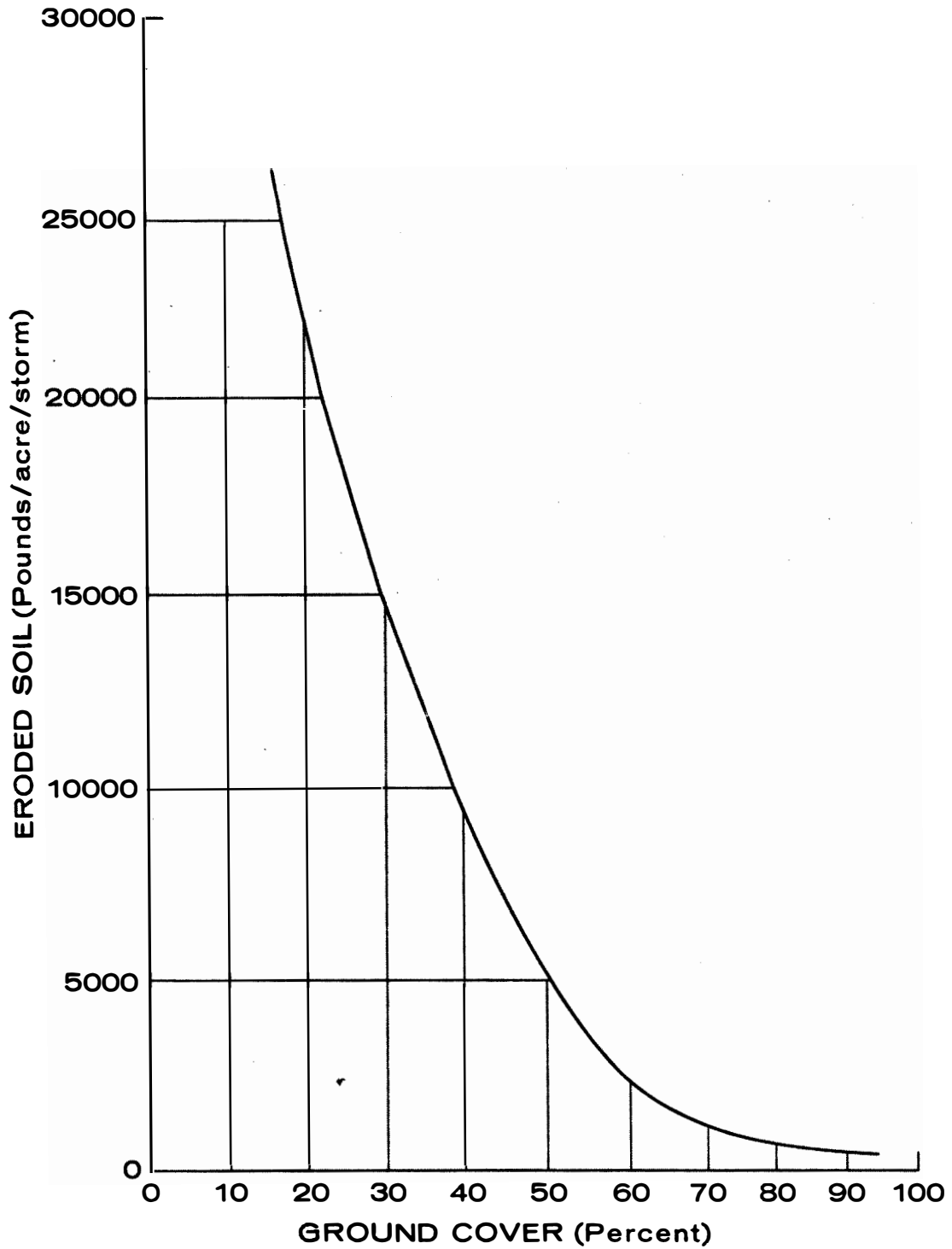


Fig. 9. Erosion rate increases exponentially with increased destruction of ground cover on mountain watersheds (U.S. Forest Service data)

the sidehill (Steinbrenner 1966). Water bars should be established where needed. For best economic return, and in the interest of watershed protection, tractor logging should seldom be used on slopes above 20%.

Rothwell (1971) has provided detailed guidelines for logging and road construction associated with timber harvesting practices in Alberta.

An important post-harvesting forestry operation is the disposal of logging slash and debris that constitute a potential fire hazard. The effects of different methods of slash disposal on infiltration is shown in Fig. 10 for a study conducted in western Montana. The broadcast burned area showed reduced infiltration capacities for approximately 2 years but recovered rapidly thereafter. Tractor roads used in skidding of logs were the worst affected in this respect. The scarified treatment, consisting of slash piling and soil scarification, showed intermediate results. The recovery of infiltration capacities of broadcast burned areas was faster than the other two treatments.

Impairment of infiltration capacities of the logged and slash disposed areas are mostly the direct consequence of mechanical compaction due to heavy machinery used in such operations. Reduced capacities can result in excessive runoff and increased erosion. The effect could be particularly damaging if low infiltration rates persist over long periods.

Vegetation, soil and topography are the prime factors influencing susceptibility of an area to accelerated erosion. However, watershed practices can be suitably designed to minimize erosion hazards. Thus, according to Dunford and Weitzman (1955) and others, the following general precautions would be helpful:-

- (a) Erosion from Roads. Plan the road network in advance of construction; learn to recognize and avoid trouble spots; keep the grade low; and provide adequate drainage. No road should be built in or adjacent to a stream channel. Earth movement should be kept to the minimum. Carefully look after the weak spots and immediately repair any damage noticed.
- (b) Erosion from Logging. The main emphasis should be on improving skidding and yarding practices: Do not yard logs along stream channels; provide adequate drainage; and avoid tractors on steep slopes and wet ground. Select logging equipment according to topographic conditions (e.g., using high-lead cable logging on steep terrain). Seed erosive areas to obtain quick protective cover.
- (c) Grazing like timber harvesting, often causes reduction of protective vegetation cover which can be kept at a desirable level by proper management. Such management for a particular vegetation type involves consideration of

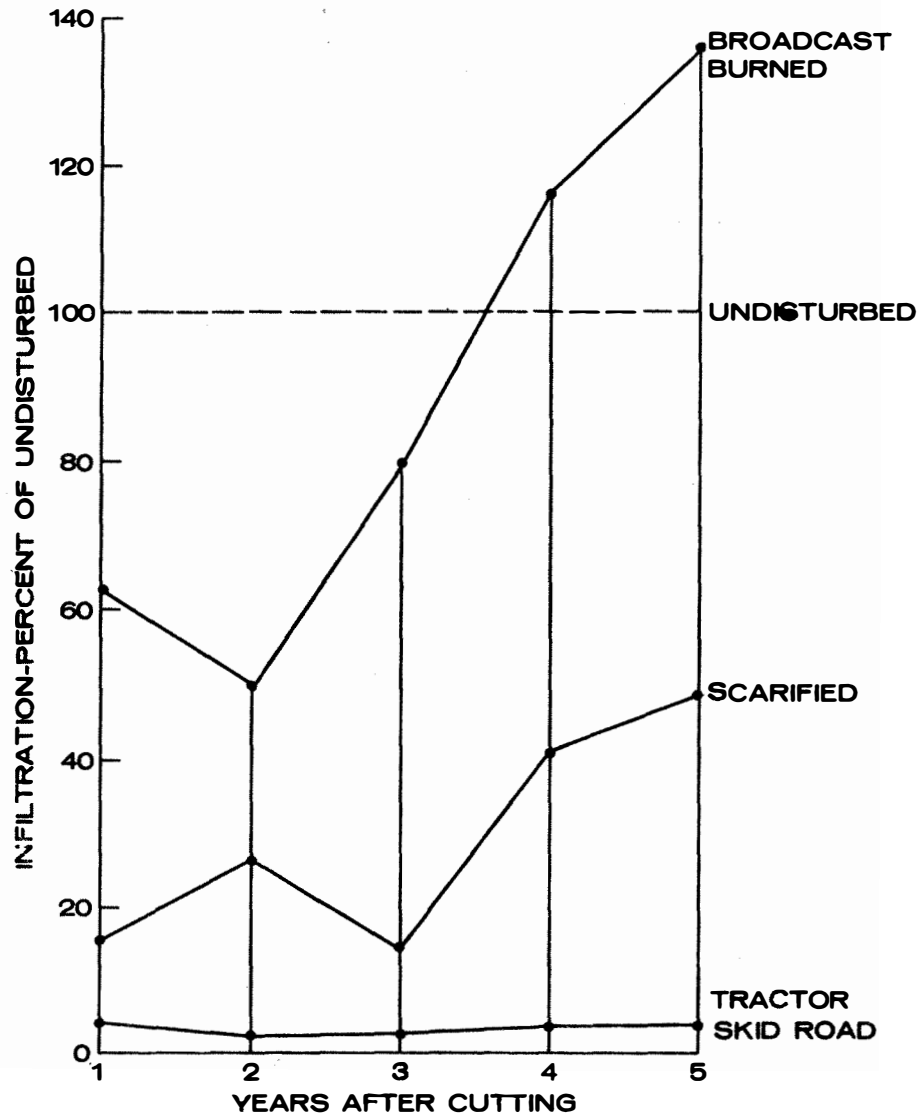


Fig. 10. Effect of three treatments on infiltration expressed as a percentage of the undisturbed (after Tackle 1962)

factors such as phenological stage, growing conditions, type of grazing animals, and the intensity and frequency of use. Range is a "cause-and-effect" relationship in which causative factors result in a particular range condition. Poor distribution, wrong type of animals, wrong season, and too many cattle, can all cause range deterioration, consequent soil erosion, and changes in water quality. Frequent inspections are therefore necessary for detecting soil and cover deterioration due to overgrazing. In general, good range management practices will keep erosion and sedimentation to a minimum.

Only a passing reference is possible here to hydrologic considerations involved in strip mining on forested watersheds. According to May (1965), some of the pertinent questions are: What is the disposition of precipitation on strip-mined areas? How much is absorbed in the bank, retained in the ponds, or runs into a stream channel, and when? Sediment contribution to streams and the chemical aspects of water quality (e.g., acid mine water) affected by such operations are important considerations. Revegetation of strip-mined areas for timely stabilization of spoil banks is an essential part of the restoration program (Peterson and Etter 1970).

Recreational use has also its impact on water quality. Table 1 presents a summary of the principal changes likely to occur in water quality as a result of recreational and the previously discussed watershed activities.

In conclusion it may be said that the quality of water is quite often at least as important as quantity; the two are inter-related. If water is of poor quality, extra quantities of good quality fresh water will be used for necessary dilution, or additional expense incurred in processing such water to bring it up to required quality standards.

REFERENCES

- Archer, R.J., A.M. La Sala, Jr., and J.C. Kemmerer. 1968. Chemical quality of streams in the Erie-Niagara Basin, New York. State of N.Y. Conserv. Dep. Water Resources Comm. Basin Planning Rep. ENB-4.
- Beattie, B. 1963. Municipal watersheds and recreation can be compatible. Water: development, utilization, conservation Western Resources Pap., Univ. of Colorado Press. p. 37-45.
- Behnke, J.J. 1969. Clogging in surface spreading operations for artificial ground-water recharge. Water Resources Res. 5(4): 870-876.
- Brown, G.W., and J.T. Krygier, 1967. Changing water temperatures in small mountain streams. J. Soil Water Conserv. 22: 242-244.

Table 1. Principal changes in water quality as a result of watershed activities (after U.S. Public Health Service 1961)

Changes in Quality of Water	Agriculture	Construction Activities	Timber Har- vesting & Mgt.	Mining	Grazing	Recreation
Bacterial contamination	X	X	X	X	X	X
Turbidity	X	X	X	X	X	X
Taste and Odor	X	X	X	X	X	X
Color	-	-	X	X	-	-
Mineral Solutes	X	X	-	X	-	-
Acidity	-	-	-	X	-	-
Toxic Chemicals	X	-	X	X	-	-
Oil Scum	-	X	X	-	-	X
Gasoline Scum	-	X	X	-	-	X
Objectionable Solids	-	X	X	-	-	X
Temperature	X	X	X	X	-	-
Erosion Sediments	X	X	X	-	X	-
Nutrients	X	-	-	-	-	-

- Bullard, W.E. 1963. Water quality problems originating on wild lands. Forest Watershed Manage. Symp., Oregon State Univ., Corvallis, Ore. p. 313-319.
- Colman, E.A. 1953. Vegetation and watershed management. The Ronald Press Co., New York. 412 p.
- Copeland, D.L. 1969. Relation of the coniferous forests of the Northern Rocky Mountains to water production and use. Proc. 1968 Symp. on Coniferous Forests of the Northern Rocky Mountains, Centre for Natural Resources, Missoula. Univ. of Montana Foundation. p. 223-244.
- Croft, A.R., and R.W. Bailey. 1964. Mountain water. U.S. Forest Serv., Intermountain Forest Rge. Exp. Sta. 64 p.
- Craddock, George W. 1967. Zena Creek logging study evaluation report. U.S. Forest Serv., Intermountain Forest Rge. Exp. Sta. 63 p.
- Dendy, F.E. 1968. Sedimentation in the nation's reservoirs. J. Soil and Water Conserv. 23 (4): 135-137.
- Dortignac, E.J. 1965. Forest water yield management opportunities. Proc. Int. Symp. on Forest Hydrol. Penn. State Univ. Pergamon Press. Oxford & New York. p. 579-592.
- Dunford, E.G., and S. Weitzman. 1955. Managing forests to control soil erosion. In Water, The Yearbook of Agriculture. U.S.D.A., Washington, D.C. p. 235-242.
- Eschner, A.R. and J. Larmoyeux. 1963. Logging and trout: four experimental forest practices and their effect on water quality. Progressive Fish-Culturist 25: 59-67.
- Freeman, O.L. 1967. Foreword. In Outdoors U.S.A. The Yearbook of Agriculture. U.S.D.A., Washington, D.C. p. v - vi.
- Gifford, G.F., and R.K. Tew. 1969. Evaluating rangeland water quality with small plot infiltrometers. J. Soil and Water Conserv. 24 (2): 65-67.
- Johnston, A., and S. Smoliak. 1968. Reclaiming brushland in southwestern Alberta. J. Range Manage. 21: 404-406.
- Jones, E.B., R. Lee, and J.C. Frey. 1967. Land management for city water. In Outdoors U.S.A. The Yearbook of Agriculture. U.S.D.A., Washington, D.C. p. 183-186.
- Lassen, L., H.W. Lull, and B. Frank. 1952. Some plant-soil-water relations in watershed management. U.S. Forest Serv. Circ. 910.

- May, R.F. 1965. Strip-mine reclamation research - Where are we? Mining Congr. J. April, 1965.
- Meehan, W.R., W.A. Farr, D.M. Bishop, and J.H. Patrik. 1969. Some effects of clearcutting on salmon habitat of two Alaska streams. U.S. Forest Serv., Pac. NW. Forest Rge. Exp. Sta. Res. Pap. PNW-82. 45 p.
- ORRRC (Outdoor Recreation Resources Review Committee). 1962. Outdoor recreation for America. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C.
- Peterson, E.B., and H.M. Etter. 1970. A background for disturbed land reclamation and research in the Rocky Mountain region of Alberta. Can. Forest. Serv., Edmonton, Alberta. Inform. Rep. A-X-34.
- Rothwell, R.L. 1971. Watershed management guidelines for logging and road construction. Can. Forest. Serv., Edmonton, Alberta. Inform. Rep. A-X-42.
- Shields, H.J. 1968. Riffle sifter for Alaska salmon gold. In Science for Better Living. The Yearbook of Agriculture. U.S.D.A., Washington, D.C. p. 204-212.
- Sewell, Derrick, W.R., and Blair T. Bower et al. 1968. Forecasting the demands for water. Policy and Planning Branch, Dep. Energy, Mines and Resources, Ottawa. 262 p.
- Southern Pulp and Paper Mills. 1968. Water - how southern pulp and paper mills manage this natural resource - its use, re-use and restoration. S. Pulpwood Conserv. Ass., Atlanta, Georgia.
- Steinbrenner, E.C. 1966. Logging on watersheds: what type, where, what disturbance? Practical Aspects of Watershed Management Symp. Soc. Amer. Foresters and Oregon State Univ., Corvallis, Ore. p. 109-115.
- Striffler, W.D. 1964. Sediment, streamflow, and land use relationships in northern Lower Michigan. U.S. Forest Serv., Lake States Forest Exp. Sta. Res. Pap. LS-16.
- Tackle, D. 1962. Infiltration in a western larch - Douglas fir stand following cutting and slash treatment. U.S. Forest Serv., Intermountain Forest Rge. Exp. Sta. Research Note.
- U.S. Department of the Interior. 1968. Water quality criteria. Federal Water Pollution Control Admin. Washington, D.C. 234 p.
- U.S. Public Health Serv. 1961. Watershed control for water quality management. U.S. Public Health Serv. Pollution Control Council. Pacific N.W. Area, Portland, Oregon. 36 p.

Wiebe, A.H., and Fuller, A.C. 1934. The oxygen consumption of large mouth black bass (Huro floridana) fingerlings. Trans. Am. Fish. Sec. 63: 208-214.

WATERSHED MANAGEMENT PRACTICES
IN RELATION TO OTHER FOREST USES

by

Edward C. Wyldman

Alberta Department of Lands and Forests

Edmonton, Alberta

INTRODUCTION

What is Watershed Management?

Water is a crop. It is a by-product of the climate and soil as are other crops such as timber, forage, minerals and recreation. I will not attempt to compare the value of water with that of other resources, but suffice to say that everyone agrees it is one of the most important commodities on earth. The watershed manager's main concern is to properly manage land for the production of water. A more specific definition of watershed management would be: the conservation or management of the soil mantle by controlling vegetative cover and the movement of water into the soil and streams while providing for integrated production of all other products of the land. Or, more simple stated: the management of land for water within the multiple-use concept.

Most land use activities affect one or all of the three characteristics of the water resource - quantity, the timing of streamflow, and quality. Depending upon watershed characteristics, the yield and regime of streamflow can be altered - for good or bad - by upstream manipulation of vegetation. Water quality can be changed by management of land use practices that affect the biological, physical or chemical properties of water.

WATERSHED MANAGEMENT GOALS

The goals of watershed management are to conserve watershed condition so as to optimize water yield, timing and quality. These can be achieved through programs of watershed protection, restoration, and improvement. Such programs must be closely allied with engineering planning for flood prevention, flood control, irrigation, drainage, and power. Comprehensive basin management plans must include plans for management of the land which supplies the water to be controlled.

The effectiveness of watershed management programs is measured in the stream - by its flow and quality characteristics. These reflect the

condition of the watershed (soil, vegetation, stream channels) and the status of the inter-dependent resources on that watershed. In other words, a clear stream with stable banks usually indicates a watershed upon which land use conflicts either do not exist or are being resolved.

Perhaps the most important specific objective of watershed management is to retain as much water as possible on the area in which it falls, by inducing maximum storage in the soil reservoir. The key to achieving this is, of course, a stable soil mantle protected by an organic "sponge" which will allow water to infiltrate and percolate through the soil rather than move to streams as overland flow.

In order to compare objectives of various forest resource uses within the multiple use concept Table I lists some arbitrary single use goals as related to the watershed management objectives for each use. Although the objectives are different, it is obvious that all are highly inter-dependent. Conflicting aims will be apparent but in general, the broad resource goals are either complementary or compatible.

The multi-disciplinary aspects of watershed management are quite clear. Barring the rare occasion where water production is the prime objective, such as a key municipal watershed, the practice of watershed management generally takes place in areas of use conflict and within the multiple use concept. Land uses such as coal mining or oil development may conflict seriously with recreation values in a scenic area. On the other hand, in another area having different characteristics and use capabilities, these same activities might be compatible with other resource needs. Or, forest harvesting in narrow, properly oriented strips could be complementary with the goals of water yield improvement, fire protection, silviculture, and wildlife.

What we have been saying is that the watershed manager must be a resource manager. He must try to manage land for water according to the needs and use-priorities stated or assumed by the users of water from that piece of land. At the same time, other products must usually be produced in desired amounts with a minimum of conflict. The goals of watershed management are not necessarily synonymous with those of single or multiple use, but they are generally inseparable and may be compatible.

PROBLEMS - LAND USE CONFLICTS

The major watershed management problems in wildland areas of Alberta are (1) maintaining watersheds in protective condition, and (2) restoring protective conditions to damaged watersheds. These relate directly to water quality as affected primarily by sedimentation.

Maintenance of watershed condition involves the prevention of damage from fire, insects, disease, road and trail erosion, stream-bank disturbance, floods, and any soil disturbance caused by industrial activity. Prevention of erosion and sedimentation is the main job.

Table 1. Multiple-use objectives

Forest land use	Watershed management objective
1. <u>Timber Management</u>	
Sustained yield of wood products - minimize damage to other resources	- protection - optimize yield, timing, and quality within silvicultural constraints.
2. <u>Range Management</u>	
Sustained use of forage (livestock and game)	- maintain maximum cover - limit compaction, erosion, channel damage
3. <u>Fish and Wildlife</u>	
Provide habitat for optimum game/fish populations	- maintain maximum cover - limit compaction, erosion, channel damage
4. <u>Recreation</u>	
Recreational facilities for present/future needs	- limit fire, soil compaction, pollution
5. <u>Mineral Resources</u>	
Exploitation of mineral uses (conservation) - controlling damage	- limit erosion, sedimentation, resource damage, pollution
6. <u>Energy Conservation</u>	
Flood control; irrigation; power; drainage; pollution abatement	- limit cover depletion - restoration of disturbed area - regime regulation - protect/improve quality
7. <u>Water Production</u>	
Produce water in proper quantity and quality when needed.	- limit erosion - optimize timber production within hydrological constraints

Restoration programs are aimed at re-establishing proper drainage and mantle stability by means of re-vegetation and mechanical procedures. Table 1 describes the watershed-management objectives that must be related to specific forest land uses.

Land Use Problems and Conflicts

It is generally accepted that roads and trails constitute the major erosion and sedimentation problems in forested areas. Every land use requires some degree of access, and the faults of poor road location, erosion of bared surfaces, and inadequate drainage are common to all.

Timber harvesting, whether for sawlogs, posts and poles, or pulpwood, has great potential for watershed damage due to required roads, trails and landings. Streamcourses are the "soft points" or most sensitive parts of a watershed to the effect of forest roads. Stream stability, water quality, and fish habitat are seriously affected by roads crowding streams, by logging in small watercourses, and by inadequate buffer or filter strips. The amount of soil disturbance by logging varies considerably with conditions and type of operation, but averages as high as 10 to 12% have been reported for steep areas in the Western United States. In some areas timber management planners allow for a total production loss of 5% due to permanent disturbance from roads and landings (Binkley 1963).

Grazing by livestock and wild ungulates can, under poor management, conflict seriously with other land uses, such as recreation, and result in severe watershed damage. Proper management can ensure compatible use of the forage resource with conflicts minimized to acceptable levels.

Industrial activities such as geophysical exploration, drilling operations, pipelines, coal mining, and the associated road systems are greatly modifying the forest environment. Public concern regarding the effects of exploitation has grown tremendously and seems to be producing a consensus that industrial development of forested mountain areas especially cannot be accomplished without causing irreparable damage to watershed and aesthetic values. Undoubtedly there are also those in the resource management professions who harbor the same fears.

It has been shown, however, that much of the damage normally associated with land use practices can be either avoided or repaired. We can re-vegetate areas of bared soil; we can properly locate and drain our roads and trails. Our biggest problem is to estimate the capacity of a wildland area to absorb the total impact of a combination of uses - then to manage the uses within the capacity limits. We can only accomplish this through careful management planning which combines clearly stated objectives, adequate knowledge and proper allocation of uses.

Recreation is now a prime use in many forested areas - and the demands are just beginning. In the near future we will need more and more

access roads, ski development, recreational lakes, institutional camps, picnic areas, wilderness areas, and hunting and fishing. Yet, we realize that our productive capacity for outdoor recreation is limited. We also know that the aesthetic resource is extremely sensitive to damage from other land use activities.

Although in itself recreation conflicts very little with other forest uses, it can cause direct damage to watershed conditions by:

1. Fire, caused by forest users is of prime concern, and a fire plan must obviously be geared to recreational use. The use of more area by more people does not, however, necessarily mean more acres burned.
2. Trampling, by people and vehicles can, through compaction, greatly reduce the infiltration capacity of the soil. The areas involved are usually relatively small.
3. Drainage alteration, by vehicular use of seismic lines is a serious problem in some areas where lines have been re-grassed and cross-drained.
4. Pollution, to streams and lakes by garbage, trailer effluent, and engine oil and gas is a major problem.

Recreation can be in conflict with itself when damage is caused to aesthetic values by mis-use of campgrounds, overcrowding, heavy traffic, and dusty roads.

Water management for energy conservation, flood control, irrigation or drainage involves the handling, storage, treatment, allocation, and distribution of water. The structural approach to water control results in dams, diversions, ditches, and other engineering features which themselves can cause watershed problems and conflicts with other resource uses.

Catastrophic events such as wildfire, floods and wind damage, along with geologic damage (slumping) are obvious management problems.

WATERSHED MANAGEMENT PRACTICES

We have discussed major management problems and land use conflicts and previous papers have described in some detail methods for controlling water yield, streamflow regime and water quality. I would like to briefly mention some of the common practices and procedures which will probably play a part in our future watershed management programs in Alberta.

I. IMPROVEMENT

1. Increase yields by (a) clearcutting, (b) cover conversion (brush to grass).

2. Decrease peak flows by delaying snow melt through (a) cutting patterns, (b) drifting contrivances (fences, terrain alteration, vegetative barriers).
3. Increase low flows by (a) removing phreatophyte vegetation, (b) snowpack management to retard melting of snow and prolong its contribution to streamflow later into the summer.
4. Water quality for fish production - e.g., removal of riparian vegetation to increase water temperature.

II. PROTECTION

1. Conventional or traditional - fire, disease, insects.
2. Protection forests or zones - non-use or limited use of areas sensitive to watershed damage (includes buffer strips along streams).
3. Provision for maximum ground cover to promote infiltration and minimize overland flow - reduce compaction.
4. Prevention of damage to aesthetics, water quality, stream condition, range, regeneration, etc. by land use practices - especially roads; mines.

III. RESTORATION OR REHABILITATION

1. Restoration of eroded areas by (a) reseeding, (b) mulching, (c) diversions, (d) contour-trenching, (e) soil-pitting, (f) water-spreading, etc.
2. Correction of road-caused erosion and sedimentation by (a) drainage devices (culverts, cross-drains, dips, out-sloping, riprapping, filter strips or barriers, slash mulch or seismic lines).
3. Repair of stream channel damage by (a) channel repairs (dikes, removal of debris jams, diversions), (b) bank revegetation, (c) riprapping, (d) fencing of concentration areas, (e) blocking off stream crossings.

NEEDS IN WATERSHED MANAGEMENT

1. Delimit watershed areas that can be managed for yield and timing improvement.
2. Delimit areas where water quality protection is critical.

3. Define areas where restoration programs should be concentrated.
4. Learn how to apply existing knowledge and known practices.
5. Work closer with research (quality, yield problems, mantle stability, tolerance limits, etc.).
6. Learn more about the value of water; predict future needs and prepare to meet them.
7. Orient all land management toward the production of multiple benefits.
8. Prepare multiple-use management plans.
9. Distinguish between watershed management and water management; coordinate our efforts for total LAND + WATER approach.

In conclusion, I would like to stress that few land uses or sources of damage appear disastrous when viewed in isolation. It is the total effect - the bulking, or cumulative aspects of a number of combined sources - which should be considered in the light of the tolerance limits of the stream, watershed or region in question.

We are blessed in Alberta with some of the most valuable watersheds on earth. They are valuable now, as is the water they produce. They will become even more precious within the next few short years. We are challenged with the huge task of managing these land areas not only for the present but for the future. This job will not be accomplished by foresters, agronomists, hydrologists, or engineers alone - but by total land or resource managers. I feel that we must learn how to work as members of a team - whatever our special interest may be - towards the common goal of integrated resource management.

REFERENCES

- Binkley, Virgil. 1963. Factors to consider when selecting skyline yarding systems for site protection. Proc. Forest Watershed Management Symp., Oregon State Univ, p. 259-269.