CANADA

QUOTE FILE

DEPARTMENT OF AGRICULTURE

PRAIRIE FARM REHABILITATION

PRAIRIE PROVINCES WATER BOARD

614 Motherwell Bldg.,
REGINA, 1 Oct. 1962.

We have received ten copies of Underhill's report entitled "The Effect of a Change in Vegetation on the Runoff Characteristics of Alberta Streams." I am distributing this report as follows:

G.L. MacKenzie......	1 copy
J.A. Griffiths......	2 copies
B.W. Boyson..........	2 "
R.H. Clark...........	1 copy
P.N. Strilaeff......	1 "
R.D. May............	1 "
Retained by Secretariat.......	2 copies

If further copies are needed I would suggest that a request be sent directly to the Alberta Member of the Water Board.

E.F. DURRANT
Engineering Secretary
Prairie Provinces Water Board

Att.

DISTRIBUTION

G.L. MacKenzie
J.A. Griffiths
B.W. Boyson
R.H. Clark
P.N. Strilaeff
R.D. May

For info

(F.L. Cr[illegible]dley, Director,
(Alberta Department of Water Resources.

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This report was prepared by the Water Resources Branch, Department of Agriculture, Province of Alberta, at the request of the Prairie Provinces Water Board.

Prepared by -

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District Engineer,
Calgary, Alberta.

INTRODUCTION

Scientists have established that the climate of Western Canada is appreciably warmer today than it was fifty years ago. The shrinkage of our glaciers bear silent witness to this warming trend and to the fact that we have lost a great deal of "free" water which was stored in the glaciers since the last ice age. If this warming trend continues will it cause an increase in the rate of melting and evaporation of our glaciers? Will this increase in evaporation, if it continues, cause some of our lakes to dry up and disappear? Will the warming trend, if it should continue, detrimentally affect the flow in our streams? If the climate continues to grow warmer will this result in a need for irrigation in areas now receiving adequate supplies of water?

These are difficult problems of a hydrological nature for which hydrologists have been trying to find solutions.

These problems, along with the need for large supplies of water for agriculture, industry and domestic purposes, have given rise to the question of the adequacy of our present supplies to the means of preserving these supplies, and the possibilities of increasing these supplies.

Our present study deals with one of these questions "can we increase the flow of water from a forested watershed without upsetting nature's delicate balance".

On the eastern slope of the Rocky Mountains rises the Saskatchewan River system. The river originates at elevations of more than 10,000 feet above sea level and flows in an easterly direction through three prairie provinces into Hudson Bay.

The most prolific and dependable source of water for this river system is the eastern slopes of the Rocky Mountains and the foothill region above the 3,000 foot level. In this reach of the river the water tumbles in relatively unstable channels until it quietens to flow serenely through the prairie lands. Large amounts of water from the streams is diverted for use on the fertile prairie lands on which hangs the continual threat of drought.

It has been said that "Water is Life" and nowhere is this more apparent than in the Saskatchewan River System. The greater percentage of the people who live on the prairies live within reach of the waters of this great system and depend on it for their existence.

The need for a study of this problem becomes readily apparent when one considers the expansion in Alberta's industrial complex and the corresponding increase in our population and the demands this increase will make on our supplies of good clean water. Any means of controlling or increasing this supply must be investigated to provide for our expansion. This need for information on what changes can be made in the total supply of water by forest management has resulted in this summary of existing information being undertaken.

The report is divided into five main parts:

(a) A short introduction into the factors affecting runoff.

(b) A definition of terms.

(c) A summary of research projects and their results.

(d) A general look into the changes in Alberta and their possible results.

(e) A bibliography of existing literature.

The lack of adequate streamflow and meteorological data and information as to the magnitude of the changes which have taken place with regard to vegetation leads only to generalized conclusions and brings forth the need for research on this subject.

The Eastern Rockies Forest Conservation Board requested that reasearch be undertaken into the problem in 1960. An Advisory Committee was set up to investigate and report on a Watershed research program for the Eastern Slopes of the Rocky Mountains.

Plans have been laid and some research programs have been started. The collection of basic data is underway. Two watersheds have been chosen for intensified research programs. One is on Marmot Creek in the Kananaskis drainage basin and the other on Dry Coulee further south.

This group, once organization is completed, will be engaged in, among other things, research into the effect of a change in vegetation on the runoff from the Eastern Slopes of the Rocky Mountains.

In Alberta we have two basically different types of runoff. In the early spring the melting snow fills the streams and drainage courses of the prairie and foothill areas.

The precipitation which has been stored as snow in the mountains, during the winter, melts in the late spring and early summer causing peak flows on the streams and drainage courses of the area. These streams are usually perennial in nature and provide the main source of our water supplies.


TOTAL RUNOFF SASKATCHEWAN RIVER BASIN IN ALBERTA
TOTAL AREA SASKATCHEWAN RIVER BASIN IN ALBERTA 72,900 sq miles
RUNOFF 2,566,000 ac ft
15.7% OF TOTAL BASIN RUNOFF
IN ALBERTA
AREA 19,200 sq miles
26.4% OF TOTAL BASIN AREA
IN ALBERTA
FOREST
PARKLAND
RUNOFF 1,041,000 ac ft
6.4% OF TOTAL BASIN RUNOFF
IN ALBERTA
OF TOTAL BASIN RUNOFF
IN ALBERTA
AREA 18,600 sq miles
25.5% OF TOTAL BASIN AREA
IN ALBERTA
SUB PRAIRIE
AREA 22,400 sq miles
30.7% OF TOTAL BASIN AREA
IN ALBERTA
PRAIRIE
RUNOFF 287,000 ac ft
1.1% OF TOTAL BASIN RUNOFF
IN ALBERTA
AREA 12,700 sq miles
17.4% OF TOTAL BASIN AREA
IN ALBERTA
ALBERTA
-WATER RESOURCES-
MAP.
ALBERTA SECTION
SASKATCHEWAN RIVER BASIN

Fig. 1

It is in the mountain and foothill area that our attention must be mainly directed if we are to determine the effect that a change in vegetation has had, in the past, on the runoff in our streams and it is also the area to which we must direct our research to find out how we can best control these water resources for the future.

The forested areas produce about 80% of the water flowing in Alberta streams. In the Saskatchewan River basin the forested area produces 77% of the water available at the Alberta-Saskatchewan boundary. Of the remainder, 15% of the flow rises in the Parkland and the remaining 8% comes from the prairie region (Fig. 1).

Since 77% of the runoff occurs in the forested area, it is in these regions we must look for the major change, if any, due to a change in vegetation.

This report deals mainly with forested areas and the research which has been done on this type of area. The actual areas in which the research was undertaken are not all comparable to the forested area of Alberta and so, results cannot be directly transferred to this area. The results do, however, give an indication of what we might expect and in the cases where changes have already been made what effect they may have had on the total runoff.

This report will show that sufficient information is already available to give us good reason to believe that changes in vegetation that have already occurred in this province have definitely changed the amount and distribution of our total streamflow and that other changes could be made in line with good forest management to provide us with increased flows from the forested areas.

The following requirements for a watershed program were published by the American Forestry Association:

1. A nation wide inventory of areas that are sources of water, with special reference to the amounts, rates, qualities of water flow and the types, extents, and values of water use.

2. Classification of watershed forests in terms of their requirements and values for the highest water production, erosion prevention, and flood and sediment damage abatement.

3. Application of measures to protect and manage forests designed to maximize the contributions, for a given set of conditions with regard to the requirements for timber, recreation, and other forest products and services.

4. Intensified and more wide spread application of measures to improve the soil and waterflow in forested and damaged watersheds.

We make no claim to originality in this study because many other countries have embarked on similar studies in their own watersheds. If this study focuses attention on some of the problems involved and draws together the many loose threads of human knowledge in this area, then it will have achieved its purpose.

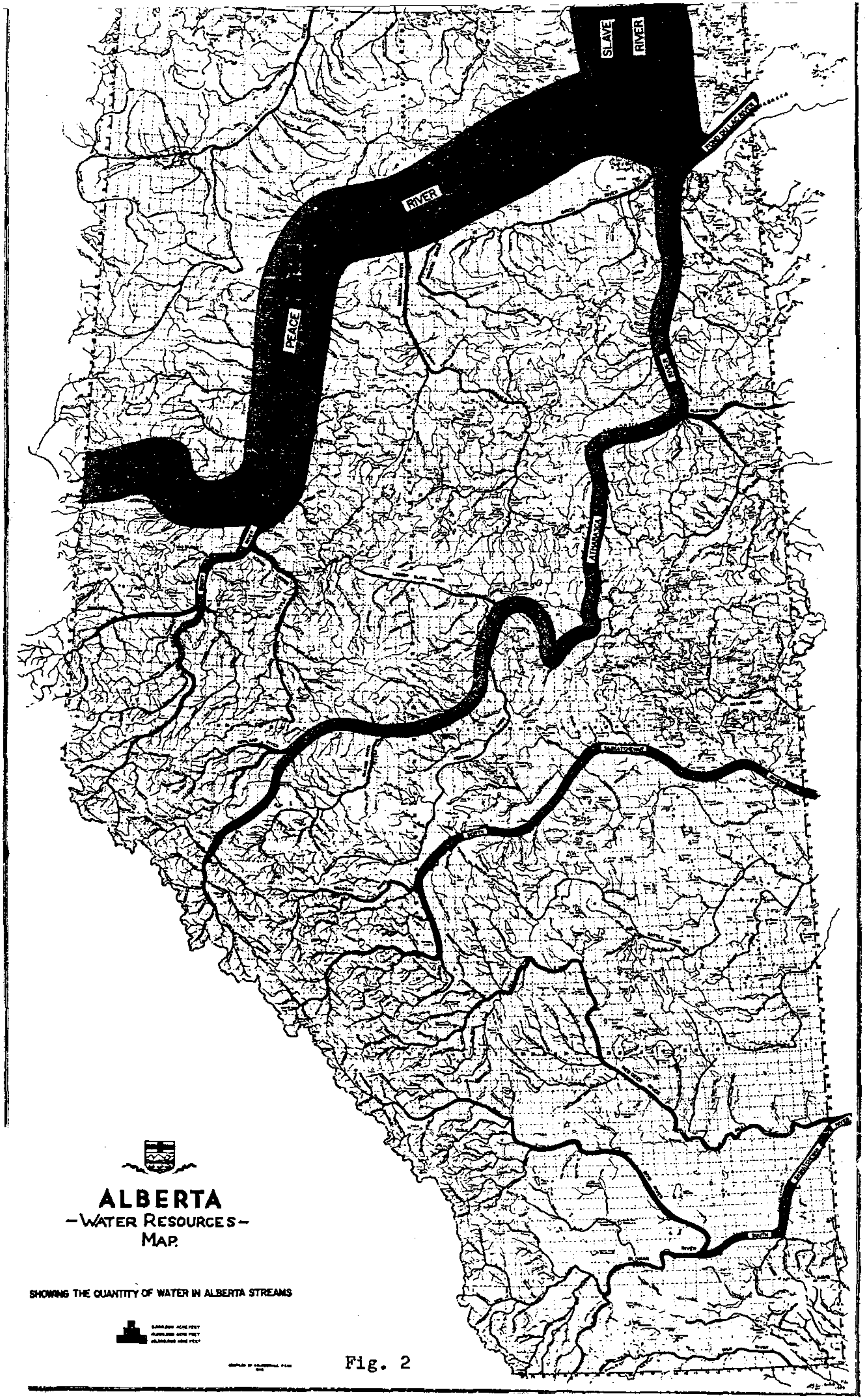

SLAVE
RIVER
RIVER
PEACE
ALBERTA
-WATER RESOURCES-
MAP.
SHOWING THE QUANTITY OF WATER IN ALBERTA STREAMS

Fig. 2

PRECIPITATION-RUNOFF RELATIONSHIPS

The effect of a change in vegetation on the runoff characteristics of an area is directly dependent on the precipitation-runoff relationships for the area. To understand these precipitation-runoff characteristics one must have a general understanding of the natural phenomena related to precipitation and runoff.

This section has been written to give a general insight into these natural phenomena.

There are four main factors which determine the size and shape of the stream flow hydrograph. Each has its own separate effect on the stream flow of an area but each, also, has an interrelationship with the other in the general effect on the total runoff.

The first and probably the most important is the climate of the drainage basin. The water which eventually reaches the stream as surface and subsurface runoff, as well as that required for plant growth and that lost in evaporation, must first fall, either in the form of rain or snow. The temperature, amount of sunshine, velocity and direction of the wind, relative humidity as well as the precipitation are all factors in the control of plant growth, rate of snow melt, evaporation by plant and ground surfaces and, therefore, the rates and amount of stream flow. The type and growth of all vegetation is dependent directly on the climate of the area.

The second major factor affecting runoff is the topography of the drainage basin. The size and shape of the watershed are permanent characteristics. Their main influence is in the time of concentration of the runoff from the area. The time of concentration is also affec-

ted by the size and number of drainage courses in the area. Steep slopes present limited possibilities for surface storage and the runoff from these areas is generally rapid and of a flashy nature. Gentler slopes provide greater opportunities for detention or surface storage and the runoff from these areas is generally slower and of a less flashy nature. Large watersheds are of a very complex nature and the determination of the effect of size and shape becomes extremely difficult. However, these topographic features cannot be modified and their effect on stream flow remains constant.

The third major factor affecting streamflow is the type and condition of the soil layer. The number, size and shape of pore spaces controls the rate of entry or infiltration of water into the soil, the rate of travel or percolation through the soil layer and the amount of water which may be stored in the soil reservoir. Surface runoff from an area will not generally start, unless the rate of snow melt or precipitation exceeds the infiltration rate, until the soil reservoir is completely filled, therefore, the condition and type of soil has a controlling effect on the amount of water which will be available for plant growth and both surface and ground water runoff.

The final factor affecting runoff is the type and density of the vegetal covering. A dense stand of trees or bushes will intercept a considerable amount of precipitation, thus preventing it from reaching the soil surface. The intercepted precipitation is generally lost as evaporation. Grasses and less dense vegetal stands intercept less water and hence more moisture reaches the soil and less is lost by evaporation on the plant foliage. The shade provided by the vegetal cover is an important factor in determining the amount of evaporation from the soil surface. The debris or plant litter has a definite effect on the evaporation from the soil surface and the rate of runoff from an area. Plant roots have an important effect on the infiltration and percolation rates as do the dead vegetal matter in the soil profile.

Evapotranspiration varies with different plants from a minimum in certain types of grass to a maximum in certain trees and plants. The latter plants are sometimes called phreatophytes or water loving plants and are generally found along streams or around bodies of water.

Therefore, the vegetal cover can have a marked effect on the total amount of streamflow from an area and also, on the rate at which this runoff occurs.

Scientists, today, consider that only two of these four factors are changeable so, if any change in the runoff rates or pattern is to occur it must be from the alteration of (a) the soil type or condition or from (b) a change in the type and density of vegetal covering.

Research workers are endeavouring to control the amount of precipitation by cloud seeding and other methods. Those actively engaged in the projects are not prepared to say they can alter the total amount of precipitation falling in the area. No doubt, this work will continue and at some time in the future man may be able to exert control on precipitation but for the present this is not considered feasible. The best hope for controlling streamflow at the present time appears to be by altering the soil condition or type or changing the type or density of the vegetal covering.

Soil Types and Characteristics

The physical characteristics of soil determine its infiltration rate, its percolation rate and its storage capacity. Each of these factors has an effect on the total streamflow from the area by determining the proportion of the water which will run off as surface flow, subsurface flow and base flow.

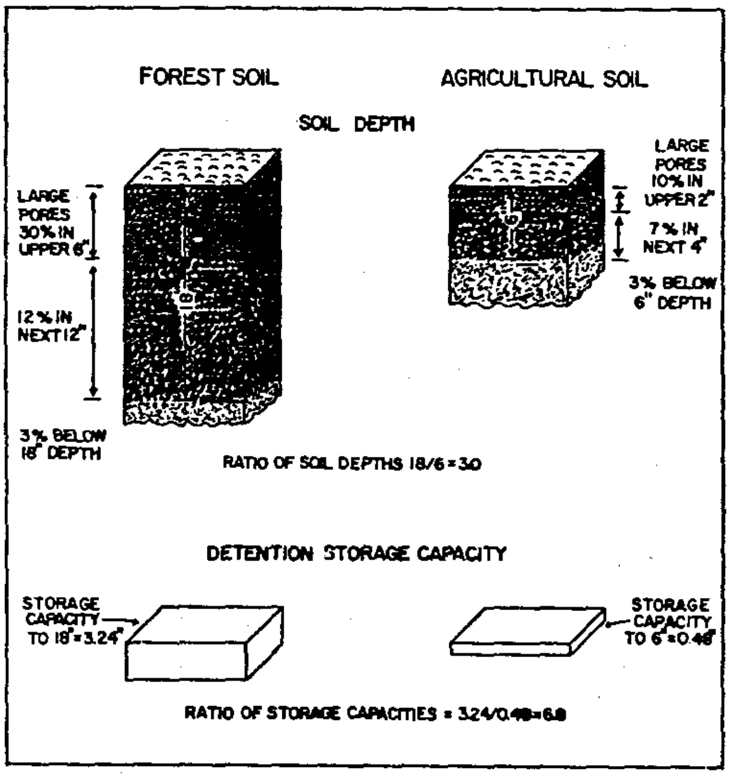
The retention of water by a soil is related to the size and arrangement of the soil spaces or soil pores. Fine textured soils have a greater porosity than coarse textured soils and hence clays can generally hold more water than sandy soils.

Fig. 2 shows the effect of different soil types on the moisture holding capacity of the soil. Above the field capacity of the soil is the detention storage. Between the full capacity and the wilting point is the capillary storage and below the permanent wilting point is the hydroscopic or non-available storage.

About 18% of a clay loam moisture is extractable for plant growth compared to only 8% in the fine sandy loam. Very little moisture is removed from the fine sandy loam after the tension reaches 4 atmospheres whereas considerable is extracted from the clay loam up to about 12 atmospheres of tension. The tension is created by the plant in its attempt to remove the water from the soil particle surfaces.

The amount of water a soil can store in its profile varies as the depth hence, soil depth is an important hydrologic characteristic.

The storage capacity of a soil is also affected by organic material in the soils. This organic matter separates the soil particles creating additional large pores which allow the moisture to move more readily through it as well as creating more storage space. Organic matter



COMPARATIVE POROSITIES, DEPTHS, AND WATER-HOLDING CAPACITIES OF A FOREST AND AN AGRICULTURAL SOIL

Fig. 3

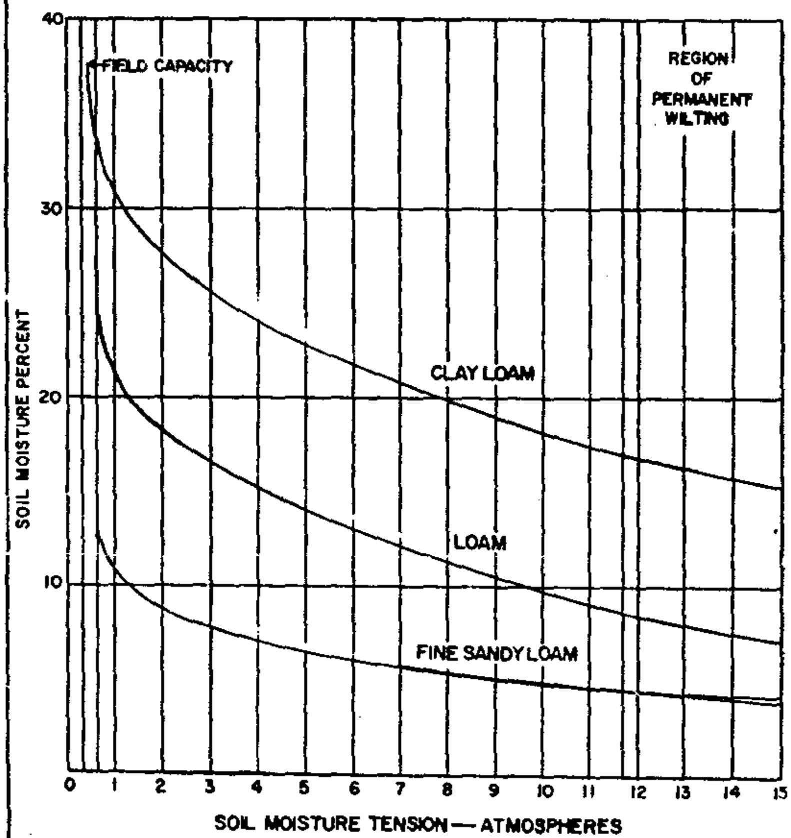


Fig. 4

U.S.D.A.

also can bind the soil material together to create pore spaces. A comparison of a forest soil and an agricultural soil will indicate the effect of this organic Material. (Fig. 1).

The forest soil has a non-capillary pore space in the upper six inches equal to 30% of the soil volume, in the next 12 inches the pore space drops to 12% of the volume and below 18 inches it equals 3% of the volume, whereas, in the agricultural soil the non-capillary space was found to be 10% in the upper two inches, 7% in the next four inches and 3% below the 6 inch depth. The effect of organic matter on the non-capillary porosity extended to a depth 3 times that of an agricultural soil and the forest soil could retain 6.8 times as much water as similar agricultural soil.

The infiltration capacity of a soil is determined by the number and size of the non-capillary pore spaces at the soil surface. Any activity or change which affects these characteristics will influence the infiltration capacity. The pore spaces can be reduced by compacting the soils or by plugging with other soil or material.

Thus overgrazing greatly reduces the infiltration capacity of a soil by compacting and sealing the pore spaces. Fires reduce the infiltration capacity by plugging the surface layer.

Rain on bare soil will break down the soil structures and plug the surface so that less infiltration can take place.

The type of frost in the ground profile can affect the soil's infiltration capacity. There are four types of frost which commonly occur in soils.

1. Concrete frost. This type of frost is composed of many small ice lenses, has a very dense structure and is very impervious. It is usually found in bare or cultivated lands and generally is associated with freezing to a great depth.

2. Honeycomb frost. This has a loose porous structure and is generally associated with shallow freezing in the early winter. It is generally found in highly organic soils under meadows or pastures.

3. Stalactite frost. This is a frost type composed of many small icicles that connect heaved surfaces to the soil. This is found in meadows and pastures and generally later refreezing into honeycomb.

4. Granular frost. This frost has a loose porous arrangement of granular crystals scattered through the soil which usually occurs with shallow freezing of highly organic soils. It is generally found mixed with honeycomb structure in forested areas.

The disturbing of forest litter generally increases concrete frost.

The persistence of frost during rain on snow melt is an extremely important consideration in determining runoff from an area. A change in land use or by a change in vegetal covering can result in marked change in the soil freezing. This, in turn, can change the infiltration, and percolation rates resulting in a change in the streamflow of the area.

Type and Density of Vegetal Covering

Precipitation falling on a forested area is first intercepted partially by the plant foliage. Part of the precipitation flows down the plant stems, the remainder is returned to the atmosphere as evaporation. The type and density of this foliage governs the amount of precipitation which is intercepted, whether it falls as rain or snow. A very dense, well matured stand of trees will intercept more moisture than a light open stand of bush or trees. Grass will intercept even less moisture.

A heavily forested area will intercept greater amounts of precipitation than a sparsely treed or open cultivitated or pasture area. Thus the heavily forested area will lose more moisture as evaporation. The result will be less moisture evapotranspiration and runoff.

The heavy dense type of vegetal cover prevents the sunshine from reaching the ground surface and reduces evaporation. It also reduces the wind velocities in the area and this also reduces evaporation from the soil surface. In an open area both tho sun and the wind are able to exert their maximum effect on the soil surface evaporation.

Different types of vegetation require different amounts of water for evapotranspiration. By altering the type of vegetation it is possible to change the water requirements of the area and thus change the amount of water available for streamflow.

Similarly a change in the density of the vegetation results in a change in the evapotranspiration requirements. This results in a change in the water available for runoff and in the evaporation from both the plant foliage and soil surface.

In forested areas, where snow is the main form of precipitation, significant changes in total runoff can be made by changing the vegetal cover both with respect to the type and density. The creation of small openings in the forest cover to allow more snow to reach the ground surface instead of being intercepted by foliage seems to be one of the most successful methods of increasing streamflow. A change in the vegetative type has also resulted in a change of streamflow.

The root structure of the plants is another factor in the study of vegetal covers effect on runoff.

A deep root can draw water from all the soil pores through which it passes, a shallow root can only draw water from that shallow area, therefore, if a large deep rooted plant is removed and replaced by a small shallow rooted plant the depth from which the plant can draw moisture is reduced and in the future it will require less water to fill the soil reservoir and a change in streamflow should result. Of course many other factors enter into the amount of change in runoff that will occur, i.e., the foliage of each new plant will alter the interception and soil evaporation, the amount of litter on the soil floor will alter the soil storage and evaporation, the amount of humus in the soil will affect the infiltration and percolation, the type of ground cover will influence the type and depth of frost. The effect of all these items on the water use would control the water available for streamflow.

On prairie lands the change in vegetation would have less effect on the runoff of the area since most of the runoff from these areas occurs during the early spring and is from melting snow. At this time the ground surface is generally frozen and the type of vegetation would have little effect on the amount retained in the soil profile.

In the heavy brush and bush areas of the lower foothill country the effect of a change could be more marked. Brush tends to retain snow melt and the frost penetration of these areas is generally not as great due to the litter accumulated in these areas.

The use of land for heavy grazing can materially affect the area's ability to store water in the soil profile. Compaction of the soil due to trampling, removal of ground litter, removal of the shrubs and the low bushes by grazing all have an effect on the potential streamflow from the area. Heavy grazing can reduce the amount of water stored in the soil for plant use.

If this grazing is sufficiently heavy the reduction could be sufficient to reduce plant growth, which in turn will reduce plant cover, which in turn will reduce the interception of precipitation. This increase in precipitation reaching the soil, along with the reduced soil cover and reduced infiltration could start erosion which in time would ruin the area. The importance of careful management of grazing, especially in the frosted areas is receiving considerable attention all over the United States and Canada.

Another consideration is the effect of forest fires on the streamflow of an area. There is little doubt that the major effect is the increased rate of runoff which in turn causes a tremendous acceleration in the erosion of the burned area.

A fire leaves the area open to the erosive effects of rainfall which would tend, along with the effects of the fire, to plug the soil surface and make it more or less impervious. Thus the infiltration rate would be reduced but at the same time the area is now exposed to increased evaporation. The interception losses are reduced to almost nil and for the first couple of years the transporation almost ceases. Most burned areas become covered with vegetation quite rapidly but it is many years before the conditions will return to those existing before the fire.

A forest fire should increase the total streamflow as well as the peak flows for a period of some years after the fire.

The burning of stubble on grain fields tends to reduce infiltration since it tends to plug the pore spaces in the surface layer and the fire deprives the soil of humus which would enlarge the pore spaces and provide better infiltration. Thus, the burning of stubble in dry areas can be dangerous and as well would reduce the amount of moisture which would enter the soil.

Along our streams, and in all places where the water table is high a type of plant generally known as phreatophyte, grows. These water-loving plants are noted for their luxuriant and rapid growth. They consume large amounts of water and, other than preventing erosion, they are of little value along the stream channel. The replacement of these plants by other types of vegetation will save water while still protecting the banks against erosion. It is estimated that in the 17 Western States in the United States 15 million acres are covered by phreatophytes and they use 20 to 25 million acre feet of water per year. In this area these heavy water using plants are willows, cottonwoods and various types of marsh grass.

Thus, a change in vegetation of an area may result in a change in total water yield for the following reasons:

(1) Removal of vegetation having a heavy foliage and replacing it with a less dense type of foliage would decrease the interception losses and allow more water to reach the soil so that a greater amount would be available for streamflow.

At the same time, however, the less dense vegetation will allow more sunshine to reach the ground and greater wind velocities in the area and thus the evaporation from the ground surface should increase.

(2) The thinning out of dense heavy foliage or removal of the understory would have much the same effect.

(3) Removal of a deep heavily rooted plant and replacing it with a shallow rooted plant would decrease the amount of the soil storage reservoir in use. Therefore, it would require less water to fill it and more water would be available for runoff.

(4) Removal of litter from the forest ground surface will decrease the detention storage reservoir. This will increase the peak and surface flows. At the same time the removal of the litter may allow greater evaporation from the soil surface which would decrease the total amount of water available for runoff. The removal of litter may result in the plugging of the surface layer, which would cause a decrease in infiltration and an increase in water available for streamflow. Another result of the removal of the litter may be erosion.

(5) The frost conditions and types may be changed by the removal of the litter or a change in vegetative cover resulting in a change in runoff conditions.

(6) Removal of high water using plants from along stream or canal channels will increase streamflow.

In addition to vegetal changes, over grazing may change the streamflow by compacting the soil and reducing the size of the soil reservoir, removal of the understory and the ground litter. This would tend to increase the peak flows, cause erosion and increase the total amount of runoff.

No mention has been made of the use of artificial means to control runoff. Dams, dykes, ditches, etc., have all been used to control the flow from areas and are a necessary part of good land management. These things do not change the total runoff but rather control it for better use.

The control of the soil and its condition, and the type and density of vegetal covering is part of good land management. In the forested areas where most of the runoff occurs good forest management is extremely important especially in view of the impending expansion of water use throughout the country.

DEFINITION OF TERMS

Base Flow is the minimum flow maintained at a point on a stream throughout the year.

Capillary Porosity is the volume of small pores within the soil that hold water against the force of gravity.

Capillary Water is the water retained in the fine pores of the soil surface by surface tension that moves as a result of capillary forces.

Concrete Frost is a type of frost composed of many small ice lenses, has a very dense structure and is very impervious. It is usually found in bare or cultivated lands and generally is associated to great depths.

Consumptive Use is the water used by plants in transpiration and growth, plus water vapor loss from adjacent soil or snow, or from intercepted precipitation at any specified time.

Deep Percolation is a term for the downward movement of soil beyond the reach of plant roots.

Detention Storage is the amount of water which can be held temporarily in the soil profile.

Evapotranspiration is the loss of water from a soil by evaporation and plant transpiration.

Field Moisture is the water the soil contains under field conditions. It is the difference between field moisture capacity and the moisture content at the permanent wilting point.

Field Moisture Capacity is the amount of water retained by the soil after the free water has been allowed to drain away into the drier soil beneath. It is the greatest amount of water a soil will hold after free drainage.

Film Water is the water on the soil particles which does not drain away, although it moves rapidly under suction gradients. Most of this water is available to the plant roots.

Forest Land is the land bearing a stand of trees of any age or stature, including seedlings, and of species attaining a minimum of 6 feet average height at maturity; or land from which such a stand has been removed, but on which no other use has been substituted.

Granular Frost is a loose porous arrangement of granular ice crystals scattered through the soil which usually occurs with shallow freezing of highly organic mattaer. It is generally found mixed with honeycomb structure in forested areas.

Gravitational Water in soils is the water in the largest pores that drains away under the force of gravity with free under drainage.

Ground Water is the water that fills all the unblocked pores of underlying material below the water table, which is the upper limit of saturation.

Honeycomb Frost is a loose porous ice structure and is generally associated with shallow freezing in the early winter. It is generally found in highly organic soils under meadows or pastures.

Hydroscopic means capable of taking up moisture from the air.

Hydroscopic Coefficient is the amount of moisture in a dry soil when it is in equilibrium with standard relative humidity near a saturated atmosphere (about 90%) expressed in terms of percentage on the basis of oven dry soil.

Infiltration Capacity is the maximum rate at which water can enter the soil surface. Infiltration rate is the rate at which water enters the soil surface.

Interception Loss is that portion of the precipitation that does not reach the ground surface but is caught on the leaves, branches, etc., of the plant growth.

Moisture Stress is the tension at which water is held by the soil.

Moisture Tention is the force at which water is held by the soil usually expressed in atmospheres. Moisture tension increases with dryness and indicates the degree of work required to remove soil moisture for use by the plants.

Percolation Capacity is the rate at which water can move through the subsurface soil layer.

Percolation Rate is the rate at which water moves through the soil profile.

Permeability is the quality of the soil horizon which allows water or air to move through.

Pore Space is that fraction of the total space within a soil that is not occupied by solid particles.

Porosity is the degree to which the soil mass is permeated with pores or cavities.

Retention Storage is the amount of water which can be retained in the soil after all runoff has ceased.

Root Zone is that part of the soil profile that is invaded by plant roots.

Seepage is the escape of water through soil, or water emerging from an area of soil along an extensive line of surface, in contrast to springs where the water emerges from a local spot.

Soil Climate is the moisture and temperature condition existing within the soil profile.

<u>Stalactite Frost</u> is a frost composed of many icicles that connect heaved surfaces to the soil. This condition is found in meadows and pastures and may later refreeze into honeycomb frost. (see above).

<u>Subsurface runoff</u> is that portion of the precipitation which upon reaching the soil surface enters the soil profile and moves laterally to some drainage course through the soil profile.

<u>Suction of Soil Water</u> is the pressure required to extract water from the soil.

<u>Surface Runoff</u> is that portion of the precipitation which reaches the ground surface that proceeds directly over the surface to reach a drainage course.

<u>Total Runoff or Streamflow</u> is the total amount of runoff that occurs from all sources including surface flow, subsurface flow and base flow.

<u>Transpiration</u> is the loss of water vapor from the leaves and stem of living plants to the atmosphere.

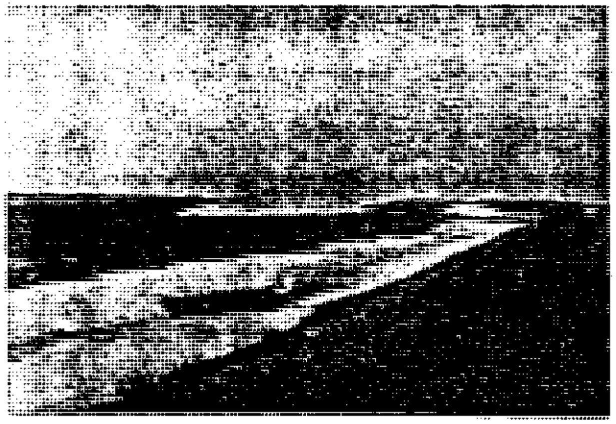
<u>Watershed</u> is the total area above a point contributing to a stream flow of that area at that point.

<u>Water Table</u> is the upper limit of the soil or underlying rock material which is saturated with water.

<u>Wilting Point or Permanent Wilting Point</u> is the moisture content of a soil at which plants wilt and fail to recover their turgidity when placed in a dark humid atmosphere. This represents the lower limit of available moisture.

SNOW STORAGE IN A

FOREST TYPE AREA



THE EFFECT OF SNOW FENCES

ON SNOW RETENTION

THE EFFECT OF TREE BELTS

ON SNOW STORAGE

THE EFFECT OF ROAD DITCHES

ON SNOW RETENTION

Fig. 5

RESEARCH

Water shortages are becoming a common occurrence on this continent. The expanding industrial might of this country requires tremendous amounts of relatively pure water. The resulting population increase requires additional supplies of this product. Both in the United States and Canada the forecasters and engineers are predicting an imminent shortage of water.

It is with this general awareness of the situation that interest has been aroused and researchers are investigating the source of our water supplies and means of augmenting these supplies. Most interest has been focussed on the mountain areas and the effect of changes in vegetal cover on the stream flow from these areas.

This section of the report deals with the results of experiments which have been completed or are under way. These experiments will show the trends in research and the need for confirming the results of this in this province.

One must realize that we cannot transfer the results of the experiments completed elsewhere under different conditions or even somewhat similar conditions to this area and assume the same thing will occur here. The experiments and the results listed hereafter should however, give us an indication of what we may expect and give us an idea of the type of research we require in this area to be able to obtain the information we need.

A veritable library of reports have been written on the subject and only a few of these are covered in this report.

In 1890 in the Emme valley in Switzerland was one of the first recorded studies on runoff conditions. Two watersheds, the Sperbel with 97% forest cover and the Rappen with 31% forest, 5% in field and pasture and 64%

in pasture were studied. Results consistently showed that less total streamflow occurred on the forested Sperbel watershed than on the mixed Rappen watershed. Higher peak flows occurred on the Rappen watershed than on the heavily forested Sperbel.

A 4 inch depth of water required about 2 minutes to infiltrate the forest soil while it required over three hours to infiltrate the pasture soil. The pasture soils were compacted whereas the forest soils were not.

If we assume, as the writer Burger did, that both watersheds were originally forested and similar, then this study provides quantitative evidence that the conversion of forest to grassland and the subsequent use of the grassland for pasture has reduced the soils permeability and thus increased the surface flow. This increase, in the surface flow, has been at least partially responsible for the increase in the total streamflow of the Rappen watershed.

The first large scale experiments in the United States were started at the Wagon Wheel Gap in the Rocky Mountains in Colorado in 1909. In this experiment two watersheds slightly larger than 200 acres each were gauged for a period of 8 years. At the end of that period all the woody vegetation was removed from one area. Streamflow, precipitation, temperature and other records were continued for another seven years. The original areas were thinly covered with douglas fir, spruce and aspen. The aspen rapidly sprouted after treatment restoring cover to the denuded area thus reducing the effectiveness of the treatment. Results show, however, that during the three years following treatment, the total stream flow increased by 17% on the denuded watershed. Peak flows on the denuded area area increased by 50% over those from the uncut area.

Over the seven year period this increase in total runoff dropped to 15% probably due to the rapid regrowth of the aspen cover. The authors suggest that the main cause of the increase was due to decreased interception losses. They agreed that the water losses due to evaporation and transpiration added together were about the same for the treated and untreated watersheds.

In 1912 the Intermountain Forest and Range Station in experiments at Ephraim Canyon in Utah showed that total runoff and erosion had increased by removal of the herbaceous cover from one of the watersheds tested. The second watershed was used as a control.

On the Fernow plots on Northwestern Forest Experiment Station the commercial cutting of timber on the forested plots increased the total runoff 1.6 inches. Cutting was found to have increased the peak flows, low flows and erosion on the watersheds as well as the total streamflow.

At the Coweeta Hydrologic laboratory in North Carolina a 23 acre forested watershed was gauged from 1934 to 1939. In 1939 the area was cleared and prepared for farm use. The methods used were the old sidehill type of agriculture, which is still quite common in the area. The area was split as follows, 6 acres of corn, 10 acres returned to bruch and 7 acres of pasture land.

By 1949 the cornfiled yields were no longer profitable and by 1953 the area was completely degraded.

The infiltration of the forested area was 6 inches per hour as compared to 0.56 inches per hour in the pasture. The cornfield dropped from 3.02 inches per hour to only 0.62 inches per hour after the equivalent of thirty animal days of grazing per acre.

The stream channel widened and deepened after the land was changed from mature forest cover to cultivated crop.

The stream flow peaks increased by as much as 8 times that recorded prior to the treatment.

In 1954, rehabilitation of the area commenced and the land was returned to forest cover. Later reports on these experiments will show the results of the change back to forest cover.

On another watershed all the vegetation was cut but not removed. Yearly cutting has kept the regrowth down. The first year after cutting the increase in the total runoff amounted to 17 inches of water over the area or 27% of the total precipitation. On the assumption that evaporation and interception were not greatly altered during the first year, this increase in total runoff was considered to be due only to the transpiration being completely stopped due to cutting. Maximum increase in streamflow occurred during the winter period when flows normally were lowest. The maximum peak discharge and the distribution of runoff were not appreciably altered.

Research into the effect of the removal of all vegetation was carried out on another test watershed. The regrowth was allowed to occur naturally after the cutting. In the first year after cutting the total runoff increased by 17 inches or 27% of the total precipitation. After 15 years the natural regrowth had reduced the increased total runoff to 4 inches or 7% of the total precipitation. No increase was noted in storm peaks, surface runoff or the distribution of storm runoff.

The next watershed had all the understory removed. The first year after treatment streamflow increased by 2.8 inches over the area. Six years later, without any further cutting the yield has dropped to 1.3 inches. On the basis of these results after ten years the streamflow would return to normal.

Another watershed, a 22 acre plot, had all the riparian vegetation removed along the stream channel. The strip amounted to 12% of the drainage area. Diurnal fluctuations, which prior to cutting were quite marked, ceased. These diurnal fluctuations, reappeared as the vegetation regrew only altered by change in the type of vegetal cover. The first year saw an increase in streamflow equal to 27% of the annual precipitation. This increased yield disappeared by the end of the third year when the new vegetation had reached the density of the original vegetation.

The increase noted in cutting was found to be comparable to the watersheds where all the vegetation was removed for the period immediately after cutting, in this case at least, stream side vegetation was using the same amount of wateras the vegetation on the whole watershed.

At Coweeta these experiments and others are continuing to establish a more definite relationship between the various factors governing runoff from forested areas.

The Tennessee Valley Authority have two research areas in operation.

At White Hollow 1715 acres, which were occupied by settlers, were taken over and after a calibration period returned to forest cover. Results here show no appreciable change in total runoff. The increased shading, which causes reduced wind velocities and greater humidity, evidently reduces the evaporation on the soil surface by an amount equal to the consumptive use. Stream flow peaks have been greatly reduced and the distribution of runoff has been materially changed since reforestation.

On the Pine Tree watershed steps were taken to reforest and rehabilitate 88 acres of critically eroded land in West Tennessee after a five year calibration period had expired.

The results indicate a decrease in surface runoff but an increase in subsurface runoff. A slow progressive decrease has been noted in the total runoff. Peak streamflows have been markedly reduced. Individual storms show a reduction of as much as 90% in peak flows. The groundwater levels do not appear to have changed.

At the Fraser Experimental Forest in Colorado a large number of research projects have been completed and others are under study. Among these are the following projects which are of interest.

Research into the factors affecting snowmelt and stream flow indicate that when areas of a watershed are altered by harvesting timber, fire or insects, the interaction of the various factors used in forecasting water yields will also be changed. The resulting stream flow will also be altered.

In experiments it was found that decreasing the density of a stand of lodgepole pine increased the water available for streamflow by 20%. The increase would nearly all be the result of decreased interception losses.

Research into the effect of selective cutting was carried out on 20 plots of 5 acres each - 16 plots were subject to selective cutting, the other 4 were maintained as control. On the control plots 42% of the annual precipitation was available for runoff whereas 54.9% of the total precipitation was available for runoff on the heavily cut plots. The increase in the water available for runoff on the heavily cut over plots was 13% of the total precipitation.

On the White River Drainage basin in the Fraser Experimental Forest harvesting of timber on plots showed that the total streamflow can be consistently increased by cutting.

Bark beetles on this drainage basin killed Engleman Spruce and Lodgepole

Pine on a 226 square mile area. This resulted in an increase in the snow accumulation which gave an increase in total streamflow of 22% of the annual precipitation. The rate of snow melt also increased indicating the various climatic factors had been so modified by the death of the trees that both the character of the snow melt and the total volume of streamflow were changed.

Research into the effect of cutting open spaces or strips in the forest cover was undertaken on the Fool Creek watershed. On this watershed, which consisted of 714 acres located between 9,600 feet and 11,000 feet, 278 acres were cleared of timber. Appreciable increases in streamflow were noted following the removing of half the native timber. Snow accumulation increased in the strips or openings and amounted to as much as 3½ times that stored in the dense forest.

Another investigation into the effect of timber cutting was made on a Lodgepole pine forest. Three plots were used, on one the commercial timber was cut, on the second a portion of the stand was cut and the third remained as a control plot. Snow storage increased 26% by the heaviest cutting and 5% by the timber stand improvement. The snowmelt was completed at about the same time on all three plots.

On the plot on which the heaviest cutting took place the average amount of precipitation reaching the ground was increased by 32% in the spring and 35% during the summer.

The amount of water available for streamflow on the uncut plot was 10.34 inches or 42% of the precipitation. On the heaviest cut plot, the yield was 13.52 inches or 55% of the precipitation. This is an increase of 32% in the quantity of water available for streamflow. No visible signs of erosion have appeared as a result of the timber cutting.

At the San Dimas Experimental Forest in Southern California, a set of 6 plots and lysimeters were used to see what effect forest management had on total streamflow and erosion. The experiments brought out two important points (1) when we convert from brush to grass we must maintain the site in grass alone or the soil moisture saving by the change will be lost to deep rooted shrubs and weeds. (2) Soil moisture savings were obtained only at depths of greater than three feet. Thus, evaporation and transpiration will use all the available moisture on shallow soils regardless of the kind of plant cover.

The results of the experiments using San Dimas Lysimeters were:

Disposition of annual average Rainfall (1)

San Dimas Lysimeters

Vegetation	Surface Runoff	Infiltration	Seepage	Loss (2)
Bare	13.0	7.7	0	7.1
Pine	5.6	15.1	0	15.1
Chamise	4.1	16.6	0	16.5
Grass	4.0	16.7	1.7	15.3
Buckwheat	3.5	17.2	0	17.2
Scrub Oak	3.3	17.4	0	17.5

(1) Average - 20.7 inches (Oct.1/52 to Sept.30/56) range 16.01 to 25.39 inches

(2) Loss = Rainfall (runoff ≁seepage - increase or ≁decrease in soil moisture storage during period). Includes evaporation from soil, transpiration, and interception loss.

Also at San Dimas investigations are being carried out on the effect of forest fires on the brush covered mountains of the area.

Prior to a 1953 fire which affected part of the research area rainfall and runoff records had been kept of the area. As a result of the fire a marked increase in peak flows occurred. Under dry soil conditions the peak flow after a storm increased 67.7 times the normal and under wet soil conditions the increase was 15.6 times the normal. The erosion on the burned area increased by 23 times that of similar non-burned areas. Total runoff records are not supplied for the area.

The University of California experiments showed that a change from brush to grass resulted in increased total streamflow. Part at least, of the increase was due to a decrease in interception losses by a grass cover. The influences, however, of a grass cover on the soil condition, infiltration, and the hydraulics of surface flow are also important considerations.

In the Sierra Mountains in California experiments on 7 major watersheds where brush was replaced by grass indicated increased water yields of as much as 10 inches over the area under favourable conditions.

The Davis County Experimental Watershed carried out an experiment in Farmington Creek to try to assess the water lost to riparian vegetation. Measurements of evapotranspiration loss from the canyon bottom was made by observing the diurnal fluctuations in stream flow. Fluctuations in stream flow coincided with temporary changes in weather, seasonal changes in weather, and with the freezing of the leaves on riparian vegetation. The evapotranspiration loss was found to be about 1/3 ofthe total flow during the late summer when the demand for water for other purposes is greatest.

The Parrish plots experiment was another research project at the Davis County Experiment Watershed. Sixteen forested plots were set up to measure the relationship between vegetal covering and total runoff. The plots were calibrated for an eleven year period before and experimental changes were undertaken. After the changes in vegetal covering were made another eleven years of records were collected.

The results of the tests were many and varied. Reasearchers found that plant cover can be used to minimize storm surface runoff and soil erosion. A well vegetated area can be converted into a potential flood and erosion source by removing the vegetal covering. Any treatment that bares the soil sets into motion powerful forces that accelerate erosion and runoff. In order to achievea minimum amount of soil erosion and to have only 5% of the precipitation appear as surface flow the ground must have a surface cover of vegetation and surface litter in excess of 65%. Removal of the aspen trees but leaving the understory, reduced the consumptive use of water by 4 inches per year without causing any erosion. The removal of all vegetation, including litter, reduced the consumptive use of water by 8 inches per year but this treatment caused severe erosion.

The following table shows the way in which different treatments affected the use of available precipitation.

	Cover Conditions		
	Bare	Herbaceous	Aspen
Precipitation	52.77 inches	52.77 inches	52.77 inches
Water losses and uses			
Snow Evaporation	3.00	2.75	2.50
Rainfall Interception	0	0.77	1.16
Winter Transpiration	0	0	1.00
Summer Evapotranspiration	11.21	14.83	17.70
	14.21	18.35	22.36
Water available for stream flow			
Overland flow	.40	.02	.01
Seepage flow	38.16	34.40	30.41
Total available for stream flow	38.56	34.42	30.42
Soil loss (average annual)	184.4	0	0

In Utah at the Intermountain Forest and Range Experiment Station on the Wasatch Plateau experiments are being conducted into the part played by snow in watershed recharge, snow melt rates and factors that influence them, movement of melted snow water through the snow, overland flow beneath the snow and on bare surfaces, infiltration capacities of snow covered surface and subsurface soils and the duration and movement of gravitational water in the watershed mantle.

They noted the principal source of high total runoff from the area was the water yielded by a saturated soil and not by surface flow of melted snow water. Peak flows occurred when 8% of the drainage basin area was still covered with snow and when 98% of the total water stored in the snow on the entire watershed had been released.

Removing aspen from an area and leaving only forage species would save approximately 13% of the annual precipitation and this would be added to the total streamflow without increased danger of erosion.

Removing all the vegetation would have saved 27% of the annual precipitation but this increased streamflow would have caused severe erosion.

In Idaho experiments, results show, that a dense stand of Ponderosa pine retained 14 to 20% of its total snow water after an adjacent clear area was free of snow. They also indicated that small openings improve the water yield when compared to a stand with dense continuous cover. Experiments, also indicated that the young vegetative growth has a great influence on snow melt.

Results indicated that 25% of the annual snowfall could be intercepted and dissipated by mature tree crowns but at the same time melting could be retarded 10 days by these mature trees. Research also indicated that over a considerable range of forest climate and forest types the net rainfall reaching the ground varied from 66% of the total precipitation under Douglas fir to 97% under leafless poplar.

In Oregon at the Blue Mountain Research Centre experiments were carried o into the relationship between snow pack in a lodgepole pine forest and on a meadow.

Results showed that only 76% as much snow reached the ground in forested areas as compared to the meadows or 24% of the total was intercepted by the forest cover and lost.

Snow depths on the forested plots averaged 62% of the depth on the meadows. Water content averaged only 55% of that of the snow in the meadow. Openings as small as 20 feet received more snow than the surrounding timber and in some dense douglas fir areas no snow reached the ground.

In Northern Minnesota at Lake States Experiment Station the effect of forest cover on water behaviour is being studied as part of a general program of research.

In their experiments on the effect of change of vegetation on snow cover they found that open fields lost the snow earlier and faster than forested areas. More snow accumulated in hardwoods than in conifers but the conifers retained it longer. The stand density in coniferous types influenced to some degree the amount of snow that accumulated and the rate of melt. The lighter stands caught more snow but the dense stands retained it longer.

Also, experiments were carried out into frost depth under various types of cover. In the area tested frost penetrated over 8 feet under the open ground, 6 feet under Balsam fir, 3.5 feet under aspen and 2 feet under white pine. The depth and type of frost affects the infiltration rate and hence, the total runoff from the area.

In South Western Wisconsin experiments were carried out on the effect of trampling by livestock on the infiltration rate. The results were that the soil under ungrazed native oak woods showed an infiltration rate of 7.46 inches per hour whereas the soil under grazed native oak woods had an infiltration rate of .05 inches per hour. The soil under ungrazed scotch pine had an infiltration rate of 11.02 inches per hour whereas after grazing the infiltration rate was 1.23 inches per hour.

In Ohio experiments into the rate of movement of water through forest soils as compared to cultivated soils showed that the transmission rates in forest soils were nearly double those of cultivated areas. The transmission rates of forest subsoils were found to be as much as 5 times those of a cultivated area. Thus, the precipitation can move through a forest soils profile much more rapidly than through a cultivated area soil profile. The amount of moisture removed by transpiration will vary according to the characteristics of the vegetation, the most important item being the depth of the root zone.

Studies at the Sierra Ancha Experiment Forest in Arizona found that the amount of water lost from a bare soil by evaporation was nearly equal to evaporation plus transpiration by plants. Shrubs use more water than grass. Vegetation uses water at different periods of the year depending on the type of the plant. Of 32 inches of natural and artificial precipitation that fall on the chapparral in the San Bernardino area 27 inches was lost by evaporation and transpiration. Therefore, 84% was lost in this manner and 16% remained for streamflow. A seasonal precipitation of less than 19 inches is usually consumed by the brush cover before any portion reaches the ground water. On grass, 10 to 12 inches is usually consumed. Therefore, 7 to 9 inches more water is available for runoff if the chapparral is removed and replaced with grass. During a 30 day period (April 28 to May 27) there was a 12.9 inch consumption by native vegetation along the stream channel, this was 3 times the evaporation from the free water surface of a lake.

In Canada experiments on farm plots at Guelph have not been in operation long enough to yield any worthwhile results.

Experiments on the effect of grazing on runoff are varied and wide spread.

In Arizona at the Sierra Ancha Experiment Forest researchers found that surface runoff accounted for 15% of the total runoff on overgrazed land as compared to 5% on an ungrazed area and 9% as the average.

In Utah at the Parrish Canyon plots, the destruction and modification of the plant cover by overgrazing appears to be the dominant cause of the recent cycle of erosion.

In Idaho a sheepfoot packer was used to show how overgrazing increased total runoff and erosion.

Colorado experiments showed that overgrazing caused increased flow.

California experiments proved that overgrazing is the cause which starts an erosive cycle.

Pennyslvania experiments indicated that compaction decreased the infiltration rate and hence increased runoff.

At Coweeta in North Carolina, after a seven year calibration period a test area was overgrazed. Then for a period of 9 years after the grazing was completed records were continued. Results indicate peak flows increased by 3 times and that surface runoff occurred from areas where prior to the overgrazing it had not been observed. The sediment load carried by the streams was increased appreciably.

A general conclusion could be drawn that overgrazing has increased surface runoff and erosion.

The effect of forest fires has received considerable attention on the basis of the effect of forest fires on peak flows but little research has been done into the effect on total streamflow.

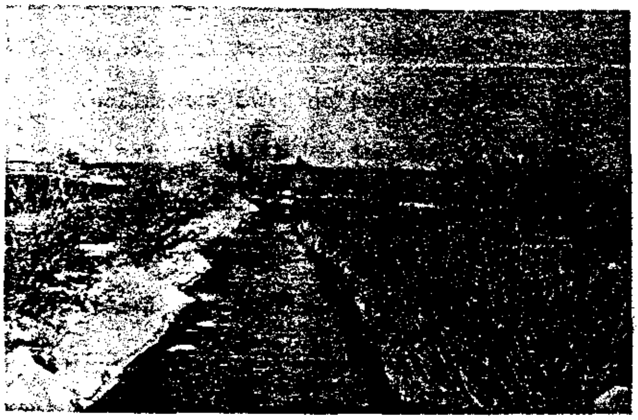
A CHANGE IN VEGETAL COVER

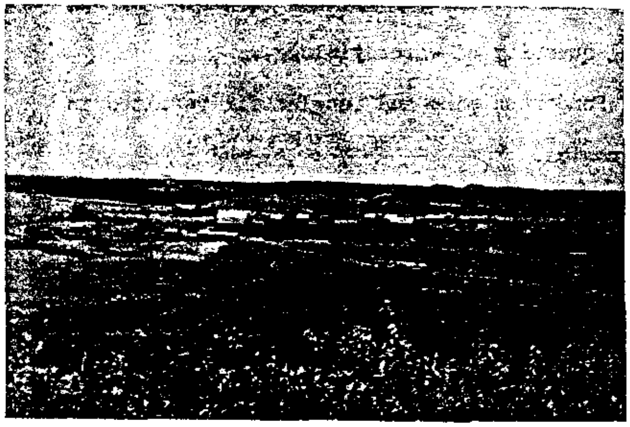
FROM FOREST TO GRASSLAND

PHREATOPHYTES

OR WATER LOVING PLANTS

ALONG AN IRRIGATION CANAL





A CHANGE IN VEGETAL COVER

FROM CROP LAND TO FARMSTEAD

COMPLETE DENUDING OF THE UPPER

SLOPES CAUSED BY FOREST FIRE

Fig. 6

In the San Gabriel Mountains of California a fire on Fish Creek Watershed increased the annual water yield for several years. In the first six years the average annual increase in runoff was 29%. The increased peaks also were recorded as was a definite increase in sedimentation.

Also in California on the Central Sierra the annual burning of woodland chapparral reduced interception losses and thereby increased the amount of precipitation which reached the soil. The fires also reduced the infiltration capacity of the soil which resulted in an increase in surface runoff. No significant increase was noted in total quantity of water yielded.

In Arizona the burning of Ponderosa pine and Douglas fir resulted in an increase in surface runoff and erosion.

Similar results were noted in Texas, Oklahoma and North Carolina.

Those experiments where fire has occurred naturally appear to be the main source of present information so, the need for further research is apparent.

Phreatophytes or well plants have always been considered as users of large amounts of water and so the researchers have done some work in this field in an effort to find their effect on stream flow.

All experiments have found an increase in total runoff has been obtained by the removal of this vegetation or of the channelling through the area.

On the Gila River basin 9,300 acres of Saltcedars, Cottonwoods, Willows, Bacchares and Mesquite in a 46 mile stretch use some 28,000 acre feet per year.

On the Rio Grande in the Pecos River delta above McMillan reservoir dense saltcedars use an estimated 5,000,000 acre feet which would be available for other uses if all this vegetation could be removed.

In Nevada they estimate 1,500,000 acre feet are used by phreatophytes with 375,000 acre feet or 25% being salvageable or enough to irrigate 133,000 acres.

On the Rio Grande the construction of a channel 32 miles long through a phreatophyte area increased the flow by 100,000 acre feet per year.

In this report we have attempted to include most of the more recent information on research experiments being conducted in the United States. It is well to repeat here that while this information may indicate results in particular cases it should not be transferred to other areas but only used as a guide to show what one might reasonably expect.

The information from other centres only tends to emphasize the need for further research into most phases of vegetal-runoff relationships and especially the need for this type of research in Canada.

ALBERTA

The problem of assessing the effect that changes in the land use have had on the total runoff from the province's streams is a complex and difficult one to answer. Here we can only list the changes that have taken place and point out some possible results of these changes. Until we are able to complete research work into the effect of these changes on our own area we cannot come up with any conclusive report on the result of these changes. However, we hope in this section to give some indication of the possible results of past changes and some indication of those which may occur in the future.

The importance of knowing what effect of changes in land use and vegetation can only be realized when we look at the need for water of our present day civilization.

In the United States the average water used is about 145 gallons per person per day. In agriculture for every pound of dry stock, leaf or seed produced 300 to 1,000 lbs of water must be used by the plant. In industry a ton of steel requires 285 tons of water, a gallon of gasoline 25 gallons of water and a five pound newspaper 150 gallons of water. The five pounds of rayon fibre required for a man's suit requires 11,000 pounds of water for its creation.

With the increased industrialization of the province since the discovery of major oil and gas reserves only just beginning, Alberta can look forward to a period of tremendous growth and with this growth will be an accelerated demand for water. Along with this industrial expansion will be a corresponding increase in population which will also require water for both domestic and agricultural purposes.

This development, which has been predicted by many experts will tax our available water supplies in amny localities and will bring into the forefront the need for conserving every available drop of water for use. If by good forest management we can increase the supply then attention must be focused on that phase now, so that when the demand arises we will be able to get the most water from our watersheds.

In the case of the Saskatchewan River basin, where already, conflicts between downstream hydro and upstream consumptive use are foreseen , the management of available supplies becomes of paramount importance. The need for planning in our uses and for research into all means for increasing this supply, compatible with good land management, is urgent.

Another point worthy of consideration is that any increase in the total runoff that can be attributed to the management of our water resources in Alberta, i.e., land and forest management, drainage, etc., would in all probability belong to Alberta, regardless of any interprovincial commitments that may be made regarding the natural flow from our streams.

The importance of adequate water supplies is only now being realized. No industry or development can take place in areas where the supply of water for their present needs and future expansion is not assured.

In the United States it has been estimated that the use of water for all purposes will increase from the 173,000,000 acre feet used in 1950 to an estimated 392,000,000 acre feet by 1980. The increase in use is some 44% and represents some 24% of the total supply of surface water available. By 2070 they indicate that the demand for water will reach 92% of the total surface supply. This means that if the forecast is correct or nearly correct, the United States will have to have control of 92% or more of the available water supply. At the present time this is considered almost impossible.

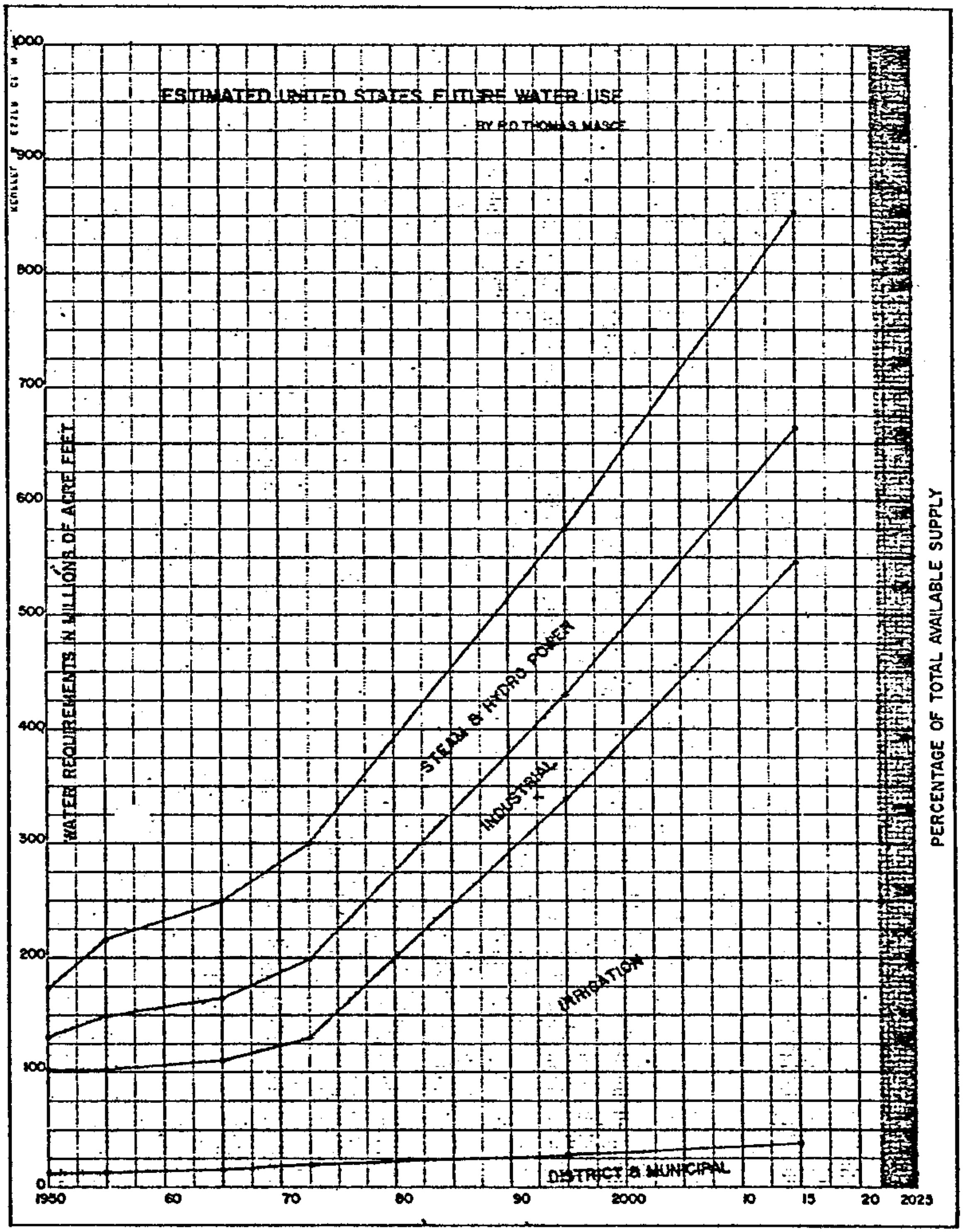

ESTIMATED UNITED STATES FUTURE WATER USE
BY R.O. THOMAS M.ASCE
WATER REQUIREMENTS IN MILLIONS OF ACRE FEET
PERCENTAGE OF TOTAL AVAILABLE SUPPLY
STEAM & HYDRO POWER
INDUSTRIAL
IRRIGATION
DISTRICT & MUNICIPAL
0
100
200
300
400
500
600
700
800
900
1000
1950
60
70
80
90
2000
10
15
20
2025

Fig. 7

Figure one shows the estimated uses in the future development for the period up to 2015 in the United States. It indicates that by 1980 the domestic and municipal requirements will reach 23,000,000 acre feet, industrial 75,000,000 acre feet, irrigation 177,000,000 acre feet and steam and hydro will require 117,000,000 acre feet or a total use of 392,000,000 acre feet. By 1980 the forecast shows only 18% of United States power to be hydro the remainder being some form of steam generation. By 1980 the population of the United States will have increased to 220,000,000 people from 150,000,000 in 1951. Municipal and domestic use would be 93 gallons (United States) per person per day by 1980. The report also estimates that 2/3 of the total crop land in the semi-arid and humid areas in the United States will be receiving some form of irrigation by the year 2070. By 1980 they estimate an increase of 10% in the area irrigated as compared with 1950.

These estimates show the trend in the thinking of American Water Resources people and the emphasis they must place on control and storage now if they are to be prepared for the future.

If a similar trend were forecast for Alberta by 1980 there would be a need for water to supply an industrial and agricultural complex capable of sustaining a population of 2,200,000 people. This would mean that by 1980 the water requirements for all uses in Alberta would be double our present use.

It indicates the needs for emphasis to be placed on conservation and best use of all available water and the need for research into means of supplementing this supply.

One only needs to look at the water supply problems in the more highly developed areas of the world to realize the need for planning and to control the available supplies. The proper management of our land and forest resources are part of this water supply problem. The use of vegetation is one of these means and this report is made to bring up to date the work that has been and is being done in this regard.

The report is also made to bring to the attention of those concerned with Water Resources on the Prairies the changes that have resulted in Alberta and the other provinces from the change in vegetative cover.

Many changes have taken place since the white man invaded this land. Cultivation of large areas for agricultural purposes has resulted in the removal of forest, brush and the breaking of grass lands.

Forest fires have resulted in a continuing change in the effect of forest cover on runoff. Logging has removed vegetation from areas which over the ages will return to native forests.

Miles of roads and trails have been constructed. Ditches provide faster means of removing the water from these areas and the road surfaces are more or less impervious. Railways have also altered drainage patterns.

Cultivation and drainage of low areas have also resulted from the white man's attempt to use some of the lands.

Towns, cities, farm buildings, etc., have been constructed where in the early days there was only native vegetation.

These are a few of the major changes that have taken place since the white man came west. Each of these changes, along with the many smaller changes, have resulted in a change of vegetative cover of the area and a resulting change in runoff conditions and characteristics.

The Province of Alberta has a land area of 163,400,000 acres. Some 42,000,000 acres of this area can be divided into 4 zones:


ALBERTA
-WATER RESOURCES-
MAP.
SHOWING NATURAL VEGETATIVE ZONES OF ALBERTA
ZONE 4
ZONE 3
ZONE 2
ZONE 1

Fig. 8

1. Zone one consists of the brown soil area of the province and generally is covered with short prairie grass with few trees or clumps of brush. It consists of 12,500,000 acres and is generally used for ranching and farming.

2. Zone 2 consists of the dark brown soil area which is north and west of zone 1 and comprises 16,000,000 acres. These are prairie grass lands which have clumps of trees and brush throughout. This is mainly the wheat growing area of the province.

3. Zone 3 is the black soil area of Alberta and is known as Parklands. They consist of grasslands invaded by trees which are mainly poplars. This area consists of some 10,000,000 acres in the area north and west of zone 2 with small local areas in the Peace River country around Grande Prairie and Peace River.

4. Zone 4 lies west and north of the black soil area and is covered by the grey wooded soils. It consists of 110,000,000 acres or ¾ of the Province's area. This includes virtually all the forested area in the province.

The remainder of the area, approximately 15,600,000 acres, is Federal parks and is all within the forested area.

In 1956 the province had 46,000,000 acres occupied, 24,000,000 acres of which has been improved. The 24,000,000 acres was divided into 15,000,000 acres in crop, 7,100,000 in summerfallow, 1,300,000 acres in pasture and 600,000 acres in other uses.

The maximum estimated area , which may be developed for agricultural purposes, is 68,000,000 acres. It is estimated that by 1980 some 48,000,000 acres will be occupied, of which 3,500,000 will be in zone 1, 9,100,000 in zone 2, 7,600,000 in zone 3 and 5,700,000 in zone 4. This will mean an increase over the 1951 figures of 500,000 acres in the parkland and 2,000,000 acres in the

grey wooded soils. During the period from 1932 to 1951 there was 5,100,000 acres of new land broken. From 1951 to 1980 it is estimated an additional 2,500,000 acres will be broken.

In Alberta there are an estimated 105,700,000 acres of land which are covered with forest. The Federal parks occupy 9,200,000 acres of this area. The Eastern Rockies Forest Conservation Board manages an additional 5,500,000 acres and the remaining 91,000,000 acres are managed by the Alberta Department of Lands and Forests.

The 91,000,000 acres is further classified as 38,600,000 acres of productive forest land, 25,700,000 acres of potential forest land and 26,700,000 acres of non-productive forest lands. Potential forest lands are the lands which have been burned, on which natural restocking has not yet taken place. Non-potential lands are the alpine barren lands and swamps covered with timber, of no commercial value, and water.

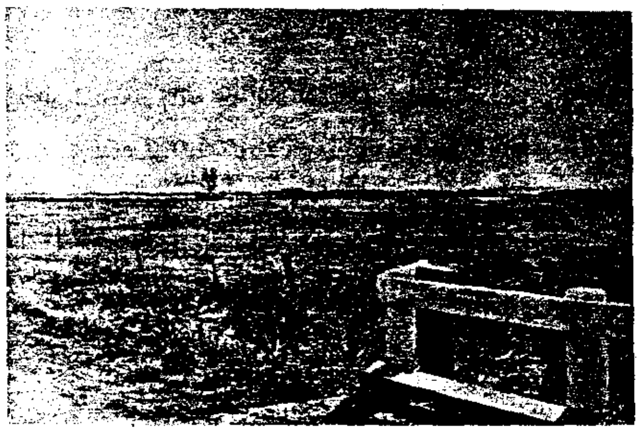
The forest areas are made up of 51% coniferous trees and 49% decidous trees. The coniferous trees are 23% white spruce, 3% balck spruce, 2% balsam fir and 23% jack and lodgepole pine. The deciduous trees are poplar, aspen and white birch.

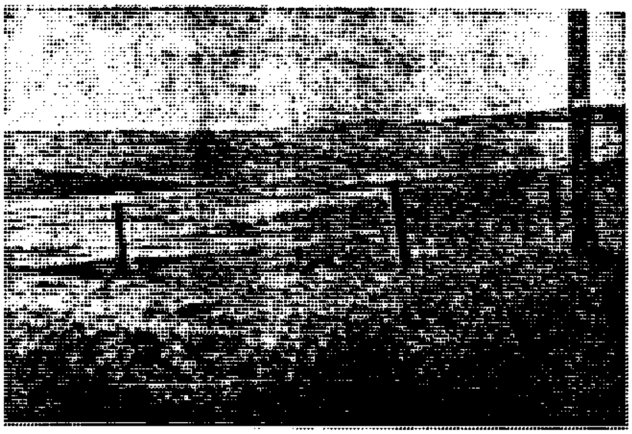
The population of Alberta in 1956 was 1,123,116 people of which 56% live in the cities and towns and 44% live in the rural areas. In 1958 the 10 cities had almost 50% of the total population in the province. The Dominion Bureau of Statistics shows the population of Alberta, at January 1st, 1960, as 1,268,000. By 1980 the population may reach an estimated 2,200,000 people.

These statistics are needed to indicate the changes that have taken place in Alberta and those which are anticipated in the future.

As an example the prairie soils in zone 1 of Alberta, which cover some 12,500,000 acres, according to the report on Alberta's Economic prospects, are

TYPICAL PRAIRIE LAND IN ZONE I

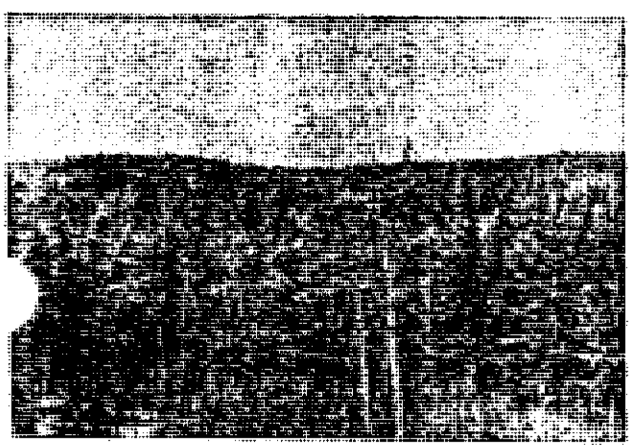




TYPICAL SUB-PRAIRIE LAND

IN ZONE 2

TYPICAL PARKLAND IN ZONE 3



TYPICAL FOREST LAND IN ZONE 4

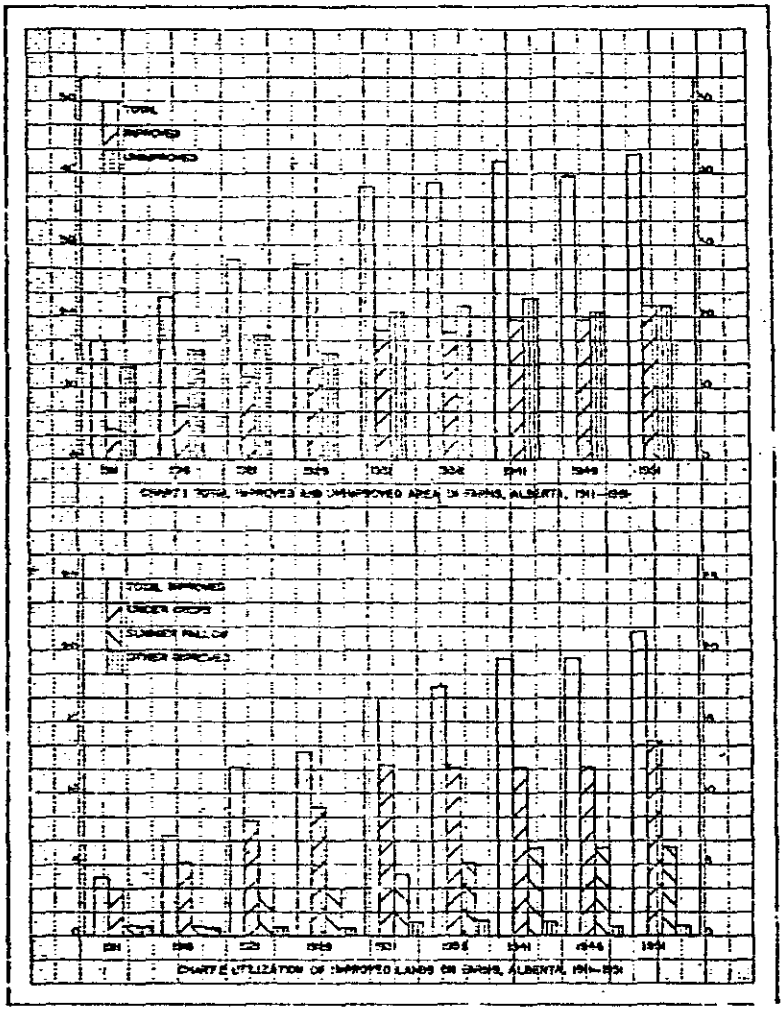


Fig. 10

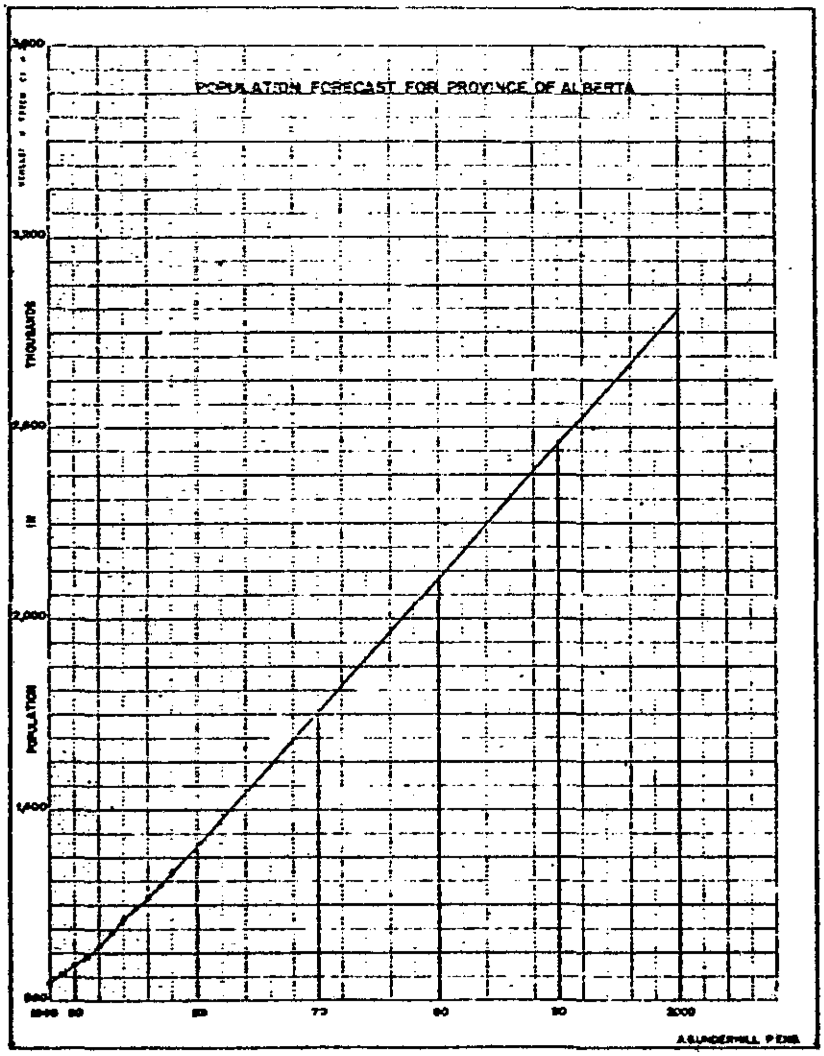

POPULATION FORECAST FOR PROVINCE OF ALBERTA
POPULATION IN THOUSANDS

Fig. 11

developed as far now as they will be in 1980. This indicates that since the beginning of agricultural development in the west we have improved 3,500,000 acres of the 12,500,000 acres of this zone, i.e., 28% of the area is under cultivation of some sort, 72% in native grass and will continue that way until 1980.

In zone 2, 8,000,000 acres of the 16,000,000 acres available were under cultivation in 1951. By 1980 it is estimated that an additional 1,100,000 acres will be developed. This indicates that since agriculture began in zone 2, 50% of the land has been broken and that in future, by 1980, 57% will be cultivated, leaving 43% in native vegetation at that time.

In the Parkland zone, zone 3, some 7,100,000 acres of the 10,000,000 acres were developed by 1951, leaving 29% in native brush and trees. By 1980 the total cultivated will have risen to 7,600,000 acres and thus, only 24% of this zone will remain in native vegetation.

In zone 4, which comprises 30,000,000 acres of land suitable for agriculture, only 3,700,000 acres were developed by 1951. This represents only 12% of the area suitable for agricultural purposes. Estimates indicate that by 1980 an additional 2,000,000 acres will be developed bringing the total to 5,700,000 acres, which represents 19% of the area available for agriculture and 5% of the total area in zone 4.

TABLE 1

Zone	Total Area	Maximum Agricultural Area	Development By 1951	Percentage of total Area	Estimated Development By 1980	Percentage of Total Area
1	12,500,000	12,500,000	3,500,000	29	3,500,000	29
2	16,000,000	16,000,000	8,000,000	50	9,100,000	57
3	10,000,000	10,000,000	7,100,000	71	7,600,000	76
4	110,000,000	30,000,000	3,700,000	3	5,700,000	5
	148,500,000	68,500,000	22,300,000	15	25,900,000	17

The Canada year book gives 53,500,000 acres of the province as not being covered by forest. Thus, when the maximum land use of 68,000,000 acres presently contemplated, for agriculture is reached some 14,500,000 acres will have been removed from forest areas. Even today a considerable clearing has been done in our forested areas and on the fringe of these areas.

By 1951 some 22,300,000 acres of land had been improved, thus the native vegetation had been changed by man to some degree. An additional 22,160,000 acres were occupied and the use of these lands, even though no improvements had been made, had changed the native vegetative conditions. What effect these changes have made on the total runoff has never really been assessed.

Fire losses in Alberta represent another major source of vegetative change. In the period, from 1930 to 1953 inclusive, 6,731 fires burned over some 11,403,000 acres, or an average of 280 fires destroyed all or part of the timber on 475,000 acres per year. This represents an average yearly loss of 1.2% per year.

If the fire rate were to continue at this rate during the period 1950 to 1980 we would have some 14,250,000 acres burned which represents 36% of the total forested area. The change in the total runoff and the runoff characteristics would be quite marked in these areas for the first few years after the fires.

Transportation has also resulted in changes in land use and hence a change in runoff conditions. By 1958 the Province of Alberta had some 87,430 miles of improved roads. Of this amount some 2,758 miles were hard surfaced and 38,537 were gravelled. The building of these roads along with their drainage ditches have provided accelerated drainage channels through which the water may pass. They have drained sloughs and in some instances lowered the water table. They also provide impervious surfaces for the moisture to run off.

Railways, too, have contributed to this change. Alberta has some 5,782 miles of railway grades.

Airplanes require airports with runways and taxi strips all of which contribute to the changed conditions.

The building of farmsteads have also resulted in vegetative change in many small areas, all of which will add to the total. In 1956 we had some 487,292 farm people which made up 122,155 farm households. Even though many of these people no longer reside in the actual farm lands buildings they are maintained at these locations. Even if each set of farm buildings only occupies one-half acre the area becomes appreciable.

Also in 1956 we had an urban population of 635,284 which was made up of 171,192 households. This, along with the industrial and commercial complex that makes up a city, has resulted in a change in natural conditions.

The fact that at least 25% of the city area is probably completely impervious and that a highly complex drainage system moves the water away from these areas has increased the runoff.

Many other things have resulted in changing the vegetative cover and the runoff conditions. Drainage ditches, both in drainage districts and local drainage, have resulted in changed conditions.

Snow fences and tree belts result in snow, which would otherwise be spread thinnly over a large area, being concentrated in small local areas where it melts slower and provides local areas with more water for infiltration and runoff.

Since the majority of the runoff in Alberta rises in the forested areas this report deals mainly on the effects of changes in those areas. (See Fig.12, 13, 14,15).

While we have mentioned the effect of the prairie areas it is in the forested and parkland areas where the change in vegetation could make the greatest impact on the runoff in our streams.

We have included the results of and experiments that are continuing at some of the major forestry research stations in the United States. To try to apply these results directly to our area would be impossible. However, they will show us trends we may expect here. These trends will have to be checked and confirmed by our own experiments in this area.

The value of all this information is only to show that a change in vegetation will definitely result in a change in the runoff characteristics of our streams. How much or what form it will take requires investigation under our own forest conditions. This is also true in the parkland and prairie areas which also have undergone and will, in the future undergo changes. The latter zones which yield about 25% of the runoff water in Alberta do not present much opportunity for increasing the runoff but nevertheless we should know what to expect. If we consider the possible effect of the various changes it should provide an indication of what has happened.

(a) The vegetation changes in zones 1 and 2 will have little effect on the total runoff from the area since the majority of the runoff occurs from the melting of winter snows. At the time in the spring when the melting occurs the ground is generally frozen and its surface condition then makes little difference.

(b) In the parkland zone we have cultivated 7,100,000 acres of land which was originally covered by brush or trees. Since the brush and trees were greater users of water than most of the present crops and since the brush and trees retained the water longer and thus allowed it to seep into the ground whereas the present cover does not hold the moisture as long, we would expect greater runoff now occurs from this area.

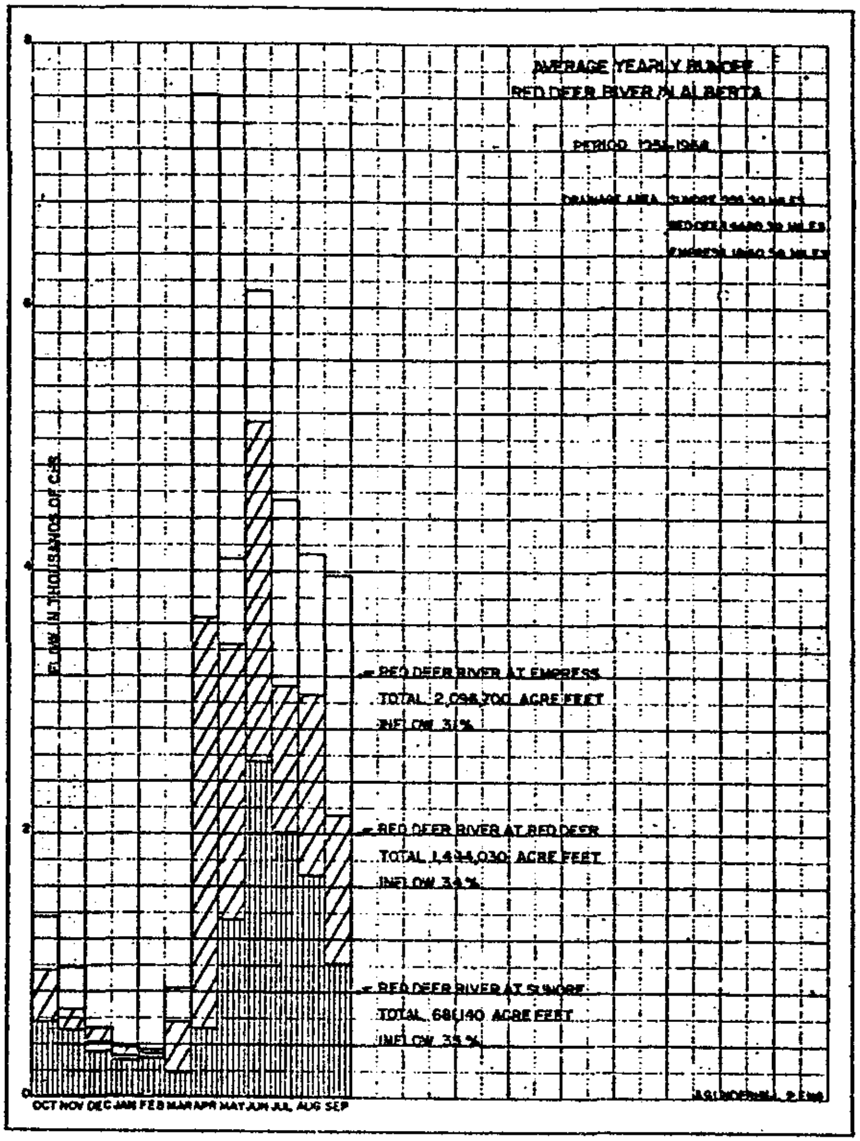

AVERAGE YEARLY RUNOFF
RED DEER RIVER IN ALBERTA
RED DEER RIVER AT EMPRESS
RED DEER RIVER AT RED DEER
TOTAL 1,434,030 ACRE FEET
FLOW IN THOUSANDS OF C.F.S.
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP

Fig. 12

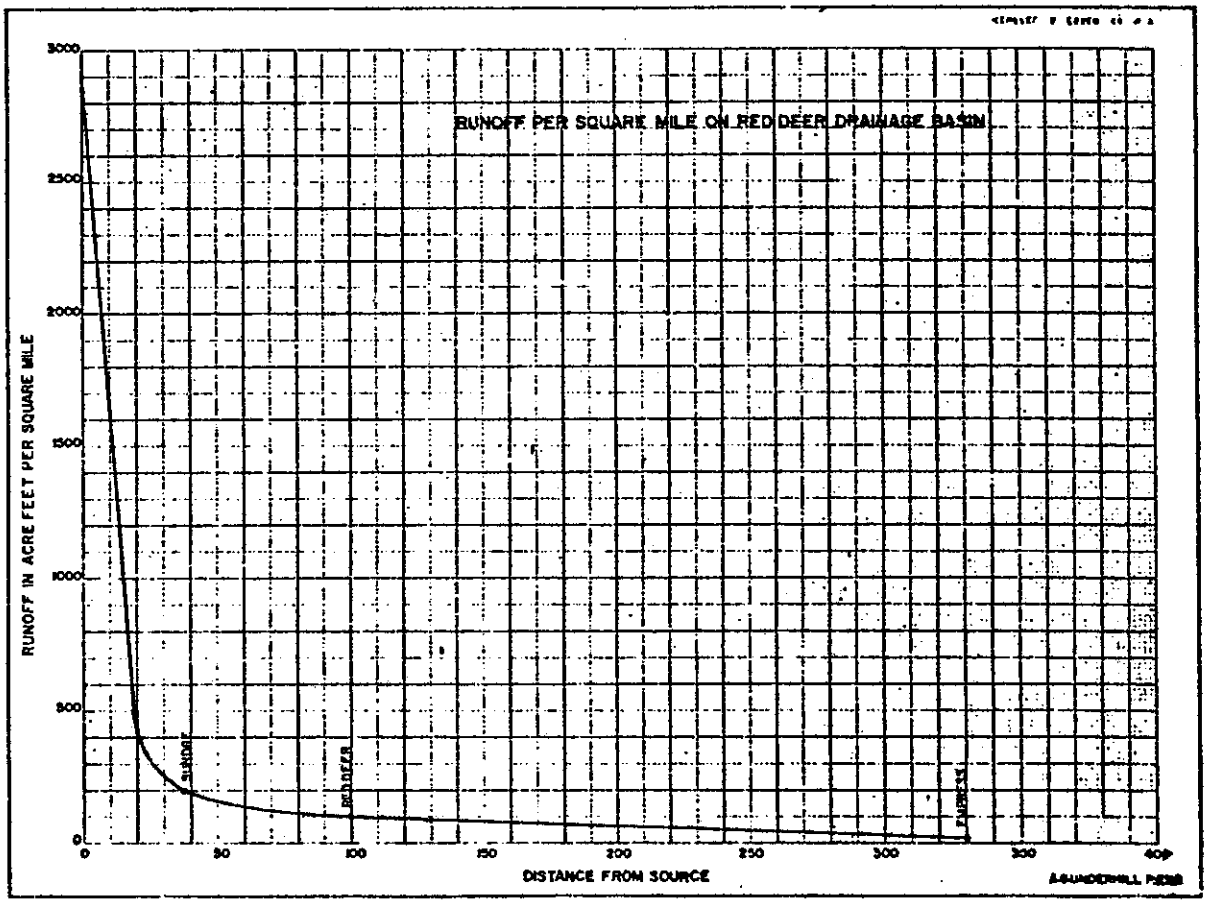

RUNOFF PER SQUARE MILE ON RED DEER DRAINAGE BASIN
RUNOFF IN ACRE FEET PER SQUARE MILE
3000
2500
2000
1500
1000
500
0
DISTANCE FROM SOURCE
0
50
100
150
200
250
300
350
400

Fig.. 13

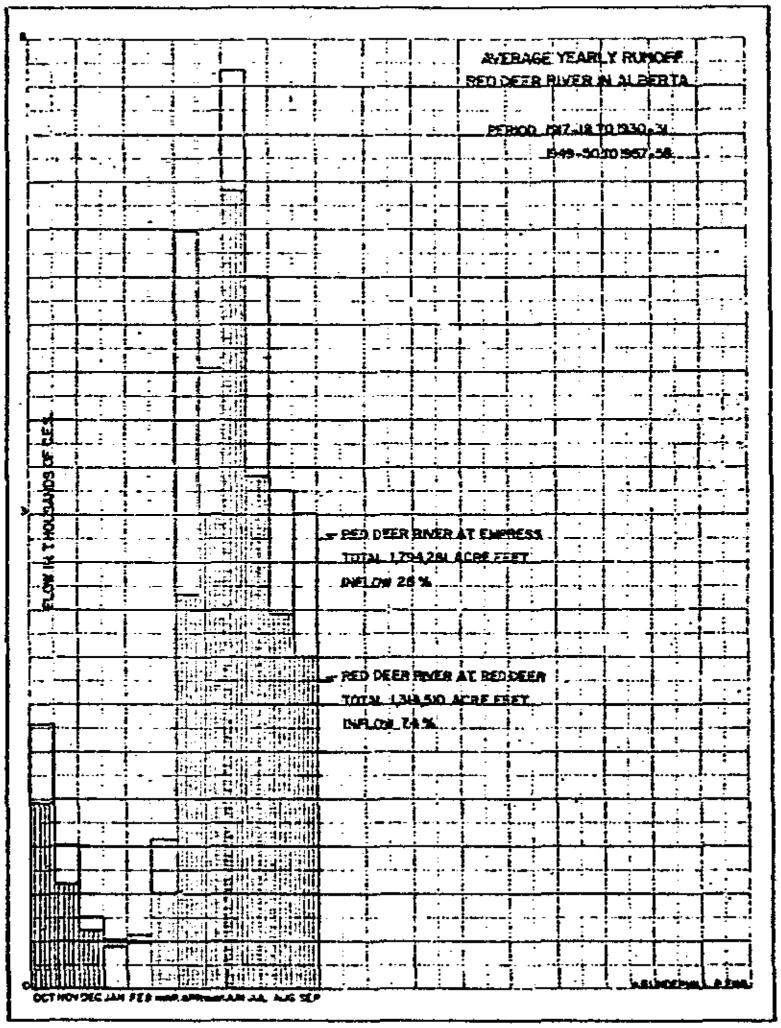

AVERAGE YEARLY RUNOFF
RED DEER RIVER IN ALBERTA
PERIOD 1917-18 TO 1930-31
1949-50 TO 1957-58
FLOW IN THOUSANDS OF C.F.S.
RED DEER RIVER AT EMPRESS
TOTAL 1,794,281 ACRE FEET
INFLOW 26 %
RED DEER RIVER AT RED DEER
TOTAL 1,348,510 ACRE FEET
INFLOW 74 %
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP

Fig. 14

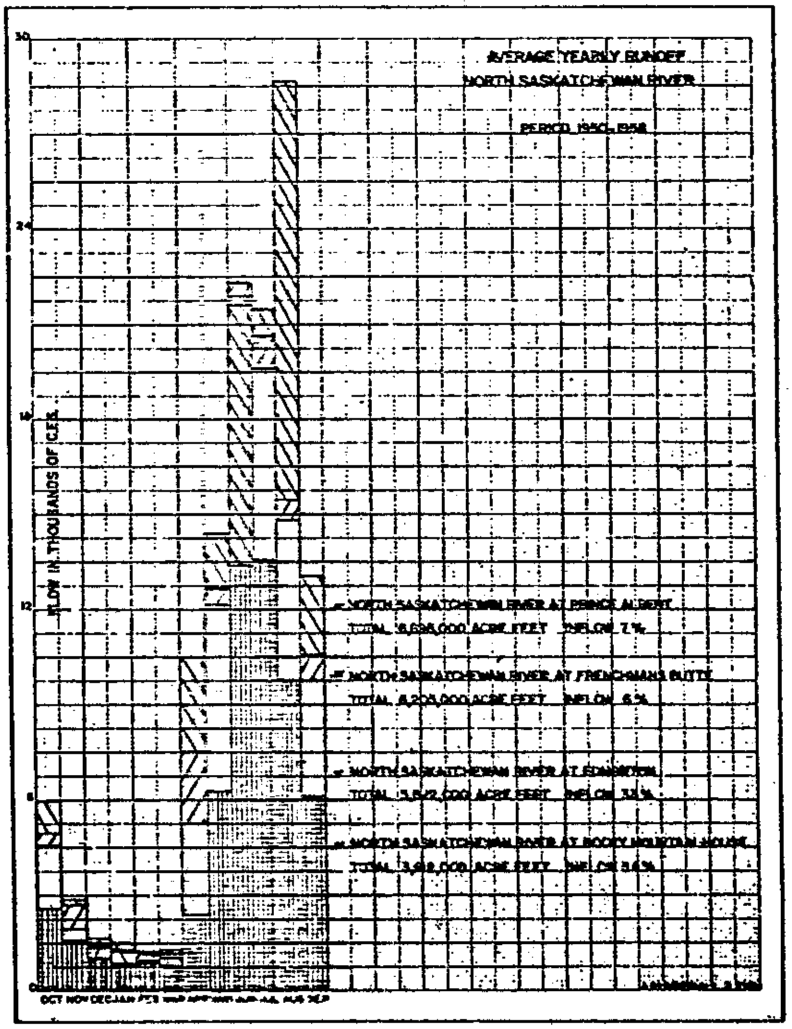

AVERAGE YEARLY RUNOFF
NORTH SASKATCHEWAN RIVER
FLOW IN THOUSANDS OF C.F.S.

Fig. 15

(c) In the forest zone, zone 4, 3,700,000 acres have been cleared and cultivated. In these areas we could expect greater runoff due to the reduced interception losses and the smaller root zone of the crops.

In this area the effect of logging must also be considered. Here too, this change in vegetation due to the removal of the commercial timber would be expected to yield greater volumes of total runoff.

Forest fires have had a tremendous effect on our forests and for the first few years after the fires occur it would be expected that increased water yields would result.

(d) In Alberta we have 87,430 miles of roads of which 2,758 are hard surfaced and 38,537 miles gravelled. This represents an area of over 700,000 acres that have been changed and in many cases made almost impervious. The road ditches also act to collect snow thus giving us additional runoff. The snow otherwise might be absorbed in the fields. The snow fences along the roads collect the snow and cause additional runoff. The road ditches drain areas rapidly that would drain slowly allowing less time for infiltration. Sloughs and other water bodies are drained in road construction. Sometimes water tables are lowered. All of these items contribute in their own small way to the runoff from the road area.

(e) Farm homes generally cause an area to be packed and made, more or less, impervious and thus the precipitation cannot enter the soil and must run off or be evaporated. Some 122,000 of these sets of farm buildings represent considerable impervious areas.

Tree shelter belts trap snow and allow it to melt more slowly.

(f) Then we have constructed cities with all the impervious areas to go with them along the highly developed drainage systems to get the water away from the areas.

(g) The railways present another source of change. Some 5,782 miles of railway exist in the province along with the drainage ditches that run parallel to the lines.

(h) Many other changes each small in the individual but they as a total create quite a change in the runoff picture.

It is easy to see that since the time of the white man in Alberta major vegetative changes have resulted in the alteration of the natural runoff conditions. The amount of this change has never been considered. The total change possibly would show that we in Alberta have by our alteration of native conditions increased the total runoff from Alberta's soils by an amount greater than the water we have removed from these streams for irrigation, domestic, industrial and other purposes.

It is therefore, essential that we investigate the value of these changes so that we can at least estimate with some degree of accuracy the amount of change that has taken place.

Research should be undertaken into the effect of a change of vegetation, or land use, on the runoff characteristics of streams in Alberta with special reference to the four zones.

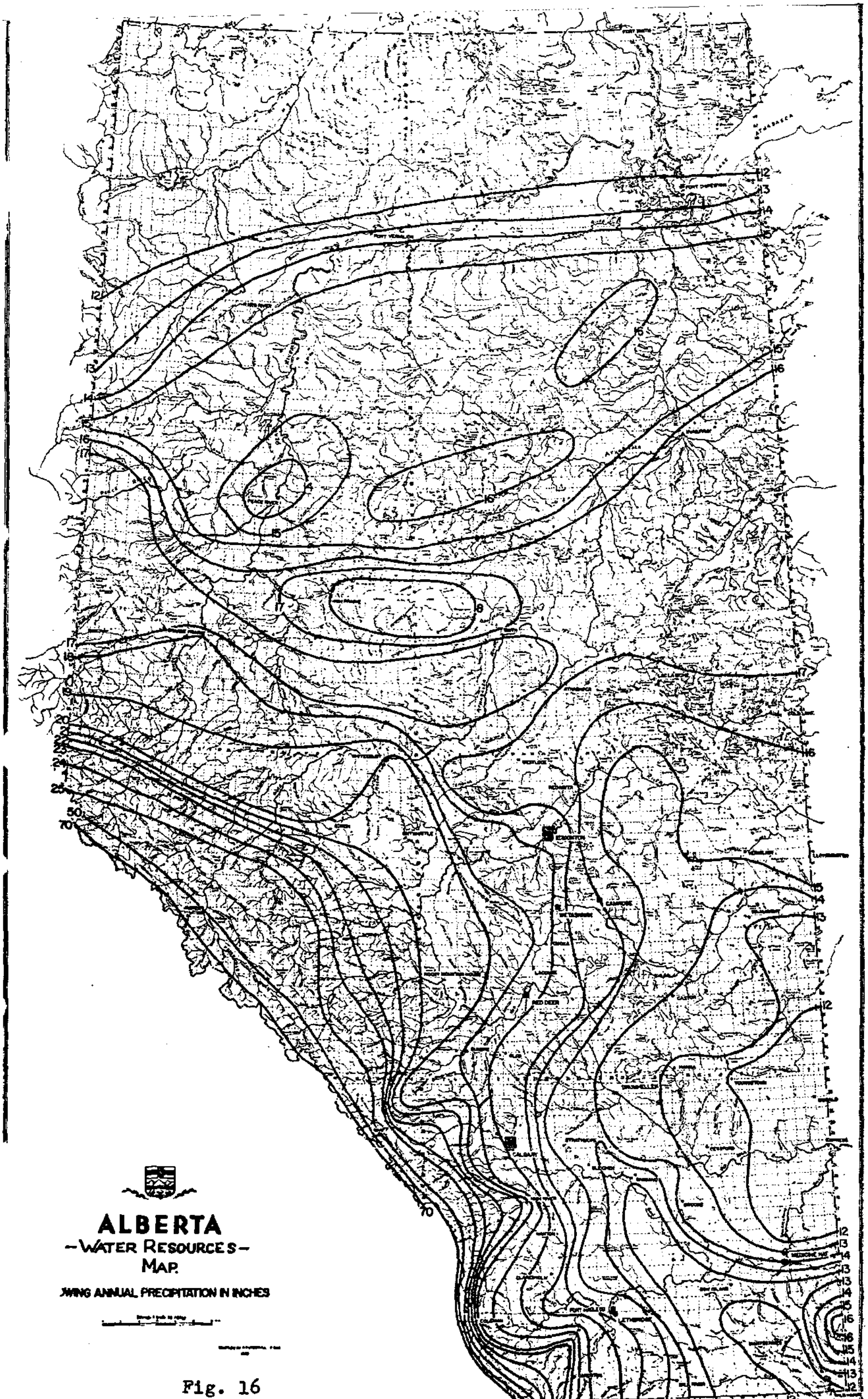

ALBERTA
-WATER RESOURCES-
MAP
WING ANNUAL PRECIPITATION IN INCHES

Fig. 16

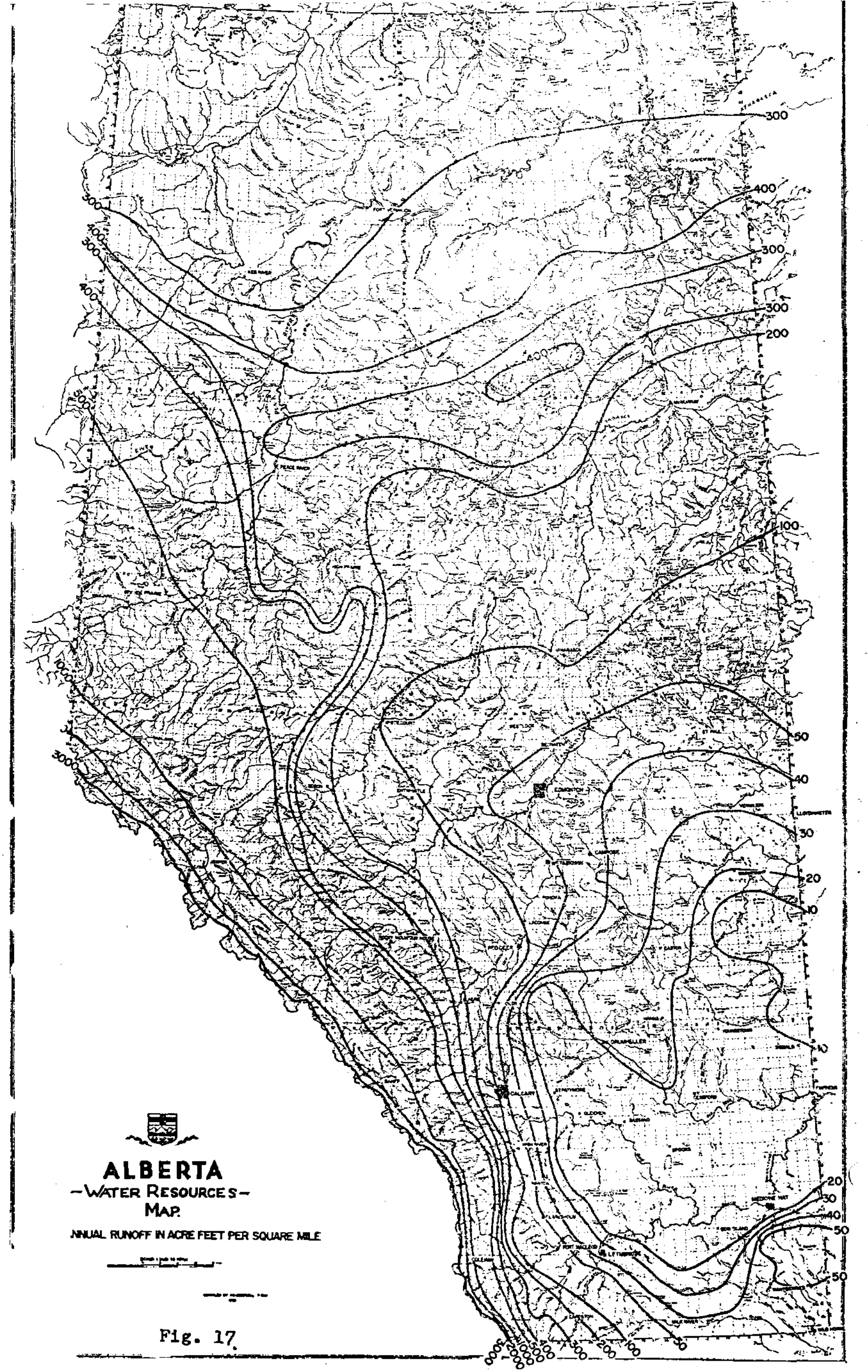

ALBERTA
-WATER RESOURCES-
MAP
NNUAL RUNOFF IN ACRE FEET PER SQUARE MILE
300
400
300
300
200
100
50
40
30
20
10
10
20
30
40
50
50
100
200
300
500
1000
2000
3000

Fig. 17

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Selected Reading Marked #

ANDERSON, H.W. and TROBITZ, H.K.
1949. Influence of some water variables on a major flood. Jour. Forestry 47 (5): 347-356.

Whether increased flood peaks and sedimentation result from forest fires has been a question of long standing, owing to the lack of quantitative methods for relating burning to runoff and soil erosion. Using multiple regression analysis, Anderson and Trobitz found a way to isolate the effects of watershed variables, particularly the density of plant cover, on peak discharge and sediment production so that the effects of burning can be measured. Behavior of 40 gaged watersheds in southern California during the major storm on March 1938 was appraised. The study included such variables as peak flow, deposition of sediment, maximum 24-hour precipitation, size and physiography of watershed, the extent and age of old burns, length of stream channels, and reservoir capacity at beginning of storm. Reservoir sedimentation was found related quantitatively to the maximum 24-hour precipitation, density of forest cover, extent of barren area, area of old burns, and area of the individual watershed. Peak discharges were found related to forest cover density, maximum 24-hour precipitation, watershed physiography, and watershed area. Under 1938 conditions, if 20% of a watershed were burned over, a peak discharge increase of 55% would be expected the first year after the fire.

ANDERSON, H. W.
1949. Does burning incre se surface runoff? Journal Forestry 47 (1): 54-57

Anderson comments on the Adams-Ewing-Huberty publication "Hydrologic Aspects of Burning Brush and Woodland-Grass Ranges in California", pointing out that some of the specific findings and methods which led to those findings needed further critical inspection. He noted that the long time effects of repeated burning in site productivity should be considered, and that southern California data not reported by the authors would have clarified the findings quoted as well as the needs for future research. Anderson points out that one study which led to the conclusion that runoff was not accelerated by burning can be interpreted differently. This conclusion was drawn, he shows, from an unclassified and unweighted sample. By rearranging the data according to the kinds of plant cover, Anderson found that burning did increase surface runoff in 3 of the 4 brush types studied.

ANDERSON, H. W.
1952. How will you have your water?
Jour. Forestry 50 (2): 135.

Refuting claims that logging has no influence on floods of the Williamette River, Oregon, Anderson shows that flood peaks actually increased 30 oercent after logging. This was shown by comparingdischarges of the logged Williamette and the unlogged MacKenzie Rivers. Even with flood control dams in place, flood peaks on the Williamette remained 13 percent above those of the prelogging period.

ANDERSON, H. W.
1955. Detecting hydrologic effects of changes in watershed conditions by double-mass analysis.
Amer. Geophys. Union Trans. 36 (1): 119-125, illus.

Measuring the effects of wildfires on reservoir sedimentation and on flood peaks is difficult because of the many variables involved, and the short term records of sedimentation and floods. Anderson shows a way of evaluating the effects of wildfire and estimating the long-term effects from the short records usually available. By this method the sedimentation of Gibraltar Reservoir, which supplies water to the city of Santa Barbara, was found to have increased markedly after wildfires, then decreased as the watershed vegetation recovered. Peak inflow to the reservoir was affected similarly, but the total annual inflow showed no change.

ANDERSON, H. W.
1956. Forest-cover effects on snowpack accumulation and melt, Central Sierra Snow Laboratory, Amer. Geophys. Union Trans. 37 (3): 307-312.

Snowpack accumulation and melt within snow courses were related to the amount of shade to the south of snow measuring points, and to the amount of shielding from trees to the north of the points. Water equivalent of the snowpack beginning April 1 was studied. By covariance analysis a high degree of association was found between the snowpack and forest cover variables. The study is interpreted in terms of timber cutting patterns that would result in maximum snow accumulation, minimum melt rate, and delayed release of snow water.

ANDERSON, H. W.
1957. Watershed management in the snow zone. Paper presented at Intersociety Conference on Irrigation and Drainage sponsored by Amer. Soc. Civ. Engin., Amer. Soc. Agr. Engin., and Soil Sci. Soc. Amer., San Francisco, Calif., April 29-30, 9 pp. (Processed).

Describes the snow management research program of the California Forest and Range Equipment Station in co-operation with the California Department of Water Resources. Reports studies under way to determine if, by how much, where, and how lands in the snow zone can be managed to improve California's water supply.

AYERS, GORDON A.

A progress report on Investigation of the influence of Reforestation on Streamflow in the State Forests of Central New York, 1949.

An area of brush and weed covered land was replanted with trees and the report deals with 15 years of data collected and the results which may be drawn from this information.

BETHLAHMY, N.

Surface Runoff and Erosion-Related Problems of Timber Harvesting, 1960.

Logging affects the hydrologic characteristics and behaviors of watersheds. The effects depend upon the methods used, degree of planning, and the attention paid to details in execution. The harmful effects of roads can be minimized by good planning. Research is needed into the type of logging best suited to a particular site and also to assess the effect of controlled burning as a meand of eliminating debris.

BURGY, ROBERT H.

Water Yields as Influenced by Watershed Management. From - Journal of the Irrigation and Drainage Division- American Society of Civil Engineers.

Hydrologic studies on small brush covered watersheds in the coast range and Sierra Nevada Mountains of California show appreciable increases in runoff can result from replacement of brush by grass. Water yield increases of as much as ten inches have been measured under favorable conditions without serious acceleration of soil erosion. These measurements practices also result in improved forage production on previously marginal land. Factors in precipitation disposal are discussed in relation to the influence of watershed vegetation on runoff.

BURGY, R. H.

The Erosion Hazard in Obtaining Increased Water Yields on Dry Lands. From - American Society of Agricultural Engineers, 51st Annual Meeting.

Rapidly expanding populations has caused scientists to look into the possibility of increasing runoff by changing vegetative cover. The increase in runoff increases the hazard of erosion. The measurement and study of cause and effects and possible remedies is covered in the report.

BURGY, R. H. and POMEROY, C. R.
1958. Interception Losses in Grassy Vegetation.
From - American Geographical Union Transactions, 1958.

Studies of the interception process in grassy species are reported for a series of laboratory tests. Procedures, equipment, and techniques were developed to determine the magnitudes of rainfall interception on grasses and to measure the resultant losses. It was found in vigorously growing grass that the evaporation of a given amount of intercepted moisture was accompanied by a like reduction in the amount of evapotranspiration from the plants. Total moisture use was approximately the same in plots with wet and dry leaf surfaces. The interception storage component and precipitation passing through the vegetative canopy as combined stemflow, throughfall and drip (STD) were measured to determine the relationships and magnitudes. Storage capacities were observed to agree essentially with those reported by other investigations although some variations can occur with different storm types and intensities. Value of STD were found to be quite significant even at the beginning of small storms.

COLMAN, E. A.
1953. Vegetation and Watershed Management. New York, N.Y., 412 pp., illus. #

Examining the close relationship of vegetation to water supply and control, Colman's book provides the first systematic estimate of the opportunities and methods of managing vegetation on watershed lands.

The volume points out how the management of vegetation is related to the control of water in streams and ground-water basins. It describes the influence of vegetation on the hydrologic processes of interception, infiltration, soil-water drainage and storage, evapo-transpiration, surface runoff, and erosion. It indicates how proper management can augment ground-water supplies, check soil erosion and the siltitation of rivers and reservoirs, and reduce flood peaks.

Colman analyzes the significant experimental work done in the United States and abroad that bears on vegetation management as it affects the control of water on the land. He places this research against the background of the current water situation, stressing those aspects which the treatment of vegetation can favorably affect - flooding, extreme seasonal fluctuations of streamflow erosion, etc. Research sections conclude with summaries showing what has been achieved and the further research needed before vegetation management can be widely applied.

COLMAN, E. A.
1954. Water control and timber management. #
45th Annual Western Forestry Conf. Western Forestry and Conserv. Assn. Proc. 1954: 24-26.

Discusses ways in which timber production can be integrated with land management for controlling water flow in the western United States.

COLMAN, E. A.
1953. Watershed management in California. Statement of joint meeting of California State Board of Forestry and the State Water Resources Board, January 8, 1954. 25 pp. (Processed). #

Colman appraises the overall watershed management problem in California and methods of solving it. He explains the functions of watershed management, what can happen without it, and what can be done to maintain, repair, and improve watershed conditions. He discusses the water problems, opportunities for water yield control, and the research needs of the 4 water-producing regions of the state, the chaparral, brush and woodland-grass, timber below the snowpack level, and the snowpack lands. After summarizing the past and present watershed research in California, Colman recommends that (1) research be put on a more sound,,long-time basis; (2) a statewide watershed survey be made to pinpoint watershed management problems; (3) a handbook be prepared to summarize our present knowledge of watershed management for use by the people on the land; and (4) research be strengthened.

COLMAN, E. A.
1955. Where will your water come from? Talk presented at statewide meeting of County Agricultural Commissioners, Quincy, Calif., June 8, 1955. 6 pp. (Processed).

Noting that forestry has progressed from the sate of "cut out and get out" to the stage of orderly management of all wildland resources, Colman discusses the struggle to provide adequate water for California, and the part that forest management can play in improving water yield. He tells the importance of forest cover in regulating water yield in southern California, in the forest belt below 5,000 feet and in the snow zone above 5,000 feet, and describes research that is under way and planned to increase water yield in these areas.

COLMAN, E. A.
1955. Operation wet blanket: proposed research in snowpack management in California. Paper presented at Pacific Southwest Regional Meeting. Amer. Geophys. Union, Berkley, California, February 5, 1955. 10 pp., illus. (Processed).

Discusses possibilities of impeoving water yield on snowpack lands, and the need for snow research in California. Proposes a research project on the physics of snow and the water-yield consequences of snow management with particular reference to logging patterns. A letter-size map shows the extent of the major water-yield areas in California, together with their acreages and estimated average annual water yield. (this map is reproduced on the inside front cover of this report).

CROFT, A. R. and MARSTON, R. B.
Some recharge Phenomena of Wasatch Plateau Watershed - in Transactions of American Geophysical Union, 1943.

One of the biggest gaps of our knowledge of hydrology of high watersheds is the lack of understanding of the phenomena which occur from the time a deposit of snow begins to melt and the time that part of the melted snow appears as streamflow. This paper reports the measurements and observations of some of these phenomena on a 99 acre watershed in Central Utah.

CROFT, A. R.
1948. Water Losses by Stream Surface Evaporation and transpiration by Riparian Vegetables.

For the period August to October, 1944, evapotranspiration losses from the streamflow in Farmington Creek in Northern Utah have been estimated to be about one-third of the total streamflow. Observations included streamflow, wet and dry bulb air temperatures, evaporation and water temperature. The analysis involved consideration of fluctuations in streamflow diurnally, seasonally with changes in weather, and with freezing leaves.

CROFT, A. R. and HOOVER, M. D.
1950. The Relation of Forests to our Water Supply. Presented to Society of American Foresters.

Public concern and a demand for water has demonstrated to the Foresters that the water from the lands may have a value equal to or greater then the timber. The object of forest management for maximum water production is to get the maximum amount of water into the soil reservoir and on the other hand take the minimum amount out by evaporation. This would permit the maximum amount to percolate through the soil and reach the streams to form streamflow. No problem of the future is greater than that of sustaining a usable water supply.

CROFT, A. R. and MONNINGER, L. V.
1953. Evapotranspiration and other water losses on some Aspen Forest Types in Relation to Water Available, for stream flow.

This paper reports the effects of altering on forest cover in Utah on evapotranspiration losses, overland flow, erosion, and mantle storage deficits during three successive growing seasons. These date, together with supplemental measures of winter precipitation and estimates of evaporation from snow, provided a basis for estimating amounts of water available for stream flow. Removal of aspen trees, leaving herbaceous understudy and litter undisturbed, reduced evapotranspiration losses and increased the amount of water available for stream flow by about four inches without seriously increasing the overland flow or soil erosion during summer rains. Removal of the remaining herbaceous cover further reduced evapotranspiration losses and increased the amount of water available to streams by an additional four inches but resulted in an undesirable increase in summer rainfall runoff and soil loss.

DILS, R. E.
A guide to Coweeta Hydrologic Laboratory,
For U.S.D.A. - Forest Service,
South-eastern Forest Experiment Station. #

This report deals with the projects and research undertaken by the Coweeta Hydrologic Laboratory, their results and their future.

DILS, R. E.
1953. Influence of forest cutting and Mountain Farming on some Vegetation, Surface Soil, and runoff characteristics.
For - South-eastern Forest Experiment Station,
U.S.D.A. - Forest Service. #

The need for hydrometric and meteorological data has become apparent when reasearchers started to investigate the effects of vegetation on runoff. Only small specially prepared areas have sufficient data available to assess the results. Experiments on the drainage areas yield various conclusions as to the effect of various treatments on runoff yields. It is impractical to leave all the land in forests no matter how excellent the supply of water thus assured would be. Land must be used, but must be carefully managed to assure the most good for the greatest number of people.

DUNFORD, E. G.
1955. A Watershed Research Program for the Pacific Northwest.
From Proceedings of 1955 - Society of American Foresters Meeting. #

In 1955 the area began research into the problem of Watershed Management. The shortage of water in the Pacific Northwest for development was one of the problems requiring solution. It has been found possible to increase the runoff and to control to some extent the rate of runoff by forest management. Research is required to prove the effectiveness of this control in the Pacific Northwest.

DUNFORD, E. G.
1960. Effect of Logging and Forest Roads on Stream Sediment.
To - Water Quality Conference, Pullman, Washington.

Logging alters the forest environment in two important respects, (1) more water is made available for streamflow because of reduced interception by tree crowns and lowered moisture demandsfor tree growth, and (2) normal movement of water through the soilis obstructed or diverted. The second of these effects often leads to erosion and stream damage.

DUNFORD, E. G. and WEITZMAN, SIDNEY
1955. Managing Forests to control Soil Erosion.
From - Water, U.S.D.A., 1955.

The undisturbed forest best exemplifies the controls of erosion that operate most effectively. However, forest use means that these natural controls are changed and the managing of these changes to minimize or control erosion creates a problem. This paper deals with the problem and the means of control.

FLETCHER, HERBERT C. and ELMEFORF, HAROLD B. #
1955. PHREATOPHYTES - A serious problem in the west.
From - Water, A year book of Agriculture, 1955, U.S.D.A.

Phreatophytes means"well plant". These plants grow mainly along stream courses, where their roots enter the capillary fringe overlying the water table. They consume large amounts of water which could be conserved and put to beneficial use. This report points out that in the Western States some 11,090,000 acres of phreatophytes waste an estimated 16,750,000 acre feet of water per year. Experimental development of the conservation procedures necessary to save this waste are needed. The use of chemicals to control these plants appears to hold promise. These phreatophytes have been used successfully in erosion control structures but could be replaced by other, less water hungry plants.

The saving of the water used by non useful phreatophytes presents another gosl for development of the best use of water resources.

GARSTKA, W. O., LOVE, L. D., GOODELL, B. C. and BERTLE, F. A.
Factors Affecting Snow Melt and Streamflow. #
For - Fraser Experiment Station, 1958.
U.S.D.A. and U.D.D.I. (Bureau of Reclamation).

This is the fourth report prepared on research being conducted on the Fraser Experiment Station at Fraser, Colorado, and deals with the period 1947 to 1953 inclusive.

Analysis of runoff hydrographs show the major importance of long-term recession flows in the snow melt hydrographs. Relations are developed between the daily snow melt hydrographs and the melt-causing meteorological factors that lead to the development of techniques for forecasting the shape of the snow melt hydrograph is explored for one year when detailed mapping of the snow-covered area was pursued. The effect of evaporation during the snow melt season was analyzed by use of Light's equation. Instrumentation at the station is described and samples of the available data are shown.

Work is continuing to determine the effect of forest management on the water yielded from the snow-fed drainage basin.

GOODELL, B. C. and WILM, H. G.
How to get more snow Water from Forest Lands. #
From – The Year Book of Agriculture, "Water", 1955.

Snow provides winter protection for young trees and abundant moisture in spring and early summer, and the forest in its turn affects the accumulation and melting of snow in many ways. Snow stored in the forest bears a close relation to water yield of streams. Losses of snow from the forest canopy by interception, evaporation and sublimation present a source of water which may be used for streamflow. Removal of timber increases total streamflow, peak flows and erosion potentials. The control of this timber cutting presents a method of increasing water yields from snow.

GOODELL, B. C.
A preliminary report on the First Year's Effect of Timber Harvesting on Water Yield from a Colorado Watershed.
For – U.S.D.A. – Forest Service.

This report summarizes the effect of 12 years streamflow records before harvesting and one year after completion of the timber cutting on the Fool Creek watershed in Colorado. Increases in total streamflow occurred both in 1956 and 1957. The increases occurred mainly during the spring runoff but a smaller increase occurred throughout the entire year. The peak discharge increased measureably the first year but decreased slightly with control during the second year. Sediment yields have been low since cutting. Snow accumulation increased on thecut strips as expected.

GOODELL, B. C.
1958. Watershed Studies at Fraser, Colorado.
From – Proceedings, Society of American Foresters, 1958.

The first year since completion of cutting on the Fool Creek Watershed in Colorado indicates that for the particular locality and climate, steep cutting in a dense forest stand significantly affected water yield from winter snow fall. 39% of the watershed was cleared and if all the increase can be ascribed to this area an 80% increase in the average pretreatment yield occurred. This study tends to confirm results of Wagon Wheel Gap where an increase in water yield was concentrated mainly during the spring runoff period with slightly higher summer flows.

HAMILTON, E. L. and HOWE, P. B.
1949. Rainfall Interception by Chaparral in California.
Calif. Dept. Nat. Resources, Dov. Forestry, 43 pp., illus.

Rainfall intercepted by shrubs was measured at 3 locations in California. In the central Sierra Nevada foothills, 81 percent of an average annual rainfall of 42 inches reached the soil as throughfall and drip from the brush cover, and 14 percent as flow down the stems; 5 percent was lost by evaporation from the vegetation. On another area in the same vicinity with a different type of brush cover, 8 percent was interception loss. In San Gabriel Mountains in Southern California, 81 percent of an average annual rainfall of 22 inches reached the soil as throughfall and 8 percent as stemflow; 11 percent was interception loss. Amounts of throughfall, stemflow, and interception loss varied directly with storm storm size.

HAUPT, H. F.
A method for controlling Sediment from Logging roads, 1959.

Controlling sediment from logging roads in Ponderosa pine lands in in southern Idaho is an acute problem. The method of control and design is proposed to minimize the erosion problem of logging roads. The method was developed from an understanding of the processes involved in erosion from roads and how these processes after an area has been logged.

HEWLETT, J. D.
1958. Pine and Hardwood Forest Water Yield.
From - Journal of Soil and Water Conservation, 1958.

Two watersheds comprising 70 acres at Coweeta Hydrologic Laboratory in North Carolina have been cleared of native hardwoods and converted to pine to find out the effect of the change on the streamflow from the area.

HOPKINS, Walt.
More good Water.
For U.S.D.A. Forest Services.

#How much water can be produced by research-guided management?". This question requires an early answer, and this paper deals with the equipment and experiments being made.

HUMPHREY, R. R.
Forage and Water.
Presented at 83rd annual meeting of American Forestry Association.

Vegetation may affect water in three principal ways, by interception, retention and by evapotranspiration. Different types of forage vegetation use different amounts of water. Native grass uses less water than cultivated crops while shrubs and trees use more water than grasses. Vegetation along stream channels can use more water than that evaporated from the surface of freewater. Runoff has been increased on plots due to a change in the vegetative cover.

HURSCH, C. R.
1951. Research in Forest Streamflow Relations.
From U.N.A., SYLVA, 1951.

Less is understood about the management of water than any other resource. High yielding streams are generally associated with forest lands. The report points out the need for further research and mentions the strides that have already been made. The effects on streamflow, of steep land farming, woodland grazing, logging and the effect of removing all or part of the natural vegetation, is discussed in relation with watershed management.

JOHNSON, E. A. and KOVNER, J. L.
1956. Effect on Streamflow of cutting Forest Understory.
From - Forest Service, 1956.

In the Coweeta Hydrologic Laboratory experiments were carried out to show the effect of cutting the dense understory from a forested area. Later the understory was allowed to grow back. Six years later it had reduced to 1.24 inches and it is expected in time to return to its former rate once the understory has reached its former density. Where the objectives of watershed management favour increased streamflow through special cutting of forest vegetation, there is evidence that treating the understory vegetation only provides worth while gains.

KOTOK, E. I.
1931. Vegetative Cover, the Water Cycle and Erosion. Agr. Engin. 12 (4), 112-113.

Reviewing the controversy between foresters and engineers over the effects of forest cover in regulating a streamflow and preventing floods, Kotok cites George Marsh's work "Man and Natyre" (1863) as the first to recognize accelerated erosion as a prime destructive force in watershed management. Kotok discusses the Wagon Wheel Gap experiment and reviews Lowdermilk's experiment that showed the value of plant litterin aiding infiltration and preventing accelerated runoff and erosion. In California, Kotok concludes, plans for the state-wide water system require quantitative knowledge of plant cover as a safeguard against accelerated erosion.

KOTOK, E. I.
1931. A report to the Hoover-Young Commission on Water Resources, describing forest and wild lands as the principal source of water in California, summarizes the area, character of cover, and ownership of these lands. Discusses the relationship of land management to the water crop, and the obligations of federal, state, and local agencies for watershed management. Cites preliminary results of studies showing that the destruction of plant cover by burning, overgrazing, and lumbering may greatly accelerate surface runoff and erosion. It states the need for expanded studies on the problems of water and forests, and for men technically trained to carry on this work.

KOTOK, E. I.
1939. Watershed Management for Water Production. South. Calif. Water and Soil Conserv. Conf., Los Angeles, Calif. Nov. 9, 1939: 1-4. (Processed).

Kotok discusses the history, status, and needs of watershed management work and reviews the significant federal legislation, from the creation of the Forest Reserves in 1891 to the flood control Act of 1936. He defines a watershed and lists watershed-management objectives. In the early stages of watershed-management, he says much work will go toward curbing destructive land uses and healing the sore spots created by past abuses, as shown by Swiss, Austrian and French experience. At the same time we must carry on research to gather the factual data needed before we can write a watershed-management prescription for any given parcel of land.

KOTOK, E. I.
1932. Solving the Forest and Water Riddle.
Amer. Forests 38 (9): 488-491, illus. Also published as solving the water riddle. Illus. Canad. Forest and Outdoors 28 (11): 415-418.

After explaining the basic reasons for different opinions about the effects of forest cover on flood flows, Kotok surveys the scope and seriousness of land abuse in the United States. Examples of erosion accelerated by the white man's use of the land are cited. Against the back ground Kotok points out that plant cover, which he terms the keystone of conservation, must be maintained on forest and range lands in order to keep rivers and harbors navigable and to protect our water resources. He calls for a co-ordinated land policy to make effective conservation possible.

KOVNER, J. L.
1956. Evapotranspiration and Water Yields following Forest Cutting and Natural Regrowth.
From - Proceedings - Society of American Foresters, 1956.

Evapotranspiration from a natural area should depend to some extent on the nature and condition of the vegetation but at present it is impossible to prove this from a theoretical approach. Experiments at Coweeta Hydrolic Laboratory have shown that a change in vegetation can markedly alter the transpiration from a given watershed. This basic principal may have a very practical application in Watershed management aimed at increasing streamflow.

The effects of a 17 year watershed experiment Coweeta shows what happens to the water yield when the forest stand is cut down and allowed to grow back.

LARSEN, L., LULL, H. W. and FRANK, B.
Some Plant-Soil-Water Relations in Watershed Management, 1952. #
From - U.S.D.A. - Forest Services.

This publication has been prepared in response to the growing need by land managers, engineers, hydrologists and others for more adequate information on how forests and range watersheds function. In an attempt to bring together the available technical knowledge of the more important natural principles which appear to govern the interrelation of plant, soil and water. It also provides a means for appraising the effects of given land conditions, treatments, and uses on stream behaviour.

LOVE, L. D.

Can Watershed Management Alleviate the need for larger storage projects.
From - Second Annual Water Resources Conference, Montana State University, 1957.

A change in the character of water yields from a watershed could conceivably alter the need for large storage projects.

Watershed Management activities, coupled with changes produced in temperature, wind, humidity and solar radiation on timber harvested areas, exerts a profound influence on the daily and seasonal streamflow from snowmelt in the mountain storage reservoirs.

The care and use placed on these mountain lands today will form the basis on which the rising generation can enjoy life, liberty and the pursuit of happiness.

LOWDERMILK, W. C.

1928. Forest Litter aids in Conserving Water for California farms. U.S. Dept. Agr. Yearbook, 1928: 326-327.

Noting that water is the limiting factor in the development and growth of California, Lowdermilk recognizes the need for more storage facilities, but points out that the principal source of water for agriculture will continue to be wells tapping the great underground basins of California's valleys. Controlled experiments show, he reports, that muddy water will not percolate effectively to recharge underground basins, and that maximum recharge is achieved by keeping streamflow clear.

LOWDERMILK, W. G.

1928. The Water Cycle; a discussion of theoretical considerations and the point at which practical application may be made. Jour. Forestry 26 (3): 352-354.

In this paper Lowdermilk analyzes the sources of rainfall, the water cycle in nature, and the best point at which man can act to regulate the cycle for his own benefit. Theoretically, he says, man cannot control the moisture brought by cyclonic winds from the ocean to land. Practically, however, man can control the moisture at the point where rain strikes the land surface - where it becomes either surface flow or seepage. Calling vegetation "... our most dependable ally in the control of the absorption of precipitation waters", Lowdermilk points out that the destruction of vegetation and conditions for its regrowth may cause great acceleration of erosion. Measuring the extent of erosion acceleration he says, gives us an index to the extent of our control over precipitation.

LOWDERMILK, W. C.
1929. Further studies of factors affecting surficial runoff and erosion.
Internatl. Cong. Forestry Expt. Sta. Proc. 1929: 606-628, illus.

After referring to previous attempts, dating from 1841, to measure the effects of plant cover upon surface runoff, erosion and infiltration, the author reports findings of plot studies at Devil Canyon, in southern California, then describes the Berkley experiment which was designed to measure the influence of forest litter on rainfall disposition. At Berkley soil-filled tanks were used and artificial rain was provided. Runoff from the tanks with burnedover, bare soil was 3 to 30 times that from tanks with littercovered soil. Erosion from the bare soil was 50 to 6,000 times as great as from the covered soil. The "sponge" effect of forest litter in absorbing rainfall was found unimportant in comparison with the ability of the litter to maintain the maximum infiltration capacity of a soil profile. How the litter accomplished this was shown by a separate experiment in which muddy and clear waters were led to pass through columns of soil. The muddy water percolated at a small fraction of the rate for clear water, owing to the deposition of suspended particles that tended to seal the soil surface. This proved the previously unrecognized function of forest litter in stabilizing the soil surface, thus keeping rainwater clear, and maintaining the soil's infiltration capacity.

LOWDERMILK, W. C.
1931. Studies of the Role of Forest Vegetation in surficial runoff and soil erosion.
Agr. Engin. 12 (4): 107-112.

Lowdermilk explains the interdependence of vegetation and soil, the geologic norm of erosion, accelerated erosion, the formation of erosion pavement, and the reasons for using runoff plots instead of entire watersheds to measure specific factors affecting surface runoff and soil erosion. The instrumentation of plots and soil tanks (now called lysimeters) used at Berkley and North Fork is described, and the results of experiments showing the relation of runoff to slope of the ground and intensity of rainfall are presented. Lowdermilk concludes that the highest community interest, in the long run, will be served by discovering and specifying the conditions under which land may be cultivated or used otherwise without inducing accelerated erosion.

LOWDERMILK, W. C.
1931. Managing brush and forest lands primarily for yield of irrigation water.
2nd National Water Users Conf. San Francisco, February 9-11, 1931, 14 pp. illus. (Processed).

Stating that Water is becoming more and more the chief natural product from the mountains of western United States, Lowdermilk presents a comprehensive review of watershed management - its importance; establishment of the National Forests to protect both water and timber supplies; questions about the relations of plant cover to water yield; and the studies under way and planned to answer these questions. He continues with a discussion of the complexity of problems to be solved; analysis of the supply and disposition of meteoric waters; findings about runoff, erosion, retention, and evapo-transpiration; and the importance of making a full accounting of evaporation and transpiration losses. Water balance sheets for several experimental areas are included.

LOWDERMILK, W. C.
1933. Forests and Streamflow, a discussion of the Hoyt-Troxell report. Jour. Forestry 31 (3): 296-307. (Also in Amer. Soc. Civ. Engin. Proc. 59 (3): 484-490.

Hoyt and Troxell concluded that after denudation of mountain watersheds in Colorado and southern California (1) total runoff was increased, (2) more than half of the increase occurred in non-flood periods, (3) maximum daily discharge was increased, (4) summer runoff was increased, (5) summer minimum flows were increased and prolonged, (6) winter minimum flows in Colorado were not affected, and (7) erosion was increased by surface runoff. From these results they deduced that (a) forest maintenance for "conservation of the water supply" may have an effect opposite to the one desired, and (b) where water supply is a controlling economic factor, careful study is needed as to whether the acknowledged benefits of maintaining forest cover may not be outweighed by the water consumed by forest growth.

Lowdermilk reviews the Colorado and southern California studies reported and analyzez the author's interpretation of geologic, soil, and vegetation factors and watershed treatment. He points out that the "denuded" watershed in Colorado was never really denuded. He notes inadequacies in the measurement of rainfall in southern California study and the authors' failure to distinguish chaparral vegetation growing in the drained soils of mountain slopes from the riparian vegetation that grows within reach of abundant water in the stream bottoms. Lowdermilk states that destruction of the riparian vegetation stops transpiration, and causes an immediate increase in streamflow; but this is not true of slope soils because they drain quickly to field capacity and no water is available for release to streamflow when the vegetation is removed by summer fires. In view of the importance of the questions raised, particularly in southern California, Lowdermilk calls for a thoroughly executed study to answer the questions raised by the findings of Hoyt and Troxell.

LOWDERMILK, W. C.
1933. Studies in the Role of Forest Vegetation in erosion control and Water Conservation.
5th Pacific Sci. Cong. Proc. 5: 3963-3990.

After reviewing the status of knowledge on the relation of forest vegetation to climate and streamflow, Lowdermilk notes that contrary conclusions as to several aspects of the relation have been reached by serious students. These divergent conclusions result, he says, from a misunderstanding of the basic factors affecting streamflow. To resolve the differences, Lowdermilk proposes studies of the hydrologic processes in undisturbed and disturbed areas suitable for comparison. He defines geologic and accelerated erosion, analyzes the supply and disposition of precipitation, and describing runoff and erosion studies made in China and in California. From these studies he concludes that the destruction of plant cover by fire, grazing, cultivation, or other land uses, reduces infiltration, increases surface runoff, and accelerates soil erosion. In regions of critical water supply, he says, the management of watersheds for maximum beneficial yield of water must become paramount.

MARSTON, R. B.
1952. Ground Cover Requirements for Summer Storm runoff Control on Aspen sites in n0rthern Utah.
For - Journal of Forestry.

It has long been recognized that living plants and litter generally minimize overland flow and erosion. The specific degree to which the ground surface on forest and range lands should be kept covered by vegetal material to prevent excessive storm runoff and accelerated erosion, however, is not so well known. Results of studies conducted on the Parrish Creek watershed in northern Utah shed some light on the amount of ground cover which appears to be necessary for watershed protection.

Marston, R.B.
1958. The Davis County Experimental Watershed Story.
For Intermountain Forest and Range Experiment Station, U.S.D.A.

The purpose of this guide is to sketch the flood history of the area; to explain the significance of the restoration of damaged watersheds in preventing devastating floods and to describe the research program aimed at determining how watersheds function. The program covers the significance in plant cover in flood prevention, the disposition of precipitation and the consumptive use of water by plants. The results of experiments completed and projects under way are discussed.

(Get graph from page 29 showing effect of cutting, and table 3)

MINER, N. H. and TRAPPE, JAMES M.
1957. Snow Interception, Accumulation, and Melt in Lodge Pine forests in the Blue Mountains of Eastern Oregon.
U.S.D.A. - Forest Research Note N 153, 1957.

The effect of forest cover on the amount of precipitation reaching the forest cover varies with the denseness of the forest canopy. Snow melt characteristics are different under different covers.

MUNSON, S. M.
1938. Kings River branch watershed study units.
U.S. Forest Ser. Calif. Forest and Range Expt. Sta.
Tech. Note 11. 19 pp., (Processed).

After describing the need for additional irrigation water in the upper San Joaquin Valley of California, water which is obtainable from the adjacent Sierra Nevada Mountains, the author describes research undertaken at the Kings River Branch Station, east of Fresno, to develop principles for managing the mountain watersheds for the maximum yield of clear, usable water. Munson reports the objectives, status, and procedures of the project, and describes the Big Creek and Teakettle Creek groups of watersheds.

NORTHEASTERN FOREST EXPERIMENT STATION, 1958.
Annual Report - Upper Darby, Pa.
For - U.S.D.A. - Forest Services.

This report deals with the various problems and research work being carried out at this station. Fernow experimental plots show an increase in water yield by commercial cutting of four plots.

PACKER, P. E.
Some terrain and Forest Effects on Maximum Snow accumulation in a Western White Pine Forest.
From Western Snow Conference Proceedings, 1960.

The maximum amount of water stored as snow in a western pine forest is influenced by the degree to which timber cutting opens the forest canopy. An understanding of how forest and its treatment affects the accumulation characteristics of snow is requisite to the development of management methods.

PACKER, P. E.
Watershed Management Problems in the Rocky Mountains Region, 1959.

A description of the problems encountered and the research required in Watersheds in the Rocky Mountains region.

PIERCE, R.S., LULL, H.W. and STOREY, H.C.
Influence of land use and Forest Condition on Soil freezing and Snow depth.
From - Forest Science, 1958.

Frost is much more common in open lands than under forest stands and when frost occurs in forest soils, it usually does not penetrate as deep. Four types of frost were noted during the collection of data in the field but this report deals only with concrete frost.

The relative incidence, depth and persistence of concrete frost in the various land use and forest conditions studied provide new insights into forest frost relationships and responsible forest influences, and suggest broad management practices for minimizing frost.

REINHART, E. G.
1958. Calibration of Five Small Forested Watersheds.
For - Transactions American Geophysical Union.

On the Leinow Experimental Forest in West Virginia, five forested watersheds are close together, for the most part contiguous, and are similar in topography, soil, forest cover, and stream flow characteristics. The methods and problems of calibration should interest other investigators in this field because seldom has a group of watersheds been calibrated for forest watershed research to determine the effects of range cutting treatments. After calibration, four watersheds will be cut over, using different cutting practices. One watershed will be used as control. Effect of treatment on the stream flow will be measured. Methods of Wilm and of Kovner and Evans were used to determine the length of calibration period based on anaylis of annual monthly peak and low flows. Problems of treatment assignment are are discussed.

REINHART, K.G. and PHILLIPS, I.J.
Poor logging makes Muddy Streams.
From - Conservation Magazine, 1959.

Forest practices do affect the quantity and quality of streamflow, total flows, peak flows and low flows according to the Fernow experiments. Logging unless carefully controlled causes erosion and hence increases the turbidity of the water.

ROSA, J.M. and CROFT, A.R.
1956. Water yield and Public Land Management.
From - Journ. of Soil and Water conservation.

This country has become vitally concerned with water for every human need. Droughts and short water supplies have plagued many regions. Land management agencies are faced with the mounting pressure to make watersheds yield all the water that can be safely produced without unleashing serious floods or erosion. Over the years much has been spent to restore the plant cover to damaged watersheds but some water users are now wondering if some, "useless" vegetation isn't being watered from their pot. The paper deals mainly with past grazing use and its effect on water yield.

ROWE, P.B.
1941. Some factors of the hydrology of the Sierra Nevada foothills. Amer. Geophys. Union Trans. 1941 (1): illus.

Reports on hydrologic studies by the Forest Reserve at North Fork, California, to determine the influence of woodland-chaparral on water yield, surface runoff and erosion. The methods and instrumentation used as described and the results of studies are presented. It was concluded that: (1) size of area, character of precipitation, and soil moisture are important factors in the hydrology of the Sierra Nevada foothills; (2) undisturbed woodland-chaparral cover is effective in the control of surface runoff, erosion and floods; and (3) woodland-chaparral cover is highly beneficial in the production of usable water.

In the following discussion section (pp. 100-101) F. J. Veihmeyer states that 2 plots are not enough on which to base conclusions, as shown by his own experience; extension of plot data to large areas is hazardous because flow retardation of the kind reported will not prevent floods; and he has found direct evaporation from bare soil to be very small in comparison to evapotranspiration losses. He interprets tha data as showing that the few small plants grew on the burned plots depleted the soil moisture to the same extent as the many large plants on the undisturbed plots. To these contentions Rowe replies, in the author's closure, that 5 pairs of plots were used at North Park, and that their data were in quantitative agreement with the results from over 400 plot-years of data from 75 plots in 12 different chaparral areas throughout the state. The total water yield from anually burned and unburned plots was approximately the same, but the quality and distribution of water yield were definitely better from the undisturbed than from the burned areas.

ROWE, P.B.
1943. A method of hydrologic analysis in watershed management. Amer. Geophys. Union Trans. 1943 (2): 632-643, illus.

An approach to hydrologic analysis for the purpose of determining the physical effects of watershed conditions, particularly those subject to change through land management, on floods and streamflow. A detailed accounting of the course of precipitation is made, from its occurrence to its final disposition in watershed. The determination of the character and extent of the effects of watershed conditions on floods and streamflow is dependent upon the evaluation of the physical elements and processes controlling them. The techniques used and sequence of procedures followed can be adapted to different watershed conditions and to the objectives of individual analyses.

Essential steps of the procedure include (1) delimination of watershed complexes of similar hydrolic characteristics based upon such factors as precipitation, vegetation, soil type, geologic type, and land use under present and expected future conditions; (2) construction of infiltration-capacity curves of individual hydrologic complexes; (3) determination of storm-precipitation patterns and streamflow hudrographs, interception and evaporation losses, depression storage, available water storage capacities of the soil and rock, and surface and subsurface runoff relations; (4) adjustment of infiltration-capacity curves of the hydrologic complexes to measured storms and stream discharges; (5) application of established precipitation. infiltration, runoff, and soil water relations to streamflow predictions for present and expected watershed conditions.

ROWE, P.B.
1948. Influence of Woodland Chaparral on Water and Soil in central California.
Calif. Dept. Wat. Resources, Div. Forestry, 70 pp. illus.

Reports a 9-year study of water yield and erosion as affected by chaparral burning in the Sierra Nevada foothills. Runoff and erosion were heavy in the burned plots, and infiltration was reduced. Little surface runoff and no appreciable soil loss occurred on the unburned plots. Although 20% of the annual precipitation was intercepted by brush cover, 15 percent reached the soil as strm-flow; consequently, only 5 percent was lost by evaporation. Percolation to 4-feet depth was 39 percent of annual precipitation on the burned plots and 58 percent on unburned plots. Thus the brush covered areas yielded more water than the burned areas, and at the same time protect the soil.

ROWE, P.B. and COLMAN, E.A.
1951. Disposition of Rainfall in the Two Mountain areas of California.
U.S. Dept. Agr. Tech. Bu. 1048. 84 pp., illus.

An evaluation of some of the hydrologic processes involved in the disposition of rainfall in the Two Mountain areas. One area is near North Fork in the Sierra Nevada of Central California, and one is in the San Dimas Experimental Forest in San Gabriel Mountains of southern California.

The first part of the study was made on hillside plots in forest (ponderosa pines) and brush types of the two areas. These studies showed that annual burning of the vegetation, although reducing interception loss, did not appreciably affect total evapo-transpiration loss. It did reduce the infiltration capacity of the soil, thereby increasing surface runoff. The reduced interception loss resulted in increased water yield (surface runoff plus seepage), but this increase was achieved by greatly increased surface runoff and erosion, and correspondingly reduced underground water yields. Removing the vegetation, trenching to prevent root intrusions, and maintaining a bare soil surface on the brush plots eliminated all interception and transpiration loss. Total evaporation loss was reduced but as in the case of annual burning, surface runoff and erosion was greatly increased. During the long dry period of each summer, the bare soils lost appreciable quantities of water from all depths, but drying was slower and less complete in deep than in shallow soils. Total water yield was greatest from the plots with bare soil. However, underground yield was greatest from plots with natural vegetation.

The second part of the study was carried on in Monroe Canyon, a typical 875-acre brush-covered watershed of the San Dimas Experimental Forest. Average annual rainfall during the 2-year period of the study (1943-44 and 1944-45) was about 31.0 inches. Interception loss averaged about 2.4 inches per year and evapo-transpiration, including riparian loss, averaged 10.8 inches per year. Nearly 18.0 inches of rainfall was accounted for by the evaporative loss, but of this amount only about 4 inches appeared as streamflow. Thus more than three times as much water appears to have been yielded from the watershed as underground flow than as streamflow.

ROWE, P.B.
1956. Possible ways of increasing stream flow yield of the Salt River drainage by watershed modification.
Arizona Watershed Progress.
Recovering Rainfall, Part II: 197-207.

Rowe discusses means of increasing streamflow without regard to the effects that possible land treatments may have upon the land, floods, or soil erosion. For the several cover types in the Salt River Watershed he estimates the deposition of rainfall before and after cover conversion from brush and timber to grass, and the control of riparian vegetation. He urges that complete hydrologic studies be made before an action program to increase water yield is begun.

SINCLAIR, J.D., HAMILTON, J.E., HORTON, J.S., ROWE, P.B., REIMANN, L.F.
Fire - Flood Sequences on the San Dimas Experimental Forest.
For - U.S.D.A. Forest Service.

Wildfires in the brush covered mountains of Southern California have repeatedly been followed by debris-laden floods downstream, but detailed information concerning both watershed conditions and flood flows before and after the fires has usually been meager. This report describes fireflood sequence on the San Dimas Experimental Forest in the San Gabriel Mountains of Southern California. Here records of rainfall and streamflow from a watershed practically burned over in December, 1953, are available, before and after the fire. Further the behaviour of this watershed can be compared with records of rainfall and streamflow from two comparable wayersheds, one of which was partially burned in 1938 while the other one has been nearly free of fire for more than half a century.

SINCLAIR, J.D. and HAMILTON, E.L.
1954. Stream Flow Relations of a Fire-Damaged Watershed.
Presented at Hydraulic's Meeting A.S.C.E., 1954.

A wildfire in December, 1953, destroyed the brush and Forest cover on portions of a watershed in the San Gabriel Mountains of Southern California. Rains, in January, 1954, produced debris-laden flood flows from this watershed. Records of rainfall and streamflow from the partially burned watershed and from a comparable unburned drainage, before and after the 1953 fire, analyzed. The analysis showed that peak flows and storm discharges from the damaged watershed were greatly increased by the effects of the fire. The effect of the fire on erosion on the watershed also received attention.

SINCLAIR, J.D. and HAMILTON, E.L.
1955 Streamflow reactions of a fire-damaged watershed.
Amer. Soc. Civ. Engin. Proc. 81, Separate 629, 17 pp., illus.

After reviewing other studies of the relation of watershed burning to streamflow and erosion, the authors report streamflow reactions of two watersheds in the San Gabriel Mountains of Southern California before and after their partial denudation by fire in 1953. Precipitation and streamflow in these watersheds, on the San Dimas Experimental Forest, had been measured continuously for nearly 20 years before the fire, giving an excellent base for comparison of post-fire flows. The authors report and analyze the rainfall amounts and intensities, streamflow reactions, and erosion measurements for the storms of January, 1954. They conclude that (1) abnormally large peak flows bulked by debris from fire-damaged watersheds complicate the problem of flood control in Southern California; (2) the increased volume of storm discharge from fire-damaged watersheds is not an accurate measure of increased water yield because the flow were bulked with unmeasured quantities of debris; and (3) adequate wild-land fire protection in the mountains of Southern California will aid in regulating flood flows and debris movement.

STOECKLER, J. H.
Trampling by Livestock Drastically Reduces Infiltration rate of Soil in Oak and Pine Woods in Southern Wisconsin. #
For Technical Notes #556 - Lake States Forest Experiment Stations, U.S.D.A. - Forest Service.

The paper shows that a 93% reduction in the infiltration rate occurred in an Oak and Pine Forest when subjected to trampling by livestock.

STOREY, HERBERT C.
Effects of Forest on Runoff.
From - Soil and Water Conservation.

The effect of forest on runoff is dependent on the inter-relationship of a large number of factors, including the type and condition of the forest, type and amount of precipitation, topography, soils and geology, and various elements of climate. Part of the precipitation is intercepted by the forest cover, a part infiltrates the soil and some evaporates and part of the moisture runs off as streamflow. Increased runoff and change in streamflow characteristics are possible but not compatible.

STONE, E.C., WENT, F.W. and YOUNG, C.L.
1950. Water absorption from the atmosphere by plants growing in dry soil.
Sci. 111 (2890): 546-548.

The ability of Coulter pine to survive long periods of drought on soils at or below the wilting point was investigated to determine the possibility of the plants taking up water from the atmosphere. A 2-year old Coulter pine seedling, growing in a sealed container to which no water had been added for 10 months, was sealed in a chamber which enclosed the vegetative portion of the plant and in which the initial humidity could be adjusted. Measurements with a temperature-humidity sensing unit indicated a lowering of the humidity in the chamber from 98 to around 90 percent in 3 to 9 hours.

TENNESSEE VALLEY AUTHORITY - DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH.
Effect of 15 years Forest Cover Improvement upon the Hydrologic Characteristics of the White Hollow Watershed. (1951). #

In 1934 the Tennessee Authority acquired the land of the White Hollow Watershed and decided to use the area for research into the hydrologic effects of land management on the area. This program has now been under way for fifteen years and this is a report of the work done during that period. They show the effect of the improved cover on watershed hydrology in the area.

It is significant that during the 15 years of this study the improved forest and other cover resulting in the greater watershed protection has not been at the expense of overall water yield.

The greatest reduction observed was in peak flows and in the amount of sediment carried.

TENNESSEE VALLEY AUTHORITY - DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH. Technical Monograph No. 86. #

Influences of Reforestation and erosion control upon the hydrology of the Pine Tree Branch Watershed, 1941 - 1950, 1955.

The Tennessee Valley Authority started research into the hydrologic changes that would take place during reforestation of the 88 acre Pine Tree watershed in 1941. Trees were planted, erosion control works were built and good forest management was practised. The effect on surface runoff, erosion, evapotranspiration were studied. The report shows that there is some indication of a decrease in runoff due to the increased vegetative cover but a longer study is required.

A reduction in the peak flows and a retardation of those peaks has also occurred. A reduction in sediment is also noted.

TRIMBLE, JR., G.R. and SARTZ, R.S., and PIERCE, R.S.
How type of Soil frost Affects Infiltration.
From - Journal of Soil and Water Conservation, 1955. #

Hard frozen ground at times of heavy rains and quick thawing snow often cause surface runoff hazard and accompanying loss of potential ground water. Freezing of the soil does not invariably result in an impermeable medium, soils of low moisture content often become granulated and more permeable, and very wet soils have a greatly reduced permeability.

TRIMBLE, JR., G.R.
A problem analysis and Program for Watershed Management Research in the White Mountains of New Hampshire. #
From - North Eastern Experiment Station, U.S.D.A. Forest Service, Paper No. 116.

Water is a national resource that may be limited in quantity and quality of supply; at times of flood flows it can be highly destructive. Little or quantitative research has been done for the region on the influence of forest treatment on streamflow. Studies are required on on sedimentation, water quality, flood control, the hydrolic processes. This pamphlet discusses the needs and the approaches to be made to initiate a research program of watershed management.

TRIPP, N.R., and LULL, H.W.
Management problems and Opportunities on Forested Watersheds in the Northeast.
From - Society of American Foresters, 1957.

Water is the only foreseeable factor that can stop expansion of this area in the United States. 60% of the area is covered by forests so forest management can play an important part in the control of runoff from this area. A second part is the reduction in pollution and sedimentation of present supplies. Research is the key but it is a long slow process.

U.S. SENATE SELECT COMMITTEE REPORT
Evapotranspiration Reduction.
Select Committee on National Resources.

This report is divided into two parts, one dealing with Phreatophytic and Hydrophytic Plants along Western Streams and the second dealing with Vegetation Management and Water Yields in 17 states.

The first contains information concerning the growth of plants which have their roots in the ground water table, their effects on water supplies and possibilities of salvage of water through eradication.

The second deals with the opportunities for increasing water yields from watersheds in the west through management of vegetation.

WEITZMAN, SIDNEY and BAY, R.R.
1959. Soil Behavior in Forests of Northern Minnesota and its Management Implications.
For - Lula States Forest Experiment Station.
U.S.D.A. Forest Service, Paper #69, 1959.

How forest cover affects water behavior is now being studied as a part of an overall program of watershed management research in the lake States area. This report covers the first results of one phase study snow accumulation and melt in the forests of Northern Minnesota in the winter of 1956-57. The data collected shows the interrelationship between forest runoff and forest management.

WHELAN, D.E.
Effects of Land Use on Streamflow.
From - Alabama Academy of Science.

The way in which land is managed has a definite effect on streamflow. The things we do to the vegetal cover and soil, affect how much water runs off over the surface of the ground, and infiltrates into the soil profile to relieve soil moisting defects, to recharge the ground water table, and to runoff laterally into streams as subsurface flows.

WILM, H.G.
1939. Translation of Investigations and results of research into the influence of vegetation on streamflow from mountain drainage basins of Kychova and Zdechovka, 1928 to 1934 by Z. Valek.
U.S. Forest Service, Div. of Forest Mangt. Res. Trans. 365. 12 pp. (Processed).

WILSON, H.G. and DUNFORD, E.G.
1948. Effect of timber cutting on Water Available for stream flow from a Lodge Pole Pine Forest.
U.S.D.A. Publication #968, 1948.

There are two methods of increasing the available supply of water for an area. (1) transmountain diversions, additional reservoirs, etc., (2) planned watershed management. The regulation of the density of timber so that the consumption of water will not be excessive is a task for the future manager. Test plots show an increase in runoff can be obtained by planned forest management and timber cutting.

YOUNG, A.A. and BLANEY, H.F.
Use of Water by Native Vegetation. #
For - Division of Water Resources, Department of Public Works, State of California.

This is a comprehensive report on the available research data dealing with the consumptive use of water by various non-crop plants native in California and the Southwestern States of America in general. It analyses the economic and practical importance of the water use of these plants and is an important document in shaping the effective conservation and use of water in this area.

ZAHNER, R.
Managing the Forest for Soil Moisture Control.
To American Society of Foresters, 1961.

On upland forest soils, moisture depletion is essentially equal to evapotranspiration. Forest management practices which control species and stocking levels, regulate soil moisture depletion and recharge patterns. Forest hydrologists understand, in theory at least, the mechanics of water regime, and there is much evidence of the behavioral patterns of water as regulated by soil, weather and vegetation. Electronic computed programs can perhaps now be used to inventory the soil water balance.

ZON, RAPHAEL
1912. Forests and water in the light of scientific investigation.
Final report on the National Waterways Commission, pp. 205-302.
Reprinted with revised bibliography, 1927, as Senate Document No. 469, 62nd Congress, 2nd Session, 106 pp. illus.

ZON, RAPHAEL
1920. Review of the effect of forests upon streamflow, by Arnold Engler.
Jour. Forestry 18 (6): 625-633.