THESIS

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# SNOW SURVEYS AND FOREST MANAGEMENT IN THE ROCKY MOUNTAINS OF COLORADO

Submitted by

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for the Degree of Master of Forestry
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TABLE OF CONTENTS

# SNOW SURVEYS AND FOREST MANAGEMENT IN THE ROCKY MOUNTAINS OF COLORADO

## INTRODUCTION

The proper management of the water resource of the United States is essential to the health and prosperity of the American people. The use of water for human consumption, for domestic animals, for hydroelectric plants, and for innumerable other uses gives this resource a value beyond measure. A single indication of the value of the water resource is the fact that nineteen states west of the Mississippi River depend upon irrigation water for successful agricultural practice (9). The negative values of uncontrolled water are important in American economy. Floods, erosion of fertile soil horizons, destruction of fishing waters, and other damages are a heavy drain on American assets.

In Region Two of the United States Forest Service 28,000,000 acre-feet of water are produced in an average year, two-thirds of this total being produced west of the Continental Divide (14). The great drainage basin of Region Two and adjacent regions, the Colorado River Basin, covers 242,000 square miles in the United States. Of this area, twenty-nine percent is covered by forests. One-fourth of the forest area is coniferous vegetation (9). Measurements on a tributary of the Colorado River revealed that seventy-four percent of the annual runoff occurred in the period April to July. It was determined that this large percent of the total runoff was associated with snow melt, snowfall at high elevations being the one important factor in the production of the water carried by this tributary (9). It is obvious that the influence of high altitude forests on streamflow is of great importance to the people of the West.

Water is as much a product of forest land as is timber, forage, or game animals. Saunderson (14), in a discussion of intergrated land use, has shown that water values on Western watershed areas are the major values of such lands. The protection value of Western upland watershed lands averages thirty dollars per acre. The land owner, having no title to the water crop from his land, may have little or no regard for the quantity or quality of the crop or of the damage it may cause others. For this and other reasons, protection of the water resource has become a public function. Protection forestry is essentially public forestry (10).

Protection forestry has been slowly accepted by American foresters as a necessary part of forest practice. In many countries the importance of protection forestry has been realized. Most European countries, Japan, and several other countries have established protection forests which are defined by law and which must, regardless of ownership, be managed in accordance with definite prescribed standards. Most of the government-owned forests of the world are in mountainous regions and must be regarded as being essentially protection forests (9).

A necessary part of protection forestry and watershed management is the snow survey. While not taught as a part of a professional course in forestry, the number of foresters engaged in snow surveying indicates that this and allied procedure should be a part of every forester's store of knowledge.

Snow surveys and other snow studies are conducted by several government agencies. Those organizations at work at the present time are:

1. Forest Service -- Surveys to predict streamflow, in cooperation with the Soil Conservation Service and other agencies. Experimental work is in progress on designated areas to determine the best systems of land management applicable to intergrated use of forest lands.

2. Army Engineers -- Experimental work on snow characteristics and melting. Snow surveys to predict streamflow.

3. Soil Conservation Service -- Snow surveys, most of which are cooperative in nature. This agency is interested in the management of the water resource for agricultural use.

4. Bureau of Reclamation -- Experimental work of various types is conducted by Bureau personnel. One project is designed to find means of correlating standard Weather Bureau data with records of melting conditions and applying the results to large areas.

Streamflow data is used by the Bureau in developing spillway designs and in planning other engineering projects.

5. Weather Bureau -- Snow surveys for use in river and flood forecasting.

6. National Park Service -- Snow surveys on watershed areas within National Parks. The data obtained is used by other agencies in preparing forecasts of streamflow.

7. Fish and Wildlife Service -- Snow surveys on lands managed by the Service. Forecasts are useful in predicting water availability on areas managed for wildlife production.

8. Geological Survey -- Snow surveys are used in the forecasting of streamflow.

9. Office of Indian Affairs -- Snow surveys are made on Indian lands in cooperation with forecasting agencies.

Cooperating agencies not in the federal government include State engineers, State agricultural experiment stations, cities, power companies, and irrigation companies. Some organizations employ snow surveyors even though cooperative agreements with government agencies are not in effect. A power company in California which uses oil as a means of producing electricity during periods of low streamflow has found it desirable to employ snow surveyors. Data gathered by snow surveyors permits the company executives to estimate the stockpile of oil they must accumulate prior to the dry season. An acre-foot of water may be equal to a barrel of oil in the production of electricity.

Typical of work being done by research personnel of the Forest Service is that in progress at the Fraser Experimental Area, Arapaho National Forest, Colorado. This area is located in the Colorado River Basin, in the zone of high altitude forests from which comes much of the water of the Colorado River. Studies at Fraser have provided information as to the relative value of the cover types (aspen, grass, and coniferous forest) on snow accumulation and retention. Further studies in the coniferous forest are in progress to determine the management practices that will result in the maximum yield of timber and usable water. The Fraser Experimental Area is managed by personnel of the Rocky Mountain Forest and Range Experiment Station. Much of the information contained in this paper was obtained in the Fraser area.

## SNOW AND FORESTRY

Trees, especially coniferous species, exert a powerful influence on the amount of water in the form of snow stored under the forest canopy.

The effect of interception in a forest of ponderosa pine, Table One, is indicative of the importance of this phenomenon.

Table One

Percent of total winter's snowfall intercepted by ponderosa pine stands (10)

| Composition of stand | Interception Percent |
|---|---|
| Virgin, with understory | 27 |
| Mature, no understory | 22 |
| Open ponderosa pine - lodgepole pine | 8 |

Observations in the subalpine forests of the Rocky Mountains of Colorado indicate that the relative efficiency of the tree species in snow interception appears to be: 1. young lodgepole pine, 2. alpine fir, 3. Engelmann spruce, 4. mature lodgepole pine, 5. aspen and other deciduous species. Mature lodgepole pine is low in ability to intercept snow due to the irregularity of the crowns of mature trees of this species.

In a forested area managed as a watershed, a balance must be reached between interception by the trees and the sheltering effect of the forest canopy. Trees reduce the amount of snow reaching the ground and reduce the rate of melt of that which is accumulated. A moderate rate of melt is desirable in watershed areas. Management of the vegetation cover will promote the development of a satisfactory rate of removal of snow during the period of rapid melt in the Spring. In any area managed for both water and timber the density of the stand must be

Figure One - Trees intercept a portion of each snowfall. Some of the snow intercepted falls to the ground or melts and drips to the ground but a portion of it evaporates and is lost to the watershed.

such that both these products of the land are produced in the maximum amounts and with satisfactory quality.

Forests exert a powerful influence on the amount of evaporation of water from snow. In a forest of ponderosa pine in Idaho it was found that wind movement in the forest was one-ninth that in nearby openings (10). Forest watershed management must include considerations of evaporation loss. That evaporation from the snow cover is a factor of considerable importance has been proven by data obtained in Colorado during the winter of 1939-40. It was found that 3.5 inches of water out of the total of 7.4 inches that fell was lost due to evaporation from the snow pack. Of the amount evaporated, 2.75 inches of water was lost during the Spring melting months of April and May (1).

Soil freezing may be the cause of failure in seedling establishment in regions of low rainfall. Freezing at the soil surface draws water up from depths as great as thirty-six inches. This water then evaporates into the air (2). Management of the forest cover so as to promote snow accumulation will greatly reduce the amount of freezing of the soil. Hardwood stands are more favorable than spruce stands in this respect (3) due to reduced interception by hardwoods.

Many other problems in forest and snow management could be cited. In the measurement of conditions as they exist, snow surveys are necessary.

## SNOW AND WATER SUPPLY

In developing water supply forecasts from snow survey data it is assumed that a relationship exists between the water content of the snow cover on a drainage area and the runoff from that area (8). A forecasting chart for a particular drainage basin is developed from snow survey data and runoff data for several consecutive years. Forecasts are most accurate in those areas where most of the precipitation occurs as snow at high altitudes.

Water supply forecasts are useful to agencies engaged in: irrigation, flood control, operation of hydroelectric plants, watershed protection, accumulation of stock water, accumulation of municipal water supplies, estimating loads on structures, farm-loan servicing, crop estimating, mining operations, wildlife management, and the movement of logs by flumes or by driving.

Snow surveys must be made at a time when the snow cover has reached a maximum for the year. The general program for the Western United States calls for a survey each month, at the beginning of the month, from January to May inclusive at a limited number of key courses. Surveys are to be made on all courses on March first and on April first. Local conditions vary the relative importance of the dates. The forecasting services set April first as the date of the important forecast of the year. March first surveys are considered as being necessary, especially for preliminary work. January first surveys are usually of little value and often may be omitted. May first surveys reveal data on late season runoff. A period from four days before to four days after the first day of the month is set as the period of survey (8). Weather and other conditions prevent the setting of definite dates for measurement work.

While snow surveyors, district rangers, and others gathering forecast data must follow the prescribed time schedule, surveyors on experimental areas need not conform to such schedules. Surveys are scheduled to permit accomplishment of the work in the manner called for in the work plans. Initial surveys of the season must be made before melting has progressed far enough to cause passage of water into the soil. Whether or not melting has occurred may be determined by observation of the soil withdrawn while snow cores are being taken.

Reliable forecasts are possible if certain conditions exist at the time of snow measurement. Important factors are (8):

1. Measurements must be taken at elevations where little or no melting occurs until after April first.

2. The snow courses must be sufficiently accessible to insure continuity of the surveys.

3. Measurements must be made at a sufficient number of fixed points on an established marked course to insure that the average of the measurements will not be unduly affected by drifting or wind-swept snow.

4. The surveys must be made on a sufficient number of courses properly located on each drainage basin to cover the varisbility of storms over the area.

## SNOW COURSES

It has been stated that snow courses must be located in accessible areas in locations which will permit adequate sampling of the drainage basin. After the selection of the location of the course an adequate system of marking is necessary to permit repeated sampling of the course in the desired manner and without the exercise of personal opinion on the part of the surveyor.

Snow courses measured periodically for the forecasting of streamflow may be improved by clearing out trails along the courses and by providing rock-free sampling points. Markers of metal, elevated on posts or trees so as to be visible during the surveying season, mark the course. An example of a course used in collecting forecast data is one established for the Soil Conservation Service in the Main Range in Colorado. The course has two lines of stations laid out in the form of a cross. The four ends of the cross are marked by standard Soil Conservation Service markers. Stations along the course lines are located by pacing definite distances along the legs of the cross. The snow surveyor is provided with a map of the course to aid him in locating its limits and as a guide for pacing distances. Any map of a snow course should show the general layout of the course, the location of the beginning station, the location and designation of each station, compass orientation, and any characteristics of vegetation or topography which will aid the surveyor in locating the course.

Trails to snow courses must be blazed or otherwise marked to insure safety of personnel and quick travel by surveying crews. At least one member of the party must be familiar with the course to be surveyed. Only by observing this precaution can wasted time and danger be avoided.

On experimental plots where research in forest influences or related fields is in progress, the courses are not improved beyond the degree incidentally provided by the preparation of the area during the work phase of the problem. Where watershed studies are in progress it is advisable to construct trails along the course, following as far as is practicable the specifications for courses used in the collection of forecast data. Where snow sampling is to be done on plots harvested by various silvicultural methods it is convenient to mark each station. Suitable markers can be made of wooden stakes which are painted orange and marked with the designation of the station. Pieces one inch thick and three inches wide make suitable stake material. The stakes must be high enough to permit location and identification of each station at the time of maximum snow accumulation. To eliminate personal bias, staked stations on plots should be set in at random. Snow measurements must be taken at distances from the stakes sufficient to eliminate the effects of melting and drifting around the stakes. For convenience these distances are specified in terms of section lengths so that they may be measured roughly with the snow tube.

## EQUIPMENT

Several items have become standard for the measurement of snow to determine water content. Other equipment is widely used for the measurement of snowfall on an area during the period following snow survey.

The snow tube, or snow sampler, is the means by which the surveyor collects data on the amount of water contained in snow. There are several types of tubes, all of them alike except in weight and diameter. The Federal Mount Rose tube and the Utah Mount Rose tube are 1.485 inches in diameter. The two models differ in weight. The Mount Rose tube is 1.50 inches in diameter (8). The Federal and Utah tubes are designed so that the diameter of the snow core is such that the weight in ounces of the snow is equivalent to the water content in inches. The Mount Rose tube, varying in diameter from other models, is weighed by means of a specially calibrated balance which is graduated in terms of inches of water.

A snow tube consists of a slotted metal tube which can be disassembled to its component thirty-one inch long sections by means of threaded joints. To the lower end of the first (one to thirty-one inch) section is attached a cutter. The exterior surface of the tube carries a scale in inches which is stamped into the metal. Graduations are provided for each inch and half inch of length, each inch graduation being numbered. The graduations of the scale and the slots on the tube are so spaced that the length of a snow core within the tube can be measured directly.

The Utah snow tube provides accurate measurements when handled by well-trained personnel. A single snow tube should be used for all measurements to be compared with each other (11).

Snow tubes are transported assembled or in canvas cases. On long trips the thirty-one inch lengths of tube are secured in a case which permits easy transportation and prevents loss or damage to the equipment.

Weighing of the snow tube and the snow core is accomplished through the use of a balance fitted with a cradle which holds the tube parallel to the ground. The Federal balance, capable of weighing twelve and one-half or twenty feet of tubing, is tubular in shape and functions through a spring which is held under tension. The tubular balance which can weigh twelve and one-half feet of tubing will measure loads up to sixty ounces. The Federal and Utah tubes, constructed so that the scale reading in ounces is equivalent to depth of water in inches, may be weighed by any scale accurate to one-half an ounce. One acceptable scale is the Chatillon Circular Spring Balance which is available in several models.

For measuring periodic snowfall several types of gages have been designed. All function in the same manner. An initial "charge" of water, oil, and calcium chloride is placed in the gage. The weight of the gage and the "charge" is determined using a Chatillon balance or one of similar design or is measured with a dip stick. Following a snowfall the weight or depth of the solution is determined. By means of conversion tables the increase in weight or depth is converted to inches of water. Calcium chloride is used in the initial "charge" to prevent freezing of the "catch." This chemical is more efficient in lowering the freezing point than is any other inexpensive and readily available substance. Oil, SAE 10, is added to the charge to prevent the evaporation of water from the gage. The oil forms a film on the surface of the solution.

The Sacramento gage, capacity one hundred or two hundred inches of water as commonly used, is useful for obtaining seasonal or annual "catches." The Sacramento gage is constructed of heavy sheet metal in the form of a truncated cone. The expanding walls of the gage are designed to reduce the amount of snow that will adhere to the inner walls of the gage so that the maximum amount of the "catch" will be absorbed by the solution (4). A valve at the bottom of the gage permits the investigator to draw off the accumulation. The one hundred inch capacity gage is thirty-nine inches in depth, has an opening eight inches in diameter, and a bottom twenty-one inches in diameter. Snowfall gathered by this gage is most conveniently measured by determining the depth of solution in the gage and converting this reading to inches of water. The Sacramento gage shown in Figure Two is installed in a region of moderately heavy snowfall and is used to measure total winter precipitation.

The modified Weather Bureau rain gage is useful for measuring snowfall at weekly or other short intervals. When so used, the cone insert of the gage and the inner cylinder are not utilized. The modified Weather Bureau gage is eight inches in diameter and seventeen and one-half inches in depth. This gage is most conveniently measured by weighing the gage and solution. The weight is converted to inches of water by means of tables prepared for use with gages of this size.

The Alter snow shield is used in connection with a gage installed to measure snowfall. The shield is constructed of strips of metal arranged to form an inverted truncated cone. The metal strips are spaced so that half of the surface area of the cone is closed. By deflecting wind downward around the gage, wind velocity across the top of the gage is approximately what it would be were the gage not there. The amount of snow falling into the gage is thus not affected by eddy currents. The shield is held in place with lengths of water pipe or similar material. The upper rim of the shield should be two inches above the level of the opening in the gage. Under certain conditions the use of an Alter shield may result in inaccurate "catches." The Sacramento gage shown in Figure Three was fitted with a shield and installed in a spruce-fir stand at 10,000 feet elevation. Note that a snow cap has formed over the gage and around the shield. The throat of the gage is completely closed. Five and six-tenths inches of precipitation

Figure Two - A Sacramento gage fitted with an Alter snow shield. This gage, at 10,000 feet elevation, is a source of data used in forecasting streamflow for the Colorado River.

Figure Three - A Sacramento gage fitted with an Alter snow shield. The throat of the gage has capped over, preventing further catch of precipitation.

weře retained by the cap and were not included in the gage "catch." If the surveyor had not employed special means of determining the water content of the cap, a serious error in the recorded data would have resulted. Capping is probably due to the absence of wind during snow storms. Regardless of the occasional difficulties that occur, shielded gages are more accurate than similar unshielded types. (4).

Seasonal snowfall measurements based on gage "catch" may not agree with data obtained by measuring the snow cover on the ground using conventional snow surveying procedure. In Table Two, seasonal "catches" by Sacramento gages are compared with data obtained by measuring the adjacent snow cover with a Utah snow tube. The ground measurements were obtained at the same time that the gages were measured. Spring melt had not begun at the time of measurement.

Table Two

Seasonal precipitation records obtained with Sacramento gages compared with snow tube measurements.

| Gage Number | Inches of water | |
|---|---|---|
| | Gage reading | Ground Measurement |
| 1 | 15.25 | 23.11 |
| 2 | 11.25 | 11.75 |
| 3 | 9.25 | 13.80 |
| 4 | 9.25 | 14.15 |
| 5 | 10.35 | 28.80 |

The reasons for the variations are difficult to determine. Gages must be located in places where the wind will sweep Alter shields clear of snow to prevent capping of the gages. Ground measurements must be used with caution when obtained in narrow valleys or where the ground is swampy throughout the year. There appears to be a tendency toward the replacement of snow surveys with gages. It is obvious that such changes must be made only after thorough investigation of local conditions.

In research work the snow surveyor may have occasion to operate stream gaging stations, hygrothermographs, and other instruments. The nature of the problem will determine which instruments are applicable to supplement snow survey data.

SNOW SURVEYING PROCEDURE

Snow surveying procedure is not difficult to learn or to apply. The difficulties in snow surveying do not come from procedure but from the terrain and weather conditions encountered during the survey. During difficult weather and with the supervisor many miles away there may be a tendency for carelessness or incomplete work on the part of the members of the party. All members of a snow surveying party must know the reason for their work and the necessity for accuracy.

The most efficient surveying crew is one composed of two men. Under certain conditions a third man may be added effectively. If the terrain to be traversed is dangerous or if supplies are to be carried by the party the presence of a third man is a decided advantage. In the discussion of procedure that follows, the work is outlined in such a manner as to apply to a two man crew.

One member of the party, the tube operator, carries a snow tube and the carrying case. The second member of the party, the recorder, carries a balance and the forms used in recording the data obtained. When the party reaches the first station of the course the tube operator assembles the snow tube, being certain that the sections are assembled in the proper order. Proper assembly will preserve the numerical sequence of the linear graduations on the tube. If the sections are not joined in the proper order, mistakes in measurement of snow depth will occur. The section which carries the cutter must be used. This section is graduated from zero inches depth and must be used to obtain proper depth measurements. The cutter determines the diameter of the snow cores to be obtained. If the diameter of the core varies from that for which the tube was constructed it will be impossible to obtain accurate measurements of the water content of the snow cover. The number of sections of tube to be used on a particular course depends on the depth of the snow present. The minimum number of sections that can be used is always the desirable number.

The tube operator makes certain that the tube is clear prior to taking any measurements. The tube is held vertically, cutter down, and is forced into the snow until the cutter touches the ground, as shown in Figure Four. A smooth, steady thrust of the tube

Figure Four - The snow tube is held vertically and is forced into the snow pack smoothly and steadily.

should be used. Rotating of the tube should be avoided unless it is necessary to use the cutter to penetrate ice layers in the snow cover. Stopping the downward thrust or penetrating the snow cover too rapidly may cause packing of the snow in the tube so that the snow core obtained is incomplete. When the cutter touches the ground the tube operator reads the depth of the snow using the graduations stamped on the exterior of the tube. This figure is recorded by the second member of the party. Depth is recorded to the nearest one-half inch. After the depth reading has been obtained the tube operator rotates the tube so as to drive the cutter into the ground, as shown in Figure Five. A plug of soil or litter is obtained in the cutter to prevent loss of snow while withdrawing the tube. Only enough soil should be taken into the tube to hold the snow core and to assure the operator that the ground level was reached. An excess of soil is troublesome and is to be avoided. The operator removes the snow tube from the snow pack, pulling it up vertically with a smooth motion. As the tube passes through the operator's hands he should wipe any accumulation of snow off the outside of the tube. The operator then holds the tube horizontally or with the cutter end slightly lower than the upper end and carefully removes the soil plug. A convenient tool for this purpose is a headless nail driven into a block of wood which has been shaped into a handle. All material other than snow must be removed from the tube.

The snow tube with its contained core of snow is placed on the cradle of the balance. The balance may be suspended from a ski pole or a ski but is most conveniently used when suspended from a thong around the neck of the second member of the party. When so carried, the balance is always ready for use. The second man, sometimes called the "post," leans forward to permit the balance to hang free. The tube operator reads the weight of the tube and core. This reading is in ounces when using Federal or Utah equipment and is in inches of water when using Mount Rose equipment (8). The second member of the party records the weight. Figure Six shows the procedure when the tube operator and the "post" work together.

Snow is emptied from the tube by inverting the tube and permitting the core to slide out. Tapping the tube on a ski or snowshoe is usually necessary to remove all traces of snow from the tube.

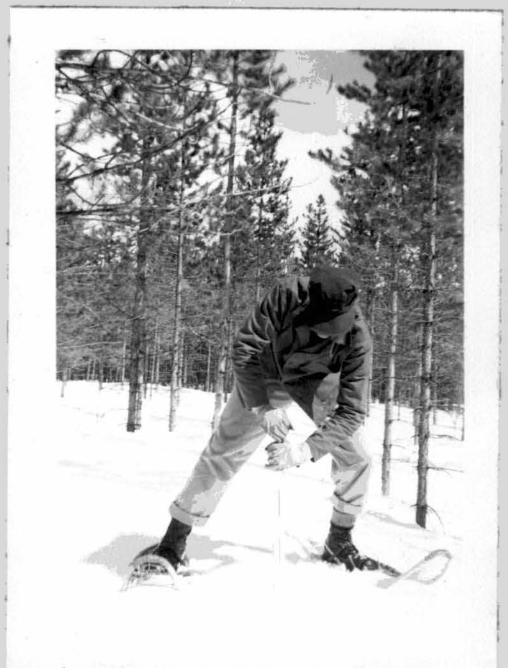

Figure Five - After the snow tube touches the surface of the ground, the tube is rotated to force a plug of soil into the cutter.

Figure Six - Obtaining the weight of a snow tube and snow core using a Chatillon balance fitted with a cradle.

After taking the first readings of the day, the weight of the empty tube must be determined. The empty tube is weighed in the same manner as that described for weighing the tube and core. The weight is recorded in the appropriate space on the form being used. The tube is weighed after at least one reading has been taken because moisture and snow particles in the tube may be present in sufficient amounts to affect the weights obtained. It is sometimes desirable to weigh the empty tube several times while sampling a course.

The slots in the tube permit measurement of the length of the snow core at any time during sampling. Some snow surveyors maintain that the length of a snow core must be at least ninety percent of the depth of the snow cover. This cannot be regarded as correct in most cases. If a snow core is obtained in the manner described herein and if the snow cover is not extremely deep, a measurement of core length is unnecessary. In such cases the column for core length on standard forms is not used. In regions where snowfall is heavy, one hundred and thirty inches for example, measurement and recording of the length of the snow core may be necessary. In deep snow the tube operator may not be able to determine when the cutter touches the surface of the ground. When core length is used to determine the completeness of sampling, a relation between core length and snow depth should be used as the criterion for judging measurements. This core length-snow depth relation will vary with the course, time, and snow conditions.

Snow density measurements taken with the Utah tube are affected downwardly by old sampling holes for a radius of eight to fourteen inches. Where a station is to be sampled periodically, sampling points should be one foot from previous sampling points (5).

Sacramento gages or variations of Weather Bureau rain gages are useful to determine snowfall for definite periods or to determine the amount of snowfall on a course in the period following snow survey on the course. The frequency of measurement of gages depends on the reason for the use of the gages. Sacramento gages used in the forecasting of streamflow may be measured on the first day of March, April, and May. Modified Weather Bureau gages used in forest influences research may be measured weekly or following each storm.

The Sacramento gage is measured by using a dip stick. When the depth of the "charge" of water, calcium chloride, and oil is known and when the depth of solution at the time of measurement has been determined, the snowfall in inches of water may be calculated. Personnel using Sacramento gages should prepare tables showing the water equivalent for various depths of solution.

Modified Weather Bureau gages are small in size and light in weight so that measurements may be taken by using a balance graduated in pounds and ounces with a least graduation of one-half ounce. Any accurate commercial balance may be used. The balance is held by one man while a second man reads the scale as shown in Figure Seven. The original weight and the weight obtained at the time of observation are converted to precipitation in inches of water by means of tables. The increase in inches of water is the snowfall for the period.

## CALCULATIONS

Snow surveyors sampling a snow course with standard equipment obtain two sets of values, (1) the depth of the snow cover, and (2) the weight of the tube and the snow core. A third value, the weight of the empty tube, is obtained one or more times while surveying a course.

The water content of snow, expressed as inches of water, is obtained by subtracting the weight of the empty tube from the total weight of the tube and core when Federal or Utah equipment is used.

Water content = total weight - weight of empty tube.

The water content of the snow cover is computed for each station of the course. An average water content for the course is obtained by determining the arithmetic mean of the data. With the Mount Rose snow tube the balance is set at zero with the empty tube on the cradle. Scale readings obtained while sampling are in terms of inches of water and no further computation for this value is necessary other than to obtain the average for the course. Standard forms of the various snow surveying agencies have spaces for the entry of each water content determination and for the entry of the average. These values are determined by the surveyors.

Figure Seven - Weighing a modified Weather Bureau gage to determine the amount of snowfall for the previous week.

Average depth of the course is obtained by determining the arithmetic mean of the depths measured during the survey. The average depth is entered on standard forms.

Density of the snow cover is obtained by dividing the average water content in inches by the average depth of the snow cover.

Density = Water content in inches ÷ Depth in inches.

Some forms are so prepared as to require the computation and entry of the density value. On the survey forms of some agencies, density values are not required. Density of the snow cover is an indication of the progress of melting. Density increases as melting progresses until maximum density is reached and the snow cover disappears. In the high mountains of Colorado maximum density is about thirty-five percent. The value of density determinations depends upon the purpose for which the survey data is to be used.

The sample sheet shown in Form One is a reproduction of a record obtained in the Fraser Experimental Area, Arapaho National Forest. Survey data in this case is to be used in forest influences studies. The form was made up accordingly. A column to record length of snow core is not included because the procedure previously described was used. The presence of soil or litter in the cutter was used to determine whether or not a complete core had been obtained.

The form for federal and state cooperative snow surveys provided by the Soil Conservation Service has nine columns:

1. Description or number of course
2. Sample number
3. Depth of snow, inches
4. Length of core, inches
5. Weight of tube empty
6. Weight of tube and core
7. Water content, inches
8. Density percent
9. Remarks

The cooperative form varies from the Fraser form due to different purposes of the surveys and to permit variation in procedure from that described herein. "Snow Surveying," United States Department of Agriculture Miscellaneous Publication 380, should be

SNOW DEPTH AND WATER CONTENT
(Snow tube measurements)

Branch Station: FRASER    FIELD CREW: BG CM JG
Study: YOUNG LODGEPOLE    Date: 3/28/47
Block and Plot: 2A    Wt. of tube: oz. 40.5

| Station Number | Snow depth inches | Total Wt., Ounces | Water, Inches |
|---|---|---|---|
| 1 | 28.5 | 46.2 | 5.7 |
| 2 | 35.5 | 48.5 | 8.0 |
| 3 | 32.5 | 50.1 | 9.6 |
| 4 | 38.0 | 51.4 | 10.9 |
| 5 | 23.5 | 45.9 | 5.4 |
| 6 | 27.5 | 47.7 | 7.2 |
| 7 | 32.0 | 49.1 | 8.6 |
| 8 | 29.5 | 48.7 | 8.2 |
| 9 | 31.5 | 49.3 | 8.8 |
| 10 | 30.5 | 49.5 | 9.0 |
| 11 | 31.0 | 50.3 | 9.8 |
| 12 | 33.0 | 49.5 | 9.0 |
| 13 | 32.0 | 49.5 | 9.0 |
| 14 | 23.0 | 47.1 | 6.6 |
| 15 | 22.5 | 45.6 | 5.1 |
| 16 | 25.5 | 47.6 | 7.1 |
| Total | 476.0 | 776.0 | 128.0 |
| Average | 29.75 | 48.50 | 8.0 |

Form One - Reproduction of the form used by snow surveyors at the Fraser Experimental Area.

consulted for procedure recognized as satisfactory by the Soil Conservation Service. The calculations involved in the use of the cooperative survey form are the same as those required for the Fraser form except that the cooperative form calls for density calculations.

The determination of snow accumulation in gages is quickly accomplished when conversion tables are available. The initial depth or weight is converted to inches of water using the appropriate table. The depth or weight of the solution in the gage following a snowfall is similarly converted to inches of water. The increase expressed in inches of water is the amount of precipitation collected by the gage.

## SNOW SURVEYS AND FOREST RESEARCH

As information on watershed characteristics was accumulated it became increasingly evident that management plans for such areas were necessary and that such plans should emphasize the protection value of watershed forests. It is possible that cutting practices may vary from those designed solely for wood production in order to increase water yield or to stabilize stream flow (6). Many research projects are in progress to determine the factors involved in the management of a watershed area for water and other forest products. The projects described herein are in progress in the Fraser Experimental Area, Colorado. The forest consists of Engelmann apruce, alpine fir, and lodgepole pine. Aspen stands and grass meadows cover a small portion of the total area. Subalpine coniferous forests are important in Western water yield due to the great snow accumulation typical of the type and to the large area (7) of the subalpine stands.

A great deal of research has been done in lodgepole pine stands to determine the best management practices for joint water and timber production.

Wilm and Collet have shown that slope-percentage, slope height, and position on the slope have little or no measurable effect upon volume of stored snow in well-stocked lodgepole pine stands (15).

Tentative conclusions are that open fields and aspen store more snow than does a closed pine forest but that melting in open fields proceeds more rapidly (1).

More water is stored and the melting rates are faster in heavily cutover stands of lodgepole pine than in uncut stands (17).

In virgin stands of lodgepole pine the amount of snow stored in the Spring is directly correlated with the size of openings in the crown canopy. Records covering a two year period showed that five inches of water was stored directly under the trees as compared with nine inches of water in the center of openings sixty feet in diameter (1). In a mature lodgepole pine stand snow storage and melt-duration were at a maximum in the largest canopy openings studied. It appears that the size of opening providing maximum storage of snow in mature stands of lodgepole pine has a radius of thirty feet or more (15).

In immature stands of lodgepole pine the greatest amounts of snow are stored in openings the diameter of which approximately equals the height of the surrounding trees (1). Immature lodgepole pine stands with twenty foot openings store the most snow. Stands with openings sixteen to seventeen feet in diameter provide maximum accumulation and prolonged melting. It may be desirable to make the crown openings elliptical in shape with the long axes east to west (12). Observations at Fort Valley, Arizona (13) that snow accumulation on the north sides of tree groups is more than that in the open supports the belief that elliptical openings are probably more desirable than those of other shapes.

Management plans are being developed for each timber type in areas where snowfall is important in water yield. The study of snow accumulation and cutting methods being conducted at the Fraser Experimental Area in lodgepole pine stands is designed to reveal the type of cutting most useful for maximum production of both water and timber in high altitude lodgepole pine stands in the Rocky Mountains. Six blocks of plots have been established. Each block is subdivided into three plots, each three-quarters of an acre in area. Treatment for the plots within a block consists of:

a. Trees thinned to an eight and one-half foot spacing resulting in 625 trees per acre.

b. One hundred crop trees selected per acre and freed for a distance of eight feet in all directions.

c. Control plot.

Within each plot sixteen stakes have been set at random to mark the location of sampling points for snow survey and for soil moisture studies. Table Three shows the results of snow sampling on the plots in March, 1947. All measurements were taken prior to the beginning of Spring melt.

Table Three

Seasonal Accumulation of Snow in Immature Lodgepole Pine Stands, 1947.

| Block Number | Treatment | Water equivalent Inches |
|---|---|---|
| 1 | 8½ foot spacing | 8.80 |
| 1 | Crop tree | 7.17 |
| 1 | Control | 6.39 |
| 2 | 8½ foot spacing | 8.00 |
| 2 | Crop tree | 7.52 |
| 2 | Control | 6.34 |
| 3 | 8½ foot spacing | 9.23 |
| 3 | Crop tree | 9.29 |
| 3 | Control | 8.44 |
| 4 | 8½ foot spacing | 7.80 |
| 4 | Crop tree | 7.79 |
| 4 | Control | 7.23 |
| 5 | 8½ foot spacing | 8.56 |
| 5 | Crop tree | 8.22 |
| 5 | Control | 7.05 |
| 6 | 8½ foot spacing | 8.72 |
| 6 | Crop tree | 7.48 |
| 6 | Control | 6.60 |

The data obtained in 1947 shows that cutting to an eight and one-half foot spacing is the best method of treatment of those tested. By variance analysis, the spacing method gives results which are significantly greater than those obtained from the other types of plots. The values indicating increased snow accumulation in the treated plots over the control plots are highly significant. Since these comparisons are based on the data of a single year they must be regarded as being tentative results and not conclusive.

The snow survey data collected in the stands of immature lodgepole pine is being supplemented by:

a. Snowfall records for the period from the date of snow survey to the end of snowfall for the season.

b. Rainfall records during the period when precipitation occurs as rain.

c. Spring and Fall measurement of soil moisture to depths of four feet.

Compilation and examination of all four types of data gathered over a period of years will be necessary to determine the treatment best suited for the management of lodgepole pine stands for water and timber production.

Studies being conducted in spruce-fir stands are similar to those described for lodgepole pine. The block for which 1947 data is summarized in Table Four is divided into four plots, each eight acres in area. Three plots were treated to remove sixty percent of the volume. The fourth plot was left as a check plot. The treatments utilized are:

a. Alternate strips one chain wide cut to a ten inch diameter limit.

b. Group cutting to a ten inch diameter limit, the groups one chain in diameter.

c. Single tree selection.

d. Control.

Those portions of the first three plots not included in the specified treatment received a salvage cutting. Within each plot thirty stakes have been set out to mark the sampling points for snow surveys and for soil moisture determination.

Table Four

Seasonal Accumulation of Snow in a Stand of Engelmann Spruce and Alpine Fir, 1947.

| Plot | Treatment | Water equivalent Inches |
|---|---|---|
| A | Strip cutting | 15.98 |
| B | Group cutting | 16.53 |
| C | Single tree selection | 16.48 |
| D | Control | 13.58 |

Variance analysis of the data shows that treated stands are more effective in snow accumulation than are untreated stands, the results being highly significant. No significant difference exists between the three cutting methods in the accumulation of snow. These conclusions must not be considered as conclusive due to the small amount of data being considered, a single block being measured for one year. Additional blocks are being prepared to permit replication. Data on growth, reproduction, and precipitation are being obtained for the spruce-fir plots to permit more accurate evaluation of the cutting methods.

## BIBLIOGRAPHY


1. ___________. 1940. Research Highlights. Rocky Mountain Forest and Range Experiment Station. Page 1.

2. Anderson, H. W. 1947. Soil freezing and thawing as related to some vegetation, climatic, and soil variables. Journal of Forestry 45:94-101.

3. Belotelkin, K. T. 1941. Soil freezing and forest cover. Transactions of the American Geophysical Union 1:173-75.

4. Church, J. E., et al. 1946. Research Committee on Snow, Western Snow Conference, 1945. Transactions of the American Geophysical Union 27(3):417.

5. Dunford, E. G. 1943. Snow evaporation study, progress report 1942. Rocky Mountain Forest and Range Experiment Station, Unpublished.

6. Granger, C. M. 1946. Foot to earth, eye to the sky. Journal of Forestry 44:814-18.

7. Ives, R. L. 1942. Atypical subalpine environments. Ecology 23:89-96.

8. Marr, J. C. 1940. Snow Surveying. United States Department of Agriculture Miscellaneous Publication 380. PP 45.

9. Munns, E. N. 1946. Water in wildland management. Journal of Forestry 44:799-804.

10. Munns, E. N., et al. 1933. Watershed and other related influences and a watershed protective program. Senate Document 12, Separate 5. PP 299-461.

11. Niederhof, C. H., and E. G. Dunford. 1941. Some possible errors in snow sampling. Rocky Mountain Forest and Range Experiment Station. Unpublished.

12. Niederhof, C. H., and E. G. Dunford. 1942. The effect of openings in a young lodgepole pine forest on the storage and melting of snow. Journal of Forestry 40:802-4.

13. Pearson, G. A. 1942. The Fort Valley forest experiment station. Forest Service. PP 5.

14. Saunderson, M. H. 1947. The national forest officer looks at resource values. Journal of Forestry 45:244-8.

15. Wilm, H. G. and M. H. Collet. 1940. The influence of a lodgepole pine forest on storage and melting of snow. Transactions of 1940 of the American Geophysical Union.

16. Wilm, H. G., and E. G. Dunford. 1941. Problem analysis-forest influences. Rocky Mountain Forest and Range Experiment Station. Mimeograph.

17. Wilm, H. G. 1946. The status of watershed management concepts. Journal of Forestry 44:968-71.