# PROGRESS IN DEVELOPING FOREST MANAGEMENT GUIDELINES FOR INCREASING SNOWPACK WATER YIELDS

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## INTRODUCTION

Snowmelt is a major source of runoff and water yield for the reservoir systems in Arizona, and it also contributes to the recharge of groundwater aquifers. Much of the snowmelt runoff occurs in the ponderosa pine forest. This suggests the possibility of using forest management methods to enhance snowmelt water yield if trees and their spatial arrangements affect the snow regime. Basic research indicates that forest management does affect the snowpack (Anderson, 1963; Berndt, 1961; Goodell, 1965; Packer, 1962), and can cause increases in snowmelt runoff (Hoover and Leaf, 1967).

Another aspect of these encouraging water yield results supports the feasibility of their ultimate application in operational management programs. There is reason to believe that thinning and clearing of timber overstories can be made compatible with wood, forage, and wildlife production, and recreational use of forest lands.

The goal of the research project discussed in this progress report is the preparation of forest management guidelines for increasing water yields from snowpacks in the ponderosa pine type on the Salt-Verde River Basins. These Basins yield runoff for the municipal, agricultural, and industrial developments in the Phoenix and central Arizona area. Since this area is so important

to the economy and welfare of the State, the project study areas have been centered on the Salt-Verde River Basins. However, the potential results should apply to comparable forest and physiographic conditions found elsewhere in Arizona, and may be applicable to forest regions outside Arizona where snowfall is an important component of the annual water yield.

## BACKGROUND

Considering the application of forest management practices for attempting to increase recoverable water yields from snow, two basic options are available.

1. Reducing Forest Densities - thinning practices, including various intensities and combinations of intensities.
2. Removing Forest Overstories - clearing practices, including different arrangements and patterns.

Water yield improvement experiments on experimental watersheds (Brown, 1969; Hewlett and Hibbert, 1961; Reinhart, 1965) have demonstrated that increased snowmelt runoff may result from a reduction or removal of forest overstories, although the hydrologic mechanisms involved have not been completely identified and quantified. It is known that more snow accumulates in sparsely stocked forest stands, and in clearings in the forest overstory (Anderson, 1963; Goodell, 1965; Hansen and Ffolliott, 1968; Packer, 1962; Rothacher, 1965). The greater accumulation of snow in forest clearings may be a contributor to the increased runoff from experimental cuts. If this hypothesis is accepted, and if water equivalent of the snowpack can be maximized just prior to spring runoff by forest management practices, then perhaps the quantity of usable runoff can be maximized.

The assumption that maximum runoff occurs from maximum snow accumulation provides a basis for testing a variety of thinning and clearing options in varying timber stocking conditions, because changes in snow accumulation on site resulting from forest management practices can be measured. By this means, the management practices that will cause the greatest increase in snow accumulation prior to spring runoff can be identified for given timber stocking conditions.

Another consideration in developing forest management guidelines for increasing snowpack water yields is concerned with the identification of physiographic and climatic factors which partially determine the quantity of runoff yielded. Conceivably, comparable forest management practices on two sites of equivalent vegetative characteristics may yield different amounts of runoff if the sites have differing slope-aspect combinations, soil characteristics, or precipitation regimes. The land manager may wish to first implement water yield improvement programs on sites with the greatest apparent water yield. In this case, the decision would be based on physiographic, and possibly, climatic factors, since vegetation conditions are the same.

One measure of the effect of physiographic and climatic factors on the amount of runoff yielded is runoff efficiency, defined as the percentage of snowpack water equivalent at peak accumulation that appears as runoff (Garn, 1969). Runoff efficiency on small watersheds in the ponderosa pine forest of Arizona can vary from less than 20 to over 90 percent (Ffolliott, 1970). Conceptually, both fixed and variable factors determine runoff efficiency. Fixed factors include soil depth and type, slope percent, aspect, and basin configurations.

Variable factors include year-to-year differences in antecedent soil moisture conditions and rates of snowmelt.

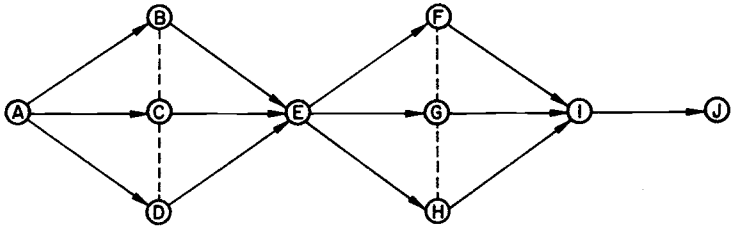
## DEVELOPMENT OF INVESTIGATION FRAMEWORK

To establish a framework for study which may ultimately lead to forest management guidelines for increasing snowpack water yields, alternative courses of action were simulated. The simulation technique used to achieve an effective and efficient program was based on PERT (Program Evaluation and Review Technique) analyses (Davis, 1968). Essentially, a PERT system identifies the relationships between activities comprising a project, the estimated time required to complete each activity, and the probabilities of success in completing the activities and project within the time constraints specified. At this stage of the research effort, only the relationships between activities in the project have been considered.

The investigation framework of the research project as established by a PERT analysis indicates the required activities within the project and the general ordering of prerequisite activities. Diagrammatrically, study activities are arrows (directed arcs) ending at specified events (Figure 1). Several activities may end at one event, in which case the event occurs only when all activities are completed. Once an event has occurred, succeeding activities may begin.

In the investigation framework, study activities consist of the following:

1. Identifying pertinent populations.




EVENT IDENTIFICATION

- (A) Start of Project
- (B) Physiographic Inventory Report
- (C) Climatic Inventory Report
- (D) Vegetation Inventory Report
- (E) Identification of Test Sites
- (F) Reduction of Forest Densities Report
- (G) Reduction of Forest Overstories Report
- (H) Report on Physiographic and Climatic Factors Affecting Snowmelt Runoff
- (I) Preliminary Integration of Previous Events
- (J) Final Report

Fig. 1. A PERT network illustrating the investigation framework for a research effort designed to develop forest management guidelines for increasing snowpack water yield.

a. Physiographic (arc AB).

b. Climatic (arc AC).

c. Vegetative (arc AD).

2. Delineating test sites

a. In terms of physiographic features (arc BE).

b. In terms of climatic features (arc CE)

c. In terms of vegetative features (arc DE).

3. Implementing experiments.

a. Reducing forest densities (arc EF).

b. Removing forest overstories (arc EG).

c. Effect of physiographic and climatic factors on runoff (arc EH).

4. Developing preliminary evaluations.

a. Reducing forest densities (arc FI).

b. Removing forest overstories (arc GI).

c. Effect of physiographic and climatic factors on runoff (arc HI).

5. Preparing comprehensive report (arc IJ).

## IMPLEMENTATION OF INVESTIGATION EFFORT

As indicated by the PERT network, identification of pertinent descriptive populations (physiographic, climatic, and vegetative) is a necessary initial activity. This step is needed to establish sideboards on the array of potential test sites for evaluation. With the completion of this event, priorities regarding the experimental development of forest management practices designed to increase snowpack water yields may be formulated. Given a fixed research effort, these priorities will delineate areas of initial and primary concern.

Three inventory evaluations are being conducted to attempt identification of pertinent populations for investigation. A physiographic evaluation of the ponderosa pine forest on the Salt-Verde River Basins has been initiated to describe slope, aspect, elevation, and soil interactions associated with this

study area. The results of this inventory will provide a basis for estimating proportions of these Basins exhibiting specific physiographic features.

Concurrently, climatic and vegetative evaluations are being conceived and implemented. Zones of similar precipitation input, radiant energy components, snowpack accumulation, and snowmelt will be spatially located. Vegetatively, proportions of the study area that support given forest overstory densities that may affect the snowpack and runoff will be quantified to estimate the operational feasibility of proposed management systems.

Once the inventory evaluations are completed, and pertinent populations are identified, test sites can be established to represent the hydrologically significant physiographic, climatic, and vegetative features. Hopefully, test sites representing given interacting features can be replicated throughout the study area. As a minimum goal, however, test sites will be located on areas judged to be potentially high in snowpack water yields, as determined by observed contributions to the reservoir systems.

After appropriate test sites have been delineated, studies designed to evaluate (1) forest management options for increasing water yields from snow, e.g., reducing forest densities and removing forest overstories, and (2) physiographic and climatic factors which may help determine the quantity of snowmelt runoff yielded, will be implemented. Experimental evaluations will analyze a range of forest management opportunities on sites characterized by arrays of runoff efficiencies as described by physiographic and, possibly, climatic criteria. The ultimate goal of these evaluations will be the prescription of forest management opportunities that will maximize the water equivalent of the snowpack at peak accumulation on sites of high runoff efficiency.

Some studies of the snow regime as affected by forest density levels and clearings in forest overstories have begun, based on preliminary assessments of physiographic, climatic, and vegetative factors. Snow accumulation and melt have been measured for three years on study plots of different forest densities in the White Mountains and near Flagstaff. Additionally, the snow regime in forest openings and clearings has been measured on exploratory study sites this past winter. These efforts will be intensified on the basis of the above-mentioned inventory studies this coming year. In addition, the U.S. Forest Service is evaluating the effect of forest management practices on snow accumulation and melt in the Salt-Verde River Basins. Our work is coordinated with these efforts.

Preliminary assessment of physiographic factors that affect the magnitude of snowmelt runoff has also begun. This assessment utilizes the physiographic inventory (arc AB) to index fixed factors affecting runoff and the climatic inventory (arc AC) to index the variable factors. In addition, the combined effect of fixed and variable factors on runoff efficiency has been measured on small watersheds near Flagstaff. Although unique to these particular watersheds, these data provide some insight on the variability of runoff efficiency in space and time.

After field studies are completed, a preliminary and integrating evaluation will be prepared for the ponderosa pine lands that are potentially suitable for snow management. The relationships of proposed forest thinning and clearing practices to the production of timber, forage for livestock, and wildlife will be included in the evaluation. Impacts on recreational and

esthetic values of the forest will also receive attention. The evalution will be submitted to federal, state, and private organizations that may have interest in such management guidelines. Review comments and criticisms from these organizations will be considered in the preparation of a final comprehensive report.

Acknowledgments. The authors express their gratitude to the U. S. Forest Service for assistance in establishing study sites and providing supplementary data. The assistance of the Salt River Project is also appreciated.

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