

Design of Operational Programs for Water Yield Management

by

Ralph Maloney
Chief, Branch of Water Yield Management
Division of Watershed Management
Forest Service, U.S.D.A.
Washington, D. C.

Introduction: To meet the pressures imposed by rapidly expanding and constantly shifting needs of people and their economy, the land manager of today must apply steadily increasing intensity of management to obtain the fullest possible sustained yield of the products and services these lands can provide. Scientifically designed management programs that improve water yields and yet maintain or improve soil stability and quality of the environment and permit optimum utilization of the other resources of the area, can play an important role in meeting those needs.

On most forest lands, particularly on the public lands such as those administered by the Forest Service, operational programs of water yield improvement must be harmonized with other resource values--forage production, timber production, fish and game habitat, outdoor recreation, and scenic and esthetic values. Despite this restraint, the vast sum of knowledge provided through years of observation and research on fundamental plant-soil-water relationships and on the effects that various types of land use can have upon those relationships forms a sound basis for scientific management to improve water supply.

My purpose today is to explain the approach currently being used by Forest Service scientists to evaluate alternative management opportunities on National Forest watersheds as a basis for design of coordinated operational programs of water yield improvement. This involves a systematic assessment of the economic, social, environmental, and ecologic effects of alternative management programs. The evaluations serve as a basis for judicious application of research findings in the design of management programs to achieve optimum utilization of the soil and water base in a manner which will most efficiently meet total public needs. They also serve as a means of appraising the potential contribution of water yield improvement programs on forest and range lands as compared with alternative methods of augmenting water supplies.

The term, "water yield improvement," as used in this paper, means any management practice which will improve the timing of water yields, improve the quality of water yields, or increase the quantity of water yields. It includes water which reaches storage in an aquifer as well as that which appears as streamflow.

Program Planning. A program may be small or large, simple or complex, and serve one purpose or several, but it must be based on a sound analysis of natural characteristics and environmental factors and be designed to harmonize with broad goals and policy direction for the area.

Each watershed is composed of many complex landscape units, each of which is unique in its particular combination of physical, geologic, and soil characteristics, microclimate, and composition and density of vegetation. The characteristics of each of these variables and the effect of management programs upon them has a direct influence on the hydrologic behavior of the watershed following various climatic events. And, these characteristics are seldom constant in a dynamic natural environment in which the ecosystem is subject to continual and often unpredictable change. Variations in the type and sequence of climatic events and conditions; constant changes in age, density, and composition of vegetation; and, occurrence of natural catastrophies such as wildfire and mass earth movement, are all a part of this dynamic environment.

Any program that is undertaken without a scientific assessment of these natural characteristics and environmental factors may produce results contrary to those desired.

One of the main objectives in program planning is the determination of the program's feasibility. Each program purpose and each increment of its size and scope must justify inclusion by some appropriate measure of feasibility or justification which is usually related to the present or anticipated need it serves, the benefits it produces in relation to costs, the investment it repays, and its advantage over alternatives available. This involves investigations and surveys permitting sound analysis and resulting conclusions with respect to the technical-economic-social parameters governing program objectives. The specific objectives and scope of the proposed program determines what must be investigated with respect to the potentials, hazards, and limitations for water yield improvement within the watershed.

Framework for the Investigation. Due to the many demands for physical products and social use of most forest lands, it is usually necessary to develop and analyze a variety of scientifically designed watershed treatment prescriptions. Only in this way can the full range of possibilities and resulting outputs be ascertained. The basic framework for watershed investigations made by Forest Service scientists is intended to not only provide data showing the optimum mix of soil and water dependent activities that will meet a stated management objective for a watershed, but to also permit analysis of the variations in soil and water output resulting from changes in management programs. In other words, the investigation provides information in a manner which suggests which on-the-ground activities and the resulting output levels, from alternatives available, should be undertaken to best meet objectives for managing the soil and water resources of an area.

An analytical survey system is used to define, measure, and evaluate the economic and social contribution made by the water resource to output from the forest property, and to the downstream economy dependent upon forest produced water. It identifies output from water used as a raw material by resources and programs within the forest, and water as a product produced from the forest and utilized by the downstream economy. The results of the survey identify:

1. The specific areas benefiting from forest produced water.
2. The incremental cost of producing additional water and reducing sediment.
3. The economic contribution of forest produced water for onsite, transitory, and downstream use including the contribution to economic stability and growth, and
4. The economic and social consequence of a water production program on other resource uses and programs.

To evaluate each of the alternative management opportunities, four broad types of input information are required. These are:

1. Activities - An alternative management opportunity or use on a given unit of land.
2. Commodity - Products produced from a given unit of land under a given activity.
3. Constraints
 - 3.1 Physical - acres suitable for production of a commodity.
 - 3.2 Management - stated objectives for managing the water and soil resource in terms of total quantities of output.
4. Net Benefits - Net economic and social benefits derived from utilizing quantities of water and soil in, and resulting from, alternative activities on a given unit of land.

An investigation is made to identify the availability and use of precipitation and ground water inflow in terms of water volume used onsite for growing vegetation--including volumes used for production of fiber, forage, browse--and that required by vegetation having primarily a soil holding and natural beauty value. Present and projected amounts of water consumed by forest programs and uses are calculated, including volumes required for fish, wildlife, and recreation. Thus, water requirements for the various quantitative levels of commodity production serve to define the opportunities for making more water available for downstream dependent users.

Once parameter values are established for the water resource within and yielded from each survey watershed, a detailed analysis is made to determine the water yield improvement opportunities on each of the landscape units within the watershed based on defined variations in climatic events and climatic years. This usually includes periods of drouth, sustained high flows, maximum peak flows, as well as average annual yield. Hydrologic response to various types and levels of activity on each individual unit are then related to the hydrologic behavior of the survey watershed as a whole.

In designing treatments that will exist over a period of time, it is necessary to develop information reflecting the watershed's response under the variety of climatic events to which it may be exposed. To express this response, data from long term climatic records are used to predict probable climatic event input. From this we develop long term commodity output, in accord with climatic event variation, for the various activities represented in the treatment situation. The average of the output as controlled by climate and the production capacity of the site, then become the technical coefficients used in the analyses and evaluation.

Intensity of Investigation Required. There is no simple rule for determining the intensity of the investigation which is necessary for design of any particular program. It should be planned and executed so that the probable technical and economic soundness of the program will be determined as early and as inexpensively as possible. To accomplish this objective, the investigation is usually divided into three stages.

The first, or reconnaissance stage, which is based largely upon existing data supplemented by low-intensity field surveys, is designed to provide generalized information on the overall resources, problems and needs of the area and on the potentials, hazards, and limitations as they relate to reaching management objectives. It includes, in the instance of snow information, a determination of the extent of the snow pack zone and of the characteristics of natural snow accumulation and melt within that zone as affected by topographic situation, terrain features, vegetation types and conditions, wind, aspect, degree of exposure, etc. It also includes a thorough review of research findings applicable to the general area and of the conditions under which the research was conducted. This reconnaissance information is used to identify specific areas suitable for project development and as a basis for decisions on whether to proceed with more detailed investigations.

Basic data for the reconnaissance survey are usually available in the form of maps, resource records, aerial photographs, streamflow and climatic records, geologic reports, census, use, and market statistics, snow survey records, previous investigations, etc. The scientist evaluates these data, supplementing them with data collected during the field survey, and conceives a preliminary basic plan that utilizes available resources to meet the needs. This basic plan is then compared with alternatives to accomplish the desired management objectives on progressively increased or diminished scope and scale.

The second, or feasibility stage, which is based upon a more detailed investigation on each of the potential project areas identified by the reconnaissance survey, determines the scope, magnitude, and essential plan and feature of each alternative program and project proposal. This includes, for example, the development and evaluation of various alternative patterns for harvesting timber in the snow pack zone and of various alternative sequence of harvest in relation to total water yields, timing of those yields, flood peaks, etc., at a given point downstream. It also includes an assessment of the approximate benefits and the dollar and opportunity costs of each alternative proposal and a determination as to whether economics are possible through coordination with other resource development activities. In areas where weather modification programs can be anticipated, the probable effects of those programs on alternative proposals must also be evaluated. The information thus obtained is used to prepare a comprehensive report which presents to the land manager alternative means of meeting specific soil and water management objectives and allows him to determine the course of action which best meets the overall management objectives for the area.

The third, or specification stage, supplements the feasibility stage to the degree needed for preparation of final plans and prescription for project installation. It includes reanalysis of the data for each project area in view of the resource coordination requirements or restraints as determined by the land manager.

General Procedure for the Investigation. The investigation involves the inventory, interpretation, and analyses of basic data relating to the area. It is intended to provide answers to the questions: What do I have? Where do I have it? What's happening to it? Why is it happening? and What does it mean?

Inventory. The inventory consists of collecting, assembling, and summarizing data on the basic factors that reflect how and why a drainage handles the water that is applied to it. These are the factors affecting the hydrologic cycle and can be generally described as: slope; aspect; microclimate; lithography; geomorphology; soil characteristics, and productive capabilities; type, density, rooting characteristics, and age of vegetation, and ground cover; and drainage characteristics and conditions.

The water handling qualities of a watershed represent the integrated effects of all the factors and all the variations in each of the factors. Variation in a single factor on a large watershed negates the possibility of trying to assess the factors as single units on such areas. We have found that a logical approach is to stratify or partition the watershed into areas where the characteristics of all of these factors are essentially "homogeneous" with respect to the way they handle the water that is applied to them. We refer to these areas as hydrologic units.

When dealing with a continuum with an infinite range of components and combinations of components such as is found in a hydrologic unit or units, the word "homogeneous" is somewhat limited in scope. Obviously, some subjectivity is introduced when a decision is made that an area is "homogeneous," hence, the quotes on the word are used to signify its limited meaning. Actually, the variation that occurs in the various factors is recognized where possible and more important--described.

For example, it is not practical to evaluate the effect of ground cover on time of concentration of runoff by every individual type and percent of ground cover on a given slope. Depending on the intensity and purpose of the investigation, these may be expressed as density classes such as 0-10 percent, or 0-30 percent, etc. Research findings, analysis of stream-flow hydrographs, and experience enter into the judgment of what affects each general range in ground cover density will have on timing of runoff. Where time of concentration can be a critical factor affecting management decision, we often make a preliminary analysis of detailed information to help guide our decision on the group classes to be used for that particular investigation.

A similar technique is used to inventory the other variables such as slope, soil, and type of density of overstory vegetation.

Interpretation. Interpretation of basic data obtained during the inventory is perhaps the most critical element of the investigation. The data must be translated into meaningful quantitative terms before they can be used in the analyses.

Each characteristic of each variable is interpreted to assess its effect on the hydrologic processes of interception, evaporation, surface storage, surface runoff infiltration, soil and rock storage, transmission, and transpiration for each climatic event and sequence of events. The accuracy of future projections regarding the effects of land management practices which modify characteristics of one or more of the variables on the area is dependent in large part on the accuracy of these interpretations. A fundamental knowledge of plant-soil-water relationships, a good working knowledge of research results and of the conditions under which the research was conducted, and experience provide the best tools to do this job.

One of the most difficult and sometimes one of the most important factors in assessing the opportunities for delivering more water to any given point in a watershed is that of interpreting the hydrologic significance of geologic features. For example, one of our watershed scientists on the Mark Twain National Forest in Missouri recently discovered, through use of dye tracing techniques, that water flow at the lower end of one drainage had originated at a gravel-filled swallow hole in another drainage channel 17 miles away. The dye tests indicate that it takes from 7 to 14 days for the water to make its journey through the rock formation between the two points. Interbasin flow which results in deletions from or addition to the surface water supply is not an uncommon occurrence in many parts of this country and one which must be recognized in designing programs of water yield improvement to meet local needs.

We have found that available climatic data together with streamflow and ground water records, ecological and growth reports, records of past resource use and disturbance, old aerial photographs, reservoir sedimentation data, flood reports, etc. are extremely useful as a check of the validity of the interpretations.

Analysis. Once we know what we have to work with, where it is, and what is happening on it, we need to find out why it is happening and what it means. The analyses phase of the investigation helps us to find the answers to these questions. Each characteristic of each watershed variable is quantitatively evaluated to determine its relationship to characteristics of the other variables on each hydrologic response unit and to the hydrologic behavior of the watershed as a whole. Predictions of anticipated effects of alternative management programs are based on an analysis of the anticipated effects of each alternative on the hydrologic characteristics of the watershed variables.

The analyses include a determination of the hydrologic potential of the watershed: what it can produce or can be made to produce in units of total volume of water, timing of water yield, or water quantity, and in units of reduced flood flows and soil erosion or sediment rates under present or probably achievable future physical conditions of the site. For example, the newly adopted water quality standards set by each State usually contain limitations on the range of turbidity which will be accepted; therefore, the colloidal content of the soil often has a direct bearing on the extent of area that can be exposed at any one time to stay within those limits.

The factors of supply and detention of water, together with data on the water loss potential of the surface soil and snow, the interception by the vegetation, the productive capacity of the soil, and the transpiration by the various vegetation types, provide the bases for determining the water yield potential for each unit of landscape.

To appraise the effect that treatment on any particular unit will have on water reaching a stream channel, the water yielded as surface and subsurface flow from each upslope unit must be routed progressively over and through each of the downslope units accounting for use or detention of water which might take place on each of those units. This use will vary with the volume of waterflow and the time of year and depth below ground surface that it is flowing.

An additional appraisal of stream channel characteristics and conditions is required to determine how much of the water that initially reaches a stream channel will be available at various downstream points. For this appraisal we must know the amount of additional water which reaches the stream channel as precipitation or subsurface flow, the occurrence of geologic formations which might redirect flow to points outside the channel, the amount of water used by streamside vegetation, streambank storage characteristics, storage and transmission capabilities of alluvial deposits within the stream channel, and the amount, kind, and location of debris within the channel.

The sedimentation potential is made up of the erosion, sediment transport, and sediment deposition factors. Sediment potential is affected by all the factors which influence the water yield potential and, in addition, the characteristics of the soil's resistance to erosion, the capacity of the site to retain soil once it has been exposed, and the channel characteristics affecting deposition of material.

The water quality potential is influenced by the supply of organic and inorganic materials furnished by the surface soil during the surface runoff, by the geologic and soils materials contributing to ground water runoff, and by the pickup or trapping of organic and inorganic matter in the channels during runoff.

There is no single analytical procedure that has universal application to every investigation. Differences in types and accuracy of data require different approaches. However, choice of analytical procedures has considerably broadened with introduction of high-speed computers and subsequent development of new techniques for analyzing large volumes of data. We now have a number of operational summarization and analytical computer programs which have been designed by our watershed systems development unit. These include programs to compute a water balance and to make erosion computations and estimate present and future sediment production. The water balance program has been extremely valuable due to its simulation capabilities which allow the user the option of carefully adjusting the various parameters

controlling the several hydrologic processes described in the program. Other computer programs now under development include a management model and a map assemblage, data storage, and retrieval system.

Data and experience from previous investigations and installed programs provide the best sources of information for the analyses. The Forest Service system of barometer watershed is beginning to prove an invaluable source of information from which to develop local "volume tables" as they relate to the soil and water resources in each major hydrologic province.

Water Yield Improvement Through Snow Pack Management. Research findings and operational experience indicate that, as a general rule, opportunity for water yield improvement becomes increasingly favorable where most of the precipitation comes in the form of snow. Studies in the snow pack zone have shown that the installation of carefully designed and located snow fences and the manipulation of forest to change the crown density, the pattern of openings, or the size, shape, and orientation of the openings can have a marked effect on snow accumulation and rate of melt. Other supplemental practices, not yet fully tested under management situations, include intentional avalanching, reshaping terrain, the use of evaporation suppressants, and the use of carbon black and other materials to control the rate of snowmelt.

One of the greatest challenges to the land manager is his ability to recognize the opportunities to utilize this research knowledge in planning and carrying out day-to-day activities. Opportunities to incorporate water yield improvement practices into activities in the snow-pack zone existing every time we locate and build a road, harvest timber, thin a stand of trees, or install a new ski run. This is particularly true in the vast areas of commercial timber lands in this country where scientifically designed harvesting techniques can be economically and effectively utilized for water yield improvement as part of the timber harvest program. I'm sure that those of you who are land managers can think of many more opportunities on the lands you own or administer.

We still have a lot to learn about the aerodynamic process involving the transport of snow and about the factors that affect the characteristics of snow. But, we cannot afford to wait until we have all the answers before applying the vast amount of information already available.

In Summary:

1. We have the knowledge, based on years of research, on which to base operational programs for water yield improvement.
2. We have a system for translating that knowledge into the quantitative terms needed to evaluate alternative programs to meet the public needs for more water, better timing of water yields, and improved water quality, as well as for the other resources of an area.
3. In many areas, there are needs for water dependent commodities produced on the watersheds, as well as for the water itself. These water dependent products--wood fibre, forage, fish and game, outdoor recreation--also have an economic and social value to people; and, in some cases, these values may override the value of water per se. The design of water yield improvement programs must include an assessment of the needs for and use of water in transit and downstream as well as onsite.

As we gain more knowledge through continued research and through continued efforts to learn how to translate research findings into operational programs, we can and will improve our ability to incorporate water yield improvement in management programs to meet the needs of people and their economy.