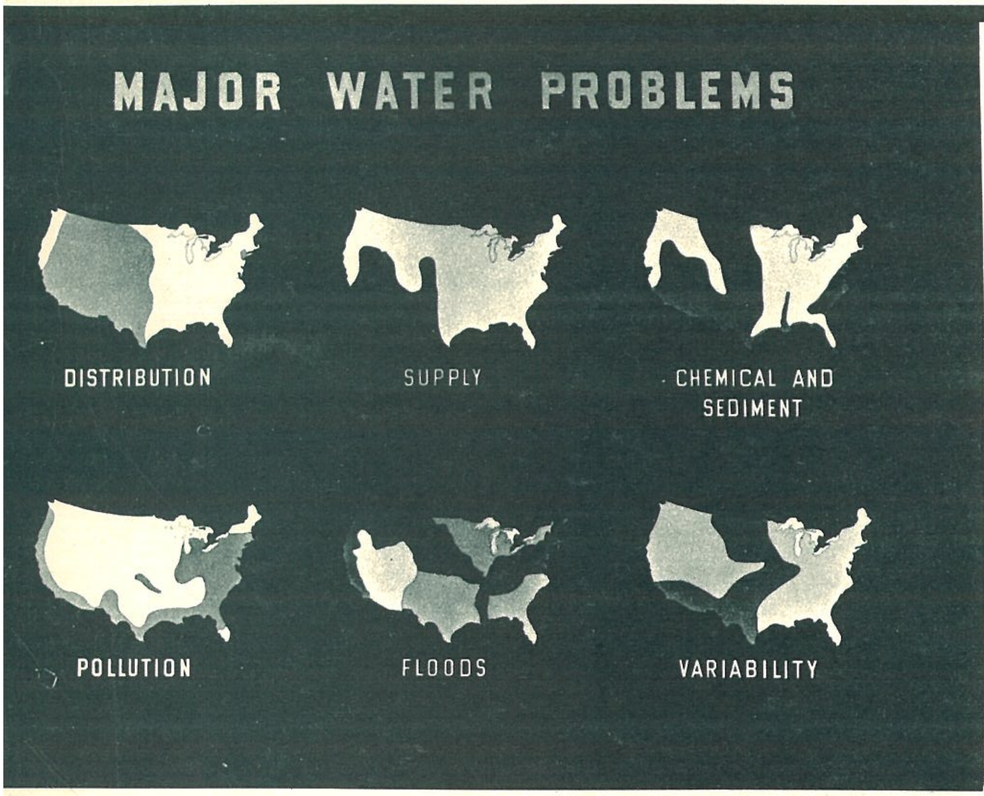
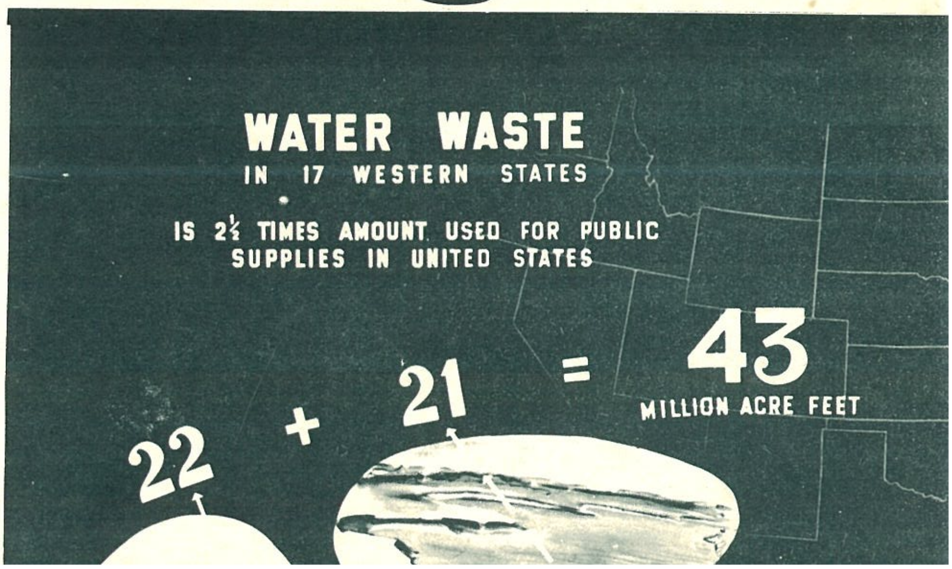
Fifth Annual New Mexico Water Conference

NOVEMBER 1-2, 1960



Watershed Management



NEW MEXICO STATE UNIVERSITY

MILTON STUDENT CENTER
UNIVERSITY PARK
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NEW MEXICO WATER CONFERENCE

Sponsored by

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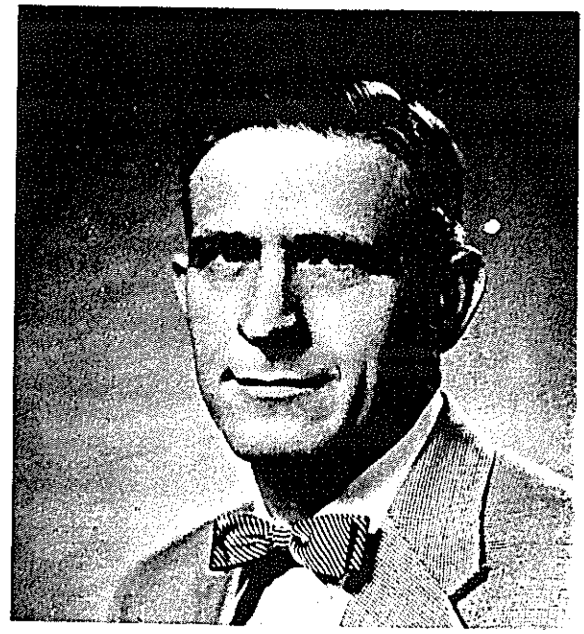
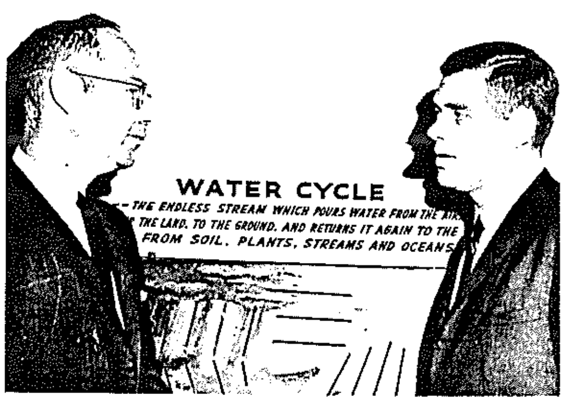
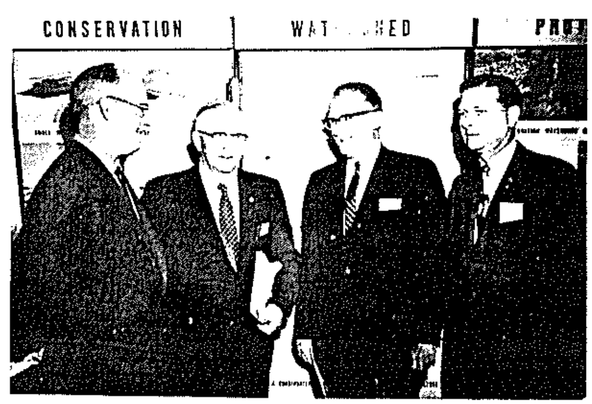
A. L. Miller, M. D., Office of Saline Water, Washington, D. C. told the Conference that by 1980 it is estimated that this country will be using about 600 billion gallons of water daily. This is 85 billion gallons more than is presently available. The research now in progress to convert saline water to fresh water may help fill the new needs.



State Engineer, S. E. Reynolds, stated that New Mexico's economic development can be greatly extended by developing substantial quantities of water to which the state is entitled, and by an orderly redistribution of water among beneficial uses under one state law. Water salvage and water conservation can further extend our economic base.



Dr. P. J. Leyendecker, Dean and Director of Agriculture, New Mexico State University, left, and George W. Abbott, Assistant Secretary of the Interior, Washington, D. C., right, were speakers in the opening session of the conference. They gave a broad outline of the importance of water to the southwest economy.



General C. M. Woodbury, left, Roswell City Manager, Dr. A. L. Miller, Dr. Roger B. Corbett, President of New Mexico State University, and Rogers Aston, Southspring Foundation, Roswell, consider the importance of the Roswell Saline Water Plant to New Mexico, Roswell, and the New Mexico State University.

FOREWARD

The subject of the Fifth Annual Conference was Watershed Management. This subject was chosen because watershed management has an important bearing on the States' total water supply.

A yearly average of over 90 million acre feet of water falls on the 77,866,240 acres of New Mexico. This comes as rain, hail or snow. An average of about 2.5 million acre feet enters by stream flow, which is our only other source for increasing our available supply each year.

The moisture disappears from the land surface where it falls, by evaporation, run-off into stream channels, used by grass, trees, shrubs and crops, and by seepage into the ground water basin. How the watershed is managed has an important bearing on the quantity and quality of the annual precipitation which is later available for irrigation, recreation, municipal and industrial uses and as ground water. It also has an important bearing on the amount of grass and timber produced on our range and forest lands. Evaporation is the greatest source of water loss and the type of watershed management can increase or decrease this loss by evaporation.

Every citizen in New Mexico is dependent on our present and future water supplies. The watershed management has much to do with these supplies. Watershed management is controlled by many public and private groups and individuals. Also, the water from the watersheds is used by many public and private groups and individuals. Often these groups are not made up by the same people. For this reason this conference attracted a wide variety of interests.

The Conference was arranged in sections, (1) Problems of Watershed Management, (2) Research in Watershed Management, and (3) The Public in Watershed Education. General sessions were held to bring these interest groups together to discuss Water Needs of Tomorrow and the State Water Program. In each of these sections papers were presented on selected topics. Adequate time was provided for discussion. Consideration was given under each section to the agricultural, recreational, municipal and industrial needs for water and how watershed management affected those needs. The Conferences are open to every interested person and are designed to permit free and constructive consideration of how our New Mexico water resources can be conserved and developed. Milton Student Center, on New Mexico State University Campus, has been the site of each of the five conferences.

The Water Conferences are sponsored by New Mexico State University through the Agricultural Experiment Station, Agricultural Extension Service, College of Agriculture, College of Engineering, and Cooperative Agencies of USDA-Agricultural Research Service, and Soil Conservation Service, with the cooperation of the Water Conference Advisory Committee, the New Mexico Department of Development and the South Spring Foundation.

The papers appearing in this publication are in the order in which they were presented. The program which follows this statement will serve as an index to the papers.

H. R. Stucky

H. R. Stucky, Head
Department of Agricultural Economics
and General Chairman of New Mexico
Water Conference

NEW MEXICO WATER CONFERENCE

New Mexico State University
November 1 - 2, 1960

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WATERSHED MANAGEMENT RESEARCH

George F. Ellis[1]

This will be a short report of my experiences as a member of the Advisory Council for the Rocky Mountain Forest and Range Experiment Station.

This experiment station is concerned primarily with basic research in watershed management. The purpose of the Advisory Council is to guide the station as to types of projects conducted. Meetings of the council are held once or twice annually. They may be either office meetings or field trips to inspect projects proposed or in progress. Membership of the council consists of representatives of most Federal and State agencies concerned with water use and watershed management in the southwest. There are also two ranchers on the council of which I am one.

The council has taken the position that research projects should be designed to develop information that will lead to a balanced program of watershed management to best serve the needs of the main interests concerned.

There are four groups mainly concerned with the use of watersheds. They are:

1. Water users. This group consists of those who need water for irrigation, towns and cities who must have water for domestic use and industries who need water for their operations.
2. Grazing interests. Since range livestock production is still the most important industry in the southwest proper range management on watersheds is extremely important economically.
3. Timber interests. Timber is one of the major resources of this area. Relations of timber production and proper watershed management need careful study.
4. Recreation. With a growing population with more leisure time the demand for more recreational facilities is growing. This aspect of watershed management needs to be studied.

Projects now being conducted by the research people include.

1. Watershed treatments of various kinds to determine which produces the greatest long time yield of water. In these studies cost of treatment, effects on silting of reservoirs and possible invasion by brush all need careful study. Timber management is being studied here too.
2. Range management studies. These include reseeding investigations and efforts to find proper rates of stocking. Proper time of use is also being investigated.
3. Various soil treatments to find their effect on water yield, erosion and forage production.

Many people feel that careful investigation is needed before any large scale watershed treatment is undertaken. In one of our neighboring states great pressure developed for immediate action to get more water from the water-

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1/ Chairman, Research Advisory Council, Rocky Mountain Forest & Range Experiment Station sheds. Consequently about a million acres have been cleared of timber. No one knows if this will work. First, the cost seems to be out of all reason. Second, there is great likelihood of more erosion and silting of reservoirs. Third, there is danger of brush coming in to take the place of the timber. It might use more water than the trees. Fourth, seeding of grass in many of the areas cleared has not been successful to date.

This serves to illustrate the complicated nature of the whole watershed problem. Careful measurements need to be made on small pilot watersheds before any large scale treatments are applied. Several such projects are now in progress. Water yields of several watersheds are being measured before treatment. Various treatments will then be applied so that an accurate comparison can be had.

But all research takes time. This is especially true of work which needs to be done on our watersheds. I believe the work could be speeded up a great deal, but this costs money. Perhaps it all depends on how much we are willing to spend for more water.

WATERSHED MANAGEMENT BEGINS ON THE LAND

J. L. Merritt 1/

What happens to our water after it falls upon the land as rain and snow, is dependent upon the climate, topography, geology and use or uses made of land resources within the watershed. The questions of whether we have enough water or too much water at certain times, or whether the water is available when and where we need it depends greatly on how we use and treat our watersheds.

In using lands we invariably alter their original conditions. These changes can result in changes in water movement. This, in turn can change plant cover and growth, change wildlife habitat, or change the character of the soil which may affect water intake rates and water holding capacities and on and on. This cause and effect chain reaction is complex and far-reaching and beyond the scope of my comments. I do, however, wish to emphasize that we must not fail to recognize that any action taken anywhere in a watershed that affects one resource will inevitably affect others.

Research and experience has shown that each piece of land is better suited for some one use or combination of uses than another piece of land in the same watershed. Thus, our watersheds must be managed on the capabilities of the land and treated on the basis of what is needed to be done to provide optimum utilization of resources, And this must be accomplished with a minimum amount of conflict among the various beneficial uses associated with the entire watershed.

I don't believe it is necessary to elaborate greatly on the many beneficial uses that our watersheds have in New Mexico. The one single use which all watersheds share in common is that they receive precipitation which falls on the land. Our watersheds are the source of our water supplies for our homes, our farms and ranches, and for industrial uses. It is true that some of our watersheds produce more water than others. For example we know that upstream watersheds on the Rio Grande produce more usable water than Tortugas watershed just south of the campus. Each of these watersheds do not function under the same set of environmental conditions. Thus each watershed differs in its capacity of use. Each watershed must be treated differently to afford optimum utilization of its resources.

Someone has said that watershed management is one of the most complex activities undertaken by man. It is complex because many different needs and purposes must be served. In our state the situation is further complicated by competing and conflicting needs among all water users. For example, downstream water users view with alarm any upstream activity which appears to encroach upon or reduce maximum surface runoff. Fish and Game enthusiasts likewise frown upon streambed practices to control and eliminate phreatophytes. On the other hand, there are proponents who advocate that watershed planning and management should be based on the multiple-use concept. The object of this approach is to seek efficiency in the manner of water use among all beneficial users - along with justice in the allocation of water rights.

1/ President, State Association of Soil Conservation Districts, Yeso, New Mexico

Efficiency of water use, as I understand it, is the ratio between our available water supply and the resulting beneficial uses. In our state water is the limiting factor in development and growth. Because of this we must be extremely careful in planning future water requirements to meet increasing population demands and changing beneficial uses. Certainly it appears logical to conclude that our watershed management programs must be developed to assume the greatest good to the greatest number of people in the long run. If we fail to build upon this thesis, we may find that our water problems will become more acute--the costs of water development will be prohibitive and we will fail in our attempts to develop, conserve and wisely use our meager water supplies.

THE WATERSHED MANAGEMENT PROGRAM OF THE U. S. DEPARTMENT OF AGRICULTURE

Carl B. Brown1/

It is gratifying to have this opportunity to outline for the Fifth Annual New Mexico Water Conference the watershed management programs of the Department of Agriculture.

Definition

The term watershed management connotes quite different sorts of activities to different audiences. In the Department, in fact, it encompasses a wide variety of activities which often have materially different objectives. To some people, especially in the Southwest, watershed management is identified with the land above the irrigated valleys. Watersheds are commonly thought of as the forested or brush·covered drainage areas of the mountains and foothills from whence comes the life-giving water for crops and livestock and domestic use. Watershed management to western water users may be protection of timber stands from cutting or from fire; it may be the clearing of brush or selective cutting to produce greater water yield; it may be erosion control to reduce the heavy sediment load that threatens destruction of valley storage reservoirs.

In other sections of the country, however, watershed management may mean something quite different. In the Southeastern Coastal Plain, or the Minnesota pothole country, it may mean a well developed system of drainage canals and laterals on lands so flat that only a transit will reveal watershed divides. In the Southern Piedmont or the rolling plains of Texas and Oklahoma it may mean a system of crop and range land treatment supplemented by floodwater-retarding structures to prevent excessive flood damages. In most sections of the country people think of watershed management as including all the lands of the watershed, the flood plains or valleys, as well as the sloping uplands or mountains.

Several Department programs either <u>are</u> watershed management, or contribute materially <u>to</u> watershed management. These programs fall in two categories: (1) the action programs, and (2) the supporting programs. Supporting programs include research into many aspects of watershed management by the Agricultural Research Service and by the Forest Service. These research programs, we are happy to report, have been generously supported and greatly strengthened in the past 5 years. They are giving us progressively better tools with which to do an increasingly effective watershed management job. Another supporting program is the Federal-State Extension Service work which shows private landowners the need and value of watershed management, thus paving the way for action to apply the knowledge gained from research.

1/ Watershed Program Specialist, Office of the Assistant Administrator for Watersheds, Soil Conservation Service, U. S. Department of Agriculture.

Action Programs

The action programs of the Department that directly provide or support watershed management may be catalogued as:

(1) The soil and water conservation assistance provided to individual landowners and operators or small groups of landowners by
  (a) technical assistance from the Soil Conservation Service supplied through local soil conservation districts,
  (b) cost sharing in the application practices provided through the Agricultural Conservation program,
  (c) the Great Plains Conservation program operating in ten Great Plains States administered by the Soil Conservation Service, and
  (d) loan assistance for application of soil and water conservation measures provided through the Farmers Home Administration;

(2) The watershed management work of the Forest Service on the National Forests; and

(3) The small watershed program providing technical and financial assistance to local organizations authorized by the Watershed Protection and Flood Prevention Act, Public Law 566, and administered by the Soil Conservation Service, with assistance of the Federal public land management agencies.

The programs of assistance to individual landowners and operators all contribute to watershed management. They are, in fact, an essential part of it. They are not in themselves watershed management, however, for their basic objective is the conservation and development of soil and water resources on the individual farm or range, the field or pasture, the acre or timber lot. The benefits that accrue to the watershed as a whole are the incidental dividends not the planned purpose of these programs.

If watershed management programs have a distinguishing characteristic--and I believe that they do--it is that they are based on a watershed plan and a schedule for its accomplishment. They necessarily encompass and take full advantage of all of the other kinds of conservation programs that can contribute to the scheduled accomplishment of the plan. They add only the necessary additional inputs of technical, financial, or other resources needed to reach the planned goal. The goal itself nearly always includes objectives that are impossible to accomplish by separate action of individual landowners or through continuing annual programs on public lands. Such objectives, which generate the need for watershed management programs, include flood prevention, irrigation water supply and distribution, drainage systems, municipal and industrial water supply, fish and wildlife development and recreation, pollution abatement, etc.

There is a growing demand for complete multipurpose watershed programs. This is manifested in many ways. One is the recently enacted National Forest Multiple-Use Act, Public Law 86-517. Another is the increasing number of multipurpose objectives such as municipal water supply, fish and wildlife development, etc., being included in P.L. 566 applications for assistance.

Interest is being widely expressed in bringing into small watershed projects still other purposes such as pollution abatement, phreatophte control or mine waste disposal, in fact any and all purposes that are required to provide the complete solution of the land and water problems of upstream watersheds.

This trend makes it apparent that we must all broaden our concept of watershed management. We should no longer conceive of it as just the management of vegetative cover on the mountains above our irrigated valleys nor the construction of systems of floodwater-retarding reservoirs, or storage and conveyance systems for irrigation or drainage. We must increasingly conceive of watershed management as the total job of land and water development, conservation, and proper utilization in all the natural hydrologic sub-basins of our great rivers.

The two action programs of the Department for which funds are appropriated under the general heading of watershed management or watershed protection are (1) the public land program of the Forest Service and (2) the small watershed program administered by the Soil Conservation Service.

Watershed Management on National Forests

The Forest Service administers approximately 186 million acres of public lands including national forests and national grasslands. One-fifth of the eleven Western States is national-forest land. This land, because of its mountainous character and generally high elevation, receives one-third of the precipitation and furnishes over half the streamflow. Western national forests are major sources of water for hundreds of towns and cities, and for an intensely irrigated agriculture. Over 600 hydroelectric developments depend on national forests for water. Over one-third of all big game in the Nation is found on national forests, along with 81 thousand miles of fishing streams and over two million acres of natural lakes and impounded waters. About 11 percent of the lands in New Mexico--some 9 million acres--are administered by the Forest Service. These areas and intermingled ownerships produce approximately three-fourths of the total usable water of this State.

Watershed management on the public lands administered by the Forest Service consists of three principal phases. These are protection, restoration, and improvement. These phases may overlap and in all cases must be correlated with the management of other wildland resources as part of the multiple-use objectives for these lands.

Protection may be defined as management to maintain existing and acceptable watershed conditions. It includes the inventory and analysis of watershed conditions and requirements as they relate to soil and water resources.

Under multiple-use management full consideration is given to the perpetuation of all resources. In general, water is favored in applying this management. Uses for forage, big game, wildlife, recreation, timber and other resources are oriented toward soil conservation and maximum development of the water resource. In some cases values other than water may be dominant but the overall resource management will still be harmonized with proper watershed functioning to control erosion and retard runoff. Thus, the job of the forest land manager includes an appreciation and appraisal of the impacts of the combined uses of resource upon individual watersheds.

Restoration involves the correction of undesirable watershed conditions, many of which are of long standing and existed before the establishment of the national forests. Work in this activity includes such measures as contour terracing, pitting, water spreading, gully and channel stabilization and erosion control on roads, trails, and other disturbed areas. It also includes revegetation for watershed purposes--not ordinarily considered in regular tree planting and grass seeding operations primarily for increased timber and forage production.

Since 1956 restoration projects have been undertaken on some 80 national forests. Examples of those carried out in New Mexico may be found in the multiple-use project in Taos Canyon, and the restoration of abandoned roads on the Carson National Forest; and the Glorieta Mesa project on the Santa Fe National Forest.

Improvement is research and pilot plant trials on new methods of watershed management. The Forest Service is continuing studies concerning maintenance of soil stability, improvement of infiltration, retardation of rapid storm runoff, and prevention of siltation, all of which help to make more water usable. Work of this kind is well under way in New Mexico on the Rio Puerco watershed. Modification of management practices to improve water yields is also being studied in experimental watersheds in the Santa Fe National Forest. An outstanding illustration of this research work is the Salt River project in Arizona, the results of which may also apply to some New Mexico watersheds. Here dense thickets of young pine are being thinned by several methods.. Heavy stands of low value juniper are being rooted out with tractors followed by grass seeding. Experiments in controlling chaparral with chemicals are being tried. Timber stands at high elevations are being cut patchwise to allow more snow and rain to get to the ground. From the standpoint of water supply and quality the results are being measured by stream gages and sediment basins. It is hoped that from these studies more progress will be made in watershed management practices which will increase the annual yield of usable water from national forests and other similar lands.

The Public Law 566 Program

On privately owned lands, the Department's principal watershed activities are those authorized by the Watershed Protection and Flood Prevention Act, Public Law 566. Work is continuing on eleven watershed projects comprising about 30 million acres authorized in the Flood Control Act of 1944, and is nearing completion on some 60 pilot watersheds provided for in the USDA Appropriation Act of 1954.

Few conservation Acts have created as much popular interest and activity in such a short time as has Public Law 566. Although the sixth anniversary of its enactment occurred only last August, local organizations have prepared applications for assistance under its provisions in some 1600 watersheds. As of October 1, 1,367 applications had been approved by designated State agencies in 47 States and Puerto Rico, and had been transmitted to the Department of Agriculture. These applications cover over 95 million acres. In order to enable more effective State and local participation in this program, the legislatures of 40 States had enacted more than 150 pieces of State legislation. Additional new legislation is being prepared for consideration by the legislatures of several States next year.

As of October 1, the Soil Conservation Service had provided planning assistance to 593 watersheds containing over 41 million acres. Based on completed plans, approved administratively or by congressional committees, as required, 285 projects containing about 17 million acres had been authorized for operations and an additional 19 completed plans are in the process of approval.

New Mexico stands very high in taking advantage of this program. It ranks sixth in the Nation in number of applications, sixth in number of projects approved for operations, and fifth in acreage included in these projects.

The popularity and support of the P.L. 566 program throughout the Nation indicates that it truly meets a long-felt need for organized action to fill a gap in our national resource conservation and development. Prior legislation had provided, on the one hand, for programs of public land conservation and for technical, educational, cost-sharing and credit assistance to individual private landowners and operators. On the other hand, the Reclamation, Flood Control, TVA, and other Acts had authorized large programs of Federal development of downstream river resources, including vast irrigation schemes, hydro-power development, flood control, navigation and, secondarily, fish and wildlife development, recreation, and municipal or industrial water supply.

The gap left by these programs occurs in the small watersheds, generally those of less than 250,000 acres. The small watersheds have many of the same needs for land and water management that exist on the larger rivers. More than half of the flood damage in the Nation occurs in these upstream watersheds. A large percentage of the irrigated farmlands of the West are within or get their water supply from small watersheds. Most drainage needs in the East are confined to small watersheds. Thousands of towns and small cities use surface water supplies from such watersheds. Fish and wildlife and recreational development must be greatly accelerated on small watersheds if the need for such development is to be brought within reasonable distance and cost to the average citizen. Many of the problems of erosion, as along water courses, or of phreatophyte control can be effectively solved only by public action programs in small watersheds. In fact, of all water resource developments only navigation and hydro-power seem to be confined to, or even predominant on, our larger rivers.

Although the gap in resource development in the small watersheds was widely recognized for a long time, a crucial issue was how it was to be closed. Were Federal public works programs to be extended further and further upstream until they reached the individual farm? Or were local groups with little help from State government to be left to contend ineffectually with small watershed problems?

The Public Law 566 program was a response to this need hammered out in the Federal executive and legislative branches in the early 1950's. Its fundamental principles are (1) local initiative and responsibility, (2) Federal technical and financial aid, and (3) State review and approval of local proposals with the wide open opportunity for State financial and other assistance.

The P. L. 566 program already provides the opportunity for meeting a large part but not all of the land and water management needs of small watersheds. At present watershed projects may include all needed measures for land treatment and stabilization on public as well as private lands and additional structural measures for flood prevention, irrigation, drainage, fish and wildlife development, and municipal and industrial water supply. To the extent that any needed purposes are not presently included in the scope of the Act it seems more than likely that the legislation, already amended five times since its original enactment, will be still further improved during this decade. The kinds and amounts of Federal, State, and local cost sharing may be modified from time to time. Changes in emphasis and priority are likely. But in my judgment the basic pattern of local, State, Federal partnership will not change. It has appealed to farmers and city dwellers alike as being basically sound and fundamentally right in the framework of our American system of government.

The Conservation Needs Inventory - Watershed Phase

Other participants in your Conference will spell out some of the details of operation of the P. L. 566 program, and how it is progressing in New Mexico. In the few minutes remaining to me, I would like to outline the national scope of small watershed treatment needs as revealed by the Department's soil and water conservation needs inventory. Many of you here, I am sure, participated in this inventory over the past three years either as members of the State CNI committee or of County CNI committees. These committees included representatives not only of all the principal USDA agencies concerned with soil and water resource conservation, but also of other Federal, State, and County agencies having responsibility in this field. The inventory was made in two parts. The first part dealt with conservation needs on the land itself--adjustments of use within capability and treatment according to needs that can generally be accomplished by the landowner with appropriate forms of technical and financial assistance. The second part dealt with watershed needs that required group action through project-type undertakings by public agencies--local, State, and Federal.

My discussion here relates only to the second part of the inventory. The figures are still tentative as a few States have not yet been fully checked out, but they are close enough.

Except for a few large primarily arid areas in the West, the United States was divided into 12,717 watersheds, all less than 250,000 acres in size. The problems which would require project action for solution in each watershed were studied by the County CNI committees using various kinds of data compiled by participating agencies for the committees. Based on these studies and combining their multiple judgment, the County committees estimated the acreages and quantities of needs for flood prevention, irrigation improvement, drainage, and other water resource purposes. The County reports were reviewed and correlated by the State CNI committees and the State reports are now being reviewed and correlated by a national CNI committee.

The State reports show a need for project-type action on 8,288 watersheds or 65 percent of the total number in the Nation. These watersheds contain approximately one billion acres or 55 percent of the Nation's land area. The inventory shows an estimated 61 million acres needing project action for flood protection in upstream watersheds, 15 million acres needing project action for irrigation, and 43 million acres needing project action for drainage.

In New Mexico 451 watersheds were delineated and 134 of them containing 18 million acres were considered by County committees to need project-type action programs. The problems delineated in these watersheds included 633,000 acres needing flood protection, 67,000 acres needing irrigation improvement, and 2,000 acres needing drainage improvement.

Dimensions of the Watershed Job Ahead

Against these and other related estimates it is possible to make some first approximations of the magnitude of the small watershed job ahead. In this inventory it was impossible to evaluate the economic feasibility of meeting the appraised physical needs by reference to existing standards of benefit-cost analysis. On the other hand, standards of benefit evaluation as well as costs change with time. They are more than likely to be quite different in the year 2000 than they are today if present population and economic projections are realized.

Applications have been received under P. L. 566 for Federal assistance on over 95 million acres. The total treatment costs, Federal and non-Federal, on the first 267 watersheds comprising 16½ million acres authorized for operations under the P. L. 566 programs, is $21.69 per acre. Treatment costs on the 30 million acres in the 11 authorized watersheds are about the same. If it were assumed that average future treatment costs would be $25 per acre, and that 80 percent of the one billion acres were within economically feasible watersheds, an ultimate aggregate outlay of $20 billion of local, State, and Federal funds would be indicated. In the current fiscal year we estimate that the total local, State, and Federal outlay for watershed project programs will approximate $95 million.

The relation of this estimate to projections of total water resource needs is of interest.

The Department of Commerce has published a report entitled, "Water Resources Developments, Capital Investment Values 1900-1975" (June 1959) which projects water resource needs to 1975. In this report the Department estimates for the period 1954-1975 a total capital investment need, expressed in constant 1958 dollars to meet existing deficiencies, supply the increasing population and overcome obsolescence of $214 billion. This includes municipal and industrial water supply, sewage and waste collection and treatment, pollution abatement, power, irrigation, navigation, flood control, fish and wildlife development and recreation. Of this amount some $53 billion, more or less, represents the estimated needs for Federal expenditures if Federal responsibilities or cost sharing under existing authorized programs is continued. These projections made by the Department of Commerce include part but not all of the watershed program needs as estimated independently from the Conservation Needs Inventory.

As large as the watershed program needs may seem when considered independently, the estimated $20 billion constitutes only some 5 percent of the total needed capital investment in water resources.

SEEDING OF SUMMER CUMULUS CLOUDS

A. Richard Kassander, Jr. and Louis J. Battan1/

Introduction

As a result of basic studies of the properties of summer cumuli carried out during the period 1953 to 1957 by the University of Arizona and the University of Chicago, it was established that building cumuli in southeastern Arizona are generally supercooled to levels colder than -10° C. Furthermore, it was found that over the mountain ranges surrounding Tucson, Arizona, there are large convective clouds for 40 to 50 days each summer and that most of these clouds do not rain naturally. It was concluded that the prevalence of supercooled cloud droplets indicated a deficiency of effective ice nuclei, and that as a result, these clouds might be amendable to modification through the introduction of artificial nuclei.

On the basis of present-day theories of clouds and precipitation, a program of observations was devised from which it was possible to obtain these measurements which would permit a study of natural physical processes and an evaluation of the effects of artificial nuclei.

Field experiments were conducted during the summers of 1957, 1958, and 1959. The first year's program consisted of a joint operation by the Universities of Arizona and Chicago. The research was sponsored in part by a National Science foundation grant to the University of Chicago. The investigations conducted in 1958 were conducted by the University of Arizona under Grant Number NSF-G5607 with an equal contribution of State funds. This report summarizes the results of the research conducted through 1959.

Design of Experiment

The design of the seeding experiment has been discussed in some detail in an earlier report (1).2/ Briefly, the procedure involved an objective prediction, made prior to 0900 MST of each day, as to whether or not cumulus congestus or cumulonimbus clouds would form over the Santa Catalina Mountains. The main criterion for the prediction was whether or not the precipitable water at Tucson, Arizona, exceeded 1.10 inches. When this occurred, the day was considered to be suitable for seeding, and an envelope was opened which specified which of two adjacent suitable days would be seeded. If more than one unsuitable day separated two suitable days, the first day of the pair was rejected and a new pair was started. The scheme of randomized pairs was adopted in order to take into account day-to-day correlations and to assure that there would be an equal number of seeded and not-seeded days.

1/ Institute of Atmospheric Physics, University of Arizona

2/ Drs. K. A. Brownlee and W. Kruskal of the Department of Statistics of the University of Chicago assisted in the design of this experiment.

The actual seeding was carried out with an Australian-type airborne silver-iodide generator suspended under the wing of a Supercub airplane owned and flown by the Hudgin Air Service. The flight plan involved repeated passes at about the -6° C. level on a track upwind from the mountain range. The pilot normally started the generator at about 1230 MST and continued his flight until all the seeding material was exhausted or the burner went out. Normally the seeding period was of the order of 4 hours. The generator consumed a 20 percent solution of silver iodide in acetone at a rate of 2 to 2-1/2 gallons per hour.

Observations

In order to permit studies of cloud and precipitation processes a variety of observations were made.

Properties of visual clouds.--A pair of carefully calibrated ground-located K-17 aerial cameras was installed at the ends of a 3-mile base leg. Both cameras were triggered simultaneously at 10-minute intervals. When particularly interesting clouds were present photographs were taken at 1-minute intervals. From the pairs of photographs it was possible to make accurate calculations of cloud top heights (4).

Time lapse photographs at 7-second intervals were also taken with a 16-mm. camera.

Precipitation formation as revealed by radar.--An AN/TPS-10A radar set was operated throughout the summer. This set was modified to give a symmetrical one-degree beam. The scanning rate was rigidly controlled so that the vertical scanning rate was exactly one per second and the azimuthally scanning rate was exactly one degree per second. The region over the mountain range was examined once every 3 minutes.

From the film records of the radar scope, it is possible to study the location of the initial precipitation echoes, the rates of spread of precipitation, and the frequency of large convective clouds.

Rainfall.--A network of 29 recording rain gauges was installed to measure the amount and distribution of rainfall.

Lightning.--A lightning counter of commercial design and a Weather Bureau electric field meter were installed on Mount Bigelow, a peak which has an elevation of about 8,500 feet. Various difficulties prevented consistent lightning observation with these two instruments; however, two observers made reliable visual observations of cloud-to-ground lightning strokes.

Results

The number of pairs of days investigated during 1957, 1958, and 1959 were 16, 16 and 20 respectively. On the basis of preliminary statistical and physical analysis one of the 1959 pairs has been tentatively rejected. One of the days of this pair had an extraordinary amount of precipitation. The difference between the rainfalls on the seeded and not-seeded days fell more than six standard deviations away from the mean of the other pairs.

Although the analysis is still in progress, the results to date suggest that the AgI seeding caused some important changes in the natural cloud processes. The results obtained thus far are briefly summarized in subsequent paragraphs.

There have been fairly large differences in the results from year to year. The data accumulated in 1957 and 1958 favored the hypothesis that AgI seeding increased rainfall, caused more large thunderstorms, more lightning and more precipitating clouds (2). In 1959 the results were generally in the opposite direction. There was more rainfall, more lightning, and more large thunderstorms on the not-seeded days. Could this have been a result of the seeding or was this an accidental result which came about because the clouds on the seeded days were smaller and less vigorous than on the not-seeded days? In order to minimize the effects of differences of clouds on seeded and not-seeded days randomization has been employed. It should be recognized, however, that randomization will assure similar samples of seeded and not-seeded clouds only if the samples are large. Twenty pairs do not represent large samples. From observations of the clouds during the summer of 1959, it seemed evident to the authors that, on the whole, the convective clouds on the not-seeded days were more numerous and more vigorous than on the seeded days. In order to arrive at valid conclusions it is necessary to group the data together. The experiments are designed so that this can be done. Final evaluations must await the completion of the planned five years of experiments. In the discussion of the results, statistical evaluations are given, but the reader is urged to treat them with reservations.

Rainfall.--When the data for three years were combined it was found that the mean rainfall per gage was 7 per cent higher on the seeded days. However, the probability that the observed differences in the mean rainfall occurred by chance was very high, 0.30. This value was obtained from a sign-rank test (see reference 4, page 596) which made use of a ranking of the differences of the mean rainfall on pairs of days.

A comparison of the extreme rainfalls on seeded and not-seeded days was made by taking the differences of the maximum rainfalls at any station on days of each pair. During 1957 and 1958, heaviest rains fell most frequently on the seeded days. In 1959 the reverse was true. A sign-rank test showed that the probability of obtaining the observed differences by chance was 0.33.

It is evident that the rainfall data have failed to show that seeding causes increases in precipitation. However, it is also clear that rain gages spaced 4 to 5 miles apart have serious shortcomings when one wants to measure precipitation from convective showers having diameters of 2 to 3 miles. Evaluation procedures which make use of observations of large regions of the cloud should more readily detect changes if any are produced by cloud seeding.

Heights of thunderstorms.--An objective way to measure the relative frequencies of large thunderstorms is to take radar observations every 30 minutes and note whether there is at least one echo extending above any particular altitude. The results for the first three years of operations are given in table 1. It can be seen that the data for 1957 and 1958 are more numerous than that presented in an earlier report (1). This has come about because the evaluation was changed in order to include more observations. During 1957 and 1958, the radar film was changed on the hour. As a result there were many missing photographs exactly on the hour. In the new evaluation, the film was examined during the period five minutes before and five minutes after the hour and the film closest to the 30 minute marks was analyzed. As was the case with the original film analysis, it was done by someone who was not apprised of which days were seeded.

Table 1. Frequency of observations with thunderstorms exceeding the indicated altitudes (in thousands of feet)

	Altitudes			
	≥ 30	≥ 35	≥ 40	≥ 45
Seeded	135	75	48	11
Not-Seeded	104	55	36	8
Ratio s/NS	1.30	1.35	1.33	1.38
P	0.21	0.21	0.16	---

It is evident that on the seeded days there were 30 to 40 percent more large thunderstorms than on the not-seeded days. By taking the differences by pairs of days one can make use of a sign test (see reference 4, p. 598) to calculate the probabilities of obtaining the observed differences by chance. The results of such an analysis are given in the last row. The indicated probability (P) values of the order of 0.18 are encouraging but certainly not conclusive.

Lightning.--Lightning observations were not made in 1957. In 1958 it was found that on the seeded days there was about nine times more lightning. In 1959, the seeded days had only about half as many strokes as on the not-seeded days. See Table 2.

Table 2. Number of observed lightning strokes.

	Seeded	Not-Seeded
1958	1265	138
1959	357	692
Totals	1622	830

When both years are combined, the ratio of strokes is close to two with more having been observed on the seeded days. A sign-rank test revealed that the probability of chance occurrence of the observed ranking of the differences of strokes on pairs of days was about 0.14. This is considerably higher than the value of 0.015 found from the 1958 data alone.

Initiation of precipitation.--By means of the cloud camera and radar data, it was possible to note the vertical extent of clouds (and thus cloud-top temperatures) and whether or not they contained precipitation. When a sufficient number of clouds have been examined it becomes possible to speak of the "probability of precipitation" of clouds whose summit temperatures are between -12° and -18° C., or any other temperature interval. Figure 1 shows a summary of the observations made during 1957, 1958 and 1959.

It should be noted that this evaluation of the results of seeding differs from the others discussed in earlier paragraphs because it does not depend on the total number of clouds on seeded or not-seeded days. Instead, it examines the ratio of clouds with rain. Thus the presence of more clouds on seeded (or not-seeded) days should not materially affect the results provided the number of clouds are sufficiently large.

It is evident from Figure 1 that at all subfreezing intervals between -6° C. and -37° C., the likelihood of precipitation echoes was higher on seeded days. The differences were particularly large in clouds whose summit temperatures were below -18° C. Over the temperature interval -6° C. to -36° C. the fractions of cloud with radar echoes on seeded and not-seeded days were 0.37 and 0.24 respectively. These data strongly suggest that the AgI nuclei induced precipitation in clouds which would not have precipitated naturally.

Altitude of initial echoes.--A study is being made of the altitudes and temperatures at which the initial radar echoes formed. The results of the analyses of all the 1957 and most of the 1958 observations are shown in Fig. 2. Several features of these diagrams are worthy of comment. First of all, it is noted that on the seeded days, there were considerably more initial echoes at all altitudes except in the 10,000 to 12,000 ft. interval. However, the difference may not be immediately assumed to have been a result of seeding. A sign-rank test of the differences of numbers by pairs of days failed to show them to be significant.

The diagrams also show that distribution curves on seeded days were shifted to higher altitudes and lower temperatures. These data suggest that the silver iodide crystals may have caused the cloud particles to reach detectable sizes at higher elevations in the clouds.

Also shown in Fig. 2 are the data on initial echoes obtained by Braham (5) from an analysis of radar observations made at the University of Arizona in 1955. It is seen that the distribution curve is shifted to even lower altitudes than the not-seeded curve. Ackerman (6) analyzed Arizona data collected in 1956 when there was no seeding. She also found a maximum frequency in the 18,000 to 22,000 ft. interval, but the peak was flat, with the next highest interval only slightly less frequent. The mean heights of the tops initial echoes during non-seeded periods were 19,500 ft. in 1955, 21,500 ft. in 1956 and 21,800 ft. for 1957 and 1958. On the other hand, on seeded days during 1957 and 1958 the mean height of the echo tops was 22,600 ft.

The data show that on the seeded days, the initial echoes tops had a mean temperature of -11.3° C. while on the not-seeded days it was -9.4° C.

The shift of the mean echo top to higher altitudes and lower temperatures on seeded days, _if_ it were caused by seeding, may have come about in two ways. First, the introduction of the nuclei may have caused precipitation to form in clouds which would not have formed echoes naturally. If this were to occur, and data presented in Fig. 1 suggest that this did happen, it would be expected that clouds having temperatures substantially below -5° C. would be necessary. The AgI particles may be active at this temperature but the crystal must be in supercooled cloud for perhaps 10 minutes before it can be detected. If the nucleation occurs in a region of ascending air, the initial echo would not be expected to be found until the particles have been carried upwards perhaps 10,000 ft. Figure 1 shows that a large difference between the likelihood of precipitation in seeded and not-seeded clouds was not found until cloud top temperatures of -18° C. were considered. If the reasoning here is valid, one would expect that if precipitation were _initiated_ in clouds which would not have precipitated if they were not seeded, the mean echo height in these clouds would be higher than in naturally precipitating clouds represented by the dashed lines in Fig. 2.

A second way in which seeding may influence the location of the initial echo might be through accelerating the precipitation process in clouds which would have precipitated naturally. Braham (5) and Ackerman (6) have shown that about half the convective echoes they observed had reached their maximum height at the time of initial detection. It could be argued that just before the particles reached detectable size they were either ascending or descending according to whether the echoes ascended or descended immediately after initial detection. If this were true, then acceleration of the growth process may cause the "artificial initial echo" to be either lower or higher than the "natural initial echo" would have been. The observed factor of one-half suggests that statistically this effect of seeding would be difficult to detect.

Summary

The results of experiments conducted during the first three summers of a five-summer research program strongly suggest that the AgI seeding produced some important effects. However, on the basis of the statistical tests, one must still admit the possibility that the results were brought about by chance. The continuation of the program should permit the accumulation of sufficient data to answer, in definite terms, whether or not the results observed were caused naturally or artificially.

References

1. Battan, L. J., and A. R. Kassander, Jr., 1958. _Randomized Seeding of Orographic Cumuli, 1957. Part I._ Tech. Note No. 12, Dept. Meteor., Univ. Chicago, 17 pp.

2. ____________ and ___________, 1959. _Seeding of Summer Cumulus Clouds._ Sci. Rep. No. 10, Inst. Atmos. Phys., Univ. Arizona, 10 pp.

3. Kassander, A. R., Jr., and L. L. Sims, 1957. Cloud Photogrammetry with Ground-Located K-17 Aerial Cameras. _J. Meteor._, _14_, 43-49.

4. Wallis, W. A., and H. V. Roberts, 1956. _Statistics, a New Approach._ Free Press, Glencoe, Illinois, 646 pp.

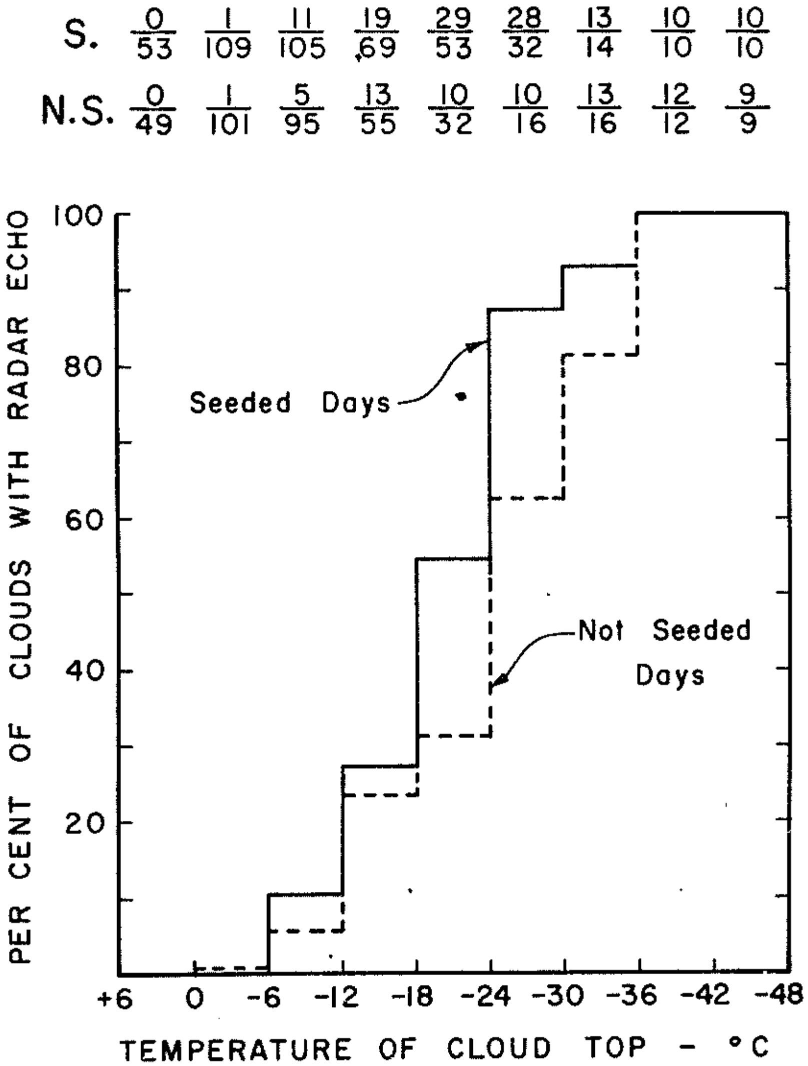


Figure 1

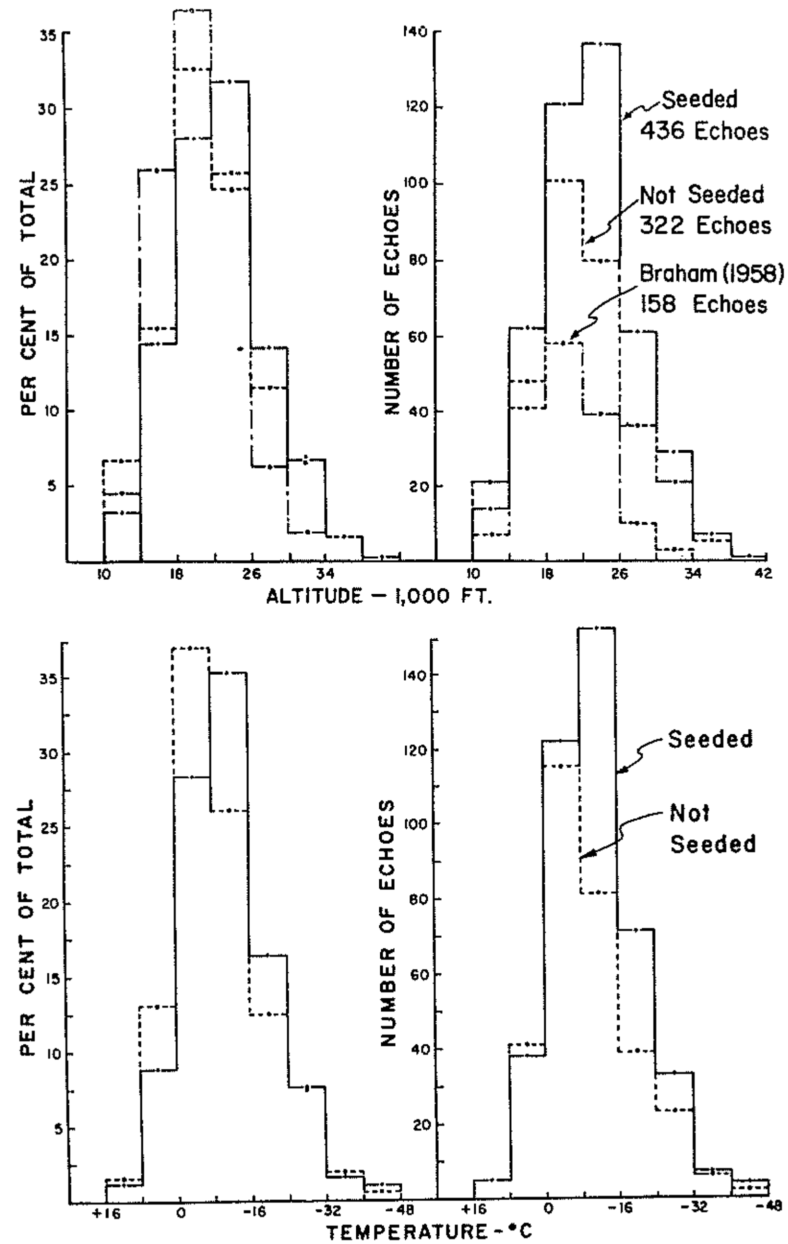
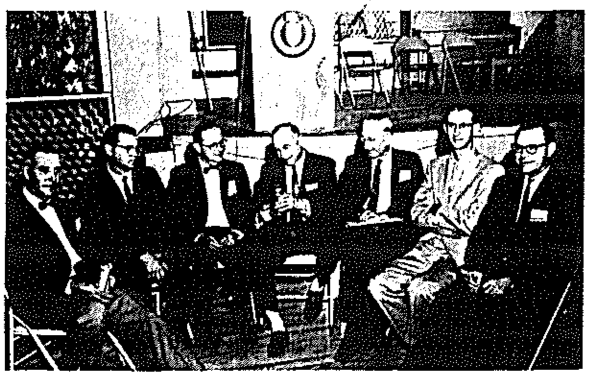


Figure 2

5. Braham, R. R., Jr., 1958: Cumulus cloud precipitation as revealed by radar - Arizona, 1955. J. Met., 15, 75.

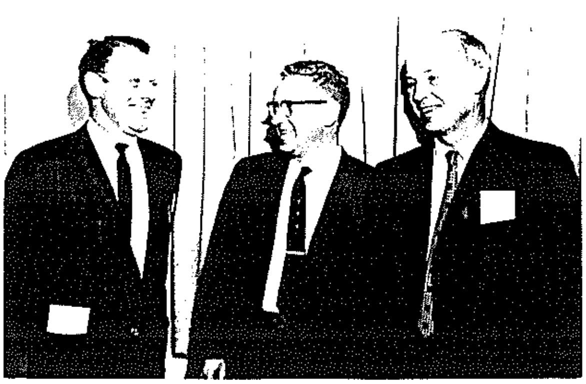
6. Ackerman, B., 1959: Characteristics of Summer Radar Echoes in Arizona, 1956. Sci. Rep. No. 11, Inst. Atmos. Phys., Univ. Arizona, Tucson.



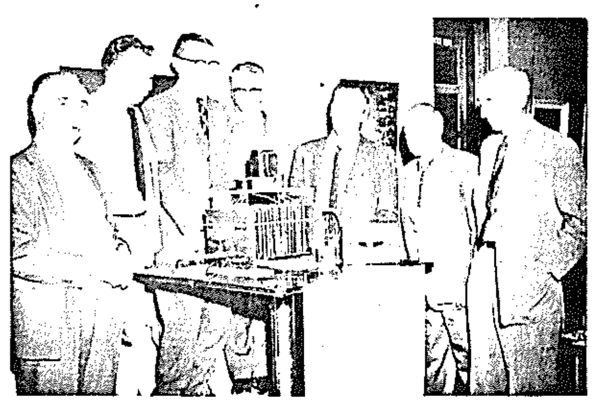
Research in Watershed Management was the subject for discussion by left to right, Fred Arle, Agricultural Research Service, Phoenix, Arizona, Jesse Lunsford, Civil Engineering, New Mexico State University, L. D. Love, U. S. Forest Service, Ft. Collins, Colorado, E. J. Dortignac, U. S. Forest Service, Albuquerque, New Mexico, A. S. Curry, Associate Director, Agricultural Experiment Station, New Mexico State University, Wayne J. Whitworth, Weed Control Expert, New Mexico State University, and Orlan J. Lowry, Bureau of Reclamation, Amarillo, Texas.

Water Use and Development is of interest to this group. Jack Koogler, State Engineers Office, Ralph Charles, Bureau of Reclamation, J. L. Merritt, Farmer and Chairman, State Association of Soil Conservation Districts, Robert Young, State Conservationist, SCS, and Dr. H. R. Stucky, Professor and Head of the Department of Agricultural Economics and Agricultural Business, New Mexico State University and Chairman of the Annual Water Conference.

Jack Campbell, Roswell Attorney, discusses the Governor's Water Committee Report with David Jones, U. S. Park Service, Santa Fe, New Mexico left, and Lloyd C. Calhoun, President of Hobbs Television Company, Hobbs, New Mexico, right.



Weather Modification by Dr. Richard Kassander, center, and Physical and Social Problems in watershed management by Dr. A. L. McComb, right, were the subjects presented by this pair of professors from the University of Arizona. They are joined here by Professor W. P. Stephens, Agricultural Economist, New Mexico State University, and member of the Water Conference Committee.



This machine to convert salt water to fresh water was exhibited at the water conference by the New Mexico Institute of Mining and Technology. Those viewing the machine are left to right, H. G. Reynolds, U. S. Forest Service, Peter Van Dresser, Consultant, Santa Fe, New Mexico, David Jones, U. S. Park Service, Santa Fe, New Mexico, E. F. Sorenson, State Engineers Office, George Worley, Pack Foundation, University of New Mexico, E. J. Dortignac, U. S. Forest Service, and Eastburn Smith, U. S. Bureau of Land Management.

SOME RESEARCH FINDINGS ON THE ALAMOGORDO CREEK EXPERIMENTAL WATERSHED

R. V. Keppel and J. L. Gardner 1/

The climate of more than three-quarters of the land surface of New Mexico is arid or semiarid. Such lands yield only a very small proportion of their low annual precipitation as useable water for downstream areas. On the other hand, they contribute the major part of the sediment entering reservoirs.

Most of this vast area is devoted to the grazing of livestock, but there is little reliable information concerning the relation of range conservation programs on water and sediment yields from ranges receiving limited rainfall. In 1951, therefore, the Operations Division of the Soil Conservation Service requested its Research Division to initiate research aimed at furnishing such information, using watersheds of approximately 50-square miles with annual precipitation of 12-16 inches. Accordingly, investigations were started in 1953 on the Walnut Gulch watershed at Tombstone, Arizona, and in 1954 on the Alamogordo Creek watershed southeast of Santa Rosa, New Mexico. The work was subsequently transferred to the Agricultural Research Service and is being continued in cooperation with the Agricultural Experiment Stations of New Mexico and Arizona, the Soil Conservation Service, the local Soil Conservation Districts, and the ranchers upon whose land the research is being done.

Originally, one possibility considered was to collect hydrologic data from pairs of watersheds, treating one of the pair with a practical range conservation program and leaving the other untreated. The difficulty of finding two comparable, continguous, 50-square-mile areas, however, led to adoption of the present plan of a calibration period long enough for a reasonable sampling of climatic variation, followed by at least a similar period of treatment. The work is still in the calibration phase.

Alamogordo Creek is an ephemeral tributary of the Pecos, entering just above the Alamogordo reservoir. The area under study comprises 67 square miles on the upper reaches of the south branch. The vegetation is mainly grassland, with some pinon and juniper on the breaks and some of the shallower soils. Annual precipitation averages approximately 14 inches; but it is highly variable from point to point and from year to year. Precipitation is measured in 60 recording raingages; runoff, by a prerated, critical depth flume at the watershed outlet. It is planned to install additional instrumentation on several subwatersheds representing the different soil-vegetation complexes.

A distinctive feature of the hydrology of these semiarid regions is the very small areal extent of runoff-producing rains. A high proportion--90 percent or more--of the runoff results from summer convectional thunderstorms. Five years of data from the dense raingage network on the Alamogordo Creek watershed show that 80 percent of the runoff-producing storms have covered

1/ Agricultural Engineer and Botanist, respectively, Watershed Technology Research Branch, Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, Tucson, Arizona.

areas of no more than three square miles. Several such storms may occur simultaneously on the watershed, and the resulting runoff hydrograph is strongly influenced by the pattern and intensities of the storms.

Owing to the small size of the runoff-producing storms, the resulting runoff from one or more of them may flow through an extensive network of dry channels before reaching the watershed outlet, and much of it may be absorbed. On the 58-square-mile Walnut Gulch watershed at Tombstone, Arizona, where runoff from several subwatersheds is measured, these transmission losses have amounted to 20 acre-feet per mile of channel during a single flow. Since subwatersheds have not as yet been instrumented at Alamogordo Creek, these channel losses have not been measured. Because of finer-textured channel material, however, they are not expected to be as large as those at Walnut Gulch. This phase of the problem will receive more attention as we become able to extend the instrumentation on the watershed.

Although yearly precipitation has been highly variable, runoff has depended more on areal extent and intensity of individual storms than on yearly total precipitation. In 1956, a very dry year on the area, precipitation recorded by different gages varied from two to seven inches. Total runoff from the 67 square miles was 0.22 inch, of which 98 percent resulted from a single intense storm. This storm, which came in July, accounted for about half of the yearly precipitation on that part of the area upon which it fell. Precipitation in 1958 was higher than usual over most of the area: the gage receiving the lowest amount recorded 8.5 inches; that receiving the highest, 24 inches. Total runoff that year was 0.15 inch, of which 75 percent came from August storm of smaller size and lower intensity than the July, 1956 storm. The remaining 25 percent of the 1958 runoff resulted from several small storms of relatively low intensity.

This effect of storm size and intensity is further emphasized by the rain and resulting runoff of June 5, 1960, which covered nearly 50 square miles of the watershed with two inches or more of precipitation. Rainfall over much of the storm area was very intense, and runoff from the 67-square-mile study area was 0.93 inch, which exceeded the total amount recorded for the preceding four years.

Although the period of study has been too short to permit drawing firm conclusions, a few tentative ones are emerging:

Where variability in thunderstorm and runoff occurrence is so great, a relatively long calibration period is necessary before beginning watershed treatment. As yet, the period is insufficient at Alamogordo Creek.

Since during the past five years more than 80 percent of the total runoff at Alamogordo Creek resulted from four large runoff events, it appears probable that application of range management practices that might affect the smaller runoff events could have little effect on total water yield from such upstream areas.

Continuing research on the Alamogordo Creek Experimental Watershed will provide additional basic information on storm patterns, rainfall-runoff relationships, and effects of conservation programs on water and sediment yields from rangeland watersheds of the Southwest.

VEGETATION MANAGEMENT FOR WATER YIELD IN THE SOUTHWEST

Hudson G. Reynolds[1]

The Southwest (Arizona and New Mexico) is a region of comparatively low water yields. Most streamflow is now impounded and subject to consumptive use; ground water sources are being rapidly depleted. Moreover, an increasing population is demanding more water per individual. Hence, there is urgent need to develop watershed management practices that will ensure the optimum quantity and quality of water, consistent with other returns from watersheds, such as timber, forage, wildlife, and recreation.

This paper analyzes some of the factors influencing water yields, reviews some principles of vegetation management in relation to water yields, and indicates some possibilities for favoring water yields of Southwestern watersheds. Recommendations are based largely upon the watershed management research program of the U. S. Forest Service in Arizona, which was designed to obtain fundamental information for improving management of watershed lands in the Southwest (Price and Hoover, 1957). Intensive research is now conducted in most major vegetation types (Reynolds, 1959A).

Water yield management is emphasized. Other important areas of watershed management, such as flood control, and stabilization or rehabilitation of deteriorated watersheds, are mentioned only incidentally.

General Physical Characteristics

In general, the Southwest lies within the southern portion of the Rocky Mountain uplift. Elevations range from 137 feet along the Colorado River in southwestern Arizona to above 14,000 feet in the Sangre de Cristo mountains of northcentral New Mexico. Topography is extremely variable, ranging from high, rough, mountainous terrain to low, desert, alluvial plains.

Climate varies from tropical in the low, hot valleys to arctic in the higher mountains. Mean daily temperatures during the summer range from about 90°F in the deserts to less than 50°F in the mountains; average annual temperatures vary from over 70°F to less than 40°F.

Average annual rainfall is less than three inches in southwestern Arizona and more than 35 inches in the high mountains of northern New Mexico. April-through-September (growing season) precipitation varies from about 40 percent of the total annual in western Arizona to over 75 percent in eastern New Mexico.

Vegetation in the Southwest varies with the many different climatic conditions. For any given area, vegetation is an expression of the interactions of climate, parent soil material, and geologic history of plant complexes. The main vegetation types of the Southwest, as referenced to dominant plants, are: arctic-alpine, spruce-fir-aspen, pine-fir, ponderosa pine, pinyon-juniper, chaparral, sagebrush, mixed grassland, desert grassland, desert shrub, and cresote bush (Fig. 1).

1/ U. S. Forest Service, stationed at Tempe, Arizona, in cooperation with Arizona State University.

WATER YIELDS

Areas of Yield

In general, precipitation increases and temperature decreases with a rise in elevation. As a result, the higher water-yielding areas of the Southwest are associated mostly with the higher elevations (Fig. 1).

The highest water-yielding lands are located in the headwaters of the Rio Grande and San Juan Rivers in Colorado where water yields may exceed 35 inches annually. Higher lands of the Sangre de Cristo and San Juan Mountains in New Mexico produce from 10 to 30 inches annually. In Arizona, the best water-yielding zones are found along the Mogollon Plateau, where annual yield is about two to ten inches.

Areas yielding more than 10 inches annually make up less than two percent of the total land area of the Southwest. Annual yields from one to 10 inches makes up about 10 percent of the area (Reynolds, 1960). Thus, about 12 percent of the land area of the Southwest contributes nearly 65 percent of the water yield; and 50 percent yields about 90 percent of the flow (Fig. 1).

Several relations are evident when water yields are compared for the different vegetation types (Fig. 2). Interpretations of these data are conservative since most of them are limited to only two or three years of precipitation-runoff measurements. In this regard, Rich (1959), in analyzing three years' data in the ponderosa pine type near Alpine, Arizona, stated that the first year was characterized by very little runoff, the second year by much runoff from a summer precipitation, and the third year by runoff from snowmelt. Glendening (1959) noted similar variations among and within chaparral watersheds near Prescott, Arizona.

In general, streamflow decreases with elevation as does precipitation. Exceptions suggest, however, that other factors in addition to total annual precipitation determine water yield. The alligator-juniper watershed on Beaver Creek seems to be a particularly good water producer. This may be associated with rain falling on snow-covered or moisture-saturated soils.

Most water appears to be yielded during the winter months. In spite of Arizona's receiving about one-half of its precipitation during the summer months, only a small portion is yielded as streamflow.

March and April consistently seem to be months of highest streamflow. When streams are primarily snow-fed, April appears to produce highest streamflow. The Willow Creek spruce and the Beaver Creek alligator-juniper watersheds are good examples.

Perennial streams from small watersheds seem to be the exception in Arizona. Confluence of several small, high-elevation watersheds is necessary to produce a perennial stream.

Precipitation Distribution and Water Yield

Period of year in which precipitation falls affects timing and amount of streamflow. For the growing season (April through September), the percent of total rainfall varies from less than 40 percent in western Arizona to more than 75 percent in eastern New Mexico.

The importance of winter precipitation in producing streamflow is shown by data from experimental watersheds on the Sierra Ancha Experimental Forest. Here, 87 to 93 percent of total streamflow is yielded during the winter season. About 65 percent of total annual rainfall fell during this period (Table 1).

Variation in Streamflow

Streamflow of Southerwestern rivers is highly variable. The following tabulation compares relative variability of runoff from the Verde River and rainfall for Prescott for the period 1901-1960:

	Rainfall	Runoff
Coefficient of variation (%)	33.9	68.5
Coef. vs[2/]	7.70	7.60

Both annual rainfall and runoff are highly variable, as indicated by the coefficients of variation; there is a great tendency for high and low years to occur in groups. Also, runoff appears to be more variable than rainfall, possibly because of the complicating effects of difference in sequence of storms, antecedent moisture in the soil, and storm intensities.

Vegetation Characteristics and Streamflow

In addition to kind, amount, intensity, and distribution of precipitation, numerous other factors also affect streamflow. Important factors are: (1) drainage basin characteristics, such as nature and form of rock, and shape, size, slope, and channel density; and (2) the soil-plant complex. Although plants and soil are interrelated, they are discussed separately where possible.

When precipitation first encounters a vegetated watershed, some moisture is retained by the foliage. The amount varies with the kind, density, height, and arrangement of the canopy. In the pine-fir type of the Sierra Anchas, Cable[3/] measured interception of 34 percent for storms of less than one-half inch, and 13 percent for storms more than one-half inch. In pole-sized stands of ponderosa pine in northern Arizona, Aldon (1959) found between 11 and 25 percent of the gross rainfall intercepted, with sparse stands intercepting significantly less rainfall than dense stands. These values for interception are similar to those obtained elsewhere in the United States (Kittredge, 1948).

Litter that accumulates under a cover of vegetation retains a certain amount of moisture; but also protects the soil from raindrop impact, reduction of which may improve infiltration and reduce moisture loss from deeper soil

2/ The coef. vs was devised by Clawson (1947) to test the tendency for above- and below-average years to occur in "bunches." Clawson (1950) classifies a coef. vs above 4.0 as "high."

3/ Cable, D. R., Unpublished data in files of Rocky Mountain Forest and Range Experiment Station, Tempe, Arizona.

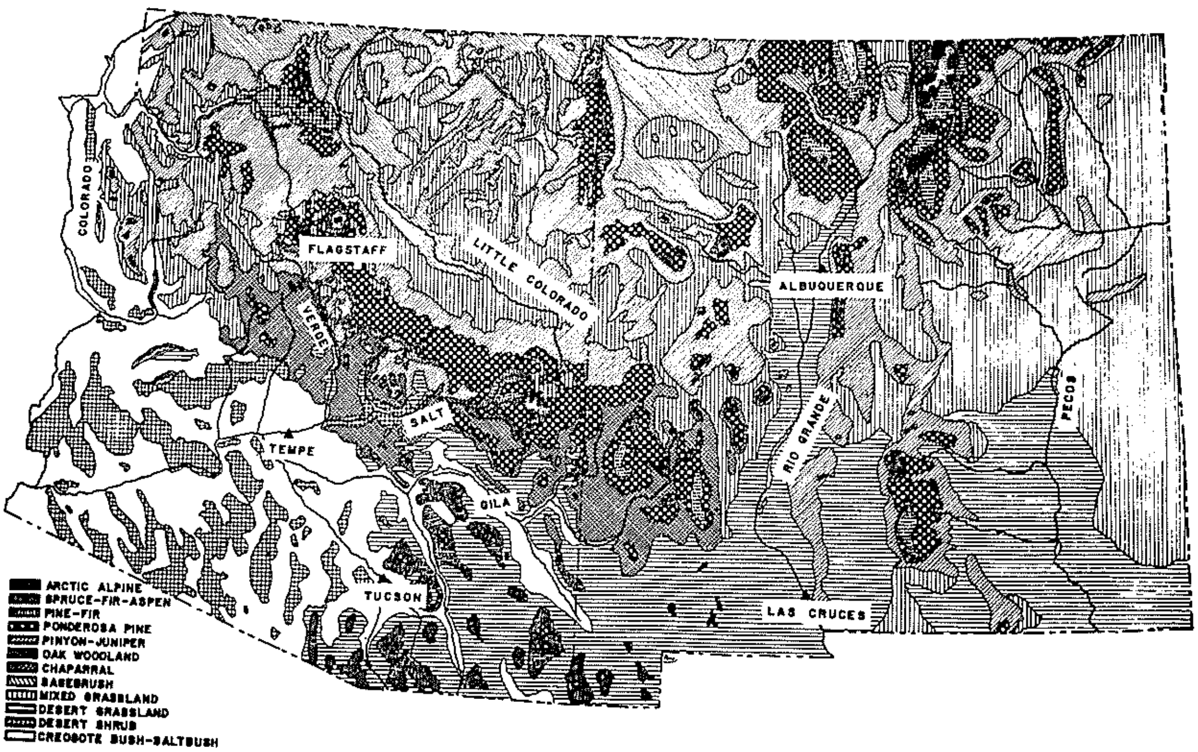
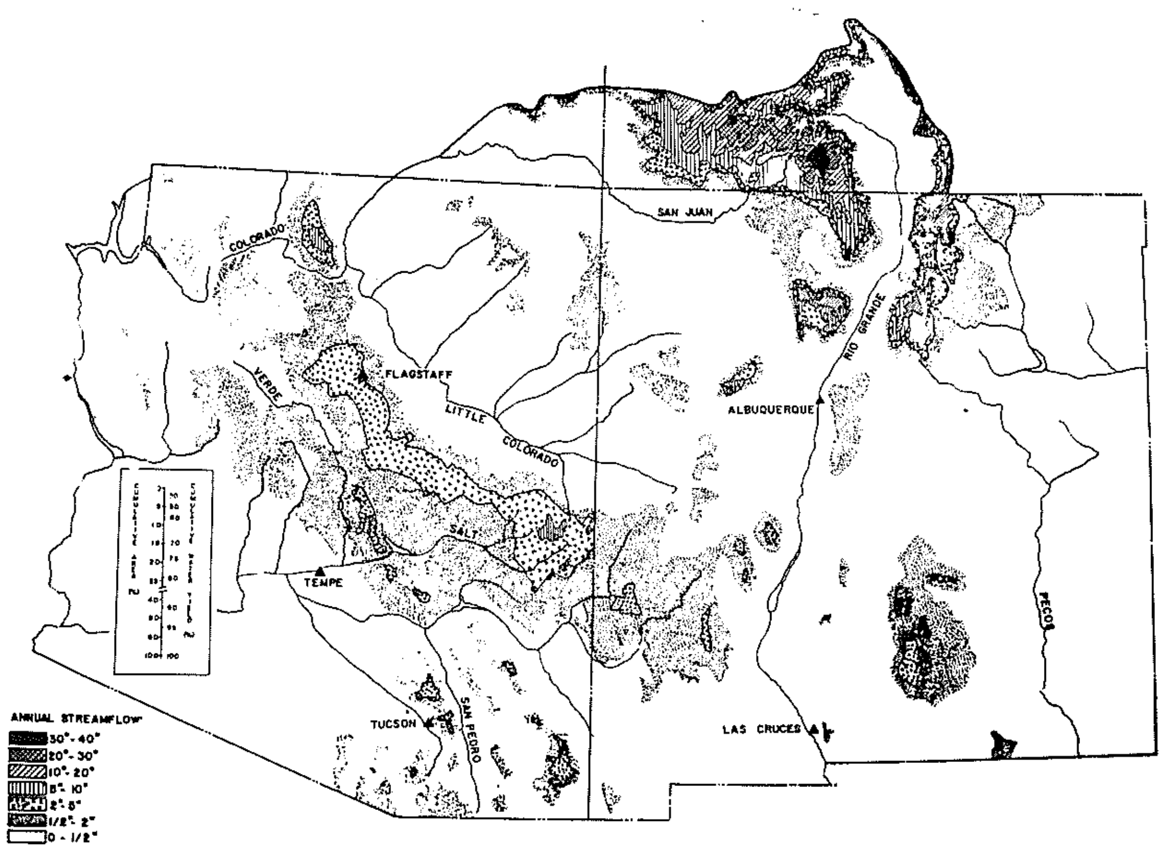


Figure 1. Above - Major vegetation types of the Southwest (Arizona, after Nichol, 1952; New Mexico, after Castetter, 1956). Below Location of important water-yielding areas in the Southwest (Source: Soil Conservation Service preliminary compilation of annual water yields of some Southwestern states).



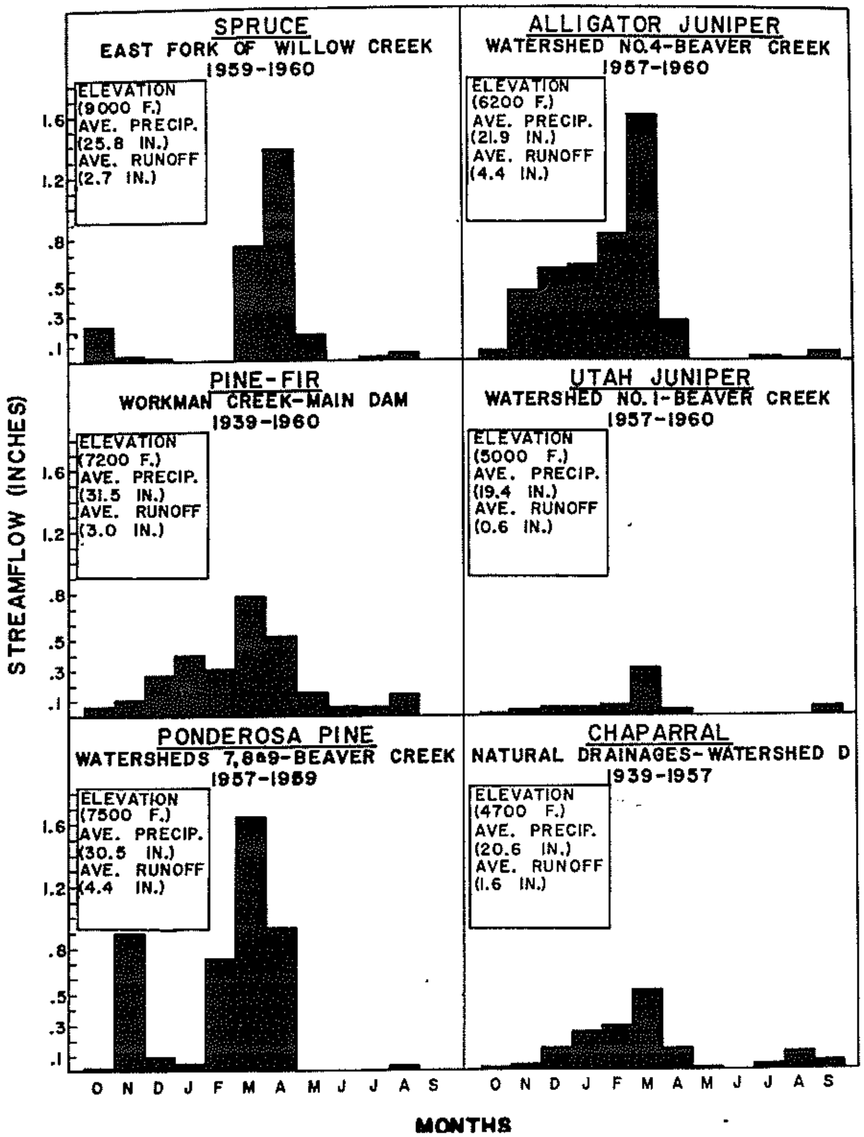


Figure 2. Monthly streamflow distribution from watersheds located in several vegetation types of the Southwest.

layers. Aldon (1959) found a gross rainfall loss of seven to 25 percent from four to 21 tons per acre of litter accumulated under pole-sized stands of ponderosa pine. Studies elsewhere in Canary Island pine suggest, however that a litter layer reduces soil moisture losses under a stand of trees as compared with soil moisture losses from bare soil in the open (Kittredge, 1954).

Soil affects the hydrologic characteristics of a watershed. It determines infiltration, or the rate of water movement into the soil; percolation, or the rate of downward water movement; and storage capacity.

Structure, number, size, shape, and stability of mineral and organic aggregates in the soil largely determine size, shape, and distribution of soil pores. A good cover of vegetation promotes favorable pore-space relations (Lassen, Lull, and Frank, 1952). Thus, vegetation by affecting pore space has an important influence upon how water moves into, through, and is held by the soil.

Moisture entering the soil is either retained in storage or is contributed to streamflow and deep seepage. Water is mostly removed from the soil by transpiration. Rapid loss of moisture below the surface foot can be attributed largely to root penetration and absorption (Storey, 1958).

Total evapotranspiration for a given site increases with solar radiation, vapor pressure deficit, wind, absorption of incident radiation by soil and plant surfaces, and as the amount of moisture in the root zone increases (Thornthwaite and Hare, 1955). This means that such characteristics of vegetation as composition, density, arrangement, and depth of root penetration influence evapotranspiration. Several management possibilities for favorably affecting streamflow may thus be hypothesized, such as:

1. Reducing the abundance or prolification of root systems in the soil mantle.

2. Substituting plants with shallow rooting habits for those with deep root systems.

3. Replacing plants of short growing seasons for those of longer growth and water-use periods.

4. Decreasing the size of vegetation by substituting:

    a. Tall-growth forms for low-growth forms.

    b. Young-age classes for old-age classes.

5. Reducing the density of the vegetation cover consistent with maintenance of soil stability.

6. Decreasing soil litter to the level where its protective effect on soil moisture loss is balanced against its interception loss.

7. Changing stand distribution and arrangement to favorably influence water yield from snow, and to reduce turbulence and air movement within and around a stand.

Table 1.--Relative contributions of winter and summer rainfall to seasonal runoff for four experimental watersheds on the Sierra Ancha Experimental Forest.

Vegetation type	Period	Rainfall				Streamflow				"F" values (Winter vs. summer)
		Winter		Summer		Winter		Summer		
		Inches	Percent	Inches	Percent	Inches	Percent	Inches	Percent	
WORKMAN CREEK (7,000 feet; 1,087 acres)										
Pine-fir	1939-53	20.29	65.6	10.56	34.3	2.47	87.0	0.37	13.0	61.71**
PARKER CREEK (6,700 feet; 700 acres)										
Pine-fir	1939-57	15.71	63.3	9.11	36.7	5.08	88.8	.51	11.2	54.42**
POCKET CREEK (6,500 feet; 900 acres)										
Pine-chaparral	1937-57	14.44	64.4	7.99	35.6	2.53	92.7	.20	7.3	44.33**
NATURAL DRAINAGE "D" (4,500 feet; 9 acres)										
Chaparral	1935-57	12.19	63.2	7.09	36.8	1.37	86.2	.22	23.8	11.55**

VEGETATION MANAGEMENT

Under the present system of extensive management (compared to intensive management of agricultural lands), management of watershed lands must be confined largely within the framework of possibilities of ecological succession. "Ecological succession is the orderly process of community change; it is the sequence of communities which replace one another in a given area." (Odum, 1953).

Any given plant community is largely an expression of the available resources of the entire site, resulting from the geologic history of the organisms (both plants and animals), as modified by recent history (fire, land use, etc.). The community is, however, dynamic and not static. It is continually being modified in quality, quantity, and proportion because of changes in the substrate, influence of plants upon the substrate, and interactions among the organisms themselves (Dansereau, 1957).

Community relations and successional phenomena for vegetation types of the Southwest are not completely understood. However, some general relationships are known, and progress is being made toward a better understanding of these and of others now largely unknown.

A generalized version of some successional sequences for the more important vegetation types of Arizona and New Mexico from the standpoint of water yield management are outlined below:

Arctic-alpine.--Castetter (1956) describes general successional sequences. On dry sites, the sequence consists of a moss-lichenforb stage, followed by a fairly stable cover of alpine tundra grasses, including bluegrasses (*Poa* spp.), wheatgrasses (*Agropyron* spp.), oatgrasses (*Danthonia* spp.), and fescues (*Festuca* spp.). On wet sites, sedges and rushes, represented by *Juncus*, *Luzula*, and *Kobresia*, dominate.

Spruce-fir-aspen.--The stable community consists of Englemann spruce (*Picea englemannii* Parry), and subalpine (*Abies lasiocarpa* (Hook.) Nutt.) or cork-bark fir (*A. lasiocarpa* var. arizonica (Merriam) Lemm.), with lesser amounts of blue spruce (*Picea pungens* Engelm.), white fir (*Abies concolor* (Gord. and Glend.) Lindl.), and Douglas fir (*Psedotsuga menziesii* (Mirb.) Franco).

When the type is opened up by logging or fire, quaking aspen (*Populus tremuloides* Michx.) or grasses and forbs characteristic of the subalpine grassland take over (Fig. 3). If aspen is removed, perennial grasses fully occupy the sites (Castetter, 1956).

Pine-fir.--White fir and Douglas fir are climax, occurring in mixture with ponderosa pine (*Pinus ponderosa* Lawson). Pure stands of Douglas fir sometimes develop. On drier sites, or where the stand has been opened up by logging of moister sites, ponderosa pine is a conspicuous element of the forest community.

With disturbance, such as heavy logging, New Mexico locust (*Robinia neomexicana* A. Gray) and bracken (*Pteridium aquilinum* (L.) Kuhn) become prominent in the understory (Fig. 3). With catastrophic wildfire, which destroys the overstory, bracken dominates for a few years, is overtopped by

New Mexico locust, which is again eventually suppressed by conifers.

Ponderosa pine.--Pure stands of ponderosa pine occur over extensive areas between 7,500 and 6,000 feet in Arizona, and at the lower, drier reaches of the coniferous association in New Mexico. Where the canopy is open and where grazing has not been excessive, Arizona fescue (Festuca arizonica Vasey) and mountain muhly (Muhlenbergia montana (Nutt.) Hitchc.), and miscellaneous grasses and forbs are abundant in the understory.

Occasionally, gambel oak (Quercus gambelii Nutt.) and New Mexico locust establish compact thickets in breaks in the forest. Where the canopy is dense, the ground floor may be almost bare of vegetation (Nichol, 1952). On rocky ridges or otherwise dry sites, other shrubs may be abundant including: cliffrose, (Cowania mexicana D. Don), buckbrush (Ceanothus spp.), serviceberry (Amelanchier spp.), mountain mahogany (Cercocarpus spp.), and manzanita (Arctostaphylos spp.).

The successional sequence resulting from various combinations of heavy logging, grazing, and cultivation for the ponderosa pine type of northern Arizona is fairly well known (U.S. Forest Service, 1951). When a ponderosa pine forest is logged over, understory midgrasses increase in abundance to dominate the understory. Under too heavy or improper grazing, succession then passes through retrogressive stages of: short grasses, prostrate perennial weeds, short-lived half shrubs, annuals, to bare ground. Logging denudation or unsuccessful farming of bunchgrass openings may take the succession to bare ground directly. Progressive succession may follow the reverse series of stages, or skip several stages, depending on the seed supply, conditions for germination and establishment, and grazing pressure.

Successional stages are somewhat different with a shrub understory, particularly where wildfire has occurred. In transition with chaparral and alligator juniper (Juniperus deppeana Steud.), ponderosa pine can be converted to these species by wildfires. Where gambel oak, New Mexico locust, Fendler ceanothus (Ceanothus fendleri Gray), or manzanita exist in the understory, destructive wildfire will change ponderosa pine to a dominance of these species (Chapline and Talbot, 1959).

Pinyon-juniper.--In the tension zone between pinyon-juniper woodland and grassland or chaparral, juniper tends to invade. Upon removal of juniper by mechanical and chemical means or by fire, grasses or shrubs again dominate. Under too heavy or otherwise improper grazing, grasslands pass through retrogressive successional stages, as for the ponderosa pine type (Arnold and Schroeder, 1955).

Chaparral.--The sequence of woody plant replacements in the absence of wildfire is not known for the chaparral type of Arizona and New Mexico. However, where a grass-shrub mixture exists shrubs will take over and fully occupy the site as perennial grasses are eliminated.

Something is known of the response of the type to wildfire (Cable, 1957; Pond, 1960). Most chaparral species sprout from root crowns when fire destroys above-ground parts; other species seed in rapidly after a burn because germination of seeds lying in the soil is enhanced by heat. Crown cover of shrubs appears to regain prefire conditions in seven to 10 years. Repeated

Figure 3. Examples of forest succession in Arizona. Above - Progressive succession. Young white firs and Douglas firs in the understory should eventually overtop the aspen and dominate the site. Below - Retrogressive succession. (Left) New Mexico locust in the understory is suppressed by overtopping, young pines. When dominating conifers were destroyed by wildfire (right), locust was released.

burning seems to favor the more prolific sprouters. Hence, under a combination of heavy grazing and repeated burning, when shrubs are growing in mixture, the type tends to be dominated by or to form a pure stand of shrub live oak (Quercus turbinella Greene) or manzanita.

PRELIMINARY RESEARCH RESULTS ON VEGETATION MANAGEMENT FOR WATER YIELD

Some management opportunities for favorably affecting water yields on different vegetation types are discussed in the following section. These are merely suggestions and are presented to show some possibilities. Firm recommendations will depend on more intensive research.

Spruce-fir.--Ecologically, it appears possible to manage many sites in this type for almost pure cover of perennial grass, aspen, or conifers. Thus, from the standpoint of water yield, water comparisons among these three kinds of plant cover are important.

The problem is being approached by periodic sampling of soil moisture beneath plant communities at three different sites in the White Mountains. No statistical differences in soil moisture levels for the same community were found at the beginning and end of the water year in 1960. However, when water use was compared among communities during the period of soil moisture recession (April - September), quaking aspen appeared to use significantly more water than spruce or grass, with no significant differences between the latter. Additional years of sampling will be necessary to verify this indication.

Water savings were indicated when the cover was changed from aspen to herbs in Utah (Croft, 1950). Water saving was estimated to be about four inches annually. Shallower root systems and less draft on moisture in the soil mantle among the herbaceous plants were thought to account for the difference in water use.

Preliminary measurements suggest that soil freezing may also affect water yields in the spruce-aspen-fir type of White Mountains, Arizona. In 1959-60, snow cover was greatest under grass, then aspen, and least under conifer. An inverse relation existed between snow cover less than two feet deep and depth of freezing; frost disappeared faster, the lesser the snow depth. Water may be yielded over the frost mantle, the shallower mantles yielding earlier and more water.

Pine-fir.--Ecologically, there are a number of possibilities for vegetation management in the pine-fir type. Working down the succession scale, development could be arrested at any of the following ecological stages: mixed conifer-chrub, conifer-shrub-grass, shrub-grass, or perennial grass.

Studies on the Workman Creek experimental watersheds in the Sierra Anchas were designed to determine: (1) water yield difference between the ecological extremes, and (2) the effect of advanced timber management practices upon water yield and sedimentation.

The Workman Creek watersheds are located in the pine-fir type of the Sierra Ancha Mountains between elevations of 6,590 to 7,725 feet. The major watershed contains three subwatersheds--North Fork of 248 acres, Middle Fork of 521 acres, and South Fork of 318 acres. Watersheds were calibrated between 1938 and 1953. At that time, a timber management cut was made on South Fork; and broadleaved trees were removed along the stream bottom in North Fork; Middle Fork served as a climatic check.

By the fall of 1958, no measureable change in streamflow could be detected from removing broadleaved trees along North Fork. This may be accounted for by the very small percentage of the total tree canopy that was removed when the broadleaved trees were cut. After the site was cleared, it was planted to perennial grasses and slash was largely consumed by burning (Rich, 1960).

Two years of streamflow data, following the moist-site cut, indicate that water yield has been increased (Rich, 1960). In 1959, actual streamflow exceeded predicted flow by 0.5 inch; in 1960, the difference increased to 2.0 inches. Additional years of varied climatic characteristics must be measured before an average difference, based upon statistical analysis, can be established.

No statistical change in water yield has been measured on South Fork since the cessation of timber cutting in 1955. This was in spite of a wildfire in 1957, which virtually destroyed all trees on 60 acres along one side of the watershed. Immediately after the fire, there was displacement of superficial layers of soil on the burn to lower reaches and channels of the watershed; also, peak flows increased. Lack of change in water yield can possibly be attributed to deeper soils than on North Fork and to water use of New Mexico locust, which now dominates on the burn (Rich, Reynolds, and West, 1959).

Ponderosa pine.--Because of its extensive area (particularly in Arizona), easy accessibility, and fair growth rates, the ponderosa pine type is the most important timber-producing region in the Southwest. Fairly intensive management effort is directed to this end, although other values of the type, such as water, range, wildlife habitat, and recreation are recognized.

On Beaver Creek, watersheds are being calibrated for testing water yield differences between ponderosa pine and perennial grass to bracket the ecological-economic possibilities (Kennedy, 1959). Other watersheds are also being calibrated to determine whether reducing stand density of ponderosa pine, to that judged optimum for timber yield, will affect water yield. At present, 80 square feet of basal area per acre is recommended as about optimum for timber production (Gaines and Kotok, 1954)(Fig. 4).

Pinyon-juniper.--This type in both Arizona and New Mexico serves as important range for livestock and game. At the lower elevations, pinyon-juniper mostly joins a grassland type. In many areas, juniper has invaded the grasslands. Ranchers, and State and Federal agencies, are now removing juniper from many sites to improve grasslands (Arnold and Schroeder, 1955) (Fig. 4). The possible effect that removing juniper and restoring grassland has upon water yield is being approached at Beaver Creek in two ways: one by soil moisture sampling, the other by means of experimental watersheds.

Soil moisture differences in the upper two feet of cleared areas of Utah juniper (*Juniperus osteosperma* (Torr.) Little) and alligator juniper were

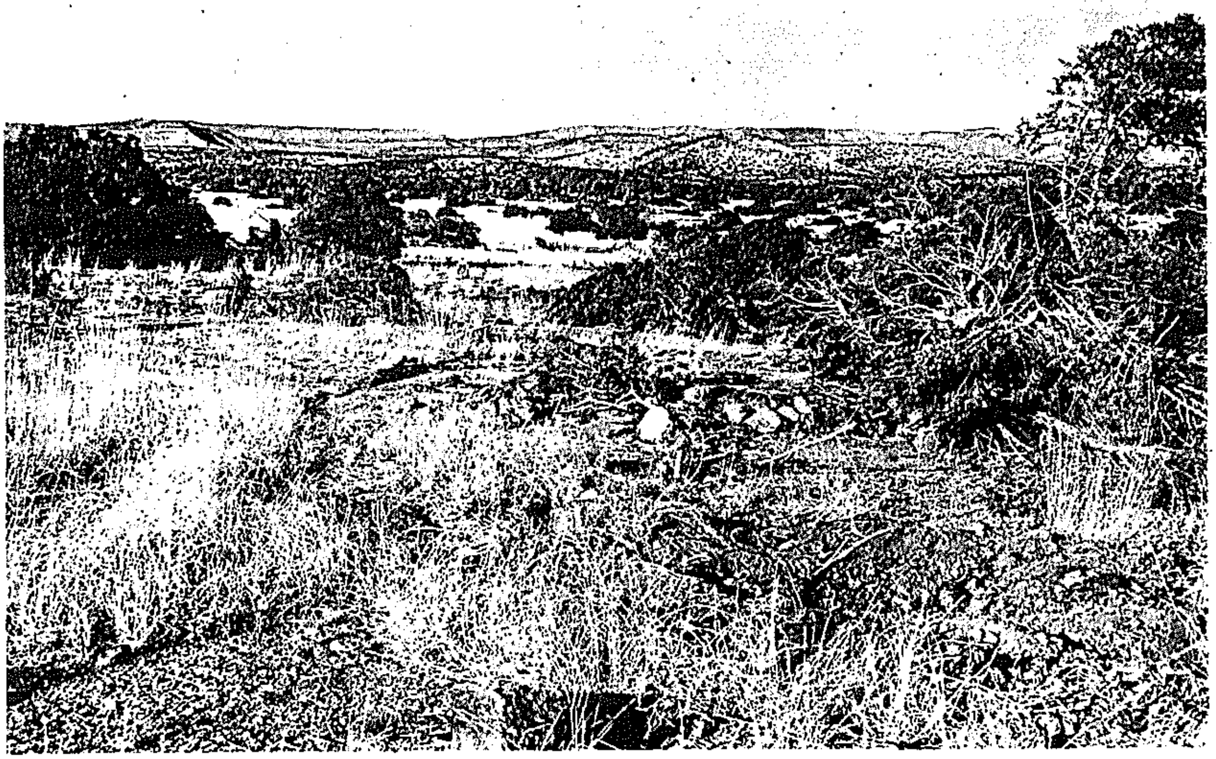


Figure 4. Land improvement practices in the ponderosa pine and pinyon-juniper types. The effect of these practices upon water yield and sedimentation are being tested on experimental watersheds at Beaver Creek, Arizona. Above - Unthinned, pole-sized, ponderosa pine on left; properly thinned stand on right. Below - Pinyon-juniper removed in area of invasion to help restore grassland to full production.

checked against adjacent uncleared areas between June 1959 through September 1960. Differences between juniper-infested and juniper-cleared areas of small magnitude were recorded only during spring and early summer. Thus, although there is a tendency toward increased water yields, unit yield will probably be small. However, small increases in water yield from an area as large as the pinyon-juniper type could make important contributions to total water yields.

Similar soil moisture differences have been observed in the pinyon-juniper type at Pine Flat, New Mexico. Soil moisture was measured in the upper 12 inches of soil under three cover conditions--pinyon trees, herbaceous cover (mostly blue grama (Bouteloua gracilis (H.B.K.) Lag.), and bare soil. It was concluded, as a result of these measurements, that replacement of pinyon trees with herbaceous vegetation would not have an appreciable effect upon water yields through percolation except during those years when precipitation was above average during the winter dormant season (Dortignac, 1956).

On Beaver Creek, experimental watersheds in both alligator and Utah juniper types (three in each type) are now being calibrated to later test the effect of juniper removal upon water yield. Two-and three-fold increases in grass are known to occur after juniper removal (Arnold and Schroeder, 1955), which is now an accepted range practice. If proper grazing is practiced after juniper removal, increased perennial grass cover should result in greater soil stability. Evaluation of the effect of juniper removal upon water yield must await calibration and treatment of the experimental watersheds.

Chaparral.--Chaparral occurs along the Mogollon front in Arizona and extends into the southern foothills of the Gila Mountains of Arizona. A proper mixture of shrubs and grass should benefit both livestock and game. One method of achieving this management objective is to completely remove shrubs with a root plow and to seed adapted perennial grasses (Glendening, 1959). Some indication of the possible effects of converting from shrubs to perennial grass is being obtained from lysimeters and small watersheds.

Chaparral lysimeters at Sierra Ancha were planted to skunkbush sumac (Rhus trilobata Nutt.), and adjacent lysimeters were seeded to green sprangletop (Leptachloa dubia (H.B.K.) Nees.) in 1953. Preliminary comparisons suggest that during the spring period more water should be available for streamflow under the grass than under the shrub cover. Presumably, this difference is associated with earlier season of water use and deeper root system of skunkbush sumac.

Differences in water yield between perennial grass and chaparral are now being compared on four small watersheds in the mixed chaparral-grassland transition at Sierra Ancha Experimental Forest. After a calibration period, shrubs were poisoned on two of the four watersheds between 1953 and 1956. Perennial grass responded to shrub removal by increasing in abundance and volume almost immediately. Hence, a comparison exists between a perennial grass-shrub mixture and a perennial grass community.

A slight increase in streamflow was measured on the grass watershed in 1957. Whether or not this difference is statistically significant will necessitate further replication of years which sample a variety of rainfall conditions (Price, 1958).

Phreatophytes.--In the Southwest, most riparian situations from high mountains to desert elevations are occupied by various species of phreatophytes. The most abundant species at lower elevations is five-stamen tamarisk (Tamarix pentandra Pall.), an exotic. At intermediate elevations, Arizona sycamore (Platanus wrightii Watts.), cotton wood (Populus spp.), willows (Salix spp.), and box elder (Acer neguendo L.) may be abundant locally. At the highest elevations, alders (Alnus spp.), maples (Acer spp.), and willows often form dense stands along live streams (Horton, 1959). Robinson (1952) has estimated that such phreatophyte associations waste many acre feet of water annually. Management of these riparian sites should favor species that promote soil and streambank stabilization, have low water use, and satisfy demands for other utilitarian uses such as recreation and grazing.

Preliminary results suggest that there might be considerable water saving and improved grazing by substituting a Bermudagrass (Cynodon dactylon (L.) Pers.) cover for tamarisk. These indications were obtained by comparing evapotranspiration of naturally vegetated but undisturbed plots of tamarisk and grass simultaneously with plots containing Bermudagrass alone. The apparatus used for measuring evapotranspiration consisted of two transparent plastic tents with ventilating blowers, sampling systems, and a highly sensitive hygrometer (infrared gas analyzer) (Horton, Decker, and Gary, 1959).

The difference in water use is probably associated with amount and height of foliage exposed to the atmosphere. Other measurements have shown that the mid-day rate of evapotranspiration for Bermudagrass is consistently higher than that for an adjacent free water surface (Decker, Cole, and Gaylor, 1960).

WATER YIELD CHARACTERISTICS OF THE SOUTHWEST

1. Most water yield of the Southwest originates in the higher mountains; 12 percent of the area yields about 65 percent of the total runoff, these are the areas that will be more intensively managed for water in the future.

2. Most water yield in the Southwest originates from winter precipitation. Vegetation management directed towards maintenance of summer - rather than winter-growing plants should favor water yields (Rich, 1951). Moreover, if summer-growing species have shallow vs deep roots, short vs tall stature, and have a minimum density and litter accumulation consistent with soil stability, water yields should be further enhanced.

3. Streamflow in the Southwest is highly variable. Provisions should be made for storing flow during wet years by fully developing lakes, reservoirs, dams, and underground aquifers, whichever are economically most feasible and socially most desirable.

GENERAL MANAGEMENT CONCEPTS

1. Watersheds exhibit individually as to size, shape, slopes, depth of soils, geology, channel density, vegetation cover, and other factors that influence water yields. Study, treatment, and management should be directed toward individual watersheds insofar as possible in overall land management planning (Reynolds, 1959).

2. Stable vegetation on a watershed results in less overland flow, less erosion, and lower peak flows during flood, than mismanaged vegetation (Colman, 1953). In the management of watersheds, soil movement should not be permitted to exceed tolerable limits for maintaining low flood hazards, clear flows of water, and soil productivity. Moreover, induced overland flow is usually at the expense of subsurface flows and increases soil erosion (Martin and Rich, 1948).

3. Proper grazing of grass-shrub watersheds does not affect water yield detrimentally (Rich and Reynolds, 1960). This concept is corroborated by plot studies in Utah, Idaho, and Colorado, which indicate that if grazing leaves a protective plant cover, fairly good control over surface flow and erosion results (Colman, 1953).

SOME MANAGEMENT INDICATIONS FOR THE SOUTHWEST

1. In the spruce-fir-aspen type, there is indication that management could be directed toward a mixture with grass favored over aspen and conifer. The best areas for treatments and their size, shape, and relative positioning are unknown. Preliminary work is underway on the effect of different kinds of patch cuttings upon timber management (Kennedy, 1959). The effect of a patchy mixture of grass, spruce, and aspen upon livestock use, wildlife habitat, and recreation is yet to be determined.

2. In the pine-fir type, removal of forest and its replacement with grass along moist bottoms may enhance multiple use values (Rich, 1960). Less costly methods and higher economic social demands will be necessary before such undertakings are practical.

3. In the ponderosa pine type, thinning to 80-100 square feet of basal area per acre is now an accepted forest management practice for improving timber yields (Kennedy, 1959). The influence of this forestry practice on water, grazing, game, and recreation values is now being determined. There is a suggestion from foreign work that forest tree density may have to be reduced below this level to affect water yields favorably (McComb, 1959).

4. In the pinyon-juniper type, juniper removal to favor perennial grass in the woodland-grassland tension zone is a generally accepted range management practice (Arnold and Schroeder, 1954). Improved water yields at the higher elevations and on specific sites are indicated, but quantitative effects are yet to be established. Also, cover relations for game in a clearing program, though known to some degree (Jantzen, 1959), need to be further determined.

5. In the chaparral type, changing from a shrub to a perennial grass cover may favorably influence water yields, at least on specific sites. Forage production for livestock is known to be improved by such a practice. Information is still needed as to sites to be treated; arrangement, and size of converted areas; and specific species of shrubs and grass to provide the most desirable combination for optimum returns from water, range, and habitat for livestock and game.

6. At the lower elevations, removal of tamarisk and its replacement by Bermudagrass in riparian situations should benefit both water yield and livestock grazing (Horton, 1960). Any action program should give consideration to

channel stabilization and to effects upon game and recreational values.

Because of the need for additional data, particularly replication in time and space, the above recommendations must be considered as tentative. It is hoped, however, that some management directions, at least deserving of pilot testing, are indicated. Future progress of research will depend upon adequate financing, effective cooperation, and industry and good fortune among researcher in unraveling Nature's riddles.

PHYSICAL AND SOCIAL PROBLEMS IN WATERSHED MANAGEMENT

A. L. McComb[1/]

Water problems are certainly fast becoming a number one topic of conversation if one takes as an indication the numerous conferences like this series in New Mexico, and the increasing number of books and publications on the subject. Nonetheless, there are many people, particularly in the eastern part of the country, who do not know there are water problems and most of us, I suspect, can only guess at the form of the ultimate solutions to these problems. On a recent flight across New Mexico a man, apparently a farmer from eastern United States, crossed the isle in front of me and from 12,000 feet looked down at the desert, remarking to his wife "My, Martha, look at all the empty land down there. Just think how many farmers could settle there, one every half mile."

Each year our water problems become more acute. This is so because as each year passes the per capita use of water increases and the number of water users also increases. In the eleven western states the per capita water use in 1955 was 4,112 gallons per day. In contrast, in eleven eastern states where there is little irrigation agriculture, use was 872 gallons per day. In the past ten years the population of the United States has increased by 30,000,000 and at the present rate of growth it will increase by another 80,000,000 by 1980. In the West existing demands are pressing hard on total supplies and in some areas use exceeds renewable supplies and ground water is being mined. None of this is new to you.

The basic problem we look forward to is how to get enough water to keep ahead of demand. The oceans represent an inexhaustible supply and if the economics of desalinization and inland transport could be solved, a major source of worry would cease to exist. For coastal areas desalinization may become economic sooner than we think. For inland areas, however, use of such water seems rather remote so we must look elsewhere for possible solutions.

Dr. Kassander has just spoken about increasing precipitation through weather modification and speeding up the cycle of evaporation and precipitation. Other solutions center around making our existing supplies go further by reducing transmission losses and increasing the efficiency of use, especially in agriculture. Still another possibility, as Dr. Reynolds has shown, centers around increased yields from our watersheds. My remarks are related mainly to the latter possibility and some of the problems involved.

Watershed management is based on the concept that land, that is the plant cover, the soil and the rock mantle, is a reservoir that receives, stores and discharges water and also supplies water for on-site use by plant and animal life which in itself performs useful services and provides valued products. The reservoir is subject to change and regulation by treatment or land use.

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Good watershed management has several goals. First, it must develop and maintain the watershed conditions which produce and put to beneficial use the maximum amount of water. Second, it must do this in a manner to assure satisfactory control of runoff and erosion. Third, these objectives must be integrated with the program providing for the optimum production and utilization of all resources of the watershed.

In considering watershed management problems two points stands out. The first is that water yield is a very complex phenomenon controlled by a considerable number of individually important factors. These factors may act together in increasing or decreasing water yields and regulating stream regimen or they may oppose each other. The relative importance of the controlling factors may vary very significantly from one watershed to another. Therefore, it is very important to know each watershed in detail and to recognize that uniform treatment and management of dissimilar watersheds will give dissimilar results. Secondly, on any one watershed there is a number of alternative solutions to the management problems which arise. These alternatives are based in part on physical and in part on social considerations. The solution to individual watershed management problems is difficult because (1) we do not have sufficient information regarding the way a variety of factors affect the physical processes going on in the watershed, (2) we are unable to accurately measure and predict the desires of people regarding alternative uses of the watersheds, and (3) there are real conflicts among watershed users, both within localities and between localities and regions as to what should be the dominant use or uses.

Some current problems about which there is much talk and some considerable research in progress concern the manipulation of plant cover on watersheds to increase water yielded as streamflow. Almost all of the existing research suggests that yields of water can be increased by either (1) decreasing the density and changing the composition of the vegetative cover or (2) decreasing the depth to which roots penetrate the soil and absorb water from it. Vegetation intercepts precipitation and causes part of it to be evaporated back into the air. Vegetation absorbs water from the soil and transpires it. Vegetation also shelters the soil and reduces direct evaporation of soil moisture and tends to increase infiltration rates and deep percolation. In general, when the density of the vegetative cover is decreased interception and transpiration are decreased more than soil moisture evaporation is increased and a net water yield increase is effected.

When a forest area is clearcut the increase in water yield would be expected to be directly related to the size of the area cleared. In the humid southeastern United States clearcutting all vegetation has resulted in a 50 percent increase in water yields. In the humid, high-elevation lodgepole pine and spruce-fir forests of Colorado a 25 percent increase has followed clearcutting of 50 to 60 percent of the land area. Where forests are selectively cut or thinned the water yield would not be expected to increase uniformly with decreasing stand density. A number of considerations suggest that between 50 and 100 percent of maximum forest density there would be only very small water yield increases and that below 50 percent density increases might be nearly proportional to decreased density.

In considering the desirability of making vegetation changes and the degree of such changes it is important to consider a number of relationships. First of all, if the region is a forested one it is not possible to practice timber growing on a sustained yield basis if much of the area is kept clear of vegetation. If it takes 100 years to mature a crop of trees the maximum area that can be cleared in any one year is 1/100 of the total. Hence, the expected water yield increase accompanying clearcutting with sustained yield forest management would be only a fraction of that obtained from small clearcut plots or watersheds even though young small trees use less water than old large ones. The larger part of the increase would come from the smaller part of the area represented by valley bottoms and lower slopes.

If the forest were clearcut and reseeded to grasses rooting more shallowly than trees a water yield increase could be expected from those areas having soils thicker than the depth of root penetration, in those localities where there is enough water to wet the entire soil profile. In many mountain areas there are no large areas of such deep soils.

If forests are thinned very heavily and water yield increased it is important to consider how much the timber yield is decreased as water yield is increased, or in other words, what is the value of the extra water consumed by trees in terms of the added growth produced. Unfortunately, we have none of this information at the present time. It generally has been assumed in the Southwest that the value of the water on-site is greater than the value of the timber growth that could be produced with that water. We need to know if this assumption is correct and if so whether a consideration of stream transmission losses would change the picture.

Still other points that need to be considered concern the effect of the vegetation manipulation on the character and timing of the runoff, on the percentage of surface runoff, on water quality, on soil changes relating to water infiltration and movement and on timber and forage production, and on erosion and silting of stream channels and reservoirs. Lastly, there is the question of the costs of changing vegetation and maintaining a different kind of cover.

The vegetation does consume water. Are the products and services it performs worth the cost in terms of water? What is the safe or desirable level of change? We do not have sufficient information as yet to confidently answer these questions.

A second problem area conserns the best place or places in a watershed to use the water that falls on the area. Mr. Dorrah of the Soil Conservation Service has estimated that on the San Simon drainage of southeastern Arizona and adjacent New Mexico only 20 percent of the water measured on-site up-stream reached possible irrigated areas near the stream mouth. On Rillito Creek near Tucson 75 percent of the water from the Catalina Mountains disappears into the stream bed in a distance of 10 miles or less. Some of this water replenishes the ground water supply and some is evaporated from the soil and transpired by uneconomic phreatophytes. We do not know how large each part is. Some of the evapotranspiration loss could be avoided by removal of phreatophytes or by conversion to less deeply rooted plants like, for example, some of the grasses.

Transmission losses increase with increasing distance the water moves. To reduce or stop these losses would require piping water from the upper, higher-elevation parts of the watershed where it is produced to lower areas where it is presently used, or to eradicate and control the phreatophytes.

What is the cost of these operations in terms of the "extra" water obtained? Would it be better to capture and use this water on the upper watershed where it might be spread on the better land for crop production or to increase range forage yields. Would it be better used for recreational purposes or for industrialization and urbanization of the presently smaller communities around a state. From the long-run social and national defense points of view, would it be better to disperse our population than to concentrate it in a few large centers like Albuquerque, Tucson and Phoenix. These are particularly important questions in view of the ever increasing percentage of our population in urban areas, the ever increasing industrialization and the problems of air and water pollution and the greatly increased demands for recreation. They suggest possible changes in water-use priorities.

A related problem concerns the relation of stream channel transmission losses to water yield increases resulting from vegetation manipulation and management. In the case of San Simon Creek, if we assume that a 10 percent water yield increase would follow a reduction in grass and forage plant density on the watershed, then if the downstream water yield was 20 percent of the on-site yield the increase in water yield downstream would be 20 percent of 10 percent or 2 percent. The question that then arises is what are the economics of using the "extra" water on the upper parts of the watershed for increased yields of grass and livestock as compared to (1) using one-fifth as much water downstream on perhaps more fertile level soil for crop production or (2) transporting the extra water downstream without evapotranspiration losses. These are particularly important questions in view of the more rapid normal erosion in arid versus humid climates and the accelerated erosion that probably would accompany a decrease in vegetation density effective in increasing water yields. Again, is the increased on-site production of economic plants and the service rendered by the plants through maintenance of soil fertility and reduction of erosion and silting worth the cost of the water involved and if not so, how far do we want to go with vegetation changes to increase water yields?

Still another problem relates to the question of how to allocate water for various uses, and to changing water-use priorities. In the Southwest there have been very large gains in urban populations in recent years. In many areas, the normal working of economics has resulted in priority shifts as housing developments and industrial plants have been placed on formerly irrigated agricultural land. In areas where water is being mined adjustments inevitably must be made. The large increase in industrialization and urbanization in the Southwest has resulted in the need for greatly expanded recreational opportunities. Much recreation centers around water in streams, lakes and reservoirs, or the plant and animal life the water produces, and providing recreation opportunity is a part of watershed management. Can recreational demands compete with agriculture and industry? If so, what water developments are needed and where should they be? A recent study by the University of Arizona Bureau of Business Research suggests that the income to Arizona from all kinds of recreation exceeds the income from agriculture, mining or industry alone. I suspect the same may be true of New Mexico

How to get people to work together in planning watershed developments is another important problem, especially where there is a wide variety of opinion among land users as to desirable goals. This is a sociological problem and outside my specialty. Much needs to be done, however, to assure optimum development and use of all watershed resources and this requires a recognition of problems, decision-making based on good information and the ability of people representing private citizens and public officials and land administrators to understand each other and to work closely together. As an illustration, since coming to Arizona 18 months ago I have been trying to assess the importance of erosion problems on the watersheds. My own impression is that there has been rather serious accelerated erosion on a considerable part of the arid lands, particularly the more fertile and better watered part, that soil productivity has been reduced, that stream discharge patterns may have changed materially, and that these conditions still persist on important areas. Somewhat to my surprise, I found some vocalized opinion to the contrary. Admittedly, it is difficult to assess what may have happened 50 to 80 years ago, and in a land of great annual climatic variability, what is happening today. Do we not know what the situation is? Or has communication among different segments of the population been inadequate. What can be done here to get closer to the truth of the matter, to communicate the facts to more people and to stimulate the collective action needed to better deal with the related problems?

Lastly, there is the very basic problem of the balance between population and resources. Our land base is fixed. Water other than that in the ocean has finite limits as do most of our other natural resources. As population increases the per capita quota of these resources decreases. For example, in 1940 there were 2.7 acres of arable land for each person in this country. In 1960 this figure had dropped to 1.9 acres and in the year 2000 it is estimated to be between 0.6 and 1.0 acre. As the per capita natural resource base decreases the pressures on all resources will increase, a pressure which in other countries has resulted in depletion and occasionally the destruction of the resource. There is a question of whether we will be able to continue to increase our standard of living or even to maintain our present standard if predicted population increases occur. If we can, it means more efficient production and use of resources. For watershed management this means reducing water use by uneconomic plants, minimizing soil moisture evaporation losses, providing the conditions for the most efficient use of water by plants both on and off the watershed and making the same water serve several uses. James N. Land, Senior Vice-president of the Mellon National Bank and Trust in Pittsburgh recently said "Because our population is expanding rapidly, we must drill deeper oil wells and exploit less productive veins of coal and other minerals and less accessible and poorer quality forest areas and go further afield for the water supplies of our cities, all of which adds to unit costs and is a drag on prosperity." Our watershed problems increase and their solution becomes more difficult and costly as population pressures increase. The margin for managerial error in resource management will become less as population increases, the probable result of which will be more regulation by public agencies and a reduction in the freedom of action to which we in this country have become accustomed. The solution to water and watershed management problems is as much a problem of dealing with population increase as with increasing our scientific knowledge and technology. We can get more water for beneficial use by various water and watershed management techniques but the probable gains appear smaller than the increased demand arising from increasing populations. Inevitably a balance, good or bad, must be achieved.

MANAGEMENT OF ALPINE AND SUBALPINE MOUNTAINOUS AREAS FOR WATER YIELD

L. D. Love[1]/

The Southern Rocky Mountains are the major water-yielding areas of the southwestern portion of the United States. Above 5,000 feet in elevation, the proportion of precipitation appearing as streamflow each year steadily rises with an increase in elevation. This proportion ranges from less than 10 percent at the lower elevations to well over 50 percent at the higher.

The Continental Divide of the Southern Rocky Mountains is the headwaters of four major rivers; the Colorado, the Platte, the Arkansas, and the Rio Grande. Characteristically, snow accumulates over-winter in these headwaters and melts during the months of May and June. At this time, swollen mountain streams are common and water is plentiful. In contrast, summer and fall flows are low and water supplies become limited. This regional characteristic of over-winter snow storage provides the opportunity for manipulating the annual snowpack where it is influenced by vegetation, soils, and climate.

Vegetation

The three predominant vegetation types in the Southern Rocky Mountains are: (1) ponderosa pine-bunchgrass type (montane), occuring between the elevations of 5,000 and 8,500 feet; (2) Engelmann spruce-subalpine fir, lodgepole pine, aspen type (subalpine), found between the elevations of 8,500 and 11,500 feet; and (3) alpine grasslands (alpine), occupying lands above 11,500 feet elevation (fig. 1). At a particular elevation where these types meet, they grade into one another. South exposures will contain the type of the lower elevation and north exposures that of the next higher elevation.

Water Yield

Although a prime source of water, the Southern Rocky Mountains receive but moderate amounts of precipitation. On areas above 9,000 feet, annual precipitation does not average more than 30 to 40 inches and decreases rapidly with lower elevation. Of the 30 to 40 inches, 60 to 80 percent occurs as snow, which begins to persist on the ground during October and accumulates with little or no loss by melting until the spring thaw in April, May, and June.

Water yield from mountain lands follows elevational changes with highest yields coming from the higher elevations and lowest from the lower (fig. 2). Yields of 18 acre-inches per acre or more come from the alpine grasslands and from that area of dwarf trees at timberline. Dense forests of Engelmann spruce, subalpine fir, lodgepole pine, and aspen yield 6 to 18 acre-inches per acre from areas above 8,500 feet in elevation. The ponderosa pine type yields 3 to 6 acre-inches per acre between the elevations of 5,000 and 8,500 feet.

1/ Research Forester, Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, with central headquarters at Fort Collins, Colorado in cooperation with Colorado State University.

Of the approximately 20 million acre-feet of water yielded annually from the Southern Rocky Mountains, it is estimated that 35 percent comes from alpine grasslands, 50 percent from Engelmann spruce-subalpine fir, lodgepole pine, aspen forests, and 15 percent from ponderosa pine-bunchgrass type.

Increasing Water Yields

Alpine Snowfields

A survey of selected alpine snowfields in the Southern Rocky Mountains during the summers of 1955-1958 confirmed the belief that such fields are important contributors to summer streamflow. This work showed that vertical ablation averaged 1.9 feet of snow per week during July and August. Specific gravity of the snow varied from 0.60 to 0.75. This means that about 1 1/4 feet of water were released per unit area of snow.

Vapor transfer studies carried out in late-lying alpine snowfields during the summers of 1957 and 1958 showed a net gain of moisture on the snow surface from condensation during a nine-day period of humid weather and a net loss of moisture from the snow due to evaporation during a period of dry, windy weather. Over a period of several months net exchange approaches zero. Even on a daily basis the net vapor transfer averaged only 2 to 3 percent of the daily melt. Never during the two test periods did it exceed 4.5 percent of daily melt. Hence, this net vapor transfer can be ignored for most practical purposes.

Winter observations of snow accumulation in the alpine for the past two years have furnished some quantitative data on local drift patterns. It has been observed that snow transport starts in the unprotected spots, with winds above 10 to 12 mph. provided the snow surface is not crusted. At some higher speed, perhaps 25 to 35 mph., all snow not in the immediate lee of vegetation or terrain irregularities is subject to wind erosion. Thus, snow drifts that develop in relatively exposed situations with light winds are carried away at higher velocities. Winds can move snow more effectively after surface irregularities are filled by snow and the terrain is smooth. Maximum accumulation of snow takes place in the natural catchment areas when strong winds follow or accompany moderate or heavy snow storms.

Experiments are under way to see if artificial barriers can be used in conjunction with natural terrain features to increase the amount of snow trapped in the natural alpine catchments. To date only standard, vertical slat and wire snow fencing has been used (fig. 3). Tests during the winter of 1956-57 showed no appreciable advantage in erecting this type of fence so that it leaned into or away from the prevailing wind nor in overlapping two sections to get greater density. A single thickness of fence on vertical poles was easier to put up and in these tests appeared to trap as much snow as the more elaborate fences.

Spruce-fir, Lodgepole Pine Type

At the Fraser Experimental Forest, the effects of harvesting timber from a mature stand of lodgepole pine on over-winter snow accumulation was an early study of increasing water yields. The stand averaged about 75 feet in height and 12,000 board feet per acre. Twenty plots, 8 acres in size, were used, four intensities of cutting applied, and comparisons made with uncut plots. The residual volumes per acre remaining under the four intensities were: 6,000, 4,000, 2,000, and

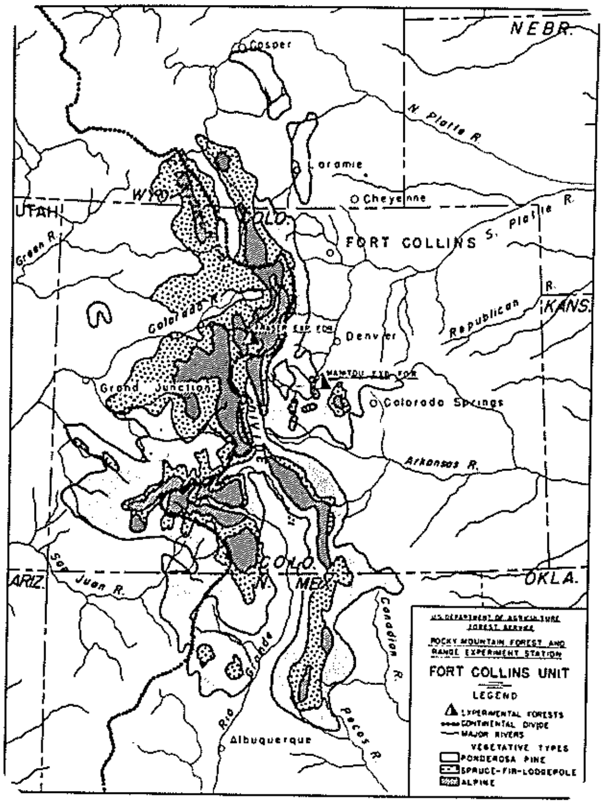

Figure 1. Predominate vegetation types, Southern Rocky Mountains.

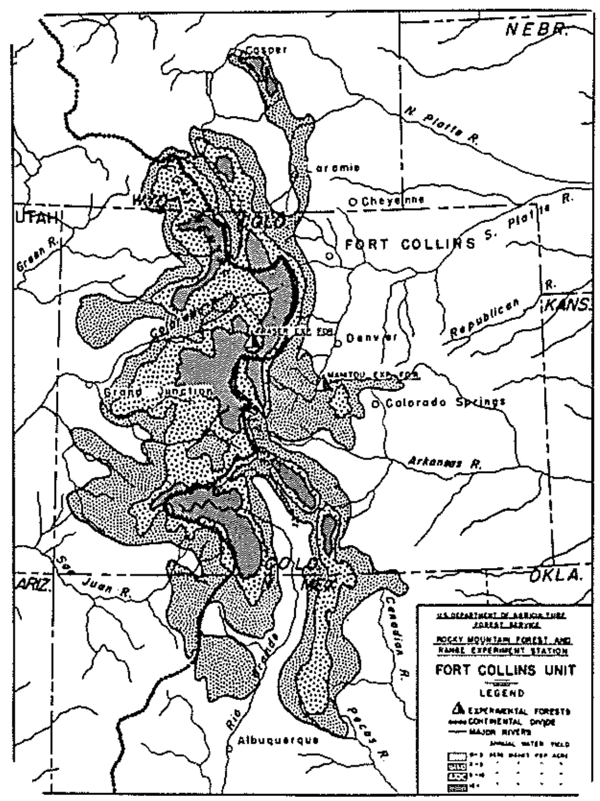

Figure 2. Annual water yield, Southern Rocky Mountains.

zero board feet in trees of sawlog size, 9.5 inches, d.b.h. or larger.

Measurements of winter snow accumulation, spring and summer precipitation, and summer losses of soil moisture over a 3-year period showed that the commercial clearcutting increased the water available for streamflow by 31 percent, or from 10.3 to 13.5 inches per year. The lesser intensities of cutting produced proportionately less increases in available water.

The effects of different patterns of timber harvesting were the subject of another plot study made in a mature stand of Engelmann spruce and subalpine fir averaging 18,000 board feet per acre and lying on a steep, north-facing slope. On each treated plot the harvesting left the same 40 percent of the original volume but the pattern differed from plot to plot. On one plot the harvesting left uncut strips 66 feet wide alternating with equal strips from which all trees 9.5 inches d.b.h. and larger had been removed. On another plot, harvesting was by group selection, whereby half of the plot area was cleared of mature timber by making openings 66 feet in diameter. From each of these plots, an additional 10 percent of the original volume was removed in a salvage cutting from the uncleared area. On a third plot, the cutting was by individual tree selection and the residual stand approximated a heavy shelterwood.

Snowpack comparisons among these plots and an untreated plot, over a 3-year period, indicated that the timber harvesting caused an average increase of 22 percent in the winter snowpack or an increase from 12.4 to 15.2 inches of water equivalent. There was no difference in the snowpack among the patterns of treatment, but the rate of spring snowmelt was slightly lower on the plot cut in a group-wise pattern, where shading from sunlight was more complete. The results indicated that on such a slope the snow accumulation was not related to the pattern of timber harvesting but only to the volume of timber removed.

The gaging of Fool and East St. Louis Creeks was begun in 1943 and continued without the logging of either watershed until 1954. The two watersheds are contiguous. That of East St. Louis Creek has an area of 1,984 acres. Fool Creek, the watershed finally treated, has an area of 714 acres of which 550 acres, or 77 percent, was in a dense mature stand of lodgepole pine, Engelmann spruce, and subalpine fir (fig. 4).

Following completion of a 12-mile road network, the logging of Fool Creek was started in 1954 and completed in 1956. The pattern of cutting was one of alternate clear-cut strips of different widths, 1, 2, 3, and 6 chains, running normal to the contours. From the clear-cut strips all live trees 4 inches d.b.h. and larger were removed. Fifty percent of the commercially timbered area of the watershed or 40 percent of the entire watershed was so cleared.

Although the final 20 percent of timber harvest was not completed until the summer and fall of 1956, that year has been classed as a post-treatment year for preliminary reporting. This gives four years of record to show the effect of the harvest. For each of these years, the excess of actual water yield over that predicted from the comparison with East St. Louis Creek is shown in table 1. Before the treatment of Fool Creek watershed, the annual water yield from this drainage averaged 13 inches; yield from East St. Louis Creek averaged 19.5 inches.

Table 1.--Actual versus predicted water yield from Fool Creek in post-treatment years.

Years	Predicted yield	Actual yield	Actual yield minus predicted yield
	---------------Area inches---------------		
1956	11.4	15.6	4.2
1957	19.6	23.0	3.4
1958	11.4	13.5	2.1
1959	10.5	13.6	3.1

Most of the increase in yield has occurred during the spring freshet period of May and June, but there has also been a small increase in the summer and early fall months. Each year the early rise of Fool Creek is more rapid than formerly, and in 3 years the spring peak has been higher than it would have been had the timber not been cut. However, in 1957, the timber removal combined with a particular weather pattern to cause a peak appreciably lower than predicted by comparison with the behavior of East St. Louis Creek.

Ponderosa Pine Type

Water yield from streams originating in the ponderosa pine type averages less than 6 inches annually. A surplus of water is built up during the winter to be released as snowmelt in the early spring, followed by a period of water deficit during the summer and early fall. Evapo-transpiration is largely responsible for this deficit and amounts to over 15 inches. For temporary periods the water deficit may be reduced and streamflow augmented during summer rainstorms that may be either of a general nature or localized thundershowers. The bulk of the annual water yield occurs in April and May, and becomes gradually less during the summer and fall.

North exposures of the ponderosa pine zone offer some possibilities of increasing water yield through the harvest of timber (fig. 5). These possibilities were pursued in a preliminary way by means of plot studies during 1957-58 and 1958-59, near the Manitou Experimental Forest.

In a mixed stand of ponderosa pine and Douglas-fir on a north exposure, two batteries of 3 one-acre plots each were established to measure the water content of over-winter snow accumulation under cut and uncut conditions.

Two plots were left uncut, on two others 60 percent of the merchantable volume was selectively cut, and on the remaining two, all merchantable timber was removed. The basal area was reduced from an average of 120 square feet per acre to 94 square feet per acre under selection cutting and to 43 square feet under commercial clearcutting. Comparison of maximum snowpacks, in inches water content, of individual commercially clearcut and uncut plots during both winters showed an average increase of 1.2 inches with a range of .24 to 2.6 inches.

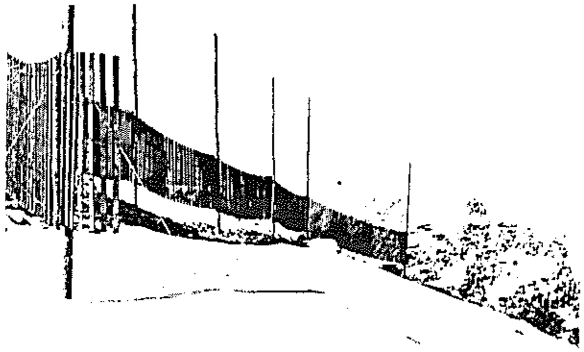

Figure 3. Vertical slat and wire snow fencing is used to trap additional snow in natural alpine catchment areas.

Figure 4. Strip cutting on Fool Creek watershed (left); East St. Louis Creek to the right. Fraser Experimental Forest.

Figure 5. Snow accumulates over-winter on north exposures (right), but disappears rapidly on south (left), ponderosa pine type.

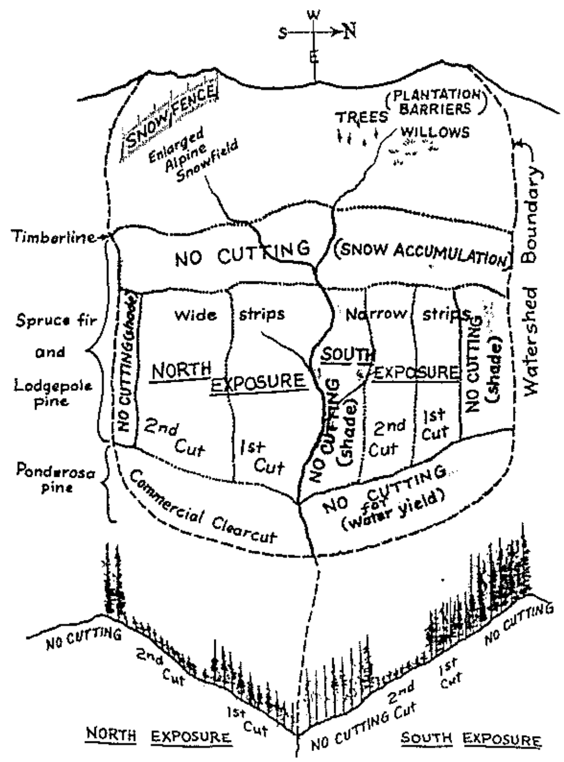

Figure 6. Sketch showing how a watershed might be managed for effective water yields.

Although snowfall during the two winters was different, the increase in water content of the maximum snowpack on the commercially clear-cut plots was significant when compared to the uncut plots. This was not true of the selectively cut plots. Snow disappeared from all plots at about the same time, indicating a speed-up in snowmelt on the commercially clear-cut plots.

Mountain Watersheds

Future management of the high elevation lands of the Southern Rocky Mountains will more and more be directed towards water as the primary product. The watershed thus becomes the basic unit of land area for resource management. In keeping with the subject of this discussion we might speculate on how a watershed might be managed for effective water yields by increasing water supplies and by altering the timing of streamflow (fig. 6). What we, and others, have learned from plot and watershed studies has been put together in a single sketch to accomplish two purposes; namely, (1) to deduce how a watershed might be managed and (2) to point up the watershed research needed before such a management program can be undertaken. All situations can't be covered nor can agreement be reached now on how to manage for effective water yield.

A watershed managed for effective water yield conceivably might include (1) snowfences or plantations to increase the size of alpine snowfields, (2) clearcut strips of varying width to increase snow accumulation in the spruce-fir lodgepole pine forests and (3) commercial clearcutting on north exposures only in the ponderosa pine, Douglas-fir forests. A considerable portion of the forests would remain uncut to allow for snow accumulation near timberline, to shade openings, to curtail windthrow, and to protect south exposures in the ponderosa pine from excessive erosion. Even with all of this manipulation there is no guarantee that increased water yield or change in the timing of streamflow would result because of variations in topography, climate, soils, vegetation density and composition.

If a watershed were to be managed for effective water yield, as described above, new problems would be created and considerably more research would be needed to warrant such intensive management measures. For example, it is yet to be proven that barriers will materially increase the size of alpine snowfields and that this increased size will result in additional late summer streamflow. What is the relation of these enlarged snowfields to either the increase or decrease of avalanche hazards?

In the spruce-fir forests little is known about the exact influence of solar radiation on snow accumulation and melt in dense forest stands, in alternating clearcut and uncut stands, and on different exposures and slopes. Likewise, information is sparse on transpiration changes from uncut to cut forest stands. Comparative studies are needed as to which individual species of trees, grasses, or shrubs are the superior watershed cover from the standpoint of water yield. The reaction of the different soils to vegetation manipulation for water yield is not thoroughly known. Nor are all the facets of silviculture and timber harvest explored in the spruce-fir lodgepole pine type. Although timber harvest has resulted in increased water yields, the reasons why the increase occurred are not readily apparent, nor have the possible changes in the timing of streamflow been investigated. Since these high elevation forests are the prime source of water in the Southern Rocky Mountains, information concerning their management for water yield is urgently needed.

Past timber harvesting in the ponderosa pine on south exposures has resulted in the deterioration of the site through accelerated erosion. Opportunities appear to exist on north exposures covered with ponderosa pine and Douglas-fir to increase water yield by commercial clearcutting. That such increases might occur is still to be proven and associated studies of silviculture, regeneration, and methods of harvest must precede such a test. As in the case of the spruce-fir lodgepole pine type, little is known concerning the influence of solar radiation on snow accumulation and melt, the transpiration of cut and uncut ponderosa pine stands, and the reaction of different soils to vegetation manipulation.

SUMMARY

Water yielded from the alpine and subalpine mountain areas of the Southern Rocky Mountains constitutes the most abundant and constant annual supply of four major rivers; the Rio Grande, the Colorado, the Plattes, and the Arkansas. These rivers provide the water needed for irrigation, industries, homes, and towns located for the most part, outside of the mountains. Water for these purposes is often used several hundreds of miles away from its source.

Present day watershed research indicates that water yields from mountainous areas may be increased through the use of barriers in alpine snow catchment basins and by the harvesting of timber in the spruce-fir lodgepole pine stands. Improving water yields from ponderosa pine stands is not so clearly indicated. Research results to date point to a possible increase in annual water yield of 20 to 25 percent but that this increase occurs at a time when water is plentiful and not at the peak of its highest demand.

Applying present-day watershed management knowledge to an entire watershed for effective water yields will result in many pitfalls. The most pressing of these is the lack of research results needed to more adequately understand the behavior of a watershed when its natural environment is altered for the purpose of increasing or changing the timing of annual water supplies. The speeding up of watershed management research in mountainous areas will provide the basis for future management measures sorely needed in the development of southwestern water supplies.

THE RIO PUERCO - PAST, PRESENT, AND FUTURE

E. J. Dortignac1/

The history of the Rio Puerco is one of man's inability to live in harmony with soil, topography, vegetation, and climate. Soil dislodgement and movement in the Rio Puerco may surpass that of any watershed in this country. It is estimated that between 600,000 and 800,000 acre-feet of soil has washed out of the Rio Puerco since 1885. Even now, this watershed which represents 28 percent of the contributing basin in the Upper Rio Grande in New Mexico produces about 45 percent of the measured sediment and only 4 percent of the water yield.

Sediment from the Rio Puerco results in considerable downstream damage through; (1) depletion of the capacity of Elephant Butte Reservoir, (2) aggradation of the Rio Grande channel, (3) increased maintenance of irrigation canals, ditches and drains, (4) detrimental deposition on lands and crops, (5) increased salinity, and (6) providing a favorable habitat for phreatophytes such as salt cedar between the mouth of the Puerco and the reservoir. Water consumed and wasted by non-beneficial phreatophytes in the Rio Grande was estimated at 240,000 acre-feet annually before the rehabilitation program of the Bureau of Reclamation.

These are current and continuing damages that are a threat to the future of downstream residents. They are in addition to the soil, vegetation, and other damages that have occurred on the Rio Puerco watershed itself. But with so much sediment coming from the Puerco, the main problem is how to control or prevent this sedimentation damage.

Description of Rio Puerco Watershed

The Rio Puerco is situated west of the Jemez mountains, Albuquerque, and Belen within 6 northwestern New Mexico counties (figure 1). It covers 3,900,000 acres, is irregular in outline, with approximate maximum dimensions of 125 miles from north to south, and 85 miles from east to west. The principal drainage, the Rio Puerco, rises in the western slopes of the San Pedro Mountains and takes a southerly course. It enters the Rio Grande about 2 miles north of La Joya and just east of Ladron Peak. The main tributaries from the west, rising along the Continental Divide, are the Rio San Jose and Chico Arroyo. The Rio Puerco currently is a permanent stream only through the upper few miles of its channel and its remaining part and all of its tributaries have intermittent or ephemeral flow.

Elevations range from 5,000 to 10,600 feet. Average annual precipitation varies from 8 inches near its mouth to about 25 inches on Mount Taylor and on San Pedro mountains. Three-fourths of the basin receives less than

1/ Forester (Research) Rocky Mountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, stationed at Albuquerque, New Mexico in cooperation with the University of New Mexico.

14 inches and only 5 percent of the drainage receives more than 20 inches annual precipitation.

Soils are derived predominantly from highly erodible sandstones and shales (mostly of Cretaceous origin) with the exception of 761,000 acres above McCartys on Rio San Jose where the surface is covered by lava flows. This latter area is not a source of flood and sediment to the main Rio Puerco and Rio Grande.

Soil Piping

A good portion of the soils in the Rio Puerco, particularly those developed from Upper Cretaceous shale are subject to "piping", a form of subterranean erosion. Cracks develop in the soil or parent material due to expansion and contraction that accompanies alternate wetting and drying. Water enters and concentrates in these cracks and eventually melts or disperses the surrounding soil and forms underground conduits or tunnels called "pipes". Also, holes formed by burrowing animals and other causes contribute to the development of this system of subsurface drainage (figure 2).

An important part of the high intensity rain that falls on the alluvium and nearby land slopes concentrates as runoff and enters these soil pipes. As the system of underground drainage develops, large quantities of runoff water may be quickly discharged into the gully system through soil pipes.

This method of waterflow delivery eventually results in the collapse of the overlying soil. It also causes sloughing or cave in of vertical gully walls following runoff producing rainstorms. Once a system of gullies has developed on these soils, control becomes difficult and costly.

This inherent characteristic of the geology and soil in the Rio Puerco has been an important contributing factor to past watershed deterioration, particularly gully formation, and must be fully recognized in a program of rehabilitation. Unfortunately, its importance has been noted only recently.

Vegetation

Vegetation in the Rio Puerco watershed is mostly pinon-juniper (Pinus edulis Engl. -Juniperous spp.) woodland and grassland about evenly divided. Sagebrush (Artemesia spp.) occupies from 3 to 4 percent of the watershed and forests an equal amount.

Historical records and reconnaissance surveys indicate that a good cover of grass mostly alkali sacaton (Sporobolus airoides Torr.), galleta (Hilaria jamesii (Torr.) Benth.) and blue grama (Bouteloua gracilis (H.B.K.) Lag.) was once present over much of the watershed. This was true even in the pinon-juniper as much of this woodland is the savanna type with widely spaced trees. Steep, rocky breaks and badland topography were no doubt always barren or sparsely vegetated and contributed high surface runoff which flooded the alluvium of the valleys (figure 3). Yet alkali sacaton and other grasses covered many steep slopes and pointed hilltops of Cretaceous shale origin (figure 4). Dead root crowns of alkali sacaton can now be found on uplands and steep slopes as well as valleys.

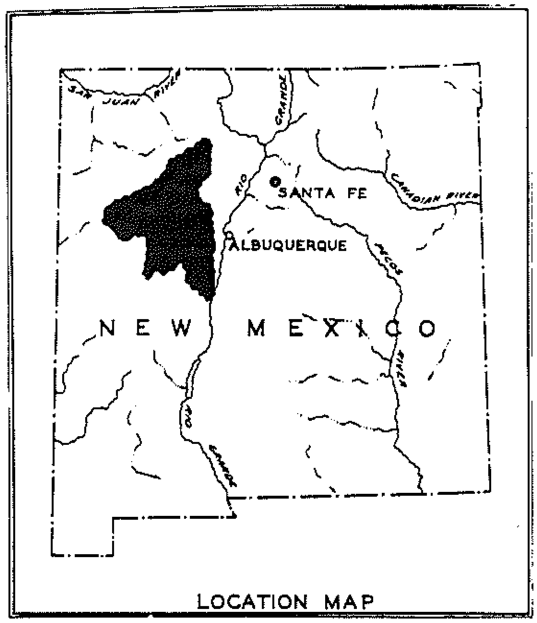

Figure 1. Rio Puerco watershed.

Figure 2A. Soil cracks develop on soil derived from Cretaceous shale (Menafee) after surface soil dries out. Presence of organic materials reduces the amount and size of cracks.

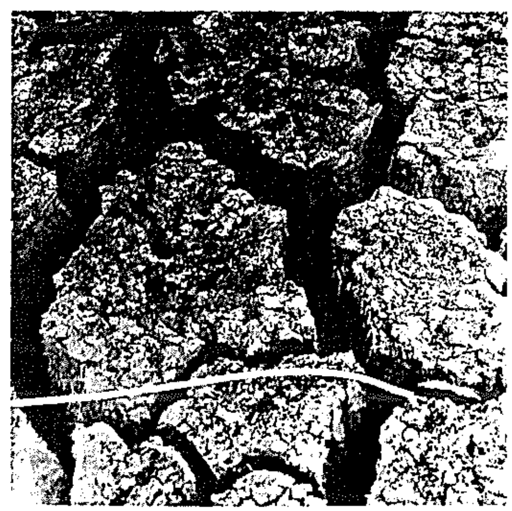

Figure 2B. Soil cracks are pronounced in dry sediment deposit derived from soils of Menafee shale origin.

The vegetation was in delicate balance with the erosive soils under the semiarid climate with recurrent droughts of long duration.

History of grazing

The coming of the Spaniards with their grazing animals may have upset this balance quite early. By 1750, thousands of sheep grazed out from the settlements on the Rio Puerco as there was little danger from Indians for a time after the Spaniards' return. Flocks were driven miles from the settlements and kept there for long periods. Many sheep wintered in the valley of the Rio Puerco where grass and brush afforded feed and protection. But by 1800, as a result of Indian attacks, herds were reduced to numbers that could be grazed near settlements. During this period, plant cover in more remote areas may have partially re-established itself. By 1855 there was little danger from marauding Indians and livestock herds built up and grazed at distances from settlements. For example, there were 185,000 sheep in Bernalillo County in 1850; 306,000 in 1860; and 583,000 in 1880.2/ Maximum numbers of livestock in the Rio Puerco were reached after 1880. According to Bryan (1928), destructive erosion followed in the period 1885-90.

Cutting of Main Stream Channel

Old records make no mention of accelerated erosion before the Spanish engaged in extensive livestock industry nor is there mention of the Rio Puerco channel being either wide or deep. Moreover, most of the early land surveys of section lines and grant boundaries beginning about 1855 recorded the width of the Puerco Channel, but few mentioned the channel depth. But in 1846, Abert (1848) found the Rio Puerco with vertical banks 10 or 12 feet high west of the village of Atrisco and about 30 feet high near the deserted settlement of Poblazon. Simpson (1852) in 1849 mentioned the presence of an entrenched channel when crossing the Puerco in the vicinity of the present village of San Luis. Streambanks of 20 to 30 feet had to be cut down to allow passage of the artillery. Four years later, in 1853, Whipple (1856) found the bed of the Rio Puerco about 100 feet wide and 18 feet below the alluvial valley near its confluence with the Rio San Jose. But later, in 1870, the flood plain was without a deep channel at Cabezon where a small bridge was used to cross the river (Bryan and Post - 1927). Likewise, in 1870 the channel was 8 feet deep at La Ventana whereas it is now approximately 50 feet in depth (Widdison, 1959). Thus, accounts of early travelers indicate the Rio Puerco was already entrenched at several places by the middle of the 19th century, but at other places the banks were low or inconspicuous. According to Bryan (1928) the Rio Puerco was, previous to the late eighties, an ephemeral stream with numerous floods of short duration, but occasionally of great magnitude. It flowed in a flood plain subject to overflow and had a discontinuous channel. In years of flood most of the valley floor was inundated and good crops of corn, wheat, and beans were raised.

Bryan and Post (1927) estimated the main discontinuous channel probably had a volume of about 17,000 acre-feet in 1885. A resurvey of the channel in 1939 by the Soil Conservation Service (1941) showed the volume to be 267,000

2/ Sheep numbers adjusted for changes in county boundaries to those existing in 1880.

acre-feet from below Cuba to its mouth.

The volume of tributary channels was estimated at 5500 acre-feet in 1885 and at 276,000 acre-feet in 1927 (Bryan and Post, 1927). It is considerably more today (figure 5).

Decline of Irrigation

Irrigated areas existed along the main Rio Puerco Valley from Los Cerros to the headwaters, being watered from small diversions in the discontinuous channel. As a result of the new deep channel forming from the mouth headward, Los Cerros, 34 miles upstream was abandoned about 1888. San Ignacio and San Francisco 62 and 73 miles upstream from the mouth were abandoned by 1896. Casa Salazar was abandoned in the late twenties and the last family recently moved out of Cabezon (figure 6).

Thus, the main cutting of the arroyo took place in the late eighties and as it proceeded headward, settlements were abandoned.

Of 16 villages and settlements along the main Puerco Valley only Regina, La Jara, Cuba and San Luis remain populated, while La Ventana has a single family. According to Harper, Cordova, and Oberg (1943) irrigated acreage from Casa Salazar to Cuba declined from 10,000 acres to 3,000 acres between 1880 and 1925. Irrigation along the main channel below Cuba ended with the destruction of the San Luis diversion dam by a large flood on July 25, 1951 (figure 7).

In 1939, more than 5,500 acres in the Upper Valley (above Cuba) were irrigated by 17 ditch systems. Much of the acreage and most of the ditches have been abandoned.

Rehabilitation and Research

Restoring a deteriorated watershed such as the Rio Puerco will be neither simple nor inexpensive. Many persons question whether this watershed can once again support a good cover of grass. For these and others may I suggest a visit to the Frank Bond Ranch. Here, winter grazing has been practiced for 36 years and a relatively good cover of grass can be found. (figure 8). Likewise, on the Howard Mayor Ranch, numerous gullies are healing and grass vegetation is improving under a soil and moisture conservation program and conservative grazing.

But on the Puerco, livestock control must be combined with vegetation and soil improvement and mechanical control of gullies. What types of vegetation, livestock, and mechanical control are needed for complete rehabilitation remains speculative. Much research and pilot testing is needed.

The Rocky Mountain Forest and Range Experiment Station is cooperating with the Bureau of Land Management and U. S. Geological Survey in the San Luis Experimental Watershed study. Three similar watersheds (338, 471, and 555 acres) are being calibrated to establish a relationship among precipitation, vegetation, surface runoff, and sediment inflow as measured at the reservoirs. Watersheds are individually fenced and cattle graze during a 5-month winter period beginning November 1-15 each year. Grazing use of the principal forage species has averaged 58 percent on alkali sacaton and 40 percent on gal-

Figure 3. Steep rocky sandstone and shale breaks on San Luis experimental watersheds (Menafee formation).

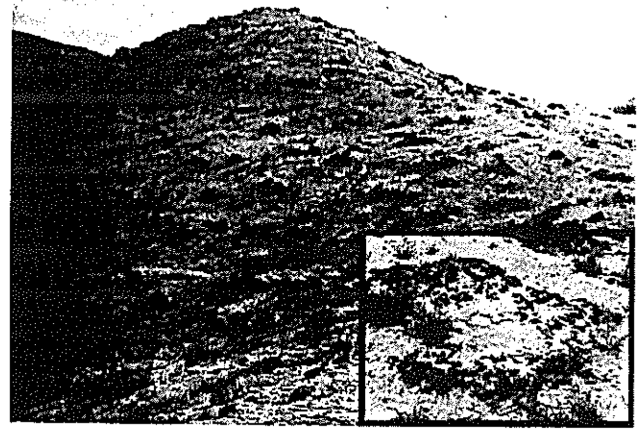

Figure 4. Mancos shale hill that once supported a good stand of alkali sacation. Note dead clumps of grass on slopes exceeding 40 percent.

Figure 5. Gully formation in tributary of Rio Puerco in 1954.

Figure 6. Abandoned village of Cabezon, 1952.

Figure 7A. San Luis Dam, 1938.

Figure 7B. Ruins of San Luis Dam, 1953.

leta during the past 6 years. This is considered heavy use of the key species alkali sacaton.

When watershed performance can be predicted for given rainstorms, the treatments on 2 watersheds will be altered and that on the 3rd watershed will remain unchanged to provide a climatic control. On one watershed, grazing intensity will be reduced to moderate (30% to 40%) use of alkali sacaton. Another watershed will receive moderate grazing use combined with a complete treatment of soil and vegetation, including control of gullies. Thus, we hope to learn what effect the soil and vegetation conservation treatments needed for full rehabilitation will have on water and sediment yield. Thus far, water yield as measured at the reservoirs has averaged about 5% of the annual precipitation. This is in agreement with runoff measured on the experimental watersheds on Montana Grant (Dortignac, 1956) and about 1.5% less water yield than from the nearby Cornfield Wash (23 sq. miles) as shown by a 5 year U. S. Geological Survey study (Kennon and Peterson, 1960). Water yield from pinon-juniper experimental watersheds at Mexican Springs averaged 4.5% of the annual precipitation.3/ This water yield and that from other pinon-juniper and lower lying lands is almost entirely surface runoff produced during high intensity rainstorms and is in marked contrast to soil water discharge from snow melting in the higher-lying Mt. Taylor and San Pedro mountains.

Annual sediment production on the San Luis experimental watersheds has averaged about three-fourths of an acre-foot per square mile. This is considerably less than on Cornfield Wash where 2.8 acre-feet per square mile has been measured. Most of the sediment comes from the extensive network of gullies. Re-measurement of soil elevation transect grids on this watershed in 1958, one year after establishment indicates an appreciable rate of aggradation on the alluvium near the bluffs. An average of 160 point elevation measurements shows about 1/4 inch soil deposition attributed to 7.05 inches precipitation, most of which (4 inches) fell in a 2-day storm in October 1957.

The 3 dams on the experimental watersheds were constructed above the heads of actively eroding gullies in 1951. These dams have halted the headward progress of cutting and are effective gully controls. This and other methods of controlling runoff, gullies, land slope erosion, and sediment have been and are currently used by the Bureau of Land Management in their soil and water conservation program on public domain lands. The Rocky Mountain Forest and Range Experiment Station is presently evaluating the effects of several mechanical treatments of soil and vegetation. One of these, soil pitting, is accomplished with the Calkins pitter.

The Calkins pitter leaves a pattern of small basins over the land surface.

This practice is being evaluated on 16 surface runoff plots, 310 square feet in size. During the first year, 9 summer rainstorms produced surface

3/ Dortignac, E. J. Water yield from pinon-juniper. Paper presented at the thirty-sixth annual meeting of Southwestern and Rocky Mountain Division of the American Association for the Advancement of Science at Alpine, Texas; May 1960.

runoff. Reduction in surface runoff caused by soil pitting varied from 10.5% on the south slope to 26% on the north aspect. Erosion was reduced from 19% to 16% during the first year.

Soil ripping is another mechanical treatment that is being evaluated by means of surface runoff plots (figure 9). During the first year, soil ripping with the Jayhawker (figure 10) eliminated practically all of the surface runoff (98%) and erosion during 12 rainstorms. There was no vegetation improvement on experimental plots. On seeded plots, alkali sacaton seedlings became established by late fall and survived the winter, but subsequently died during the prolonged spring and summer drought. (figure 11)

Though sagebrush is not extensive in the Rio Puerco, it has been chained or treated with the Marden brush cutter. But this implement may be used in the Rio Puerco for gully control (figure 12).

In view of the hazards of soil piping in the Rio Puerco, sloping and seeding gully sidewalls, or completely filling-in gullies may be necessary in many areas. Research should develop methods for refilling and vegetating the gullied channels that dissect practically all of the once productive valleys, if sediment is to be controlled. Also, research should evaluate any losses in water yield that might result from a complete program of rehabilitation and control of sediment.

LITERATURE CITED

Abert, J. W., 1848, Report of Lieut. J. W. Abert of his examination of New Mexico in the years 1846-47. House Ex. Doc. No. 41, 30th Congress, 1st Session, pp. 417-548, illus.

Bryan, Kirk, 1928, Historic evidence on changes in the channel of Rio Puerco, a tributary of the Rio Grande in New Mexico. Jour. Geol. 36: pp. 265-282, illus.

________ and Post, George M., 1927, Erosion and control of silt on the Rio Puerco, New Mexico. Report to Chief Engineer, Middle Rio Grande Conservancy District (Oct. 1927) pp. 174, illus. (Typewritten)

Dortignac, E. J., 1956, Watershed resources and problems of the Upper Rio Grande Basin. Rocky Mountain Forest and Range Experiment Station, pp. 107, illus.

Harper, Allen G., Cordova, Andrew R., and Oberg, Kalervo, 1943, Man and Resources in the Middle Rio Grande Valley. Univ. of New Mexico Press, Inter-Americana Studies II, pp. 156, illus.

Kennon, F. and Peterson, H. V., 1960, Hydrology of cornfield wash Sandoval County, New Mexico, 1951-55. Geological Survey Water-Supply Paper 1475-B prepared in cooperation with U. S. Bureau of Land Management, pp. 103, illus.

Simpson, James H., 1852, Journal of a military reconnaissance from Santa Fe, New Mexico to the Navajo country made with the troops under command of Brevet Lt. Col. John M. Washington, Chief 9th Military Dep't. and Governor of New Mexico, in 1849. (James H. Simpson, First Lt. Corps of Topographical Engineers) Lippincott, Grambo and Co., Phila., 140 pp., illus.

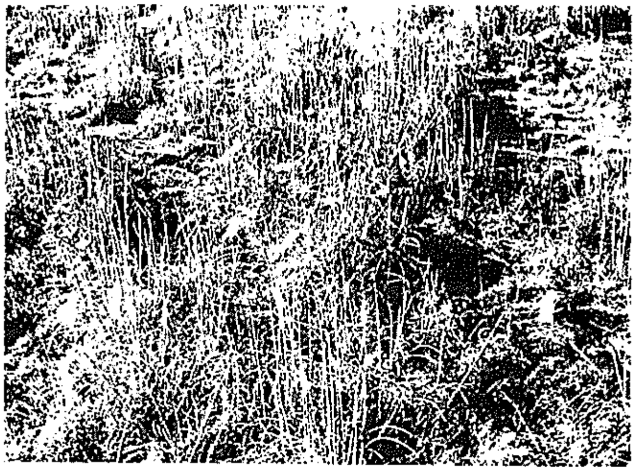

Figure 8. Stand of alkali sacaton on 15 percent slope on the Frank Bond Ranch. Soil derived from Upper Cretaceous shale.

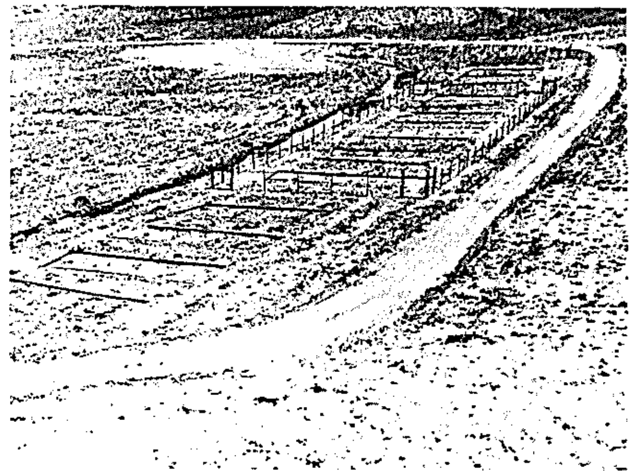

Figure 9. Surface runoff plots (each 10 x 30.5 feet) on upper slope of north aspect used to evaluate the effects of soil ripping. Soil derived from Mancos shale.

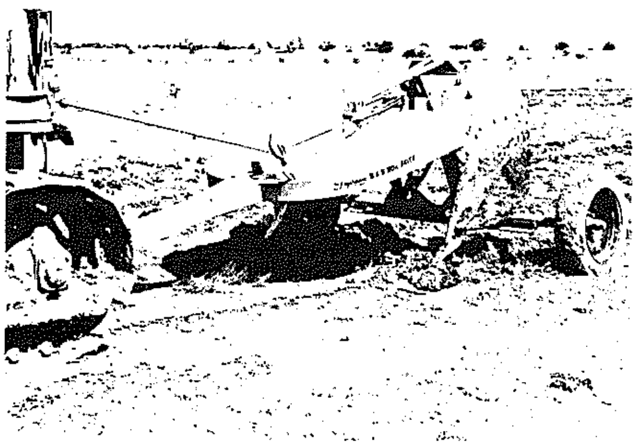

Figure 10A. Ripper is pulled by a D-8 tractor

Figure 10B. Land surface after treated with soil ripper. Depth of ripping 28 inches - soil derived from Upper Cretaceous shale.

Figure 11. Grass recovery one year after treatment with ripper - untreated on extreme left.

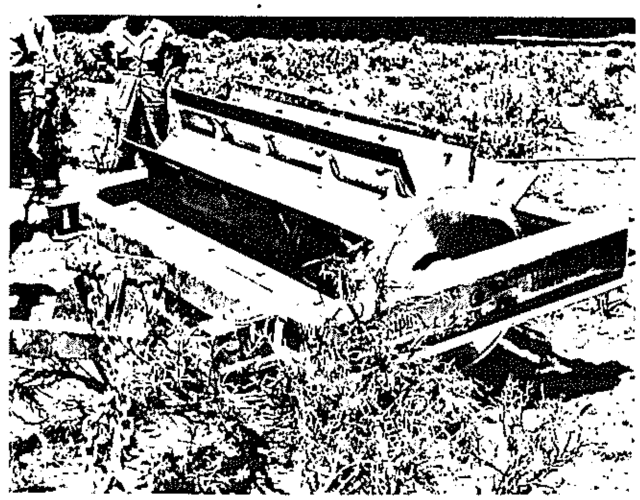

Figure 12. Eradicating sagebrush with a Marden Brush Cutter.

Whipple, A. W., 1856, Report on topographical features and character of the country, 77 pp., illus. From Reports of exploration and surveys to ascertain the most practical and economical route for a railroad from the Mississippi River to the Pacific Ocean, made under the direction of the Secretary of War. Vol. III U. S. Senate, 33rd Congress, 2nd Session, Ex. Doc. No. 78.

Widdison, Jerold Gwayn, 1959, Geography of Middle Rio Puerco Valley, New Mexico Historical Review, Vol. 34, pp. 248-284, illus.

RESEARCH ON THE CONTROL OF SALT CEDAR[1]
AT NEW MEXICO STATE UNIVERSITY

OBJECTIVES:

1) Development of more effective methods of control using currently available herbicides.

2) Investigate the effectiveness of newly developed herbicides for the control of salt cedar and the hazards to adjacent crops.

3) Determine the factors in the physiological makeup of salt cedar that are responsible for producing a foliage that is highly susceptible to systemic herbicides and a root system that resprouts vigorously in spite of repeated treatments.

PREVIOUS WORK AND PRESENT OUTLOOK:

This station has continually pointed out that any control measures that depend on herbicides alone are doomed to failure. On land that is accessible to ground equipment, salt cedar could be controlled with currently available herbicides by the same combination that has proved effective for controlling persistent perennials on farm lands, namely, tillage, chemicals and competing crops such as grasses. An outline for the control of salt cedar and research based on this principle was submitted in 1954 to the State Engineers Office at their request. The state legislature had appropriated $100,000 for the control of salt cedar under the direction of the State Engineers Office. The research outline that was submitted along with an estimated cost of $12,000 for the first year was not implemented since the attorney general ruled that the funds allocated to the State Engineers Office were for control and not for research.

Again in 1960, the importance of ecology was stressed along with the need for basic research when a research proposal for the control of salt cedar and other phreatophytes was submitted to the Crops Division of ARS at the request of the associate director, Dr. Weiss. Basic research was suggested in the fields of soils, water consumption, physiology and the establishment and management of replacement vegetation.

Even on small experimental plots the chemical control of salt cedar has been disappointing. The propionic formulations of the phenoxy herbicides have proved to be statistically more effective than the acetic formulations of 2,4-D or 2,4,5-T. However, a statistical difference has little practical significance in this case since 40 per cent control is little better than 20 per cent control. While again we may say the propionic formulations have proved statistically safer from the standpoint of injury to adjacent cotton crops, they are still not safe enough. Then too, as one might expect, the unit price of the propionic formulations is much higher than for comparable acetic formulations.

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[1] Abstract of talk given by J. Wayne Whitworth, at Fifth Annual New Mexico Water Conference, New Mexico State University, on November 1, 1960.

Because of danger of injury to adjacent cotton crops, most of our studies on salt cedar have been conducted by the use of dormant, and/or basal applications. Oil has proved to be a superior carrier to water, but even with oil, a rate of approximately 10 lb/A of 2,4-D must be applied in a drenching spray to obtain results that approach 90 per cent control. Of the susceptible periods studied by means of basal applications, November, March, and July were the months of maximum susceptibility and July and September were the months of maximum resistance. These findings may not hold true for foliage applications of herbicides.

Soil sterilant type herbicides have given erratic performance and their cost makes their use prohibitive.

Currently, we are in the process of completing laboratory facilities which will make possible a study of the movement of systemic herbicides from the foliage to the roots of salt cedar. Measurements will be made by histological as well as by tracer methods.

PHREATOPHYTES IN REGION 5

O. J. Lowry

Salt cedars, one of the predominant phreatophytes, were first noted growing along the Rio Grande and Pecos River in about 1910, and since that time they have spread and infested the river bottoms and flood plains. It is estimated that at least 145,000 acres of phreatophyte infested areas exist along the Rio Grande and Pecos River between the Alamogordo Reservoir and the State line, and Otowi and the State line on the Rio Grande. In addition to these major infestations, salt cedars are known to exist in varying densities along the Canadian, Red River, Washita, Arkansas, and Cimmaron watersheds in Texas, Oklahoma, New Mexico, southern Kansas, and Colorado. Since the southwestern part of the United States is in an area of insufficient water and where all waters are appropriated, the water to be used for beneficial purposes must be salvaged from water presently going for nonbeneficial purposes. One method for providing this salvage is by the control of phreatophytes or other plants which nonbeneficially consume precious water.

A brief resume of the work which has been conducted under the supervision of the Bureau of Reclamation, in an effort to control salt cedars and other phreatophytes, is as follows:

Pecos River

Beginning in 1948, salt cedars on the McMillan Delta area were sprayed in an effort to determine if aerial applications of herbicides could be used for the control. In the fall of 1948, 200 acres were sprayed with a formulation of 2,4-D at one pound per acre, and in the spring of 1949, 100 acres of this area were resprayed. Kills ranging up to 85 percent were observed on the salt cedar plants which received two applications. In 1951 an additional area of 2,650 acres was sprayed using various formulations of 2,4-D and 2,4,5-T; however, the results did not come up to our expectations. During this period several plots of salt cedars were sprayed with ground spray rigs to determine the most effective and economical herbicide for use to control woody plants primarily along irrigation and drainage ditches.

In conjunction with work done on the McMillan Reservoir, a 20-acre plot of salt cedar infested area was cleared and seeded to native and tame grasses. These grasses were irrigated the first two years after seeding. Of the 15 varieties of grasses that were seeded in 1950 and 1951, observations made in August this year indicated that the alkali and Giant Sacaton, Blue Panicum, and Aeluropis Littoralis have survived. Since these grasses were seeded, they have been inundated with water for short periods of time, and have been heavily grazed by livestock converging in the area. Also growing quite extensively in the area is Bermuda grass and Salt grass.

Middle Rio Grande

During the period of 1951 to 1954, a 250-acre plot of phreatophyte infested area comprised of salt cedar, cottonwood, and willow were sprayed with 2,4-D Amine in emulsion, using an aircraft. During this four-year-period five applications of herbicide were applied. However, no root kill was evident, only top kill having been obtained on the plants.

In the summer of 1953 an extensive aerial spraying program was undertaken in cooperation with the State of New Mexico, and an area of approximately 10,000 acres was sprayed using formulations of 2,4-D and 2,4,5-T. The primary results obtained here were top kill and temporary retardation of plant growth. With the floodway above Elephant Butte Reservoir having been completed, it has become mandatory that woody plants be controlled. Primarily the control of these plants has been accomplished by use of mechanical means. The towner disk and the root-cutter, which are used extensively, cost approximately from $10.00 to $12.00 per acre to operate. The towner disk affords only temporary removal of the plants, while the root-cutter so far has removed all existing plant growth.

In the fall of 1959, 1,250 acres of floodway area were sprayed with 14 formulations of 2,4-D, 2,4,5-T and 2,4,5-TP. Rates of one, two, and four pounds were applied by helicopter, and from observations made in May 1960, it appeared that the two and four pounds of 2,4,5-TP in water were the most effective rate for control of salt cedar plants. The 2,4,5-T Amine at two pounds per acre in emulsion appeared most effective for the control of broader-leaved phreatophytes, which include cottonwood, willow and baccaharis. Based on these observations, an additional area of 900 acres was sprayed in September 1960 with the helicopter, using two pounds of 2,4,5-T Amine in emulsion, primarily for the control of broad-leaved phreatophytes and silvex, or 2,4,5-TP in water for the control of salt cedar. These applications were made by helicopter at the rate of four gallons per acre. The cost of spraying the 900 acres was $12.50 per acre.

Caballo

We have long recognized that salt cedars are a high water user, and the control of these plants should yield an additional source of irrigation water. Beginning in 1951 an area on Caballo Reservoir was sprayed by fixed-wing aircraft, using formulations of 2,4-D and 2,4,5-T. This program did not prove effective; thus in 1958 a cooperative program between the Bureau and the State of New Mexico was initiated to remove the phreatophytes from Caballo Reservoir. Since that time a total of 4,700 acres have been removed from the Government-owned land of Caballo Reservoir. This clearing has been accomplished by the use of 84-inch rotary cutters and root rakes. The rotary cutters were used to cut plants which were less than two inches in diameter, and the root rakes were used to clear the large growth. After the clearing with root rakes, the debris was stacked and burned. Over a two-year period the average cost of operation for the rotary cutter was $6.20 per acre on 1,540 acres, and the cost for clearing with the root rakes was approximately $14.00 per acre covering 3,500 acres.

Since the area has been cleared, a control program has been initiated, and several methods of control are being practiced. The rotary mowers have been used extensively for the cutting of regrowth, and the cost of their operation for control of regrowth on 1,700 acres has averaged $2.20 per acre. Control by using the towner disk is also practiced; however, this method of control is only temporary, and is used primarily as a means to level the land in order that other equipment may operate more effectively.

Spraying with the trailer-mounted spray rig has also been practiced for the control of regrowth. In 1958 there were 684 acres sprayed with formulations of 2,4-D Amine and LV 2,4-D, 2,4,5-T, and 2,4,5-TP. The cost of spraying using these applications averaged $7.05 per acre. Unfortunately, this area was inundated, and no results were apparent from the spraying operations.

Beginning in 1959 an additional 630 acres were set aside in the upper reaches of Caballo Reservoir, and this area has been sprayed using 19 formulations of herbicides at rates of two, four, and eight pounds per acre. From observations which were made this past summer, it appears that the 2,4,5-TP at two and four pounds per acre in water produced the most effective results for the control of salt cedars. So far it has cost approximately $1.00 per acre to operate the ground-spray rig, plus the cost of the chemicals. During 1959 and 1960 the total cost for spraying salt cedars by ground-spray machine has been $7.00 per acre.

One of the most interesting items on Caballo Reservoir has been the spread of native and tame grasses in the area since the clearing operations have been concluded. At present Salt grass and Bermuda grass have spread almost uniformly in all of the area cleared, and are offering considerable grazing.

The above explanations have been a brief resume of the work which has been conducted in New Mexico for the control and removal of salt cedar and other phreatophytes.

SALT CEDAR CONTROL WITH CHEMICALS[1/]

H. F. Arle[2/]

Saltcedar, Tamarix pentandra, thrives in the arid and semiarid regions of western United States. Saltcedar and other vegetation, associated with areas in which the water table is at a shallow depth, have been given the name "phreatophytes". These plants habitually grow where their roots can penetrate the water table or draw from the capillary fringe immediately above. State and Federal agencies are interested in controlling saltcedar because it is an extravagant user of groundwater.

Previous studies showed that single spray applications at relatively low rates (1.25 and 2.0 lb/A) of 2,4-dichlorophenoxyacetic acid (2,4-D) or mixtures of 2,4-D and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) on mature saltcedar or regrowth following mechanical clearance usually defoliated plants and resulted in a high percentage kill of top growth but seldom was the plant population reduced. It was also indicated that an amine formulation of 2,4-D was much less effective than ester forms of 2,4-D or mixtures of 2,4-D and 2,4,5-T at equivalent rates. The results of spray applications of 2,4,5-trichlorophenoxypropionic acid (silvex) on unreplicated plots indicated this chemical to be more effective than 2,4-D or 2,4,5-T.

A current experiment is being conducted to further evaluate silvex and compare it with 2,4-D and 2,4,5-T. Following mechanical clearing and burning, applications of chemicals were made with a 21-foot boom mounted on a Dodge Power Wagon. Treatments were replicated three times on 1/3-acre plots.

The first series of applications was made during October 1956 on 6-month-old regrowth which had attained an average height of four feet. Applications were repeated each following May and October on plots that had plant survival. The following tabulation shows the percentage of plants killed following repeated treatments with chemicals which were applied each time at the rate of four pounds per acre.

Material	First Application	Second Application	Fourth Application
Silvex	30	93	100
2,4-D ≠ 2,4,5-T	23	76	95
2,4,5-T	30	88	88
2,4-D (ester)	26	82	90
2,4-D (amine)	14	62	79

1/ Investigations conducted cooperatively by the Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, and the Bureau of Reclamation, U. S. Department of the Interior.

2/ Plant Physiologist, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, Tempe, Arizona.

None of the materials caused a high percentage of eradication following the initial treatment. However, repeated treatments resulted in a high degree of plant kill. Silvex was more effective than other chemicals included in this experiment and as expected the amine salt of 2,4-D again was least effective. During May 1957, when regrowth had an average height of eight feet, another series of plots was sprayed. In this experiment the herbicidal activity of silvex was compared to the 2,4-D - 2,4,5-T formulation. Each chemical was applied at rates of 3,4, and 5 pounds acid equivalent per acre. The following tabulation indicates percentage of plants killed after each application.

Material and Rate/Acre (lb.)	First Application	Second Application	Third Application
2,4-D - 2,4,5-T			
3	46	70	93
4	50	69	95
5	65	85	93
Silvex			
3	62	67	99
4	70	89	100
5	82	84	99

Again silvex proved more effective. This is especially evident when examining the results of the initial application. At each rate of application silvex treatments gave a higher percentage of root kill. As the rates of application increased in the initial treatment better kills were obtained. This trend became less obvious, however, after the second and third applications, at which time there was no advantage for the higher rates of application.

These data indicate that repeated treatments are required for effective control of saltcedar. Since the lowest rate of application in the experiment gave excellent control when repeated three times, these results suggest the need for evaluating effectiveness of lower rates on a repeated treatment basis.

Chemicals in a Diesel oil carrier were applied to dormant saltcedar during February 1957 and the plots repeated in February 1958. All herbicides were relatively ineffective in controlling saltcedar when applied as dormant sprays. Silvex was the most effective herbicide; however, it gave only 34 percent control of dormant saltcedar. The following tabulation contains the percentage kill of saltcedar obtained with various chemicals applied during plant dormancy. Each application was at the rate of four pounds per acre.

Treatment	One Application	Two Applications
Silvex (PGBE ester)	17	34
2,4-D - 2,4,5-T (pentyl ester)	16	12
2,4-D - 2,4,5-T (PGBE ester)	5	30
2,4,5-T (PGBE ester)	6	2
2,3,5,6 - TBA	0	5

THE ARIZONA WATERSHED PROGRAM

Joseph F. Arnold[1/]

The Arizona Watershed Program is possibly the most recent of man's numerous and varied attempts to conserve and use water with ever increasing efficiency. In support of many other water management practices, the Program is aimed at recovering a greater percentage of precipitation falling on the State's watersheds. Towards this objective, large scale treatments being tested are aimed at reducing evapo-transpirational losses. Experimental treatments are essentially aimed at converting worthless vegetation types using large quantities of water to more valuable types using smaller quantities of water.

While aimed at increasing water yields, the Arizona Watershed Program is being directed to serve multiple-use objectives by also increasing production of high quality timber, increasing forage and browse for game and livestock, reducing erosion, reducing destructive wildfires and improving conditions for fishing and other forms of recreation.

Guided by recommendations of nationally recognized scientists invited to examine Arizona watersheds in 1956, the program has taken shape in a comparatively short time, through the energetic cooperation of many federal, State and private agencies. Following are some of the treatment practices being tested.

Patch Cutting of High Mountain Mixed Conifer Forests

Clear cutting in patches appears to be the most promising method of harvesting wood products from mixed conifer types, the spruce-fir-aspen-pine forests of high elevations. Clear cutting in patches not only produces wood products from a forest type so far unused in Arizona, but also provides openings for snow and rain to reach the ground and recharge springs and streams. Even though mixed conifer forests embrace but a small area of the State, patch cutting shows promise of providing important increases in water yields. Experimental watersheds on the Apache National Forest will, in the near future, tell us how much water yields can be increased by patch cutting.

When clear cut patches are reseeded, they will provide an additional benefit, namely, more forage and browse for livestock and game.

Thinning of Ponderosa Pine Forests

Open stands of virgin ponderosa pine are the best source of Arizona's high-value commercial saw-log timber. But continued production of high quality timber requires the thinning and pruning of thousands of cut-over acres now choked with dense stands of young trees making little growth.

Aimed at increasing the growth and quality of timber, increasing the production of forage and browse, improving the forests for recreation, and producing more water; the major management objective of the Arizona Watershed

1/ Director, State Land Department, State of Arizona, Phoenix, Arizona.

Program is to thin and prune these overstocked stands of pine. A few thousand acres of pine thickets have been thinned on the Coconino National Forest's Wet Beaver Creek pilot watershed project and on the Fort Apache Indian Reservation.

To protect their pine forests against devastating wildfires that usually occur in summer, foresters on the Fort Apache Indian Reservation apply prescribed burning during late fall and early winter to reduce excess forest debris and inflammable fuels.

Effects of these and other forest practices on water yields will be determined in the near future on experimental watersheds now undergoing calibration.

Juniper Removal

Of fourteen and a half million acres of piñon-juniper woodlands in the State, close to a million acres have been cleared by cabling, bull-dozing, hand chopping and burning. Large juniper removal projects, encompassing several thousand acres, occur on several National Forests, Indian reservations and Bureau of Land Management lands.

Although juniper control primarily increases forage and browse for livestock and game, it also reduces erosion. Possibilities that removal of juniper will increase water yields as forage plants replace trees is being closely watched and studied by the U. S. Forest Service, and the U. S. Geological Survey working in cooperation with the Bureau of Indian Affairs.

Conversion of Chaparral Brush

Conversion of dense chaparral brush areas to a more palatable forage cover not only increases grazing values and reduces erosion, but also shows promise of increasing water yields for the Southwest's farms, industries and growing populations.

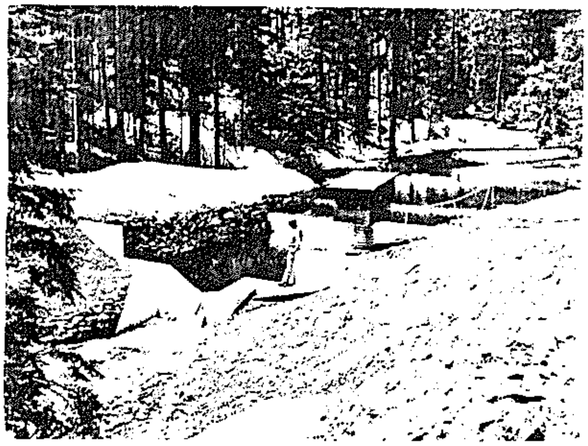
Conversion of brush to grass is another important phase of the Arizona Watershed Program. Using controlled burning, root plowing and chemicals to kill brush species, experimental tests are being made cooperatively by the U.S. Forest Service, Agricultural Research Service, Bureau of Indian Affairs, University of Arizona and the State Game and Fish Department.

Experimental watersheds on the Tonto and Prescott National Forests, now undergoing calibration, will indicate in the near future to what extent brush control can be employed to increase water yields.

Streambank Vegetation

The most extravagant wasters of water are trees lining creeks and dry washes from the top of the watersheds to the downstream dams.

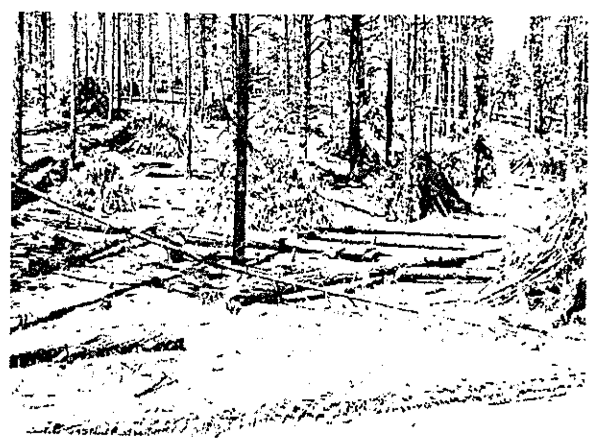
Many agencies are engaged in studying the use of water by salt cedar and possible methods of controlling this species. Another major experiment aimed at determining the wasteful use of water by cottonwood trees and possible methods of control is being conducted by the U. S. Geological Survey in cooperation with the State and the Salt River Valley Water Users Association on



Dense mixed conifer forest and streamflow gaging station. Burro Creek, Apache National Forest.

Patch logging. Sierra Ancha Experimental Forest, Rocky Mountain Forest and Range Experiment Station.

A thicket of ponderosa pine saplings.

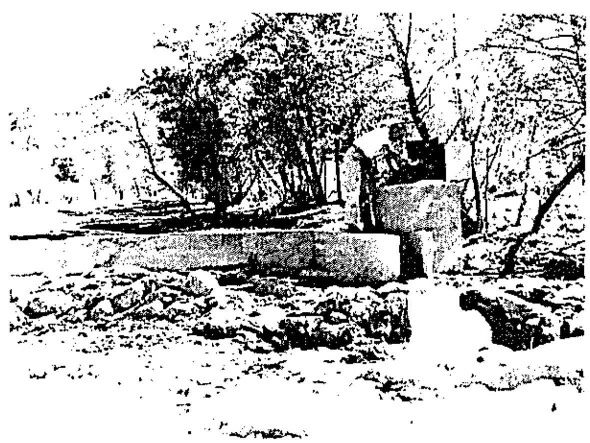


A thinned stand of ponderosa pine. Beaver Creek, Coconino National Forest.

In dense stands, juniper and pinyon crowd out grass and expose the soil to erosion.

Juniper control followed by burning and reseeding increases forage production and reduces erosion. Cedar Mesa, Fort Apache Indian Reservation.

A typical chaparral watershed undergoing streamflow calibration before conversion to a cover of grasses and weeds. Prescott National Forest.



Measuring wasteful use of water by cottonwoods. Cottonwood Wash, U. S. Geological Survey.

Cottonwood Wash, southeast of Kingman. Treatment of stream channel vegetation will be of particular importance if increases in water yields from the higher watershed zones are to reach the dams located at lower elevations.

The Arizona Watershed Program is a cooperative program dependent upon the efforts and talents of many individuals and agencies. In this Program, the Arizona Water Resources Committee, a group of private citizens representing all economic segments of the State, provides the support agencies need in carrying out the watershed tests. The Watershed Management Division of the State Land Department provides the necessary liaison between the various governmental agencies and the Water Resources Committee. But the gratifying rate of progress is largely the result of many individuals in the various agencies working together to achieve the common objective of increasing water yields from the State's watersheds.

WATERSHED MANAGEMENT TO INCREASE WATER YIELD

C. L. Forsling[1]

A potential opportunity exists for increasing the water supply in the Western United States by the management of the upland watersheds to reduce consumptive use by the native vegetation and thereby to improve the yield for downstream delivery. From the Rocky Mountains westward to the Pacific coast, streamflow is derived chiefly from the mountain forest, brush and grasslands and alpine (above timberline) areas. These producing areas occur generally above the pinon-juniper woodland zone or corresponding plant types in parts of California and Arizona. For the most part these are areas where the average annual precipitation is over 16 to 18 inches and the greater part of it occurs as winter snow or as rain (Ariz-Calif.) during a relatively short winter season.

It is common knowledge that only a relatively small portion of the water that falls upon the land as rain or snow is ever discharged from the watershed in the form of streamflow. In our western country most of the precipitation returns to the atmosphere through evaporation or transpiration (release of water by vegetation) near where it falls. Since the two are difficult to separate they are commonly referred to as evapotranspiration. In New Mexico, for example, the average annual precipitation is a little less than 14 inches. It varies from about 8" in some semidesert areas to near 40" in a few places in the high Sangre de Cristo mountains. The average statewide streamflow runoff is about 0.47 inch or 3 1/3 percent of the precipitation. This runoff is estimated to vary from as little as 1/10 inch in the semidesert to as much as 20 to 30 inches in parts of the highest mountains. Other parts of the West have corresponding, although in some cases somewhat more extreme variations.

The opportunity for increasing water yield consists of reducing the evapotranspiration in the more humid parts of the watersheds by manipulation of the vegetation. An experiment laid out in 1909 on the headwaters of the Rio Grande in Colorado was the first to indicate the possibilities of increasing water yield by changing the nature of forest cover. Since then research projects in a number of western states including Arizona, California, Utah, and Colorado have further indicated that there is considerable promise of increasing water yield by modifying the plant cover - more especially trees and shrubs.

The chances for increasing water yield, however, vary widely, depending upon local conditions. Generally, the precipitation has to exceed about 18 inches. There must be a concentration of a large part of it during the non-growing season, either as an accumulated snow fall or as winter rain. As a rule, the greater this seasonal precipitation, the greater is the proportionate amount, as well as the total amount, of the precipitation that emerges as streamflow. In most localities, except in the very high-rainfall belt in the Pacific Northwest, most of the precipitation that falls during the growing season is dispersed by evapotranspiration.

1/ Former chief of research, U. S. Forest Service, former director, U.S. Grazing Service (now the Bureau of Land Management) and a noted consultant on western watershed problems.

Among the other factors that affect the percentage and total amount of yield, under natural undisturbed conditions, are the geology and topography of the watershed, the character and depth of the soil, and the amount and kind of plant cover. For example, a watershed with deep soils that have a high soil moisture retention capacity and a good cover of deep rooted plants are likely to yield a smaller percentage of the precipitation as runoff than a similar watershed with shallow soils. The soil-moisture reservoir within the root zone of the vegetation which has been exhausted during the past growing season must be recharged to capacity during the next snow-melt or winter rainy season. This recharge process may require 2 to 3 inches of water to recharge each foot of soil in the root zone in order that percolation to the water table may take place. This recharge quantity is exhausted again by the vegetation in the following growing season so that it is a loss so far as water yield is concerned. Some species like many of the grasses, concentrate their roots in the upper foot or two of soil. Other plants like many of the trees and shrubs may send their roots to a depth of 8 feet or even much more if the soil is deep. There will be considerably less transpiration loss if the deeper rooted vegetation is replaced by shallow rooted plants. There should also be less transpiration, for a time at least, where the deep rooted plants are thinned as in the case of timber stand improvement. However, there is little to be gained by changing from tree or shrub cover to grass, if the soil is less than 3 to 4 feet in depth. In that case most any kind of vegetation will use up the soil moisture in the shallow soil mantle.

Some plant species, more especially the evergreen trees and shrubs, also cause a greater net loss of snowfall or winter rain due to interception than deciduous species and grasses. Dense stands of conifer trees, especially, intercept a considerable quantity of snow or rain and a large portion of this moisture is returned directly to the atmosphere by evaporation. Consequently, water supply may be gained if this interception is reduced by thinning or by clear cutting strips or blocks of timber stands, or if there is conversion of tree or brush cover to grass.

It is to be kept constantly in mind that any treatment to increase yield must not be at the expense of reducing infiltration of water into the soil. Except on barren rock exposures or in rare extreme storms, the upper watersheds in natural condition yield but little surface runoff. The natural vegetation and soil conditions are such as to promote infiltration of water which later emerges as streamflow. But if the plant cover has been seriously reduced the infiltration capacity is reduced to an extent that surface runoff and excessive erosion usually take place. Any treatment of the vegetation, therefore must be such as to leave adequate plant material to promote high infiltration and prevent erosion which quickly creates serious damages:

The lower plant zones, and by this is meant the pinon-juniper, and mixed grass and desert shrub and grass areas, offer no sound opportunity for increasing water yield. These generally are the zones with less than 18" of precipitation. The high evaporation rate and transpiration draft coupled with low precipitation and long growing season result in such complete dissipation of the precipitation that there is very little if any contribution to ground water storage except through arroyo bottoms during flooding stages. The water yield in these lower watershed areas consist almost entirely of flash-flood runoff over the surface of the land from the occasional high intensity summer rains. The yield at best is so little, from 1/10 to 1/2 inch, that the chance for increasing it is very small. Except in the pinon-juniper zone any increase may be obtained chiefly by skinning off the vegetation as by over grazing, and the gain in yield will be small at best. The resulting increase in erosion will cause a far greater damage than the small gain from the increased muddy flow that would result. In the pinon-juniper zone the small gain in yield, if any, will scarcely justify the cost; treatment of such areas should be based on some other purpose.

There are many problems still to be resolved in attaining a sound watershed management program for increased water yield from the susceptible acreage in the western states. The necessary hydrologic research must be carried out for all of the major climatic, geologic, topographic and botanic conditions in the western upper watersheds. These studies require 5 to 10 years of measurement of precipitation and runoff from the selected experimental watersheds to calibrate them, before experimental treatment can start. Then there must also be practical tests on operating size watersheds to develop all phases of application. These tests, also, should be preceded by 5 to 10 years of streamflow and weather measurements to determine with an acceptable degree of accuracy the effects of the treatment.

There is also the evaluation phase. Economics will play a large part in carrying on programs. So there must be determination of the costs and returns from treatment practices. This also enters into the matter of where and to what extent the water can best be used. Timber is a needed commodity also. Decision must be made from time to time whether and to what extent timber growing or conflicting uses of watersheds should be curtailed for the advantage of water production. To be considered especially is recreational use of the watershed areas. These relative values are dynamic so there must be re-evaluation from time to time to determine what is prudent action in a changing world.

The manipulation of watershed cover for increasing water yield is new but does have promise. The important point is that in view of the preliminary time required to conduct the necessary research and practical tests, the research and testing programs should be started immediately to avoid "crash" programs when the need for water becomes highly urgent. At best, programs of watershed treatment are not going to sweep the mountains like wild fire. What may be termed as a form of culture for the practice must be developed gradually, but once started programs will extend further as the many conditions are found to warrant. We need to start today to be ready tomorrow..

But some additional points are important. Increasing the yield of water from the upper watersheds will not be worthwhile if the water thus temporarily gained is lost by evaporation and transpiration between the point where it is produced and the point of divergence downstream. Reference is made here to the non-beneficial use or waste caused by riparian vegetation, by phreatophytes, by stream channel losses, and by surface evaporation from rivers and reservoirs. This loss is heavy from those streams in the Southwest which span long distances through the deserts and semideserts. Among these streams are the main Colorado and many of its tributaries, the Rio Grande, the Pecos, the Canadian, and the Arkansas.

For example, in the 160 mile stretch of the Middle Rio Grande Valley between Otowi and San Marcial in New Mexico, there is an average annual stream depletion from all causes of approximately 560,000 acre-feet. Of this, 160,000 acre-feet or less than 1/3rd is put to beneficial consumptive use in crop production, but 400,000 acre-feet are lost by non-beneficial use. This water is lost chiefly by (1) evaporation from river bed and sand bars, (2) phreatophyte use, (3) canal conveyance loss and, (4) poor irrigation practices. It should be possible to salvage a large part of this current loss.

Others at this meeting have discussed phreatophyte control and reduction of evaporation losses. I wish to mention, briefly, a watershed angle of these problems; namely, management or protection of the lower watersheds. These areas pinon-juniper woodland, the mixed grassland and the semidesert shrub and grassland occupy over three-fourths of the area which drains into our Southwest streams. The mountain watersheds produce the water but these lower--lands produce the sediment that chokes the stream beds and clogs the storage reservoirs. Most serious, however, is the fact that these sediment deposits become the seed beds for phreatophytes like salt cedar.

Waste by phreatophytes in New Mexico is variously estimated to be 500,000 to 850,000 acre-feet each year. I would guess that the amount is greater than the larger of these figures and is even greater in Arizona, because phreatophytes are spreading far and wide.

The solution to this problem has several facets including phreatophyte control, channelization of stream valleys to hasten water delivery and lower the water table, and sediment storage reservoirs. The ultimate solution, however, is control of erosion on the watersheds to keep the soil in place. One of the troubles in this connection is that the very poorest lands, which produce most of the sediment, are so poor, as some one has said, that "they are not worth fixing." This is probably true so far as a private owner is concerned, but the public cannot afford to let these lands continue to produce sediment.

The solution of this erosion problem, I believe, lies in the following (without order of priority):

1) Greatly step up the soil and moisture conservation program on the public domain and other public lands, and also on state and Indian lands.

2) Classify all lower watershed lands to determine the "bad spots" or critical areas. Many of these sore spots are so far gone they have little or no forage value and should not be grazed at all. These spots should be fenced out of all use except for wildlife and for use of the minerals. Lands of this character in private ownership should be acquired by exchange or trade, and purchase using the money derived through the sale of Federal lands not needed by the Federal government for other purposes.

3) Step up and sharpen up the program under P.L. 566. In my state, at least, this program is moving at a snail's pace and on the basis of the "early bird getting the worm" rather than on a basis of the more urgent needs first. The classification of lands to determine the more critical areas mentioned above could be used to improve selection of projects on the basis of the most urgent need. Also, the cost-benefit aspects of the P.L. 566 program should be revised and put on a much broader basis than at present. Also there should

be land-conservation-practice requirement for all project lands rather than only half of them as at present. There should also be a more strict compliance requirement.

WATER AND PEOPLE IN NEW MEXICO

H. R. Stucky[1]

Water has been a major factor in the area now known as New Mexico as evidenced by the earliest historical records and by the pattern of population settlements. The first settlements were along the major streams and their headwaters. The Rio Grande, Pecos, and San Juan rivers are the major areas where pueblo ruins and other remnants of early settlements are found. Archeological studies indicate that the earliest pueblos in New Mexico were in the Chaco Canyon in the northwestern part of the state. Stone diversion dams have been found there which evidence a considerable knowledge of irrigation. Tree ring studies at the Pueblo Bonito on the Chaco River have established its construction date at about 919 AD, nearly six hundred years before Columbus discovered America.

From this early period, water has been sought for and fought for. It is said that there have been more lives lost in this area over water than over women. However, no statistical evidence is available to support this claim. As long as the state's population did not grow rapidly and the economy was primarily livestock, with limited irrigation for food and forage production, the water problem grew gradually and did not attract particular attention except as between individuals and very localized communities.

With the advent of large scale irrigation projects along the rivers, the discovery and development of ground water supplies, the intensification of our industrial and agricultural production, and the rapid growth of our population, water has become more important to New Mexico. Just as the available water supply has been a major factor in the molding of our economy to date, it will play a more important role in the development in years immediately ahead and in the more distant future.

In order to point up this inter-relationship between water and people, I should like to cover four points in this paper: (1) average annual supply of water, (2) the average annual disappearance of water, (3) the population from 1850 to 1960 and projections to 2000, (4) the projected needs for water and some of the water problems which are of growing importance due to increasing population growth and increasing demands for water.

Figure 1 shows the drainage basins of New Mexico and the volume of flow in each. The arrows at the edge of this map where the rivers enter and leave the state indicate the volumes of water entering and leaving on each river.

Figure 2 shows the 1960 census population for each county with the percentage change since 1950. The five counties with the large population centers of Albuquerque and Las Cruces on the Rio Grande, Farmington on the San Juan, and Roswell, Carlsbad and Artesia on the Pecos account for about

1/ Professor and Head, Department of Agricultural Economics and Agricultural Business, New Mexico State University. Also serves as chairman of the Annual New Mexico Water Conference.

one-half the population of New Mexico. These same five counties according to population estimates may be the residence of nearly 60 percent of the states population over 2,000,000 by 1980, or a projected increase of about 750,000 people.

A comparison of Figure 1 with Figure 2 shows that there are large centers of populations dependent on ground water only, and where there is little possibility for that supply being replenished or supplemented by stream flow. The more important of these centers are Hobbs, Portales, Clovis and Deming.

Average Annual Supply of Water

The annual supply of water of about 92,000,000 acre feet comes from precipitation and stream inflow. Ground water is included here but should be considered differently than the annual supply.

Precipitation - An average annual precipitation of 13.88 inches falls on 77,866,240 acres of land, thus an annual average of approximately 90,000,000 acre feet of water falls on the state.

Stream inflow - There is an average annual inflow from streams entering the state, most of which enter through the San Juan and the Rio Grande of about 2,000,000 acre feet.

Ground water - Ground water supplies most of the cities and towns of the state and water for full irrigation for 443,020 acres and as a supplement to surface water for an additional 144,700 acres 2/. Much of this water enters the ground stream flow and from precipitation which perculates from annual precipitation. The balance comes from stored ground water which has been stored for centuries in the ground. No definite figures are available on the amounts from each, so no total will be added to the annual supply.

The average supply for the state then is 90,000,000 acre feet precipitation and 2,000,000 acre feet from stream flow or a total of about 92,000,000 acre feet.

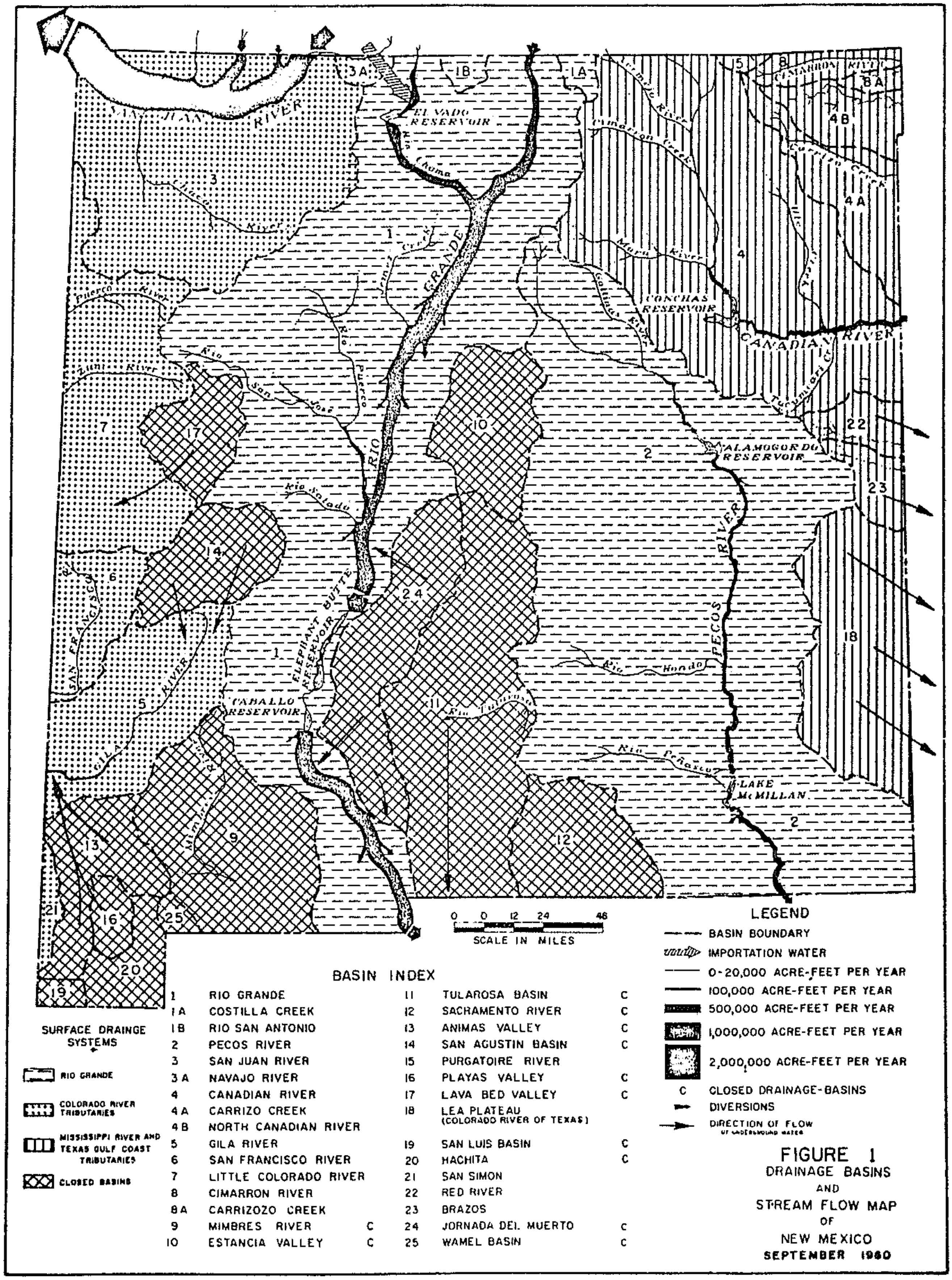
Uses of Water

The following accounts for the major uses of water in New Mexico.

Municipal, Industrial and Domestic Use - It is estimated that the 220,000 people in Bernallio County in 1960 required the diversion of 53,000 acre feet of water. 3/ This is at the rate of 214 gallons of water per capita per day. Other less industrialized communities and the farms would use no more than 150 gallons per day. On the average of 160 gallons per day the

2/ State Engineers Office, New Mexico Statement to the U. S. Senate Select Committee on National Resources - September 1959.

3/ Ibid -- page 24.



Source: State Engineer's Office, Santa Fe, New Mexico

Figure 1. Drainage Basins and Stream Flow Map of New Mexico

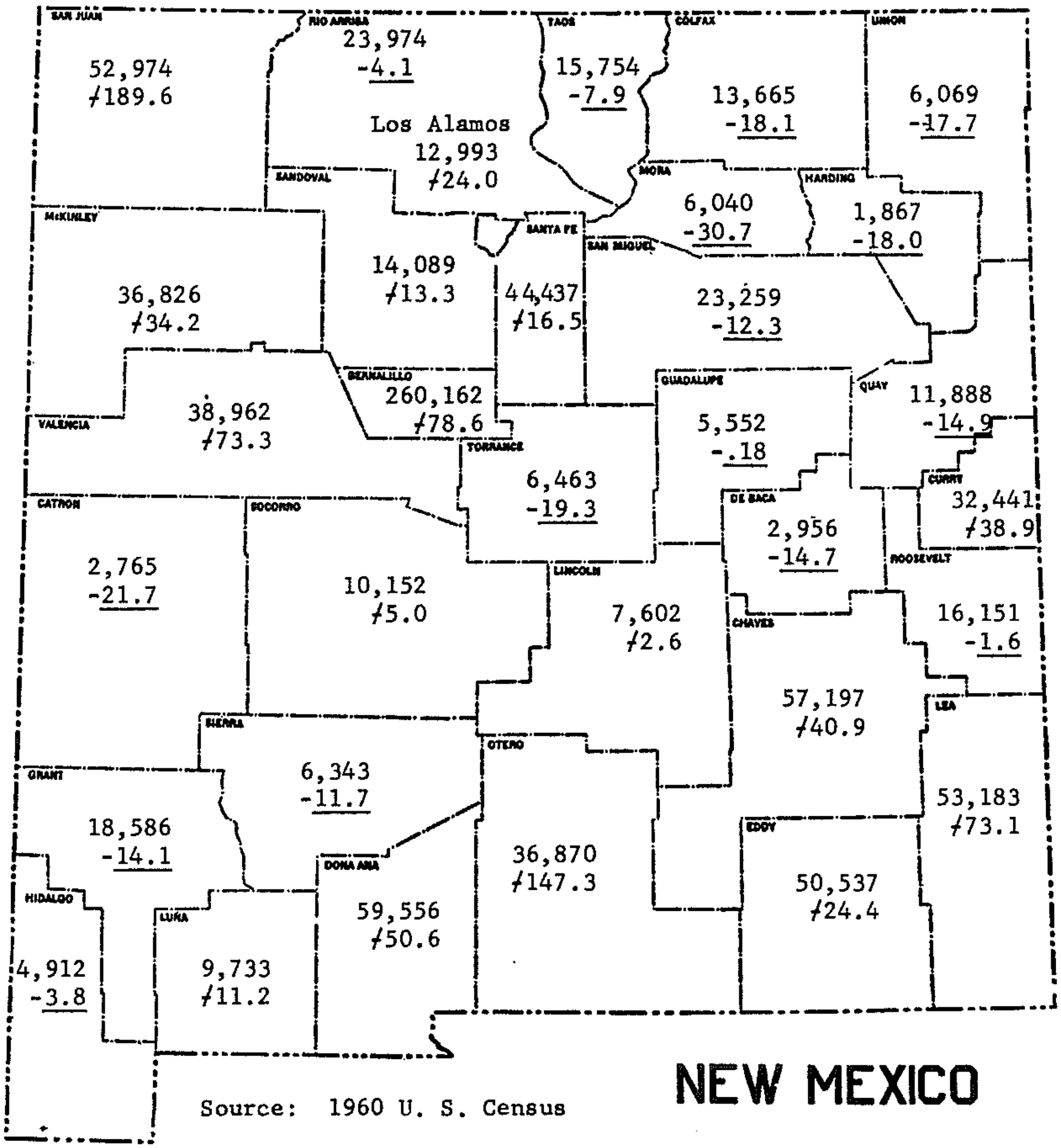


Figure 2. Population by Counties, 1960 Census, With Percentage Change From 1950.

1960 population of 951,000 people would require a diversion of about 170,000 acre feet for all uses during the year.

Irrigation - An estimated 873,000 acres of land are irrigated in New Mexico. Assuming a diversion of 3 acre feet per acre, there would be 2,619,000 acre feet required.

Other uses - Grass lands, forest lands, ground water basin perculation and the necessary transpiration from normal growths of beneficial grasses, trees, and crops may make use of ½ of the balance 87,000,000 acre feet of the available water or about 43,000,000 acre feet.

Losses - Losses through evaporation from land and water surfaces and those uses by non-beneficial plants account for 43,000,000 acre feet or more. An estimated 70% of the precipitation falling on the state during the summer months may be lost. A report based on 1955 census data, gives an estimated 942,000 acre feet of water lost from 155,000 square miles of surface water (lakes, reservoirs and streams) in New Mexico.

Stream outflow - An annual average of 2,200,000 acre feet of water flow from the state each year. The San Juan, Rio Grande, Pecos, Canadian and Gila rivers account for the majority of this flow.

These disappearances may be summarized as follows:

Uses or Disappearances		Acre feet
Municipal, Industrial, and Residential diversions		170,000
Irrigation on 860,000 acres of land		2,630,000
Other Uses to produce, trees and grass and to supply ground water		43,000,000
Losses - evaporation, transpiration, and use by non-economic plants		44,000,000
Stream Outflow from state		2,200,000
	State Total	92,000,000

Opportunities To Adjust Our Available Water Supplies

Even though water is relatively short in New Mexico, there are many opportunities for adjusting the available water to the needs of the economy and the people of the state.

The first opportunity is to develop the water which is allocated to the state by the river compacts. There are 840,000 acre feet of water allocated to New Mexico by the Colorado River Compact. About 92,000 acre feet are now in use. The balance of 748,000 is now in the process of development by the construction of the Navajo Dam and the proposed Navajo and Hammond irrigation projects, the San Juan - Chama diversion and other projects. The San Juan-Chama diversion proposes to divert from 110,000 to possibly 220,000 acre feet into the Rio Grande Watershed for municipal, industrial recreational and agricultural uses.

Also about 200,000 acre feet are allocated to New Mexico under the Canadian River Compact. The State Legislature has authorized the use of $5,000,000 for the construction of the Canadian River Dam at Logan. This would be the first step in making this water available to our industries.

The <u>second opportunity</u> is to continue work toward conserving the quantity and quality of the water we now have available. The control of seepage and evaporation losses offer large opportunities. For example, over 150,000 acre feet of water per year on the average evaporates from the surface of Elephant Butte Reservoir and over 900,000 acre feet from all the water surfaces in the state. Losses to water-loving plants such as Salt Cedar have increased rapidly in the past 30 years. It is variously estimated that 500,000 to 850,000 acre feet per year are lost to these plants. Work of channelizing the Rio Grande thru the silt delta in the upper reaches of the Elephant Butte Reservoir and the river channel below San Marcelle has made an estimated savings of 165,000 acre feet of water and still more can be saved. This saves water by keeping it moving through the silt delta rather than having it spread out and evaporate and it also keeps water away from thousands of acres of Salt Cedar which use up to 6 acre feet per acre of those plants.

The <u>third opportunity</u> is the conversion of saline ground water to fresh water by processing it through a saline water conversion plant, such as the one approved for construction at Roswell. This is one of the 5 experimental plants authorized by Congress. No estimates can be made on the volume, but it is assumed that the major use of such water will be for municipal and industrial purposes because of the relatively high cost per 1000 gallons converted.

A <u>fourth opportunity</u> is to conserve our present water in all its uses. Water used for irrigation may be used more efficiently than now by more careful uses on the land, by use of lined ditches, and accurately applied amounts of water. Use on the lowest value crops may be eliminated. Losses of water through use in evaporative coolers in homes and in offices may be eliminated. Re-use of water in industrial plants can be increased. Only low water using industries should be established in New Mexico. Industrial and other contaminations of water must be reduced.

The <u>final opportunity</u>, as municipal, industrial and recreational needs increase, it is always possible for these higher value uses to secure additional water through the normal functioning of our economic system. When a housing development or an industry needs land it goes out into the normal land market and purchases the desired amount at the normal existing price. Water for such developments can be purchased in the same manner as land and there are relatively large quantities of water available.

A recent New Mexico study developed the following estimated values for water. These values were based on what an acre foot of water would yield in value added when put to various uses.

	Value per acre foot
Municipal & industrial	$3,304
Recreational	198
Agricultural	18

The higher values will, of course, apply only to limited quantities. For example, Albuquerque and vicinity now diverts 53,000 acre feet of water per year. How much would the people there be willing to pay now for an additional 53,000 acre feet? Not very much, until there is an immediate use but, as the demand for more water develops the city will make the necessary expenditures to supply the needs and the people can and will pay the necessary rate to supply their needs.

As indicated in the population tables below an increase of over 1.3 million in our population from 951,000 in 1960 to 2,256,000 will require about 340,000 additional acre feet of water. The estimated use for irrigation assuming 3 acre feet per acre on 850,000 acres of irrigated land would be 2,550,000 acre feet. Thus the water required for an addition of 1.3 million people would require a transfer of about 14 percent of that presently used by agriculture. However, a transfer of this amount is not required since we have the 200,000 acre feet of water in the Canadian River and the 600,000 acre feet in the San Juan yet to be put to use. If only ½ of this 800,000 were used for municipal and industrial uses, the 1,300,000 people could be added to our present population without any change in our present water uses. Of course, the problem of having the water available where the people are will cause certain shifts in the present uses in most areas of the state, even with these amounts of additional water available.

The following shows the estimated population, use per day increases, and the approximate acre feet of water required for diversion to meet these needs:

Year	New Mexico population	Estimated water diversion per person per day (gallons)	Estimated diversion required (acre feet)
1950	681,187	147	112,000
1960	951,023 *	160	170,000
1970	1,583,000	185	328,000
1980	2,256,000	200	505,000

* U. S. Census

The New Mexico Problem

The problem in New Mexico is for all persons interested in water development, conservation, and use to understand the above conditions of supply and disappearance. It is necessary for all to understnad that much of the water now in use is allocated to that use by the laws of prior appropriation and beneficial use by the State Constitution and by many court decisions.

Considering these three points it is then necessary to determine the answers to each of these three questions. One, how can the water supply be increased, or two, how can the present use be made more efficient, or three, how can the water needed for a particular use be transferred from its present use?

All three of these questions will receive much more consideration as the demand for water increases with the expanding population. The volume of water for municipal and industrial use is so great that needed water for these purposes can attract funds to either develop water sources or purchase water from present uses, especially from agriculture. The volume of water needed for recreation is not large relative to that used in irrigated agriculture. Also the value of water for recreation is roughly 10 times the value for agriculture. This water can be secured by investments in new sources or by attracting it through our present economy by purcahse from agriculture by offering the necessary price to secure the needed water.

The mechanisms by which municipal and industrial developments secure the needed water is well developed. These groups have sources of funds and can purchase or develop the needed water. Recreation may have to arrange to have its demands for water expressed more directly by offers to develop or purchase its needs. This could be effectively implemented if the many thousands of recreational users of water were organized in such a way that each user would be paid something for his use privilege rather than depending entirely from public funds. Disneyland is an example of a recreational enterprise paid for entirely by use payments. Small payments for camping, boating, and picnicking would make large amounts of money available. Recreation probably should pay something for certain uses of water just as does irrigation, municipal and industrial uses.

The increasing population in New Mexico will cause each citizen of the state to be more concerned about the economical use of water in all its uses. This conference and the discussion here today is intended to stimulate thinking regarding the availability of water for each use.

WATER NEEDS OF TOMORROW

A. L. Miller1/

Someone has said "a <u>thirsty</u> person cares not for reason, listens not to justice, nor are his knees bent by any prayers." In other words, he recognizes that water is an absolute essential to life. It regulates where you live; what you do; and the growth of any community.

The problem of many areas of the world is not only food and how to get enough to eat, but water. For water is essential in the production of that food.

The importance of water in our everyday life cannot be overestimated. Our very activities in what we do are completely dependent on our ability to get a potable supply of water. The Office of Saline Water is in the business of trying to find a cheaper way of getting fresh water from the oceans and the brackish waters that underlie many areas of the United States. The oceans represent potentially inexhaustible supplies of good water. The success and well-being of every citizen, whether he be in the livestock business, a teacher, a preacher, a businessman, or plain citizen Joe, is fully dependent on an adequate supply of sweet water.

President Eisenhower in his Message to Congress in 1953 recognized that the Government had a real responsibility in managing the Nation's natural resources for the benefit of ourselves and future generations. A Special Committee in the Senate is studying what has gradually come to be recognized as our most vital natural resource, water. After long and exhaustive hearings in many States, they will soon make an important report to the Nation. The President's Water Commission made a report which points up the urgency of our water situation. Presidents Roosevelt and Truman recognized the importance and seriousness of the water problem. They, along with President Eisenhower, appointed committees to study and furnish information on our future water needs.

We must realize that all of the world's people live on less than one-quarter of the globe's surface. They are dependent for life entirely on the fresh water upon and beneath the inhabitable land. Man's epic struggle to survive on this planet could be written in terms of his constant concern and need for water.

Through the ages, natural supplies of water, fluctuating in an unpredictable manner, have governed the rise and fall of civilizations. Some of the most creative and cooperative ventures in the annals of human advancement were applied to the development of water resources. When these developments were successful the Nation prospered. When they failed, the Nation perished.

The lessons of history are clear and the predicted use of water in the United States is a matter that should deeply concern every citizen. Today, we are using nearly 300 billion gallons of fresh water daily. By 1980 we

1/ Director, Office of Saline Water, U. S. Department of Interior, Washington, D. C.

expect the demand to reach nearly 600 billion gallons of water a day. This immense increase is equal to the daily flow of 20 Colorado Rivers, exceeding by 85 billion gallons our total available daily supply. If we ponder for a moment the serious water shortages that periodically plague various areas of the Nation at today's rate of demand, what will be the situation in just twenty years when the demand will more than double?

Can you picture a city without ample water to operate its sanitary sewer system? Without enough water to fight a serious fire? Unable to supply the water demands of its industry?

Without water a city or a Nation will die. Without water man faces the same fate.

While it is difficult to glamorize a glass of water, it is impossible to get along without it. Nationally we have been blessed with such ample and readily available supplies of water that we have been able to turn a faucet any time, almost anywhere, and obtain good, pure, hot or cold water, at an average price of less than 10 cents a ton--delivered.

There are already many soft spots, however, in our water supply picture, especially in the more arid areas here in the Southwest where an adequate supply of water has been quite difficult to provide and, in turn considerably more expensive than the national average.

Our population is increasing at the rate of 8,000 a day, or at the rate of a city approximately the size of El Paso, Texas, every month. I think we can safely say our population is growing at a chain-reaction speed, and at the same time our industrial complex is expanding at an unprecedented rate placing new demands on our existing reserves of fresh water. Some of the industrial water requirements may surprise you. It takes as much as 240 thousand gallons of water to manufacture a ton of acetate; 660 thousand gallons are needed to produce a ton of synthetic rubber, and as much as 65,000 gallons to produce a ton of finished steel and a like amount to produce a ton of newsprint. To refine a gallon of gasoline from crude oil requires seven gallons of water for each gallon produced.

Agricultural interests are constantly pressing for more and more water. When we speak of the water required to maintain agricultural production, we really get into volume water requirements. Grains take over 650 thousand gallons per acre to produce a crop. An acre of alfalfa needs over a million gallons per acre per season.

WATER USE AND DISTRIBUTION

Flush a toilet	3 gallons
Tub bath	30 to 40 gallons
Shower bath	20 to 30 gallons
Wash dishes	10 gallons
Run a washing machine	20 to 30 gallons
Alfalfa requires about	35 inches of water
Sugar beets	30 inches
Cotton	25 inches
Potatoes	20 inches

To produce a single pound of beef for the dining room table requires an estimated 3,750 gallons of water.

Examined within the framework of these figures it is not difficult to see that the task of providing ample supplies of fresh water for the America of tomorrow may indeed be our No. 1 domestic problem.

You folks living in Texas, New Mexico, and the West, live in what is generally know as the arid part of the West. The West is in the business of growing meat. Irrigation has helped to diversify your crops. This fits in with the business of producing meat. Meat has made a tremendous contribution to the American diet. American people have always been big meat eaters. Meat was a planned diet for human beings from the very beginning of time.

I know, as a doctor, that the human body is and has been adapted to the consumption of the meat produced. I have said before that there is no food which nature has so largely and lavishly endowed with the necessary proteins, vitamins, minerals and fats, as it has meat. Meat is the masterpiece of nature's laboratory. It contains 22 amino acids; 10 of which are absolutely necessary to keep our bodies healthy. Yet meat is mostly water, and there must be water to produce the meat that the nation consumes.

The people of the world that are big meat eaters are generally large in stature and have great energy. The Hindus, Chinese, Japanese, and the inhabitants of Okinawa, who eat little meat are small in stature.

Why did I mention meat and its importance in the diet when I am talking about water? I did so because no meat, no vitamins, amino acids, or food crops could be produced without the proper amount of water.

We are quite sure that in the coming years many areas of our Nation and the world will have to rely on water from the sea for a substantial percentage of their supply. In the Office of Saline Water we are racing the clock, hopeing to be able to develop processes that will make this water available to cities and industries when they need it, and at an economically competitive price.

There is a false philosophy that the water in some parts of the world should be essentially free to the consumer, just like air. The philosophy is self-defeated because water projects cost taxpayer dollars.

It is estimated that capital expenditure for public water facilities was more than a half-billion dollars in 1959. Sewage disposal projects took another quarter of a billion dollars. The water treatment plants for just the chemicals alone required more than a billion dollars. It is estimated that more than 60% of all water today has to be treated and that about 80 per cent of the water is "hard" water. The annual treatment of water bills including chlorination may reach 3 billion dollars by 1980. About 75% of our American cities derive their water from wells.

In the Office of Saline Water, we carried on in 1960, 54 separate contracts involving saline water problems with Universities, technical institutions, or private industry. Private industry engaged in about half of these 54 projects and generally put in a part of the actual cost or supplied technical equipment and experienced personnel.

There is no limit to where scientific minds may go or what they may do if they are given the green light and the minimum amount of Government interference. They are making tremendous progress in the saline water field.

It is my humble opinion that the plants we build today will be "horse-and-buggy" type ten years from now.

We are now engaged with the Army Engineers in running a small pilot plant at Roswell, New Mexico, in an effort to determine how these particular well waters will react to a vapor compression process. The well waters are around 22,000 parts per million dissolved salts. We are also experimenting with some drop-wise condensation equipment supplied by the Struther Wells Company. This salt content is higher than we generally consider for brackish water.

The Office has received more than 600 ideas on how to desalt water. Some of these were good and quite feasible; some, of course, bordered on the crackpot ideas. The Office has a large group of scientific men and women that we may call upon to help evaluate the different processes.

I have always told my engineers when a new suggestion comes to the Office that they must never say it will not work. I want men and women around me who will say they will find a way to do the job. It is quite possible that some obscure approach may in the end be the method that will solve the difficult problem of making drinking water from the ocean. You and I know that many of the great inventors of the past were thought to be "crazy" because they advanced certain ideas that today are commonplace.

There are about 17,000 towns and cities in the United States that have a public water supply system. They serve about 115 million people. Can you imagine what might happen if the citizens in a large town would turn on the faucet and be without water? Indeed, that has happened. Some cities during the 10-year drought were buying water, paying as much as 50¢ a gallon. Recently I read an article where the breweries in Miami had closed down and were bottling water in order to sell it to the people at Key West who had their supply of fresh water interrupted by hurricane Donna. The violent storm wiped out over a mile of their 130-mile pipeline and caused at least six other serious breaks in the line. Key West was without water and faced the serious problem of possible bacterial invasion.

The 150,000 residents of Tijuana, Mexico, are depending on trucked-in-water to meet an emergency water shortage.

The British Crown Colony of Hong Kong can supply its teeming population with fresh water only two or three hours each day. The Virgin Islands have for years used barges to bring in part of their fresh water. They will soon have a distillation plant in operation.

These are examples, and I could cite many more, where they may soon solve their water problems by converting sea water to fresh.

The Office of Saline Water has been consulted by the Navy about the problem of supplying water to our base at Guantanamo Bay in Cuba. The renegade

Castro's next move may be to shut off the slender thread and vital life-line of water supply to the base. He can easily do this because the water used at the Guantanamo Base arises in the Cuban inland. This Office has made some suggestions to the Navy on using some distillation units now in old "Liberty Ships" to meet the emergency needs of the base. We have one company under contract, Struther Wells of Warren Pennsylvania, that has offered to build a 250,000 gallon per day freezing plant for $1.00 profit to supply the base. In my opinion, the emergency at Guantanamo Bay will be accentuated as soon as Castro decides to move in and attempt to push our troops off this vital point. Water could well be the determining factor, but, thank goodness, we now have several methods of getting fresh water from the ocean that can meet the needs of the base.

Cities are having a real problem on how to handle detergents. While it is possible to sterilize water and treat sewage water and make it potable again, the detergents from mother's washing machine and her dishwasher have caused the water to foam in city water supplies 20 miles away. There is going to be a real problem for the scientists and chemists to handle this new problem of detergents. I have seen the Potomac River in Washington boiling like soapsuds a few hours after washday was concluded. In modern treatment, plants are quite capable of cleaning sewage wastes out of water and making it perfectly safe to drink. People don't like to think they are drinking that kind of water, but some of them are doing just that now. There is a problem, however, of screening out the detergents. People like a head on their beer but not their drink of water.

The Office of Saline Water was established by Congress in 1952 with an entirely new concept in mind. To develop processes for an abundant supply of fresh water for human, industrial, and agricultural uses--<u>at low cost</u>.

As late as 1952 the cost of converting a thousand gallons of sea water to fresh ranged upward from $4 to $5, which is far too expensive for general use; but as the cost comes down more and more areas will find converted sea water to be the most reliable and economical source of supply.

In 1958, President Eisenhower approved legislation that set the stage for a new pioneering effort. The legislation directed the Secretary of the Interior to select from the most promising of the presently known processes five different methods for use in plants designed to demonstrate their reliability, engineering, operating, and economic potentials. These five processes and sites have been selected.

Their very selection gives a measure of the rapid progress that has been achieved during the eight short years the Office of Saline Water has been in existence. Three of these methods did not exist as a saline water conversion process in 1952, and the two that were known at that time have been vastly improved. The fruits of our labors are made available to the world through publications.

Recently I had the rewarding experience of participating in the ground-breaking ceremony for our first demonstration plant which is now under construction at Freeport, Texas. Using a process developed wholly under Office of Saline Water sponsorship, this plant will produce fresh water from the sea at the rate of 1 million gallons per day at an anticipated cost of about $1 per thousand gallons.

A process that could be classified as no more than a laboratory phenomena in 1952 will utilized in a 250,000 gallon per day plant at Webster, South Dakota, to demineralize the brackish well water of that City. Construction bids for this plant were opened on October 4. The successful bidder will be announced shortly.

On October 18th we opened bids for a second one million gallons per day plant to be located at San Diego, California. This plant is also expected to produce fresh water from the sea for about $1 per thousand gallons. As exciting as this prospect may be, we stand on the threshold of fresh water from the sea at a price considerably below that figure. As in many operations, savings can accrue from quantity production. Our studies indicate that when these processes are incorporated in plants of 25 to 50 million gallons per day, we can expect fresh water for less than 50 cents per thousand gallons.

In 1957, a year of moderate drought, over 1,000 cities and communities in the United States were forced to restrict the use of water. Some cities are close enough to sea or brackish water sources so they can get relief by installing proper equipment.

While I am not posing as a prophet, it is my firm belief that before 1980 there will be more than a thousand alert and progressive cities that will have averted a water crisis by using conversion units--units that are being developed today--to provide tomorrow's water.

This Nation has always had new frontiers to conquer. And each era has produced its own hardy band of pioneers to accomplish the task.

We must place greater emphasis on basic research for new scientific knowledge--the most challenging and exciting frontier we have ever tried to conquer. Our ability to compete in world markets in the coming decades will be determined by the research and development we are willing to support today in order to penetrate the ever-expanding frontiers of science.

The trails today's pioneers are blazing in the laboratory are vastly more important than any traveled by earlier pioneers. I am convinced that there is no limit to what science can accomplish when free men and women make up their minds to reach their goals. Chemical engineers are performing and will continue to perform a vital role in the development of low-cost conversion processes that will assure ample supplies of fresh water to meet needs of the future.

The development of our West has largely been due to the fact that we have made use of our western resources, including the conservation of water. The development of our country has come about because of wise political, economical and spiritual leadership. It makes little difference which party is in power as long as they carry out the ingredients of that prescription. We may doubt and question what wise political, economical and spiritual leadership may be, but we can never doubt the wisdom of developing our water resources.

Our forefathers when they went into a new country first looked to the water supply. They dug their own wells by hand. It was necessary to have water if they were to live on the new frontiers. They did this with a minimum amount of government interference. They carved out their own destiny and determined their own future by planning, courage and action. They had to have some iron in their blood and granite in their backbone. They conquered the inhospitable prairies; they carved out their homes and towns; built their churches and their schools and raised their families, which are the communities of today. They had no guaranteed prices for their crops; no social security; no unemployment compensation insurance. They fought hard winters and long droughts but with confidence in the land and through their own strength and determination, they carved an empire that became America. This heritage was handed down to us and made a strong America, whether you were raised in Kimball, Nebraska, my hometown, or in Roswell, Pecos or Santa Fe, New Mexico.

In all of this development, water has been the one thing that is needed. It is just as essential to the lone sheepherder on the range as to the teeming millions in the city.

I think the efforts of the Office of Saline Water are well expressed in the words of Daniel Webster that are carved on stone over the Speaker's chair in the House of Representatives: "Let us develop the resources of our land, call forth its power and build its institutions, promote all its great interests and see whether we also in our day and generation may not perform something worthy to be remembered."

STATE WATER PROGRAM

Steve Reynolds[1/]

It is often said that water is the limiting factor in the economic development of our State. The statement is a truism, but it is too often implied that we are already at, or very near, the limit of economic development because of the scarcity of water in New Mexico. Such an implication is certainly not justified. Substantial quantities of water which we are entitled to have not yet been developed for beneficial use; also, our economic development can be greatly extended by the orderly redistribution of water among beneficial uses under our law, by the salvage of water now lost to nonbeneficial evaporation and transpiration, and by improving the efficiency of agricultural water use.

Undeveloped Water

The average annual recorded outflow from the State in the San Juan River is about 2,200,000 acre-feet. Under the Colorado River compacts the State of New Mexico may deplete the flow of the Upper Colorado River system by about 840,000 acre-feet per year. Present depletions of the San Juan River in New Mexico amount to only about 92,000 acre-feet per annum. Additional uses now authorized will bring our depletion to about 275,000 acre-feet per year.

Plans for further development of our share of the waters of the San Juan River under the Colorado River Storage Project are well advanced. These plans have been developed by the Bureau of Reclamation and Bureau of Indian Affairs in close cooperation with the State. The Colorado River Storage Project was authorized by Public Law 485 in April of 1956. The act provides for four large reservoirs on the Upper Colorado River system which will insure deliveries to the lower Colorado River Basin in accordance with the 1922 compact, provide a regulated supply for uses in the upper basin, and produce electrical energy. The revenues from this power will be used first to repay the cost of the main storage reservoirs, and then to repay a large share of the construction costs of irrigation projects in the Upper Basin states.

The first unit of construction in New Mexico, Navajo Dam and Reservoir, with a capacity of 1,700,000 acre-feet, is now about 75% complete. This regulatory unit of the storage project will store water for the proposed 110,000 acre Navajo Indian irrigation project and 3900 acre Hammond Irrigation Project, which is now under construction, as well as water for future municipal and industrial needs in the San Juan Basin. The unit will also provide excellent opportunity for recreation and fish and wildlife propagation, as well as flood and sediment control benefits.

Plans for the development of the waters of the San Juan Basin also include the proposed Animas-La Plata Project which would use the flows of the Animas and La Plata Rivers to irrigate about 60,000 acres in Colorado and about 20,000 acres in New Mexico. The Bureau of Reclamation is presently making a feasibility investigation of this project.

Our plans include the San Juan-Chama Project which would take water from tributaries of the San Juan River in Colorado through the Continental Divide in about 40 miles of tunnel and closed conduit for use in the Rio Grande Basin.

1/ State Engineer, Santa Fe, New Mexico.

The State is presently seeking authorization for only the initial stage of the San Juan-Chama Project which would be limited to an average diversion of 110,000 acre-feet per year. The diversion would provide for these depletions: 29,900 acre-feet in exchange for Rio Grande system water used on rehabilitated irrigation units on tributaries of the Rio Grande in northern New Mexico; 22,600 acre-feet for supplemental irrigation supplies for the Middle Rio Grande Conservancy District; and 57,500 acre-feet for the City of Albuquerque.

The plans contemplate that the San Juan-Chama Project would be constructed so that the works could be extended by the construction of subsequent stages to provide for total diversions from the San Juan Basin to the Rio Grande Basin averaging up to 235,000 acre-feet per year. Whether these extensions will be constructed depends upon the time at which future needs arise in the San Juan and Rio Grande Basins, and the State's judgment as to what distribution of the water resources of the San Juan Basin will best serve the public interest.

While the plans for development of the waters of the San Juan River provide large amounts of new water for agricultural purposes, large amounts are also allocated for future municipal and industrial uses. Under existing plans and authorizations the depletion amount available for municipalities and industry is about 204,000 acre-feet. This amount of water would serve the needs of more than 2 million people in an economy similar to that of the Albuquerque area.

Our plans for the development of the San Juan River must be carried out soon if the growing water needs of the State are to be met. In May of 1959 the United States Senate approved a bill introduced by Senators Anderson and Chavez to authorize the Navajo Irrigation Project and the initial stage of the San Juan-Chama Project. On May 19, 1960, the Secretary of the Interior recommended to the Congress the authorization of these projects. On May 20 a House committee held hearings on bills introduced by Congressman Morris and Congressman Montoya to authorize the projects, but there was not time for the committee report to be presented to the House for action.

Authorization of these projects has been impeded by objections raised by the State of Colorado. The controversy with Colorado seems to be resolved and I think we are justified in being cautiously optimistic about the authorization of these projects by the first session of the 87th Congress.

One of the provisions of the Canadian River Compact is that New Mexico shall have free and unrestricted use of all waters originating in the drainage basin of the Canadian River in New Mexico below Conchas Dam, provided that the amount of conservation storage in New Mexico for impounding these waters shall be limited to an aggregate of 200,000 acre-feet. Within this limitation we should be able to develop an additional firm supply of at least 70,000 acre-feet per year.

The 1959 legislature authorized the New Mexico Interstate Stream Commission to issue bonds guaranteed by $5 million of severance tax revenues to finance construction of dams on the Canadian River or its tributaries between Conchas Dam and the Texas border. The act also provides that the severance tax funds used to pay the interest and principal of the bonds shall be repaid from water revenues as they become available.

Preliminary studies indicate that the initial stage of a dam and reservoir having an ultimate capacity of about 365,000 acre-feet can be constructed for about $5 million. The dam would be constructed on Canadian River just below Ute Creek. The initial stage having a total capacity of about 170,000 acre-feet would yield a firm supply of about 40,000 acre-feet of water annually. There is some potential for agricultural use of this water, but at this time it appears likely that a substantial part of the water would be available for municipal and industrial use. Preliminary estimates suggest that the water in the reservoir could be made available to industry at a cost of around 1.4 cents per 1000 gallons. The price should be attractive to industry and there is good reason to believe that the second stage of construction which would make available an additional 15,000 acre-feet of water per year could be financed with water revenues when the water is needed. We expect that the project will also yield very substantial recreation, and fish and wildlife benefits.

The legislative authorization does not require a showing of economic feasibility before construction is undertaken. The legislature is betting that if the water is developed, users, willing and able to pay the cost of development, will be attracted. I think this is a good bet.

Redistribution Among Types of Use

The State's water program reflects a recognition of urgent need for the development of water for both agricultural and municipal and industrial use. A crucial feature of our water problem is the fact that agricultural pursuits will provide little opportunity for increased employment. If current projections of the State's population are correct, progressively larger amounts of the State's water supply must be put to municipal and industrial uses to meet what will be spectacular increases in our economic base and population. To put this in perspective - experts of the Bureau of Business Research at the University of New Mexico predict that our 1960 population of 943,000 will increase to about 2¼ million by 1980. Whether or not these increases will occur depends, of course, on a number of factors, including the manner in which we manage our water resources.

The State's program for the waters of the San Juan and Canadian Rivers should meet the growing municipal and industrial needs in the San Juan Basin, the lower Canadian River Basin, and in at least the Albuquerque area of the Rio Grande Basin for several decades.

In other areas of the State growing municipal and industrial needs can be met by acquiring water rights presently being exercised for irrigation. Our statutes permit the change of point of diversion, and the change of place and purpose of use of water rights, if such changes will not impair other existing rights to the use of water. Both municipalities and counties have the power under New Mexico law to condemn water rights for public purposes. The process of condemnation, of course, requires fair payment to the owner whose water rights are taken.

At present time about 93% of all water diverted in New Mexico is used for irrigation. Most of the balance of 7% is used for municipal and industrial purposes. It follows that our municipal and industrial usage could be doubled by a reduction of only about 7½% in the amount of water used in the agricultural economy of the State.

A recent report by Dr. Nat Wollman of the University of New Mexico states that about $50 is the value of an acre-foot of water applied to agriculture in New Mexico, while the value of that amount of water applied to industrial use is about $4000. Also, in most cases the cost of water is a very small fraction of the initial investment and operating costs of an industry. The necessity to pay a fair price for the redistribution of water from agricultural to industrial use should be no deterrent to the establishment of industrial economy. Numerous water right transfers already on file in my office substantiate the soundness of that statement. I don't think it can be questioned that, under our law, water can be redistributed to growing municipal and industrial requirements, through the exercise of the power of eminent domain and the effects of economic competition.

Water Salvage

We seem to have an excellent opportunity to increase our economic base and our ability to support a growing population by the development of water which presently flows out of the State, and by redistributing water to new uses. We can also increase the usable amount by salvaging water which is now being lost to evaporation and transpiration by nonbeneficial plants.

In 1950 the Bureau of Reclamation estimated that nonbeneficial losses from the Rio Grande in New Mexico amounted to about 570,000 acre-feet annually exclusive of evaporation from reservoirs. A major part of this loss resulted from the need for flood and sediment control and improved drainage, and from losses to salt cedar, cottonwood, willows and tules. An attack on this problem was launched with the authorization of the Middle Rio Grande Project in the Flood Control Act of 1948. Under this authorization 57 miles of leeves have been completed in the Albuquerque-Belen reach of the river; Jemez Dam and Reservoir Project near the mouth of Jemez River is completed; Abiquiu Dam is under construction on the Chama River; 112 miles of river channelization and rectification have been completed; rehabilitation of the drainage works of the Middle Rio Grande Conservancy District is almost complete, and about 60,000 acres of nonbeneficial water consuming vegetation has been sprayed or cleared.

The Flood Control Act of 1960 authorized the construction of Cochiti and Galisteo Reservoirs for flood and sediment control. Cochiti Dam will be built on the main stem of the Rio Grande at the head of the Middle Valley, and Galisteo Dam will be built near the mouth of Galisteo Creek to control both Galisteo Creek and the Santa Fe River. Expenditures by the Bureau of Reclamation and the Corps of Engineers on the Middle Rio Grande Project through this fiscal year will amount to about $54 million. The completion of work now authorized, including Cochiti and Galisteo Dams will being total expenditures to about $111 million.

The State has cooperated with the Bureau of Reclamation and the Middle Rio Grande Conservancy District in drainage and water salvage works to supplement the work authorized under The Middle Rio Grande Project. State expenditures from Ferguson Act funds from 1952 thru June 20, 1961, will total $760,000. An additional $125,000 of these funds will have been spent for water salvage work in the Caballo Reservoir area below Elephant Butte Dam.

It is estimated that work under the Middle Rio Grande Project and the supplemental cooperative work will salvage approximately 165,000 acre-feet of the 570,000 acre-feet which was being lost in 1950. Large amounts will still be lost to evaporation and transpiration from the Rio Grande in New Mexico, and further studies of potential water salvage measures have been initiated by the

Bureau of Reclamation with an allocation of $66,000 in federal funds in this fiscal year, plus an additional State contribution of $6600 from Ferguson Act funds.

The Pecos River in New Mexico is plagued by the same problems which beset the Rio Grande. Federal agencies, the Pecos River Commission, the States of New Mexico and Texas and local interests are cooperating to develop solutions to the problems on the Pecos. The Corps of Engineers has been authorized to construct Los Esteros Dam of the river about 7 miles above Santa Rosa. These works would provide flood protection and conservation storage to replace conservation capacity in Alamogordo Reservoir. Under present conditions siltation will make Alamogordo Reservoir ineffective as upstream storage for the Carlsbad Irrigation District within about 40 years. The Corps' plan requires that a part of the capacity of Alamogordo Reservoir be used for flood control, and, therefore, that a part of the irrigation district's storage capacity in that reservoir be transferred to Los Esteros Reservoir. The State is making hydrologic studies so that the District can be fully advised concerning the effects of the proposed transfer on its water supply.

The delta of McMillan Reservoir, terminal storage reservoir of the Carlsbad Irrigation District, is choked with salt cedar which use large amounts of water each year. Bureau of Reclamation studies indicate that approximately 24,000 acre-feet of water per year could be saved in the delta. The Carlsbad Irrigation District has accomplished some channel improvement and drainage work in the delta, but the losses are still high. The Bureau of Reclamation has been authorized to construct a low-flow conveyance channel and cleared floodway through the delta, but the authorizing legislation provides that the floodway shall not be cleared until provision is made to replace McMillan Reservoir storage capacity that would be lost by accelerated siltation resulting from floodway clearance. The Bureau is currently studying the feasibility of constructing a low-flow conveyance channel without a cleared floodway and the practicability of utilizing as a part of the low-flow channel the work already constructed by the District.

A recent reconnaissance report by the Bureau describes a plan of development for water salvage, flood control, and replacement of conservation storage on the Pecos. Data in the report suggest that the total amount of water salvagable under present conditions on the river is approximately 100,000 acre-feet per year. The report emphasizes that unless corrective action is taken, nonbeneficial consumptive use may be expected to increase markedly in the next 50 years, ultimately depleting the water supply by almost 340,000 acre-feet anually.

Among the possibilities discussed in the Bureau's report is the construction of Brantley Dam and Reservoir at a site about 4 miles downstream from the existing McMillan Dam. Brantley Dam and Reservoir with a capacity of about 300,000 acre-feet would provide badly needed flood protection for the City of Carlsbad, conservation storage for the Carlsbad Irrigation District to replace that function of McMillan Reservoir, and capacity for sediment control. Construction of Brantley Dam would permit the abandonment of McMillan Reservoir for conservation storage, and thus make it possible to do a full scale water salvage job in the McMillan Reservoir delta. The report suggests a permanent pool in Brantley Reservoir for recreation and fish and wildlife propagation, and the reservation of some storage capacity in McMillan Reservoir for fish and wildlife.

The State has requested a feasibility grade investigation of Brantley Dam and Reservoir Project, and I am advised that the Bureau has scheduled the study for next fiscal year.

Desalinization

As Dr. Miller has told you experimental work which has been carried out under the Department of the Interior's Office of Saline Water gives good reason to hope that new techniques for the desalinization of brackish waters and brines can materially enhance the water resources of our State. The techniques can be employed to improve the usefulness of present supplies as well as to make usable abundant brackish water resources presently unsuited for agriculture, domestic, or industrial use.

You have already heard excellent reports on this subject, so I will restrict my remarks to reporting that a proposed agreement, under which the State of New Mexico would contribute up to $100,000 to the construction cost of the demonstration plant to be built at Roswell, has been submitted for the approval of the Board of Finance at their meeting on November 10. The 1959 session of the legislature authorized this contract. I feel that the people of Roswell and the State of New Mexico should be grateful for the opportunity that we have been given to help point the way to a most promising new source of water for beneficial use.

Watersheds

I have discussed at some length the programs of the Department of the Interior and the Corps of Engineers in the State, and it would certainly be amiss if I were not to mention the programs of the Department of Agriculture in a conference whose theme is watersheds.

The Department of Agriculture's Watershed Protection and Flood Prevention Act, better known to some of you as Public Law 566 program, has been well accepted in New Mexico. This program can make important contributions through flood and sediment control, and improved water usage. You have heard a lot about sediment in the last two days, but I can't resist adding a few comments of my own. The problem only starts with the loss of valuable land through erosion. Siltation shortens the life of our flood control and conservation storage reservoirs, increases the cost of operation and maintenance on our irrigation projects, and chokes stream channels creating flood problems and breeding grounds for the nonbeneficial plants which rob us of so much badly needed water.

Not long ago an official of the Department of Agriculture advised me that New Mexico ranked third in progress under the Watershed Protection and Flood Prevention Act. I ought to give you a few statistics to illustrate the progress that we have made. Fifty-nine applications for planning assistance involve a total of 6,800,000 acres. Field examinations have been completed on 24 projects involving 2,110,000 acres. Work-plans have been authorized for 18 projects involving 1,407,000 acres. Construction has been authorized for 11 projects involving 649,000 acres at an estimated cost of $3,785,000. Construction is presently underway on four projects involving 399,000 acres, with an estimated cost of $1,678,000. Construction has been completed on three projects involving 25,200 acres at a cost of about $553,000. I think this is a record we can be proud of.

Some downstream water users are concerned over the possible effects of the Public Law 566 program on water supply. This concern is shared by the federal agencies engaged in soil and water conservation work and water development work. About two years ago the Bureau of Reclamation and the Department of Agriculture initiated a cooperative study to determine the effects of watershed treatment on streamflow. The problem they have attacked is an extremely difficult one. It is my understanding that as yet no method has been found that will consistently measure the effects of land treatment on streamflow from river basins, or even prove that such effects do or do not exist. I am hopeful that these agencies will continue the study until they have an answer to this baffling question. The final answer, to arrive at net effect, will have to go beyond the effect of watershed treatment on measurable surface runoff. The net effect includes the increase in water supply which must result from improved stream channels, the increased reservoir life resulting from sediment control, and the increase in groundwater recharge ultimately reappearing as streamflow.

The Public Law 566 program in New Mexico has been characterized by close cooperation with the State and strict compliance with State water laws. Reserving the right to be wrong, I doubt that the program carried out in this manner will have any material adverse effect on downstream water users, and may well benefit such users.

The Department of Agriculture through the Rocky Mountain Forest and Range Experiment Station at Albuquerque has undertaken a research program in the Sangre de Cristo Mountains above Santa Fe to determine the effects of forest management on water yield. I know you have heard a good bit about this subject here, and I will restrict my remarks to reporting that the Interstate Stream Commission will include in its budget proposal to the legislature, sufficient funds to undertake, in cooperation with the U. S. Geological Survey, the streamflow measurements necessary to this research project. The potential benefits to New Mexico from research of this nature are great, and the work certainly deserves the State's cooperation. As Jack Campbell has told you, the report of the Governor's Water Resources Committee recommends State support of research along these lines.

Other activities of the Department of Agriculture, particularly through the Soil Conservation Service and Agricultural Conservation Program are making important contributions to the more efficient use of water on irrigated farms in the States. Since so much of our water is used in agriculture, improved efficiency in this use can result in a sizeable increase in the total useable amount.

Conclusion

I regret that it has been necessary for me to neglect any mention of a number of the aspects of our water program and our water problems which are of interest to you - programs such as 1) the administration of our interstate stream compacts, 2) the administration of water rights in New Mexico, 3) our program of basic data collection and our ground-water investigations in cooperation with the U. S. Geological Survey, 4) the problems of declining water tables, and 5) the numerous smaller construction projects and investigations that are being carried out in New Mexico by federal agencies and the Interstate Stream Commission. I sincerely and cordially invite you to talk to me or any of the representatives of my office who are here if time is available after adjournment, and if time is not available here to call on us or write to us in Santa Fe.

REPORT ON GOVERNOR'S WATER RESOURCES COMMITTEE

Jack M. Campbell 1/

As has been indicated, I am Chairman of the Governor's Advisory Committee on Long-Range Planning Regarding the Conservation, Development and Use of Water Resources in New Mexico. I should like to present a brief report of the work of our Committee.

The Governor's Committee is composed of myself, as Chairman; S. E. Reynolds, State Engineer; Dr. H. R. Stucky of New Mexico State University; Dr. Harold Busey, a research scientist at Los Alamos; J. L. Merritt, President of the New Mexico Association of Soil Conservation Districts; James L. Dow, City Attorney of Carlsbad; and State Senator Charles Mumma of Farmington.

The Committee in its report stated its understanding of the purpose of its work as follows:

"This purpose requires continuing study of methods and management which will (1) encourage the efficient absorption of natural precipitation into the soils and underlying strata by way of intensive watershed planning and development; (2) utilize efficient surface and underground storage; (3) provide for construction of works for sediment control and salvage of water from non-beneficial plants along stream channels; and (4) result in efficient beneficial utilization of water, serving, where possible, multiple uses. All of this must be done within the limits of existing interstate compacts and state laws and without impairing existing rights. In other words, we must attempt to provide for efficient management of our waters from precipitation, down from the vast watersheds of the State through natural streams and underground reservoirs so that we may utilize a maximum amount of this valuable resource within the limits stated."

It is significant, it seems to me, that the first matter mentioned for continued and intensified study involves watershed planning and development. This same matter was the major theme of recent Fifth Annual Water Conference, held here at New Mexico State University. It should be apparent to those who study water problems that our first and perhaps foremost job is to educate the public, and water users in particular, as to the necessity for and advantages of watershed planning which will increase the utilization of our annual precipitation of approximately one hundred million acre feet. Only about 5% of this precipitation presently becomes divertible as surface or ground water.

Our Committee, in its deliberations, also gave serious consideration to the social and economic impact of watershed planning and development. It is certainly significant that the high altitude watersheds of New Mexico are the areas which have for a number of years been in a condition of economic distress. It takes only a glance at the geographical distribution of welfare payments in our state to recognize and appreciate this fact. For this reason proper watershed planning and management can serve not only the purposes of flood control, soil conservation and the utilization of more of our pre-

1/ Chairman, Governor's Water Resources Committee, Roswell, New Mexico cipitation, but it can assist materially in enabling some of the people residing in mountainous areas of New Mexico to become more self-sufficient in the operation and management of their agricultural and other pursuits without leaving their present homes, or otherwise seriously disrupting their way of life. Thus, such a program could have advantageous social effects and could make available additional public funds for uses other than welfare purposes.

These social and economic implications of proper watershed planning and management are pointed up by the present pilot project in the Penasco Basin. Our Committee heard a brief report of the work being undertaken on this particular project and we consider it to be of extreme importance as a possible pilot area for future watershed planning in our state.

Now just a few words about the general suggestions made by the Committee. These are more fully set out in the report itself.

1. We recommended careful and complete studies of the many watersheds in New Mexico and suggested that state and federal agencies intensify cooperative watershed studies.

2. We suggested the continuation of efforts to encourage the Federal and State governments to improve channelization of streams from the point of view of flood control and water conservation.

3. We suggested the continued and intensified use of state agencies for research programs relative to corrective action to eliminate non-beneficial consumptive use of water by evaporation and transpiration.

4. We urged full cooperation with federal agencies in their efforts to develop economically feasible desalinization techniques and suggested a close association with the research effort now getting underway at a pilot plant at Roswell.

5. We recognized the urgency for planning for the supply of water for rapidly growing municipalities and for industrial development in New Mexico and we suggested cooperative studies by municipalities and state agencies for the possible use of treated sewage water at least for industrial purposes.

6. Continued use of Interstate Stream Commission loans to local water agencies for water conservation purposes was encouraged.

7. We suggested that the work of the New Mexico Mapping Advisory Committee involved in supervising the very elementary matter of complete mapping of the state should be stepped up.

8. It became apparent to the Committee that in the field of water resources we need much more basic research to keep pace with the requirements of operational activities in certain areas of water conservation and use. This basic research needs to be in conjunction with applied research which will establish economic feasibility of various methods of conservation and use of water.

9. We urged that the state and its various agencies in cooperation with local and federal agencies make maximum multiple use of water resources in planning and operation of water facilities.

All of these thing, it should be apparent, require a great degree of cooperation and co-ordination of effort by the federal, state and local agencies and with private organizations interested in water resource planning and development. As the Committee stated in its concluding remarks,

"Through all of this study of the need for planning in the field of water resources - as is undoubtedly the case in planning other resource development-we find apparent the necessity for the planning to be in relation to other factors affected by the population growth and migration in our state. This necessitates a co-ordinated planning effort not only with regard to multiple use of water as a resource but planning for the development of various resources in full recognition of their interrelationship."

The Annual Water Conferences sponsored by New Mexico State University can go a long way to bring together representatives of all these various groups interested in water problems for an exchange of ideas and it is my hope that at some time in the future we may devise a way by which this type of conference may provide the basis for actual working arrangements both in the field of cooperative planning and in the field of development of those plans.

SALINE WATER PROJECT ROSWELL -- DEVELOPMENT

Roger Aston1/

Before we begin any discussion of present developments or future prospects regarding any water project we need to consider just what has occurred prior to the present stage of development.

My remarks will be primarily introductory:

1. Roswell's water problems are not unusual...More than 1000 communities were forced to curtain the use of water in recent years.....45 states felt water shortages..... ROSWELL WAS ONE OF 55 cities that made application for this plant.

2. Why was Roswell successful?
   Teamwork - State government, State Engineers, Roswell City authorities, Roswell Chamber of Commerce, Artesian Conservancy District, Farm Bureau, Private organizations, Individual Citizens.
   Prospectus - Careful preparation of the Roswell Story.
   Government - Office of Saline Water... Dr. Miller, Under Sec. of Int. Elmer Bennett, J. W. O'Meara, Ernest Eaton, The USGS, Anderson & Morris.

3. Exploratory search and self-help
   Water worth 7½ times what crude oil is?
   Projects must be economically sound.

4. Education
   We are a nation conditioned to abundance. We take our blessings for granted. We expect our CUP TO RUN OVER with cool, clean water at the simple turn of a tap - Why treasure that which COSTS US LESS THAN 10¢ PER TON DELIVERED?

   We need to give our citizens a better sense of values. Much needs to be done in the field of resource education.

5. Engineering and Politics
   The problem is one of engineering - the solution is basically political.... Political solution must be directed by a combination of well informed voters and dedicated political representatives. Should be accomplished under a free enterprise system.

6. Conclusions
   New Mexico is most fortunate to have the Brackish Water Conversion Plant for the Arid Southwest... Let's keep our shoulders to the wheel on this project that holds such wonderful promise for the Land of Enchantment.

1/ Southsprings Foundation - Roswell

WHAT THE SALINE WATER CONVERSION PLANT MEANS TO THE CITY OF ROSWELL, NEW MEXICO

General C. M. Woodbury1/

The City of Roswell is a community of approximately 40,000 people located in the Pecos Valley in the southeastern part of New Mexico. The growth of the past ten years has been gradual, but it has generally increased at a rate of approximately 90% in ten years. It is increasing at a higher rate than the national increase, or for the Southwest, and this continual growth of the community results in an ever increasing problem, as it does nationally, a needed source of potable water.

The present water supply is obtained from the Pecos Valley Artesian Basin, one of the few remaining artesian basins left in the world. This basin is protected by the State. The water withdrawn is fully appropriated, in the amount of approximately 300,000 acre feet, annually. This, or a high percentage, supplies a highly agriculturally developed area, and the community.

The Artesian Basin is unique in that approximately forty miles west of Roswell, the basin, in good years, receives a recharge of approximately 275,000 acre feet per year, which, without any great amount of mathematics, it is immediate to see that the basin is over appropriated, approximately 12½%, and in many years this figure is exceeded.

However, a greater problem than the over appropriation is to the east and slightly north of the City of Roswell, and underlying the lower line of the easternmost extremity of this basin along the Pecos River, is a highly concentrated saline area, which, during the period of high pumping of fresh water from the basin, lowers the pressure of the fresh water and allows this saline water to encroach into the fresh water supply. This problem is becoming more acute yearly, as most of the agricultural wells in the area east have become too saline for use, and also the water in some of the supply wells in the City of Roswell.

This saline encroachment is becoming more noticeable each year, to the degree that if this serious encroachment continues, it will be necessary to abandon some of the easternmost supply wells.

When the Department of the Interior made inquiries relative to the location of the Brackish Water Conversion Plant, the City of Roswell immediately recognized the potential of what this process could do, first, to furnish between 250,000 to 1,000,000 gallons of demineralized water, and secondly, by the location of the supply wells for this plant in this area of saline encroachment, could reduce the pressure that the saline water is exerting on the fresh water basin and thus retard the encroachment and possibly allow the fresh water to reclaim some of the area already lost. The possibility of a demineralized supply aroused a great deal of local interest.

1/ City Manager, Roswell, New Mexico

In the early concept, it was felt that possibly the electro-dialysis method of conversion would be used. This process has been used commercially in several parts of the country. As this plant's source of energy is electrical, immediately we investigated the power rates, availability of electric power and the cost. As this type of plant reduces the saline content of the brackish water by ½ by each stage, it would have to be determined how many stages would be necessary to reduce the water to potability. We used, originally, 4,000 parts per million which approximately takes four stages to reduce to 250 parts per million. From the best information we had, approximately, each stage of this type of plant would approximate $1,000,000.00, therefore we had a plant of $4,000,000.00 investment and also took into consideration replacement of membranes, operation and general upkeep of the plant, and we came up with a price of 77 cents per thousand gallons. Into this price went amortization, operation and maintenance. It is my understanding at a later date, that some places in operation are producing potable water at a lesser amount. This type of plant being one that takes the salt out of the water, by-product of brine coming through this plant leaves a concentration of four times that of the raw water, and you have a disposal problem in the area.

The disposal problem, of course in many areas, if it is a sea water plant, the water could be returned to the ocean, but in an inland area the problems are more complex. If a large river were available you could run this brine into the river at high water. However, in the arid southwest, you have an alternative of either putting it back in the aquifier. However, a legal problem would result if anyone's well turns saline and they would of course, hold the city responsible. So, we investigated the possibility of evaporation.

First, we determined the heat intensity of the sun in this area and found it to be approximately 525 langlies. This, of course, not having a heliometer available, we interpolated between Albuquerque and El Paso, Texas, then checked the maximum sunshine available to the Roswell area and determined it was approximately 75%. Next the average humidity and the velocity of the wind. This established the fact that it would be possible to evaporate 10 feet of water annually. So it was determined actually, by making a series of tanks approximately 120 feet wide and 3/4 to 1 mile long, and some 300 acres of surface area, this could be accomplished. The City agreed in the original proposal with the Department of Saline Water, Department of the Interior that although we produce water for 8 cents a thousand gallons, we could pay 60 cent a thousand gallons for product water. However, after the possibility developed, whereby this quantity could be increased to 1,000,000 gallons, we determined that we could use 1,000,000 gallons at 40 cents a thousand gallons. Now, this of course, is paying a premium water price, however, if it accomplishes the purpose of aleviating the salt encroachment, we felt this could be charged to the source of supply as treatment.

After many months of anxiously awaiting the outcome, it was determined that Roswell would be selected for one of the experimental plants. However, not the electro-dialysis method, but a vapor-compression, forced circulation, distillation process.

Immediately the problem was attacked from the angle of finding water suitable for this type of plant and the co-operation of the Pecos Valley Conservancy District, who agreed to furnish the water to the plant, if it was possible to locate the wells in the high saline area. So far we have drilled three wells.

In the area of approximately five miles east of Roswell, behind the interface of the highly saline water, we drilled the first well, approximately 720 feet deep and it flowed at a rate of 400 gallons per minute. However, this water was analysed and found to contain a good deal of free hydrogen-sulfide gas and a very high total of disolved solids. Upon the completion of this well, we moved a mile south in the same general area and drilled a second well. This well was drilled to the top of the water bearing strata and was determined to be the same water, less the hydrogen-sulfide gas.

The analysis of this well is as follows:

	No. 1	No. 2	No. 3
pH	7.1	7.1	7.3
Total Hardness	2,380 mg/1 as $CaCO_3$	3,066 mg/1 as $CaCO_3$	2,008 mg/1 as $CaCO_3$
Calcium	1,736 mg/1 as $CaCO_3$	2,252 mg/1 as $CaCO_3$	1,562 mg/1 as $CaCO_3$
Magnesium Hardness	644 mg/1 as $CaCO_3$	814 mg/1 as $CaCO_3$	446 mg/1 as $CaCO_3$
Alkalinity	154.6 mg/1 as $CaCO_3$	155.6 mg/1 as $CaCO_3$	139 mg/1 as $CaCO_3$
Chloride, CL	7,210 mg/1	1,190 mg/1	2,670 mg/1
Sulfate, SO_4	1,995 mg/1	2,700 mg/1	1,750 mg/1
Silica, SiO_2	14 mg/1	10 mg/1	14 mg/1
Iron, FE	3.3 mg/1	0.20 mg/1	0.10 mg/1
Turbidity	20 mg/1	None	None
Residue on Evap.	15,940 mg/1	24,280 mg/1	7,760 mg/1
Total Disolved Solids (Calculated)	14,728 mg/1	22,253 mg/1	6,930 mg/1

However, as it is in the upper brackets of brackish water, we moved a mile south and drilled the second well (No. 2, above). A seven inch casing was set and cemented in. This well flowed at a rate of approximately 150 gallons per minute. The total number of disolved solids, as you see from the analysis, was approximately 24,000 ppm, which is in the upper bracket of brackish water, three quarters that of sea water.

We moved a mile east, set a third well and set an eight inch casing of approximately 600 feet, and this was determined by analysis to be a different water, having a total amount of disolved solids of 7,760 ppm and a chloride count of 2,670 ppm.

At present the corps of Engineers is running tests on No. 2 well, with a vapor compression plant and are prepared for the experimentation, using forced circulation and treatment to take out the Calcium Sulfate.

RIO DE PENASCO WATERSHED PROJECT

David J. Jones[1/]

A Search for a New Land Use Development Pattern

This is an attempt at comprehensive planning of a small watershed by State and Federal agencies and private organizations sponsored by the State Planning Office. I want to present just the schematics - the planning approach.

These slides give you an image of the Rio de Penasco watershed: 300 square miles in a high water yield section of the Sangre de Cristo Mountain Range just south of Taos. A population of 7,000 is scattered through 12 Spanish American villages, and the Picuris Indian Pueblo.

For many years it has been one of the economically depressed or a lagging area of Northern New Mexico. What solutions have been proposed for this problem? One is to let it deteriorate, then replace it with something better. Yet when you ask, "What do you mean by something better?", the answer is not convincing.

Is it possible that this area is economically depressed because money people evaluate this land and the people in it in the following ways:

a. The land is cut up into small tracts either by ownership or steepness of the terrain and is thus unsuited for agriculture. This is true if your stereotype is the large flat tracts of land in Kansas or at Bluewater, New Mexico, and you think only in terms of machinery now available.

b. The amount of water available is not great and it fluctuates in volume. Therefore, large scale industry or agricultural development is out.

c. There is no large consumer market here. This precludes input-output schemes such as building a suburb---then a shopping center---enlarge the suburb---expand the shopping center.

d. The land titles are those more typical of Latin America. They do not meet the standards derived from Anglo-American practices; consequently the people cannot get the kind of loans ordinarily available.

e. There are no railroads - no super highways; therefore it is unsuited to industry in general. The image in the mind of this appraiser is Detroit, Los Angeles, Camden with heavy transportation facilities, abundant water, rich sources of raw materials, close proximity to manufacturers of components and sub-assemblers, ready markets and sources of trained labor.

f. The forest is not extensive - does not produce high quality timber. Therefore, the large scale lumbering such as in the Northwest is out.

1/ U.S. Park Service, Chairman for the Inter-Agency Committee for Area Development, Santa Fe, New Mexico.

g. The people are "different." Development projects based upon Anglo-American values are not necessarily those endorsed enthusiastically by Spanish Americans or Picuris Pueblo Indians.

What is the result of this kind of evaluation of land and people? There is no investment. Whereas the people of uplands New Mexico were once successful in a barter-purely agricultural economy, they fail today when they try to compete in a dollar economy. Culturally this is an enclave. What is the impact of this money approach? It makes them feel at a tremendous disadvantage and they see no way of getting out of their situation. They have no way of producing money in the volume required. If someone offers them some in the form of welfare or relief, many of them readily accept.

The only resource now becoming scarce elsewhere that is abundant in the Penasco area is land which is habitable, attractive, sparsely populated. Here on this land, already in existence, is a way of life that is the verbalized ideal of many of us living elsewhere in the high density population centers. What can we do to remedy this problem? EITHER: We do nothing and let the area become a recreation place. People more and more will move in whose income is not tied to this landscape; residents will derive few of the benefits. The inevitable population sprawl will engulf the area, destroy every vestige of its culture and much of the landscape. OR: We develop new measures for the potential of this land.

In the Inter-Agency Council there are people interested in developing these new measures. They ask, would it be possible to develop a pattern of culture here which does these things:

a. Supports more people.

b. Enriches rather than depletes the soil, perhaps by making extensive use of forest waste products.

c. Conserves and makes more efficient use of water in the area.

d. Turns the agricultural character of the land to advantage. The production of chili for example, could be greatly expanded if processing facilities were improved to meet interstate requirements.

e. Takes advantage of the most recent development in light rapid transportation...since there is no tax burden from heavy transport investments... to establish communication with markets, sub-assemblies and suppliers.

f. Turns the need for small cash income to advantage for small, light industry that can be developed with little capital.

g. Uses handcraft and handcraftsmen as the basis for cottage industries.

h. Encourages growth and change by developing upon the sound cultural values that already exist.

i. Explores uses of resources, growing of crops new to this area.

Objectives such as these have been or are being achieved in this country and elsewhere. For example, the growing and harvesting of agricultural and forest product crops has been brilliantly solved for certain kinds of terrain and climate, but not here. Techniques and machinery for it have been well developed. Can the problems here be approached with same creativeness used elsewhere. Can this become an area of opportunity for smallness as opposed to bigness, for initiative instead of dependence...a place for people without large amounts of capital, but with energy and ideas?

How could this type of planning and development be accomplished? There is a great emphasis upon the use of private consultants today. In Federal, State agencies and private organizations there is a surprising amount and variety of land-use planning talent that never appears on the consultant market. In the watershed are individuals and groups who are venturesome and want to work with the participating agencies and organizations. Bringing these elements together on a planning and development project presents hazards. Very competent people have tried before us, and, for various reasons failed. We say the need is great and that we have modified the approach and maybe it will work this time.

To achieve the real cooperation of the various agencies and private organizations is absolutely essential. We have organized the Inter-Agency Council for Area Development Planning. Twenty Three State and Federal agencies and two private organizations are participating. We have adapted the River Basin approach to a 300 square mile watershed. It is a small enough area so that everyone can get to know it. It is close at hand. Differences of opinion arise, but if you can get out on the job to reach decision, the problem will often speak for itself in a way it never does in a central office.

The Inter-Agency Council has designated a nine man committee to direct the project. The planning and investigation is carried out by five work groups, namely: Croplands utilization, Forest and Range Utilization, Utilization of Community and Cultural Resources, Enterprise Facilitation, Socio-economic studies. The chairman of these groups have broad authority to act. By having State and Federal agencies as well as private organization in the project we think we have thrown off-balance the bureaucratic tendencies in each of us long enough to get something done. Already we have found the value of having individuals who know land-use problems and who are not connected with any agency. They can speak up when agency representatives cannot, since it is not cricket for one agency to criticize another. The potentialities of this approach are considerable: A wide variety of planning talent can be brought to bear on a problem. The agencies or individuals who will have to finance and carry out a project will have ample opportunity to assess its merit. Situations such as this bring out the venturesome qualities in otherwise conservative agencies and individuals. Relatively big things can be done with relatively small amounts of money.

The people of the Penasco watershed are the most important element in the solution. It all depends upon their cooperation. We are not attempting to appeal to the entire population, just the venturesome ones. To them we think we can demonstrate that ideas and energy create wealth. We believe there is a greater number of venturesome people living along the Rio de Penasco than you would believe, and that they will identify themselves.

Assistant Secretary of the Interior, George W. Abbott stated yesterday the need for a single, integrated plan rather than a multiplicity of plans by separate agencies. I think the Penasco project will demonstrate one way to achieve this.

Mr. Abbott felt, however, that the degree to which you have more than one agency determining what is to be done in a given area is the degree to which you dilute the effectiveness of the result. With this I take issue. We have found that the State and Federal agencies are concerned with the need for cooperative research, planning and action. We are all convinced that this cooperation can be achieved at the given area level sooner and more efficiently than it can be in Washington. Furthermore, the success of the whole effort might well depend upon the comprehensiveness of the initial planning and the subsequent development. Here lies the advantage of multiple agency participation. It provides comprehensiveness that could not be achieved by a single agency. There are too many facets to the problem for the limited talents available in any one agency.

I have attempted to outline schematically our approach to the Penasco project. If you have questions you may call upon me or any of my very able associates who are in this audience: George Worley of the Pack Foundation for watershed Conservation Education; E.J. Dortignac of the U.S. Forest Service; Earl Sorenson of the State Engineer Office; Charles Collier of the New Mexico Land Planning Association; Donn Hopkins, Acting State Planning Officer; or Peter van Dresser who was Field Director of the project. If one can say that any single man is responsible for conceiving and organizing this project, it is Mr. van Dresser who deserves the credit.