Proceedings of the

Tenth Annual New Mexico Water Conference

Theme: People and Water in River Basin Development

April 1 & 2, 1965

Agriculture Building

New Mexico State University - University Park, New Mexico

NEW MEXICO WATER CONFERENCE

Sponsored By

NEW MEXICO STATE UNIVERSITY DIVISIONS

of

Agricultural Experiment Station
Agricultural Extension Service
College of Agriculture

College of Engineering
Engineering Experiment Station
Cooperative Agent, USDA-ARS, SCS

and the

WATER CONFERENCE ADVISORY COMMITTEE

Membership New Mexico State University

WATER CONFERENCE COMMITTEE

Dr. John W. Hawley	- Geologist, USDA
Clark D. Leedy	- Resources Development Specialist Extension Service
Dr. Harold E. Dregne	- Agronomy - Soils
W. P. Stephens	- Agricultural Economics
Dr. Roger B. Long	- Agricultural Economics
K. A. Valentine	- Animal Husbandry - Range Management
Dr. N. N. Gunaji	- Civil Engineering
Eldon G. Hanson	- Agricultural Engineering
James F. Cole	- Agricultural Economics
O. F. Baca	- Assistant County Agent Leader Extension Service
Gene O. Ott	- Farm & Business Management Specialist Extension Service
Dr. H. R. Stucky	- Water Resources Research Institute Conference Chairman

Membership of

WATER CONFERENCE ADVISORY COMMITTEE

Robert Emmet Clark
University of New Mexico
Albuquerque, New Mexico

S. E. Reynolds
State Engineer
Santa Fe, New Mexico

Rogers Aston
South Spring Foundation
Roswell, New Mexico

Cooper Malone
New Mexico Farm Bureau
Lake Arthur, New Mexico

Claud Tharp, Member
NMSU Board of Regents
Las Cruces, New Mexico

W. E. Berthoff, II
New Mexico Institute of Mining & Technology
Socorro, New Mexico

E. O. Moore, Chairman
State Soil Conservation Committee
Dexter, New Mexico

James Anderson, Acting Director
Bureau of Land Management
Santa Fe, New Mexico

Ladd S. Gordon, Director
New Mexico Department of Game & Fish
Santa Fe, New Mexico

Ralph Charles
U. S. Bureau of Reclamation
Albuquerque, New Mexico

W. H. Gary
Interstate Stream Commission
Hatch, New Mexico

Sam West
U. S. Geological Survey
Albuquerque, New Mexico

Drew Cloud
Farmer's Home Administration
Albuquerque, New Mexico

Lloyd A. Calhoun, Director, Hobbs
Industrial Development Corporation
Hobbs, New Mexico

Fred Kennedy, Regional Forester
Forest Service, USDA
Albuquerque, New Mexico

C. A. Tidwell, State Director
Soil Conservation Service
Albuquerque, New Mexico

Fred W. Moxey, Executive Director
New Mexico Gas & Oil Association
Santa Fe, New Mexico

Donald C. Rider, Executive Director
New Mexico Municipal League
Santa Fe, New Mexico

Robert J. Hoffman, Director
Department of Development
Santa Fe, New Mexico

During the "Water Break" Governor Jack M. Campbell is assisted with a drink of water by NMSU's President R. B. Corbett. Dr. Corbett gave the Address of Welcome and Governor Campbell the Keynote Address in the opening session of the Tenth Annual New Mexico Water Conference.

FOREWORD

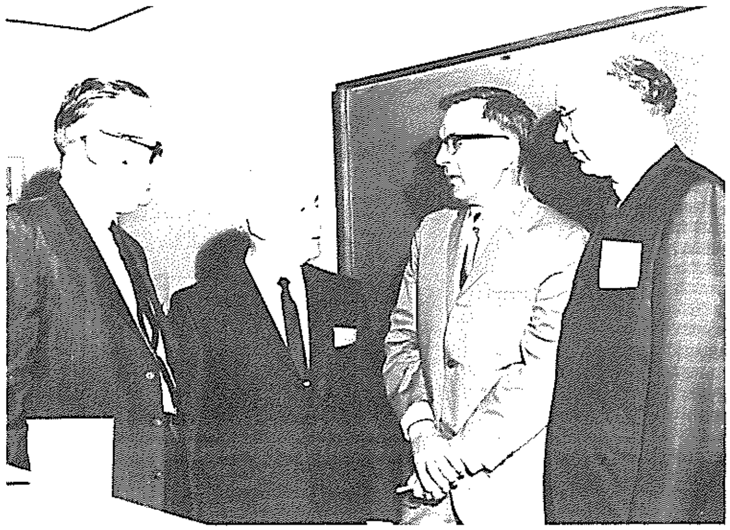
The Tenth Annual New Mexico Water Conference marks a decade of progress in the understanding of our water problems and methods by which they may be solved. One of the greatest steps forward has been that all groups have met together and discussed water in all of its aspects. This has permitted the municipal, industrial, recreational and agricultural groups to understand their own problems and those of each other group a little better. It has also brought the realization that we as citizens of New Mexico must work together to make our water supply serve the State and each individual and group to the fullest extent possible. In addition, it has brought out the need for neighboring states to work together in the Regional, National and International programs to forward our total water development, use and conservation objectives.

New Mexico State University is proud to have had the opportunity to sponsor the ten Annual New Mexico Water Conferences and to have had nine of these held on our campus. The Eighth Annual Conference was held July 1 and 2, 1963 in connection with the dedication of the Saline Water Conversion Plant at Roswell. The University is assisted with the planning and conduct of the conferences by a dedicated and progressive Advisory Committee of nineteen members, whose names are listed on the inside of the cover page. Also, a University committee assists with the program development and the carrying out of the conferences.

The theme of the conference was <u>People and Water - In River Basin Development</u>. The papers presented appear in this proceedings in the order in which they were presented at the conference. The program which follows will serve as an index to the papers.

H. R. Stucky

H. R. Stucky, Chairman
New Mexico Water Conference, and Director
New Mexico Water Resources Research Institute

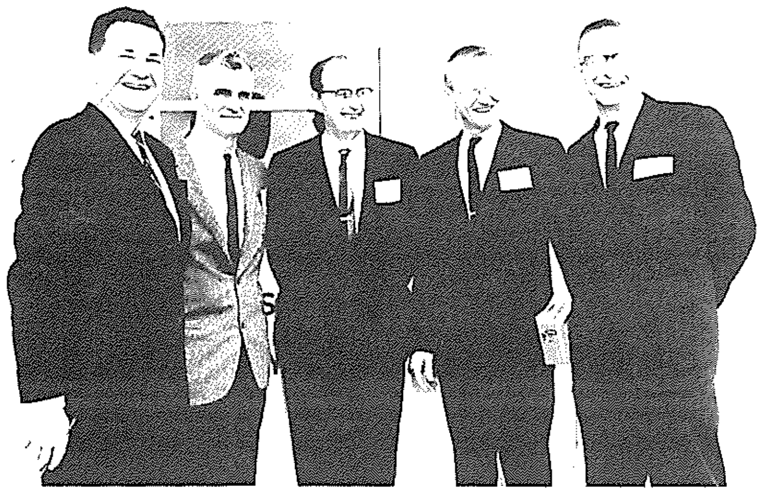


Dr. Roland R. Renne, Director of the Office of Water Resources Research, U. S. Department of Interior, visiting with President Corbett. At the left C. D. Harris, Roswell Attorney and J. F. Cole, Vice President for Administration, NMSU, on the right, visit prior to the opening session of the Conference in which they all participated.

Program participants (left-right) Carl Slingerland and Earl Sorensen, both from the State Engineer Office, and Dr. Harold Busey, Physist at Los Alamos and Technical Advisor to Governor Jack M. Campbell.

NEW MEXICO WATER CONFERENCE
April 1 and 2, 1965

THEME OF THE CONFERENCE - "PEOPLE AND WATER IN RIVER BASIN DEVELOPMENT"



(left-right) Randall Montgomery, Hobbs oil man; W. W. Dresskell, Regional Director, Bureau of Outdoor Recreation, Denver; Fred Thompson, Assistant State Director, Department of Game and Fish, Santa Fe; Dr. Harold Dregne, Professor of Soils, NMSU; and Steve Reynolds, State Engineer, Santa Fe, were effective participants in the Water Conference program.

A toast, with water, participated in by George Maddox,U. S. Geological Survey, Ground Water Geologist, Roswell; Wilbur Heckler, U. S. Geological Survey, Surface Water Geologist, Santa Fe; and Lowell Woods, Assistant Regional Forester, U. S. Forest Service, Albuquerque.

NEW MEXICO WATER LAW AS IT RELATES
TO THE PECOS RIVER WATERSHED

C. D. Harris[1/]

Water law may have been the first law developed in that area we now call New Mexico. As Remi A. Nadeau pointed out in his book The Water Seekers:

> "Bleak ruins stand today in the cliff country of the Four Corners of New Mexico, Arizona, Utah and Colorado, uninhabited for more than six hundred years. From the time of Charlemagne to the last Crusades the cliff dwellers flourished there, making advances in irrigation, architecture, rudimentary engineering. But, beginning in 1276, an appalling twenty-three year drought struck the Southwestern country. It cut the roots of the cliff dwellers' civilization. Defeated by nature, they moved southward in quest of water, leaving behind the shells of their communities in the Colorado cliffs."

> "In the sun-drenched Gila Valley of New Mexico and Arizona are the remnants of another Southwestern society -- The Hohokam people. A thousand years ago they had achieved an advanced civilization through the wise use of water. By patient, plodding labor, they built elaborate canals up to twenty-five miles long, irrigating more land than any other people on the American continent in their time. They were fast developing an agricultural empire of the kind which founded the first-known civilizations of the Nile, Tigris, and Euphrates valleys. From about 1450 the Southwest was stricken once more with long years of drought. The great irrigators failed to find an answer to the terrible water famine which gripped their homeland. They migrated elsewhere, leaving their parched canals to stand unused for several hundred years."

I suggest that in all probability one of the first laws developed by the Hohokam and cliff dwellers societies was the law of waters.

Certainly the precedents for our present day law of waters go back many centuries in New Mexico history. One of the first proclamations after the conquest of Mexico by the United States was the Kearny Code of September 22, ~~1918~~ 1846 which provided in part:

> "that the law theretofore enforced concerning watercourses should continue in force,***"

1/ Attorney at Law, Roswell, New Mexico

Among the early pronouncements by the Territorial Supreme Court was to the effect that:

> "the doctrine of prior appropriation has been the settled law of the territory by legislation, custom and judicial decisions." U. S. vs. Rio Grande Dam & Irr. Co., 9 N.M. 292.

Although the basic philosophy of our water law and the early decisions were established by conditions arising from the Rio Grande Watershed, the bulk of the legislative enactments and court decisions since statehood has arisen from conditions on the Pecos River Watershed. In fact, as early as 1909, the legislature provided for the regulation of artesian wells (New Mexico Laws of 1909, page 177, also Laws of 1912, chapter 81).

In the early 1920's, in an attempt to bring some order to the water rights controversies in the Pecos Valley, the United States Government undertook to adjudicate all of the water rights along the Pecos from the Carlsbad Irrigation Project to the headwaters of the Pecos. After ten years of hearings, the Federal Court entered the final judgment in the United States vs. Hope Community Ditch, et al.

In spite of all the time, effort and money spent on this case, the water law of the Pecos River was still unsettled, and many problems remained unresolved. Inevitably, claims were made that lands and parties were omitted, rights on the tributaries were not adjudicated, and no attempt was made to adjudicate ground water rights.

Shortly after the turn of the century, the potential of the Artesian Basin in Chaves and Eddy Counties was discovered. A large scale agriculture economy developed in the Roswell and Artesia communities. Alas, early in the 1920's the economy based upon artesian wells was threatened. Many wells ceased to flow. Tributary streams dried up. Mortgages were foreclosed.

Probably at the insistence of the mortgage holders, the people of the Pecos Valley determined to enact a water code to control the appropriation and use of ground water. New Mexico was not the first state to enact ground water legislation; however, in 1927 the legislature declared the water of underground streams, artesian basins, reservoirs, and lakes having reasonably ascertainable boundaries to be public.

The Supreme Court in 1930 declared the 1927 Act unconstitutional for technical reasons, but again re-affirmed the doctrine of prior appropriation and held that it had always been the law of New Mexico that ground water as well as surface water belonged to the public and was subject to regulations by the legislature. Our water law was re-enacted in corrected form in 1931, and

New Mexico was the first state to put in operation an extensive ground water code, and has set the pattern of ground water law in the Western states.

The constitutionality of the 1931 Act was upheld by the New Mexico Supreme Court in 1950 and by the United States Supreme Court in the following year. State vs. Dority, 55 N.M. 12, Dority vs. State, 341 U.S. 924.

Since 1955 the Supreme Court of New Mexico has written over 35 decisions concerning water controversies arising from the Pecos Valley. In 1955 the court held that the appropriator had the burden of proving that his application would not impair existing rights. Spencer vs. Bliss, 60 N.M. 16. Since that time the court has held that drainage water is private and not public. Langenegger vs. Bliss, 64 N.M. 218. That waste of water was not of beneficial use, State vs. McLean, 62 N.M. 264, and that in a case where the ground water contributed to the flow of the stream, the appropriator from the stream could trace his water to the source by drilling a well, Templeton, et al. vs. Pecos Valley Artesian Conservancy District, 65 N.M. 59. In the case of Kelley vs. Carlsbad Irrigation District, 71 N.M. 464, the Supreme Court held that the District Court in reviewing a decision of the State Engineer was limited to the record before the engineer.

In spite of all of the litigation during the last decade, there remains many unresolved problems concerning water law. It now appears that there are more questions to be answered than ever before.

In order to bring more stability to property rights on the Pecos River Watershed, the P.V.A.C.D. and the State Engineer filed a petition in 1956 asking the court to adjudicate and determine all ground water rights in the Roswell Artesian Basin.

Over 1900 defendants have been named, over 300 days have been taken in presenting evidence in court, property rights valued at over $70,000,000.00 have been involved in this one lawsuit. This does not include the value of the water rights from municipalities and industries. The court has adjudicated over 140,000 acres of land as having valid water rights, including separate adjudication suit involving the lands under the Hagerman Canal.

The plaintiffs have now asked for the two adjudication suits to be combined and the court has set down the final hearing for May 18, 1965. At the time of the final hearing the court will consider requested findings of fact and conclusions of law, requests for provisions for final judgment, corrections of mistakes, omissions, and errors, and will consider procedures for the administration of the final judgment, determination of whether a water master should be appointed, determination of whether measuring devices should be installed and assessment of costs.

This case involves hard and dramatic decisions for the court. The results of this adjudication will have dramatic and far reaching effects upon the people of the Pecos Valley and for the State of New Mexico.

It appears to this writer that the year of 1965 will be THE YEAR OF DECISION.

To illustrate the complexities of the problems, you should bear in mind that under all the permits issued by the State Engineer, the appropriator has been limited to three acre feet of water per acre per annum. The special master and the court have determined that on all the irrigated acres adjudicated that the duty of water is three acre feet per acre per annum measured at the well; yet, U.S.G.S. studies made in 1956 show that for the period from 1951 to 1956 approximately 3.2 acre feet of water was used on the average on each acre of irrigated land. I understand that more recent studies show that since 1956, four acre feet or more have been applied on the average on the over 140,000 acres of irrigated land in the Roswell Artesian Basin.

If meters are required to enforce the provisions of the final judgment, many problems will remain. The questions that will be presented requires determination of who will pay for the meters. Will the defendants be required to pay for and install the meters under the supervision of the water master appointed by the court?

There is a possibility that the Pecos Valley Artesian Conservancy District can aid in financing the meters or might even consider paying for all or part of the cost of the meters as a part of its conservation program. Certainly there should be a good possibility that the Conservancy District can act as purchasing agent in order to expedite the buying of the necessary meters. Even if meters are installed, there will remain the problem of administration of reading of the meters, of enforcing the court's allocation of the water, and of paying for the costs of administration.

Even if meters are required and the appropriation of water can be reduced from something like 560,000 acre feet to 420,000 acre feet, this will still not mean that the Valley is living within its water income. Hydrologists tell us that a significant percentage of the recharge of the Pecos River comes from ground water sources and that this recharge has been depleted by pumpage from the shallow and artesian wells of the Roswell Artesian Basin. Certainly there is a shortage of surface water on the Pecos River. New Mexico is faced with the possibility of a priority call from surface users. In the event of a priority call, will junior water users be enjoined from using water until the senior users recover their supply? Unlike the priority call of a surface stream, a priority call on ground water users would be extremely complicated and very expensive in the economy of this state. If the junior ground water users were enjoined from taking water, it might take many years for the reduced pumpage to help the surface users.

Heretofore I have primarily discussed the competition for irrigation water in the Pecos Valley, but it may well be that the big problem of the next decade will be the problems of insuring a dependable source of water for industrial and municipal uses.

Right now the city of Carlsbad is considering expenditure of money for water rights. I understand that these figures may involve over a million dollars. In the adjudication of the Roswell Basin the Special Master held and this ruling was affirmed by the court that the cities of Roswell and Artesia had the right to extend use of the well to the limit of their capacities for extending city use.

At the present time the city of Roswell uses approximately 12,000 acre feet of water per annum, but its well capacity at the time of the adjudication was 27,190 acre feet. In 1931 Roswell was using 2100 acre feet of water per annum. It can be seen at the time of the adjudication, Roswell was using approximately five times as much water as it was using in 1931 and it may have the right to use 2½ times its present use. If the population of Roswell was 40,000 at the time of the adjudication, its paper rights may be sufficient to serve a population in the neighborhood of 100,000. At the time of the adjudication, Artesia was using approximately 3,000 acre feet of water per annum and apparently the court held that it had the right to appropriate to the capacity of its wells which would amount to 5,806 acre feet.

Unless there are objections at the time of the final hearing to adjudicate rights of the municipalities, it is apparent that the municipalities, without acquiring any additional water rights, may increase their withdrawal from the basin many times, but in the case of Roswell particularly, there are severe physical handicaps in its search for additional water. In the area adjudicated, Roswell to the north and east, the salt content of the ground water had increased to alarming proportions.

At the time the isochlor map was drawn in 1960, approximately 5,000 acres of irrigated land were in an area where the water contained over 1,000 parts per million of chlorides. By 1965, there were over 8,000 acres of land being irrigated from sources having over 1,000 parts of chloride per million. Probably over 6,000 of these acres have a priority of 1920 or earlier.

Any increase in pumping for municipality uses will probably cause corresponding increases in the salt content of the water. Roswell was faced with the prospect of locating its well field farther and farther to the west, but if I understand the hydrology correctly a program of moving wells to the fresh water area to the west of Roswell may well be self-defeating.

I understand that all the students of hydrology agree that the salt water encroachment can only be stopped by increased Artesian pressure. Conversely, increased pumping of Artesian water would have to decrease the Artesian pressure and allow further encroachment of salt water. Moving wells to the west would apparently only decrease the Artesian pressure and allow the salt water to move in the fresh water zones at an increased rate. It appears to me that we have not yet been willing to face the problem of water deficiency as a matter of individual and public responsibility. We have not yet been able to develop techniques in law to live within the water income.

As a layman in the field of hydrology and as a student of water law, I do suggest the following beginning steps in a program of survival:

1. The elimination of illegal pumpage which would require a program of metering so that all users would be limited to their legal duty.

2. A transfer of water rights from agricultural to industrial and municipal uses to take care of the increased appropriation of water by municipalities, by Walker Air Force Base, and by industrial users. This would require purchase or condemnation of water rights by the cities of Artesia, Roswell, and Walker Air Force Base. I submit that the cost of acquiring water rights would be less than the cost of importation or the relocation of well fields far removed from the users of the water.

3. An increased program of retiring water rights by the Pecos Valley Artesian Conservancy District. This might require an increase of the taxes levied for this purpose.

4. A stepped-up program of conservation which has been going on in the Pecos Valley for many years and which has been accelerated by the program of long term loans by the Pecos Valley Artesian Conservancy District in cooperation with the Interstate Stream Commission.

5. Although it might not be necessary, since I believe that the cities could purchase sufficient water rights at a reasonable cost, it would be helpful if the laws defining the cities rights of condemnation could be clarified and strengthened.

Steve Reynolds, the State Engineer, at one time said that if the projected population increase of New Mexico were borne out, that by 1975 New Mexico could expect to have a population of 2½ million, and to have sufficient water to serve this population, it would require a deduction in irrigation of 7 per cent.

Although a reduction in our irrigation would be painful we can afford to pay this price.

We need to have some system of allowing transfer of water rights in this arid state from users of low economic value to users of high economic value. Bear in mind that it requires approximately 1 million gallons of water to irrigate one acre of land; whereas the same 1 million gallons of water will take care of many more people in a municipality.

I do not underestimate the agricultural value of water nor the economic value of our irrigation community, but I do feel that it would be better for farmers to be given just compensation for their property rights before their wells run dry and they are reduced to bankruptcy.

Since this is a water deficient state and since the Pecos Valley is a water deficient area our laws and institutions will have to be geared to the proposition that we get the highest possible value out of each gallon consumed.

I think that a program of survival, no matter how costly it would be, would be better than allowing salt water to ruin an entire basin; to contaminate the Pecos River; and to result in a condition where either there is no water, or the water is unfit for use.

In 1930 when the Supreme Court approved the doctrine of appropriation it said:

> "We are hereconsidering 'artesian basins, reservoirs, or lakes, the boundaries of which may be reasonably ascertained by scientific investigations or surface indications.' Such bodies of subterranean water are the principal resource of the localities where they occur. Their employment to the best economic advantage is important to the state. According to the 'correlative rights' doctrine, each overlying owner would have the same right - the right to use whenever he saw fit. The right does not arise from an appropriation to beneficial use, which develops the resources of the state. It is not lost or impaired by nonuse. Regardless of the improvements and investments of the pioneers, later comers or later developers may claim their rights. The exercise of those rights which have been in abeyance will frequently destroy or impair existing improvements, <u>and may so reduce the rights of all that none are longer of practical value, and that the whole district is reduced to a condition of non-productiveness."</u>

> "The preventive for such unfortunate and uneconomic results is found in the recognition of the superior rights of prior appropriators. Invested capital and improvements are thus protected. New appropriations may thus be made only from a supply not already in beneficial use. Nonuse involves forfeitures. A great natural public resource is thus both utilized and conserved."

We are still faced with the problem of developing law and institutions that will allow us to survive while utilizing and conserving a great natural public resource. We cannot fail. We must develop the necessary institutions and laws to survive in this desert.

WATER RESOURCES RESEARCH IN THE UNITED STATES

Roland R. Renne[1]

INTRODUCTION

I am pleased to have this opportunity to participate with you today in your Tenth Annual Water Conference. I am pleased for many reasons.

First of all, because Dr. Ralph Stucky, Director of the New Mexico Water Research Institute located here at this university, was an associate at Montana State for many years. Ralph, as you know, is a Montana native, and we are proud of the work which he has done over the years, and particularly in the years since he has been with you in New Mexico. I understand that he was instrumental in getting the first water conference going, and this Tenth Annual Conference is excellent evidence of the contribution which these annual sessions have made to a better understanding and utilization of the water resources of New Mexico by the leaders and people of the state.

I am very pleased to be here today because the President of New Mexico State University, Dr. Roger Corbett, has been a long-time friend and fellow worker in our National Association of State Universities and Land Grant Colleges, and I have developed a very high regard for him and the work which he has been doing here at your State University. It is indeed a pleasure to be on the campus today and to participate in this program with President Corbett.

Still another reason why I am happy to be here is that I have worked for some 35 years in the West and have had the opportunity to serve on several committees, both national and regional, which have dealt with western water problems, so that I feel that I have some understanding of the problems which are common to our western region and to New Mexico. I feel very much at home on your campus and among you, and am happy to be with you this morning.

I will confine my remarks primarily to the Federal water research program since Dr. Stucky tomorrow will cover the work contemplated by the New Mexico Water Resources Research Institute under the 1964 Act. The Act established a partnership arrangement between the Federal Government and the state land-grant universities and other universities in the states in a coordinated water resources research program. Under this cooperative or partnership research program, the role of the Federal Government is principally one of stimulating, encouraging, advising, and assisting the state water research centers to do an effective research and water scientist training job. These responsibilities include establishing guidelines or general policies for operation of the program, advising as to the most-needed types of research that might be undertaken, coordinating research operations to keep unnecessary and unproductive

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

duplication of effort to a minimum, providing resource material such as catalogs of on-going research projects, assisting principal investigators and research workers to consult with other research workers on similar problems or related efforts, and noting what may be neglected or overlooked important areas needing research.

The Office of Water Resources Research in Washington will not perform any research, but will make funds available as appropriated by Congress under the 1964 Act to provide for a more adequate research program to solve our more major water problems. The state institutes or centers, such as the one which has been established here at New Mexico State University, will conduct research of both a basic and practical nature. There will be 51 such centers throughout the Nation (one in each State and one in the Commonwealth of Puerto Rico). These centers provide an institutional structure conducive to a multidisciplinary attack on water research problems which, up to now, has been generally lacking. By working closely with scientists interested and competent in the field of water resources at the University at Albuquerque and the New Mexico Institute of Mining and Technology at Socorro, the entire research competence and training of the State will be utilized most effectively.

GREAT INTEREST IN WATER PROBLEMS

New Mexico has been concerned with significant water problems for many years. Your senior Senator, Senator Clinton P. Anderson, has taken a leading role in the United States Senate to get legislation adopted which will help to bring sound and satisfying solutions to our major water problems. The Senate Select Committee on National Water Resources, in its report in January 1961, pointed out the extent and character of water resources activities required to meet the water related needs of the United States for various purposes to the years 1980 and 2000, and drew attention to the need for a coordinated Federal scientific research program on water. The hearings of this Committee and its reports (some 32 Committee Prints) were instrumental in providing the background which led to the passage of the Water Resources Research Act of 1964, signed by President Lyndon B. Johnson on July 17, 1964. Your own Senator Anderson sponsored this bill (S. 2) in the Senate, and was instrumental in securing its passage. This session of the Congress has now passed the Water Resources Planning Act, which provides for coordinated planning of water and related land resources through establishment of a water resources council and river basin commissions, and provides financial assistance to the states in order to increase state participation in such planning. Again, your Senator Anderson led the way with his Senate Bill 21 in getting this legislation through the Congress. There are still some minor matters to be settled by conference committees since the bills passed by the House and the Senate are not exactly alike, but it is not anticipated that these minor matters will prevent reaching agreement soon.

The Water Resources Research Act of 1964 and the Water Resources Planning Act of 1965 constitute the legislative basis for a speeded-up and more effectively coordinated nationwide water research and development program.

Our rapidly growing population and our tremendous industrial growth have put tremendous pressure on our water supplies. In the nearly 400 research projects which have been submitted to our office in Washington by the State water research institutes or centers, we note that research proposals dealing with the quantities of water available predominate in states west of the Mississippi, while those concerned with quality of water predominate in the states east of the Mississippi. In our southwest region we are all familiar with the very serious water problems which we face in securing an adequate amount of water to meet the needs of the rapidly expanding industries and population of the region.

SOUND AND SATISFYING SOLUTIONS

Research is vital if we are to discover sound and satisfying solutions to our major water problems. Everyone, of course, would like to think we could have dramatic breakthroughs almost overnight, such as discovery and development of a very low cost method of taking salt out of sea water which would solve some of our more urgent problems, but thus far this has not occurred. Some of the scientists working in the complex fields of water research indicate that they think a "workthrough" is more likely than a breakthrough, meaning that there are many bugs to be removed through advancing technology and applications of scientific research before we will find sound and satisfying solutions to many of our water quality and quantity problems.

We all know that research takes time, especially when applied to some of our most difficult and complex problems. The agricultural experiment stations established by the Hatch Act of 1887 have a wonderful record of achievement. However, they have been in operation for nearly 80 years, and it is only in the last three decades that we have noted the most apparent evidences of their success. Today we harvest less land than we did 20 to 30 years ago, but we produce 60 percent more farm production. The Federal-State research program as exemplified by the agricultural experiment station system has indeed paid off with tremendous dividends, but we must not forget that it took many years of dedicated, tedious, sound research effort by many fine scientists before we reaped such dividends. The same may be true of our water research efforts. Fortunately, we are getting the program under way before it is too late, but certainly there is no time to lose.

THE UNITED STATES WATER RESEARCH PROGRAM

The Federal research program in water involves eight major departments: Agriculture; Commerce; Defense; Health, Education, and Welfare; Interior; Atomic Energy Commission; National Science Foundation; and the TVA. In 1964, nearly 65 million dollars was spent by these Federal agencies on water resources research and surveys. In 1965, the estimated expenditures are 75 million dollars -- or an increase of 10 million over the 1964 level. Budget requests for the 1966 fiscal year total approximately 102 million, or over 26 million more than the budget for the current fiscal year. Most of this increase is budgeted for the Department of the Interior, and is for efforts to advance desalting technology, and to provide support for the State water resources research institutes and related programs. Other increases in the budget for 1966 will provide additional funds for studies in water yield improvement; erosion, sediment, and pollution control; and more adequate research facilities.

Some 1,545 Federally supported water research projects are currently under way. The breakdown of these by agency is: Agriculture, 533; Interior, 532; Health, Education and Welfare, 223; Defense, 98; Atomic Energy Commission, 61; National Science Foundation, 46; Commerce, 26; and the Tennessee Valley Authority, 26.

More than half the total current Federal budget for water research is appropriated to the Department of Interior with nearly 40 million (53%), followed by the Department of Health, Education, and Welfare and the Department of Agriculture with approximately 13 million each, and the remaining less than 10 million spent by the other five Federal agencies mentioned above.

STATE WATER RESEARCH PROGRAMS

State water research programs are revealed through nearly 400 projects which have been submitted to the Office of Water Resources Research for funding under the allotment and matching grant programs. The fourteen institutes which have already been funded submitted 82 projects in connection with their allotment program, or an average of about six per institute. Of the 37 as yet unfunded State water research centers, 26 submitted 260 projects, or an average of ten projects each (eleven centers have not as yet submitted specific projects for funding).

It is interesting to note that more than three-fourths of the projects submitted by State research centers fall into four categories of the nine major categories of water research developed and used by the Committee on Water Resources Research of the Federal Council for Science and Technology, Office of Science and Technology. These four categories are: (1) Water Cycle --

including precipitation, evaporation and transpiration, ground water and hydrogeology, and forecasting; (2) Water and Land Management -- including water movement in soils, water, and plants, watershed protection, water yield improvement, erosion and sedimentation, irrigation, and drainage; (3) Development and Control -- including water supply, hydropower, navigation, urban and industrial water-use problems, recreation, fish and wildlife, and flood control; (4) Qualitative Aspects -- including characterization of wastes, effects of pollution on water uses, interactions of wastes, disposal of waste effluents, effects of development on quality, quality characteristics, and aqueous solutions. Nearly a fifth of all projects submitted fell into each of these four major categories.

RESEARCH MOST URGENTLY NEEDED IN THE SOUTHWEST

In addition to continued efforts to find an economical means of taking salt out of sea water or brackish water to make it useful for human use, and weather modification research to increase precipitation and water supplies, there are three other major areas of research of particular interest to New Mexico and the Southwest. The first of these is water use management applied in the most scientific ways possible to reduce water waste to a minimum, particularly in agricultural areas, so that the same amount of water will be able to go further and do more work. Second, re-use of water. Reclaiming water already used for one or more previous purposes holds much promise, provided research discovers methods of such treatment to make such re-use economical and safe. Third, more adequate classification of water, setting up needed standards to meet certain uses and then carrying out use programs which will utilize the quality suitable for the particular use. Today, much class A or uniformly excellent-quality water suitable for any purpose is utilized for uses which could be satisfied with lower-quality water. Much research, as well as effective classification and administration through effective control, is needed for more efficient utilization of water based upon quality classification.

CONCLUSION

Through annual water conferences such as this, and concerted effort on the part of our Federal, State, and local governments, public and private agencies, universities, experiment stations, research institutes, and individuals, we will be able to solve our more perplexing water problems in the years ahead. The steps taken by the Congress by passage of the Water Resources Research Act in 1964 and the Water Resources Planning Act of 1965 point the way by which our country may be assured of adequate water supplies for continued economic growth.

WATER IN THE ECONOMIC DEVELOPMENT OF NEW MEXICO

Governor Jack M. Campbell[1/]

The story of the relationship between man and water in New Mexico is a long and dramatic one. It is not surprising that the central character in a Pulitzer prize-winning book by a New Mexico author should be a river. I am referring, of course, to Paul Horgan's epic of the Rio Grande -- "Great River." The Rio Grande is the center of our country's oldest known inhabited area. New Mexico is the oldest irrigated area in the nation. When Coronado came this way in 1540, he found irrigation works dveloped by the Indians of that period along the river. The relationship has sometimes been less than friendly where New Mexicans and water are concerned. As one of our state's favorite writers, Erna Fergusson, wrote: "Water is what New Mexico never has enough of -- except where and when it has too much."

April 1, 1965 finds us continuing our centuries old struggle to secure enough water in the right place at the right time. Our tools and strategy may range from the very old to the very new: windmills, ditches, an experimental desalinization plant, dirt dams, a $13 million tunnel through the Continental Divide, pipelines and professional rain makers. We use every means at our disposal to provide that precious liquid that makes life not only pleasant, but possible, and, I believe, we are making progress. Thanks to new public and private projects and the programs of educational and research institutions such as New Mexico State University, I am optimistic about our future. We have some of the finest water laws in the nation and an outstanding agency, the State Engineer's office, to administer them. The state's water program generally reflects an official recognition of the need for development of water for agricultural, municipal and industrial use with increased attention to the demands for water-related recreation.

New Mexico, like other states, has moved from a rural to an urban economy in the past three decades. This population shift has brought changes, some of them painful, to the organization and administration of education, government and business in this state. There is no reason why water priorities should escape the effects of this social and economic evolution. The philosophy of utilization of all natural resources is undergoing a transition throughout the West. When this area was first settled, those who exploited its timber, oil and minerals, its grass, water and farmland were a powerful economic and political force.

They still are. However, the sportsman, the conservationist and the tourist, also are beginning to exert public pressure, alongside the traditional interests of the mine owners, cattlemen and lumbermen.

1/ Governor of New Mexico, Santa Fe, New Mexico

Since 1950, the West, including New Mexico, has grown twice as fast as the nation. There is a surge of new life, much like the frontier spirit. What has been called "The great western tilt" is pouring millions of people into these states. There is new interest in bridging the gap between what our economy now produces and what it might produce in human benefits. This process of wiping out the distance between the actual and the potential is what we call economic development. Education is speeding up this process throughout our nation, and in New Mexico, colleges and universities are playing an increasingly important role in the efforts of government and industry to promote economic growth.

A recent water study indicated that the value added to our economy by use of an acre-foot of water applied to agriculture in New Mexico is about $50, while the value of that amount added to industrial use is about $4,000. As you know, at the present time about 93 percent of all water diverted in New Mexico is used for irrigation. Most of the other 7 percent goes to municipal and industrial purposes. Conferences such as this one can help point the way toward development of all our resources, including water.

WATER SUPPLY

Although New Mexico is located generally in a semi-arid area, we do have water. Precipitation averages about 13 inches a year over the state -- for a gross product of roughly 85 million acre-feet. About 3 million acre-feet of that sum appears as runoff in streams. The remainder returns to the atmosphere through evaporation and use by natural vegetation, or it percolates into the earth as recharge to underground aquifers, which do not discharge to streams within the state.

In addition, New Mexico receives about 2.5 million acre-feet annually of stream flow from Colorado, via the San Juan River and Rio Grande, and about 2,000 from Arizona, via the San Francisco River. Of the combined inflow and in-state surface water yield, about 2 million acre-feet is used up in New Mexico and about 3.5 million is discharged to downstream states. When New Mexico has fully developed her surface-water resources within the allowances of the seven interstate compacts to which she is a party, river inflow to the state will approximately equal outflow, and this state will use about the amount of streamflow that she produces.

In addition, New Mexico is fortunate in having large quantities of water in underground storage -- estimated by the U. S. Geological Survey to total 20 billion acre-feet, of which a fourth, or 5 billion acre-feet, is thought to be fresh or only slightly brackish. Of course, not all the ground water in storage is physically and economically extractable, and we cannot rely on these quantities in planning our future.

WATER DEMANDS

In New Mexico, we are presently diverting about 2.7 million acre-feet of water annually for the irrigation of about 960,000 acres of land. Of that amount, about 1.6 million acre-feet is diverted as surface water and the remaining 1.1 million acre-feet is pumped from wells. About 135,000 acres of the 960,000 irrigated is furnished water from both wells and surface sources, with the underground source being used when surface supplies are deficient.

Most of the irrigated acreage in three of our major irrigation districts -- the Carlsbad Irrigation District on the Pecos River, and the Middle Rio Grande Conservancy District, and the Elephant Butte Irrigation District on the Rio Grande -- are served with both surface and ground water.

Only about 170,000 acre-feet of water is used annually for municipal and industrial purposes. About 70 percent of this amount is taken from ground water sources. All but a few of our major cities rely entirely on ground water sources for municipal supply.

GROUND-WATER PROBLEMS

Use of ground water in New Mexico for irrigation and other purposes increased from less than one-half million acre-feet in 1940 to about one million in 1960. New Mexico's ground-water code, vesting in the State Engineer authority to supervise the appropriation and use of ground water, dates from 1931. Thus far the State Engineer has declared 20 basins, embracing a total of about 25,000 square miles -- more than a fifth of the state's area.

The locations of all large supplies of economically usable ground water in New Mexico are believed to be generally known and an increase in ground-water usage in the next 20 years, comparable with that of the past 20 years cannot be anticipated. However, the problems of administration are certain to increase in number and complexity as demands continue to rise, as supplies diminish, and as competition stiffens.

Most of the 1.1 million acre-feet of ground water being pumped in New Mexico at present is being "mined." That is, in most areas the average withdrawal from the aquifer exceeds the average annual recharge, and water levels are declining. It is desirable that groundwater resources be available to future generations; however, the mining of water can be justified as readily as the mining of our other natural resources, such as gold, oil or coal.

In some instances, it may be possible to meet these problems by adjustment of the area economy. The municipal and industrial market for water can bear much higher costs than irrigation agriculture.

Thus, when reduced yields per well or excessive pumping lifts make pumping for agriculture uneconomic, the residual water may supply the municipal and industrial needs of a vigorous nonagricultural economy for many years. The problems of the future may be met in part by importation of water and by desalinization of locally available saline and brackish waters.

FUTURE WATER DEVELOPMENT

There are several ways in which the growing need for water in New Mexico can be met. One of these is to develop the substantial amounts of the water which New Mexico is entitled to use under our interstate compacts and which have not yet been put to beneficial use.

San Juan River .

Under the Colorado River Compact of 1922 and the Upper Colorado River Basin Compact of 1948, New Mexico may deplete the flow of the San Juan River and its tributaries in New Mexico by 800,000 acre-feet or more annually. We are presently depleting the flows of the San Juan system by about 100,000 acre-feet per year, or one-eighth of the depletion to which we are entitled.

The Colorado River Storage Project Act of 1965 authorized the Bureau of Reclamation to construct four large storage reservoirs. The first major unit to be completed was Navajo Dam and Reservoir near Aztec three years ago. Besides providing one of the best boating and fishing lakes in the Southwest, this unit will store water for the Navajo Indian Irrigation Project and the small Hammond Irrigation Project. The Navajo project is presently under construction and will irrigate 110,000 acres on the reservation in the San Juan Basin. The $135 million completed arrangement of canals, tunnels, siphons, pumps and power plants will also supply municipal, industrial and recreation needs.

Also under construction is the San Juan-Chama Transmountain Diversion Project, sponsored by the federal government to bring dramatic expansion in recreation, conservation, agriculture and industry in northern New Mexico and the Rio Grande Basin. When completed in 1971, it will bring an average of 110,000 acre-feet of water a year from Colorado through the Continental Divide into New Mexico.

Digging began early this year on the first tunnel of the $89 million project with the use of a new machine, called the Mole, chewing its way through the mountains west of Chama. In addition to conservancy district and tributary units allotments, this system will supply 53,000 acre-feet annually for the city of Albuquerque, and 5,000 acre-feet to maintain the Cochiti recreation lake to be formed on the Rio Grande between Santa Fe and Albuquerque.

The total cost of works constructed and authorized for New Mexico as part of the Colorado River Storage Project appears to come to more than $270 million.

Canadian River

The Canadian River Compact, executed in 1950 by New Mexico, Oklahoma and Texas, allots to New Mexico free and unrestricted use of all waters originating in the drainage basin of the Canadian River below Conchas Dam, with a 200,000 acre-feet limit for conservation storage.

The Ute Dam was built in 1961-62 with $5 million of state funds near the village of Logan in Quay County. It was the first major dam in New Mexico to be constructed entirely with state financing. A number of communities in eastern New Mexico are planning a pipeline transmission system and negotiating with the Interstate Stream Commission for purchase of water from Ute Reservoir. With a 50,000 acre-feet permanent pool for recreation, it appears the recreation usage alone will go a long way toward justifying the state's investment.

Gila River

We also hope to develop additional water for use in New Mexico on the Gila and San Francisco Rivers, which rise in our state and flow through Arizona to the Lower Colorado River. Studies indicate it would be possible to construct Hooker Dam in western New Mexico and increase our uses by 50,000 acre-feet per year in an exchange for Colorado River water if the Central Arizona Project is authorized. We have not yet been able to persuade Arizona officials to agree to this exchange. I am optimistic that agreement can be reached, although it may be delayed by what is sometimes called "hydropolitics".

FUTURE WATER DISTRIBUTION

Current plans for the development of the unused 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 at least the Albuquerque area of the Rio Grande Basin for several decades, and at the same time provide for substantially increased agricultural usage and recreation opportunities.

In other areas of the state, growing municipal and industrial needs can be met by acquiring water rights presently being exercised for irrigation. It seems clear that the necessity to pay a fair price for redistribution of water from agricultural to industrial use should be no deterrent to the establishment of an industrial economy. Industries that come to New Mexico are those that do not place a heavy demand on water resources: minerals development and processing, lumber products, food processing, electronics and instrumentation.

Generally speaking, competition among various types of water users in New Mexico is not intense at this time as the industrialization and urbanization which the experts anticipate for New Mexico is just beginning. In 1950 our population was 681,000. It passed the million mark last year, and it has been predicted by the New Mexico Bureau of Business Research that there will be more than two million residents here by 1980. Whether or not these projections are realized will depend on a number of factors, including the manner in which we manage our water resources.

In projecting population and water needs, we realize that agricultural activities will provide little opportunity for increased employment. For example, it is estimated that the proposed 110,000 acre Navajo Indian Irrigation Project will provide for the livelihood of about 18,000 people on the Navajo Reservation. The operation will divert about 508,000 acre-feet of water and will deplete the supply by 254,000 acre-feet, a depletion of about 14 acre-feet per person. In an urban-industrial economy, such as that presently existing in the Albuquerque area, the depletion requirement is only about one-tenth of an acre-foot per person. So, if current projections of 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 a spectacular rise in our economic base and population.

Also, the demand for water-related recreation is bound to boom as we experience continued growth in number of people and hours for leisure.

RECREATION WATER

Those who think of New Mexico as a desert state will find it difficult to believe that the State Park and Recreation Commission has registered almost 9,000 boats.

There are 14 important storage reservoirs in New Mexico, reservoirs having a usable capacity of 30,000 acre-feet or more. While some of these are primarily for flood control, at least 11 of them provide substantial recreational opportunity. Two of them -- the Navajo and the Ute -- also are designed for municipal and industrial uses.

Recreational facilities will be found at the Alamogordo Reservoir on the Pecos River; Bluewater Lake on Bluewater Creek; Caballo on the Rio Grande; Conchas on the Canadian River; Eagle Nest on Cimarron Creek; Elephant Butte on the Rio Grande; El Vado on Rio Chama; Lake McMillan on the Pecos River; Morgan Lake on La Plata River; Navajo on the San Juan; and Ute Reservoir on the Canadian. Cochiti Pool on the Rio Grande will provide recreational opportunities for the most heavily populated area of New Mexico when it is completed.

New Mexico has some of the best trout streams and lakes and warm-water fishing in the Southwest. The state's fish and game resources attract sportsmen by the hundreds of thousands, thus bolstering the economy by many millions of dollars annually. In the mountainous northern sections and in the southwestern mountains are hundreds of miles of clear, cold, trout water, where one can find various species from Loch Leven to Brown. Lake fishing offers crappie, sunfish, largemouth black bass, catfish and walleye.

Most of the warm water fishing is provided by four large reservoirs: Conchas Lake, Elephant Butte, Caballo and Alamogordo. In addition, there are about 175 smaller lakes and reservoirs in the state, totalling 375,000 surface miles. There are about 15 fishing streams that are 20 feet wide and have a combined length of 1,300 miles. There are 250 fishing streams under 20 feet in width and totalling 2,250 miles in length.

MODERN NEW MEXICO

I have mentioned this morning a few of the reasons why I am optimistic about New Mexico's future, not only in regard to meeting our water needs, but in every aspect of economic and human progress.

I would like to add that our state's economy is entering its fifth year of uninterrupted growth. I believe the advances we have seen the past few years indicate what we can expect in the future if we continue to utilize efficiently our natural and human resources.

You have all heard by now of the article that appeared in a national magazine last year describing New Mexico as a center of scientific-related industry and smokeless think-and-theory businesses. The emergence of the Land of Enchantment as a leader in the new age of atomic energy and space travel has been the result of world history, our unique geography, and finally, recognition of the economic value of brainpower.

History provided World War II and the demand for a super weapon to stop that slaughter. Geography provided in New Mexico the wide open spaces and isolated mountain region suitable for secret production and testing of the secret bomb.

A desolate area not far from Las Cruces provided space for the first nuclear blast that early morning 20 years ago this coming July 16. Later, it offered enough room for the testing of rockets and missiles as the United States aerospace program took its first tottering steps across White Sands Missile Range. Just for good measure, nature threw in the largest deposits of uranium in the free world in northwestern New Mexico.

Developments up to that point had been the result of coincidences in history and geography. Then education and government realized the practical value of these mysterious research and testing centers. New Mexico State University and the University of New Mexico strengthened their scientific disciplines and recruited top personnel to direct their departments. Laboratory and research facilities were improved and enlarged, and they received valuable contracts to conduct important projects for the military services and the Atomic Energy Commission. The State Department of Development took a survey and found that New Mexico had more citizens per capita with advanced degrees in scientific and engineering fields than any other state.

I believe the future of New Mexico, including the development of its water resources, lies in giving top priority to quality education at every level and to the attraction of scientifically oriented personnel and industry. The high growth businesses of tomorrow will be based on brain power and human excellence. This kind of industry will not be looking so much for communities with railroad sidings and low-cost water as for intellectual climate receptive to new ideas and unconventional ways of doing things. This is the kind of climate that this institution and you who are present at this conference are helping to create.

I believe the Land of Manana can move into the 21st century of nuclear-powered space ships, without sacrificing its friendly charm and colorful mingling of Spanish, Indian and Anglo cultures. We do not need to neglect our traditional economic base of agriculture, mining and oil production, while luring technical and electronic operations, and promoting tourism and outdoor recreation. The type of person who works at a laboratory or research center will enjoy the kind of scenery and outdoor activities to be found in the Southwest.

You might be interested in some of the things that state government and private enterprise are doing cooperatively to bring visitors and new residents to New Mexico. When I leave here this afternoon, I will go to Albuquerque to take part in our second statewide conference on tourism, conventions and recreation. We will meet with people from all areas of New Mexico to help them promote their particular type of enchantment. Our national advertising campaign has been expanded this year to seven major magazines and 15 newspapers. The State Department of Development is assisting White Sands Missile Range officials in establishing tourist information facilities at road blocks set up during missile firings. The Junior Chamber of Commerce is going all out to help sell the New Mexico Magazine. Our state will be represented at the New York World's Fair again this year with an exhibit financed out of private funds in cooperation with state development leaders.

New Mexico streams and rivers will receive 50 percent more trout this year over last as the result of the recent construction of new and improved fish hatchery facilities by the State Game and Fish Department. The State Park and Recreation Commission has doubled the number of facilities at state parks the past two years. Boat launching ramps, access roads and other public facilities have been built at Elephant Butte and Caballo recreation areas, which have been turned over to the state by the federal government for operation.

CONCLUSION

In conclusion, I would like to repeat that there is no phase of economic development in New Mexico in which water does not play some role, usually an important one. That is why I appreciate this conference and you who have come here to exchange ideas and to help us find ways of using efficiently the water that we have and finding new sources of this indispensable resource. Water has been the key to great happiness and the cause of great misery to the people of the Rio Grande for many centuries. I believe the challenges we New Mexicans face in 1965 are as exciting and hopeful as any in the history of man.

In a message to Congress in 1962, our late President John F. Kennedy said, "Our nation's progress is reflected in the history of our great river systems. The water that courses through our rivers and streams holds the key to full national development." He went on to add: "Our goal, therefore, is to have sufficient water sufficiently clear in the right place at the right time to serve the range of human and industrial needs."

I am confident that with the counsel and leadership of citizens like yourselves, we in New Mexico will meet and solve these problems successfully.

GEOGRAPHIC AND CLIMATIC CHARACTERISTICS OF THE PECOS RIVER BASIN IN NEW MEXICO

Frank E. Houghton[1/]

ABSTRACT

The Pecos River is the principal tributary of the Rio Grande River, arising on the second highest peak in New Mexico and leaving the state at its lowest ground elevation. The river drops rapidly in its headwaters, and then gradually through the widening, north to south sloping valley, where there is intensive agriculture. The general semi-arid, continental climate of the Pecos River Basin is described, including the various influencing air masses. The annual march of climate from cool, dry winter, through changeable, windy spring, hot, rainy summer, and cooling, drying fall is outlined. Average annual sunshine, cloudiness, wind, evaporation, and relative humidity are described, and deviations noted.

TOPOGRAPHY

The Pecos River originates on South Truchas Peak in the Sangre de Cristo Mountains which is the second highest point in New Mexico, elevation 13,102 feet above mean sea level. The river flows southward in New Mexico, entering Red Bluff Reservoir, Texas just beyond the southern New Mexico border. In Texas, the Pecos River meanders south-eastward, joining the Rio Grande River, of which it is the principal tributary, just above Del Rio, about 900 miles from its origin. The lowest elevation in New Mexico is at the point where the Pecos River leaves the state, 2,840 feet. The Pecos River Basin in New Mexico covers an area of approximately 25,000 square miles, which is about 55 percent of the total Pecos basin area of New Mexico and Texas combined.

The Pecos River Basin in New Mexico is bounded on the east by the Caprock escarpment, formed by erosion, which rises several hundred feet above the valley terrain and is the boundary of the High Plains to the east. This escarpment is a west-facing wall in southern New Mexico running northward along the eastern border of Chaves and Roosevelt counties, then turning northwestward through Guadalupe County and merging with the foothills of the Sangre de Cristo Mountains in San Miguel County. In its first 30 miles of southward travel to the town of Pecos, the river drops over 6,000 feet in elevation. Its slope then decreases and the river goes southeastward at the base of Glorietta Mesa, to the southwest, and on to Santa Rosa and Alamogordo Dam, 4,300 feet mean sea level. In this portion of the basin are the tributaries from the east, the main tributary being Gallinas River flowing past Las Vegas, and Alamogordo Creek flowing into Alamogordo Dam.

1/ State Climatologist, U.S. Weather Bureau, Albuquerque, New Mexico

To the west of the Pecos Valley in southern New Mexico is a north-south series of mountain ranges; composed of the Jicarillas, Sierra Blancas, Capitans, Sacramentos, and Guadalupes, the latter extending about 20 miles south of the Texas border and having the highest point in Texas, Guadalupe Peak, elevation 8,751 feet. These mountains rise abruptly to elevations of mostly 7,000 to 8,000 feet, but peaks above 12,000 feet are reached in the Sierra Blanca area.

Most tributary streams to the Pecos River rise in these mountains to the west, while the Pecos River flows close to the eastern edge of its basin. Among the primary tributaries from the west are the Rio Hondo, Rio Felix, Rio Penasco, and Black River, which are perennial only in their upper reaches. Numerous arroyos approach the valley floor from the mountains and downward sloping rolling hills. Slopes of the southern mountains are part of the Lincoln National Forest, and the headwaters are in the Santa Fe National Forest.

The lower portion of the Pecos Valley in New Mexico is oriented north-south, is about 100 miles wide, and extends about 200 miles north of the Texas border. Intensive cultivation produces cotton, truck gardens, and row crops, which are grown under irrigation. Much of the area is used for grazing, and there are rich sources of potash, gas and oil in the southeast.

GENERAL CLIMATE

The climate of the Pecos River Basin is predominantly continental, characterized by rapid temperature changes, marked temperature extremes, and large daily and annual temperature ranges. Small areas have mountain climate, cooler throughout the year than the adjacent lowlands. Temperatures are generally mild, increasing in an irregular pattern from north to south in response to latitudinal and elevation changes.

Precipitation amounts generally increase with elevation. However, because of the high plateaus or mesas, mountain ranges, canyons, and valleys, there are great variations in climate over short distances. Although much of the southern Pecos River Basin in New Mexico receives an average annual precipitation of near 12 inches, it increases at higher elevations to become 24 inches or more in the small areas of higher mountains. An annual total of 62.45 inches was measured at White Tail, in the Sierra Blanca Mountains, in 1941, while only 2.61 inches was measured at Lake Avalon during the year 1917. Large variability may be noted at a given location over a period of time, also, as illustrated by an annual total precipitation at Lake Avalon of 36.27 inches in 1941, compared to the 2.95 inches accumulated in 1917, a range of over 33 inches.

Temperatures in the Pecos River Basin have ranged from extremes of 116 degrees Fahrenheit at Artesia, June 29, 1918, which ties with Orogrande for the highest temperature in New Mexico, to 27 degrees below zero Fahrenheit at Cowles in February 1899. Summer temperature at the mountain located station of Cowles has been as high as 90 degrees, despite its 8,000 feet elevation.

In general, the Pecos Basin slopes upward from southeast to northwest, and it is the gradual rise that plays a very important role in the weather and climate of the area. Air flowing over the area from the northeast through south is cooled adiabatically as it is raised by the terrain, and when moist, condensation results in increasing low cloudiness, fog, or drizzle. This effect is most pronounced with a southeasterly or easterly flow, and least pronounced with a southerly flow. Persistent southeasterly flow for several days will, at times, result in low cloudiness all the way from the Gulf of Mexico to the mountains of central New Mexico. The same lifting, particularly during hot summer weather, helps to trigger the thunderstorms.

When the airflow over the Pecos Basin is from the southwest through northwest, adiabatic heating results from the downslope movement. This results in warming temperatures, and when from west to southwest brings minimum cloudiness.

The central New Mexico mountains help to block moisture bearing air from the Pacific Ocean source region from the Pecos Basin. Already, much moisture has been lost from the air through condensation and precipitation in passing over the mountains of California, Arizona, and New Mexico. Meager rains and snows result when the supply of moist Gulf of Mexico air is cut off from southeastern New Mexico, because this is its major source of moisture.

AIR MASSES

The predominant air mass in the Pecos River Basin is tropical maritime, being present practically all of the rainy season, May through September. The Bermuda high pressure area strengthens and extends westward in late spring and summer, and southeast to south circulation about this high brings warm, moist air from the Carribean and Gulf of Mexico into the Pecos valley and against the central mountains of New Mexico. Entry of this air is favored by the lower elevation and broader expanse of the valley at the south. Orographic lifting of the air as it flows upward over the valley floor towards the mountains to the north and west produces the frequent showers and thunderstorms of the rainy season. Squall lines may often form over the mountains and move eastward across the valley and high plains. Air mass flow from the Gulf of Mexico may also occur, but with less frequency, during the winter months, after the Bermuda High has retreated eastward.

Hot, dry topical continental air from over the high plateaus of Mexico and desert area of California and Arizona occasionally intrudes into the Pecos Valley in late spring and early summer. This hot, very dry air brings almost cloudless skies, and is responsible for the occasional "heat waves" which seldom last for more than a few days.

Polar maritime air occasionally enters the Pecos Valley from the northwest. Because of the high mountain barriers to the west which remove much of the moisture as condensation and precipitation, this air usually arrives in eastern New Mexico as cool, relatively dry air, ordinarily bringing but light precipitation. High winds and blowing dust may accompany this air, and frequently cloudiness arrives just behind its leading edge.

Polar continental air masses are most common in the winter and early spring, entering the Pecos Valley from the Great Plains and northward. This air brings the intense and sustained periods of cold weather which occasionally reach southeastern New Mexico. The degree of cold depends upon the source, region, and southward penetration of this cold air and the amount of warming as the Canadian or Arctic air moves overland. Precipitation generally does not occur, except when this air mass interacts with moisture bearing air masses, and then is usually light snow in the higher elevations and light rain in the lower elevations of the south. Winds may be strong and gusty along the leading edge of this cold air mass.

SEASONAL CLIMATE

WINTER - Four seasons are generally definable in the Pecos Basin. Winter, December through February, is the cold, dry period, but usually mild in the afternoons. Average high temperatures range from 50 degrees at Las Vegas to 61 degrees at Carlsbad, while average low temperatures range from 18 at Las Vegas to 30 at Carlsbad. Temperatures drop to freezing on most days in the north and about two-thirds of the days in the south, but seldom do temperatures fail to rise above freezing during the day, or drop to zero or below. January is the coldest month, but lowest temperatures may occur almost as often in February. Temperature changes are frequent, but cold spells seldom last more than two or three days. The average change in mean temperature from one day to the next is 6 degrees, but has been as great as 21 degrees. At Roswell, only 8 percent of these mean temperature interdiurnal changes exceed 11 degrees, but have been as great as 26 degrees. Precipitation in the Pecos Valley averages near one-half inch in each of the winter months, the driest season of the year. Much of the winter precipitation falls as snow in the mountains and high plains, but little snow falls in the lower elevations. The average annual snowfall at Carlsbad is 3.1 inches. In the north part of the basin about half of the seasonal snowfall occurs in the three winter months, averaging an annual total of 30.7 inches at Las Vegas and 81.2 inches at Cowles. The daily range of temperatures is large, averaging about 31 degrees, a daily range which changes but little throughout the year.

SPRING - The months of March through May - is the season of most rapid and pronounced weather changes, especially March and April. There is a rapid succession of warm and cold spells, but with slightly less frequency and range than in winter. Average maximum temperatures range from near 64 degrees at Las Vegas to 80 at Carlsbad, and average minimum temperatures from 33 at Las Vegas to 47 at Carlsbad. Average temperatures near these values occur again in the fall. Monthly temperatures gradually rise about 16 degrees from March to May. Strongest winds and most severe dust storms of the year occur during spring, and also the most adverse flying weather of the year. Average monthly precipitation increases in March and April, and much more rapidly in May as maritime air from the Gulf of Mexico increases its flow into the Pecos Valley. Thunderstorm season begins in May, accompanied by occasional tornadoes. The average date of the last spring temperature of 32 degrees or lower falls in the spring ranging from early April in the south to early May in the north. The tornado season begins in the spring, with most occurrences in May, and continues into June and decreases in July. Two-thirds of the years in the past 49 have gone without tornadoes, and the maximum number in any one year was 6 in 1962. Because of the open nature of the land, few tornadoes cause damage, and but one injury due to flying materials has been reported

SUMMER - the months of June through August - is the hot and rainy season. July has the highest average temperature of the months, but is little higher than June due to the moderating effect of the increasing rains. Average high temperatures range from 84 degrees at Las Vegas to 96 at Carlsbad, while average low temperatures range from 52 at Las Vegas to 67 at Carlsbad. Maximum temperatures of 90 degrees or greater are frequent in the south, the average number of days per year at Carlsbad being 122, while only 14 occur at Las Vegas. On many of these days the temperature may reach 100 degrees or more. A few 90 degree or greater days occur in May and September in the north and several in the south. In the north portion of the Pecos Valley, July and August are the months of greatest precipitation, while a small decrease from May is seen during June. In the southern portion, however, the precipitation is more evenly distributed from May through September, with some of the heaviest rains in late spring and early fall. Nearly one-third of the annual precipitation falls during the months of July and August, while over half the annual rain falls during the four-month period, June through September. Twenty-four hour total rainfalls of over 5 inches have been most frequent in July and August, but may occur from June through October. Heaviest amounts of 6 and 7 inches have occurred in the fall months of September and October. The greatest 24-hour amount of record at usual measuring stations in the Pecos Valley was 7.71 inches at Meek, Lincoln County, September 16, 1919; however, a total of 11.5 inches was unofficially measured at Dave McColleum Ranch, in the Guadalupe Mountains, September 20, 1941.

FALL - the months of September through November - has a combination of moderate temperatures, relatively low wind speeds, and frequent intrusions of mild, dry polar air, making fall the most pleasant season of the year. Average temperatures lower throughout the season and precipitation falls off sharply after September. Fall frosts occur, with the average date of the first fall temperature of 32 degrees or lower ranging from near October 8 in the north, to late October in the south. This limits the average "growing season" to a period ranging from 153 days in the Las Vegas area to 216 days (or over 7 months) at Carlsbad.

SUNSHINE AND CLOUDINESS

Throughout the year sunshine is plentiful in the Pecos River Basin, which is not too far distant from the area of maximum sunshine in the United States, near the California-Arizona border. About 75 percent of the possible time of sunshine is experienced, with little difference by season of the year. About 3,300 hours of sunshine may be expected annually, ranging from a total of near 220 hours during the shorter days of January to near 340 hours during the longer days of July.

Average cloudiness is less than one-half the sky covered by clouds, and thin cloudiness included in this average allows sunshine to reach earth. Averages during a 16 year period at Roswell show an annual number of 183 clear days (those with 0 to 3 tenths average cloudiness), 99 partly cloudy days, and 83 cloudy days (those with 8 tenths cloud cover to overcast).

WINDS

The prevailing direction of surface winds in the Pecos River Basin closely follows the course of the river, but opposite to the water flow. At Carlsbad and Roswell the annual prevailing direction is from south-southeast, while at Las Vegas on the Gallinas River branch it is from southwest. Prevailing monthly wind directions deviate from the annual by backing to south in winter at Las Vegas, and by veering to west-southwest during winter and early spring at Carlsbad. Wind speeds are generally lightest from north through east-southeast, particularly in the fall, averaging near 9 miles per hour. Strongest average wind speeds are from south-southwest through west-northwest, primarily in the spring, averaging near 14 miles per hour. Annual average wind speed is near 12 miles per hour through most of the basin, but Roswell has less wind with an average nearer 9 miles per hour.

EVAPORATION

Solar radiation, temperature, and wind movement are major influences on amount of evaporation. Values generally increase from north to south in the Pecos Valley, with a range, measured from standard "Class A" evaporation pans, of from near 75 inches in the Las Vegas area to near 115 inches annually at Lake Avalon. This potential evaporation is 10 times the average annual precipitation measured at Lake Avalon. About two-thirds of the evaporation occurs during the six-month primary agricultural season, May through October. Spring months generally have greater evaporation than the fall months, mainly because of the stronger winds of spring. Extremes of annual evaporation have been as high as 131 inches at Lake Avalon, and as low as 86 inches at Bitter Lakes Wildlife Refuge. Lower evaporation amounts in the north and mountains result largely from their lower mean temperatures.

RELATIVE HUMIDITY

Because relative humidity is a function of temperature, there is a general gradual decrease from north to south in the Pecos River Basin of New Mexico, but annual values remain in the low and middle fifties. The higher humidities are usually measured in the early part of the day, the average being near 65 percent at 6:00 A.M., mountain time. During the hotter part of the day, the relative humidity averages near 40 percent. Lowest monthly average humidities are in the spring and early summer, and are about 20 percent lower than in the late summer and early fall rainy season.

BOOKS RECOMMENDED

Books recommended as sources of further details of geographical and climatological characteristics, and historical development of the Pecos River Basin in New Mexico and Texas include: Robert T. Lingle and Dee Linford, THE PECOS RIVER COMMISSION OF NEW MEXICO AND TEXAS, The Rydal Press, Santa Fe, New Mexico, 1961, 284 pp.; and Robert B. Orton, THE CLIMATE OF TEXAS AND THE ADJACENT GULF WATERS, U. S. Department of Commerce, Weather Bureau, Washington, D. C., 1964, 195 pp. Detailed daily, monthly, and annual climatological data for the Pecos River Basin in New Mexico may be found in monthly and annual issues of CLIMATOLOGICAL DATA, NEW MEXICO, U. S. Department of Commerce, Weather Bureau, and a general summary in CLIMATES OF THE STATES, NEW MEXICO, Climatography of the United States No. 60-29, available from Superintendent of Documents, Washington, D. C. 20402.

AVAILABILITY AND QUALITY OF GROUND WATER
IN THE PECOS RIVER BASIN

George E. Maddox[1/]

INTRODUCTION

The ground-water regimen of the Pecos River basin can be divided into five segments, each of which constitutes a separate ground-water unit. The occurrence of ground water in each unit, the differences in the chemical quality of water in the various aquifers, and the development of ground water in each unit is related to the drainage system of the Pecos River. Geological factors guide the movement of ground water within and between the ground-water units; however, the Pecos River is the unifying hydrologic feature. The five ground-water units are outlined in figure 1. Hydrologic conditions within each ground-water unit within the Pecos River basin will be discussed in downstream order -- that is, from north to south along the Pecos River. General data on water use, chemical quality of water, potential yield of wells, source of recharge, and status of aquifer development are shown in table 1 for all principal aquifers along the Pecos River.

UNIT 1 - HEADWATERS OF PECOS RIVER TO ANTON CHICO

In the segment, or reach, of the Pecos River from its headwaters to Anton Chico, nearly all the base flow of the river and its upper tributaries comes from ground water discharged by the Magdalena Group (Griggs and Hendrickson, 1951). Rocks of the Magdalena Group overlie crystalline bedrock and form the first aquifer above the geologic basement. Hydrologic information and related data on the Magdalena Group and other aquifers in this reach of the Pecos River are described in table 1.

In this reach of the Pecos River a constant supply of fresh water is discharged into the river from aquifers. Owing to the availability of this fresh water, plus the fact that wells in this area are generally of low yield (fig. 2), surface water is the major source of water for irrigation in Unit 1 (fig. 3). Ground water, however, is an attractive source of supply for needs other than irrigation because of its shallow depth and general low salinity (figs. 4 and 5). Data are not available on the volume of ground water pumped in Unit 1; probably the volume is quite small.

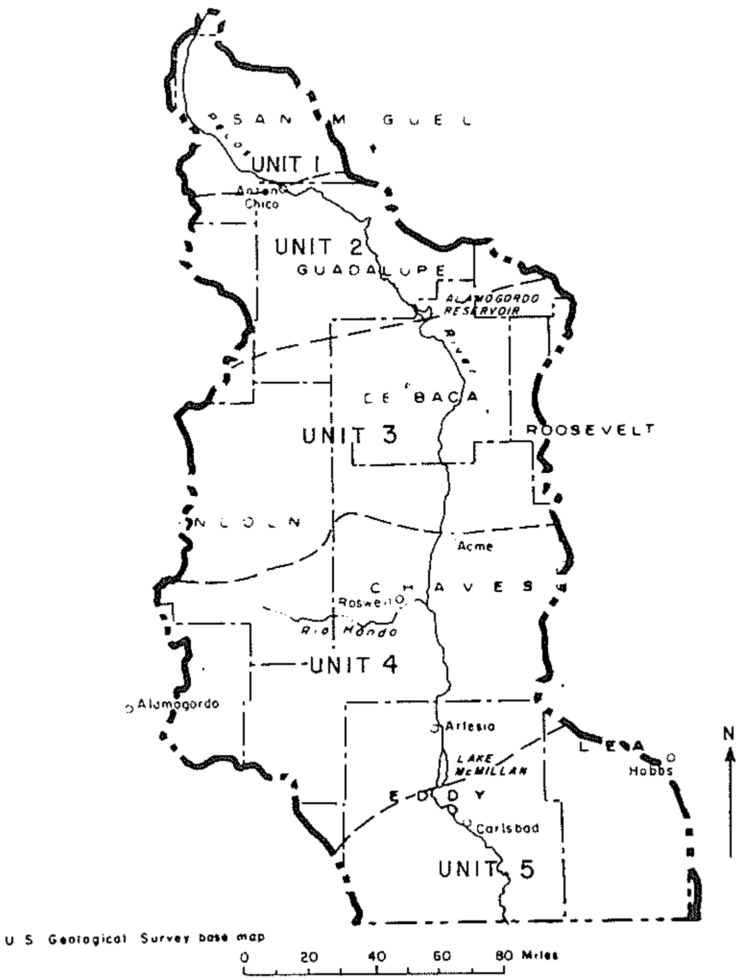
UNIT 2 - ANTON CHICO TO ALAMOGORDO RESERVOIR

This reach of the Pecos River basin is similar to Unit 1 above Anton Chico except that the aquifers are in geologically younger rocks. Because the older aquifers lie at increasing depths southward, they are not within practical drilling depth in this reach of the basin.

1/ Geologist, U. S. Geological Survey, Ground Water Branch, Roswell, New Mexico

Table 1.--PRINCIPAL AQUIFERS IN THE PECOS RIVER BASIN

System	Geologic source	Series	Headwaters of Pecos River to Anton Chico	Anton Chico to Alamogordo Reservoir	Alamogordo Reservoir to Acme	Acme to Lake McMillan	Lake McMillan to State line	Water use	Water quality	Potential yield (Gallons per minute)	Source of recharge	Aquifer development
Quaternary	Alluvium		X	X	X	X	X	Industrial, irrigation, stock, domestic.	Water is hard, but low in dissolved solids.	From 4 to 2,000.	Surface-water flow over outcrops, return irrigation, ground-water flow from other aquifers, and direct precipitation upon outcrops.	Overdeveloped in most areas.
Tertiary	Ogallala Formation		X	X				Domestic, stock.	Water quality varies widely but in general is fair.	Less than 1 to more than 1,600.	Small amounts of recharge from direct precipitation on outcrops.	In the Pecos River basin the formation covers only a small area and is not strongly developed.
Cretaceous	Mesaverde Formation					X		Stock.	Poor quality water, with bicarbonate and sulfate as the most dominant constituents.	From 5 to 20.	Direct precipitation on outcrops.	Poor quality of water limits its use and consequently the aquifer is not strongly developed.
Cretaceous	Mancos Shale					X		Unsatisfactory for all uses.	Poor quality water, highly mineralized.	From 6 to 75.	Unknown, probably the recharge is negligible.	Very little development because of poor quality water.
Cretaceous	Greenhorn Limestone			X				Stock, domestic.	High in sodium bicarbonate, fair to poor quality.	Less than 1.	Direct precipitation, flow from other aquifers. (Water occurs in fractures in the limestone.)	Owing to low yield, aquifer has not been widely developed.
Cretaceous	Graneros Shale							Stock.	Water is of poor quality, has a fluoride content greater than 3, a hydrogen-sulfide odor, disagreeable taste, and cloudy appearance.	Less than 1 to greater than 10.	Upward leakage from underlying Dakota Sandstone.	Because of poor quality of water and low yield there has been very little development.
Cretaceous	Dakota Sandstone		X			X		Domestic, stock.	Water is generally of good quality except where water flows into the formation from adjacent aquifers.	Between 1 and 125.	Streamflow over outcrops, direct precipitation on outcrops, flow of ground water from adjacent aquifers.	Despite low yield the aquifer has been extensively developed.
Jurassic	Morrison Formation		X	X				Domestic, stock.	Water is hard and is of poor to fair quality.	From 1 to 5.	Direct precipitation, surface-water flow over outcrops.	Despite low yield and poor quality the aquifer has some development.
Jurassic	Entrada Sandstone		X	X				Domestic, stock.	Good quality, soft water with sodium bicarbonate as the main chemical constituent.	Less than 1 to more than 50.	Small amounts of recharge by flow of surface streams over outcrops.	Present use of water from the Entrada is such that the aquifer is not overdeveloped; however, limited recharge indicates the aquifer could be overdeveloped if subjected to more intense pumping.
Triassic	Chinle Formation			X		X		Domestic, stock.	Fair to poor quality of moderately hard water.	Less than 1 to more than 50.	Surface-water flow over outcrops, direct precipitation on outcrops.	Widely developed for stock and domestic use.
Triassic	Santa Rosa Sandstone			X	X	X		Stock and domestic.	Water ranges from fair to poor quality with sodium bicarbonate in amounts detectable by testing.	From 1 to more than 750. (Locally under artesian pressure.)	Surface-water flow over outcrops, direct precipitation on outcrops.	Do.
Permian	Rustler Formation	Ochoa Series				–	X	Stock.	Water is of poor quality. Some saturated brine.	From 1 to 10. As much as 600 at Malaga Bend 20 miles south of Carlsbad.	Direct precipitation on outcrops, lateral and vertical leakage from subjacent and superjacent rocks.	Because of poor quality water, the aquifer is not strongly developed.
Permian	Castile Formation						X	Stock and domestic.	High in sulfate and of poor quality.	From 1 to 10.	Direct precipitation on outcrops, surface-water flow over outcrops.	Not strongly developed because of poor quality and low yield.
Permian	Tansill Formation						X	Stock, domestic, irrigation.	Fair quality, potable water high in bicarbonate.	2,300 to 3,000.	Leakage from Lake Avalon, streamflow over outcrops, direct precipitation on outcrops.	Strongly developed.
Permian	Yates Formation	Artesia Group				X	X	Stock, domestic.	Fair to poor quality, high in chloride and sulfate.	Up to 2,000.	Streamflow over outcrops, direct precipitation on outcrops.	Not strongly developed because of poor quality in most areas but possible good quality of water in outcrop areas west of the Pecos River.
Permian	Seven Rivers Formation					X	X	All uses -- irrigation, industrial, municipal.	Water is hard but of good quality in most areas.	From 10 to more than 1,000.	Surface-water flow over outcrops, direct precipitation, return irrigation, vertical and lateral leakage from superjacent and subjacent aquifers.	Overdeveloped in Acme to Lake McMillan area, but underdeveloped in some areas south of Lake McMillan.
Permian	Queen and Grayburg Formations				X	X	X	Irrigation, domestic, stock.	Water is of good quality in general, but locally contains high amounts of chloride and sulfate.	10 to 2,000.	Surface-water flow over outcrops, direct precipitation on outcrops vertical and lateral leakage from subjacent and superjacent aquifers.	Strongly overdeveloped in Acme-Lake McMillan area.
Permian	Capitan Limestone						X	All uses -- industrial, irrigation, domestic, stock.	Good quality water in most places, but water is saline from Carlsbad eastward.	Up to 2,500.	Direct precipitation on outcrops, surface-water flow over outcrops	Fully developed.
Permian	San Andres Limestone		X	X	X	X		All uses -- irrigation, industrial, municipal.	Water is generally of good quality but contains hydrogen sulfide in the deeper part of the aquifer, and locally has high amounts of chloride.	From 1 to more than 9,000.	Surface-water flow over outcrops, direct precipitation on outcrops, vertical and lateral flow from subjacent and superjacent aquifers.	Strongly overdeveloped in the Acme-Lake McMillan area.
Permian	Glorieta Sandstone		X			X		Domestic, stock.	Water is of good quality in most places except under the Roswell Basin where it has a high chloride content.	From 2 to 700.	Direct precipitation on outcrops, vertical and lateral flow from subjacent and superjacent aquifers.	Small development.
Permian	Yeso Formation		X			X		Domestic, stock.	Poor to fair quality. In some locations the chloride content is too high for most uses.	From 1 to 125.	Direct precipitation on outcrops, vertical and lateral flow from subjacent and superjacent aquifers.	Because of low yield and variable quality of water, aquifer is not strongly developed.
Pennsylvanian and Permian	Sangre de Cristo Formation		X					Domestic, stock.	Fair to good quality water of variable hardness.	From 1 to 15.	Surface-water flow over outcrops, direct precipitation.	Because of its low yield the aquifer is developed for stock and domestic use.
Pennsylvanian and Permian	Magdalena Group		X					Irrigation, domestic, stock, industrial (railroad).	Good quality water, but locally has a high fluoride content.	Up to 100.	Direct precipitation on outcrop.	Not strongly developed.
Precambrian	Metamorphic and igneous rocks		X					Stock, domestic.	Fair quality water.	About 1.	Direct precipitation on outcrops. Water occurs in fractures in the Precambrian rocks.	Precambrian rocks are not strongly developed as an aquifer because of the low yields obtainable.

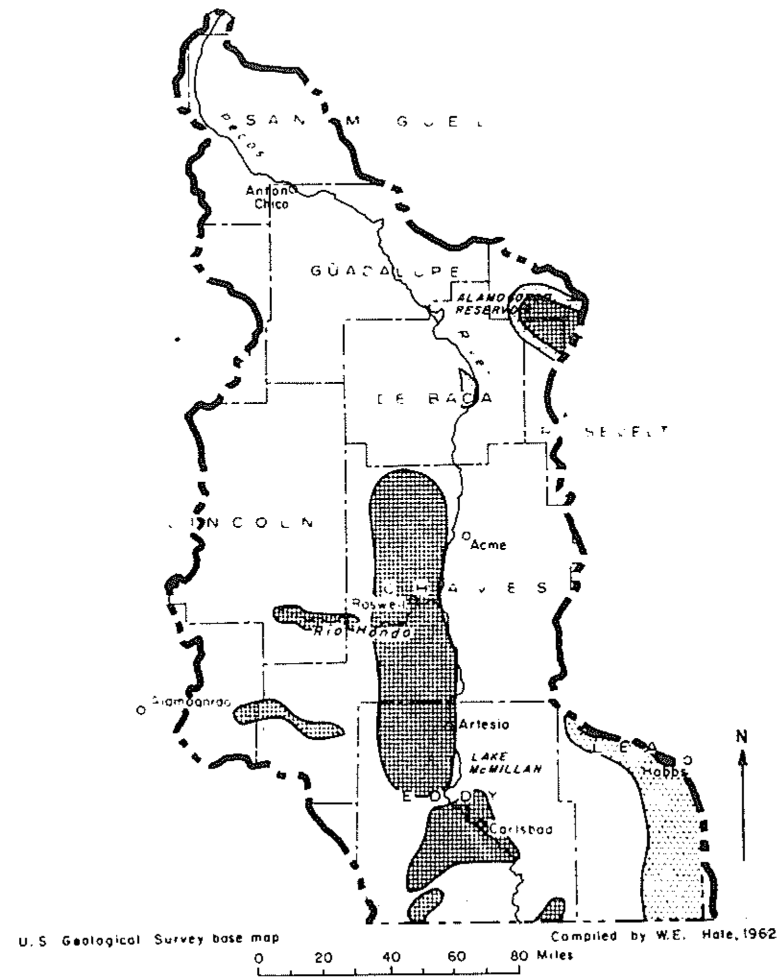


EXPLANATION

Boundary between ground-water units

Unit 1. Headwaters of Pecos River to Anton Chico
Unit 2. Anton Chico to Alamogordo Reservoir
Unit 3. Alamogordo Reservoir to Acme
Unit 4. Acme to Lake McMillan
Unit 5. Lake McMillan to State line

Figure 1.--Principal ground-water units



EXPLANATION

Less than 100 gpm, or areas for which data are inadequate for appraisal

100-300 gpm

More than 300 gpm

Figure 2.--Potential yield of wells

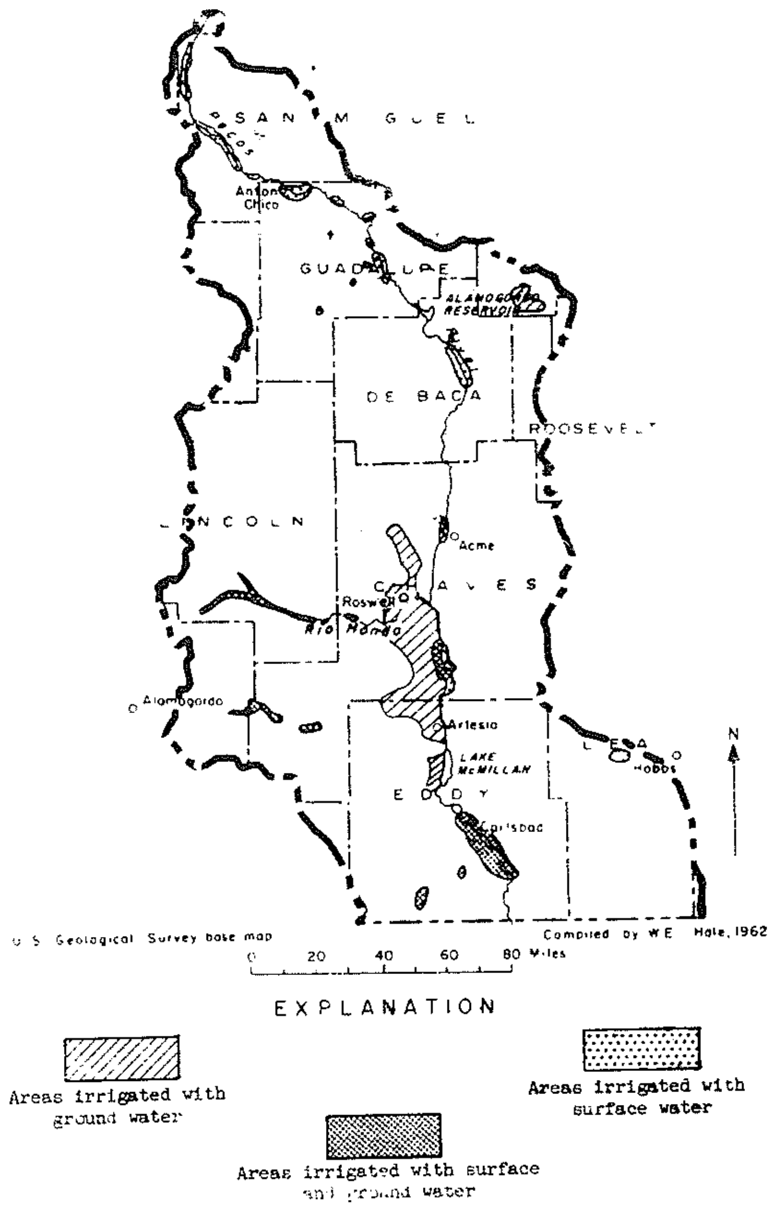


Figure 3.--Areas irrigated by ground water or surface water

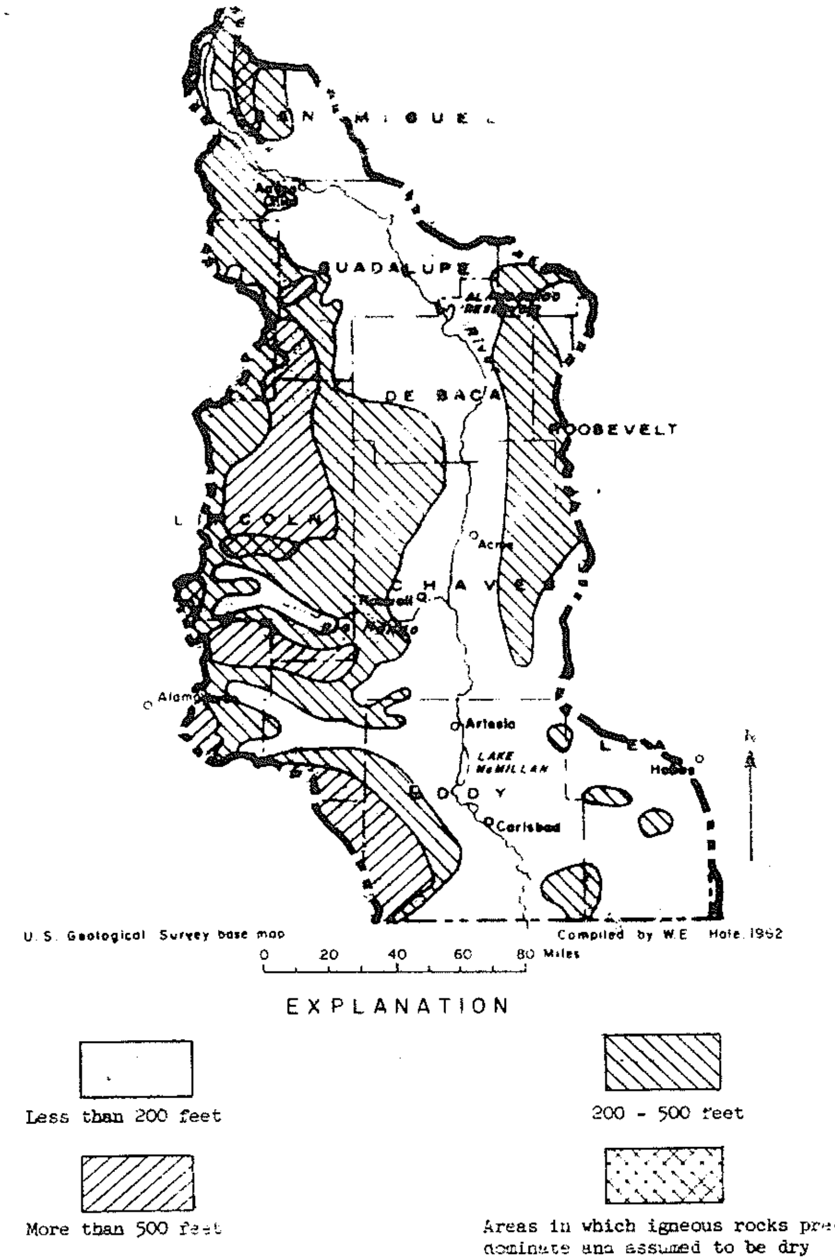


Figure 4.--Depth to ground water below land surface

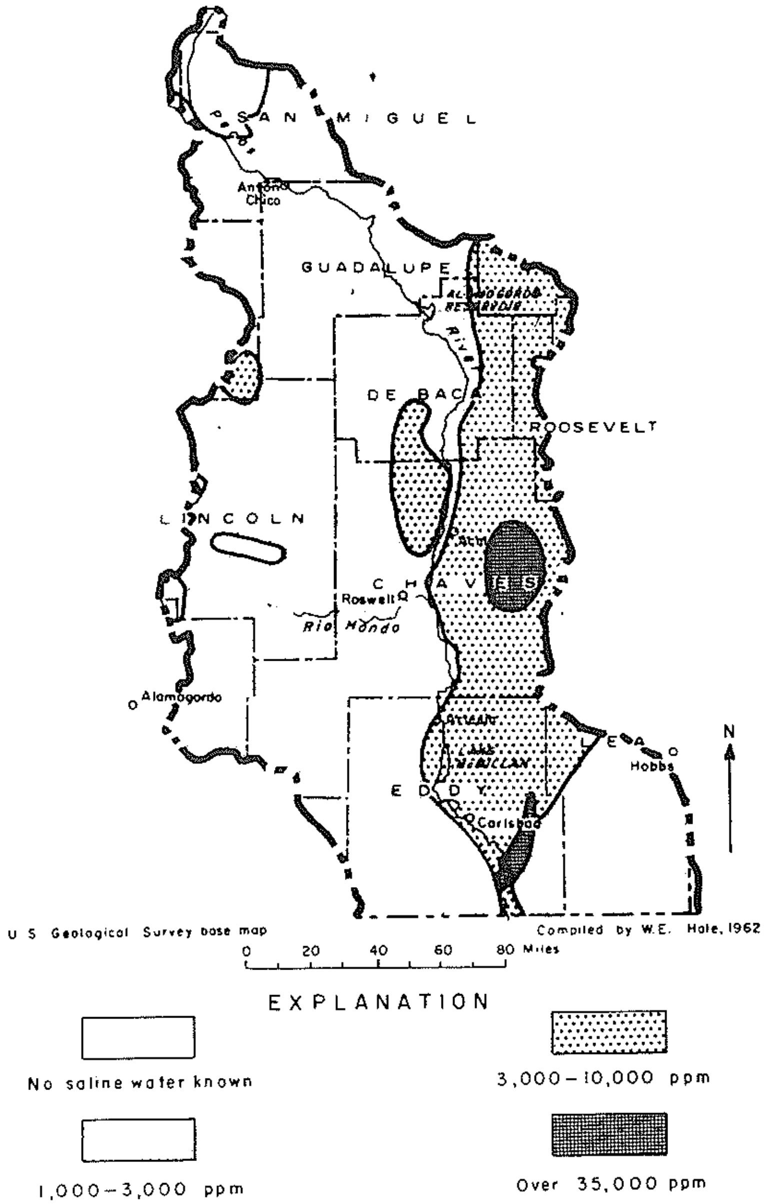


Figure 5.--Salinity of ground water

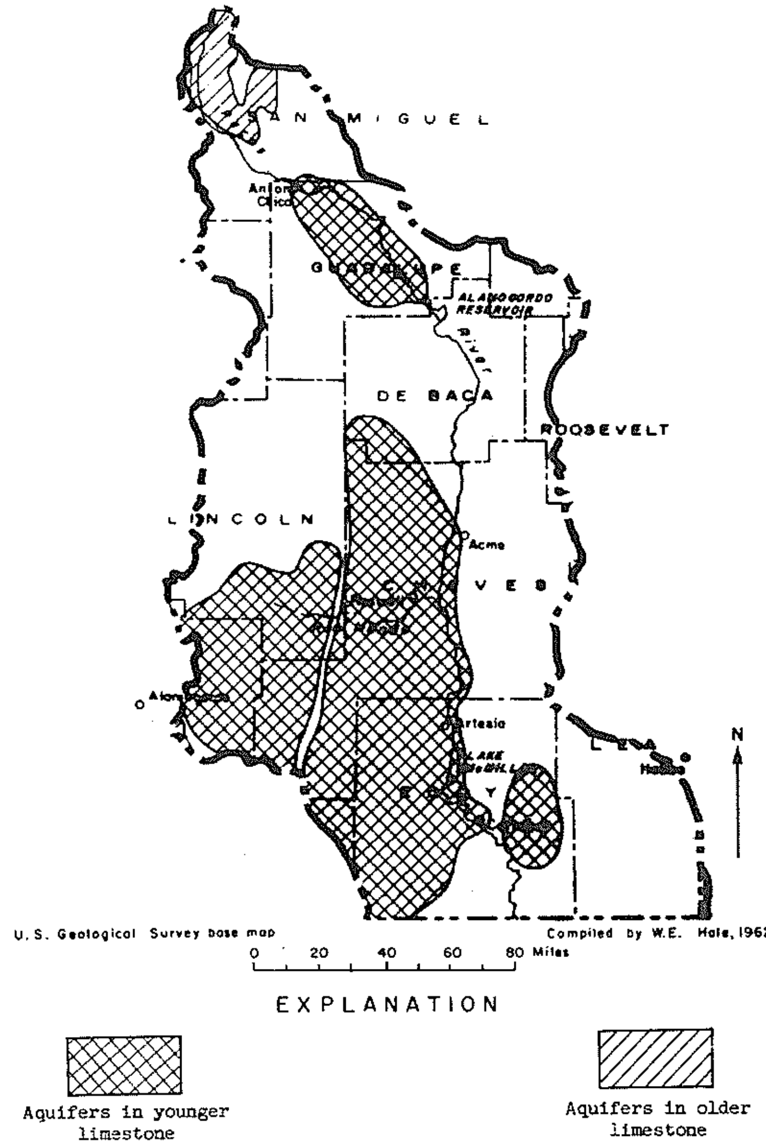


Figure 6.--Limestone aquifers

The potential yield of wells in Unit 2 (fig. 2) and the depth to ground water (fig. 4) is about the same as in the Unit 1 to the north, even though, generally, different aquifers are involved (table 1). However, the overall salinity of the ground water is as high as the most saline ground water in Unit 1 to the north (fig. 5).

The volume of water pumped from Unit 2 is probably fairly small, although it is larger than the volume pumped from Unit 1.

UNIT 3 - ALAMOGORDO RESERVOIR TO ACME

The northernmost usage of ground water for irrigation along the Pecos River is south of Fort Sumner in Unit 3 of the basin (fig. 3). In this area, ground water is pumped from alluvium and used to irrigate fields along the alluvial plain of the Pecos River (table 1 and fig. 8). The potential yield of these wells ranges from 100 to 300 gpm (gallons per minute) (fig. 2). Water levels in the alluvium reflect the elevation of the surface water in the Pecos River and indicate a ground-water gradient roughly parallel to the gradient of the river (written communication, E. C. Chavez, N. Mex. State Engr. Office, 1959). Wells yielding ground water for irrigation in the south Fort Sumner area seldom penetrate to depths greater than 200 feet where beds of clay and silt underlie the loose sand and gravel of the alluvium.

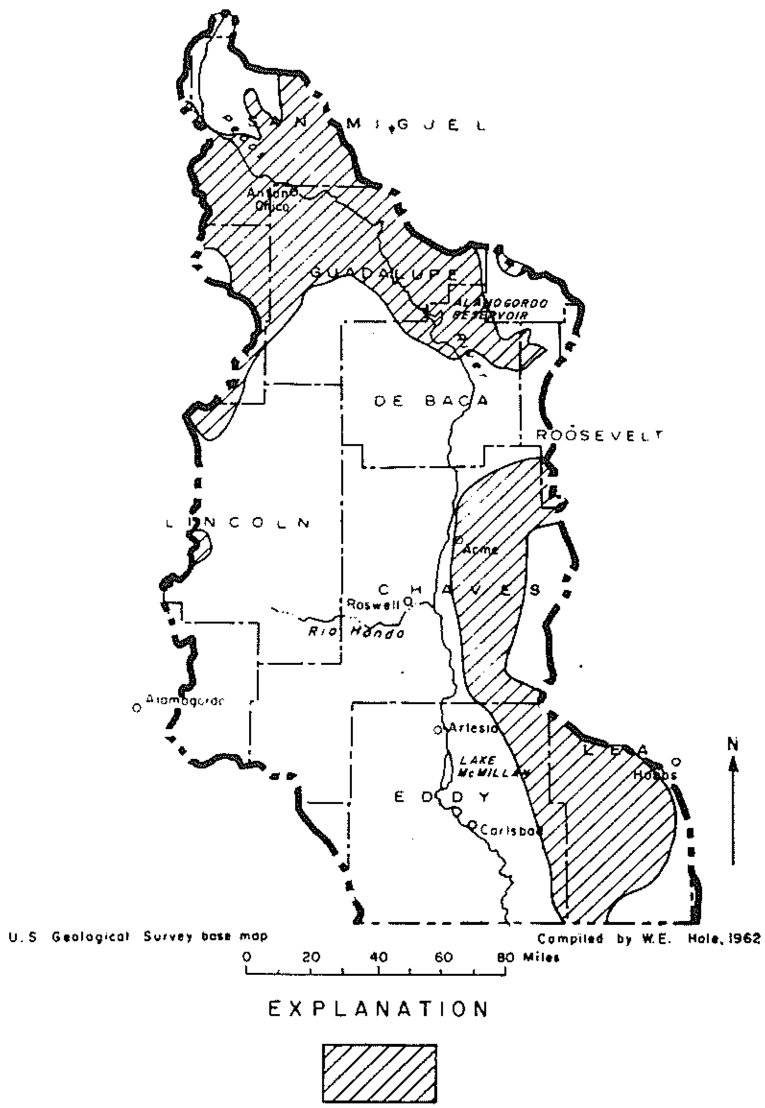
Other aquifers in Unit 3 are listed in table 1 and outlined on figures 6 and 7. These aquifers are developed only for the small volumes of water needed for stock and domestic use. The depth to water in Unit 3 increases to the west (fig. 4), where in some areas of northeastern Lincoln County ground-water levels are more than 1,000 feet below the land surface.

The northernmost large bodies of saline ground water along the Pecos River lie in Unit 3 (fig. 5). The salinity of ground water in all aquifers is such that the water is not suitable for stock or domestic use in much of the area east of the Pecos River. The only non-saline ground water east of the Pecos River in Unit 3 is contained in alluvium, which receives recharge from surface drainageways.

Data are not available on the volume of water pumped from Unit 3, but the volume is undoubtedly greater than that from either Units 1 or 2. Most of the ground-water pumpage is in the irrigated area south of Fort Sumner and in a small area of irrigation in southern De Baca County.

UNIT 4 - ACME TO LAKE McMILLAN

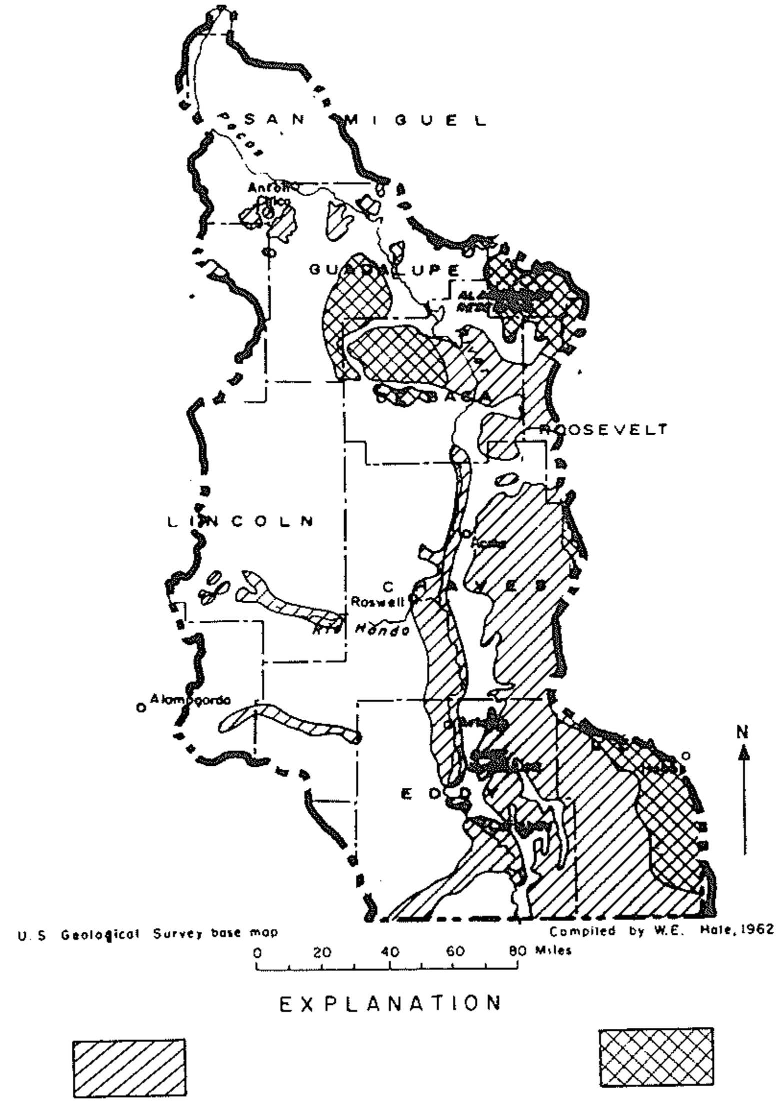
This is the largestand most important unit along the Pecos River, as it encompasses the large ground-water system of the Roswell area. The discharge of ground water from the Roswell area contributes a large



EXPLANATION

Undifferentiated sandstone aquifers

Figure 7.--Sandstone aquifers



EXPLANATION

Aquifers in younger sand and gravel

Aquifers in older sand and gravel

Figure 8.--Sand and gravel aquifers

part of the base flow of the Pecos River along this reach. In recent years, however, decline of ground-water levels due to pumping from both the shallow and artesian aquifers and to extended drought have decreased the volume of ground-water discharge to the river.

Geologic formations composing the shallow and artesian aquifers are given in table 1. The San Andres Limestone which underlies most of the area is the principal aquifer and is the limestone aquifer shown in figure 6. Overlying the San Andres Limestone are the Grayburg and Queen Formations, which do not transmit water as readily as the San Andres Limestone, and which together serve as a confining bed causing the artesian pressures so notable in the Roswell area. Overlying the aquitard is a shallow aquifer in the Seven Rivers Formation and alluvium (fig. 8).

Prior to ground-water development in the Roswell area, water from the San Andres Limestone leaked upward through the aquitard into the shallow aquifer, from which the water discharged into the Pecos River. Large-scale pumping of water from the artesian aquifer, the aquitard, and the shallow aquifer has lowered water levels in the area by the amounts shown in figures 9 and 10. As a consequence, leakage from the artesian to the shallow aquifer has decreased until, at present, ground water leaks from the shallow to the artesian aquifer during most of the year. The net result of the decreased leakage and reversal in the direction of leakage has been a decrease in the volume of gain by the Pecos River.

The quality of the ground water in the Acme-Lake McMillan reach of the basin has deteriorated because of pumping, mainly near the city of Roswell (fig. 5) where water in the artesian aquifer has become more saline, and where the rate of quality deterioration seems to be increasing (Hood and others, 1960). Test wells are presently being drilled to obtain more quantitative information on the ground-water hydrology of the area and to determine the method by which the fresh water is being contaminated.

The potential yield of wells that tap aquifers in Unit 4 is very high (fig. 2). Several wells developed in the artesian aquifer near Roswell have been tested at rates as much as 9,225 gpm. An area-wide average yield of artesian wells is 2,000 to 3,000 gpm. Wells drilled into the shallow aquifer have an average yield of about 1,000 gpm; wells producing from the confining bed have an average yield of 200 to 300 gpm.

Probably due to severe drought, pumpage from Unit 4 has been increasing steadily despite a decrease in irrigated acreage. The volume of ground water pumped from Unit 4 was 499,100 acre-feet in 1964, of which 206,400 acre-feet was pumped from the shallow aquifer and 292,700 acre-feet was pumped from the artesian aquifer.

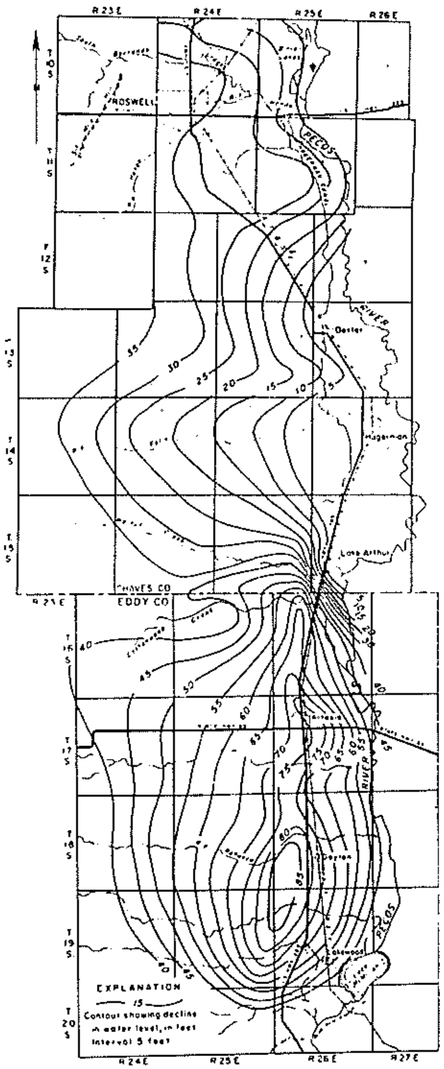


Figure 9.--Decline of piezometric level in the artesian aquifer in the Roswell area, 1944-61.

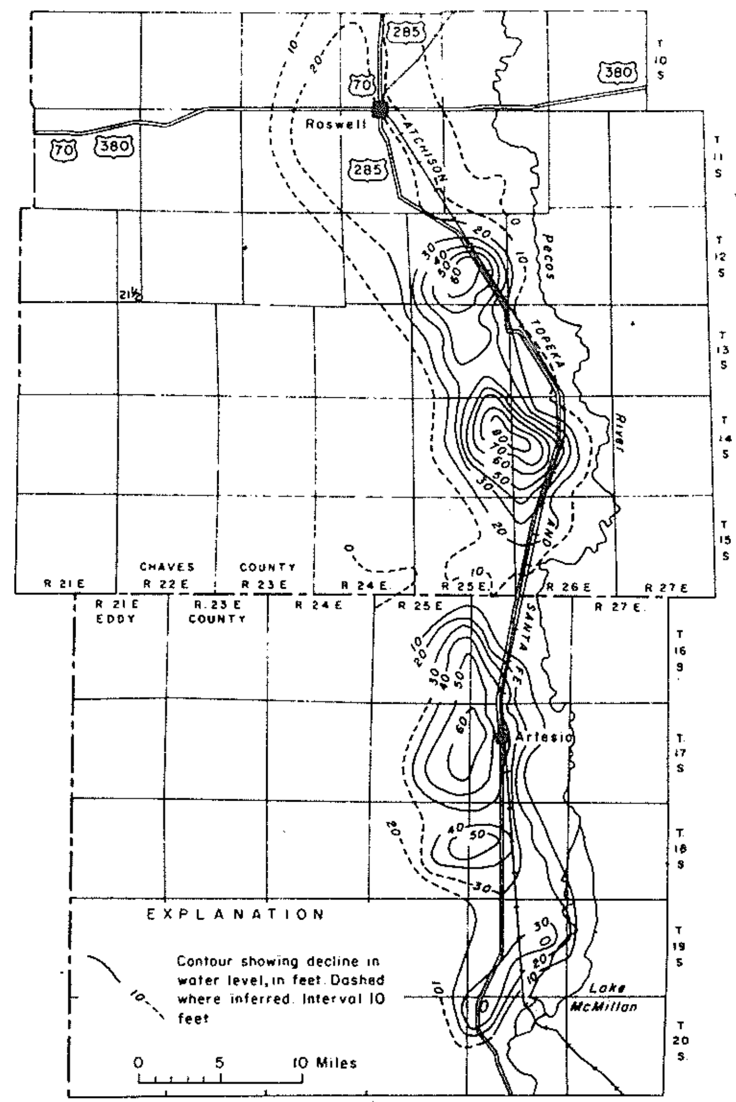


Figure 10.--Decline of ground-water level in the Roswell area 1938-60.

UNIT 5 - LAKE McMILLAN TO STATE LINE

The ground-water unit defined by this reach of the Pecos River is the most complex of all ground-water units associated with the Pecos River and hydrologically may be broken into six zones. The first zone begins near Lake McMillan where both shallow and artesian ground water is discharged out of the Roswell area through the Queen and Seven Rivers Formations. Water also leaks from storage in Lake McMillan and recharges the Seven Rivers Formation and the alluvium south of the lake. Consequently, in an area extending southward one-third the distance from Lake McMillan to Carlsbad, a highly permeable aquifer has developed in the Seven Rivers Formation. Wells drilled into these aquifers should yield a few thousand gallons per minute. (Written communication, E. R. Cox, U. S. Geol. Survey, 1965). Ground water discharged through Major Johnson Springs, about 3½ miles downstream from Lake McMillan, originates from this area of potentially high ground-water yield.

A second ground-water zone extends northward from Carlsbad one-third the distance to Lake McMillan. Here, ground water is obtained from the Tansill and Yates Formations and from the Capitan Limestone, all of which are usually referred to as the limestone aquifer. Wells drilled in this zone have high yields of relatively fresh water. Recharge to the limestone aquifer is from water moving from the southwest through solution openings in the Capitan Limestone. Some additional recharge leaks to this ground-water reservoir from surface water stored north of Carlsbad in Lake Avalon. A third zone lies between zones 1 and 2, and in this zone wells obtain small quantities of water from the Tansill and Yates Formations. In general, this third zone is an area of very low ground-water yield.

A fourth ground-water zone is in alluvium along the Pecos River, extending from Carlsbad to about half-way to the State line. Water in this ground-water zone originates as precipitation on the alluvium, flood water flowing through nearby arroyos, and return flow from irrigation with surface water. Ground water in this zone that is not intercepted by pumping discharges into the Pecos River. Ground-water gradients in the aquifer reflect the elevation of surface water in the Pecos River. A fifth ground-water zone lies south and west of Carlsbad where alluvium along a surface drainage forms a ground-water reservoir. The ground water is not hydraulically connected to the alluvial aquifer south of Carlsbad, but discharges through springs into the surface-water drainage and eventually reaches the Pecos River. A sixth ground-water zone extends northward one-half the distance from the State line to Carlsbad. Yields of wells are very low in this zone and most of the water is for domestic and stock use.

Quality of water in Unit 5 varies widely. Fresh water occurs in the limestone aquifer in the Guadalupe Mountains and saline water occurs near the Pecos River in the same aquifer and in the alluvial aquifer. In general, ground water near the Pecos River reflects the quality of the water in the river, except near the Malaga Bend of the Pecos River, about 20 miles south of Carlsbad, where a body of highly saline ground water exists (fig. 5).

Wells in Unit 5 yield as much as 3,500 gpm from the alluvium and as much as 2,550 gpm from the limestone aquifer. Wells in the low-yield zones yield from less than 1 to more than 50 gpm; most wells produce less than 10 gpm.

Ground-water pumpage from Unit 5 amounted to 79,000 acre-feet in 1964. Ground water pumped from the limestone aquifer accounted for 17,000 acre-feet of the total, and was pumped for municipal use (7,500 acre-feet), industrial use (3,500 acre-feet), and irrigation (6,000 acre-feet). All water pumped from the alluvium (62,000 acre-feet) was used for irrigation.

REFERENCES

Griggs, R. L., and Hendrickson, G. E., 1951, "Geology and Ground-Water Resources of San Miguel County, New Mexico," New Mexico Bur. Mines and Mineral Res., Ground-water report 2, 121 p.

Hale, W. E., Reiland, L. J., and Beverage, J. P., 1962, "Characteristics of the Water Supply in New Mexico," State Engineer Technical Rept. 31 (in press).

Hood, J. W., Mower, R. W., and Grogin, J. J., 1959, "The Occurrence of Saline Ground-Water Near Roswell, Chaves County, New Mexico," New Mexico State Engineer Office Tech. Rept. 17, 72 p.

SURFACE WATER AVAILABILITY AND QUALITY CHARACTERISTICS IN THE PECOS RIVER BASIN IN NEW MEXICO

Wilbur L. Heckler[1/]

INTRODUCTION

The availability and quality of the surface waters of the Pecos River are diverse and complex. The availability of the surface water is here considered by sources, magnitude, distribution, variability, channel gains and losses, floods, and depletions.

The quality characteristics are considered under constituents and concentrations of dissolved solids and sediment loads.

Surface water characteristics are intimately related to the climate, physiography, and geology of the basin; other papers given at this conference discuss these subjects in detail.

Collection of streamflow records in the Pecos River Basin in New Mexico began about 1903 and sampling for quality of water about 1937. Presently, the Geological Survey operates 36 gaging stations in the basin, 16 of which are on the main stem of the Pecos River. Chemical quality data are collected at 7 regular surface-water stations, and suspended-sediment data are collected at 2 of the main stem stations.

DESCRIPTION OF BASIN

The Pecos River Basin in New Mexico may be conveniently divided into an upper basin extending from its headwaters in the Sangre de Cristo Range to Alamogordo Reservoir and a lower basin extending from Alamogordo Reservoir to the Texas state line. Altitudes in the upper basin range from 13,102 on South Truchas Peak to 4,200 feet at Alamogordo Dam. The Gallinas River also originates in the Sangre de Cristo Range northwest of Las Vegas and is the principal tributary of the Pecos River in the upper basin. The approximate contributing drainage of the basin above Alamogordo Dam is 4,390 square miles.

The lower basin is bounded on the west by several ranges of mountains and by the Mescalero Ridge on the east. Altitudes range from 12,003 feet on Sierra Blanca Peak to 2,840 feet at the head of Red Bluff Reservoir.

1/ District Engineer, Surface Water Branch, U. S. Geological Survey, Santa Fe, New Mexico

The principal tributaries in the lower basin drain the eastern slopes of the mountains and are the Rio Hondo, Rio Felix, Cottonwood Creek, Black River, and others. Few tributaries from the east have well-defined channels; the two most important are Taiban Creek in the northern part and Long Arroyo in the central part. Approximate contributing drainage area of lower basin of the Pecos River above the Texas state line is 15,600 square miles. See table 1.

Thus, the approximate total contributing drainage area of the Pecos River in New Mexico is 20,000 square miles.

SURFACE WATER AVAILABILITY SOURCE AND MAGNITUDE

Melting snow is a source of considerable surface flow in the upper basin. Both the main stem of the Pecos River and the Gallinas River drain the southern part of the Sangre de Cristo Mountains where the snow pack accumulates. Summer runoff results primarily from flash floods caused by localized thunderstorms in the plains and foothills. However, occasional storms originating in the Gulf of Mexico contribute heavily to runoff.

In the lower basin, some flow comes from snowmelt in the higher western mountains, but the principal contribution to surface runoff is from summer thunderstorms. Intense, general Gulf storms also at times substantially augment surface flow.

Generally the availability of surface water in both the upper and lower basins is affected significantly by losses to and gains from ground water.

Precipitation, the only source of water to the Pecos River basin averages more than 14 inches of water per year, and is equivalent to more than 15,000,000 acre-feet. Figure 1 shows by width of line and isopleths of runoff the portion of the precipitation that actually reaches the drainage channels in the basin. The remainder is lost through evapotranspiration or recharges the ground water reservoirs. Available records indicate that unit runoff is strongly influenced by topography; values on figure 1 range from 0.1 inch in the plains to 20 inches in the Sangre de Cristo Mountains. Construction of such a runoff map suffers from lack of defining data. It indicates only in a general way the occurrence of runoff in the basin.

The width of line on figure 1 shows how the average annual discharge for the period of record varies from station to station. Variation in the width of line reflects the interwoven influence of several factors: tributary inflow, interchange with ground water, evapotranspiration losses, diversions, and return flow. At the measuring points on the main stem, the average annual discharge ranges from 71,000 acre-feet at Pecos to 238,000 acre-feet near Artesia.

Table 1 --Summary of gaging station records in Pecos River Basin

Period of record Water years (1900–1970)	Sta. No.	Gaging station	Drainage area (sq mi)	Average runoff acre-feet per year through 1963	Peak discharge Date	Peak discharge cfs	Peak discharge cfs per sq mi	Jarvis-Myers coef. in %
		PECOS RIVER BASIN: Part 8						
	3780	Pecos River near Cowles	160	89,770	5-27-12	1,800	11.2	1.42
	3785	Pecos River near Pecos	189	72,400	9-21-29	4,500	23.8	3.27
	3790	Pecos River near San Jose	539	-	7-14-39	2,220	4.12	.98
	3792	Tecolote Creek near San Pablo	83	-	8-17-61	10,900	131	11.9
	3795	Pecos River near Anton Chico	1,050	103,500	9-30-04	73,000	69.5	22.5
	3800	South Fork Gallinas River near El Porvenir	25	10,570	4- -19	-	-	-
	3805	Gallinas River near Montezuma	84	14,770	8- 4-57	5,400	64.3	5.38
	3810	Gallinas River at Montezuma	87	14,190	9-29-04	11,600	133	11.6
	3820	Gallinas River near Lourdes	313	10,500	8-17-61	6,680	21.3	3.76
	3825	Gallinas River near Colonias	610	13,320	6- 1-37	26,700	43.8	10.8
	3830	Pecos River at Santa Rosa	2,650	107,900	6- 2-37	55,200	20.8	10.7
	3835	Pecos River near Puerto de Luna	3,970	166,500	6- 3-37	60,000	15.1	9.52
	3845	Pecos River below Alamogordo Dam	4,390	170,900	9- 1-42	f42,800	9.75	6.46
	3855	Pecos River near Fort Sumner	5,300	173,000	9-30-04	53,000	10.0	7.28
	3860	Pecos River near Acme	11,380	157,800	5-28-37	53,300	4.68	4.99
	3870	Rio Ruidoso at Hollywood	120	7,670	7-26-57	1,070	8.92	.977
	3880	Rio Ruidoso at Hondo	290	13,760	9-29-41	12,400	42.8	7.31
	3885	Rio Bonito at Angus	45.5	-	4-22-31	121	2.66	-
	3895	Rio Bonito at Hondo	295	7,460	9-29-41	11,000	37.3	6.41
	3901	Rio Hondo at Picacho	715	-	5-14-58	3,510	4.91	-
	3905	Rio Hondo at Diamond A. Ranch near Roswell	947	18,970	9-22-41	27,000	28.5	8.77
	3936	North Spring River at Roswell	19.5	7.2	8-31-63	101	5.18	-
	3945	Rio Felix at old highway bridge, near Hagerman	932	12,520	10- 7-54	74,000	79.4	24.2
	3950	Rio Felix near Hagerman	934	20,710	5-29-37	23,600	25.3	7.73
	3955	Pecos River near Lake Arthur	14,760	211,400	5-30-37	51,500	3.49	4.24
	3960	Cottonwood Creek near Lake Arthur	199	4,180	-	-	-	-
	3965	Pecos River near Artesia	15,300	246,900	10- 2-04	h60,000	3.92	4.85
	3976	Rio Peñasco near Dunken	580	4,230	9-22-41	70,000	121	29.1
	3985	Rio Peñasco at Dayton	1,070	3,620	9-22-41	h60,000	56.1	18.4
	4000	Four Mile Draw near Lakewood	265	1,010	10- 7-54	7,650	28.9	4.71
	4010	Pecos River below McMillan Dam	16,990	77,460	a	h40,000	2.35	3.06
	4015	Pecos River below Major Johnson Springs	-	-	-	-	-	-
	4020	Pecos River at damsite 3, near Carlsbad	17,980	131,800	5-22-41	60,000	3.54	4.48
	4040	Pecos River below Avalon Dam	18,080	27,660	10- 7-54	41,000	2.27	3.05
	4050	Pecos River at Carlsbad	18,100	159,300	10- 2-04	90,000	4.97	6.66
	4055	Black River above Malaga	343	9,050	9-21-41	33,000	96.2	17.8
	4060	Black River at Malaga	360	-	-	-	-	-
	4065	Pecos River near Malaga	19,190	183,200	9-21-41	63,700	3.32	4.60
	4070	Pecos River at Pierce Canyon Crossing near Malaga	19,260	150,600	-	-	-	-
	4075	Pecos River at Red Bluff	19,540	165,800	5-24-41	52,600	2.69	3.76
	4085	Delaware River near Red Bluff	689	10,350	10- 2-55	81,400	118	31.0

For some purposes, the median flow gives a more realistic picture of surface water availability, particularly when storage is not adequate to conserve the surpluses of years of high runoff. For the period 1930-60, the difference between average and median flow for eight selected main stem stations on the Pecos River is highly variable. (See Table 2)

Table 2-Average and Median of Yearly Runoff in Acre-Feet 1930-60 For Selected Stations on Pecos River in New Mexico

Gaging Station	Average	Median	Difference between average and median
Pecos River near Pecos	71,340	65,980	5,360
Pecos River near Anton Chico	96,780	80,280	16,500
Pecos River at Santa Rosa	103,600	65,990	37,610
Pecos River below Alamogordo Dam[a]	166,400	129,900	36,500
Pecos River near Artesia	237,500	183,000	54,500
Pecos River at Carlsbad	153,200	73,800	79,400
Pecos River near Malaga	188,700	96,360	92,340
Pecos River at Red Bluff[b]	180,900	--	--

a/ Adjusted for annual changes in storage in reservoir.

b/ For 23 year period 1937 - 60.

This tabulation shows that the difference between the average and the median values becomes progressively wider proceeding from the upper to the lower end of the basin. At Pecos, average exceeds median flow by only eight percent, but at Carlsbad average flow is larger by 108 percent. The extremely high runoff that occurred in 1941 and 1942 mostly accounts for the difference, and apparently a greater part of this flow originated in the lower basin.

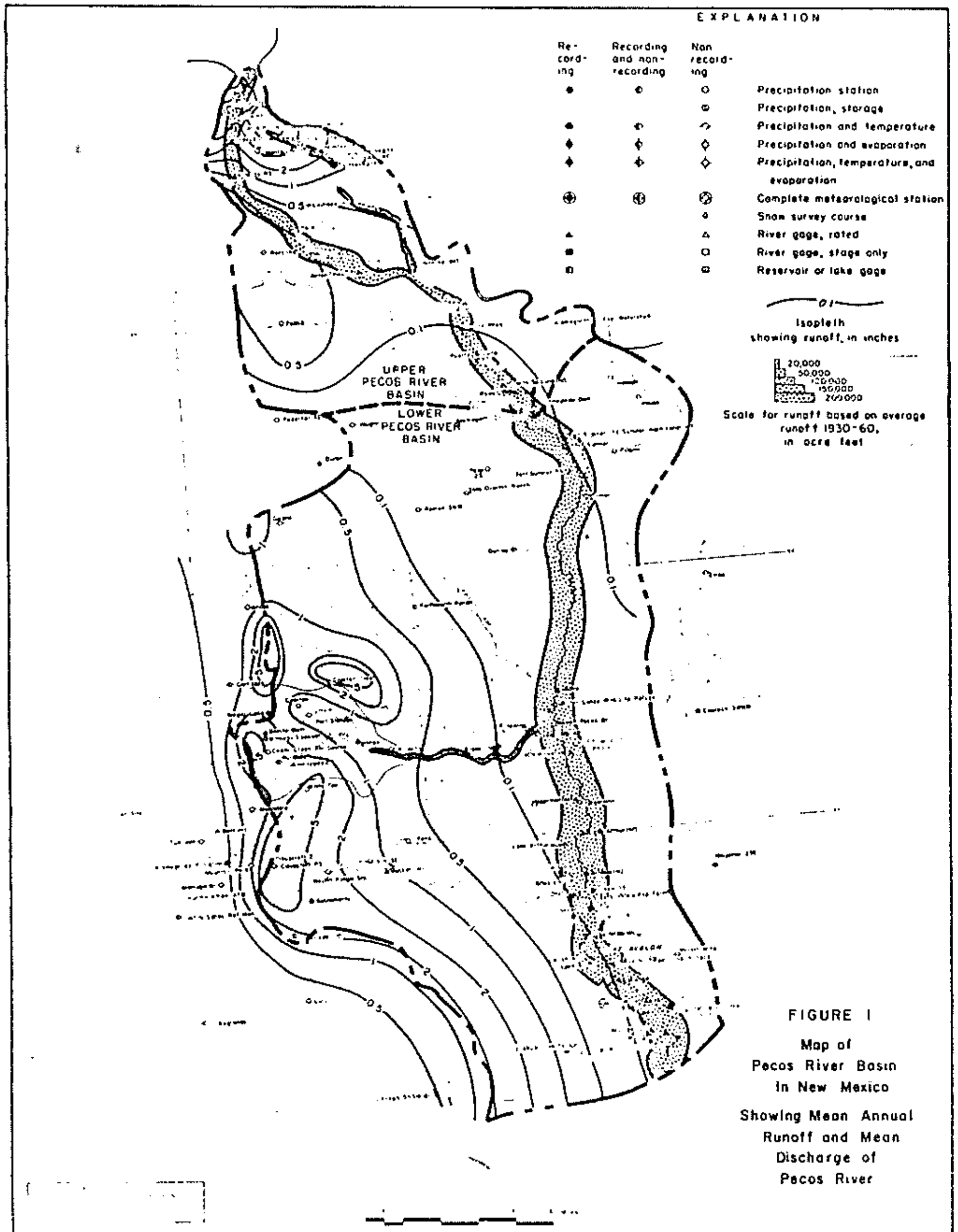


FIGURE 1
Map of Pecos River Basin In New Mexico
Showing Mean Annual Runoff and Mean Discharge of Pecos River

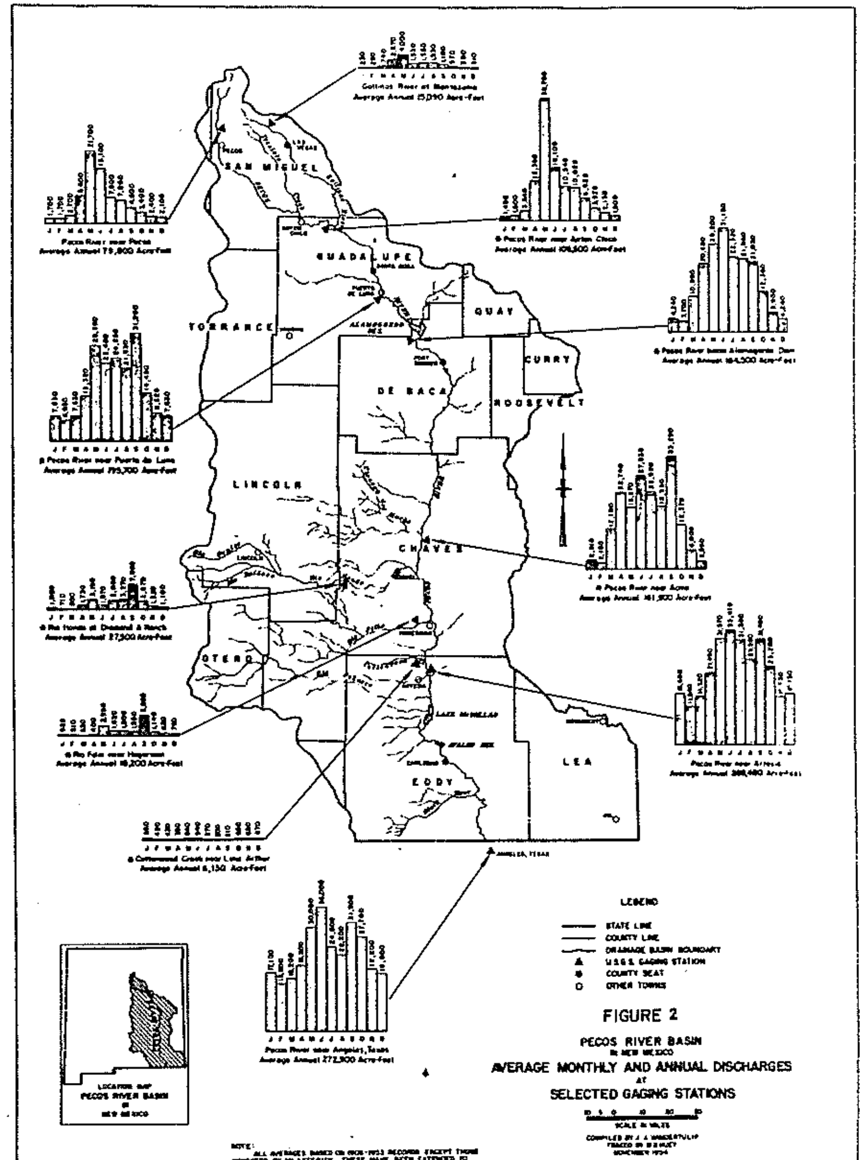


FIGURE 2
PECOS RIVER BASIN IN NEW MEXICO
AVERAGE MONTHLY AND ANNUAL DISCHARGES AT SELECTED GAGING STATIONS

From Technical Report 7, State of New Mexico, State Engineer Office, Hydrologic Summary

DISTRIBUTION

Seasonal distribution of flow in the basin exhibits patterns attributed to climate, topography, and regulation. Figure 2 shows bargraphs of average monthly discharge for period 1905-53 plotted for selected stations. In the upper basin, snow melts account for 60 percent of the annual runoff occurring in the 3-month period April through June. Proceeding downstream, the increasing effect of summer storms is shown in the graphs. At Puerto de Luna, inflow station to Alamogordo Reservoir, 66 percent of the annual flow occurs in the 5-month period May through September, and the month of maximum flow shifts from May to September.

Below Alamogordo Reservoir, the distribution patterns on the main stem of the Pecos River reflect the influence of regulation. About 75 percent of the annual discharge occurs during the irrigation season which coincides with the summer flood period. Summer flow also is dominant in the tributary streams of the lower basin even though not influenced by regulation. On Rio Hondo and Rio Felix, virtually all the runoff occurs in the period April through September and 30 percent of that occurs in September alone.

Annual distribution of flow is shown in figure 3 for two representative stations. At Anton Chico in the upper basin, annual flow for the period 1911-63 ranged from a minimum of 19,570 acre-feet in 1934 to a maximum of 354,400 acre-feet in 1941. At Artesia in the lower basin, during period 1905-63, the range is from 74,180 acre-feet in 1954 to 997,600 in 1941. These graphs show a distinct downward trend in flow which will be discussed under Depletions.

VARIABILITY

Natural streamflow variability results from variation in precipitation in turn modified by basin characteristics, primarily geology. Natural variation in flow may be altered by regulation and diversions as in the lower basin of the Pecos River. Flow-duration curves depict flow variability by showing percent of time specified discharges were equalled or exceeded in a given period. Figure 4 shows flow-duration curves plotted for stations on the Pecos River near Pecos, near Puerto de Luna, and near Artesia.

Effect of substantial storage in and contribution from ground water storage is shown in the curve for the station at Pecos by the relatively flat slope reflecting the reduced range in flow. Storage of precipitation in mountain snow packs also influences the slope in the upper reaches of the curve.

At Puerto de Luna, the flat slope of the curve below 150 cfs reflects the heavy ground water contribution. Above 150 cfs, the steeper slope reflects the influence of flash runoff from summer storms.

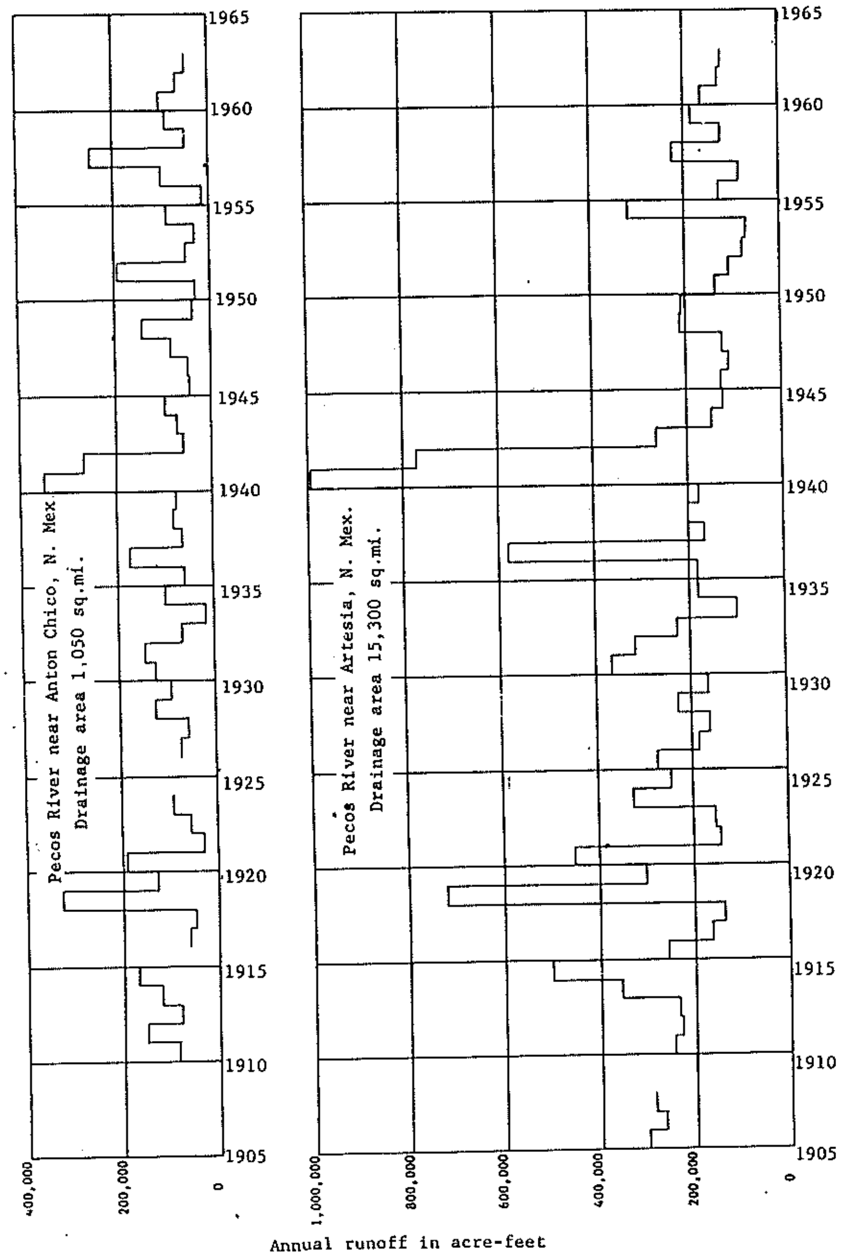


Figure 3. - Annual runoff at two gaging stations on Pecos River 1906-63

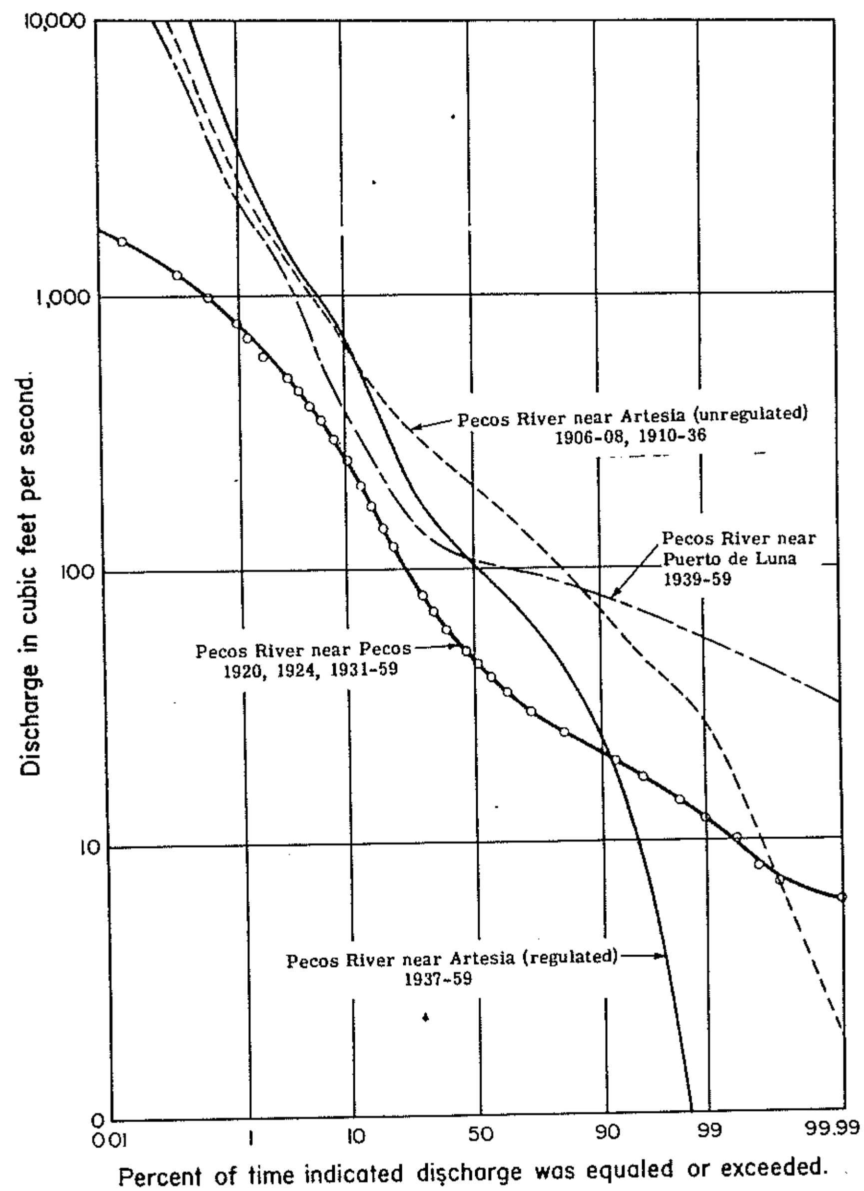


Figure 4.--Duration curves of daily flow for three stations on Pecos River in New Mexico.

At Artesia two curves are shown, one for the unregulated period prior to 1937 and one for the regulated period 1937-59. The curve for the regulated period is the steeper and reflects the influence of the high years 1937, 1941, and 1942, the large number of drought years since 1943, and increased depletions throughout the period. It has only been since 1945 that the river has dried up at times at Artesia.

CHANNEL GAINS AND LOSSES

Gains to and losses from the main stem of the Pecos River have been intensively studied since 1953 by seepage investigations in the reach from Anton Chico to the state line. These investigations have delineated subreaches which generally show losses or gains. The reach between Anton Chico and Colonias shows losses of as much as 150 cfs as indicated by the width of line on figure 1. Below Colonias, flow begins to be augmented by ground water contribution and evidently most of the losses are recovered above Puerto de Luna. Between Alamogordo Dam and Acme large losses generally occur during the summer and are greatest in the vicinity of Yeso Arroyo. Between Acme and Artesia gains are general throughout most of the reach. Seven seepage investigations between 1958 and 1963 show an average gain at low flow of 55 cfs.

Between Artesia and Carlsbad, Lakes McMillan and Avalon store water for irrigation. Lake McMillan has leaked practically from the time it was constructed, and that leakage has been known to approach 200 cfs. However, most of it is recovered about 4 miles below the dam through Major Johnson springs in the river channel. There is some seepage from Lake Avalon which is partially recovered at Carlsbad Springs.

FLOODS

The Pecos River Basin has produced many of the outstanding floods in New Mexico. Flood-frequency studies by Patterson (1963) indicate that the area of highest flood potential in the state is the eastern slopes of the Guadalupe Mountains in the extreme southwestern part of the basin. It was in this area on September 20, 1941 that the outstanding flood of record in the basin occurred in Dark Canyon at Carlsbad. The peak discharge of this flood was estimated as 100,000 cfs and has a Jarvis-Meyer's rating of 47.5 percent or 4,750 A. Only one other known flood in New Mexico exceeds this rating, and it occurred on a drainage area only about one-hundredth the size of that for Dark Canyon.

On the main stem, the maximum known discharge of 90,000 cfs occurred October 2, 1904 at Carlsbad, and may have been augmented somewhat by the failure of Avalon Dam. Magnitude and frequency of floods on the main stem analyzed by Patterson (1963) from Anton Chico to the state line are shown in figure 5. Available data do not permit reliable definition of frequencies beyond 50 years. The figure indicates the magnitude of a 50-year flood at Carlsbad to be 85,000 cfs.

From Geological Survey Water-Supply Paper 1682 by James L. Patterson.

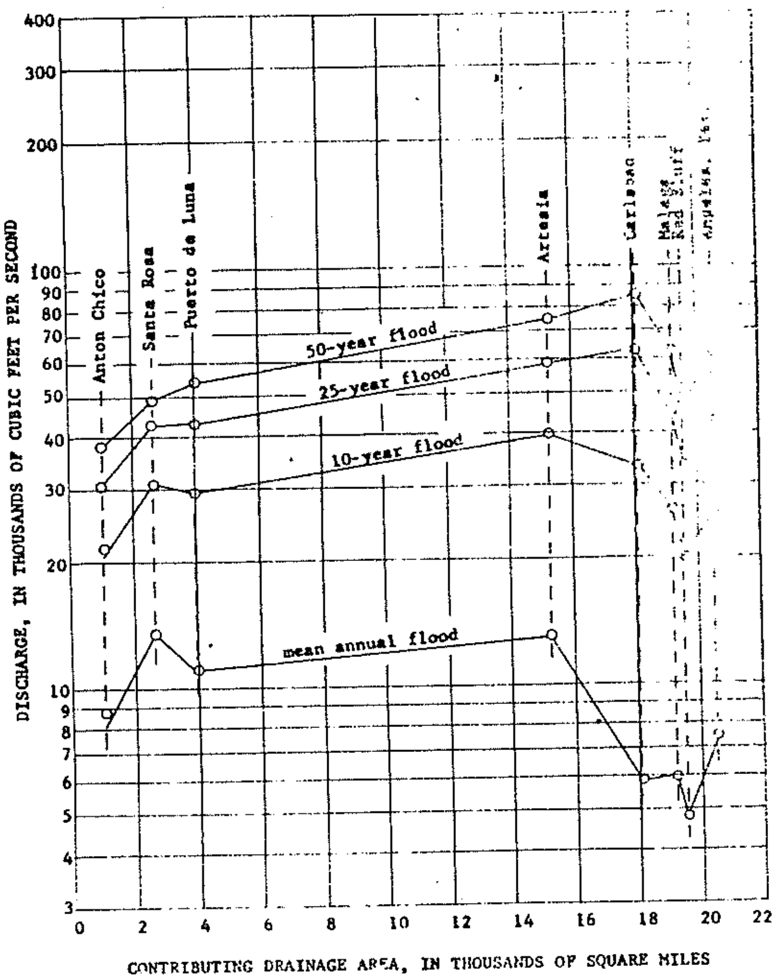


Figure 5.--Relation of discharge for selected flood frequencies to contributing drainage area. Pecos River main stem between Anton Chico and [illegible] stations are [illegible], Texas.

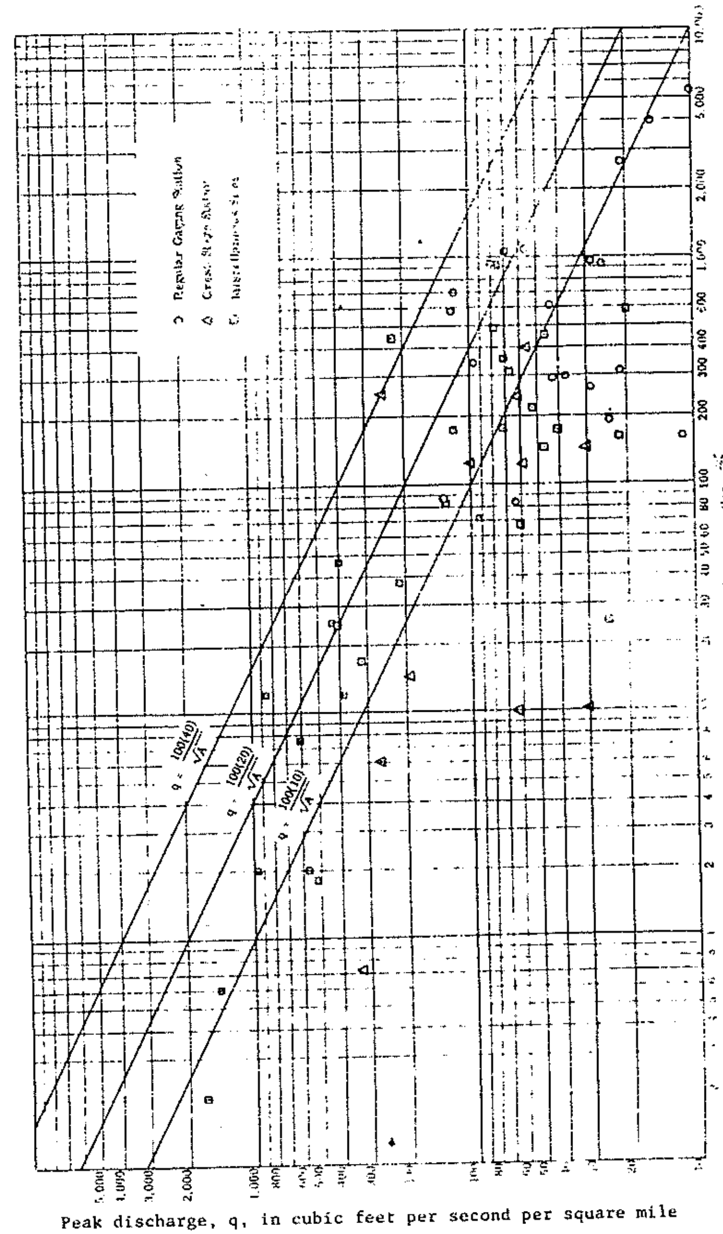


Figure 6.--Flood discharges in Pecos River Basin in New Mexico in relation to drainage area. Enveloping curves are for Jarvis-Myers ratings of 10, 20, and 40 per cent.

Figure 6 is a plotting of drainage area versus unit discharge for the more outstanding floods of record in the basin, including those occurring at crest-stage and ungaged sites. It is noted that many of these floods exceed a 10 percent Jarvis-Meyer's rating or 1,000 A.

Table 1 lists maximum discharge for the period of record at regular gaging stations in the basin and gives the Jarvis-Meyer's rating for each peak.

DEPLETIONS

Distribution of annual flow of the Pecos River for the period of record indicates a progressive diminution in flow which is especially marked in the lower basin. Thomas (1963) analyzed the factors associated with the depletion and concluded that drought, phreatophyte infestation, and ground-water development are jointly responsible for the reduction. Those who are interested in greater detail are referred to the original report, Geological Survey Water-Supply Paper 1619-G, "Causes of Depletion of the Pecos River in New Mexico".

QUALITY CHARACTERISTICS[a/]

METHOD AND SAMPLING SITES

Both the chemical quality and the suspended sediment carried by the water vary widely from the headwaters to Red Bluff Reservoir. For purposes of describing the quality of water in the Pecos River Basin in New Mexico the river has been subdivided into three principal reaches: the upper reach coincides with the upper basin above Alamogordo Dam, the middle reach is that part between Alamogordo and McMillan Dams, and the lower reach that part between McMillan Dam and Red Bluff Reservoir.

The Geological Survey collects samples daily at seven stations along the main stem and determines the general chemical characteristics at each by analyzing samples that have been composited by a standard technique. Daily samples are also collected for suspended sediment determinations at Santa Rosa in the upper reach and near Artesia in the middle reach. Prior to October 1958 Puerto de Luna was the sampling point in the upper basin. No sediment data are collected in the lower reach because problems related to sediment there are not significant at this time.

The weighted average complete analyses for chemical quality 1955-64 for the seven river stations in New Mexico and one in Texas, below Red Bluff Reservoir, are presented in tables 3-10. The maximum and minimum daily concentrations in ppm (parts per million) and load extremes in tons per day for both chemical and sediment quality for period of record are presented in table 11.

a/ This portion prepared with the assistance of Harry E. Koester, Chemist, Quality of Water Branch, U. S. Geological Survey.

Table 3.--8-3845. PECOS RIVER BELOW ALAMOGORDO DAM, N. MEX.

Annual weighted averages of chemical analyses, in parts per million, 1955-1964 water years

Water year	Mean discharge (cfs) / Total discharge	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual load (tons)
1955	180 / 65,700	12		265	39	50		124		722	61		0.7		1,210	1.65	588	822	720	0.8	1,540	7.5	215,300
1956	183 / 66,060	16		360	54	64		134		988	78		.9		1,630	2.22	805	1,120	1,010	.8	1,960	7.5	290,400
1957	164 / 58,880	16		320	37	56		125		839	71		1.5		1,400	1.90	609	950	848	.8	1,680	7.5	221,500
1958	301 / 109,900	14		170	19	35		127		405	35		.7		741	1.01	602	502	398	.7	1,000	7.5	220,200
1959	173 / 63,140	14		272	33	53		125		717	59		.4		1,210	1.65	565	814	712	.8	1,500	7.5	206,900
1960	157 / 57,460	17		330	37	57		124		853	71		.7		1,430	1.94	606	976	874	.8	1,770	7.5	220,800
1961	223 / 81,450	16		329	35	58		121		859	72		.4		1,430	1.94	861	966	867	.8	1,780	7.6	313,500
1962	187.2 / 68,330	15		319	37	55		125		830	72		.7		1,390	1.89	702	946	844	.8	1,730	7.5	256,300
1963	177 / 64,522	15		385	46	66		120		1,040	87		.2		1,700	2.31	812	1,150	1,050	.8	2,050	7.5	295,700
1964	117 / 42,856.6	15		450	55	81		127		1,240	105		1.4		2,020	2.75	638	1,350	1,250	1.0	2,350	7.6	233,800

Table 4.--8-3860. PECOS RIVER NEAR ACME, N. MEX.

Annual weighted averages of chemical analyses, in parts per million, 1955-1964 water years

Water year	Mean discharge (cfs) / Total discharge	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual load (tons)
1955	296 / 108,000	--		327	--	--		--		--	--		--		1,660	2.26	--	--	--	--	2,130	7.5	484,300
1956	148 / 49,880	17		402	75	129		127		1,160	195		1.9		2,040	2.77	815	1,310	1,210	1.6	2,530	7.5	274,200
1957	149 / 40,530	14		296	54	89		136		841	117		1.3		1,480	2.01	595	960	849	1.2	1,950	7.5	161,400
1958	288 / 101,700	16		234	31	126		145		617	159		1.2		1,260	1.71	980	712	592	2.1	1,690	7.5	363,000
1959	158 / 56,250	19		311	50	155		127		889	204		1.6		1,690	2.30	721	982	878	2.2	2,210	7.8	256,400
1960	258 / 92,620	18		380	42	161		118		1,060	213		1.6		1,930	2.62	1,340	1,120	1,020	2.1	2,430	7.7	482,100
1961	208 / 75,892	17		362	54	165		116		1,030	229		1.3		1,950	2.65	1,100	1,120	1,030	2.1	2,460	7.7	391,300
1962	167 / 60,960	20		351	48	115		136		954	149		1.3		1,700	2.31	769	1,070	961	1.5	2,170	7.8	265,400
1963	164 / 59,904	16		374	56	122		120		1,070	156		.8		1,860	2.53	824	1,160	1,060	1.6	2,290	7.5	300,600
1964	56.8 / 20,800	17		502	77	158		122		1,470	224		1.4		2,500	3.40	503	1,570	1,470	1.7	2,930	7.6	140,300

Table 5.--8-3965. PECOS RIVER NEAR ARTESIA, N. MEX.

Annual weighted averages of chemical analyses, in parts per million, 1955-1964 water years

Water year	Mean discharge (cfs) Total discharge	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual load (tons)
1955	444 162,100	24		367	89	361		142		1,110	562		--		2,580	3.51	3,090	1,280	1,160	4.4	3,450	7.5	1,127,000
1956	182 66,610	18		458	119	466		139		1,440	720		--		3,290	4.47	1,620	1,630	1,520	5.0	4,370	7.5	590,500
1957	125 44,750	20		405	94	401		152		1,220	624		--		2,840	3.86	958	1,400	1,270	4.7	3,790	7.5	341,600
1958	316 115,300	19		313	51	222		149		864	318		2.2		1,860	2.53	1,590	990	868	3.1	2,500	7.7	578,400
1959	174 63,510	29		392	91	397		141		1,200	602		3.0		2,780	3.78	1,310	1,350	1,240	4.7	3,760	7.7	475,900
1960	255 93,330	19		449	70	332		128		1,270	494		2.6		2,700	3.67	1,860	1,410	1,300	3.8	3,510	7.7	679,000
1961	227 164,100	19		444	92	377		150		1,300	589		3.1		2,900	3.94	1,780	1,490	1,370	4.2	3,880	7.7	646,600
1962	176.5 64,420	17		420	76	331		156		1,190	513		2.3		2,620	3.56	1,250	1,360	1,230	3.5	3,500	7.5	455,000
1963	167 61,076	17		459	91	377		143		1,360	576		1.2		2,960	4.03	1,330	1,520	1,400	4.2	3,900	7.5	488,000
1964	64.8 23,718	17		543	123	543		147		1,650	854		3.0		3,810	5.18	782	1,860	1,740	5.5	5,030	7.5	243,700

Table 6.--8-4050. PECOS RIVER AT CARLSBAD, N. MEX.

Annual weighted averages of chemical analyses, in parts per million, 1955-1964 water years

Water year	Mean discharge (cfs) Total discharge	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual load (tons)
a 1955	244 89,060	--		--	--	--		--		--	--		--		b 1,210	b 1.65	---	--	--	--	1,730	7.7	b292,200
1956	93.1 34,070	17		364	89	246		144		1,090	391		2.1		2,270	3.10	573	1,270	1,160	3.0	3,040	7.7	209,600
1957	25.6 9,340	20		349	116	312		169		1,120	510		2.2		2,510	3.41	173	1,350	1,210	3.7	3,460	7.8	63,290
1958	115 41,980	21		329	76	257		151		992	382		1.5		2,130	2.90	661	1,130	1,010	3.3	2,880	7.6	242,500
1959	72.9 26,610	19		396	102	347		168		1,230	525		2.6		2,700	3.67	531	1,410	1,270	4.0	3,580	7.7	193,600
1960	79.9 29,240	16		370	64	205		124		1,050	308		2.5		2,080	2.83	449	1,190	1,080	2.6	2,750	7.6	164,100
1961	71.7 26,171	16		443	113	388		153		1,380	621		2.9		3,040	4.13	588	1,580	1,440	4.3	4,090	7.7	214,300
1962	24.9 9,090	20		366	106	314		187		1,120	511		4.7		2,530	3.44	170	1,350	1,200	3.7	3,470	7.5	62,130
1963	25.5 9,318	17		311	95	266		171		971	426		3.4		2,180	2.96	150	1,170	1,030	3.4	3,010	7.6	54,700
1964	18.2 6,669.8	19		362	115	319		188		1,140	514		4.4		2,570	3.50	126	1,380	1,230	3.7	3,550	7.6	46,300

a Weighted averages not computed because period of missing record represents 55.4% of runoff (15 days of high flow in October).
b Estimated on the basis that ppm D.S. equals specific conductance (micromhos) times 0.70.

Table [illegible]. PECOS RIVER NEAR MALAGA, N. MEX.

Annual weighted averages of chemical analyses, in parts per million, 1955-1964 water years

Water year	Mean discharge (cfs) / Total discharge	Silica (SiO2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO3)	Carbonate (CO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as CaCO3: Calcium, Magnesium	Hardness as CaCO3: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual load (tons)
1955	[illegible] / 108,000	14		[illegible]	[illegible]	240		[illegible]		[illegible]	[illegible]		[illegible]		1,630	2.23	1,340	828	714	3.7	2,390	7.6	[illegible]
1956	[illegible] / [illegible]	19		[illegible]	[illegible]	560		[illegible]		1,350	[illegible]		3.9		3,490	4.75	1,050	1,640	1,520	6.0	4,790	7.7	[illegible]
1957	[illegible] / [illegible]	19		[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]		--		4,880	6.54	555	1,800	1,660	10	7,020	8.0	[illegible]
1958	[illegible] / [illegible]	[illegible]		[illegible]	[illegible]	562		[illegible]		[illegible]	873		--		3,240	4.41	1,130	1,400	1,280	6.5	[illegible]	7.7	[illegible]
1959	[illegible] / [illegible]	[illegible]		[illegible]	[illegible]	655		[illegible]		[illegible]	1,120		3.9		3,950	5.37	1,130	1,690	1,570	7.4	[illegible]	[illegible]	[illegible]
1960	[illegible] / [illegible]	19		[illegible]	206	654		[illegible]		[illegible]	1,020		6.0		3,640	4.95	1,090	1,530	1,410	7.2	[illegible]	7.6	[illegible]
1961	27.1 / [illegible]	19		533	155	871				[illegible]	1,400		6.7		4,780	6.50	1,230	1,970	1,840	8.4	6,710	7.7	455,600
1962	[illegible] / 16,8[illegible]	16		550	182	1,110		[illegible]		1,810	1,800		9.1		5,550	7.55	691	2,120	1,990	10	7,910	7.5	252,[illegible]
1963	47.6 / 37,150	[illegible]		467	172	973		[illegible]		1,610	1,560		4.7		4,880	6.64	619	1,870	1,740	9.8	7,040	7.3	225,9[illegible]
1964	25.1 / 9,192.6	[illegible]		530	200	1,270		175		1,870	2,010		5.2		6,[illegible]	8.16	407	2,140	2,000	12	6,570	7.6	146,7[illegible]

Table 8.--8-4070. PECOS RIVER AT PIERCE CANYON CROSSING, NEAR MALAGA, N. MEX.

Annual weighted averages of chemical analyses, in parts per million, 1955-1964 water years

Water year	Mean discharge (cfs) / Total discharge	Silica (SiO2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO3)	Carbonate (CO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as CaCO3: Calcium, Magnesium	Hardness as CaCO3: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual load (tons)
1955	294 / 107,300	15		243	68	449		122		725	715		5.4		2,280	3.10	1,810	880	78[illegible]	6.6	3,330	7.7	655,400
1956	113 / 41,360	17		442	142	1,090		145		1,430	1,730		--		4,920	6.69	1,500	[illegible]	1,370	12	7,090	7.7	550,[illegible]
1957	45.5 / 16,610	18		465	195	2,170		164		1,660	3,410		--		8,000	10.9	985	1,960	1,830	21	11,700	7.7	359,[illegible]
1958	124 / 45,260	17		397	122	1,000		148		1,310	1,550		--		4,470	6.08	1,500	1,490	1,370	11	6,590	7.7	544,800
1959	110 / 40,150	25		451	156	1,260		148		1,540	1,970		--		5,480	7.45	1,630	1,770	1,640	13	7,910	7.6	592,500
1960	116 / 42,460	18		438	133	1,140		136		1,410	1,800		--		5,010	6.81	1,570	1,640	1,530	12	7,290	7.6	574,600
1961	102 / 37,048	18		531	181	1,450		168		1,790	2,310		6.7		6,390	8.69	1,750	2,070	1,930	14	9,310	[illegible]	638,[illegible]
1962	51.4 / 18,760	16		550	222	2,200		149		1,960	3,500		6.6		8,530	11.6	1,180	2,290	2,160	20	12,700	7.5	431,[illegible]
1963	50.2 / 18,320	15		505	215	2,040		156		1,860	3,240		[illegible]		7,980	10.9	1,080	2,140	2,010	19	12,000	[illegible]	396,[illegible]
1964	25.2 / 9,208.1	14		547	233	2,200		169		2,040	3,480		3.6		8,600	11.7	585	2,320	2,180	20	12,800	7.5	[illegible]

Table 9.--8-4375. PECOS RIVER AT RED BLUFF, N. MEX.

Annual weighted averages of chemical analyses, in parts per million, 1955-1964 water years

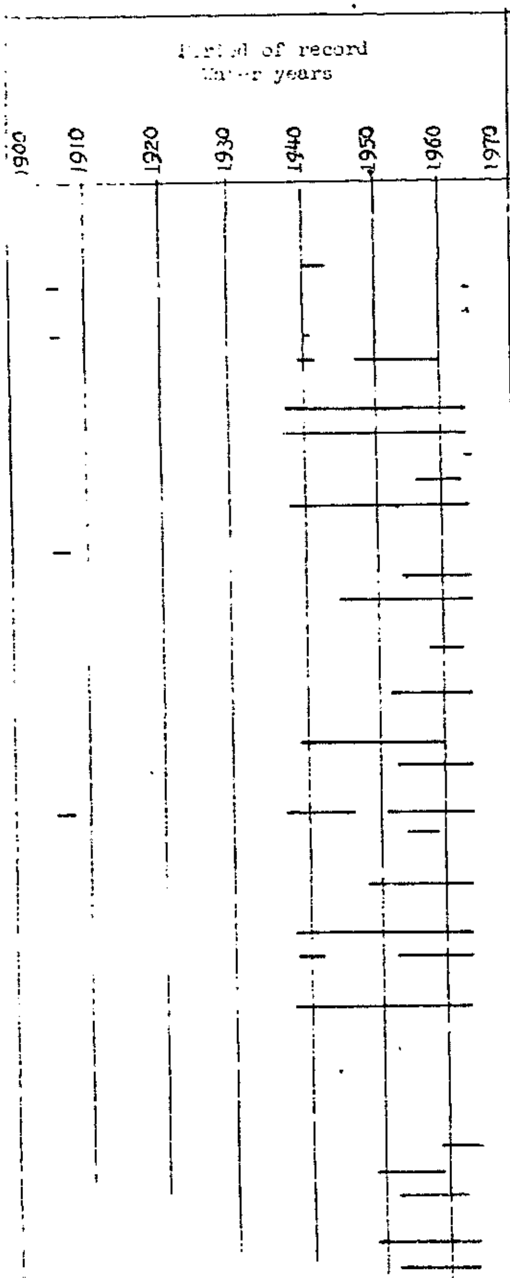
Water year	Mean discharge (cfs) / Total Discharge	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Non-carbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual Load (tons)
1955	292 106,600	13		255	73	566		143		770	884		--		2,630	3.58	2,070	936	819	14	3,660	7.5	757,200
1956	87.7 31,920	16		483	191	1,570		138		1,700	2,490		--		6,520	8.87	1,540	1,990	1,880	15	9,590	7.5	606,200
1957	46.8 17,080	--		440	201	2,070		131		--	3,260		--		8,050	10.9	1,020	1,920	1,800	21	11,400	7.5	369,600
1958	140 51,100	--		387	113	963		136		--	1,540		--		4,490	6.11	1,700	1,430	1,320	11	6,510	7.5	617,700
1959	111 40,520	--		456	149	1,280		122		--	2,020		--		5,760	7.83	1,730	1,750	1,650	13	8,050	7.5	631,000
1960	116 42,460	--		435	130	1,230		130		--	1,950		--		5,460	7.43	1,710	1,620	1,510	13	7,640	7.5	623,800
1961	104 37,898	--		526	179	1,480		151		--	2,340		--		7,170	9.75	2,010	2,050	1,930	14	9,430	7.6	732,800
1962	50.6 18,470	--		549	223	2,240		142		--	3,580		--		9,150	12.4	1,250	2,290	2,170	20	13,000	7.5	454,200
1963	49.9 18,198	13		519	216	2,280		127		1,870	3,630		1.6		9,040	12.3	1,220	2,180	2,080	21	13,100	7.3	441,900
1964	26.6 9,724	11		511	224	2,160		145		1,940	3,400		3.0		8,330	11.3	598	2,200	2,080	20	11,400	7.4	217,900

Table 10.--8-4101. PECOS RIVER BELOW RED BLUFF DAM, NEAR ORLA, TEX.

Annual weighted averages of chemical analyses, in parts per million, 1955-1964 water years

Water year	Mean discharge (cfs) / Total discharge	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Non-carbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual Load (tons)
1955	217 79,200	13		317	84	743		132		978	1,150				3,350	4.56	1,960	1,140	1,030	9.6	5,160	7.7	716,400
1956	125 45,750	13		531	131	1,090		112		1,680	1,690				5,190	7.06	1,750	1,860	1,770	11	7,340	7.9	640,600
1957	30.6 22,120	8.5		610	196	1,990		107		2,060	3,130				8,050	10.9	1,320	2,330	2,240	18	11,600	7.6	478,200
1958	73.0 26,540	11		491	147	1,390		120		1,640	2,160				5,900	8.02	1,160	1,830	1,730	14	8,620	7.6	423,800
1959	54.4 39,535.4	14		463	135	1,150		136		1,550	1,760		2.2		5,140	6.99	1,170	1,710	1,600	12	7,280		427,100
1960	62.1 22,733	12		566	201	1,900		134		2,040	2,920				7,710	10.5	1,290	2,240	2,130	17	11,000		473,400
1961	125 45,625	14		533	174	1,420		123		1,840	2,230				6,270	8.53	2,120	2,050	1,940	14	8,950		775,100
1962	61.4 22,410	8.3		666	248	2,260		118		2,430	3,520				9,190	12.4	1,520	2,680	2,580	19	12,900	7.3	551,200
1963	53.6 17,371	9.7		673	256	2,470		116		2,430	3,890				9,790	13.3	1,290	2,730	2,630	21	13,400	6.8	471,500
1964	31.8 11,650	11		641	243	2,260		115		2,320	3,550				9,080	12.3	780	2,600	2,510	19	12,600	7.0	264,216

Table 11.--Summary of chemical and sediment quality stations records for streams in the Pecos River basin in New Mexico



Sta. No.	Station	Frequency of sampling	Daily concentration (ppm) Max.	Daily concentration (ppm) Min.	Load (Tons/day) Max.	Load (Tons/day) Min.
	CHEMICAL - Dissolved Solids					
3705	Pecos River near Anton Chico	D	185	96	810	16
3805	Gallinas River near Montezuma	D-M	386	120	138	2
3810	Gallinas River at Montezuma	M	-	-	-	-
3830	Pecos River at Santa Rosa	D	2,320	174	2,490	30
3834	Pecos River at Puerto de Luna	D	2,740	220	10,020	106
3[illegible]	Pecos River below Alamogordo Dam	D	2,730	435	9,930	.31
3860	Pecos River near Acme	D	19,870	594	71,900	2.1
3[illegible]0	Rio Ruidoso at Hollywood	M	-	-	-	-
3905	Rio Hondo at Diamond "A" Ranch near Roswell	M	1,450	292	1,820	3.92
3965	Pecos River near Artesia	D	16,300	461	99,700	.4
-	Pecos River near Dayton	D	5,120	748	30,100	1,060
4010	Pecos River below McMillan Dam	M	6,070	4,930	-	-
-	Pecos River at Ford Crossing above Major Johnson Springs near Lakewood	M	6,160	1,470	-	-
4015	Pecos River below Major Johnson Springs near Carlsbad	M	-	-	-	-
4020	Pecos River at Damsite 3, near Carlsbad	W	4,970	316	-	-
4035	Carlsbad main canal at head near Carlsbad	D	7,430	552	5,700	14.5
4045.1Q	Pecos River above Carlsbad flume at Carlsbad	M	-	-	-	-
4050	Pecos River at Carlsbad	D	3,810	360	79,700	27.7
4053.5Q	Black River below Mayes Ranch near White City	M	-	-	-	-
4054Q	Black River at Harkey Crossing near Malaga	M	2,000	480	-	-
4065	Pecos River near Malaga	D	9,100	384	123,400	133
4070	Pecos River at Pierce Canyon Crossing near Malaga	D	23,700	280	e100,000	103
4075	Pecos River at Red Bluff	D	22,800	450	95,500	106
	SEDIMENT - Suspended Sediment					
3830	Pecos River at Santa Rosa	D	30,800	8	276,000	<.5
3834	Pecos River at Puerto de Luna	D	59,200	20	1,510,000	4
3905	Rio Hondo at Diamond "A" Ranch, near Roswell	D	64,900	NF	630,000	0
3965	Pecos River near Artesia	D	20,900	NF	183,000	0
39[illegible]	Rio Penasco at Dayton	D	30,000	NF	600,000	0

SUSPENDED SEDIMENT

In the upper reach of the Pecos River suspended sediment is more of a problem than is chemical quality. For the period 1955-63 the annual sediment load ranged from a minimum of 317,400 tons in 1960 at Santa Rosa to a maximum of 5,295,000 tons in 1955 at Puerto de Luna. Materials carried in suspension are roughly 2 to 20 times those carried in solution in this reach although particles in traction and in solution do make up a considerable part of the total load.

The dominance of suspended load above Alamogordo Reservoir can be attributed to the steep gradient of the river, high flows and outcropping shales. These shales weather rapidly, but add little in the way of soluble products. At Colonias, where much of the discharge is lost underground, the sediment load is released in the widened flood plain, but is picked up again during flood periods and transported downstream.

In the middle reach sediment as well as chemical quality is a major problem. Sediment load in this reach is less than in the upper reach. Between Acme and Artesia the load of suspended and soluble materials is roughly equal. For the period 1955-63, the annual load at Artesia ranged from 386,800 tons in 1956 to 1,552,300 tons in 1955.

The load reduction can be attributed to release of clear water at Alamogordo Dam, lower gradient of the streambed, increased solutes and abundant growth of phreatophytes. Some sediment is added in this reach by the Rio Hondo, Rio Penasco and other tributaries. The increased growth of phreatophytes tends to slow down velocities which reduces corrasion and bank cutting.

In the lower reach between McMillan Dam and Red Bluff Reservoir suspended sediment loads are usually insignificant. The occasional flood flows from tributaries such as Rocky Arroyo and Dark Canyon can contribute appreciable sediment. The highly mineralized waters in this reach also may act to floc or precipitate any suspended colloids of clay.

QUALITY OF WATER BY REACHES

The river and its tributaries in the upper reach generally have their origin in the core area of the Central Highlands of the Southern Rocky Mountain province where sandstones, shales, and limestones of Pennsylvanian age predominate. Sedimentary rocks of Paleozoic and Mesozoic ages (mostly sandstone and shales) outcrop generally southeast of the town of San Jose to Alamogordo Reservoir. The dilute, fresh waters north of Colonias are not greatly affected by contamination with saline waters (See classification - table 12, following, in text). The water is primarily a calcium-bicarbonate type of good quality. The river water below Santa Rosa increases in dissolved solids to Alamogordo Reservoir where the water is fresh to slightly saline. The dissolved solids load for the period 1955-64 at the lower end of the reach at Alamogordo Dam ranged from 206,900 tons in 1959 to 295,700 tons in 1963, with an average of 247,440 tons (figure 7).

Flow in the middle reach is partly controlled by Alamogordo Dam. The dissolved solids concentration at low flows between Alamogordo Dam and Acme is increased by more than twofold, and further increases are noted at Artesia; however, fresh water flood flows from the Rio Hondo and Rio Penasco result in minimum concentrations at Artesia than are recorded at Acme. The principal dissolved solid addition within this reach is sodium chloride. For the period 1955-64 the annual dissolved solids loads at Artesia ranged from 243,200 tons in 1964 to 1,127,000 tons in 1955. According to the saline-water classification, the weighted averages of dissolved solids concentrations place it in slightly to moderately saline category. (Table 12)

Table 12-Classification of Water

1. Fresh water - contains less than 1,000 ppm dissolved solids.
2. Saline waters - contains between 1,000 and 35,000 ppm dissolved solids.
    a. slightly saline - 1,000 to 3,000 ppm.
    b. moderately saline - 3,000 to 10,000 ppm.
    c. very saline - 10,000 to 35,000 ppm.
3. Brine - all waters containing more than *35,000 ppm dissolved solids.

* concentration of sea water.

The main stem in the lower reach is partly controlled by Lake McMillan and Lake Avalon. There is at least a one-third decrease in dissolved solids concentration between Artesia and Carlsbad. Most of the decrease can be attributed to inflow to the river below McMillan Reservoir from springs that have their recharge area west of the river and to some deposition of calcium carbonate (travertine) in the river channel. During period 1955-64 the annual load of dissolved solids ranged from 46,300 tons in 1964 to 292,200 tons in 1955, and consisted predominantly of calcium sulfate. Dissolved solids between Carlsbad and the state line increase significantly with downstream flow, although the stations near Malaga have occasional minimum below that at Carlsbad because of flood flows on the Black River. The flow of the Black River is borderline fresh to slightly saline water.

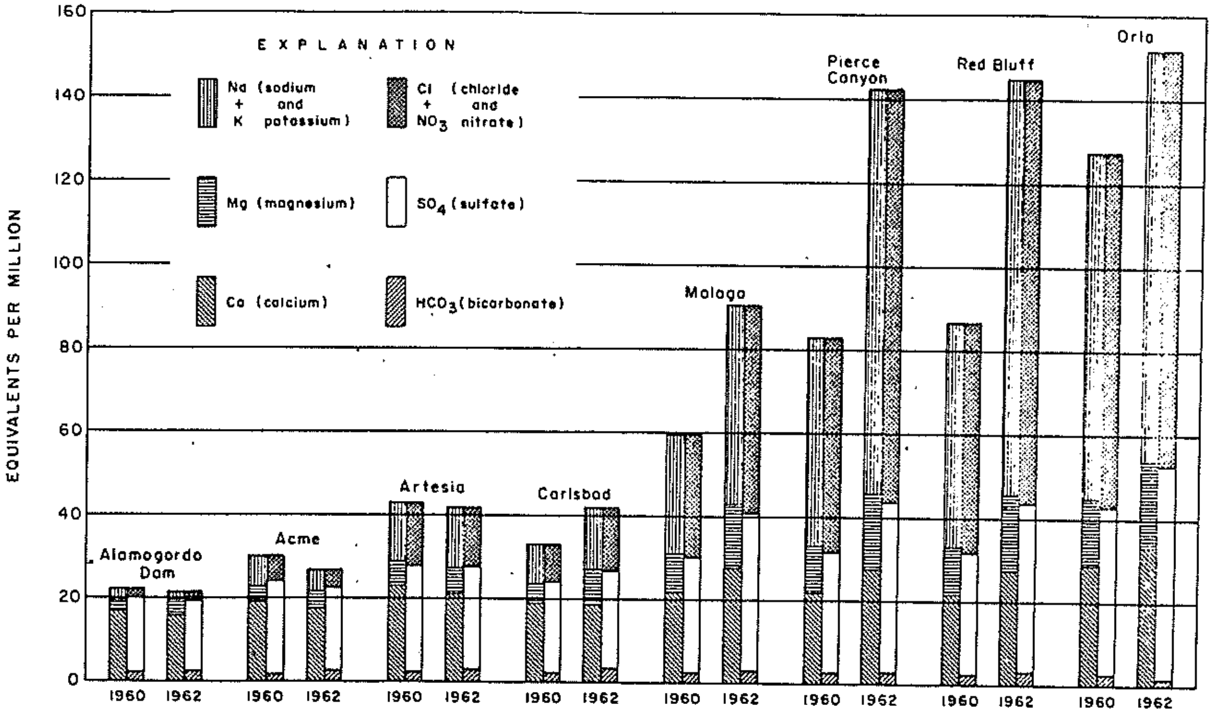


Figure 8. --Comparison of weighted average analyses for water years 1960 and 1962 at eight gaging stations on the Pecos River.

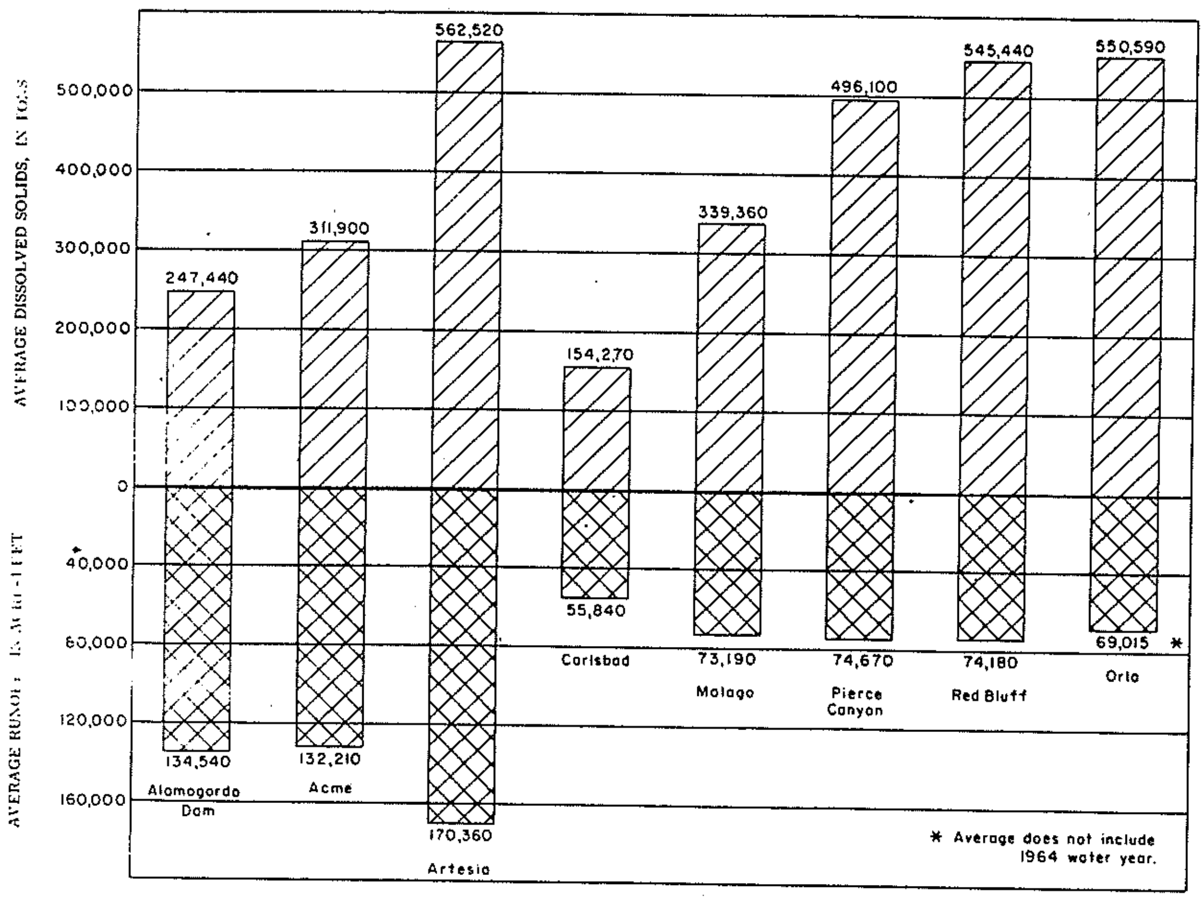


Figure 7. --A ten year average runoff and dissolved solids for 1955-1964 water years.

The Malaga Bend area contains brine springs, the waters of which have concentrations of 150,000 ppm and are saturated with sodium chloride. The dissolved solids are over four times the concentration of sea water. Considerable improvement of the Pecos River water at Pierce Canyon Crossing below Malaga has been evident since the Salinity Alleviation Program went into operation. That program involves the pumping of some of the brine from the springs aquifer into an artificial lake (Northeast Depression), thus lowering the water table and discharge of the brine springs. During the past ten years the annual dissolved solids load at the Red Bluff gaging station ranged from 727,200 tons in 1955 to 217,900 tons in 1964. Waters between the Red Bluff station and Red Bluff Reservoir fall into the moderately saline to very saline classification. The predominant ions are sodium chloride.

CHEMICAL INTERPRETATION

Along the Pecos River basin west of the High Plains escarpment, where the confining beds of the Chalk Bluff Formation have been removed by erosion, springs become an important influence in surface-water qualify. The spring waters are saturated with calcium sulphate through contact with gypsum. Where the river becomes partly subsurface, especially along sinks with deep circulation and within the Roswell basin, the influence upon the chemistry of the water is tremendous. Reaction rates are magnified many times as a result of (1) the large ratio of surface area to the quantity of flow underground, (2) detention periods are longer underground permitting even slow reactions to go to completion, and (3) underground flow is frequently under higher pressures and temperatures which aid most chemical reaction rates.

From this it can be seen that the chemical quality of surface waters in the middle and lower Pecos River reaches depends largely upon the fact that the rocks contain a large amount of soluble material. Some minor pollutants are irrigation return flows, sewage effluent, and industrial wastes which may increase the chlorides above their natural concentration. Evapotranspiration by phreatophytes will also increase the concentration of dissolved minerals to some degree.

Data indicate that saturation for calcium sulfate (or equilibrium concentration) is quickly established. Where water is in contact with gypsum continuously, it probably can occur within 5 to 7 days. Saturation for gypsum in pure water at 25 degrees Centigrade is 2.085 grams per liter (2,085 ppm) as referred to the anhydrous salt. The maximum concentration (2,100 ppm) occurs at approximately 40 degrees Centigrade (104 degrees Fahrenheit).

Above Anton Chico the water in the Pecos River is predominantly a calcium bicarbonate water. Below Anton Chico a rapid equilibrium in the suface water is attained with respect to gypsum. Saturation by gypsum is in evidence for much of the Pecos River water passing the Acme station below which the dissolved minerals in the water show a rapid increase. As the sodium and magnesium chlorides show a progressive rise in percentage of the dissolved minerals below Acme, it becomes more evident that the solubility of calcium sulfate has also increased, though not proportionately, first with the addition of sodium chloride, and finally by the addition of magnesium salts. In other words, an increase in concentration of sodium chloride acts to increase the solubility of calcium sulfate, while the further addition of magnesium chloride increases the concentration of calcium sulfate at saturation, ie.-up to 2 moles[1/] of magnesium chloride may increase fourfold the solubility of calcium sulfate (Morozova and Firsova *et al*, 1956, p. 1962). Increased temperatures toward the southern part of the state are important also when considering the gradual increase of calcium sulfate in a downstream order (figure 8).

Most of the Pecos River, especially the middle and lower basins, shows a marked decrease in dissolved solids with increased flood flow. Because of these periodic floods there is a much lower weighted average concentration for the year. At first, however, the chemical load and concentrations increase during the rise in discharge as a result of precipitation along the middle and lower reaches of the river. This results from the time required to clear all the saline pools and salt pans along the bank of the river. The lag of return to normal chemical concentrations is also noted when the river returns to base flow conditions; this probably is the result of release of bank storage.

1/ A mole is the gram molecular weight of the solute in one liter of solution.

REFERENCES

Hale, W. E., Reiland, L. J., and Beverage, J. P., 1965, "General Characteristics of the Water Supply in New Mexico," N. Mex. State Engineer Tech. Rept. 31 (in press).

Morozova, A. E., and Firsova, C. J., 1956, "Solubility of Calcium Sulfate in Mixes of Salts, Generally Occurring in Natural Waters," Proceedings of the Novocherkassky Polytechnic Institute, v. 27-41, p. 151-165.

New Mexico State Engineer, 1959, "Hydrologic Summary, New Mexico, Streamflow and Reservoir Content, 1888-1954," New Mexico State Engineer Tech. Rept. 7, p. 326.

Patterson, J. L., 1965, "Magnitude and Frequency of Floods in Western Gulf of Mexico Basins," Part 8, Geological Survey Water Supply Paper 1682, in press.

Reiland, L. J., and Haynes, G. L., Jr., 1963, "Flow Characteristics of New Mexico Streams - Flow-duration, High Flow, and Low Flow Tables For Selected Stations Through Water Year 1959," New Mexico State Engineer Special Report, p. 342.

Thomas, H. E., 1963, "Causes of Depletion of Pecos River in New Mexico," Geological Survey Water Supply Paper 1619 G.

U. S. Geological Survey, 1899-1963, "Surface Water Supply and Quality of Surface Waters of the United States, Part 8," Water Supply Paper 1312 and 1732 contains a compilation of all records in Pecos River Basin prior to 1960.

Wiard, L. A., 1962, "Floods in New Mexico, Magnitude and Frequency," Geological Survey Circular 464.

USE OF WATER IN THE PECOS RIVER BASIN, NEW MEXICO

Earl F. Sorensen[1/]

INTRODUCTION

As uses of water developed in the Pecos River basin in New Mexico, they were affected by availability of supply and the legal framework which controls such uses in the basin. In this paper, the history of water development will be outlined and the geographical areas in which the developments occurred will be described. Estimated quantities of water presently depleted in the basin will be given and depletions will be described by major categories of use.

GEOGRAPHICAL SETTING OF THE BASIN

The Pecos River is one of the major tributaries of the Rio Grande, joining that river near Langtry, Texas. The river rises in north-central New Mexico and travels some 300 miles before leaving the state south of Carlsbad. Surface water of the river sustains irrigation developments in both New Mexico and Texas. Total basin area in New Mexico is about 26,100 square miles; in Texas, the basin area is approximately 19,000 square miles. Three sub-basins or valleys are formed by the river before it reaches the Rio Grande. The lower valley extends from Red Bluff Reservoir to the confluence of the Pecos River and Rio Grande - all of which area is in Texas; the middle valley extends from Red Bluff Reservoir to Alamogordo Reservoir; and the upper valley lies north of that point. Both the middle and upper valleys are in New Mexico.

In 1960, population of the basin in New Mexico was about 157,500; basin population in Texas was 80,500. In Texas, total irrigated farming area in 1960 was about 294,000 acres, most of which was irrigated with ground water. New Mexico's irrigated acreage was about 191,000 acres, or about 20 percent of all irrigation in the state. Of the total, 125,000 acres were irrigated with ground water and 66,000 acres were irrigated with surface water or a combination of surface and ground water. Principal industries in New Mexico are oil and gas production, farming, potash production, ranching, and light manufacturing. Military activity is centered around Walker Air Force Base near Roswell.

Part or all of 14 counties lie within the basin area in New Mexico. Principal communities are Roswell, Carlsbad, Las Vegas, Artesia, Eunice, Jal, Santa Rosa, and Fort Sumner. Altitudes vary from over 13,000 feet in the north to about 3,000 feet above mean sea level south of Carlsbad. Average growing seasons vary in length

1/ Water Resources Engineer, State Engineer's Office, Santa Fe, New Mexico

from about 100 days in the northern mountain valleys to about 200 days in the south. Typical average annual precipitation is over 20 inches in mountainous areas, 14 inches at Santa Rosa, 12 inches at Carlsbad. Farm produce consists of cotton, alfalfa, corn, feed crops, vegetables, and some fruits. There is very little dryfarming in the basin and, generally, irrigation is required to mature crops. Farming enterprises range from large commercial farms to subsistence and part-time farming operations.

About one-fifth of the total area of New Mexico and about one-sixth of the state's population are in the Pecos River basin. Topography varies from level and gently rolling plains in the southern part to rolling hills and deeply dissected mountains in the western and northern portions of the basin. Perrennial tributaries are found chiefly in the higher mountainous areas; flow in the main stem itself is perennial to the approximate vicinity of Anton Chico. For many years all the river surface flow, except for occasional flood waters, has been fully utilized. In 1942, the National Resources Planning Board reported water from the river had been fully appropriated for use in New Mexico and Texas.

SETTLEMENT OF THE AREA

In 1540, Coronado observed Pueblo Indians irrigating crops in the vicinity of Pecos. Spanish settlers moved into this area during the late 1700's and settled as far south as Anton Chico. Until 1838, Indians and Spanish irrigated as neighbors; in that year the remnants of the decimated Pueblo Indian population migrated out of the basin and the Spanish acquired the Indian lands and ditches. Settlement south of Anton Chico was not aggressively pushed under either the Spanish or Mexican colonial governments. Small villages to the north were reinforced and Las Vegas had been settled by 1835. Part of the hesitancy to push settlement to the south was undoubtedly due to the threat of hostile nomadic Indian tribes.

Settlement in the middle valley did not take place until the years of the American Civil War. United States troops disciplined the nomadic Indian tribes during and immediately after the war, and settlement of the middle valley became feasible. Large cattle ranches on the plains and small irrigated farms on the upper reaches and tributaries were the first agricultural enterprises, but these were soon followed by the establishment of irrigated farming in the valley proper. With acquisition as United States territory in 1848, large areas of the middle valley had become part of the public domain. After adoption of the Homestead Act of 1862, this land became available for homesteading and increasing numbers of settlers moved into the valley to establish homes.

SURFACE-WATER DEVELOPMENT

The first irrigation farmers in the middle valley maintained individual ditches and diversion structures. This method of development was not efficient for numerous reasons and the landowners realized large reservoirs and centralized ditch systems were needed to efficiently regulate and distribute the water. The necessary construction was beyond the financial capability and resources of the individuals concerned.

Recognizing this problem, which was common in all irrigated areas, both the Territory of New Mexico and the Congress took legislative action that enabled individuals to form irrigation companies which could pool resources, borrow money, and develop the land. For example, New Mexico enacted legislation in 1887 providing that any five persons could form a company for purposes of constructing reservoirs, ditches, etc., and were empowered to raise money through the sale of stock. In 1902, Congress passed the Federal Reclamation Act to assist irrigation development in the western states.

Statistics are not available to indicate extent of land irrigated by the Spanish at the time the basin was being settled by Anglo-Americans. Probably not more than 5,000 acres were irrigated, these located primarily on the main stem and tributaries north of Fort Sumner. Once the new settlers entered the basin, irrigation began to increase and was accelerated after enactment of Territorial and Federal irrigation laws. Most lands irrigated by surface water were developed between 1890 and 1930. During this period, several irrigation companies were formed and these companies account for most of the land irrigated with surface water at the present time. Projects initiated during this period included Storrie Project (near Las Vegas); Fort Sumner Project; lands irrigated by the Hagerman Irrigation Company; Hondo Project; Hope Project; and Carlsbad Project. Initially, all areas were developed by private companies; however, the Fort Sumner and Carlsbad projects were later rehabilitated with assistance obtained from the Bureau of Reclamation. Most lands of the Hondo and Hope projects were later abandoned.

As uses of surface water in irrigation increased, users became increasingly concerned about the availability of supplies. Many feared that the area was over-developing and that sufficient water was not available to sustain all developments. In 1920, the Bureau of Reclamation, representing landowners in the Carlsbad Irrigation District, brought suit in the Federal Court of New Mexico asking that all rights served by the Pecos River above Carlsbad be determined by the court. This suit, entered as United States vs. Hope Community Ditch, et al., resulted in the first major adjudication of water rights of lands in the basin. The results of the action, commonly called the "Hope Decree," were issued in 1933 and defined rights of water use in most areas above Lake McMillan. Subsequently, areas outside those covered by the Hope Decree were adjudicated until, at present, practically all lands irrigated from surface water in the basin have been covered by court decrees that define the rights of use.

GROUND-WATER DEVELOPMENT

Irrigation near Roswell started about 1880. Water for irrigation was first obtained from large springs and diversions from tributaries of the Pecos River that cross the area. Artesian ground water was first discovered in 1891 when a well drilled in the city of Roswell was found to flow. During the next few years, drilling gradually increased, but wells were first used to water lawns, gardens, and for domestic supplies. About 1900, this source of water began to be used for irrigation and thereafter large numbers of wells were drilled for irrigation purposes. Many of the early wells flowed between 500 and 1,500 gallons per minute. The Oasis well, completed in 1926, had a measured flow of 5,710 gallons per minute. By 1905, 485 wells had been drilled and there appeared to be no noticeable decline in the artesian head. The large well yields created much interest in the region and, because no noticeable decline in discharge was recognized, the supply was considered inexhaustible. As a result, much speculation in farm lands occurred and greatly exaggerated claims were made for the area.

Extensive development was made in the period 1905-1916, but by the end of the period artesian head was declining rapidly. The original area of artesian flow comprised about 663 square miles; by 1916 the area had decreased to 499 square miles and many irrigators were forced to install pumps in order to stay in business. Lands irrigated in the west and southwestern portions began to go out of production and people began to be increasingly alarmed about the future of the artesian water supply. It was now becoming apparent that the supplies were being depleted and additional wells would hasten the process.

Over-expansion in the use of artesian water for irrigation in the Roswell area finally resulted in demand for enactment of a State law to control and regulate the use of underground waters. By 1925, more than 1,400 artesian wells were in operation and about 45,000 acres were irrigated. Water levels continued to decline and more wells failed. Banks refused to invest more money in irrigated farms until some means of protecting investments was devised. The situation affected and concerned the entire community and resulted in a quantitative study of the area by Fiedler and Nye of the U. S. Geological Survey in cooperation with Chaves and Eddy Counties and the State Engineer.

The investigation confirmed the fact that the area was overdeveloped and a recommendation was made that controls be instituted immediately. The 1927 legislature enacted a ground-water law, which, in 1929, was declared invalid by the Supreme Court of New Mexico because of a technicality. In 1931, the statute was reenacted in a form acceptable to the court, and on August 21 of that year the State Engineer established an underground artesian basin. New irrigation appropriations from the then established artesian basin have not been permitted since that date.

Shallow water in the basin had not been extensively used during the period of artesian development. Once drilling into the artesian aquifer was controlled, people began to develop the shallow aquifer as a source of supply. In 1937, the State Engineer considered shallow waters within the boundaries of the artesian basin to be fully appropriated and limited further irrigation appropriations from this source.

By 1937, non-artesian water was being used for irrigation in areas outside the artesian basin. Use of this source slowly expanded until after World War II; at that time irrigation using shallow ground water began to accelerate. To control, conserve, and protect the supply, the State Engineer declared other ground-water basins. In addition to the Roswell Artesian Basin, declared ground-water basins presently consist of Carlsbad, Fort Sumner, Hondo, Jal, and Penasco basins -- encompassing collectively some 6,500 square miles. Essentially all ground-water use in the middle valley is now controlled.

In the Roswell area, uses exceed the natural rate of recharge and a condition of ground-water mining exists. This has upset the natural balance of the area and has resulted in such noticeable effects as decrease in artesian and surface flows, increased pumping lifts, and intrusion of salt water into fresh ground-water aquifers.

The rate at which uses exceed recharge to the area is indicated as follows: The annual natural recharge to ground-water aquifers is about 265,000 acre-feet, of which some 115,000 acre-feet are naturally discharged. A balance of 150,000 acre-feet remains available for consumptive use. Total pumpage from the aquifers is estimated to be between 400,000 and 430,000 acre-feet, of which about 270,000 acre-feet are consumed and the remainder is returned to the aquifers; thus, present annual consumptive use exceeds available recharge by about 120,000 acre-feet annually.

The seriousness of problems in the Roswell area led to adjudication of ground-water rights. In 1956, the State Engineer and the Pecos Valley Artesian Conservancy District jointly filed suit in the District Court of Chaves County to obtain a judicial determination of rights, both artesian and shallow, in the area. At present, adjudication proceedings are more than 99 percent complete. During the hearings it was found that about 142,000 acres of land were irrigated, of which approximately 130,000 acres had valid rights. Irrigation of the other 12,000 acres was declared illegal and such irrigation has been enjoined. Termination of the illegal use will reduce withdrawals from the basin by about 40,000 acre-feet of water per year. This should decrease the annual consumptive use by about 25,000 acre-feet, with a corresponding decrease in the amount by which the annual consumptive use exceeds the available recharge.

THE PECOS RIVER COMPACT

In 1939, Secretary of Interior Harold L. Ickes requested that the chairman of the National Resources Committee conduct a thorough study of water problems in the Pecos River basin. The Secretary pointed out that increasingly acute problems connected with water quality and water use in the basin made a general comprehensive investigation necessary. Shortly thereafter the Pecos River Joint Investigation was made and results were published in 1942. During that same year, New Mexico and Texas began to negotiate a compact. Representatives of the states had available for use detailed basic data that had been gathered during the joint investigation. Several years were required to complete negotiations and it was not until December 1948 that the compact was signed, in Santa Fe. In 1949, the legislatures of the two states ratified the compact and Congress and the President approved the agreement. From that time forth, the compact has been binding upon the states.

The compact created a commission to administer its provisions and provide for an equitable division of water between the states. Water apportionment is based on 1947 conditions in New Mexico. In addition, salvaged water and unappropriated flood waters are apportioned.

PRESENT WATER USES IN THE PECOS RIVER BASIN IN NEW MEXICO

All of the following statistics should be understood as approximations only. Quantities are based on averages and are stated in terms of acre-feet per year. Certain items, such as reservoir evaporation, have been derived from representative periods of record; others are the results of recent inventories made in the basin. Depletion means water removed from further use in the basin, such as evapotranspiration by irrigated crops, phreatophytes, etc. Use signifies demand for water, such as that required for municipal and industrial purposes, much of which is returned to the basin supply.

Estimated depletion in the basin is about 648,000 acre-feet annually, of which 6,300 acre-feet are imported from the High Plains. Of this amount, 185,000 acre-feet are non-beneficially consumed by channel losses and by evapotranspiration of phreatophytes along the main stem of the river. Similar losses have not yet been estimated for tributary areas. In addition to the above amount non-beneficially consumed by phreatophytes and channel losses, about 40,600 acre-feet are evaporated from reservoirs and 4,900 acre-feet are evaporated from stock ponds. The remainder -- 417,500 acre-feet -- is depleted as follows: irrigation - 368,300; urban - 10,800; rural domestic and livestock - 6,500; military - 1,100; recreation, fish, and wildlife - 10,700; and miscellaneous self-supplied uses - 20,100 acre-feet. With respect to the 417,500 acre-feet, irrigation depletions comprise about 88 percent.

Urban uses are defined as those uses in communities with 2,500 or more inhabitants. These communities consist of Artesia, Carlsbad, Eunice, Jal, Las Vegas, and Roswell. Roswell is the largest user of water, diverting some 11,400 acre-feet and depleting about 8,800 acre-feet per year, all obtained from ground water. Las Vegas is the only city of this group that uses water obtained from surface sources.

The community also uses some additional water obtained from wells. Urban uses include that which is required for commercial, industrial, and manufacturing activities as well as domestic supply and lawn watering. These uses were not separately identified. Rural uses include use by communities smaller than those cited, as well as by persons who live on farms and ranches. For these purposes, about 3,500 acre-feet are diverted and 1,600 acre-feet are depleted. Ground water furnishes most of the supply, but some surface water and combined sources are used. Per capita use varies from 25 to over 200 gallons per day among rural users, and from 57 to 250 gallons per day among urban users. Average for the basin is 143 gallons per person per day -- rural, 45; urban, 200.

Livestock depletion is about 4,900 acre-feet, of which approximately 50 percent is furnished by wells. In 1963, there were in the basin approximately 340,000 cattle, 570,000 sheep, 12,000 hogs, and 162,000 chickens. A recent inventory indicates there are in the basin a total of 5,400 stock ponds capable of storing water.

Military uses deplete 1,100 acre-feet; about 2,100 acre-feet are diverted from ground-water sources to supply these uses.

Recreation, fish, and wildlife activities consume about 10,700 acre-feet annually. Of the total, about 9,000 acre-feet are depleted at Bitter Lakes National Wildlife Refuge where consumptive uses consist of evapotranspiration from grain crops, grass land, open water surfaces, and marshes. Other places of use include Carlsbad Caverns National Park and small lakes, fish hatcheries, and game refuges maintained by Federal and State agencies.

Self-supplied uses consist of commercial, industrial, mineral, and power-production activities not supplied by public utilities. Commercial and industrial activities together deplete about 900 acre-feet a year at the present time. Power production is from fuel-electric plants located near Roswell and Carlsbad that use water for cooling purposes. Both plants deplete about 900 acre-feet a year. Annual depletion by mineral industries total approximately 18,300 acre-feet, most of which is used in the production of potash. Other mineral activities include production, processing, and refining of petroleum, and some gravel washing. Of the 20,100 acre-feet depleted by self-supplied uses, about 6,000 acre-feet are supplied by surface water and 14,100 acre-feet are furnished from wells. Of the amount furnished from ground water, the potash industry obtains 6,300 acre-feet from wells located on the Southern High Plains.

A recent inventory indicates about 196,860 acres are presently being irrigated in the basin. Of this area, 39,520 acres are irrigated with surface water, 124,400 acres with ground water, and 32,940 acres from combined sources. Crop-irrigation consumptive-use requirements range from about 0.85 to 1.80 acre-feet per acre per year. Most of the acreage in the upper valley is irrigated with surface water through community-acequia systems. Estimated area irrigated in the upper valley is about 12,500 acres. Other surface-water uses for agriculture are scattered throughout the basin, along the main stem and tributaries. Ground-water uses are found primarily in the Roswell area and to the south. Combined sources are used in some tributary areas, but most uses of this nature are located in the vicinity of Roswell and Carlsbad.

Irrigation uses throughout the basin deplete about 368,000 acre-feet annually, of which 241,000 are ground water and 127,000 are surface water. Of the total depleted by irrigation, ground water furnishes 65 percent and 35 percent is furnished by surface water.

FLOOD CONTROL AND RECLAMATION PROJECTS PECOS RIVER BASIN, NEW MEXICO

Carl L. Slingerland[1/]

INTRODUCTION

The National Resources Planning Board in 1942 summarized the Pecos River Basin by saying ". . . For its size, the basin of the Pecos River probably presents a greater aggregation of problems associated with land and water use than any other irrigated basin in the western United States. These involve both quantity and quality of water supplies, the problem of salinity being particularly acute; erosion and silting of reservoirs and channels; damage from floods; and interstate controversy over the use of the waters. There is an abundance of good land so that the limit of development is the availability of water of satisfactory quality. The use of the water of the river has been fully appropriated . . ."

The United State Bureau of Reclamation, Corps of Engineers, Soil Conservation Service and the Pecos River Commission of New Mexico and Texas have played important roles in the development and control of the water resources of the Pecos River Basin.

The Bureau of Reclamation, originally known as the Reclamation Service, was established in June 1902 for the purpose of constructing irrigation works for the reclamation of arid lands. Over the years, as needs have developed, the Bureau's program has been expanded to supply water to industries and municipalities, to generate hydroelectricity, to provide water for recreation and to serve other beneficial uses. The agency has been active in New Mexico since 1903.

The water resource development program of the Army Corps of Engineers began in New Mexico in 1935. During that year the Conchas District Office was established to accomplish the necessary design work and supervise the construction of Conchas Dam on the Canadian River near Tucumcari. The water resource development program of the Corps of Engineers is chiefly concerned with flood and sediment control, municipal water supplies, and other allied purposes.

The Watershed Protection and Flood Prevention Program, administered by the Soil Conservation Service, which provides Federal assistance for multiple-purpose projects on small watersheds, has been active in New Mexico since 1955. Commonly known as Public Law 566, the Watershed Protection and Flood Prevention Act, became

1/ Staff Engineer, Interstate Stream Commission, Santa Fe, New Mexico

effective in 1954 and in the next year Congress authorized work on 60 small watersheds to serve as demonstration or "pilot" projects. Two of these pilot projects are in New Mexico. One -- upper Rio Hondo and Tributaries -- is in the Pecos Basin.

The Pecos River Compact was signed in December 1948 by representatives of New Mexico and Texas, was ratified by the respective state legislatures, and subsequently was approved by Congress, becoming law on June 9, 1949. A major purpose of the compact is to facilitate the construction of works for the salvage of water, the more efficient use of water, and the protection of life and property from floods.

The compact provides for the formation of a commission to administer its provisions. This administrative agency, known as the Pecos River Commission, has been instrumental in coordinating the work of the various Federal agencies and in obtaining legislation to carry out the major purposes of the compact.

In many instances the program of these agencies are complementary, especially when water-salvage, irrigation works or flood-protection works are needed. For example, the Brantley Dam and Reservoir near Carlsbad presently under study by the Bureau of Reclamation will provide replacement storage for irrigation, make possible the clearing of salt cedar from the McMillan delta for the salvage of water, and provide much needed flood control. In the planning of such projects, close coordination between the agencies often produces a dual or multipurpose facility which serves the needs of the area as well as single purpose projects, and at much smaller total cost.

HONDO PROJECT

The first Reclamation Service Project in New Mexico was the Hondo Project. The project was initiated in the middle 1880's by private interests and contemplated storage of flood waters of the Rio Hondo in an offstream reservoir about nine miles southwest of Roswell to irrigate some 10,000 acres of land. Financial difficulties and the disastrous floods of 1893 on the Pecos suspended construction. Late in 1902 the interests persuaded the newly organized Reclamation Service to take over the project. Surveys were started in 1903 and by 1912 the project works were essentially completed. The project was not successful; because of the leaky nature of the reservoir formation, the impounded water escaped rapidly through the floor of the reservoir.

FT. SUMNER PROJECT

Irrigation in the Ft. Sumner area dates back to 1862 when the U. S. Army established a reservation for Navajo and Mescalero Apache Indians. To make the reservation self-sufficient, Army troops built a diversion dam and several miles of canal to irrigate some 2,600 acres. The venture was not successful and in 1868 the experiment was abandoned. The project was revived shortly after the turn of the century and was operated by several interests until 1919 when the Ft. Sumner Irrigation District was formed. The newly formed district was unable to obtain financing to do more than install temporary facilities until 1935 when the Public Works Administration advanced sufficient funds to construct a concrete diversion dam and about 14 miles of canal. Floods destroyed a portion of the diversion dam in 1941 and again in 1942 when a section about 250 feet long was washed out. Temporary earth fill repairs were made, but the entire system was in need of rehabilitation so the district appealed to the Secretary of Interior for aid. In 1948 the Bureau of Reclamation made emergency repairs to the works and in 1949 Congress authorized rehabilitation of the system. The work consisted of constructing a new concrete diversion dam, concrete lining about 16 miles of main canal and 8½ miles of high line canal, installing a new 20 cubic foot per second hydraulic pumping plant to lift water from the main canal to the highline canal, and rehabilitating the system's lateral and drainage system.

CARLSBAD PROJECT

In the Carlsbad area irrigation works to serve what is today known as the Carlsbad Project, or the Carlsbad Irrigation District, was started in the late 1880's by the Pecos Irrigation and Improvement Company. Eddy Dam (now known as Avalon Dam) and the supply canal to the project were completed in 1890 and 1891, with McMillan Dam about ten miles upstream being finished in 1893. In October of 1893, floods on the Pecos River washed out Eddy Dam and only by dynamiting a section of McMillan Dam was it saved from destruction. The damage to both dams was repaired and by the turn of the century more than 13,000 acres were under irrigation in the vicinity of Carlsbad.

In 1904 floods again washed out Eddy Dam and severely damaged other works of the project. During 1906 the Reclamation Service entered a contract with the local organization to rehabilitate the project works.

Avalon Dam was reconstructed with a reservoir capacity of 7,000 acre-feet. McMillan Dam, which formed a reservoir with a capacity of 90,000 acre-feet, was rehabilitated along with the supply canal and distribution system. This work was accomplished between 1907 and 1909.

Leakage from McMillan and Avalon Reservoirs and sedimentation continued to reduce the effectiveness of these reservoirs until in 1931 the Bureau of Reclamation proceeded with plans to construct a third dam -- Alamogordo Dam -- located about 16 miles northwest of Fort Sumner. Construction of the dam was begun in 1936 and completed in 1937. The dam is an earthfill structure 148 feet high and 3,084 feet long, forming a reservoir with an original capacity of 157,000 acre-feet. The additional storage capacity provided by Alamogordo Reservoir did not solve all the problems. Water loss from the 236 miles of river between Alamogordo Dam and McMillan Dam was high and with the continuing spread of salt cedars along the river bottom, particularly in the McMillan Delta, these losses were increasing. By the early 1950's the combined capacity of the three reservoirs had been reduced from an original capacity of 254,000 acre-feet to about 165,000 acre-feet, and with increasing losses to saltcedar the shortage in the Carlsbad Project water supply was becoming critical.

In 1954 the Bureau of Reclamation issued a plan for salvaging waters lost to saltcedar in the McMillan Delta area. The plan contemplated construction of a low-flow channel about 16 miles long and a cleared floodway 2,000 feet wide through the McMillan Delta.

The low-flow channel was designed to pass 1,500 cubic feet per second -- a capacity adequate to carry normal river flows and small flood flows. Flows in excess of the channel capacity would be diverted into the floodway which would have a capacity of 40,000 cubic feet per second. The Bureau of Reclamation estimated the project would salvage about 25,000 acre-feet annually. The Bureau of Reclamation plan along with a report prepared by the Pecos River Commission was presented to the Congress in February 1958 and the project was authorized in the same year by Section 1 of Public Law 85-333.

The authorizing legislation recognized the Carlsbad Irrigation District's concern that if the saltcedar were removed from the floodway the storage capacity of McMillan Reservoir would soon be depleted as a result of increased sediment inflow. The saltcedar, while consuming large amounts of water, serve as an effective sieve to keep sediment out of McMillan Reservoir. The legislation provided that no money should be appropriated for, or no work commenced on, clearing of the floodway until provision had been made to replace any Carlsbad Irrigation District terminal storage which might be lost as a result of clearing the floodway.

To provide replacement storage for the Carlsbad Irrigation District, the Bureau of Reclamation investigated possible reservoir sites between McMillan and Avalon dams. Because of the cavernous nature of the underlying limestone formations, extensive geology studies were required to select an adequate site. In June 1960 the Bureau of Reclamation reported its findings on a location called the Brantley site, about 4 miles downstream from McMillan Dam. Following requests by the State of New Mexico and the Carlsbad Irrigation District a feasibility study of Brantley Dam and Reservoir was undertaken. The proposed dam and reservoir would provide terminal irrigation storage for the Carlsbad Irrigation District, space for 100 years of sediment deposition, flood protection for the City of Carlsbad, and fish and wildlife and recreation benefits.

While studies of possible replacement storage were being conducted, the Carlsbad Irrigation District undertook the construction of a low-flow channel through McMillan Delta where the saltcedar had encroached into the river channel and was restricting even the low flows of the Pecos River. Work has continued on the channel and now it extends from McMillan Reservoir to near Artesia. This channel, known as Kaiser Channel, has accomplished a part of the salvage contemplated in the McMillan Delta Project.

MALAGA BEND SALINITY PROJECT

Section 2 of Public Law 85-333 authorized the Malaga Bend Salinity Alleviation Project as a means of reducing the salinity of the Pecos River. In the area of Malaga Bend about 20 miles below Carlsbad, there were, prior to construction of the project, several springs and seeps which added about 420 tons of dissolved minerals daily to the Pecos River, about 370 tons of which were sodium chloride.

Construction of the project was accomplished by the Bureau of Reclamation and an evaluation program is being conducted by the U. S. Geological Survey.

The constructed project consists of a production well, about 220 feet deep and equipped with a 12-inch plastic casing, a pumping plant, and about two miles of 8-inch asbestos-cement pipe leading from the production well to an evaporation-disposal area.

Operation of the project started in July 1963 and by December of 1964 approximately 1,000 acre-feet of brine containing more than 300,000 tons of salt had been pumped into the disposal area. The head in the brine aquifer had been lowered as much as 8 feet and the brine inflow to the river had been reduced about 70 percent.

PUBLIC LAW 88-594 -- A CONTINUING PROGRAM TO REDUCE NON-BENEFICIAL CONSUMPTIVE USE OF WATER IN THE PECOS RIVER BASIN IN NEW MEXICO-TEXAS

The Pecos River Commission, Bureau of Reclamation, Geological Survey, and the State of New Mexico have been actively engaged in studies of the growth, water use, and possible salvage of water from saltcedar jungles in the Pecos Basin. As a result of these studies and in order to prevent further decrease in the supply of water in the Pecos Basin, Public Law 88-594 -- A Continuing Program to Reduce Non-beneficial Consumptive Use of Water in the Pecos River Basin -- was approved in September 1964. The law authorizes the Secretary of Interior to take such measures as he deems appropriate to carry out a continuing program to reduce the non-beneficial consumptive use of water by saltcedar and other phreatophytes.

There are between 60,000 and 70,000 acres of saltcedar along the Pecos River between Santa Rosa, New Mexico, and Girvin, Texas, with about 40,000 acres being in New Mexico. The largest concentration in New Mexico is in the 110-mile river section between the

Acme gage just above Roswell and McMillan Dam. In this section there are about 28,000 acres of saltcedar which thrives on river flows and the natural discharge of the Roswell Artesian Basin. It has been estimated that eradication and control of the saltcedar in this reach could salvage about 57,000 acre-feet of water annually.

Saltcedar in the Pecos River Basin infested the river bottom lands at a phenomenal rate. They were first noted in 1915 and by 1939 there were about 14,000 acres along the river between Alamogordo Dam and the New Mexico-Texas State line. The infested area in 1960 had increased to about 40,000 acres and estimates by the Bureau of Reclamation indicate that by the year 2010, unless corrective action is taken, some 75,000 acres will be infested.

Without a program such as is authorized by P.L. 88-594, within a few decades virtually the entire supply of the Pecos River could be depleted by these plants.

LOS ESTEROS AND ALAMOGORDO RESERVOIRS FLOOD CONTROL PROJECT

The Flood Control Act of 1938 directed the Secretary of War to make preliminary examination and surveys for flood control for several localitites in the United States among which was the Pecos River Basin in New Mexico and Texas.

The Los Esteros - Alamogordo flood control project was included as a part of the Selected Plan of Improvement in the Corps of Engineers' 1951 report entitled "Pecos River and Tributaries, Texas and New Mexico".

To create an effective flood control project it is found necessary to use a part of the capacity of the existing Alamogordo Reservoir to control flood flows originating between the proposed Los Esteros dam site and Alamogordo Dam. For this reason the Corps of Engineer's plan included conservation storage capacity for the Carlsbad Irrigation District in the proposed Los Esteros Reservoir to compensate the district for that portion of Alamogordo Reservoir that was required for flood control.

Authorized by the Flood Control Act of 1954, the project provides for construction of a dam at the Los Esteros site about 7 miles upstream from Santa Rosa and for modification of existing Alamogordo Dam.

The proposed Los Esteros Dam would control floods from about 2,480 square miles of Pecos River drainage area and would have a total capacity of 597,000 acre-feet which is allocated to flood control, conservation, and sediment. The proposed dam would be an earthfill structure about 218 feet high and 1,865 feet long; in addition, a dike about 12 feet high and 1,420 feet long would be required to block a low-saddle extending from the left abutment.

Modifications to existing Alamogordo Dam would consist of raising the main embankment 10½ feet and constructing an emergency spillway about 500 feet long, along with modification of the existing operating spillway and outlet works. The project would be integrally operated for flood control and irrigation and would effect a reduction in flood damages along the Pecos River below the project.

The legislation authorizing the Los Esteros Project provides that no appropriations shall be made for constructing the project until satisfactory arrangements have been made by the State of New Mexico for transfer of part of the Carlsbad Irrigation District conservation storage from Alamogordo Reservoir to Los Esteros Reservoir. In order that the Carlsbad Irrigation District could analyze in detail the possible effect of the project on the district's water supply, the district requested that certain river-routing studies be made.

The studies were completed by the State of New Mexico and the results made available to the district. However at this time the district has not reached a decision in the matter and no appropriation to construct the project has been requested.

TWO RIVERS RESERVOIR PROJECT

Several destructive floods have occurred in the city of Roswell which is situated on the Rio Hondo, a tributary of the Pecos River. During 57 years of record, 47 flash floods have occurred in the Rio Hondo, causing damage in varying degrees. The most disastrous flood occurred in September 1941 with other major floods in 1915, 1937, 1949, and 1954.

As a part of the Pecos Basin survey the Corps of Engineers in 1952 issued a report entitled, "Interim Report on Survey for Flood Control, Rio Hondo at Roswell, New Mexico". This report presented two plans to alleviate flood damages in and adjacent to Roswell. One plan contemplated diverting the flows from the Rio Hondo and Rocky Arroyo into a drainage south of the Rio Hondo. The alternate plan was to construct two earthfill dams -- the Diamond A on the Rio Hondo and Rocky Dam on Rocky Arroyo.

The alternate plan was authorized as the Two Rivers Reservoir Project by the Flood Control Act of 1954. Pre-construction planning started in 1956 and construction was commenced in 1960.

The constructed project consists of two earthfill dams forming a common reservoir with a capacity of 168,000 acre-feet -- 18,000 acre-feet of which are allocated to sediment storage, and 150,000 acre-feet to flood-control storage.

The project was completed in 1963; it provides flood protection to the city of Roswell and Walker Air Force Base and incidental benefits along the Pecos River below the mouth of the Rio Hondo.

OTHER FLOOD CONTROL STUDIES

The Corps of Engineers currently is preparing reports to determine the advisability of improvements for flood control and allied purposes in the Pecos River Basin above Santa Rosa and along the Rio Hondo and Rio Felix and their tributaries.

The investigation for the area above Santa Rosa is being made to determine the feasibility of improvements for flood control, irrigation, municipal and industrial water supply, and fish and wildlife and recreation. Projects being considered include a reservoir on the Gallinas River above Las Vegas and channel improvements through the urban area of that town. Consideration also will be given to multi-purpose reservoirs and channel rectification work on the main stem of the river.

The Rio Hondo and Rio Felix studies include consideration of a) reservoirs on Berrendo Creek and Rio Felix, b) diversion of Rio Hondo and North Spring River to Berrendo Creek northwest of Roswell, and c) alternate channel improvements in Berrendo Creek, North Spring River, and Rio Hondo through Roswell.

PUBLIC LAW 566 PROGRAM

The Soil Conservation Service under the authority of Public Law 566 has completed two watershed protection projects in the Pecos River drainage; Zuber Draw and Upper Rio Penasco.

The Zuber Draw project in Chaves County was sponsored by the Hagerman-Dexter, Roswell, and Upper Hondo Soil Conservation Districts and was completed in 1960. The structural measures included in the plan consist of three floodwater-retarding structures having an aggregate capacity of about 5,000 acre-feet and about 11 miles of floodwater diversion dike to divert flood flows from Thirteen Mile, Zuber, and Greenfield Draws into the Rio Felix. The project provides flood protection to cropland, irrigation systems, canals, roads, and urban property in the town of Dexter.

The Upper Rio Penasco project in Otero County was sponsored by the Otero Soil Conservation District. The structural measures of the project consist of three floodwater retarding structures with a total capacity of about 500 acre-feet. The works provide protection to agricultural lands, irrigation systems, and roads. The structural measures of the plan were completed in 1960.

In addition to the two completed watershed projects, eight others are in various stages of planning or construction. They include

Avalon-Alacran in Eddy County
Cass Draw in Eddy County
Cottonwood-Walnut Creek in Chaves and Eddy Counties
Eagle-Tumbleweed Draws in Chaves and Eddy Counties
Hackaberry Draw in Eddy County
Lower Rio Penasco in Chaves and Otero Counties
North Spring River in Chaves County
Pecos Arroyo in San Miguel County

Flood protection for farm and ranch land, roads, irrigation systems and urban development are contemplated by these watershed projects.

OTHER IRRIGATION DEVELOPMENT

The foregoing portion of this paper has been devoted to a detailed description of the several federal projects. Accomplishments by private interests which accounts for about 75 percent of the irrigation development in the basin certainly should not be overlooked. These developments include the vast individual efforts of the people on their own lands and combined efforts such as the many community ditch systems in the headwaters area, the Storrie Project on the Gallinas River near Las Vegas, the Hagerman Irrigation Company in the Roswell Basin and the Hope Project on the Rio Penasco west of Artesia.

Other local and state agencies have also assisted in the development and rehabilitation of irrigation works and in water conservation.

SUMMARY

Water development in the Pecos River Basin has long been plagued with floods, sedimentation, salinity problems, and water shortages.

The projects in operation in the basin have helped alleviate many of these problems, and those authorized and being planned will further reduce the problems, but by no means will they all be solved. Continued planning and construction of water development and control projects will be required to make the best use of the land and water resources of the basin.

THE POSSIBILITY OF INCREASING WATER YIELD THROUGH MANAGEMENT

Lowell G. Woods1/

INTRODUCTION

Demands for water in the arid Southwest far exceed the supply. The problem will worsen and become increasingly critical as the population increases and we continue to over-pump underground water supplies. In the Southwest we are always short of water. Some years we are shorter than others.

The primary sources of our water supplies are the higher mountain watershed lands, most of which are within the National Forests. Protecting watershed lands from fire and exploitation was a primary consideration when the National Forests were reserved from the public domain 60 years ago.

During the early years of National Forest administration, emphasis was placed on watershed protection, and the primary aim in watershed management was maintenance of water quality. The fundamental principle involved utilization of a cover of trees, grass, and brush to hold the soil and to facilitate water percolation and water storage within the soil.

WATERSHED MANAGEMENT POLICY FOR NATIONAL FORESTS

Significant events have occurred in recent years which are changing and reshaping watershed management policy and management direction for the National Forests in the Southwestern United States. This change reflects a response to the demands of people who are dependent on these lands for resources.

In 1957, the Chief of the Forest Service amended the policy for watershed management in the Southwest. He recognized that the Southwestern National Forests are moving into a much more intensive phase of resource management; that in some areas water is perhaps the most valuable resource from these lands; and that the more intensive phase of watershed management must not only continue to consider protective functions of the watershed, but also give important weight to other practices affecting the quantity or amount of water yield. This change in policy was significant. He directed attention to management practices that would not only protect watershed lands, but would also be designed to increase water yields where practical.

1/ Assistant Regional Forester, Division of Watershed Management, U. S. Forest Service, Albuquerque, New Mexico

MULTIPLE USE SUSTAINED YIELD ACT

In 1961, Congress passed the Multiple Use Sustained Yield Act. This Act emphasized that the renewable resources of the National Forests will be managed so that they are utilized in the combination that will best meet the needs of the American people. No resource would have automatic priority. In management decisions all resources would be considered. In water-short areas, water yields would receive major consideration. Modification of management practices to improve water yields would be undertaken when proven practical by research and trial application.

A DEVELOPMENT PROGRAM FOR NATIONAL FORESTS

In 1961, another significant event for the Forest Service was when the President of the United States sent to Congress "A Development Program for the National Forests." This was a ten year program to accelerate resource management and development work needed on the National Forests and National Grasslands to assure that the resources from these public lands will meet their full share of present and future public needs.

The development program was favorably received by Congress and has been partially implemented with funds. It has allowed for substantial increases in watershed management activities and development programs on the National Forests in New Mexico and Arizona.

The accelerated program will allow for more professional attention to all aspects of the watershed management job. We, in the Forest Service, accept the challenge with a lot of enthusiasm. One of the big jobs ahead for watershed management technicians in the National Forests is to prescribe the type of co-ordinated management practices which will increase water yields and at the same time minimize impacts or enhance other important resource values.

WATERSHED MANAGEMENT RESEARCH

To guide us in preparing proper prescriptions or management practices we have a lot of data and facts from watershed management research on which to draw. I would like to briefly review with you a few of these basic principles and significant research findings.

Studies by Forest Service research scientists in watersheds throughout the United States have established certain principles of watershed management to increase water yields. Among these are the following: deep-rooted plants create greater soil-moisture deficits than plants with shallower root systems; these deficits must be replenished before water will percolate through the soil to recharge groundwater and maintain streamflow; thinning dense coniferous stands on north slopes in areas of heavy snowfall will allow more snow to reach the ground and thereby increase water available to

Figure 1. Fool Creek Watershed has been treated to improve water yields. Fraser Experimental Forest, Fraser, Colorado.

Figure 2. North Fork of Workman Creek, Serra Ancha Experimental Forest, Central Arizona. One-third of a 240-acre watershed was cleared of timber and converted to grass.

streamflow; on deep soils conversion from deep-rooted to shallow-rooted vegetation will result in more water available to streamflow if conditions for infiltration are satisfactory and precipitation is sufficient to wet down through the root zone.

At Fraser, Colorado, watershed scientists, Love and Goodall, found that by harvesting commercial timber on a 714-acre watershed by clear-cutting in alternate strips that water available for streamflow was increased by 31 percent.

In this system, clearcut strips alternate with uncut strips to form a checkerboard pattern. The trees on the uncut strips are not logged until new tree growth is established on the strips first cut. This perpetuates the checkerboard arrangement. Streamflow had been measured for this and a neighboring watershed for several years. The flow from the two areas was so closely comparable that one could be used as a control to determine the effect of timber harvest on the other.

Cutting on the test area was completed between 1954 and 1956. Widths of cut and uncut strips ranged from 30 to 400 feet (from one-half tree height to seven times tree height). No trees were cut within 90 feet of the stream. All live trees larger than four inches in diameter on cut strips were made into logs, poles, mine props, and pulpwood. Slash was looped and scattered. There were 550 acres of merchantable forest on the watershed, of which 55 percent was lodgepole pine and the remainder was spruce-fir. The trees cut on the strips and in the clearing for roads amounted to half of the total timber volume.

They also report that least snow is found under dense groups of trees, and the deepest snow is near the center of the largest openings. Also, that reducing the number of trees per acre by thinning increased the snow accumulation by 23 percent. This increase comes from reduced interception and transpiration.

At the Workman Creek watersheds in Central Arizona, water yield has increased 55 percent following replacement of 80 acres of forest with perennial grass. The 80 acres were approximately one-third of a 240-acre Douglas fir-white-fir forested watershed at 6,500 feet elevation and 32 inches average precipitation. Only the moist-site timber closest to the stream channel was cut.

It was interesting to know that the increases in water yield from this experiment closely approximated the results from other studies in aspen plots in Central Utah that were converted to perennial herbaceous vegetation.

The increase in water yield was attributed to the removal of deep-rooted plants and the replacement of shallow-rooted plants that did not extract or use as much water through the evapotranspiration process. Thus leaving more water available for streamflow.

Figure 3. A chaparral watershed near Roosevelt Lake, Arizona, which has been converted to grass following a wild fire in 1959.

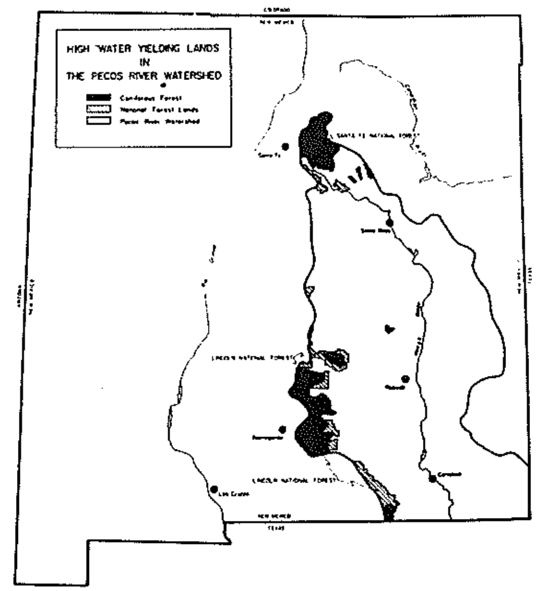


Figure 4. Pecos River Watershed, New Mexico. National Forests comprise 10 percent of the area and produce 78 percent of the water yield.

A. R. Croft, at the Intermountain Research Station, found a four inch saving of water by removing aspen trees and converting the site to a herbaceous cover. The reason water is saved by removal of aspen is found in the distribution of its roots with respect to roots of herbaceous plants. The tree roots penetrate the soil to a depth of six feet or more. This is two or three feet deeper than herbaceous roots extend. Thus, three or four inches more water was available to aspen roots than to herbaceous roots. Changing the cover from deep-rooted plants to shallow-rooted plants resulted in a water saving of about two inches per foot of soil depth. The two inches varies with soil texture.

Other studies in Arizona showed that Bermuda grass, because of shallower rooting, consumed much less water than salt cedar.

Blaney estimated that a saving of 50 percent, or about 32,600 acre feet of water per year, could be obtained by replacing salt cedar with Bermuda grass in the Pecos River channel between Artesia and Carlsbad, New Mexico, a distance of 36 miles. I understand a program is now underway for removal of salt cedar in the Pecos Valley.

At the 3-Bar Experimental Watersheds north of Roosevelt Lake, three experimental watersheds were burned by wild fire in 1959. Regrowth of chaparral species on one of these watersheds has been held in check by spraying shrubs with chemicals. Water and sediment yields increased on all watersheds after the fire. The watershed on which the chaparral species have been held in check has maintained a small but continuous flow of water, with negligible soil movement.

During the last two years, water yield on the treated watershed had doubled the water yield from the control watershed where sprouting and regrowth of the shrubs has now reached a 40 percent canopy cover. Water yield has amounted to 27 percent of precipitation for the converted watershed and less than 11 percent for the control or resprouted watersheds.

Current watershed management research throughout the west shows promise of increasing water yield by manipulating or changing the vegetation.

PILOT STUDIES

Before starting a large scale action program, research results and principles must be pilot tested on a large scale to determine the quantitative effects under local conditions, impacts on other resources, and costs and benefits of such treatments. The Forest Service is moving ahead with a program of pilot testing of watershed management practices to increase water yield. This is being done in the Beaver Creek Watershed, a 275,000-acre tributary of the Salt

River Basin. Practices now being tested are conversion of the juniper and sparse pine types to grass and thinning of pine on commercial timberlands. Measurements are being made to determine the effects of these treatments on soil stability and yields of forage, timber, wildlife, and water. Research and pilot-scale tests are being expanded to additional areas representative of other vegetative types and various methods of treatment.

At the Burro Creek Watersheds on the Apache National Forest, the Forest Service has harvested timber under various methods of clear-cutting in patches which vary in size from three to 23 acres. Different methods of slash disposal and post-treatments were applied.

The objectives of these clear-cutting tests are to appraise the fire hazard,. determine costs of slash disposal, determine rate of natural regeneration, test methods of tree planting, measure losses from windfall, and determine benefits to range forage and wildlife habitat.

Other pilot studies are underway in New Mexico. Stream gages have been installed on the Tesuque Watersheds, northeast of Santa Fe. This is a cooperative program between the State Engineer, Interstate Stream Commission, U. S. Geological Survey, and the Forest Service. The work thus far has been the installation of eight stream gages to measure water yield from the different vegetation and elevation zones.

Each year of water yield data collection brings us closer to watershed calibration. That is, a time when we have determined the relationship at one watershed to one or several other watersheds. Once this relationship is known we can then accurately predict what one watershed will yield by looking at the performance of another. In this way the effects of change within a watershed on water yield are measured. When the Tesuque watershed calibration is complete watershed treatments will be designed to test various practices of timber harvest on recreation values, water yield, and wildlife habitat.

Studies are also underway on the Santa Fe River watershed to appraise the opportunities for management of the Alpine snowfield to improve water yield.

Last year watershed management studies were started on five small pinyon-juniper watersheds on the Carson, Santa Fe, and Cibola National Forests in Northern New Mexico. While we know the pinyon-juniper type is not found in a high water yielding zone, we need to know more about the hydrologic functioning and condition of this vegetative type. We must appraise what opportunities do exist for intensive water management.

WATER YIELD

In the New Mexico portion of the Rio Grande Basin, the spruce-fir and ponderosa pine zones make up 30 percent of the land area and provide 72 percent of the streamflow. Most of these timber-land lands are in the National Forests. It is within these higher water producing areas that the opportunities exist for improving water yields.

Let's take a closer look at the headwaters of the Pecos River within the Santa Fe National Forest.

Long time records of annual water yield at the gaging station near Pecos, New Mexico, shows an average annual water yield of 74,065 acre feet from 189 square miles drainage. In acre inches this amounts to 7.35 inches annually, with 26 inches as average annual precipitation this would amount to a recovery of 28 percent of rainfall.

This compares very favorably with the rest of the high mountain watersheds in the Rockies.

In comparison, the average annual water production for the entire Pecos River Basin is four percent of precipitation. At Colonias the water yield amounts to one area inch. Most of the rainfall at the lower elevations is used to maintain the plant cover so vital to soil stability. Little is available for streamflow.

Most of the watershed lands in the National Forests are covered with spruce-fir, ponderosa pine, and aspen, with pinyon-juniper on the lower slopes. There are some natural openings, but they would be a relatively small percent of the watershed.

It was interesting to learn that the annual water yield from the Pecos River above the town of Pecos closely approximates the water yield, on an area basis, from the Santa Fe River watershed, 7.35 inches at Pecos and 6.5 inches at Santa Fe. Both watersheds are located on the southern end of the Rocky Mountains which extend into New Mexico.

ACTION PROGRAMS

These watersheds can be considered as good water producers for the amount of precipitation they receive.

No doubt there are opportunities to make them better water producers by more intensive management.

Let's look at the headwaters of the Pecos River which are located above the town of Pecos and within the Santa Fe National Forest. This is the area that produces the 7.35 area inches of water annually.

We find about 100,000 acres of commercial forest land, 72,000 acres within the Pecos Wilderness Area, and about 70,000 acres of woodland, brush and grass. These are the higher water yielding lands where more intensive management could improve water yield.

It would be premature to make any meaningful predictions at this stage of the program. However, the Forest Supervisor is currently developing a timber harvest program in the mixed conifer type which will be designed to use a system of strip or block cutting. This should favor increased water yield. Hydrologic studies will be made to furnish the basic data needed for correlating the timber harvest with water yield.

In other areas a program of maintaining the openings from scrub tree invasion is being carried out. The program is modest, but every little bit helps. At least we have an action program started.

Southwestern National Forests are moving into a much more intensive phase of resource management. The watershed management that has been practiced up to now has been directed primarily toward protection, with attendant soil stability and good quality of waterflow. The more intensive phase of watershed management which the Forest Service is now developing must not only continue to consider protective functions of the watershed, but also give important weight to other practices affecting the quantity of water yields. Responsible stewardship of National Forests requires this kind of intensive management to meet the increasing water needs of a growing population, industry, and agriculture.

SUMMARY

Water is recognized as one of the very important resources from National Forest lands. In some places and situations it may well be the most important resource.

Water yield can be increased by replacing deep-rooted plants with shallow-rooted plants.

The harvesting of timber by clear-cutting in strips or patches will make more precipitation available for streamflow.

Sound principles, based on watershed management research, have been established for increasing water yield. Pilot tests are underway to determine costs, impacts on other resources, and methodology. Modest action programs are underway.

In my judgment, the Forest Service is rapidly moving from the custodial era of watershed management to intensive multiple use management. This transition will be based on the demands of people for more products and services from the National Forests. It will be carried out under sound principles of multiple use and sustained yield management.

IRRIGATION WATER QUALITY AND QUANTITY

H. E. Dregne[1/]

Several standards have been proposed for evaluating the quality of irrigation water; the most widely used criteria are those established by the U. S. Salinity Laboratory several years ago (1). While these standards serve as general guides, their interpretation in any particular case is dependent upon knowledge of the characteristics of the soils upon which they are to be used, the quantity of water available, presence or absence of an adequate drainage system, the crops to be grown, and other factors. Since these factors cannot be incorporated into a single set of standards, the water quality criteria presented in Table 1 represent maximum limits of salt, sodium, and boron that permit unrestricted use of an irrigation water for most soils and crops. When these limits are exceeded, restrictions on use of the water are indicated and the other factors mentioned previously must be considered. The restrictions increase as the water quality becomes poorer, until finally the water may be unsuitable for any economic use. As research on the use of saline waters continues, the upper limit for usable waters continues to be raised, until now even brackish water can be used on highly permeable, well drained soils when a salt tolerant crop is grown and when proper water management is used. The experiment conducted by the New Mexico State University Department of Agricultural Engineering on the White Sands Missile Range demonstrate this with irrigation water having an electrical conductivity of 15,000 micromhos (EC x 10^6).

The salt and sodium hazards present in irrigation waters in the major irrigated areas of New Mexico are shown in Figure 1. As far as we know, we do not have a boron problem in the state although boron in the soil may be moderately high in places along the Rio Grande where the soil is highly saline. Irrigation waters in the High Plains, except for some in the Portales Valley, are of good quality, as are those in the mountains. The San Juan River and its principal tributaries have good quality water, but soils derived from marine shales in the San Juan area may be saline.

Water quality generally deteriorates along a river as water is diverted for irrigation and more saline drainage water returns to the river. Figure 2 shows the decrease in quality of Rio Grande water from Otowi Bridge, above Albuquerque, to El Paso Dam for the year 1963 (2). From Leasburg Dam, at the northern end of the Mesilla Valley, to El Paso Dam, at the southern end, the water changed from being borderline to questionable in salinity. Fortunately, most of the crops grown in the Mesilla

1/ Professor of Soils, Agronomy Department, New Mexico State University

Table 1. Standards for Irrigation Water Quality

Hazard	Satisfactory Water
Salinity	less than 750 EC x 10^6 (1) less than 500 ppm (2)
Sodium	less than 10 SAR (3) less than 1 me/l RSC (4)
Boron	less than 0.3 ppm (2)

(1) EC x 10^6 = electrical conductivity (mhos) x 10^6 = micromhos.

(2) ppm = parts per million.

(3) SAR = Sodium-adsorption-ratio = $\frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$

Ion concentrations are in Me/l

(4) RSC = Residual sodium carbonate = $(CO_3+HCO_3)-(Ca+Mg)$

Ion concentrations are in Me/l

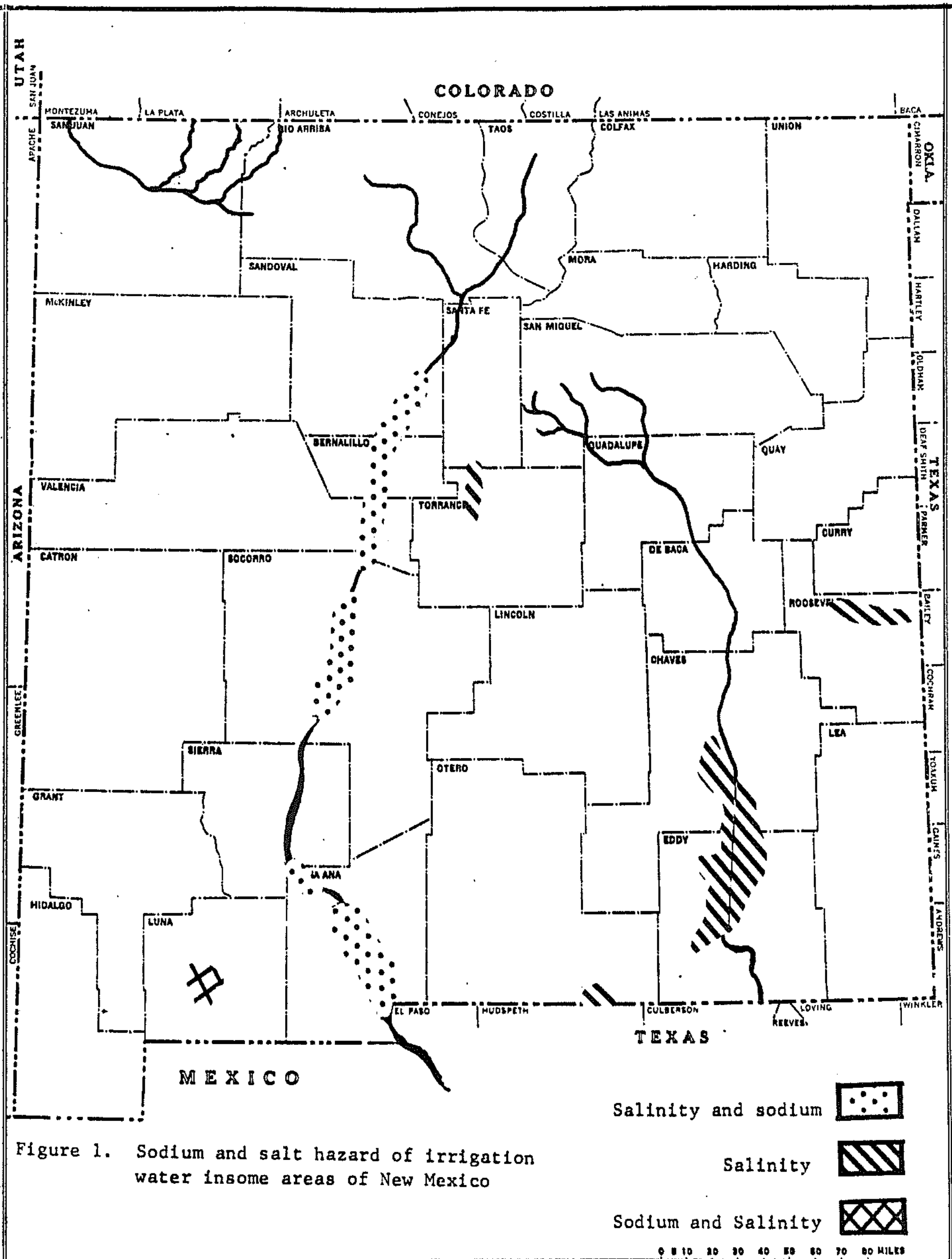


Figure 1. Sodium and salt hazard of irrigation water insome areas of New Mexico

Figure 2. Change in quality of water with location on Rio Grande, 1963

Location:	Otowi Bridge	San Marcial	Elephant Butte	Caballo Dam	Leasburg Dam	El Paso Dam
EC x 10^6:	367	705	630	692	800	1,322
SAR:	0.8	2.0	1.9	2.1	2.3	4.1

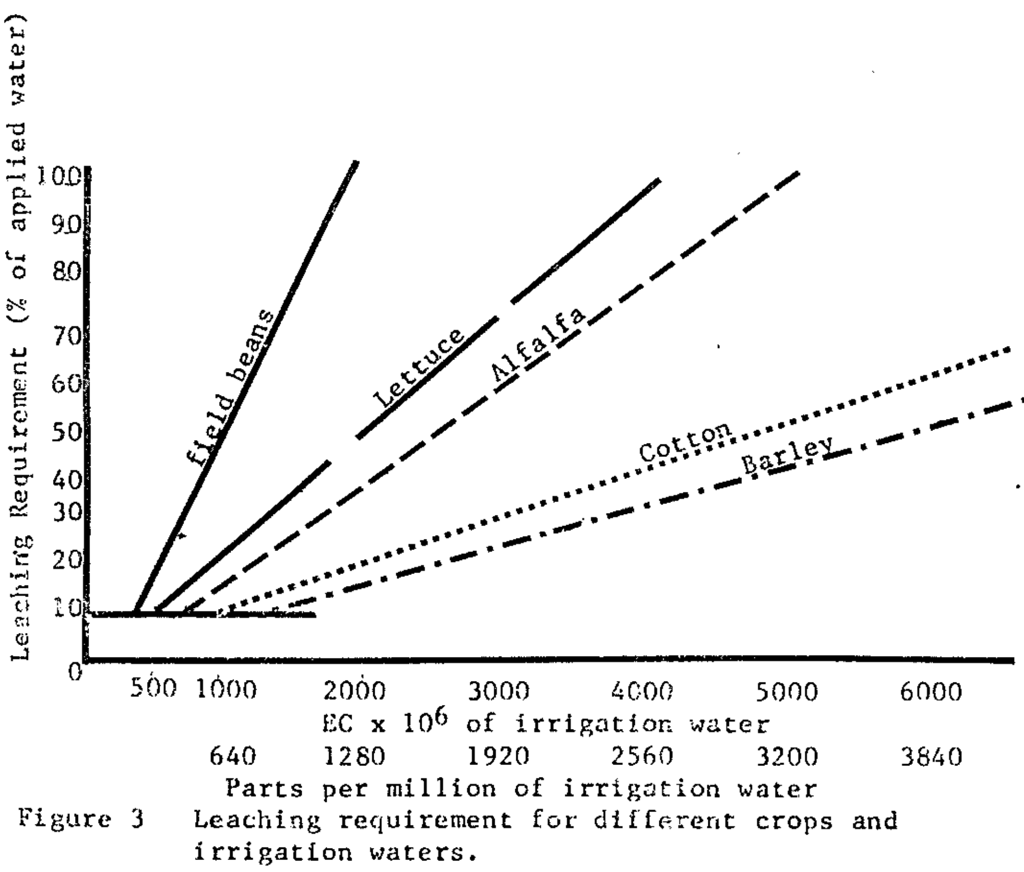


Figure 3 Leaching requirement for different crops and irrigation waters.

Valley are at least moderately salt tolerant, but salt accumulations have caused some fine textured soils to be abandoned. The sodium hazard also increases along the river, but is less of a threat than salinity. Similar deteriorations in quality occur along the Pecos and San Juan Rivers, from the standpoint of salinity.

Two factors of importance in using irrigation water that exceeds the salinity limit for unrestricted use are considered in Figure 3: leaching requirement and salt tolerance. When a water has an electrical conductivity of about 1,500 millimhos, a farmer has two major choices to make:

1. He can grow a salt tolerant crop like barley or cotton and irrigate as usual, or

2. He can grow a salt sensitive crop like beans and make frequent heavy irrigations.

The second choice means that much of the applied water will be wasted in the drainage system, making for a low water use efficiency. Leaching requirement refers to the fraction of the applied irrigation water that must be leached through the soil in order to maintain soil salinity at some given level. It is calculated from the formula:

$$\text{Leaching requirement} = \frac{ECiw}{ECdw} \times 100$$

where ECiw is the electrical conductivity of the irrigation water and ECdw is the maximum permissible electrical conductivity of the water that passes through the root zone as drainage water. ECdw depends upon the salt tolerance of the crop and is about 2,000 micromhos (2 millimhos) for beans, 6,000 micromhos for alfalfa, and 10,000 micromhos for cotton. The leaching requirement, then of an irrigation water having an electrical conductivity of 1,500 millimhos would be about 75 if beans were grown, 25 if alfalfa were the crop, and 15 if the crop were cotton. This means that, for beans, 75 percent of the applied irrigation water should be leached through the soil at each irrigation in order to keep the salt level in the soil low enough for good yields to be obtained. Similarly, 25 percent of the water must be leached through the soil for alfalfa and 15 percent for cotton. As the salinity of the irrigation increases, the leaching requirement increases for any one crop. If the water had 2,000 micromhos electrical conductivity, its leaching requirement when growing beans would be 100, meaning that all of the applied water should be leaching water. Obviously, the efficiency of water use goes down as the leaching requirement goes up. This is why the observation is made that conservation of water is not compatible with using saline water for irrigation. On the graph, the horizontal line at a leaching requirement of 10 is intended to indicate that normal irrigation leads to at least that much leaching.

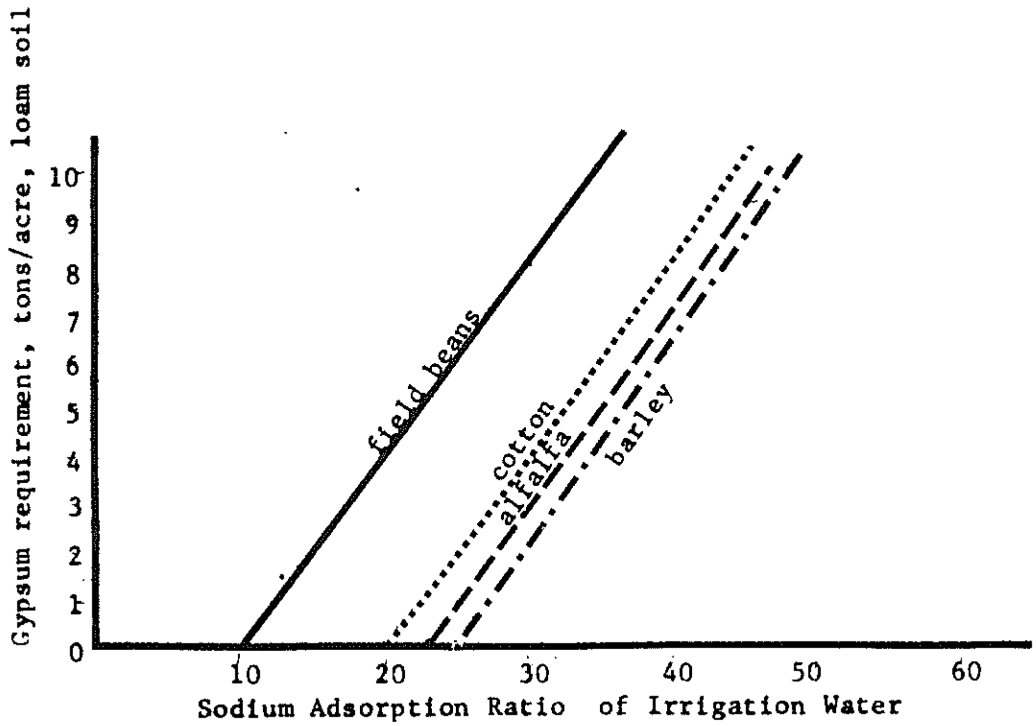


Figure 4 Gypsum requirement for different crops and irrigation waters

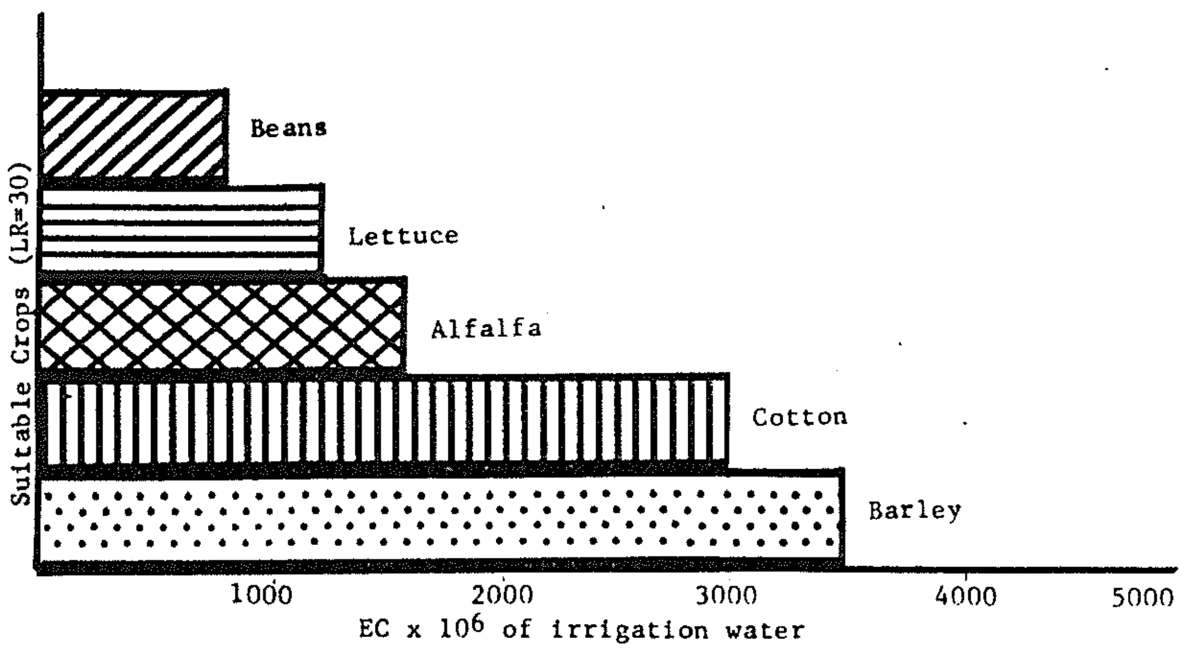


Figure 5 Choice of crops for irrigation waters of varying salinity; leaching requirement not to exceed 30.

A somewhat similar approach to using irrigation water with excess sodium is shown in Figure 4. Here the sodium hazard of the water (sodium-adsorption-ratio) is the problem and choice of crop or gypsum applications represent ways to minimize the sodium hazard. It is apparent that sodium sensitive beans would be an expensive crop to grow in a case where the water had a sodium adsorption ratio of 25 and required 6 tons of gypsum per acre every two or three years. It should be noted that the gypsum requirement is based on a medium textured soil (loam). If the soil were a clay loam or clay, the gypsum requirement would be much higher; if the soil were sandy, it would be lower.

The effect of irrigation water salinity upon the freedom of choice of crop is shown in Figure 5, which is based on the curves in Figure 3. With enough water available to permit the leaching requirement to be set at 30, any one of the five crops could be grown if the water had an electrical conductivity of less than 750 micromhos. At about 1,500 micromhos, three crops could be grown satisfactorily. At 3,500 micromhos, only barley would give average yields. If the amount of water used for leaching were doubled, any of the five crops could be grown even if the water had about 1,200 micromhos electrical conductivity.

Several other methods have been devised to minimize the adverse effect of saline water on crop growth. Farmers in the Pecos Valley in New Mexico and Texas have, for years, planted cotton on the flat or in furrows as a means of improving leaching and keeping salt concentrations low near the plant. As more is learned about water and salt movement in soils and the effect of salt on crops, new planting and watering methods have been tested. One of these successful planting methods has been the use of sloping beds that permits seeding in a position where the salt content of the soil will be at a minimum. Other research has been directed toward finding fertilizer combinations that will reduce the salt effect and determining how to make the best combined use of good and poor water.

In summary, it is impossible to say without qualifications whether any particular irrigation water can or cannot be used satisfactorily for crop production. Any water can cause problems under some circumstances. Rather than center our attention on limitations in water use, we can profitably consider how to make beneficial use of waters that are now classified as undesirable. Given a permeable soil and a deep water table, the two most important factors in using saline or high boron waters are the kind of crop to be grown and the quantity of water available. For sodium waters, these two factors plus the need for gypsum are the major considerations. Using poor quality irrigation water is costly but can be done.

REFERENCES

U. S. Salinity Laboratory Staff, "Diagnosis and Improvement of Saline and Alkali Soils," U.S.D.A. Handbook No. 60. 1954.

Wilcox, L. V., "Discharge and Salt Burden of the Rio Grande Above Fort Quitman, Texas, and Salt-Balance Conditions of the Rio Grande Project for the Year 1963." U. S. Salinity Lab. Research Rept. 106. 1964.

WATER AND RECREATION

Fred A. Thompson[1/]

The quantity of water for recreation has always been a major problem in New Mexico and it is expected that there always will be a problem. Competition of water uses are keener now than at any time in the past, and when one thinks of using water for recreation it brings a shudder to those who use water for other purposes. Water, for recreation, generally is used and not consumed. The losses in recreational use can be attributed to evaporation and perhaps some seepage. At any rate, the quantity of water used for recreation from an already oversubscribed basin, brings cries of anguish from other water users.

Admittedly, the bulk of water-based recreation is a secondary use or a fringe benefit derived from waters manipulated for another use. Lakes developed by both federal and state agencies over the past 50 years has perhaps tripled the fishing potential and just about entirely established other water-type recreation. In some instances reservoirs have been developed with acquired water rights and designed specifically for recreation. We have several small lakes developed by the Department of Game and Fish such as Lake Roberts, Fenton Lake, Charette Lakes, Lake Wall and more. Large lakes that have water for recreation are Conchas, Ute, Navajo, and in the future, we look to Cochiti and Heron with perhaps more to come.

As a side light on the national scene the Department of Interior announced that we now have 13 million acres of lakes and an expected 10 million more to be added in the next 35 years. Such lakes provide about one-third of the fresh-water fishing in the United States, exclusive of the Great Lakes.

Water is a vehicle for many forms of outdoor recreation, such as camping, picnicking, skiing, swimming, fishing, boating, and as an added bonus to designated scenic areas. All of these activities are becoming more in demand as the population increases and as more leisure time becomes available. Better roads and improved transportation contribute tremendously to the demand.

An example is the demand for one form of recreation, fishing. In 1950, the state had a population of 684,000 and 45,566 (6.6 percent of the population) bought resident fishing licenses. In 1964, with a population of 1,032,000 there were 105,595 (10.2 percent of the population) resident fishing licenses sold. This shows not only an increase in demand by virtue of population, but also an

1/ New Mexico Department of Game and Fish, Santa Fe, New Mexico

increase in interest.

In 1960, the Department of Game and Fish concluded a five-year study about Conchas Lake and the recreation area. The survey showed that in 1960, there were 736,000 visitors at the lake. There were 425,000 fishermen, 146,000 boaters, 64,000 skiiers, 40,000 picnickers, and 6,000 swimmers. Last year, the second year of use, Navajo Reservoir drew 194,000 visitors of which 63,000 were fishermen.

Many years ago, some of you may remember, there was a slogan of one of the presidential candidates, "two cars in every garage and chicken every Sunday." The candidate didn't make it, but we have gone beyond his slogan; we now have two cars and a boat in every garage and chicken every Sunday (because it is cheaper than hamburgers).

So far, little has been said of stream fishing, but it is interesting to note that Taos County leads as the area most fished with 14.80 percent of the state total. Taos County has very little lake fishing. However, San Miguel County is a close second with 14.49 percent where there is both lake and stream fishing. It is assumed that San Miguel may lead if all types of water-based recreation were considered.

At present it is estimated that the state has 2,700 miles of fishing stream and 121,339 acres (189.5 sq. mi.) of fishing lakes (when the lakes are full). The stream mileage can be increased but very little; however, they can and are being improved to carry more fish. Lake acres are continually being added.

Economically, water for recreation stands second to industrial and domestic use and is considered 5½ times more valuable for recreation than for agriculture. This does not mean that its use be converted to the highest economic yield, but rather to maintain a balance in relation to the demand.

In a recent survey of the economics of hunting and fishing in New Mexico, it was revealed that fishing alone is worth 32 million dollars annually to the state, (hunting is in for 21 million dollars). If all forms of water-based recreation are to be included we could assume a much larger figure.

The quality of water for water-based recreation is a problem in this state as it is in all states, but not to the same degree. Fortunately, from this standpoint, we are not a state of heavy industry and population; therefore, we do not have the critical volume of industrial and domestic waste. We have, however, lost fish because of polluted water. The one form of pollution that causes us trouble from time to time is excessive terrestrial run-off and erosion. When the water gets too thick to drink and too thin to plow it is rough on fish. Better use of the watersheds is eliminating a lot of these problems.

I cannot pass the item of water quality without mentioning the good work and splendid cooperation of personnel of the State Health Department. At all times they are vigilant for water quality problems that might affect our fisheries and this applies to the use of water for other recreation purposes.

If we look into the future to 1975, we can expect to see the fishing pressure double (260,000 fishermen). The rest of the water-based recreation will double also. In my estimation, the quantity of water for water-based recreation is woefully short at present and it will get worse unless a good-sized, long range program is started without delay.

REFERENCES

Wollman, Nathaniel, et al 1962. "The Value of Water in Alternate Uses."

Kirkpatrick, Thomas O., et al 1965. "The Economic and Social Values of Hunting and Fishing in New Mexico," Bureau of Business Research, University of New Mexico.

MUNICIPAL WATER QUANTITY AND QUALITY REQUIREMENTS AND EFFECTS OF USE

Robert P. Lowe[1/]

INTRODUCTION

Municipal or domestic requirements for water are most certainly a top priority in our competitive demand for the limited supplies that are normally available, and this is particularly true here in the Southwest. This is clearly illustrated in the relative costs of irrigation, recreation, and industrial waters as normally compared with municipal water. Although the value and need for municipal water cannot be questioned, other use requirements often create difficulties in our rapid concentration of population in urban areas. Availability of water is one of the major factors in limiting development in arid and semi-arid areas for uses other than the commonly envisioned agricultural development limitation.

MUNICIPAL QUANTITY REQUIREMENTS

Quantity needs for municipal use vary greatly in spite of the tendency to dwell on average use per capita in order to simplify the situation. This is commonly used as an index to indicate the increasing demand for water as our living level develops. Yes, there is a definite correlation between water use and living standards. Here in New Mexico the average per capita use ranges from less than 25 gallons per day to as much as over 300 gallons per day. Peak uses may be well over 500 gallons per day.

Water use figures are quite misleading without proper evaluation, as home irrigation, cooling water, and lack of use of meters can give wide ranges that are not strictly domestic demands. Hence, elimination of these items is necessary for comparative purposes. However, national use figures indicate an average strictly domestic requirement of from 50 to 75 gallons per capita per day. In contrast, the overall average municipal demand is now close to 150 gallons per capita per day and is expected to be about 210 gallons per day by 1980, as domestic water uses are increasing with the installation of modern household equipment such as automatic washing machines, dish washers, garbage disposals, multiple bathrooms, water coolers, etc.

MUNICIPAL QUALITY REQUIREMENTS

Requirements for municipal water supplies are covered by the Public Health Service's Drinking Water Standards that are generally

---

1/ Program Director, Water and Sewage Section, Environment Factors Division, New Mexico Department of Public Health, Santa Fe, New Mexico.

accepted by the water works industry in the United States. These standards cover source of supply, bacteriological records, chemical characteristics, and protection of the treatment and distribution facilities. Generally speaking, they are higher than for most other water uses with the exception of some specialized recreational or industrial requirements.

In general terms, domestic water should be safe, clear, and practically odorless, tasteless, and colorless. In addition, chemical characteristics should not be objectionable, as this will force customers to use other private sources of water, that could be unsafe bacteriologically. Needless to say, the present Public Health Service's Drinking Water Standards are quite detailed in comparison to the first standards that were issued in 1914 to cover bacteriological aspects only.

REUSE REQUIREMENTS

Municipal waste waters are classified as domestic sewage that contains disease organisms and decomposable organic matter. Hence, treatment is necessary prior to reuse of these waters. In New Mexico there is a great demand for the use of waste waters.

Organic solids in domestic sewage are the most noticeable objectionable feature, even though they normally amount to only about 0.02 hundredths of one percent of the total waste flow. Secondary sewage treatment involving physical settling and biological treatment will remove this objection in most instances. However, contamination in municipal waste waters still places limitations on many uses, as they are not recommended for irrigation of vegetable crops or for recreational purposes, such as swimming. Nevertheless, there are many present uses in the state such as for irrigation of cotton and forage crops, golf course irrigation, condenser cooling water, and ore processing make-up water, that involve a minimum risk in disease transmission.

Increased alkalinity and the presence of detergents are additional objectionable features in the use of municipal waste effluents. Of these two items, the detergents have created most trouble as they are a visible indicator of sewage pollution to all users. Recreational, agricultural, and domestic water consumers have encountered much difficulty with this problem, but the situation is now close to permanent control. The detergent manufacturing industry is placing a biodegradable material on the market at the present time, that will practically eliminate the foaming problem. Complete conversion is expected by July 1, 1965, and this will be six months ahead of the original schedule.

SUMMARY

Both quantity and quality requirements are increasing for municipal water use in our increasing urbanization of the population.

These demands and other water use requirements for irrigation, recreation, and industrial purposes have emphasized the competitive nature of need for water, that is particularly true here in the Southwest. In turn, this brings forth the critical need for treatment and conservation of all water for maximum possible reuse. Indeed, water will need to be "worn out" through repeated use if it is to be available for use in many areas in the future.

REFERENCES

Metcalf, L., and Eddy, H.P., "American Sewerage Practice," Volume III. Disposal of Sewage, 1935.

State of California. Report on Continued Study of Waste Water Reclamation and Utilization. State Water Pollution Control Board, 1956.

State of California. Detergent Report. State Water Quality Control Board, State Department of Water Resources, and State Department of Public Health, 1965.

U. S. Public Health Service. "Public Health Service Drinking Water Standards, 1962." P.H.S. Publication No. 956.

OIL INDUSTRY'S CONTRIBUTION TO NEW MEXICO'S WATER RESOURCES

Randall F. Montgomery[1/]

Upon reviewing in 1965 my paper presented at the Third Annual New Mexico Water Conference in 1958 entitled, The Industrial Use of Water, I find that the information is still basically valid; however, New Mexico's growth has accelerated and attention to factors effecting conservation have been accentuated. Suffice to say that the conclusions in 1958 were not optimistic enough. New Mexico is growing at such a rapid rate that pressure for the most beneficial use of water will continue to increase. An open mind on the part of those charged with regulation to new concepts and uses will enhance and increase New Mexico's economic position.

New Mexico's mineral wealth is fantastic, and its favorable population and geographic position in respect to the nation places New Mexico in an excellent position to convert its raw materials into higher value consumer items; provided, regulation in the field of water and energy does not make these two basic items so expensive that states with more favorable regulations continue to process New Mexico's raw mineral wealth. As an example, Southeastern New Mexico is rich in three depletable minerals - oil, potash and water. Not only is the mineral wealth significant to Southeastern New Mexico, but to the state and to the nation. With ninety-eight percent of our domestic potash, twenty-five percent of the nation's oil located in the Permian Basin, fourteen cubic miles of water in Lea County -- and, consider the fact that Lea County, New Mexico produces more dollar value in oil and gas than any county in the nation -- it at once becomes apparent why this area is of vast importance to the nation. The area can become of even greater importance to New Mexico if we can encourage local processing.

New Mexico has obtained considerable wealth from these depleteable minerals, and I hasten to add that these minerals were discovered and developed by speculation. However, in order to recover these minerals, water is needed; and in order to continue these operations and to maximize the economic impact on New Mexico, water will have to be readily available now and in the future! Patterns of exploration, discovery, processing, manufacturing, transportation and marketing are established on many factors. Water, readily available at a reasonable price, is one of the major factors that sets these economic patterns. If water is not locally available, the raw materials will continue to be exported.

As an individual that has been closely associated with the extractive industries and industrial development, the first question in-

1/ Member of Board, New Mexico Oil and Gas Association, Hobbs, New Mexico variably asked by a prospective investor -- "Does New Mexico have the water?" Vast quantities of water in fact are present; however, not always readily available. The hurdles that a potential investor who needs water must jump are often so complicated, at least to the uninitiated, that the frustrating experience frequently lends support to the question, "Does New Mexico have the water?" Emphatically, yes! New Mexico does have vast volumes of water.

The oil industry has taken many positive steps that have increased the water resources of this state. To summarize a few of these positive steps, I submit the following for your information:

1. The very nature of the oil industry's exploration program has caused the discovery and development of water for farmers, ranchers, and municipalities.

2. The thousands upon thousands of shot-hole formation records are on file for the water explorer's and researcher's use.

3. In many areas these thousands of shot-holes have had a side effect of allowing rainfall to immediately enter the water aquifer, thereby reducing evaporation losses and recharging the basins such as the Lea County Water Basin.

4. The oil industry has proved, with large outlays of capital, the vast Capitan-Guadalupian artesian water aquifer. This aquifer is of major proportion many times greater than the fourteen cubic miles of Ogallala water, and it lies in a semi-arid, sparsely populated grazing land that has a long growing season. Although the quality is considered marginal by many accepted standards, the Capitan water can be and is used for all purposes, including irrigation. Perhaps these accepted standards are based on exceptionally high quality, large quantity, and low lifting cost of the Ogallala. Positive action in encouraging the development of this aquifer will greatly enhance New Mexico's economic growth. I suggest a program of detailed research not only with this aquifer, but with the overlying soils.

5. A fifth area that the oil industry has been active is in the conservation of water. By virtue of discovery and development, oil has brought wealth and population to an area that formerly was poor and sparsely settled. This cause and now effect has brought pressures to bear, many of which were sound. The oil industry has met these problems head-on, particularly in the protection of water quality and water conservation.

(a) PROTECTION OF WATER QUALITY

The oil industry found, when it was pointed out by the State Engineer, that its water disposal methods could possibly affect the excellent water quality of the Ogallala, and invested in twenty-nine separate oil field disposal systems. These systems dispose of water at depths from 4,000 to 15,000 feet. A portion of this disposed water is of higher quality than many municipalities in the Southwest are presently using. It is estimated that these systems have cost in excess of $7,500,000 in capital outlay and that the operating cost to date approaches another $2,000,000. The volume of disposed water to date (which will never be recovered again) is 315,000,000 barrels--or over 40,000 acre feet -- at a cost of $232/acre foot. I am advised that water used for growing cotton has a gross value of $60/acre foot.

Secondary recovery by injection of water is relatively new in New Mexico for only a few projects have reached their final stages. I cite one for your evaluation:

Ambassador Oil Corporation
North Caprock Queen Unit 47 wells

20,005,778 barrels of water injected to 1/1/65
15,212,588 barrels of water recycled to 1/1/65
4,793,190 barrels of make up water to 1/1/65

$$\frac{4,793,190 \text{ barrels of water}}{7759 \text{ barrels per acre foot}} = 617.8 \text{ acre feet}$$

This 618 acre feet of make up water has recovered 3,256,833 barrels of oil. Assuming an average value of $2.90 per barrel, the gross value recovered to 1/1/65 is $9,444,815, or a gross per acre foot value of $15,282.87 for the water.

Directly, the governmental agencies of the State of New Mexico receives approximately $1,064/acre foot of Ogallala water used. In addition to this, since the state owns the minerals, it received in royalty $1,180,602 or a value of $1,910/acre foot of Ogallala water. Jobs were created and materials purchased. Without secondary recovery utilizing Ogallala water, this natural resource was unrecoverable.

What is wise use? If the water used to recover this oil had a value, what is the value? Is it a dollar value? Some so-called conservationists say, no, that we cannot place a dollar value on water. Perhaps this group places a social value on water. If so, the monies derived from the taxes and royalties paid, contributed to untold projects in welfare and education.

Perhaps this group places an intellectual value on water. If so, the monies derived from the taxes and royalties paid contributed a substantial portion of the money available for all levels of education and research.

Many in this group predict we will run out of drinking water. Those familiar with the vast volume of our water resources know that these prophets are not responsible for their irresponsible statements. In our part of the state, it is a basic fact that without the oil industry there would not be enough people, or water, to worry one way or the other about the many facets of water problems that can and have been created.

6. The Interstate Oil Compact Commission is presently studying the basic concepts and problems involved in making a survey of the mineralized water that is produced from great depths to determine the economic value of recoverable minerals.

7. Increased local consumption of this energy resource is occurring each year, creating more jobs and reasonable prices for New Mexico consumers, particularly power for lifting water.

8. The proper plugging and abandonment of oil wells to protect our water sands has been a practice for so many years that it is often overlooked.

9. It is estimated $30,000,000 has been spent through the years running surface pipe to protect surface waters is a practice that has been in effect for many years. It is often overlooked when assessing what the oil industry has done to contribute to the protection of the water resources of New Mexico.

Oil is a depletable natural resource just as is the Lea County Water Basin, and just as is the Hobbs-Carlsbad Potash. The ability to recover the last possible barrel of oil and the last possible ton of potash is determined by many factors, but water at a reasonable price is axiomatic. The maximum use of these three mineral resources are necessary one to the other, and the time at which the water is available is important. Foreign potash and oil have become extremely competitive in recent years. Only through aggressive development can our domestic resources continue to compete.

New Mexico's economy is spiralling and consequently its governmental expenditures are increasing. In order to help pay the tax load, we must encourage maximum utilization of our three depletable minerals. Five years ago, the total volume of secondary oil was insignificant; today it represents eleven percent of New Mexico's production from ninety-four active floods with eighteen percent of the wells engaged in secondary operations. Without secondary recovery utilizing water, it is estimated that over $1,500,000,000 will not enter into the economy of New Mexico.

The state's economic health is tied to a positive approach on the availability of water to industry and it must be available at the time required.

The oil industry has been a partner in the development and protection of our water resources and it is ready and willing not only to continue, but rather to accelerate our participation. In 1964 the New Mexico Oil and Gas Association had as its leading speakers our able State Engineer, Steve Reynolds, and the Honorable Tom Morris. After hearing these gentlemen, the Regulatory Practices Committee, Chairmanned by Mr. Jason Kellahan recommended to the association that the talks be reproduced and distributed. The committee then organized a steering committee to study, not just industry's water problem, but to offer the assistance of a vast technical pool to study the entire state. Mr. Kellahan's group then took a third step by recommending to the association that it contact other agencies interested in the water resources of New Mexico in order to initiate a joint study on a broad, comprehensive basis, and that these agencies jointly contact our water-oriented schools to determine their interest in furthering these studies. The fifth recommendation on water was that the association consider offering such financial assistance as may be feasible for such a program and to give it full cooperation, and actively solicit support in the form of grants from other organizations or foundations to further the study.

The oil and gas industry is proud to have played such an important part in the development of our great state. The New Mexico Oil and Gas Association stands ready at all times to meet its responsibility in all governmental and public affairs.

WATER RESOURCES RESEARCH ACT OF 1964 -
ITS FUNCTIONS AND IMPORTANCE TO NEW MEXICO

H. R. Stucky1/

The Water Resources Research Act of 1964 - Public Law 88-379, signed into law by the President July 17, 1964, provided for the establishment of a Water Resources Research Institute at the Land Grant College in each of the 50 states and Puerto Rico. This is a milestone in water research in New Mexico and in the nation and gives recognition to the great importance of our water problems. It also emphasizes and implements the urgency of getting the solution to many of these problems through research.

The New Mexico Water Resources Research Institute was among the first 14 approved under the Act in the country. The remaining 37 are expected to be established in the near future. (Note - By the end of May, 1965 appropriations were made for the establishment of the remaining 37.)

The Water Research Act was generally patterned after the Hatch Act of 1887 which established the Agricultural Experiment Stations at the Land Grant Colleges in each state. Senator Clinton P. Anderson of New Mexico introduced the water research bill in the Senate and Congressman Thomas G. Morris introduced the companion bill in the House. The National Association of State Universities and Land Grant Colleges Committee on Water Resources was active in reviewing the Act and making recommendations to strengthen the research program. President R. B. Corbett of New Mexico State University was an active and influential member of that committee. In the hearings on the Water Research Bill, Senator Anderson pointed out the great influence the Agricultural Experiment Stations has had on agriculture and related industries and the total national economy. It was also pointed out that while the Research Institutes program would not be a solution to all water research problems, it would make a great contribution to the advancement of our scientific knowledge and to the assurance of adequate water supplies.

Public Law 88-379, the Water Resources Act of 1964, provides in Title I a basic allotment of $75,000 to each of the several states in the first fiscal year, 1965; $87,500 in each of the second and third years, and $100,000 each year thereafter, to assist each participating state in carrying on the work of a competent and qualified Water Resources Research Institute.

The Act also provided not to exceed $1,000,000 in fiscal year 1965, $2,000,000 in 1966, $3,000,000 in 1967, $4,000,000 in 1968

1/ Director, New Mexico Water Resources Research and Professor of Agricultural Economics, New Mexico State University, University Park, New Mexico.

and $5,000,000 in 1969 and each year thereafter for matching on a dollar-for-dollar basis, money made available by the states or other non-federal sources to conduct research on specific water resources research projects.

Provisions were also made under Title II of the Act for $1,000,000 in fiscal year 1965 and increasing to $10,000,000 at the end of 10 years, for grants, contracts, or matching with educational institutions, private foundations, private firms or individuals and with local, state and federal agencies for support of specific research projects. No funds have been requested under Title II pending proposed amendments under consideration by Congress.

The New Mexico Water Resources Research Institute was established by action of New Mexico State University Board of Regents in February 1963.

The purpose of the Institute is to stimulate and sponsor investigations and experiments in the field of water and related resources.

The basic or applied research to be conducted or encouraged by the Water Resources Research Institute will include, but not be limited to, aspects of the hydrologic cycle; supply of and demand for water; conservation and best use of available supplies; methods of increasing supplies; economic, legal, social, engineering, recreation, biological, geographic, ecological, and other aspects of water problems, giving due regard to water research projects being conducted by agencies of the federal government, the agricultural and engineering experiment stations, and other agencies.

The Institute will provide education and training for undergraduate and graduate students through research employment and assistantships. It will assist in developing a professional and technical staff in water resources research and teaching.

The Institute will publish or encourage the publication of research results for public information, education, and forums on water and will assist in developing information which would permit the development of a sound water program to meet the needs of New Mexico.

This Institute will permit interdisciplinary research to be conducted with contributions being made by two or more departments as the problem demands.

The New Mexico Water Resources Research Institute according to the rules and regulations in connection with the federal appropriation, "may also plan for research, investigations and experiments to be conducted as a part of the Institute program at colleges and universities other than the college or university with which the Institute is identified." However, the Institute quote "shall be responsible for the performance of the activities of the other participating colleges and universities," to see that the work "must meet all requirements (such as scope of work, qualifications, coordination with other research) as is applicable to the other work of the Institute.

The major funding for the New Mexico Institute became available on February 1, 1965 from federal sources and will become available from state funds on July 1, 1965.

With these funds being available, ten projects are now in operation at New Mexico State University under the basic allotment and two applications have been filed for funding under the matching fund provisions.

WATER RESEARCH IMPORTANT TO NEW MEXICO

Water research is especially important to New Mexico for three reasons:

First - The Senate Select Committee on Water divided the Nation, not including Alaska and Hawaii, into 20 major drainage areas and ranked them from water-poor to water-rich areas. The Upper Rio Grande and Pecos basin was ranked No. 1 basin on the basis of estimated water scarcity by 1980. This does not mean that much water development is not still possible, but that great care in the allocation, use and conservation of our water must be exercised. Research can make a major contribution in this area.

Second - The population of New Mexico is growing at more than double the national average. The population of New Mexico in 1960, according to the United States Census, was 951,000. The population projection by the Bureau of Business Research, University of New Mexico, for 1970 is 1,200,000; 1980, 1,630,000 and 1990, less than 25 years away, 2,111,000. This means that changes in water allocations must be made to accommodate this greatly increased population.

Third - Over 25 percent of the water for municipal and industrial use and over 55 percent of the total water depletions for urban, industrial, municipal, power and agricultural uses are from gound water sources. In all of the ground water basins, except the Rio Grande and San Juan, withdrawals exceed recharge by from about one-third to almost 100 percent. This raises questions of quality and quantity, and of adjustments in type of use, adjustments in amounts used and in some cases now, and more later, actual economic adjustments because of falling water tables and depletion of almost the total supply available for certain uses, especially for irrigation. However, there are large supplies of saline water which may be converted to fresh water for use in those industries which can pay relatively higher prices than are presently being paid.

These three problem areas can not be attacked by a one, five, or ten year research effort. Neither can they be solved by our present investment in water research.

Nine major areas have been identified as urgently needing research emphasis. These are:

1. The Nature of Water
2. The Water Cycle
3. Water and Land Management
4. Development and Control
5. Qualitative Aspects
6. Reuse and Separation
7. Institutional and Economic Aspects
8. Engineering Work
9. Manpower and Research Facilities

These nine major headings emphasize the wide range of water research needs. It should be noted that water research generally can not be separated into research for municipal use, industrial use, or agricultural use without very directly involving one or more other areas. Water does not follow any state boundaries, use boundaries or research area boundaries. It flows from state to state, it moves from the land to ground and surface water supplies, on through evaporation, transpiration, stream flow, and through the entire hydrologic cycle. Each use is likely to change the water location and the quantity and quality for each next use. The list above also emphasizes the interrelationship of uses and problems and the need for research in these areas, and the need for an interdisciplinary approach to almost any single water research problem which may be named. This means that Engineers, Hydrologists, Biologists, Plant Scientists, Soil Scientists, Economists, Lawyers, Political Scientists and men from numerous other research disciplines will be involved in one project or another in working toward the solution of our many complex water problems.

The New Mexico Water Research Institute established at New Mexico State University in February 1963, and assisted by approval to receive federal research funds as of February 1, 1965, offers an avenue for encouraging more research in water and to coordinate the water research conducted at various research institutions. However, if very much is done toward seeking answers to the nine areas of research just listed, then it is necessary that more public and private funds be invested in water research and investigations as well as in plant and process improvements in all areas of water use.

BUREAU OF OUTDOOR RECREATION, P.L. 88-29; AND LAND AND WATER CONSERVATION FUND ACT OF 1965, P.L. 88-578

W. W. Dreskell[1]

INTRODUCTION

You can be sure I am pleased to meet with you today and to have this opportunity to explain the role of the Bureau of Outdoor Recreation in the overall effort to satisfy the needs and demands of all Americans for outdoor recreation.

During the last decade or two, outdoor recreation has assumed tremendous proportions in the social and economic life of our country. Today it constitutes a major use of land and water and is on an equal basis with other demands upon these resources. In many instances, it has become a predominat or a priority use of resources.

There is a big job ahead for each of us and our 50 States are in pivotal positions where they must see that important things get done.

Your State officials recognize this and they are moving New Mexico among the leaders in planning. And rightly so -- for recreation and tourism will soon be your number one or two industry. Much of your growth and future income will be gained through the wise multiple-use of your waters and related lands.

ORIGIN OF THE BUREAU

As a consequence of the "new dimension" in American living, the Bureau of Outdoor Recreation is celebrating its third birthday. In many respects we are still "toddlers", but gradually we are gaining experience, knowledge, and strength to walk and run.

A forecast of important events came in 1958 when Congress created the bipartisan Outdoor Recreation Resources Review Commission.

The Commission was directed to estimate the needs for outdoor recreation for our citizens in the future, to determine the resources available to meet those needs, and to recommend the policies and programs to achieve desirable objectives.

After three years of study, the Commission sent its report to the President and the Congress. That was January 31, 1962. This report, called "Outdoor Recreation for America," contained some 50 specific recommendations. It is well worth reading. If you haven't had an opportunity to read it, perhaps you will want to pick up one of the summary pamphlets I have provided. The Commission

1/ Regional Director, Mid-Continent Region, Bureau of Outdoor Recreation, Denver, Colorado

also published 27 Study Reports covering various facets of outdoor recreation that had been prepared for it by universities and other research organizations.

One of the recommendations of the Commission was for the creation of a Bureau of Outdoor Recreation in the Department of the Interior.

President Kennedy promptly endorsed this recommendation in his conservation message of March 1, 1962 and Secretary of the Interior Stewart L. Udall established the Bureau on April 2, 1962 by administrative order.

The Bureau's designated overall purpose is to provide a focal point and leadership in the nationwide effort by coordinating the various Federal programs and assisting other levels of government to meet the demands for outdoor recreation.

FUNCTIONS OF THE BUREAU

The Bureau's functions are authorized principally by two statutes and an Executive Order as follows:

--The Act of May 28, 1963 (Public Law 88-29) which we refer to as our Organic Act,

--The Act of September 3, 1964 (Public Law 88-578) entitled the Land and Water Conservation Fund Act of 1965, and

--Executive Order 11017 of April 27, 1962, as amended.

The authorities in these basic documents run to the Secretary of the Interior. With but one exception, they have been delegated to the Bureau of Outdoor Recreation.

As spelled out in these documents, the Bureau's functions are to:

--Prepare and maintain a continuing inventory and evaluation of the outdoor recreation needs and resources of the United States;

--Prepare a system for classification of outdoor recreation resources;

--Formulate and maintain a comprehensive nationwide outdoor recreation plan;

--Provide technical assistance and advice to and cooperate with States, political subdivisions, and private interests with respect to outdoor recreation;

--Sponsor, engage in, and assist in research relating to outdoor recreation;

--Cooperate with and provide technical assistance to Federal departments and agencies;

--Promote coordination of Federal plans and activities generally relating to outdoor recreation;

--Administer a program of financial assistance to the States for the planning, acquisition, and development of outdoor recreation resources to be operated for public use by the States and local public agencies; and

--Serves as staff to the President's Recreation Advisory Council.

A word of explanation is needed regarding our last item -- our relationship with this Advisory Council.

Shortly after the Bureau was established, a Presidential Executive Order established the Recreation Advisory Council. It is composed of the Secretary of the Interior, the Secretary of Agriculture, the Secretary of Defense, the Secretary of Commerce, the Secretary of Health, Education, and Welfare, and the Administrator of the Housing and Home Finance Agency. The chairmanship of the Council will rotate among these officials in the order named for terms of two years each. The purpose of this body is to provide broad policy advice to the heads of Federal agencies on all important matters affecting outdoor recreation resources and to facilitate coordinated efforts among the various Federal agencies.

When our Bureau works on assignments from the Recreation Advisory Council, we function independently of the Department in which we are housed. This is an important distinction which is recognized and maintained by the Secretary of the Interior and the Advisory Council. In short, the Bureau wears two hats in carrying out its responsibilities. Secretary Freeman of the Agriculture Department is our present boss in this endeavor.

The Bureau has been delegated other responsibilities of the Secretary. I will mention them only briefly:

--We review applications submitted to the General Services Administration from States and local governments to acquire surplus Federal lands for public use as parks and recreation areas, and make the compliance checks necessary to assure that such lands so acquired by the States and local governments are in fact being used for park and recreation purposes;

--The Director of our Bureau acts as the Secretary's representative on the Lewis and Clark Trail Commission which was established by Act of October 6, 1964 (Public Law 88-630). At its first meeting, on January 4, the Commission members appointed the Director to the position of Executive Officer of the Commission.

--We consult with the Housing and Home Finance Agency on the general policies to be followed by that agency, pursuant to Title VII of the Housing Act of 1961, by reviewing applications for grants and providing information on recreation planning in the area in which the grant is to be used.

Before going into the current programs of the Bureau, I would like to tell you about how the Bureau is organized.

ORGANIZATION OF THE BUREAU

In assisting the Secretary of the Interior in carrying out these responsibilities, the Bureau reports to him through the Assistant Secretary for Public Land Management. Significantly, however, we do not manage any lands or other outdoor recreation resources.

Our headquarters office in Washington is housed in the Department of the Interior building. The top staff of the Bureau includes the Director, Associate Director, and four Assistant Directors. The work of the Bureau is divided into four categories with an Assistant Director responsible for each category. These are: (1) Planning and Research, (2) Federal Coordination, (3) State, Local and Private Programs, and (4) Administration.

We have six regional offices headed by Regional Directors. They are located in Philadelphia, Ann Arbor, Atlanta, Denver, Seattle, and San Francisco.

We are a small agency. As of December 31, 1964, we had 235 employees, of which about 30 were financed from funds transferred to us by other Federal agencies for which we perform recreation planning services. This is total employment including both headquarters and regional offices. We have 20 persons in our Mid-Continent Regional Office to serve 10 States. There are no State or local offices.

CURRENT PROGRAMS OF THE BUREAU

I would like, now, to describe some of our major programs and progress made during the past three years.

THE NATIONWIDE OUTDOOR RECREATION PLAN

One of the basic responsibilities of the Bureau is to formulate an outdoor recreation plan for the Nation and to update the plan every five years thereafter. Projections of needs will be made initially to the years 1980, 2000, and 2020. We are directed by Public Law 88-29 to transmit the initial plan to the President and the Congress by no later than May 1968. This work is progressing on schedule.

Basically, the Nationwide Plan will be a guide to sound public policy in outdoor recreation to insure that the variety of recreation opportunity desired by our people will be available in the general locations they desire in sufficient quantity to serve them adequately. Although it will identify existing and potential Federal recreation areas, it will not provide blueprints for specific recreation development projects. It will, rather, be an appraisal of the supply of outdoor recreation lands and water available in the United States, the demand of the American people for outdoor recreation opportunities, and the resulting needs for additional areas and facilities to meet the public demand.

The concern of the plan will be with all kinds of outdoor recreation in the broadest sense and with the preservation of natural beauty and environment, the timely acquisition of the lands and waters of highest value for outdoor recreation, and the development of adequate facilities. It will encompass urban and rural aspects of outdoor recreation and public and private programs. In addition, the plan will develop specific recommendations for action programs at the Federal, State, and local levels and in the private sector to meet current and future identified outdoor recreation needs.

Also, the Plan will be the repository, through automatic data processing techniques, of a substantial and growing bank of information on outdoor recreation supply and demand data which will be made available to all levels of Government and to private enterprise for use in the development of their respective programs.

The Nationwide Plan will be the guide for recreation acquisition and development by all Federal land and water management agencies and of major assistance to States and other non-Federal interests, public and private, in their recreation planning.

RECREATION PLANNING FOR WATER RESOURCES DEVELOPMENT PROJECTS

The Bureau cooperates with the Federal water construction agencies in recreation planning at water and related land resource development projects. In short, it makes recommendations for recreation development and use in both river basin studies and individual project studies.

Federal water development reports are submitted to us for review and comment by the Corps of Engineers, the Bureau of Reclamation, and the Soil Conservation Service. Non-Federal public and private reservoir development proposals subject to Federal license are likewise submitted by the Federal Power Commission to us for appraisal.

We believe that the Bureau's participation in water resources is of particular significance for several reasons: (1) water-based recreation constitutes a very substantial portion of all outdoor recreation; (2) many Federal water resource developments provide extensive recreation opportunities and become important segments of the Nationwide Plan as well as of the statewide plans of the States concerned; (3) the amount of Federal investment in recreation at water development projects is large and growing each year; and (4) the Land and Water Conservation Fund, about which I will have more to say later, provides that a portion of the Fund may be transferred to Miscellaneous Receipts, as a partial offset for capital costs of future Federal water development projects which are allocated to public recreation and the enhancement of fish and wildlife values.

In order to avoid duplication of effort in this field, the Bureau of Outdoor Recreation has worked out agreements with the National Park Service and Bureau of Sport Fisheries and Wildlife on the functions of each of the Bureaus in water resource planning studies.

FEDERAL COORDINATION IN OUTDOOR RECREATION

The Bureau has initiated a broad overall review and analysis of Federal outdoor recreation resource programs and policies. This review is conducted in four general areas.

First, the Bureau provides staff services to the Recreation Advisory Council in the development of Federal policies relating to the nationwide effort to improve outdoor recreation opportunities. This includes the preparation of proposed policies for the better protection and appropriate management of scenic areas, natural wonders, primitive areas, historic sites, and recreation areas of national significance. It includes recommendations for the management of Federal lands to provide the broadest possible recreation benefit, and for cooperation with, and assistance to, States and local governments.

The Recreation Advisory Council has issued four policy statements.

1. Federal Executive Branch Policy Governing the Selection, Establishment and Administration of National Recreation Areas. March 26, 1963.

2. General Policy Guidelines for Outdoor Recreation. April 9, 1964.

3. Policy Governing the Water Pollution and Public Health Aspects of Outdoor Recreation. April 9, 1964.

4. A National Program of Scenic Roads and Parkways. April 9, 1964.

In all of these statements the Council commended the policies to all concerned Federal agencies. Furthermore, the member agencies of the Council through approval of the statement became responsible for observing these policies and for giving them force and effect in their action programs.

Six policy studies are presently underway at the direction of the Recreation Advisory Council; namely, one, on a national program of scenic roads and parkways; two, on user fee regulations; three, on measuring recreation use of Federal areas; four, on the role of the private sector; five, on non-Federal management of recreation facilities on Federal lands and waters; and the sixth, on the management responsibilities of Federal agencies at land and water resource projects.

Second, the Bureau is paying particular attention to questions of policy including gaps, overlaps, and conflicts, as well as long-range programs and financial needs.

One study is an evaluation of outdoor recreation research. This will show the status of the Nationwide effort and recommend new research efforts including the proposed role of the Bureau in this important field.

The third major effort being made by the Bureau in the field of Federal coordination relates to the examination of estimates by Federal agencies for funds under the Land and Water Conservation Fund for land and water acquisition.

The fourth major effort relates to the review, analysis, and recommendations with respect to the legal authorities of the several Federal agencies in this field. This review also encompasses such new legislation as may be proposed by any Federal agency relating to some facet of outdoor recreation.

SPECIAL AREAS STUDIES

Another important aspect of the work of the Bureau deals with studies of special areas throughout the country to determine their recreation values and make recommendations regarding their recreation use, development, and administration. These are of two types: Studies of areas which appear to have outstanding recreation potential, and studies, requested and financed by the Area Redevelopment Administration, of certain economically depressed areas where it appears that the local economy could be improved through the enhancement of tourism and recreation opportunities.

Not all of these studies are carried out independently by the Bureau. Some are undertaken in cooperation with other Federal agencies, non-Federal public agencies, and private agencies. And, in some instances, the Bureau confines its participation to review and comment.

Perhaps some examples will be helpful:

A study to determine the need for the establishment of a national system of wild rivers which are particularly suited to outdoor recreation is being completed by a joint Interior-Agriculture team headed by the Director of the Bureau of Outdoor Recreation. This study is aimed at carrying out the recommendations of the Senate Select Committee on National Water Resources and endorsed by the Outdoor Recreation Resources Review Commission "that certain streams should be preserved in their free-flowing condition because their natural scenic, scientific, esthetic, and recreation values outweigh their value for water development and control purposes now and in the future." The question is which rivers or portions thereof fit that criteria. This study began in 1963 with a preliminary examination of 64 streams. After such examination, that list was narrowed to about a dozen rivers for detailed consideration.

Just a few weeks ago bills were submitted in the Congress which, if acted upon, would set in motion a development program. Among the rivers designated would be the Rio Grande reach from the Colorado line to about Highway #96 near Pilar, southwest of Taos.

Underway, also is a study of the potential for recreation, wildlife, and historic developments along the route of the Lewis and Clark Expeditions from the Mississippi River to the Pacific Ocean. This is being conducted cooperatively by the Bureau, the ten States that are traversed by the route, and the J. N. "Ding" Darling Foundation of Des Moines, Iowa. It is the first interstate recreation program involving more than a few States. The study deals with the Trail's history, archaeology, geology, fish and wildlife, conservation, and other recreation resources and identifying key locations and access routes. The study will make recommendations regarding the need for recreational development along the trail. The Lewis and Clark Trail Commission recently created pursuant to the Act of October 6, 1964 (Public Law 88-630) provides a tremendous stimulus to marking this Trail for the inspiration and enjoyment of the American people. Among other matters taken up recently at its first meeting the Commission considered a design for an appropriate symbol for use along the Trail.

Another study now in progress in which we are cooperating is aimed at developing for Congressional consideration a national program of scenic roads and parkways. It is being made under the guidance of the Recreation Advisory Council and spearheaded by the Department of Commerce. It is being conducted in cooperation with State officials who will nominate specific routes or travel corridors for inclusion in such a system. The system would be designed to provide scenic driving opportunities for the people of America. Driving for pleasure is the Nation's number one outdoor recreation activity.

IMPLEMENTATION OF THE LAND AND WATER CONSERVATION FUND ACT

One of the outstanding products of the 88th Congress was the Land and Water Conservation Fund Act of 1965 approved September 3, 1964.

The Act became effective January 1, 1965. The life of the Fund is limited to 25 years. Revenues earmarked for a Land and Water Conservation Fund are derived from three sources: Modest entrance, admission, and user fees at Federal recreation installations or areas; the net proceeds from the sale of Federal surplus real property; and from existing Federal taxes on motorboat fuels. There is also a provision for Congress to advance up to an average of 60 million dollars a year to the Fund, starting the third year and ending the tenth. If this is done, the advance will be repaid with one-half of the other revenues coming into the Fund starting the 11th year and continuing until the advance has been repaid.

Normally, 60 percent of the moneys, as they are appropriated by Congress, will go to the States as matching grants for planning, acquisition, and/or development of recreation lands, waters, and facilities. Forty percent of the moneys can be used for certain Federal purposes. Portions may be used by the Forest Service, the National Park Service, and the Bureau of Sport Fisheries and Wildlife for the acquisition only of certain types of recreation lands. In addition, a portion of the Federal share of the Fund can go into the miscellaneous receipts of the Treasury, as I mentioned before, as partial reimbursement for capital expenditures for recreation and fish and wildlife enhancement at Federal water projects.

The Act and its legislative history make it very clear that no recreation fees can be charged: (1) for the use of any waters; (2) for travel by private non-commercial vehicle on any Federal Aid Highway, national parkway, roads in national forests or on roads on public land that are commonly used for through travel; (3) for access to private inholdings; (4) for activities on Federal lands which are not related to recreation; and (5) as a Federal hunting or fishing license.

In the apportionment of funds to States, the Act provides that two-fifths of the States' share shall be divided equally among the 50 States, but the remaining three-fifths is to be apportioned 2/5 by population, 1/10 by extent there are Federal recreation programs in the State, 1/20 by the amount of out-of-State or non-resident use of recreation facilities within the State, and the remaining 1/20 held for contingencies.

The Act provides that the States may permit lesser political subdivisions such as counties, municipalities or soil conservation districts to participate in the program and to share in its benefits.

As you are aware, this Act is a financing measure. It contains a two-pronged program, one to be carried out through certain Federal agencies, the other to be carried out through the States, hence my reference to the pivotal position of States. Both segments have the objective of providing opportunities to meet the needs of people.

Implementation of the Federal aspects of the Act calls for designation of Federal areas where recreation entrance, admission, or user charges shall be made. The President is authorized to make such designations and has recently signed an Executive Order to provide for them. He may also establish fee schedules, and provide for coordination among the Federal agencies in their application.

The Act provides for an annual admission fee to certain Federal recreation areas in lieu of a single entry or weekly fee. It is contemplated that a permit or recreation/conservation sticker will be issued for this purpose. The sticker will entitle the purchaser and all who accompany him in a private noncommercial automobile to enter, without further payment of entrance or admission fees, all Federal recreation areas designated for that purpose as often as desired over a 12-month period.

Agencies that administer areas where recreation fees will be charged are going ahead with plans to post the areas in accordance with the Act.

The Act provides for grants to States on a matching basis for planning, acquisition, and development of outdoor recreation resources, but before a State can qualify for Federal financial assistance for acquisition and development projects, it must prepare a comprehensive Statewide outdoor recreation plan.

Many States such as yours are preparing to develop their comprehensive statewide plans.

All moneys from the Fund must be appropriated by Congress before they can be made available for either Federal or States purposes. The President's budget for F.Y. 1966 recommends 125 million dollars to implement the provisions of the Act, or approximately the full amount of anticipated receipts to the Fund for that year. An F.Y. 1965 supplemental appropriation of 16 million dollars is also anticipated.

EXECUTIVE ORDER 11200 AND SECRETARY'S REGULATIONS

Since I drafted this report for you, President Johnson, on February 26, signed another Executive Order No. 11200 "Providing For Establishing User Fees Pursuant to the Land and Water Conservation Fund Act of 1965."

Briefly, this automatically now designates those Federal Areas for which charges were made in 1964 and further allows agencies to designate new areas for 1965; then provides for review and designation of areas on January 1 annually thereafter.

It outlines criteria, method of posting, the establishment of fees subject to criteria prescribed by the Secretary of the Interior, distribution and sale of the Land and Water Conservation Fund Sticker and coordination and issuance of regulations by the same Secretary.

Secretary Udall issued regulations in March that affect this agency and the National Park Service, Bureau of Land Management, Bureau of Sport Fisheries and Wildlife, Bureau of Reclamation, Forest Service, Corps of Engineers, Tennessee Valley Commission, and the U.S. portion of the International Boundary and Water Commission.

These regulations provide for an annual Admission Fee of $7.00 or optional short term fees of from 25¢ to $1.00 daily or five times the daily rate per week.

Additional user fees may be charged along the following lines.

Camp and Trailer Sites	$1.00 - $3.00 for overnight use
Picnic Sites	50¢ - 75¢ per site per day
Boat Launching	50¢ - $1.50 per day

CONCLUSION

In conclusion, I would like to say that the Bureau of Outdoor Recreation is looking forward to cooperating with agencies in the water resource field in a continuing effort to make and keep America beautiful, to enhance water and land use, and to provide opportunities for our citizens to enjoy and benefit from outdoor experiences.