WATER RESOURCES RESEARCH INSTITUTE

NEW MEXICO STATE UNIVERSITY

PROCEEDINGS

SIXTEENTH
MARCH 25–26–1971

ANNUAL WATER CONFERENCE

THEME :

Water––
A Key To A Quality Environment

Las Cruces, New Mexico

P R O C E E D I N G S

S I X T E E N T H A N N U A L W A T E R C O N F E R E N C E

March 25 - 26, 1971

THEME - WATER - A KEY TO A QUALITY ENVIRONMENT

WATER RESOURCES RESEARCH INSTITUTE

NEW MEXICO STATE UNIVERSITY

Proceedings of the
Annual New Mexico Water Conference
1956 - 1971

with

Special Report No. 1 - "WATER RESOURCES AND THEIR ECONOMIC IMPORTANCE IN NEW MEXICO," September 1956, 145 pp.

First Annual Water Conference - October 31, November 1, 2, 1956 - "GENERAL SURVEY OF AGENCY WATER ACTIVITIES," 112 pp.

Second Annual Water Conference - November 7, 8, 1957 - "WATER FOR NEW MEXICO - YOUR PROBLEM AND MINE," 109 pp.

Third Annual New Mexico Water Conference - November 6, 7, 1958 - "NEW MEXICO WATER - PRESENT USE AND NEW SOURCES," 146 pp.

Fourth Annual New Mexico Water Conference - November 5, 6, 1959 - "WATER AND WATER LAW," 144 pp.

Fifth Annual New Mexico Water Conference - November 1, 2, 1960 - "WATERSHED MANAGEMENT," 97 pp.

Sixth Annual New Mexico Water Conference - November 1, 2, 1961 - "GROUNDWATER," 104 pp.

Seventh Annual New Mexico Water Conference - October 31, November 1, 1962 - "WATER IN 50 YEARS OF STATEHOOD WITH A LOOK TO THE FUTURE," 116 pp.

Eighth Annual New Mexico Water Conference - July 1, 2, 1963 - "SALINE WATER CONVERSION," 81 pp.

Ninth Annual New Mexico Water Conference - March 19, 20, 1964 - "RESEARCH - THE KEY TO THE FUTURE IN WATER MANAGEMENT," 81 pp.

Tenth Annual New Mexico Water Conference - April 1, 2, 1965 - "PEOPLE AND WATER IN RIVER BASIN DEVELOPMENT," 126 pp.

Eleventh Annual New Mexico Water Conference - March 31, April 1, 1966 - "WATER ECONOMICS WITH LIMITED SUPPLIES AND AN INCREASING POPULATION," 157 pp.

Twelfth Annual New Mexico Water Conference - March 30, 31, 1967 - "WATER QUALITY - HOW DOES IT AFFECT YOU?", 116 pp.

Thirteenth Annual New Mexico Water Conference - March 28, 29, 1968 - "WATER FOR NEW MEXICO TO THE YEAR 2000 and 2060," 167 pp.

Fourteenth Annual New Mexico Water Conference - March 27, 28, 1969 - "WATER RESEARCH AND DEVELOPMENT," 111 pp.

Fifteenth Annual New Mexico Water Conference - March 12, 13, 1970 - "WATER -- THERE IS NO SUBSTITUTE," 113 pp.

Sixteenth Annual New Mexico Water Conference - March 25, 26, 1971 - "WATER - A KEY TO A QUALITY ENVIRONMENT," 160 pp.

STATE OF NEW MEXICO

EXECUTIVE OFFICE

SANTA FE, NEW MEXICO

PROCLAMATION

WHEREAS, WATER IS THE LIFE BLOOD OF THE STATE OF NEW MEXICO; AND THE STATE'S FUTURE SOCIAL, ECONOMIC AND CULTURAL DEVELOPMENT DEPENDS ON A CONTINUING SUPPLY OF WATER OF GOOD QUALITY; AND

WHEREAS, THE LIMITED WATER RESOURCES OF NEW MEXICO MUST BE USED IN A MOST JUDICIOUS MANNER; AND

WHEREAS, THE USE AND DEVELOPMENT OF WATER RESOURCES FOR THE STATE OF NEW MEXICO IS AND SHALL CONTINUE TO BE A MATTER OF PRIME CONCERN OF ALL RESPONSIBLE CITIZENS OF THE STATE; AND

WHEREAS, THE SIXTEENTH ANNUAL STATEWIDE NEW MEXICO WATER CONFERENCE IS BEING HELD TO DISCUSS THE VARIOUS ASPECTS OF OUR VITAL WATER RESOURCES PROBLEMS; AND

WHEREAS, TO ACCORD OFFICIAL RECOGNITION TO THE IMPORTANCE OF WATER TO THE WELFARE OF ALL OF THE PEOPLE OF NEW MEXICO;

NOW, THEREFORE, I, BRUCE KING, GOVERNOR OF THE STATE OF NEW MEXICO, BY VIRTUE OF THE AUTHORITY VESTED IN ME, DO HEREBY PROCLAIM THE WEEK OF MARCH 21 THROUGH MARCH 27, AS:

"WATER FOR NEW MEXICO WEEK"

IN THE STATE OF NEW MEXICO AND URGE ALL CITIZENS TO PAY SPECIAL ATTENTION DURING THAT WEEK TO THE IMPORTANCE OF OUR PRESENT AND FUTURE WATER SUPPLIES AND NEEDS.

ATTEST:

Betty Fiorina
SECRETARY OF STATE

DONE AT THE EXECUTIVE OFFICE THIS 19TH DAY OF MARCH, 1971

WITNESS MY HAND AND THE GREAT SEAL OF THE STATE OF NEW MEXICO

Bruce King
GOVERNOR

Governor Bruce King and President Gerald W. Thomas holding a framed copy of the Governor's Proclamation declaring March 21 to 27 as Water For New Mexico Week. The proclamation was read at the opening of the Conference by Dr. Sam Maggard, second from the right; Mr. Jesse Gilmer, Rio Grande Commissioner, and a conference speaker at the right and Dr. H. R. Stucky, Chairman of the Conference on the left.

Sixteen Annual New Mexico Water Conferences

Sixteen Water Conferences are now history. These conferences originated from a 12-week staff-graduate seminar held in the Department of Agricultural Economics in the spring semester, 1956 at New Mexico State University, A & M at that time. That seminar was organized to have various leaders from the state and federal agencies and the University explain the water program being carried on in New Mexico. H. R. Stucky organized and served as Chairman of the seminar.

As these seminars were being held, inquiries were received from numerous individuals of the public asking how they might hear these discussions. Since it was impossible to invite individuals into the class sessions, it was suggested that if the seminar speakers would agree, a session would be arranged to re-run the seminar over a two-day period. The re-run was held on October 1 and 2, 1956 with about 75 individuals participating.

At the conclusion of the re-run session, it was agreed that it should be designated as the First Annual Water Conference. There was a concensus of opinion that there was a lack of opportunity for the public to become informed about New Mexico water problems and programs, and that an annual conference would assist in correcting the situation.

The Sixteenth Annual Conference had the largest paid registration of any of the conferences. The overall attendence was not as large as some recent conferences, since the dates set a year in advance, fell on the spring vacation. Many students usually attend but they do not pay fees.

It has been the privilege of the writer to have served as Chairman of the Water Conference Planning Committee and of the Conference through each of the sixteen conferences. It has been a real pleasure to see the conference gain stature during this period, in New Mexico, the Southwest and the Nation. Senators, Representatives, Governors, Secretaries of Interior and Agriculture, University Presidents, a Supreme Court Justice, many prominent private citizens, many leading state and federal officials, Deans, Directors, and Professors, have participated in the conference programs. The proceedings of the conference go into the Library of Congress, many state and university libraries and to all of those who register for the conferences. University professors, students, and many others use the conference proceedings as a ready reference. Also, numerous foreign libraries and foreign citizens purchase the proceedings and many send continuing orders for future issues.

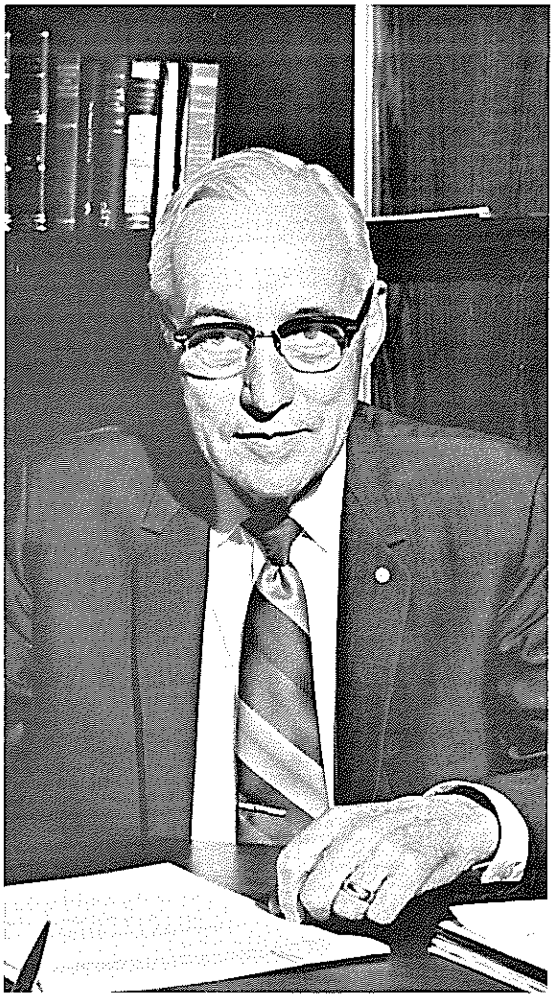
I want to express my deep appreciation to all who have participated in the planning and conduct of these annual conferences and to those who have attended and carried the information from the conference on to further consideration and action.

The Seventeenth Conference is scheduled for Thursday and Friday, April 6 and 7, 1972. Professor John W. Clark, who will become Director of the Water Research Institute on July 1, 1971, has been elected as Chairman of the Water Conference and the Conference Planning Committee. The conference will be in good hands under the leadership of Professor Clark.

Part of the funds required for the publication of this proceedings issue were provided by the United States Department of Interior, Office of Water Resources Research as authorized under the Water Resources Research Act of 1964, P. L. 88-379.

The program which follows will serve as an index to the papers.

H. R. Stucky, Chairman
Water Conference Committee



Dr. H. R. Stucky, Chairman

Annual Water Conference

1956 - 1971

and

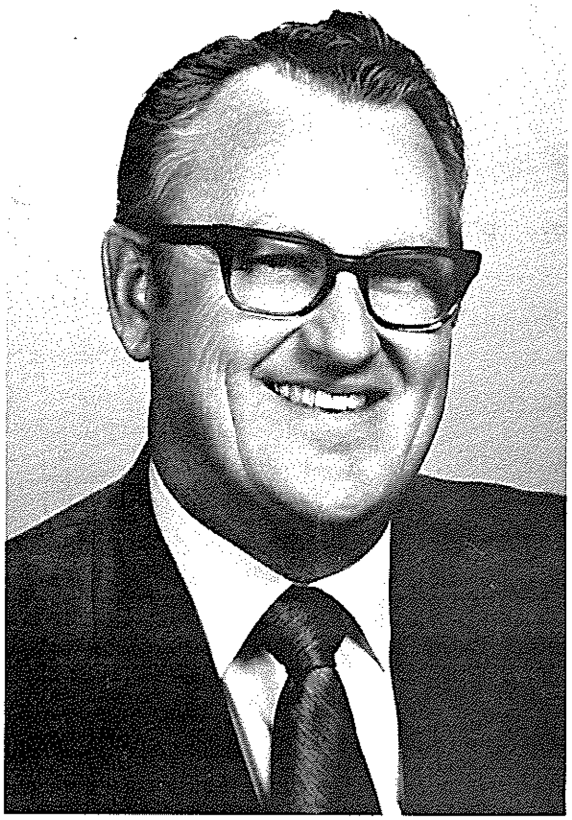
First Director - Water Resources

Research Institute

1963 - 1971

N M S U

1954-1965	Professor and Head - Department of Agricultural Economics and Agricultural Business, NMSU. Established the Undergraduate curriculum in 1964 and developed the Masters Degree program for the department in 1966.
1955-1971	Chairman - Annual New Mexico Water Conference
1962	Organized the Water Resources Research Institute at NMSU.
1963	February - Board of Regents officially approved the Water Resources Research Institute.
1963	October - named as Director of Water Resources Research Institute.
1965	New Mexico Institute was the first of the 50 State Institutes approved for funding under the Water Resources Research Act of 1964-88-376.
1965-1971	Director - Water Resources Research Institute.



PROFESSOR JOHN W. CLARK

INSTITUTE DIRECTOR

AS OF

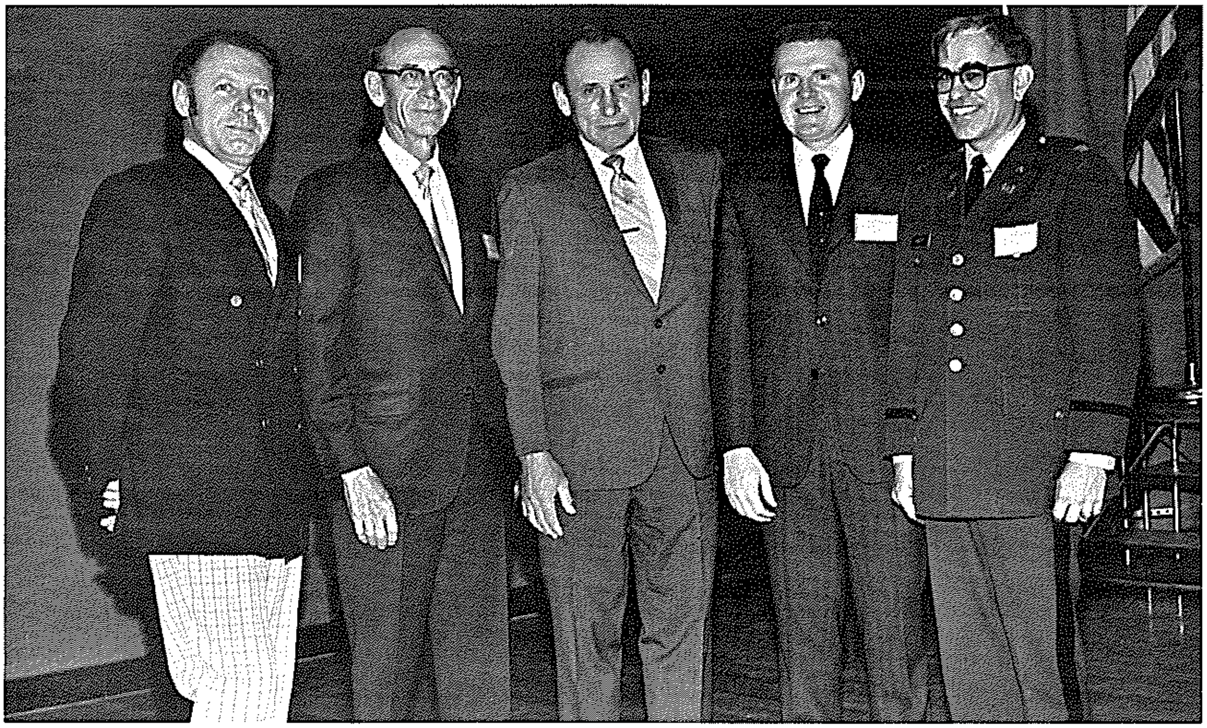
JULY 1, 1971

John W. Clark, professor of civil engineering at New Mexico State University since 1953, has been appointed director of the Water Resources Research Institute effective, July 1, 1971.

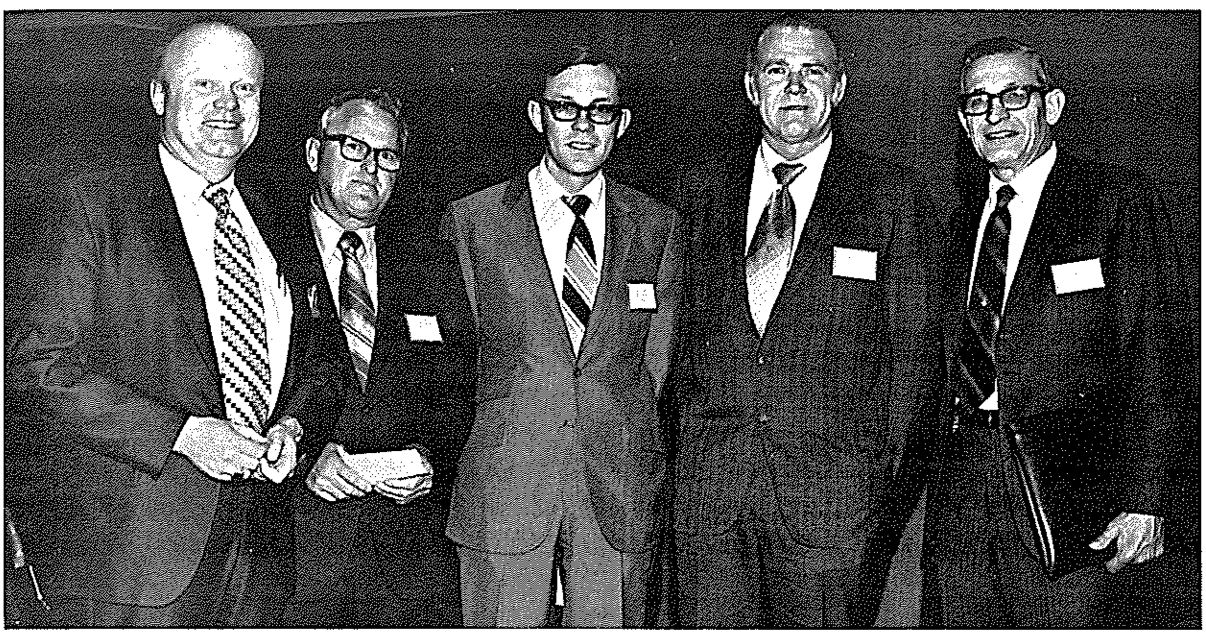
Clark, long active in water control organizations, was president of the Water Pollution Control Federation-Rocky Mountain Section in 1965, chairman of the Governor's Advisory Committee on Water Pollution Control from 1956 to 1966 and currently serves as a representative of environmental engineering appointed by the Surgeon General to the Regional Health Advisory Committee.

He received his bachelor's and master's degrees in civil engineering and a professional degree, C.E., in sanitary engineering from the University of Missouri.

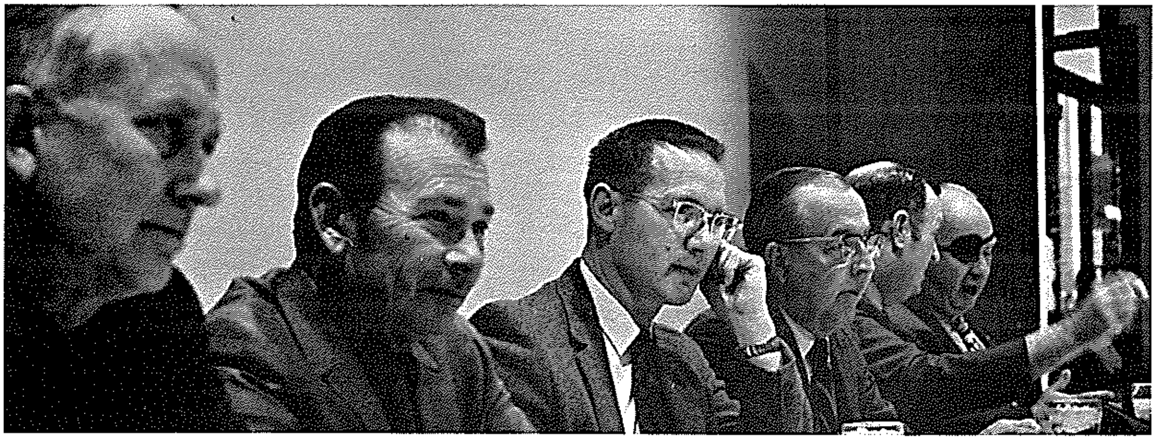
Clark organized the first New Mexico Water and Sewage Works Short School in 1955 and directed the first National Science Foundation Summer Conference on Water Resources to be held at NMSU. Since he joined the NMSU faculty in 1953, he has been principal investigator or project director on several hundred thousand dollars worth of grants and awards for such organizations as the National Science Foundation, National Institutes of Health, the U.S. Public Health Service, Department of the Interior, and other state and private groups. Professor Clark will also become chairman of the Water Conference Committee on July 1.



Speakers Group: (L to R) William P. Stephens, Agricultural Experiment Station, served as session Chairman. Ira Clark, Historian, NMSU; Ralph Bell, River Basin Planning, SCS; William Gorman, Agricultural Economist, NMSU, and Colonel Richard West, Corps of Army Engineers, were speakers in this session

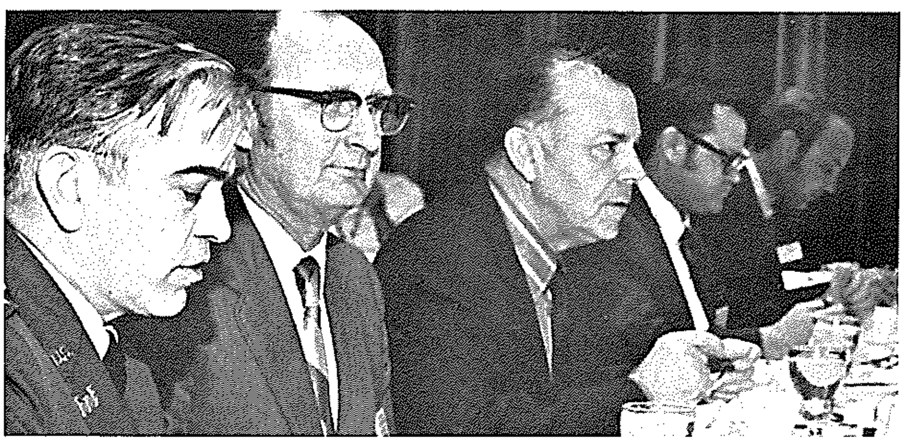


(L to R) James Kirby, Bureau of Reclamation, El Paso; John W. Clark, Wayne Cunningham, Elephant Butte Irrigation District; George Mosley, El Paso Water Improvement District No. 1, and S. E. Reynolds, New Mexico State Engineer.



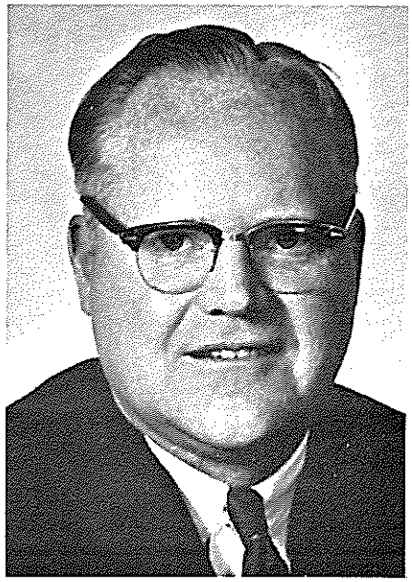
(L to R) James W. Kirby, Extension Economist; M. L. Wilson, Associate Director, Agricultural Experiment Station; James R. Gray, Agricultural Economist; Frank Bromilow, Dean of Engineering; Carrol Hunton, State Director, Farmers Home Administration; Philip Crystal, County Extension Agent, Clovis. Note - Phil is emphasizing his point.

(L to R) Ralph Fegley, President, Student Engineering Council, NMSU; Mrs. Fred Ribe, League of Women Voters; H. Ralph Stucky, John W. Clark and W. P. Stephens.



(L to R) Colonel Richard L. West, Fred A. Thompson, State Department of Game and Fish; Lloyd Calhoun, New Mexico Electric Service Company, Hobbs; Professor Jesse Lunsford, Civil Engineering, NMSU, and Ray Cauwet, Publicity Department, NMSU.

These shots taken of the 35 people attending the meeting of the Conference Advisory Committee Meeting with the University Committee.



Dr. Allen Agnew

Dr. Agnew spoke on the subject, "Solutions to Water Problems - The Time is Now".

Dr. Agnew is Director of the State of Washington Water Research Center and Chairman of The Water Committee of the National Association of State Universities and Land Grant Colleges.

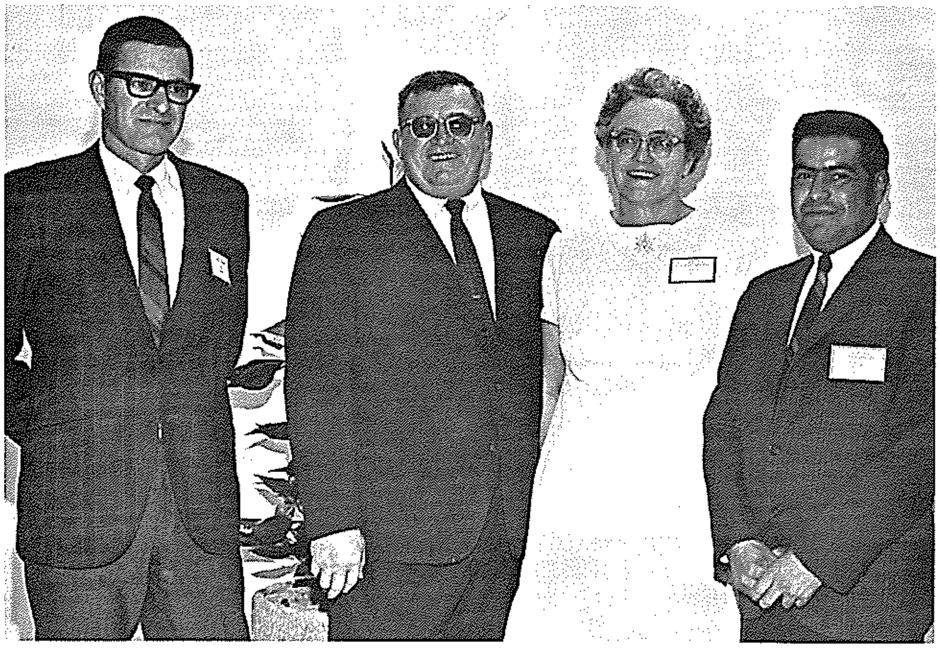
Dr. Herman Bouwer

Dr. Bouwer spoke on the topic, "Renovating Sewage Effluent for Agricultural and Industrial Uses".

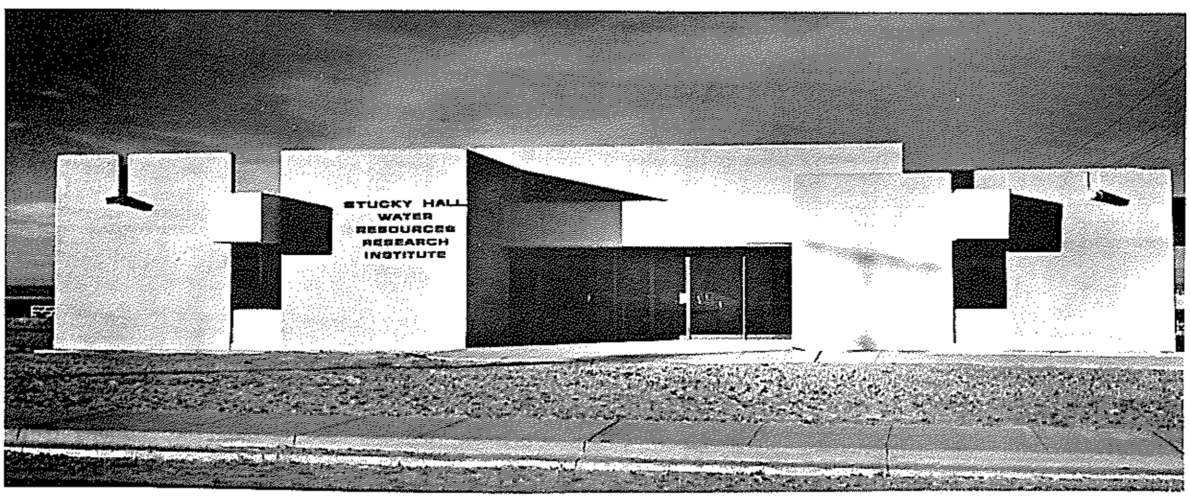
Dr. Bouwer is Chief Hydraulic Engineer and leader of a research group in sub-surface water management and waste water reservation at the U.S. Water Conservation Laboratory at Phoenix, Arizona.

Registering for the Sixteenth Annual Conference are John R. Wright, Environmental Engineer, New Mexico Water Quality Control Commission and to his right, George B. Mosley, Manager, El Paso County Water Improvement District No. 1. With them, L to R - unidentified, Joe Pierce, Dona Ana County Sanatarian, and James W. Kirby, Bureau of Reclamation, El Paso.

Robert Brasier, Engineer, Los Alamos Scientific Laboratory, one of the early registrants and one who has attended most of the recent conferences.



Mr. and Mrs. Francis C. Melton, Hatch, New Mexico. On their left is O. D. Knipe and on their right is George Garcia, both of the Rocky Mountain Forest and Range Experiment Station in Albuquerque.



The home of the New Mexico Water Resources Research Institute on Espina Street on the New Mexico State University campus. It is also the headquarters for the Annual Water Conferences. Numerous conferences on water research and development have been held in the building since it was occupied in late March 1970.

SIXTEENTH ANNUAL
NEW MEXICO
WATER CONFERENCE

RESOLUTION

WHEREAS, WATER RESOURCES DEVELOPMENT IN THE STATE OF NEW MEXICO HAS BEEN, IS TODAY, AND IN THE FUTURE, WILL BE OF PARAMOUNT IMPORTANCE; AND

WHEREAS, DR. H. RALPH STUCKY, FOR THE PAST SIXTEEN YEARS, IN RECOGNITIO AND APPRECIATION OF THE VITAL ROLE WATER RESOURCES OF NEW MEXICO PLAY IN THE PUBLIC WELFARE, HAS ASSUMED A POSITION OF TOP LEADERSHIP IN THE BROAD FIELD OF WATER DEVELOPMENT; AND

WHEREAS, DR. STUCKY, SINCE THE FIRST ANNUAL NEW MEXICO WATER CONFERENCE IN 1956 HAS SERVED EACH YEAR WITH DISTINCTION AND HONOR AS THE CONFERENCE CHAIRMAN; AND

WHEREAS, IN ADDITION TO A HOST OF OTHER PUBLIC AND PROFESSIONAL DUTIES, DR. STUCKY, SINCE THE INCEPTION OF THE WATER RESOURCES RESEARCH INSTITUTE IN NEW MEXICO, HAS SERVED WITH PROFESSIONAL LEADERSHIP AS ITS DIRECTOR; AND

WHEREAS, THE STATE OF NEW MEXICO DURING DR. STUCKY'S YEARS OF UNSELFISH DEVOTION TO THE CAUSES OF WATER DEVELOPMENT AND RESEARCH HAS AND DOES ENJOY A POSITION OF NATIONAL LEADERSHIP IN BOTH FIELDS OF ENDEAVOR, IN GREAT MEASURE DUE TO DR. STUCKY; AND

WHEREAS, UPON HIS RETIREMENT ON JULY 1, 1971, THE PEOPLE OF THE STATE OF NEW MEXICO WILL RECOGNIZE WITH APPRECIATION AND RESPECT THE MANY YEARS OF DEDICATED SERVICE RENDERED BY DR. STUCKY.

NOW THEREFORE, BE IT RESOLVED THAT THE ENTIRE MEMBERSHIP OF THE SIXTEENTH ANNUAL NEW MEXICO WATER CONFERENCE EXPRESS BY RESOLUTION ITS HEARTFELT APPRECIATION AND DEEP RESPECT FOR THE IMMEASURABLE SERVICE DR. STUCKY HAS GIVEN TO THE CITIZENS OF NEW MEXICO IN HIS PROFESSIONAL CAREER AND TO WISH FOR HIM AND MRS. STUCKY MANY YEARS OF HEALTH AND HAPPINESS IN THEIR RETIREMENT.

RESOLUTION PRESENTED
MARCH 26, 1971, BY:

Lloyd A. Calhoun

LLOYD A. CALHOUN, MEMBER
WATER CONFERENCE ADVISORY COMMITTEE

THE ABOVE RESOLUTION WAS PASSED UNANIMOUSLY AND DR. H. RALPH STUCKY WAS GIVEN A STANDING OVATION.

Gerald W. Thomas

GERALD W. THOMAS, PRESIDENT
NEW MEXICO STATE UNIVERSITY

March 26, 1971
DATE

W. P. Stephens

W. P. STEPHENS, CHAIRMAN OF SESSION
ASSISTANT DIRECTOR
AGRICULTURAL EXPERIMENT STATION

March 26, 1971
DATE

SIXTEENTH ANNUAL NEW MEXICO WATER CONFERENCE

March 25 - 26, 1971

THEME OF THE CONFERENCE - WATER - A KEY TO A QUALITY ENVIRONMENT

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WATER - A KEY TO A QUALITY ENVIRONMENT - NEW MEXICO AND THE SOUTHWEST

Gerald W. Thomas[1]

Water is truly the key to a quality environment in New Mexico and the Southwest. Furthermore, it is probably the most important - and most limiting factor - in growth and development of the area.

The demand for water is increasing at an alarming rate. We need water, not only to supply a growing population base, but to take care of increased pressures associated with affluence and technological development. The U. S. Water Resources Council estimated that, before the year 2020, industrial, municipal, domestic and power requirements for fresh water in this Country are expected to reach 1000 billion gallons per day (1). This is about three times the total withdrawn for all purposes today. Such a demand would leave no water for agriculture, which presently accounts for 41 percent of the present total withdrawals.

These kinds of projected needs not only alarm the average U. S. citizen, but they really shock those of us already faced with water shortages in the arid southwest. It is time that we ask ourselves some very serious questions about this most valuable resource -- and about our future as it may be related to water use and development.

The first and most basic question is, "How much water is required per person?" This is a simple and straight-forward question, but to arrive at an answer is very, very difficult. We know that we need only about 2 quarts daily for drinking, but, even in the early 1900's, our home use of water was about 10 gallons per person per day. Now, each of us is using about 180 gallons per day for home use. In addition, we need water to produce food, to refine oil, to manufacture automobiles and to operate our growing metropolis. Our total withdrawals in the U. S. now amount to about 1270 gallons per person per day. So, we might again ask the question, "How much water is required per person -- 2 quarts? 180 gallons? or over 1200 gallons per day?"

Let's approach the question in a different way. What standard of living are we willing to accept? A recent study in California will serve to illustrate the general relationship between standard of living and water use. In 1968, residents of Beverly Hills, where per capita income was $4929, used an average of 313 gallons of water per day for home use. This compares with 89 gallons per person per day in Compton where the per capita income was only $1727 (2). Should we be satisfied with 89 or go to 313 gallons per person per day for home use, or should we get by with the 20 or 30 gallons common to most people of the world in metropolitan areas?

1/ Preisdent, New Mexico State University

It should be fairly simple to calculate the per capita water requirements for business, industry and municipalities, but what about water for food production? To grow a pound of wheat in the field will require about 1,500 pounds of water. If we follow this wheat on through the milling processes, with average losses, and to the completed bread, we find that over 2,500 pounds of water are used to produce 1 pound of bread. To produce 1 pound of rice may require as much as 2 tons of water.

As we introduce animal protein or other essentials for balanced diet, the water requirements are increased correspondingly. For example, on some brush infested semi-arid rangelands in New Mexico, from 100 to over 500 tons of water are involved in the process of producing 1 pound of beef -- measured at the supermarket level.

This does not mean that 100 tons of water are "required" to produce a pound of beef -- but it does mean that this much water is "involved in" or "associated with" the production of a pound of beef. Much of the water involved in range beef production is dissipated by undesirable weeds and brush or evaporates from the unprotected soil surface. Also, most of the water necessary to the process of photosynthesis in range plants is transpired through the plant and returned to the atmosphere.

Purely from a water efficiency standpoint, we can increase the effectiveness of water use for beef production at least 10 times by producing animal feeds on irrigated lands and confining the animals to a dry-lot during the production period. But this is only part of the story. A "quality" environment involves considerations other than efficiency or economy of water use.

I would like to go back and enlarge on a statement that I made earlier -- namely, that more units of water are required per person as our standard of living rises. Canada and the United States utilize over 1600 pounds of grain per person per year compared with 400 pounds for Iran, Morocco, Japan, UAR, Pakistan, Thailand, and India. This difference in grain use is four-fold, but if the U. S.-Canadian levels were projected across the world's population, the grain use would be nearly 8 times the present world production (3). In terms of water use, Canada and the U. S. would require 1600 tons of water per person per year to produce their grain needs, but India and Pakistan must get by with 400 tons of water per year -- assuming the same level of efficiency.

The U. S. has increased its beef consumption from 48 pounds per person per year in 1930 to over 110 pounds per person in 1970. Japan gets by on about 16 pounds. Even with good efficiency, our water requirements for beef consumption per capita would be over 1100 tons compared with 160 tons per year for the average Japanese.

Research on both cropland and native range areas indicates that, as a general principle, we can increase the effective use of water in the agricultural sector by concentrating our limited water resources on a smaller area of land. On range areas this means more attention to mechanical land treatment, land shaping for modified water harvest, contour furrowing, water spreading, and micro-climate modification. On cropland this means level benching, other forms of water concentration and irrigation.

Man first started using water for irrigation in ancient times. During the Bronze Age, in the Biblical period of Abraham, complex irrigation systems were designed and used in the Mediterranean region. Irrigation has changed the geographical pattern of food production more than any other single factor. It has moved intensive agriculture into arid and semi-arid regions and has become accepted as a risk-reducing factor in humid and semi-humid areas.

Irrigation, or other methods of water control, makes possible the full use of technology in food production. It brings out the genetic potential of plants. It increases the effectiveness of fertilizers. It allows for crop rotations designed to maintain organic matter or reduce erosion. Water management increases the production of land two- to four-fold.

In the early sixties, irrigation was used on 380 million acres in the world -- about 11 percent of the total arable land. The major regions of the world had the following percentages of the total world irrigated land: Europe - 5.9, the Soviet Union - 8.3, Asia - 64.8, Africa - 3.8, Oceania - 0.6, South America - 3.2, and North America - 13.4 percent.

The United States now has approximately 42 million acres of agricultural land under irrigation. Most of this irrigation - both from surface and underground water sources - is in the semi-arid and arid west. This irrigated cropland, although only 10 percent of the total U. S. cropland, contributes nearly 20 percent of the total farm income from crops.

In addition, studies have shown that water used for irrigation may generate considerable income off the farm due to the multiplier effects on the economy and the value of water-based recreation. For example, studies in the Texas High Plains, where there are 63,500 irrigation wells and 5.5 million acres under irrigation from a depletable underground aquifer, show that irrigation generated $3.40 off the farm for every dollar at the farm level (4). A similar study in Nebraska indicated that for every one dollar net increase in crop production due to irrigation, a total of $6.68 in new business was generated throughout Nebraska.

With the growth of industry and the development of metropolitan areas, the competition for water has increased. At the present time, water for food production is in a lower priority than the use of water by metropolitan areas or many industries. Predicted water deficiencies by the year 2000 therefore may lead to a shift in some intensive farming back to the higher rainfall areas. If this change occurs in the United States, we can anticipate substantial increases in the cost of production. Reasons for this expected cost increase relate to highly variable and low fertility soil conditions, smaller operations, increased land prices, more insect and disease problems, and other factors associated with the humid zones in the Eastern United States.

We are all concerned about water pollution. This problem ranges from direct contamination by improperly treated effluent discharge from towns and cities, to the problems of chemicals and siltation from erosion. Farmers in the United States have made great strides in the conservation of soil and water since the the dust bowl period. Yet much remains to be done. Water pollution also seriously inhibits water based recreational activities. About one-fourth of all outdoor recreation is now dependent upon clean water.

The approach to water pollution control is, of necessity, quite different in the agricultural sector than for other business, industry, or for municipalities. While water is truly a renewable natural resource, it can be cleaned up, pollutants removed and recycled in the short run by municipalities and industry rather rapidly with a technological and economic input. On the other hand, water used for food and fiber production can be reused only in the long run as it moves through the complicated hydrologic cycle. The use of this water as it passes through the cycle is the basis for life itself.

This leads to another important consideration as we discuss water - the key to a quality environment. Water is most often the limiting factor in vegetation production. The key to the quality of the air that we breathe is the Co_2/o_2 balance -- although certain specific pollutants may be critical at any one time, such as sulfur dioxide, lead, etc.. The only way that we can maintain our oxygen supply is through plant growth. The process of photosynthesis is still the most important chemical reaction in the world. Through this process the plant can convert carbon dioxide back to oxygen. Thus, as a generality, we can say that all vegetation can be classified on one side of the system as an asset to the environment while all other forms of life, and technological development, tend to be detrimental. Thus a man-vegetation balance is essential -- particularly with reference to environmental quality. Some estimates indicate that the United States is now producing only about 60 percent of our total oxygen needs. Without the vast ocean areas to supply an inflow of oxygen to the great land masses, man could not be sustained at even the present population level.

From an ecological viewpoint, I believe it would be well to point out that some of our so-called "solutions" to environmental issues are not really solutions for society when we look at the impact on large eco-systems -- even though they may be satisfactory "solutions" for certain individuals or interest groups. Let me illustrate this point with an example. If the 3.6 billion people in the world had to depend upon "organic" farming and chemical-free backyard food production, our land resource requirements would triple -- our water requirements would be so great that many people would be without this essential element for life -- and our pressure on the environment and problems of pollution (of a different type) would be greater and not less.

Ecological understanding and "management" orientation are essential to our survival. Our earth in its natural state could maintain only about one human being per square mile (5). By modifying his environment, man has added millions of acres to his production potential and created desirable living situations in hazardous climates for both rural and metropolitan living. Water has played a key role in this development. Our future is still tied to this important renewable resource. This is the time to strengthen our research programs on water, to increase our efficiency of use, and to improve our understanding of the role of water in environmental improvement.

REFERENCES

1. U. S. Water Resources Council. "The Nation's Water Resources", Washington, D. C., 1968.

2. Associated Press News Release dated February 6, 1969.

3. Gerald W. Thomas. "The Ecology of Food Production -- Can the World Afford to Feed Itself?" Contribution No. 79, International Center for Arid and Semi-Arid Land Studies, Texas Tech University, Lubbock, Texas, 1970.

4. Herbert W. Grubb. "Importance of Irrigation Water to the Economy of the Texas High Plains", Texas Water Development Board Report No. 11, January, 1966.

5. Thadis W. Box and Gerald W. Thomas. "Ecology and The Use of Water Resources", Proceedings of the West Texas Water Institute, Texas Tech University, February, 1970.

COMPREHENSIVE STUDY ON THE RIO GRANDE - SAN MARCIAL, NEW MEXICO TO FORT QUITMAN, TEXAS

Jesse Gilmer[1]

It is an honor for me to be present at this water conference and to discuss with you a program of investigation which we believe you will want to consider carefully and participate in. In the 1930's the states of Colorado, New Mexico, and Texas negotiated and accepted a compact which simply stated, provided for a fair division between the three states of the waters of the Rio Grande above Fort Quitman, Texas. The agreement, called the Rio Grande Compact, became the law of the three states, and was passed by the U. S. Congress as a public act and signed by the President of the U. S. on May 31, 1939. The first paragraph of the compact states in part, as follows:

> The state of Colorado, the state of New Mexico and the state of Texas, desiring to remove all causes of present and future controversy among these states and between citizens between one of these states and citizens of another state, with respect to the use of the waters of the Rio Grande above Fort Quitman, Texas, and being moved by considerations of interstate commodity and for the purpose of accepting an equitable portion of such waters, have resolved to conclude a compact for the attainment of these purposes.

The compact provided that the Texas Commissioner would be appointed by the Governor of Texas, and would, as such commissioner, represent the area of the Rio Grande from San Marcial, New Mexico to Fort Quitman, Texas. This is the area of this great southwest covered by my assigned subject. For the past two years, a group of people whose vocation and avocation are both water, have been looking at this area in great length and depth. The people closest to the study have been the board and management of the Elephant Butte Irrigation District, the El Paso County Water Improvement District, and the Hudspeth County Conservation and Reclamation District, and responsible leaders of the Bureaus of the USDA and Interior, and state governments of New Mexico and Texas as well as some of the great universities of both states.

Action was started when the irrigation district managers, working with New Mexico and Texas members of the Congress, arrived at an agreement with the Secretary of the Interior, that the department, acting through the Bureau of Reclamation, would assume the responsibility and leadership for organizing and directing an investigation, which we now refer to as a regional environmental study of the Rio Grande Valley for Elephant Butte Reservoir to Fort Quitman, Texas.

The purpose of the study is to determine the scope of the economic role that the area can attain in the decades ahead. How that role can be adapted to the changing economy of the region involved. And, perhaps more importantly, how that role can be performed so as to create acceptable economic and

1/ Rio Grande Compact Commissioner, El Paso, Texas

environmental conditions for the individuals of the area, who in the aggregate, will be responsible for perfecting it. The study, therefore, would embrace subordinate disciplines in the fields of economics, sociology, environments, and the physical sciences relating capture, extraction, and utilization of water and other basic resources. The over-riding goal is continuation and creation of an acceptable and dignified way of life for those who live in the area in future decades and centuries.

The area of study lies in the more arid portion of North America. Average annual rainfall at El Paso, Texas, for example, is less than eight inches. Under these desert conditions, the future social and economic history of the area will be determined largely by how well the available waters in the area's streams and sub-surface sources are used by the men who live in the area. Thus, the study proposes, among other matters, a search for new water sources to support the growing area economy and to integrate additional water use into a planned overall area use for attainment of maximum future social, economic and environmental value. Heretofore the area has used available waters well.

In a large degree, the present economy of the Rio Grande is a reflection of the effective use that has been made of the surface flow of the Rio Grande, and to some extent, tentative exploitation of local underground water sources. The growth of the area in the last several decades has been rapid. If it is to continue, and the growing population is to be appropriately supported, new water must be identified and conveyed to points of use. It is worthy of note that the past competition for water of the Rio Grande has been so keen that total use of the waters of this historic stream above Fort Quitman is now being made; and that this use in three states and two nations is rigidly governed by interstate and international water compacts and treaties.

In many ways the area is a geographic, economic, and social unit because of its physical location and isolation. From El Paso it is 600 miles to Austin, Texas, with virtual desert over half the entire distance. From El Paso westward, there is a stretch of 320 miles to the first large city, which is Tucson, Arizona. From Elephant Butte Dam to Santa Fe, the capital city of New Mexico, it is 215 miles.

The area, with political responsibilities to the three states and the two nations is so far removed from the power centers of these government units, that it is almost an entity within itself; responsible in a large degree for its own past development, its future growth, and the way of life that it will provide for the individuals that will inhabit it. The area is a product of cultures -- the Indian, the Latin, the Anglo-Saxon -- to the advantage of each. Each culture has contributed a heritage of its skills and crafts to blend a unique culture profiting well from diversity of origin.

It is an area rich in history. In 1610, Franciscan fryors trekked northward through El Paso del Norte to found the oldest church in America, at Santa Fe. Coronado passed through the area in 1542, only 50 years later than the voyage of Columbus, enroute to his futile search for the cities of gold. The valley has been farmed in modern times since 1650; over 120 years ago, the gold rush in California augmented many cattle drives that began their overland trek from the El Paso area to the west coast. Area growth in the present century has reflected the energy of the people and effective use of resources available. The area is a lush, thin, green strip of profitable irrigation bordering the Rio Grande on both sides. And like the Nile in Africa, is surrounded by hundreds of miles of desert in every direction. It is a green and profitable oasis in a desert land. A good place in which to live, and one that can and will be made better. The irrigation effort is organized and based on one of the earliest projects of the Bureau of Reclamation. It has been phenomenally profitable and is a basic bulwark of the present area economy.

Total gross area income for the project since 1915 exceeds $1,261,000,000, and the current annual gross income from the enterprise is over $40 million. Current studies in the El Paso and Las Cruces area indicate that these figures are multiplied by approximately seven times through the interplay of trade at the basic income generates. Urban areas in the region have expanded both as a result of profit from irrigation and a continuing local creation and influx of various types of industry. Major U. S. urban centers are El Paso and Las Cruces, with a combined 1970 population of 385,000 compared with a population of 105,000 in 1940. The city of Juarez, Chihuahua, Mexico has a population in excess of 600,000. Urban growth has been accomplished by a demand for more water.

The area now faces the circumstance that new water sources must be sought to support further urban expansion, which otherwise can occur only by reducing or eliminating irrigation through conversion of part or all of the irrigation water supplied to other uses. This alternative is not desired, as neither the area nor the affected states and nations can afford the resulting economic losses.

To support future growth, the proposed study, therefore, will establish facts concerning water sources within and adjacent to the area, and will explore new water sources for import into the region at acceptable costs. The main theme will be emphasis on efforts to use more effectively what we now have, and to help ourselves solve our problems before we ask help from other states or from other water basins. One aim of the study will be to determine whether the region's economy can be strengthened through changes in the kinds of economic goods that it produces, -- in order to use national needs to better advantage. Since the future growth of the area will be a direct function of optimum use of known water supplies, and the availability of new water supplies, it might seem that the only matter issue is a water-supply project. This, however, is not the case. The era in which a water-supply project could be developed with little concern for its complex interrelationships with all other facets of the economy that it helps support, is past. New water projects can only be successfully proposed in the framework of careful consideration of their interrelationship with the multitude of factors that will govern the future environment of the area and that they will help serve. While the region is geographically isolated, its full economic potential can occur only with its full awareness of its future economic relationships with other regions. This interrelationship must be examined to determine what adjustments within the region would be desirable. The study, while it proposes to seek new water resources, more importantly proposes an examination of all related factors that will affect the area's economy and environment for a decade to come, so that new water will be used to make the maximum practicable contribution to achievement of an acceptable future environment.

It follows that the study will involve a variety of disciplines. The overall state leadership must come from our governors. These men represent all of the citizenship and because a political state line crosses the area, it must be recognized as artificial and non-existant for study purposes. The total skills of the Department of the Interior will be required, together with those of the Federal Water Quality Administration, the U. S. Department of Agriculture, the International Boundary and Water Commission, the Bureau of Mines, and many other U. S. government agencies. The great agencies of our state governments, such as the New Mexico State Engineers Office, the New Mexico Interstate Streams Commission, the Texas Department of Agriculture, the Texas Water Development Board, the Texas Water Rights Commission, and others. The Soil Conservation District, the Irrigation District, the Council of Government of both states and many others.

I would place primary reliance on two great universities that have intimate knowledge of the areas past and its potential. These are New Mexico State University at Las Cruces, and Texas Tech at Lubbock. I would have these universities provide leadership for a group of other universities composed of the University of New Mexico at Albuquerque, New Mexico Institute of Technology at Socorro, University of Texas at El Paso, Texas A & M at College Station, and the University of Texas at Austin. Scientists and engineers from these universities would investigate a variety of areas, including opportunities for production of new crops, in that area which will be in national demand as tastes of a growing national population change. Social studies are needed to determine the scope of labor available for growing industry. Studies of educational levels, and perhaps the need for improvements in the area as new types of industry demand a higher level of personal skills. The universities will investigate new industrial potentials that will permit more effective utilization of area resources on an integrated areawide basis. Marketing procedures for all area products must be studied and surveys made for improvement so that the area's economy and living standards keep pace. Studies are needed relative to the practicality of recycling water for reuse and reuse again. Climatological studies are needed to explore opportunities for increasing surface water runoff, a procedure which appears to gain in practicality year-by-year. Studies of this potential will be needed from the St. Louis Valley southward throughout the entire region. Institution studies will be needed.

As the area is virtually a separate and distinct geographic, geologic, economic and social entity, it is obvious that its greatest advances will occur by accepting this circumstance and providing for future integrated development on an areawide basis without being stopped at state lines. The possibility for increased trade between the two countries involves detailed scrutiny.

Other types of studies are needed, which are too numerous to be described in detail here. For example: land classification, non-agricultural resources, recreation, retirement, review of energy available, areawide in-put and out-put studies, cost benefits, marketing, weather, education, and labor. The aggregate of the studies to be made will permit recommendations to the areas and state agri-business communities for new paths to the future that will extract optimum benefits from the sources available and simultaneously help provide an area environment more conducive to greater individual dignity and freedom from want.

It is emphasized that the study need not be of a "crash" nature. None of the urban centers in the area face immediate depletion of water sources now supporting their growth. Such will occur, however, in the predictable future. The purpose of this study is to preclude cessation of growth by identifying new water resources and planning their orderly development. We will learn to live in the area and learn to use the god-given natural resources of the area, the most important of which is people, or we will, in the next century have as our largest export from the area, people.

PROBLEMS AND PROJECTS OF THE ELEPHANT BUTTE IRRIGATION DISTRICT

Wayne Cunningham1/

There are three distinctive points that I would like to discuss today. The first is the history of the Elephant Butte Irrigation District, second is Arroyo Control and finally modernization of irrigation and drainage facilities.

The Rio Grande Project, constructed and operated by the Bureau of Reclamation, in cooperation with the Elephant Butte Irrigation District of New Mexico, and the El Paso County Water Improvement District No. 1 of Texas, is located in central and south central New Mexico and in extreme west Texas. The project furnishes a full irrigation supply for about 178,000 irrigable acres of which 159,650 acres are water-right land and electric power for communities and industry in the area.

All project lands in New Mexico belong to the Elephant Butte Irrigation District while all lands in Texas belong to the El Paso Water Improvement District No. 1. The division of the two districts at the state line is probably as irregular as exists between any two states within the nation; yet the canals are continuous from one district to the other across this line. This is not inappropriate, however, since the entire Rio Grande Project is considered as Texas for the Rio Grande Compact purposes.

The Bureau of Reclamation maintains and operates the entire system including Caballo Dam, Elephant Butte Dam, and the hydroelectric power facilities through a project office at El Paso. The Bureau has an irrigation office at Las Cruces, New Mexico and one at Ysleta, Texas, and the Power Branch field office at Elephant Butte, New Mexico, to handle the actual field work. The Las Cruces Division serves the entire irrigated area above El Paso, while the lower division serves the irrigated area below El Paso. Thus, there are two distinct irrigation entities (one above the other insofar as this relates to river location), and in two separate states with operation and maintenance carried on by the Bureau through two division offices, the upper division of which overlaps into the lower district as far down as El Paso.

The system is further complicated through the supply of irrigation water to Mexico from project storage capacities and the management of this feature is under the International Boundary and Water Commission. The project is large, management is complex and the problems involved are extremely intricate at times, particularly during years of short water supply.

The districts are political entities of their respective states with authority to issue bonds and collect taxes for construction, operation and maintenance and to construct new works with requirements for reference to the electorate

1/ Manager, Elephant Butte Irrigation District, Las Cruces, New Mexico

of the districts in accordance with the respective state laws. Each district is qualified under the state laws to execute a repayment contract with the Federal Government under the provisions of the Reclamation laws.

The physical features of the project include Elephant Butte and Caballo storage dams, 5 diversion dams, 581 miles of distribution system, 483 miles of land drains, a hydroelectric powerplant, 491 miles of transmission lines and 11 substations.

Waters of the Rio Grande are stored in Elephant Butte and Caballo Reservoirs and released as needed to meet irrigation requirements. The river bed serves as the principal conveyance channel to major diversions. The irrigable area starts just downstream from Caballo Dam and extends for some 155 miles downriver. Project lands occupy the river bottomland of three separate and distinct valleys: the Rincon Valley in Sierra and Dona Ana Counties, New Mexico; the Mesilla Valley in Dona Ana County, New Mexico, and El Paso County, Texas; and the El Paso Valley in El Paso County, Texas.

A short distance downstream from Caballo Dam, the point of irrigation releases to the project, the Rio Grande enters the Rincon Valley. This valley is about 32 miles long and averages 3 to 4 miles in width. The Rincon Valley terminates at the entrance to Seldon Canyon, a short narrow defile about 7 miles long. The Mesilla Valley begins at the mouth of Seldon Canyon. This valley, the largest geographical subunit of the project, extends for 62 river miles to the "Pass" in the Franklin Mountains at El Paso, Texas. The Mesilla Valley averages about 4 to 5 miles in width. The rich alluvial lands of these two valleys comprise the lands of the Elephant Butte Irrigation District with a maximum water-right area of 90,640 acres.

The mild climate, rich soil, and easily accessible irrigation water of the Rio Grande Valley have attracted human habitation for many hundreds of years. Spanish explorers found the Pueblo Indians irrigating crops in the first half of the 16th century using primitive methods which persisted until the early part of the 20th century.

American settlers arrived in the area between 1840 and 1850. Various areas of the valley were irrigated by constructing canals and simple diversion structures at strategic points along the Rio Grande. These structures because of their inability to withstand the river at flood stage were a source of continual annoyance.

About 1890, extensive settlement and irrigation development in southern Colorado, in addition to that which had already taken place in Central New Mexico, absorbed the normal summer flow of the Rio Grande, causing it to be dry at El Paso during more frequent and longer periods. Several small and local storage developments were proposed, but conflicting interests, including Mexico's claims for loss of water based on ancient prior right, were resolved by the Treaty of 1906, recognizing the plan proposed for developing the project under the Reclamation Act, when it was reported in 1904 that a reservoir could be created by construction of a dam at Elephant Butte which would provide sufficient water to meet the requirements of all interests.

The Rio Grande project was among the first to receive the attention of Federal Reclamation soon after the passage of the Reclamation Law of 1902. Investigation surveys were begun on the project in 1903 and a feasibility report was made in 1904.

Construction of the Rio Grande project was authorized by the Secretary of the Interior December 2, 1905, under the provisions of the Reclamation Act, and funds were allocated to initiate construction of the first diversion unit. The Reclamation Act was extended to the entire State of Texas June 12, 1906, following a partial extension for Engle (Elephant Butte) Dam in 1905.

Congress authorized the construction of Elephant Butte Dam February 25, 1905, and on May 4, 1907, $1 million nonreimbursable funds were appropriated as the State Department's share for allocation by treaty of 60,000 acre-feet of water annually to Mexico.

Construction started in 1906 with the building of Leasburg Diversion Dam and Canal. The dam and 6 miles of canal were completed in 1908 and first water was delivered through project works to three old community ditches, providing permanent diversion facilities to them.

Construction of Elephant Butte Dam was begun in 1908 but progress was delayed when difficulty in obtaining reservoir land developed. Construction of the dam proper began in 1912 and was completed in 1916, but storage operation began in January 1915.

The Elephant Butte Water Users' Association was organized and incorporated under the laws of the Territory of Arizona. The association, jointly with the El Paso Valley Water Users' Association of Texas, made its first contract with the United States for construction and repayment of the cost of the storage facilities, diversion dams, and canals on June 27, 1906.

On June 15, 1918 the district entered into a contract with the United States for construction and repayment of the irrigation distribution and drainage systems and for operation and maintenance. Additional and supplemental contracts with the United States have been negotiated since that time. The contract dated November 9, 1937, relieved the irrigation district of the repayment of its proportionate share of the cost of Elephant Butte Dam, which cost was to be repaid from power revenues. Under the terms of this contract, the district assumed the obligation to repay the remaining $5,509,135.61 of construction cost of the irrigation and drainage facilities; agreed to advance operation and maintenance funds; and also agreed to pay a storage charge of $0.10 an acre-foot of water released from storage annually for district lands. Adjustments were again made by the contract dated October 1, 1939, in which the district agrees to make 56 semiannual payments of $62,160.91 each and a final payment of the remaining balance on September 1, 1967. However, construction charges were deferred annually by the Secretary under congressional authorization for 4 years from 1955 through 1958 because of serious water shortages, making the last payment due March 1, 1971.

Additional project works authorized under more recent congressional action include Caballo Dam, a combined flood-control and power-regulating structure financed with a $1,500,000 nonreimbursable allotment transferred from the

State Department to the Bureau of Reclamation in accordance with an interdepartmental agreement dated October 9, 1935, and with additional reimbursable allotments made to the Bureau during the period 1936 to 1941; and the Elephant Butte Power development, for which funds were initially made available under the Interior Department appropriation act, fiscal year 1939.

Project Facilities

Elephant Butte Dam and Reservoir

Elephant Butte Dam is a rubble concrete straight gravity structure, 306 feet high from foundation to parapet, with crest roadway 200 feet above the riverbed, and an overall length of 1,674 feet including spillway. The reservoir has a capacity of 2,195,000 acre-feet.

The powerplant contains three identical generating units; each with a nameplate capacity of 9,000 kva which at 0.9 power factor is capable of producing 8,100 kilowatts. The Bureau of Reclamation owns 491 miles of 115,000 volt transmission lines on appropriated funds. Eleven substations are included in the system, which is interconnected with the four major private utility systems in the operating area. Through the Bureau's system, electric energy is delivered to REA cooperatives, defense installations, a municipal system, and two other power users in New Mexico.

Power generation at Elephant Butte is generally a seasonal operation depending on availability of water for irrigation. The transmission system, however, is interconnected with the Colorado River Storage Project; therefore, power is wheeled through the power system when water is not being released for generation of power.

ARROYO CONTROL PROJECTS

There are two categories of arroyo control projects. The first category of these projects is where arroyos that originate in the adjacent hill areas bordering the valleys discharge water directly to the floor of the valley. This water then spreads out over irrigated land and the irrigation, distribution and drainage facilities. Many times the irrigation facilities have been washed away completely by the flow of this water. Other times, the water accumulates in the distribution drainage system, and passes eventually to the river. Due to the large amount of trash involved in these arroyo flows, it is quite common for the structures in the system to become plugged. All of these problems are largely eliminated by the construction of arroyo dams and reservoirs.

The second category of these arroyos are the ones that discharge directly to the Rio Grande. These arroyos generally have much larger watersheds than the ones in the former category. These arroyos also bring large amounts of sand, gravel, silt, and trash to the river. The silt is then immediately carried into the irrigation system and deposited in the bottoms of canals and laterals. The sand moves downriver and eventually is carried into the irrigation system where it is also deposited in canals and laterals. The removal of this silt and sand from the irrigation facilities costs literally tens of thousands of dollars annually. In addition, these deposits choke the capacity of the ditches to the extent that sometimes it is difficult to adequately meet peak demands on the system. The discharges from several of these large arroyos that may occur at the same time creates a flooding situation that is potentially very hazardous to downriver communities and lands.

The district's program that has been completed, is now under construction, or is contemplated for the future would largely eliminate all of the problems mentioned above. The benefits from these works are realized not only in the Elephant Butte Irrigation District, but as well in the downriver communities such as El Paso and Juarez and lands of the El Paso County Water Improvement District No. 1 and the Hudspeth County Conservation and Reclamation District No. 1.

MODERNIZATION OF THE IRRIGATION AND DRAINAGE FACILITIES

The Rio Grande Project of which the Elephant Butte Irrigation District is the larger part, is an old project, dating back to the period 1915-1925. Additionally, many of the irrigation ditches now in use go back well beyond that point in time. In fact, some ditches on the project go back to the late 1600's. When the project was formulated, many of these old ditches were incorporated into the system that we know today. Furthermore, the Rio Grande was re-directed and re-channeled in the 1930's. Thus, many irrigation facilities that were placed by virtue of a former position of the Rio Grande have now no real reason to be in their present location.

In contemplating modernization of such a system as this, it would seem logical to re-examine and re-engineer the distribution facilities to minimize and eliminate as many of these redundant facilities as possible. Accordingly, it has been suggested that a complete re-evaluation of the distribution system be made. This concept, known as the Archer Plan, very briefly would consider the following: A re-regulating reservoir would be constructed somewhere on the project downstream from the last diversion in the Mesilla Valley. The primary canals would remain in their same general locations. From these primary canals, laterals would extend at about right angles from each side of the canal to the river or hill line. These laterals would be spaced at about one mile intervals and would serve from about 600 to 1800 acres each. It is contemplated that these laterals would be in a pipe conduit. The main canals would be equipped with a system of on-site automatic checks and a series of wasteways that would discharge to the river and ultimately to the re-regulating reservoir. These automatically controlled checks would maintain a constant head over the pipe conduits, thus permitting a non-varying irrigation head. Fluctuations caused by turning on or off of irrigations in the pipelines would be compensated for by the automatic checks in the primary canal. If, for instance, irrigations were turned off to a large extent in the evening, the extra water accumulating in the primary canal system would be automatically released to the river, and thence to the re-regulating reservoir. If next morning, irrigations were turned on again, the fluctuation again would be taken care of by the automatic checks, reducing the amount of water being wasted to the river and the re-regulating reservoir. This system would operate within the capacity limits of the main canal. Releases from storage reservoirs would be of proper amounts to satisfy all systems and irrigation water would be re-regulated for downstream use at the re-regulating reservoir.

It is felt that with a system of this sort, several major benefits would accrue. Demand irrigation would be possible. That is to say that a wateruser could plan his irrigation for a certain hour of a certain day and be reasonably confident of going out and turning on his irrigation water at that precise time and getting it in the amount that he ordered. Another major benefit would be that irrigations could be largely turned off during the evening hours or weekends or holidays. Finally, such a system would involve much less operating labor than is currently used on the existing system. Another bonus would accrue from the vastly reduced maintenance in going from an open earth system to a pipe system. This reduction in labor could perhaps do much toward paying for the cost associated with re-engineering the system.

RENOVATING SEWAGE EFFLUENT BY GROUNDWATER RECHARGE[1]/

Herman C. Bouwer, J. C. Lance, and R. C. Rice[2]/

Sewage effluent is commonly used for irrigation (14). It contains enough nutrients (Table 1) to meet the fertilizer requirements of a number of crops if the sewage supplies all or most of the water for the crop. The most critical use of sewage effluent from a public health standpoint would be sprinkler irrigation of lettuce and other crops that are consumed raw. This requires a well treated effluent, usually consistent with the quality obtainable by secondary treatment and disinfection, to yield total coliform densities of less than 5000 per 100 ml and fecal coliform densities of less than 1000 per 100 ml (13, 14). In some cases, however, the requirements are much stricter. The State of California, for example, requires filtration of coagulated waste water through natural soil or filter media and disinfection to obtain total coliform concentration not exceeding 2.2 per 100 ml before the effluent can be used for sprinkler irrigation of produce (7). Less stringent requirements are generally used for effluent that is used for irrigation of nonedible crops or crops that are processed before they are consumed (7).

Table 1. Normal range of mineral increase in water by one cycle of domestic use (6).

	Parts per Million	Pounds per Acre-foot
Total salts	100-300	270-820
Boron (B)	0.1-0.4	0.3-1.1
Sodium (Na)	40-70	110-190
Potassium (K)	7-15	19-41
Magnesium (Mg)	3-6	8-16
Calcium (Ca)	6-16	16-44
Total nitrogen (N)	20-40	55-110
Phosphate (PO_4)	20-40	55-110
Sulphate (SO_4)	15-30	41-82
Chloride (Cl)	20-50	55-140
Alkalinity (as $CaCO_3$)	100-150	270-410

1/ Contribution from the Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture.

2/ Chief Hydraulic Engineer, Research Soil Chemist, and Research Agricultural Engineer, respectively, U. S. Water Conservation Laboratory, Phoenix, Arizona.

If more sewage water is applied than needed for crop growth, the excess water will move deeper into the ground to become "renovated" water, which can be allowed to move naturally to streams or lakes, or can be collected with wells or drains for rather unrestricted reuse. Sometimes, waste water renovation is the major objective of land disposal, and agricultural use of the disposal fields is of secondary importance, particularly if permeable soils are available so that large land areas are not required. Another objective of land disposal systems could be to keep the waste water out of streams or lakes, to reduce pollution of surface water.

Because of the increasing need for using sewage effluent for purposes with a higher economic return than irrigation of nonedible crops, interest in land application as a form of tertiary treatment is rapidly increasing. The waste water would then be used for groundwater recharge, employing basins, furrows, or sprinklers to infiltrate the water into the soil, and drains or wells to collect the renovated water for unrestricted irrigation, recreation, and industrial and municipal uses.

The performance of a system for renovating waste water by groundwater recharge depends on the local conditions of climate, soil, and groundwater. An experimental project is, therefore, frequently desirable to obtain design information for the operational system so that renovated water with the desired quality can be obtained at minimum cost. An example of such a pilot facility is the Flushing Meadows Project near Phoenix, Arizona, which will be discussed in the following sections.

REUSE OF SEWAGE EFFLUENT IN THE SALT RIVER VALLEY

Most of the sewage effluent of the cities in the Salt River Valley is treated by the 91st Avenue Plant, which is an activated sludge plant handling sewage from Phoenix, Tempe, Scottsdale, Mesa, and Glendale. The plant discharges some 50 mgd of secondary effluent which may increase to about 250 mgd by the year 2000. At 4.5 feet average annual water use, this could irrigate about 70,000 acres, which may be more than the agricultural land remaining in the Salt River Project at that time. The urban waste water would thus be sufficient to meet all agricultural demands in the not too distant future while leaving some for recreation and other purposes.

Because of the varied agriculture and the use of canal water for irrigation of parks, playgrounds, private yards, and for recreational lakes, large scale return of sewage effluent to the canal system requires that the effluent be given tertiary treatment. Since the hydrogeological conditions in the Salt River bed are favorable for groundwater recharge, the most economical way for renovating the sewage effluent could be by groundwater recharge with infiltration basins in the river bed. This bed is normally dry below Granite Reef dam (a diversion structure 25 miles east of Phoenix) and it attains a width of about one-half mile in the western part of the valley. The movement of the effluent water through the sands and gravels of the river bed could be expected to remove essentially all biodegradable materials and microorganisms and to reduce the concentration of other substances in the effluent. This would yield a renovated water suitable for unrestricted irrigation, primary-contact recreation, and other purposes.

To study the feasibility of renovating sewage effluent by groundwater recharge, an experimental project, called the Flushing Meadows project, was installed in 1967. The project is located in the Salt River bed about 1-1/2 miles west of 91st Avenue. It is a cooperative effort between the U. S. Water Conservation Laboratory of the U. S. Department of Agriculture and the Salt River Project, and it was partially supported by a grant from the Federal Water Quality Administration.

FLUSHING MEADOWS PROJECT

Description of System

The project contains six parallel recharge basins, 20 x 700 ft each and spaced 20 ft apart (Figure 1). Secondary effluent is pumped from the discharge channel of the 91st Avenue treatment plant into the basins at one end where the flow is controlled by an alfalfa valve and measured with a triangular, critical depth flume (10). The water depth in each basin is controlled by an overflow structure at the other end, where the outflow is measured with another flume. Water depths of 0.5 and 1 ft have been used. The infiltration rate for each basin is calculated from the difference between the inflow and the outflow rates.

The soil beneath the basins consists of about 3 ft of fine, loamy sand underlain by a succession of coarse sand and gravel layers to a depth of 240 ft where a clay deposit begins. The original saturated hydraulic conductivity of the fine, loamy sand top layer was about 4 ft/day. The underlying sand and gravel layers, which have been described in detail (3), can be considered as one anisotropic medium. The hydraulic conductivity of this medium is 282 ft/day horizontally and 17.6 ft/day vertically. These values were obtained by electrical analog analysis and confirmed by permeability tests on the observation wells in the project area (3). The static groundwater table is at a depth of about 10 ft. Observation wells consisting of 6-inch diameter cased holes open at the bottom were installed at various locations in the project area (Figure 1). These wells, which range from 20 to 100 ft deep, are used to obtain samples of the reclaimed water for chemical and bacteriological analyses and to measure the response of the groundwater level to groundwater recharge.

In conformance with the theory of groundwater mound formation below infiltration basins (1), the groundwater level rises rapidly after the start of a new inundation period, but reaches a pseudoequilibrium level in a few days. When a dry-up period is started, the groundwater levels recede and reach their original levels in a few days. Because of the high hydraulic conductivity in horizontal direction of the aquifer, the height of the groundwater mound during recharge is relatively low, i.e., 1.09 ft per 1 ft/day infiltration rate.

Infiltration Rates

To evaluate the effect of surface condition of the basins on infiltration rate, one basin was covered with a gravel layer, another was left in bare soil, and the four remaining basins were planted with bermudagrass in 1968. Inundation schedules ranged from 2 days wet and 3 days dry to 3 weeks wet and 3 weeks dry (periodic drying of the basins is necessary to restore infiltration rates and to allow oxygen to enter the soil). The infiltration rates were generally be-

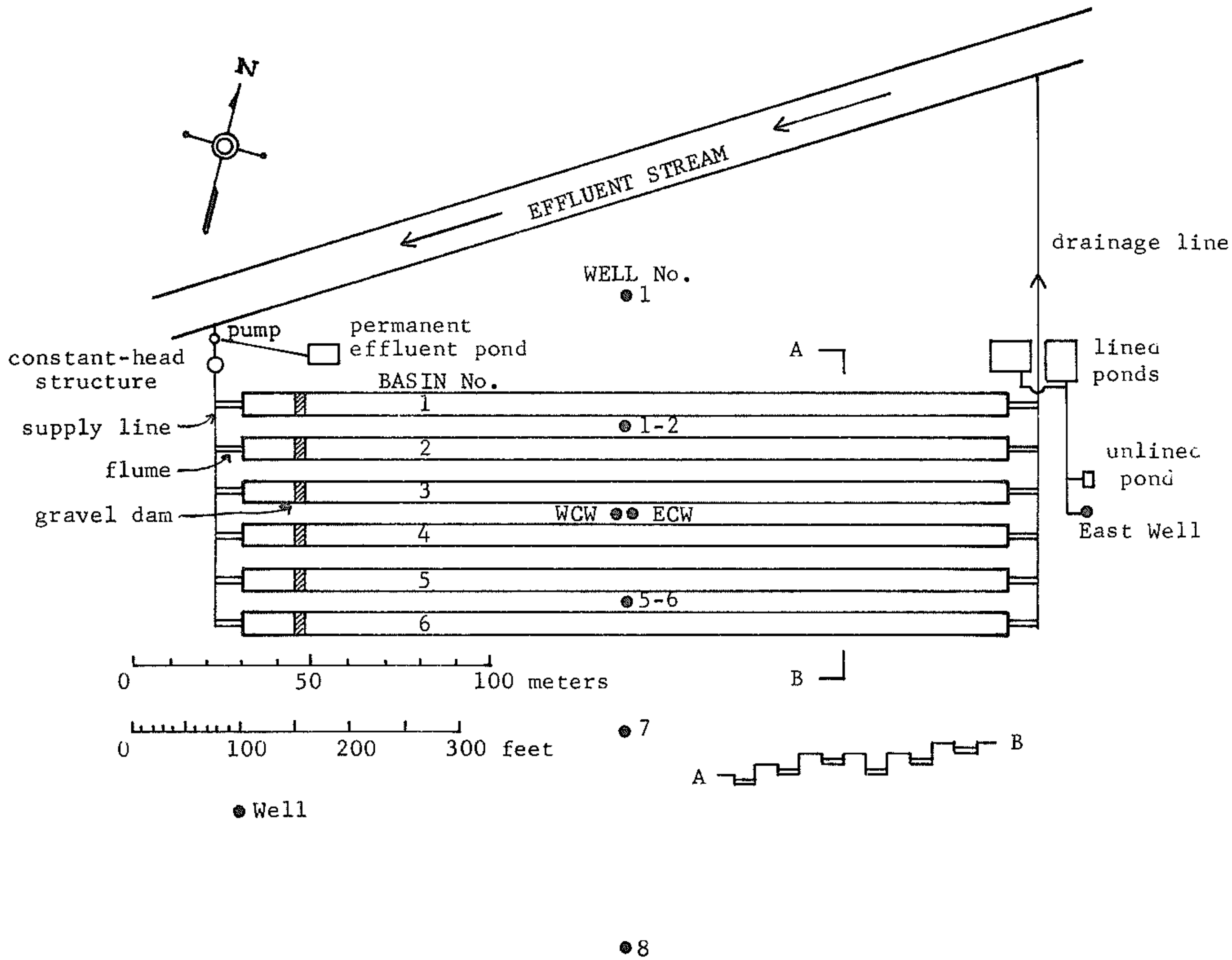


FIGURE 1. Plan of Flushing Meadows Project.

tween 1 and 4 ft/day, depending on the water depth, the suspended solids content of the effluent, and the length of the inundation and dry-up periods. During inundation, the infiltration rate usually decreased almost linearly with time. Tensiometer measurements in the soil beneath the basins and measurements of the effect of water depth in the basins on the infiltration rate indicated that the decrease in infiltration during inundation was mostly caused by clogging at the soil surface.

After accounting for the soil variability between the basins, the infiltration in the grass basins was about 20% higher, and in the gravel-covered basins 50% lower, than in the bare soil basin (4). The higher infiltration rates in the grass basins were attributed mainly to the prevention of algal growth on the bottom of the basins. The low infiltration rate in the gravel basin was probably caused by poor drying of the soil beneath the gravel with consequent slow recovery in the infiltration rate.

Maximum hydraulic loading or long-term infiltration was obtained with inundation periods of about 2 weeks and dry-up periods of about 10 days in the summer and 20 days in the winter. With this schedule, the average accumulated infiltration for the year 1970 was 400 ft. Thus, one acre of recharge basin can renovate 400 acre-feet per year, or 0.36 mgd.

Quality Improvement of Water

The East Center Well (ECW, Figure 7) is 30 ft deep. Water pumped from this well has traveled vertically about 8 ft from the basin bottom to the groundwater table, and 22 ft from the water table to the bottom of the well. Since the well is located midway between basins 3 and 4, the water has also traveled about 10 ft horizontally. The time required for this travel ranged from 1 to 2 weeks, depending on the infiltration rate. Quality parameters of the water from this well, which receives reclaimed sewage water that has infiltrated in basins 3 and 4, and of the reclaimed water from the 20-ft-deep wells 1 and 7 outside the basin area (Figure 1) are shown in Table 2 in relation to the quality of the sewage effluent (see also (4)).

Oxygen Demand

The data in Table 2 show that the 5-day BOD of the reclaimed water is essentially zero. The chemical oxygen demand (COD) is reduced from 50 to 17 ppm. which is about the same as the COD of the native groundwater.

Nitrogen

The nitrogen in the effluent is almost all in the ammonium form. This is mostly converted to nitrate in the reclaimed water if sequences of short inundation periods (2 days wet - 3 days dry) are used. With longer inundation periods (2 weeks wet - 2 weeks dry), nitrate nitrogen concentrations in the reclaimed water are much lower (Table 2), with those below the grass basins being lower than those below the nonvegetated basins. In 1968, for example, the NO_3-N concentration in ECW-water during sequences of long inundation periods dropped from about 10 ppm to about 0.2 ppm after the bermudagrass had reached maturity in basins 3 and 4, but the NO_3-N concentrations in the water from well 1-2, which had infiltrated in the nonvegetated basins 1 and 2, remained in the 5- to 10-ppm range.

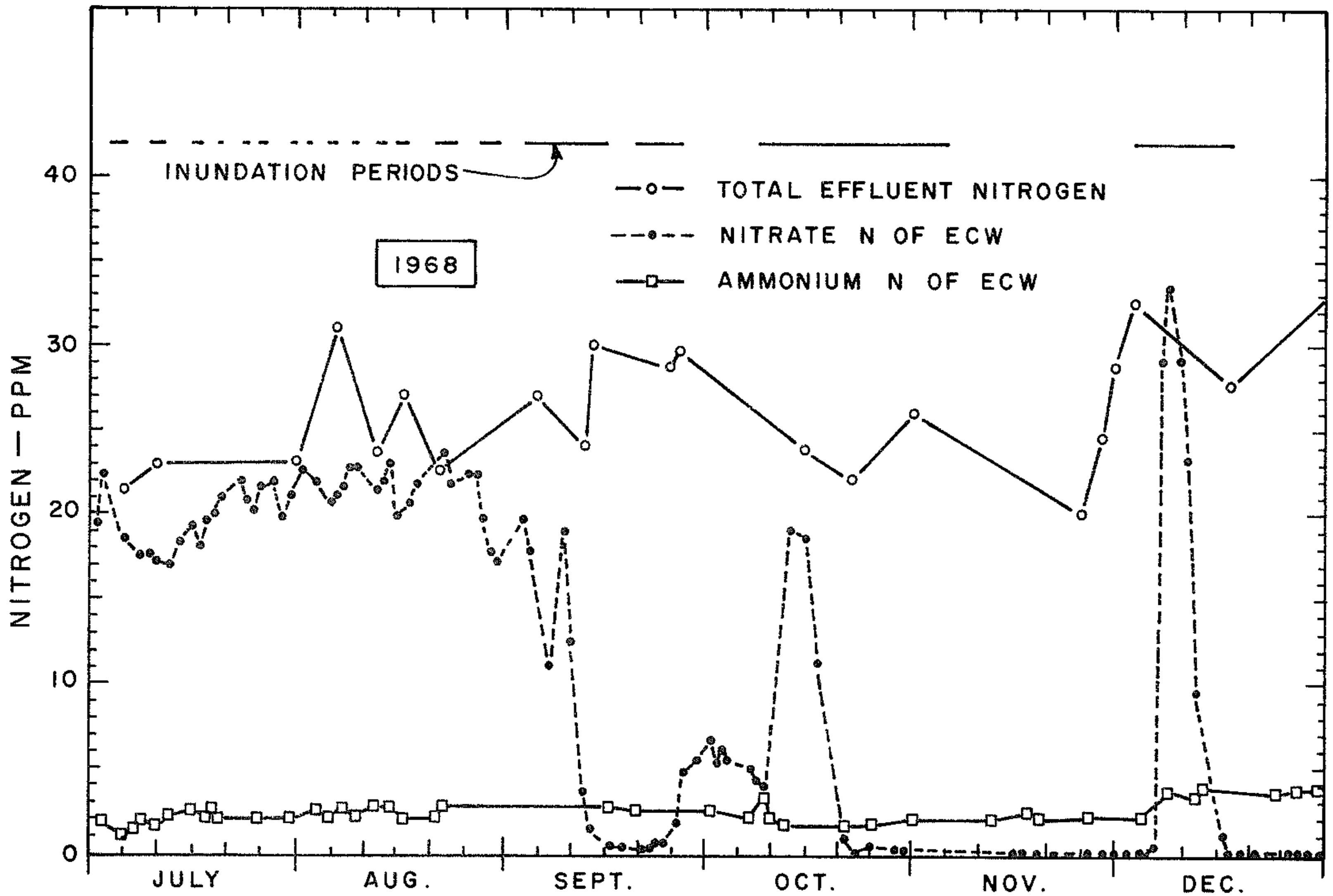


FIGURE 2. Total nitrogen in sewage effluent and nitrate and ammonium nitrogen in reclaimed water from East Center Well in relation to inundation schedule (July-December 1968).

Table 2. Chemical and bacteriological parameters (average values) of secondary effluent and reclaimed sewage water from observation wells (in milligrams/liter, except for pH and coliform density).

(1)	Effluent (2)	ECW (3)	Well No. 1 (4)	Well No. 7 (5)
BOD_5	15	0.3		
COD	50	17	14	14
Organic N	1	trace		
NH_4-N	25	10	3	1
NO_3-N	0.1			
short inundations		15		
long inundations (bare)[a]		9		
long inundations (grass)[b]		0.2		
PO_4-P	13	5	1.5	1.5
F	4.5	2.5	1.7	2.1
B	0.7	0.7	0.7	0.7
Dissolved salts	1020	1060		
pH	7.9	7.2	7.7	7.4
Fecal coliforms (MPN/100 milliliters)	10^6	20[c]		10[c]

a - reclaimed water below bare-soil basins
b - reclaimed water below grass-covered basins
c - median value (range 0-100)

The dependence of the NO_3-N concentration in the reclaimed water on the length of the inundation period is illustrated in Figure 2, which shows that for the short inundation periods in July and August 1968 the NO_3-N concentration was about 21 ppm. For the long inundation periods for the rest of the year and with full grass cover in basins 3 and 4, NO_3-N concentrations were close to zero after the passage of a NO_3-peak. This peak, which always occurred a few days after the start of a new inundation period when sequences of long inundations were held, is due to the arrival of nitrified sewage water that was held as capillary water in the soil during the preceding dry-up period. Also, nitrate may have been formed by nitrification of ammonium held by the exchange complex in the soil. The NO_3-peak arrived in ECW from 5 to 11 days after the start of an inundation period, depending on the infiltration rate in the basins. Thus, the underground detention time of the water pumped from ECW is in the 5- to 11-day range. At greater distances from the recharge basins, the peaks become less distinct.

The NH_4-N content of the reclaimed water usually ranges from 5 to 15 ppm and apparently is not much affected by the length of the inundation periods used at the Flushing Meadows Project. Thus, before and after the passage of the NO_3-peak, the total nitrogen in the reclaimed water during long inundation periods in the vegetated basins is about 40 to 80% less than that in effluent.

The nitrogen behavior in the renovated water is probably due to adsorption of ammonium by the clay and organic matter in the soil, which could begin after the start of an inundation period when oxygen for nitrification is no longer available. Before the adsorption capacity for ammonium is reached, the basins should be dried. The presence of oxygen in the soil will then cause nitrification of the adsorbed ammonium. Part of the nitrates formed in this process can subsequently be denitrified, either during dry-up or during the next inundation, with the nitrogen gas escaping to the atmosphere or moving out as dissolved nitrogen with the downward moving water. Storage of nitrogen in the soil was small and could not account for the amounts of nitrogen removed from the sewage water.

Phosphates

Phosphorus, which occurs mainly in the form of orthophosphates in the effluent, is reduced from about 13 ppm P in the effluent to about 5 ppm P in the reclaimed water from ECW (Table 2). Further reductions in P-content occur with additional lateral movement of the reclaimed water below the water table (see P-contents for wells 1 and 7 in Table 2). Extrapolation of the P-removal in relation to distance of underground travel shows that at a distance of about 100 to 200 ft from the recharge basins, very small P concentrations can be expected.

In the sandy and gravelly materials of the Flushing Meadows Project, P probably is removed by precipitation of calcium-phosphate complexes such as apatite. Assuming that all P is precipitated as apatite in a soil volume 30 ft deep and 4 times as wide as the width of the recharge area, the apatite would occupy 0.5% of the total volume after a period of 200 years. Assuming a porosity of 20%, the apatite would thus take up about 2.5% of the pore space. This is small and will likely not have a significant effect on the hydraulic conductivity of the aquifer. If the soil is rich in iron and aluminum oxides, high rates of P-removal can be expected over shallow depths of soil (8, 12).

Fluorides

The removal of fluorides also continues as the water moves laterally below the water table, as indicated by the lower F-concentrations in wells 1 and 7 than in ECW, which in turn contains about half as much fluorides as the effluent (Table 2). Fluorides may be adsorbed on clay minerals (5) or be precipitated as fluor-apatites or calcium fluoride.

Boron

The boron concentration is about 0.7 ppm and remains unchanged as the water moves downward through the soil and laterally below the water table (Table 2). Thus the sands and gravels appear to contain few aluminum and iron oxides, which are effective in removing boron (11). Boron concentrations above 0.5 ppm in irrigation water can be damaging to some of the more sensitive crops such as citrus, stone and pome fruits.

Salts and pH

The average salt concentration of the reclaimed water is 1060 ppm, which is about 4% higher than that of the sewage effluent (Table 2). This can be attributed to evaporation from the water in the recharge basins (average annual evaporation from a free water surface in the Phoenix area is about 6 ft). The pH of the reclaimed water is somewhat lower than that of the sewage effluent (Table 1), probably because of CO_2 production by the soil bacteria.

Coliform Density

The total coliform density in the reclaimed water from ECW, determined weekly with the multiple-tube fermentation technique, was higher during sequences of inundation periods of 2-3 weeks than during inundation periods of 2-3 days, i.e., median MPN-values were about 200 per 100 ml for the long periods and 5 per 100 ml for the short periods.

The fecal coliform density in the reclaimed water was very low and often zero (Table 2). The number of fecal coliforms tended to increase somewhat after the start of a new inundation period when newly infiltrated water had arrived at the bottom of the well. The same trend was true for the presumptive MPN of coliforms, which sometimes reached a value of several hundred per 100 ml. After the end of an inundation period, the presumptive MPN of coliforms in the ECW water generally decreased and reached a value of close to zero in about 3 weeks. Therefore, it is concluded that an additional underground detention time of about 1 month should be sufficient for essentially complete removal of all coliform organisms. Regrowth of nonfecal coliforms, such as *Aerobacter aerogenes* in sewage water as it moves through the ground has sometimes been observed (9).

Economic Aspects and Large-Scale System

The cost of reclaiming water from sewage effluent or other liquid waste by soil percolation and groundwater recharge depends on the climate and on the topographic and hydrogeologic conditions. On flat land, the effluent may be applied by basins or furrows. On sloping land, contour furrows or sprinkler systems may be used. Where the infiltration rates are low, large land areas may be required and it may be more economical to combine the recharge system with agricultural utilization of the land (2, 8, and references therein).

The design of groundwater recharge systems for waste water reclamation should be based on three criteria: (a) avoiding a rise of the groundwater table below the recharge basins above a certain maximum elevation, (b) locating the facilities for collecting the reclaimed water (wells, drains, or trenches) a certain distance from the recharge areas to allow sufficient time and distance of underground travel for the reclaimed water, and (c) minimizing the spread of reclaimed water into the aquifer outside the recharge system. For a more detailed discussion of the design of recharge systems for renovating waste water and of techniques for evaluating hydraulic properties of aquifers and predicting water table positions and underground detention times, reference is made to (3).

For the Salt River bed, recharge basins could be located on both sides of the river bed (Figure 3). The distance between the two recharge strips would be about 1000 ft. Wells for pumping the reclaimed water could be placed in the center of the river bed, thus insuring a minimum underground travel distance of about 500 ft for the renovated water. With an annual infiltration of about 330 ft in the basins, about 900 acres of recharge basins would be required to

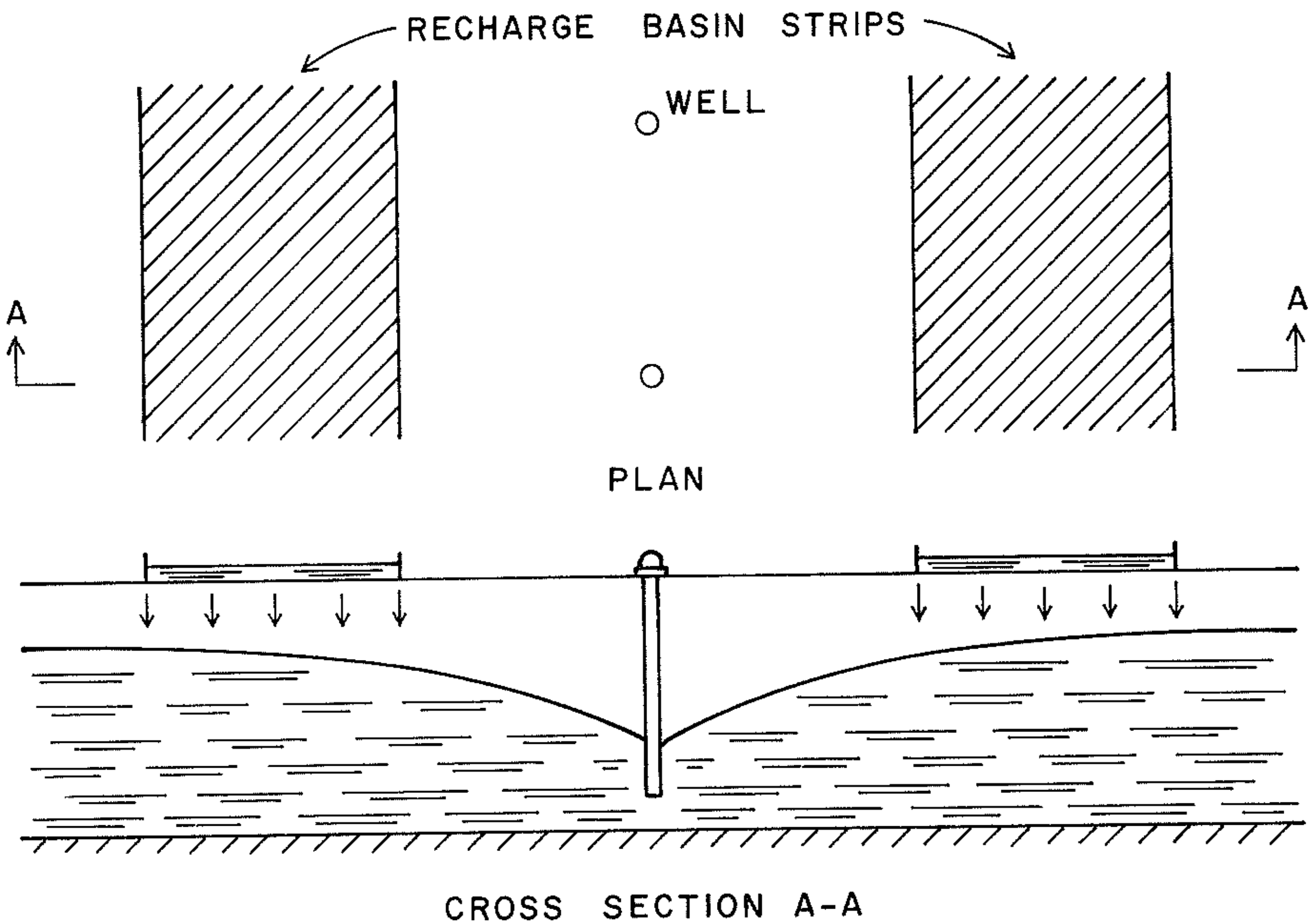


FIGURE 3. Plan and cross section of two parallel recharge strips with wells midway between strips.

renovate the annual volume of 300,000 acre-feet of sewage water expected by the year 2000. The cost of reclaiming the sewage water in this manner is expected to be about $5 per acre-foot, including amortization of capital investment and operating and pumping costs. The cost of in-plant tertiary treatment to obtain reclaimed water of similar quality would be at least ten times as much (2 and references therein).

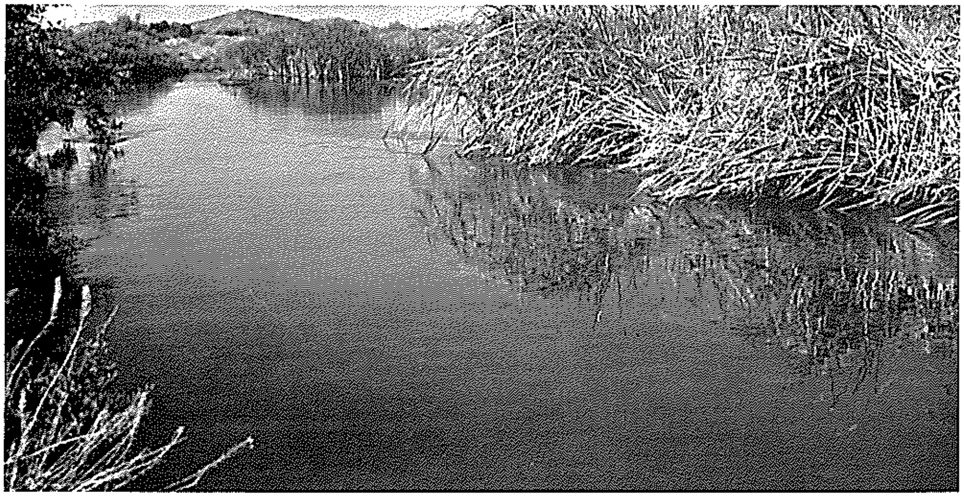
SUMMARY

Due to continued population growth in the Salt River Valley, Arizona, reuse of municipal waste water becomes essential. A pilot project was installed in 1967 to determine if the tertiary treatment necessary to permit large-scale reuse of sewage water for irrigation and recreation could be obtained effectively and economically by groundwater recharge with infiltration basins in the normally dry Salt River bed. The hydrogeological conditions of the Salt River bed, i.e., about 3 ft of fine, loamy sand underlain by sand and gravel layers to great depth and a groundwater table at about 10 ft depth, are favorable for high-rate waste water reclamation by groundwater recharge. Results so far indicate that the infiltration rate in grass-covered basins is 25% higher, and in a gravel-covered basin 50% lower, than in a bare soil basin. Alternating 2-week inundation periods with 10-day dry-up periods (17 days in winter) yields an annual infiltration rate of about 400 ft.

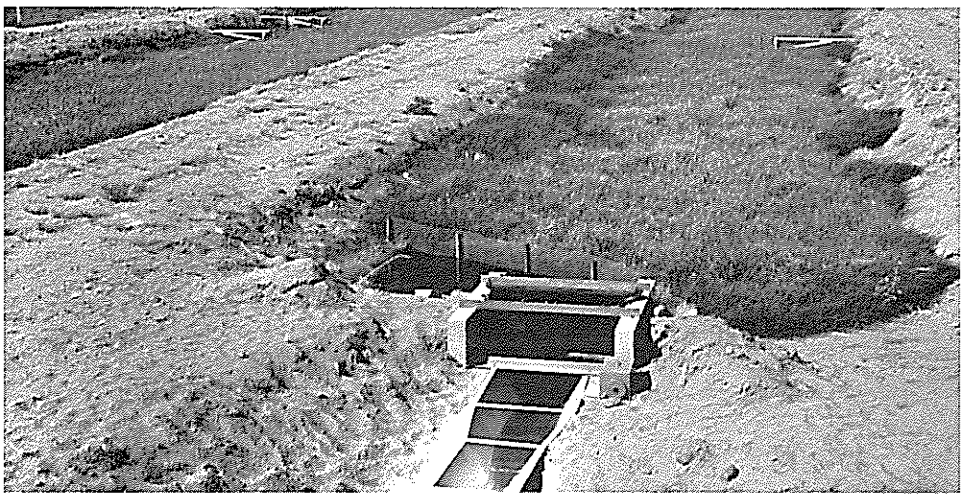
Reclaimed water, pumped from 30 ft depth in the center of the recharge area, has a biochemical oxygen demand of about 0.5 mg/liter (BOD of the sewage effluent is about 15 mg/liter) and a median fecal coliform density of 10 per 100 ml. Nitrogen, which is almost all in the ammonium form at a concentration of 25 ppm N in the sewage effluent, is essentially all converted to the nitrate form in the reclaimed water if sequences of short inundation periods (3 days or less) are held. With inundation periods of 2 to 3 weeks, the reclaimed water has about 40 to 80 percent less nitrogen than the sewage effluent, except for a short period occurring 1 to 2 weeks after the start of a new inundation, when a nitrate peak occurs in the reclaimed water. This peak is due to the arrival of nitrified effluent water held as capillary water in the soil during the preceding dry-up period. The nitrogen removal is probably mostly due to denitrification and adsorption of ammonium in the soil. More nitrogen was removed under vegetated infiltration basins than under nonvegetated basins.

Phosphate concentrations in the reclaimed water pumped from 30 ft depth in the center of the recharge area are around 5 ppm P, as compared to 13 ppm in the effluent. Further horizontal movement of the reclaimed water below the water table gives additional reduction in the phosphate content, as indicated by the concentration of 1.5 ppm P in the water pumped at 100 ft distance from the infiltration basins. Fluorides are reduced from 4.5 ppm in the effluent to 2.5 ppm at 3 ft depth in the center of the area and to 1.9 ppm at 100 ft from the basins. Boron removal does not take place because the sands and gravels contain little or no iron or aluminum oxides. The boron concentration is around 0.7 ppm, however, which is slightly above the level where the yield of the more sensitive crops will be affected when the water is used for irrigation.

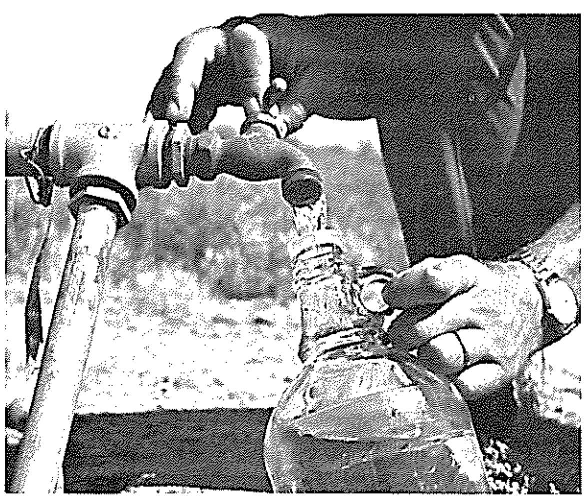
To reclaim the sewage flow of about 300,000 acre-feet per year that is expected in the Phoenix area by the year 2000, about 900 acres of infiltration basins would be required. These basins could be located on both sides of the Salt



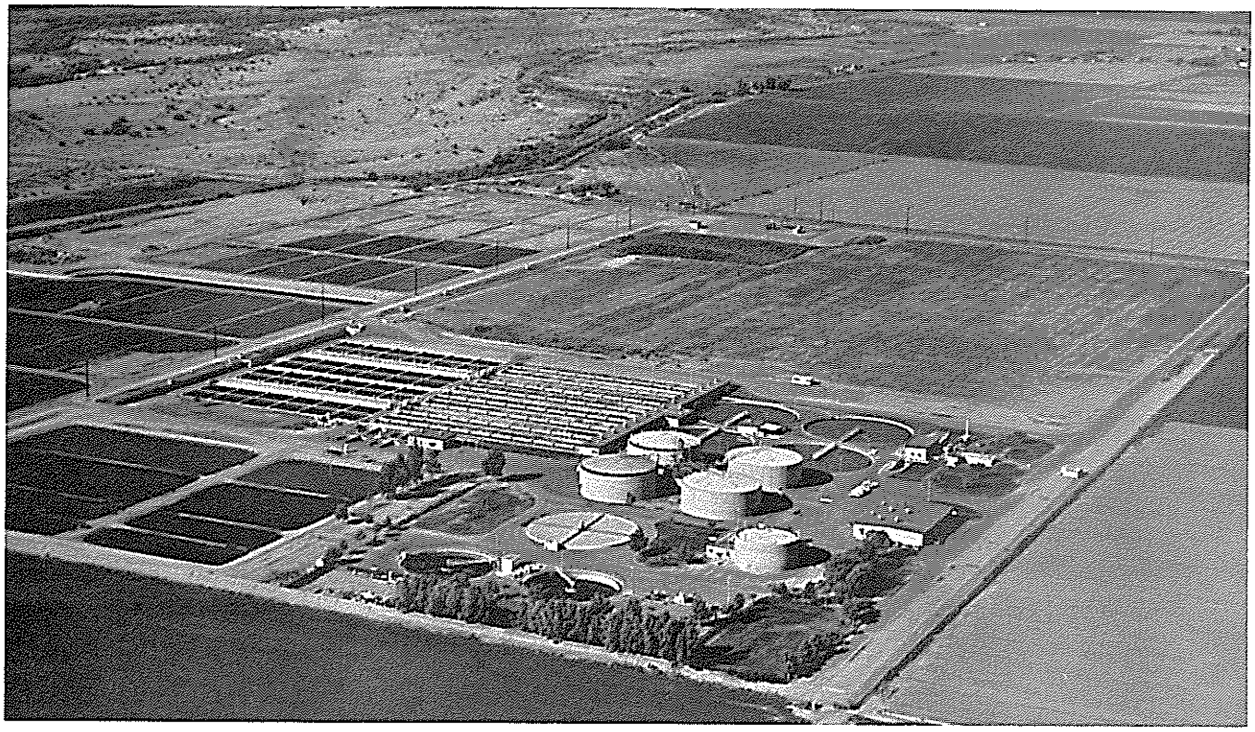
Aerial view of effluent channel and infiltration basins for renovating sewage effluent by ground-water recharge (Flushing Meadows Project).



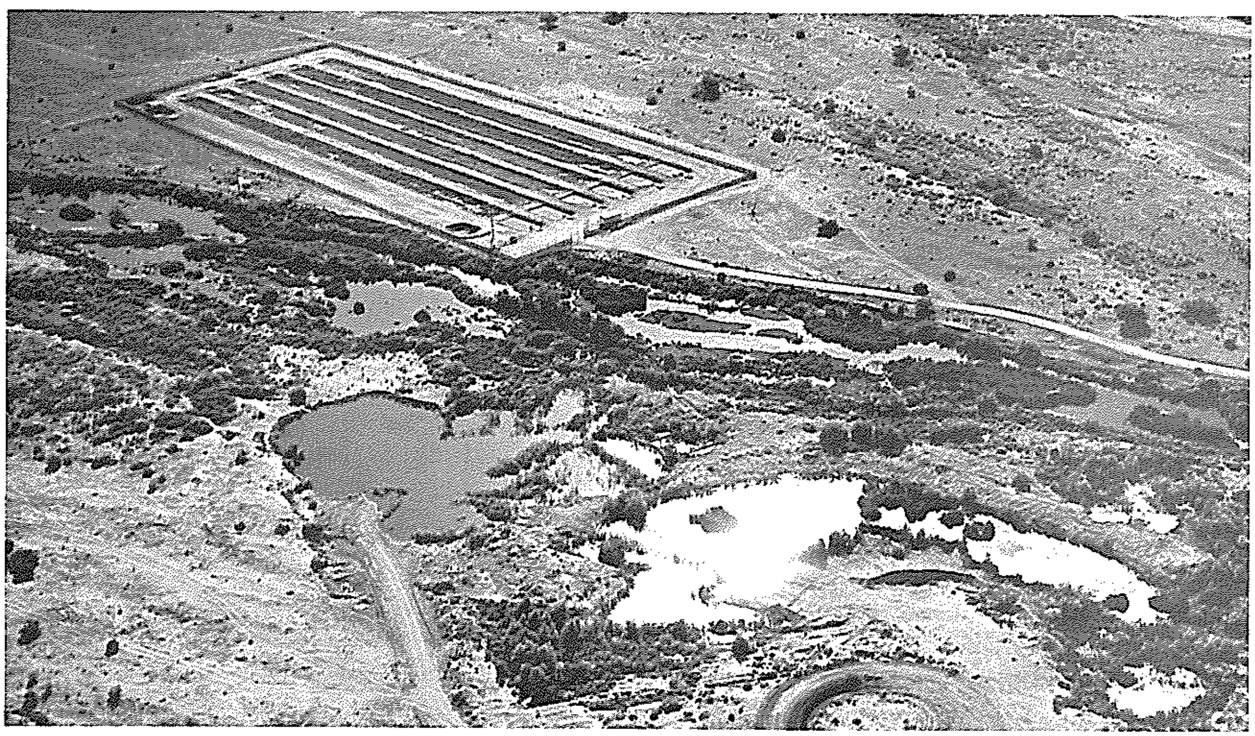
Effluent channel in Salt River bed west of Phoenix, carrying a flow of about 50 mgd (about 80 cfs).



Sampling renovated sewage water pumped from 30-ft depth in the center of the Flushing Meadows Project.



Aerial view of Phoenix Sewage Treatment Plant at Salt River bed west of Phoenix and infiltration basins of experimental ground-water recharge project (in center of picture about 1 inch from top).



Infiltration basins with bermuda-grass and flume for recording outflow (foreground).

River bed. The reclaimed water would be pumped up by wells in the center of the river bed. The minimum underground travel distance and detention time would be about 500 ft and 1 month, respectively. Cost of reclaiming water in this manner would be about $5 per acre-feet, which is less than one-tenth the cost of equivalent, in-plant tertiary treatment.

REFERENCES

1. Bouwer, Herman, "Analyzing Groundwater Mounds by Resistance Network," Journal, Irrigation and Drainage Division, American Society of Civil Engineers, 88(IR 3), 1962, pp. 15-36.

2. Bouwer, Herman, "Returning Wastes to the Land -- A New Role for Agriculture," Journal, Soil and Water Conservation, 23, 1968, pp. 164-168.

3. Bouwer, Herman, "Groundwater Recharge Design for Renovating Waste Water," Journal, Sanitary Engineering Division, Proceedings, American Society of Civil Engineers, 96(SA 1), 1970, pp. 59-74.

4. Bouwer, Herman, "Water Quality Aspects of Intermittent Systems Using Secondary Sewage Effluent," Paper No. 8, Artificial Groundwater Recharge Conference, University of Reading, England, sponsored by Water Research Association, 21-24 September 1970.

5. Bower, C. A., and Hatcher, J. R., "Adsorption of Fluoride by Soil and Minerals," Soil Science, 103, 1967, pp. 151-154.

6. California Department of Water Resources, "Feasibility of Reclamation of Water from Wastes in the Los Angeles Metropolitan Area," Bul. 80, California Department of Water Resources, Sacramento, 1961.

7. California Statewide Standards for Safe Direct Use of Reclaimed Waste Water for Irrigation and Recreational Impoundments. Calif. Adm. Code, Title 17, Chapter 5, 1968.

8. Kardos, L. T., "Waste Water Renovation by the Land - A Living Filter," In Agriculture and the Quality of Our Environment, N. C. Brady, editor, Publication 85, American Association for the Advancement of Science, Washington, D. C. 1967.

9. McMichael, F. C., and McKee, J. E., "Research on Waste Water Reclamation at Whittier Narrows," W. M. Keck Laboratory of Environmental Health Engineering, California Institute of Technology, Pasadena, 1965.

10. Replogle, J. A., "Flow Measurement with Critical Depth Flumes," International Commission on Irrigation and Drainage, Proceedings, 7th Congress, Mexico City, Question 24, R15, 1969, pp. 215-235.

11. Sims, J. R., and Bingham, F. T., "Retention of Boron by Layer Silicates, Sesquioxides, and Soil Materials: II. Sesquioxides," Proceedings, Soil Science Society of America, 32, 1968, pp. 364-369.

12. Taylor, A. W., "Phosphorus and Water Pollution," Journal, Soil and Water Conservation, 22, 1967, pp. 228-242.

13. Water Quality Criteria. Report of Nat. Techn. Adv. Comm. to Secretary of Interior. Federal Water Quality Administration, April 1, 1968, Washington.

14. Wilson, C. W., and Beckett, F. E., Edtrs., Municipal Sewage Effluent for Irrigation. Louisiana Polytechnic Institute, Ruston, July, 1968.

WATER AND NEW MEXICO'S WELFARE

Bruce King[1]

Certainly it's an honor and a pleasure for me to have the opportunity to address the Sixteenth Annual Water Conference. I see many people in the audience that I've worked with for many years, and I know of your great interest in our soil and water; and certainly no one is any more aware of the need to conserve our water and to see that it does not become contaminated than I do. I might not know nearly as many of the answers as many of you would know as to what we can or cannot do, in fact I'm sure I don't. But I know of the values, I know that New Mexico depends on how we do handle our water and our other natural resources -- but particularly our water.

As I flew along this morning coming from Santa Fe to Las Cruces, I thought to myself, "Now what would those fine people like to have me address myself to?" I thought a good little bit, and I immediately was reminded of the story of the young man who was asked to deliver the commencement address at a high school in a somewhat rural area. He prepared himself very very well, he went to a great deal of trouble and he had many notes. When he was introduced, he went right into his speech and he knew exactly what he wanted to relate to the listening audience and he got along exceptionally well. He thought to himself, now I've done a real fine job today, I couldn't have done any better. After he had delivered his address and it was all over, not too many people had complimented him on his speech. He was standing out by the door and a farmer from the community came by and the young man said to him, "Say, mister, what did you think of that speech?" And the farmer said, "Oh, I guess it was alright." The young man said, "I thought that was a real good speech, I put a lot of time into it." Then the farmer said, "Well, yeh, it was a good speech, but you didn't say anything that a half or a three-quarter inch rain wouldn't have done a lot more good." So I know that's going to be the way it is with me today. When we have the high winds that we have today, and certainly we do need moisture all over New Mexico, and hopefully we will receive them.

Since the legislature has just completed their work, I thought you would like to have a little bit of my analysis of what the legislature did accomplish and how I felt that we would be able to carry out the on-going programs for the next year. I would say this, we had a very hard working legislative group. They were very dedicated, they worked very long and hard hours. One thing I would like to point out, and I feel very strongly about it, is that 60 days is not sufficient time for studying the many problems we have confronting us in New Mexico and the many areas that the legislature must consider. I think they had 1,000 pieces of legislation introduced that they had to act upon. They certainly tried to give everyone an opportunity, whether they were for or against that particular legislation, to make their thoughts known. In my opinion they did a good job along these lines until about the last 5-6 days. The first 50 some odd

1/ Governor of New Mexico

days, they certainly analyzed the legislation well, and had worked along exceptionally well. And I would like to say that I enjoyed working with the legislature, with the leadership of both houses. I think we had excellent leadership both in the Democratic party and the Republican party. They attempted to keep things moving along as best as they could. But when they realized that there was only about six days left, they had to immediately take action on many of the bills -- either pro or con. That's one thing about being in the legislature, when it comes time to vote, you don't vote "maybe" on these bills -- it has to be either yes or no. And, as we all know, nothing is either black or white. So, there is a certain gray area that you do have to consider. In order to point up the problem, I had received on my desk for signature about 135 pieces of legislation until the last three days of the session. Today I find myself with 230 bills on my desk which were passed in the last three days of the legislative session. So it is impossible to give each piece the individual attention that the legislators would like to give the legislation. Needless to say, some legislation that could pass falls by the wayside from lack of time. And other legislation that probably should not be enacted or probably should not be passed, does pass.

What I am attempting to relate to you is the fact that we should extend our legislative sessions by about 30 days in the odd-numbered years. I think it would be good if we could introduce the legislation the first 30 days and perhaps have a 2-week break to go back to their constituents to see what they think of the legislation that has been introduced, and then come back and have 60 days to complete their work. We attempted to have the time amended in the Constitutional Convention. We advocated 120 days, and then let the legislation decide how they would use the 120 days in the two year period. I think this would be very advantageous and we should at some point in the next 2-3 years, attempt to amend the constitution to where we could do this. The legislators would be able to do a better job of serving the people of New Mexico.

The legislature stayed within the guidelines that I suggested to them -- that we do not have a tax increase, and that we try to live within the amount of revenue that would be available for the 60th fiscal year. I feel that certainly they were able to accomplish this. The public education received 8.2 million dollars of new money, and certainly they could use more, but this was an increase that we will be able to upgrade our public education. There were many other things suggested. I know one thing that I was particularly interested in was a Senate Memorial introduced by the Majority leader, Senator "Tibo" Chavez, that would make evaluation possible in the local school district. They would be working with the State Department of Educational Finance, and with the local governing school boards, and with the interested parents in the community to evaluate exactly what the schools had accomplished. In the areas of institutions of higher learning, I feel that they were treated fairly. And certainly you will be able to continue, Dr. Thomas, with the fine program that you have in operation at New Mexico State University and the University of New Mexico and all the other fine institutions of higher learning that we do have. And I want to say that this goes largely -- the thanks should go to Representative Bill O'Donnell for Dona Ana County.

Because he was very insistant that the institutions of higher learning did receive sufficient funds. And I know that many days were very difficult and that many attempts were made to even move back from what the Board of Educational Finance had recommended that they do appropriate for the institutions of higher learning. But after it is completed, I feel that they were taken care of properly.

The other area that comes in for a large proportion, a large percentage, of the appropriations, is the Health and Social Services Department. And they, too, were treated very fairly and received a much larger appropriation than they did in the last fiscal year. And still, all of this was able to be accomplished and stay within the expected revenues. The expected revenues for the 60th fiscal year is $261.5 million, and the appropriations should run somewhere in the neighborhood of $268 million. But we had a $22 million surplus, or expected to have it at the end of the 59th fiscal year, but immediately we set aside $10 million of this (of which $8.5 million had already been set aside) for a reserve fund, in the event the revenues did not reach the expectations, we would have $10 million in reserve, which I think is good. This left us with $12 million of money left in the general operating funds. This was one thing that was somewhat of a disappointment to me. We found that we did have approximately $6 million of needed deficits money in order to complete the 59th fiscal year. The legislature appropriated $242 million, but actually the expenses would amount to about $248 million, so this was half of the surplus. The other half can be used for the difference between the $261.5 million and the $268 million.

There are many things that appropriations were made for, besides the three major areas. It is probably about 15% of the money, but still it is certainly the necessities of the state government. And this is where the executive branch of government does receive its funds, and we did have many things that would be advantageous. The State Police department received increased funds, and certainly they will be able to do a better job to protect you and the rest of New Mexico. We did have a $100 thousand appropriation for a drug abuse program, which I think is very very good. And there were many other things that we were able to accomplish. One or two that I would like to mention is a $1 million service tax issue bond that was passed that would make a cancer research facility at the University of New Mexico in conjunciton with the May-son facilities at Los Alamos. And they also appropriated $100 thousand from the 59th fiscal year fund for the operation of the cancer research center. Another area was the $1 million that was appropriated for Vocational Education to be used at my discretion, along with federal matching funds. Hopefully, we can improve the Vocational Education aspects in New Mexico. So this is just, very briefly, some of the things that your hard working legislature was able to accomplish.

Now, I would like to give you some of my views about what we do need to do in the area of water and water conservation. Mr. Steve Reynolds, our State Water Engineer, I see is in the crowd this morning. He is much better informed than I am, and certainly we are very proud that he continues the good job that he's done for us for many years in New Mexico and he will be able to brief you much more as to what we will be attempting to do as the official state government of the state of New Mexico in the area of water. I think the San Juan Trans-continental diversion is working well, and will be advantageous to us in New Mexico. This is the type of thing we should be studying and reviewing to see if we could not have more of this type of project in New Mexico. We need all of the water we have, and we certainly want to see that it is beneficially applied. Much of our water does not produce the maximum benefits for New Mexico. We could certainly do a better job in transporting the water from the high mountain watersheds to the areas such as the Rio Grande Valley, in this area and higher up in the Rio Grande, and the same would go for the Pecos. But we must not ever forget that we must continue to make progress along these lines. Whether it be channeling, or whether it be the eradication of the salt cedar, or other plants that might absorb the water before it does reach the destination. These are things that we must continue to make progress on and continue to work with our state officials and with our national officials in accomplishing the endeavors that we all know we must accomplish. And, of course, I notice glancing over the program, that you will have experts that will be giving you the views of importing other water to New Mexico from the high plains area. We know that this will be drastically needed in the very near future. It's needed now, but in the next 15-20 years, we will have to have more water in the high plains area if we are going to continue at the same level we are now, much less to make progress that we would all like to see made. I think that we should certainly not cease to study the possibility of bringing water from the Pacific Northwest. I know we will run into difficulties, and that it will be expensive, but at least we should continue to study and to make plans to where perhaps we would be able to bring water from these areas into the areas that we do need the water so badly for irrigation, and for industry and the other things that we will be needing water for in the next two or three decades. Certainly we must develop plans for the time when we will need the water as badly as we will be needing in the year 2000, 2020 or later. Of course, we must continue to protect our underground water basin, and to explore it and to see exactly how much reserve we do have in this particular area. This is an area that I'm very familiar with, having farms and ranches in the Estancia Valley area, and irrigating from the underground water basin. This is very feasible, very practical, as long as you have water. If we do deplete the water resources, then certainly we will see a tremendous change in the economy of the areas where we do irrigate from the underground water basin. I will put in the plug for Steve -- whenever he says we have sufficient wells, don't be alarmed, because he's only trying to protect you further down the road. We will continue to conserve our underground basin water, as we will attempt to utilize the present water that we do have.

I think perhaps one area that we do overlook many times, is that the fact that we've not been able to make the progress that I would like to see us make in the area of artificial rainfall and snowfall. I'm sure that in the next decade or so we will see improvements along these lines, and certainly we could increase our snowfall by 20% or so in the high mountain areas -- it would add a great deal to our watershed and to the gallons of water that would be available for beneficial use in New Mexico. The same would be true if we could increase the rainfall by 10 to 20%. Not only would it assist the water usage, but it would be beneficial to the overall aspects of the economy of New Mexico and particularly the farming and ranching industry. Certainly we should continue to study and work in this area.

Another area that we should continue to work in is the desalinization of our water, our brackish water, we should continue to see if we could develop feasible plans to where we could purify the water to where it could be used in a beneficial manner. These are some of the areas in which we must continue to study to where we will be prepared when the crucial need does arrive. I was happy to see the speaker prior to my address, where he was pointing out the need for keeping our water as pure as possible. We must attract the type of industry that does not draw heavily on our water, that would take tremendous amounts of water, and certainly we want the types of industry to where we could reuse the water, and that it would not be polluted to where it would be unusable in the process. This can be carried out, and we must insist that it is carried out.

I will be working with you and others in New Mexico to see that we do not contaminate our water and that we do keep our streams as clean as we possibly can -- to where we do have the fish and we can use it as recreational water as well. We will have a much higher need for recreational water. I'm happy to be in the area to where we will be having the Cochiti Lake, and many other lakes that we do have in New Mexico. All of these add to the progress that we are able to accomplish to contain our water and to better utilize our water.

In ending, I want to tell you that I certainly do want to work with you; I want to cooperate with you; you are the experts in this area. No one person can be an expert in every area. So the Chief Executive in your state does have to rely on you to make suggestions and to work with our State Engineer and give him the suggestions and he will relate them to me and we will certainly continue to work along with you.

I will close by telling you about a story that does sometimes bring light to the very confusing subjects that we do consider, such as the water problems that we do have. It seems as though there was a church that had received more money than they had to have for the actual operation of the church. They had a little bit of extra funds in the treasury, so they decided that they should buy something a little bit extraordinary for the church. So they had a board meeting, and the pastor said to the board members, "What suggestions do we have to spend the money for something lasting, something that would be real good for the church." They discussed it for a while and came up with several suggestions, and finally it all pretty well boiled down to the suggestion of purchasing a chandelier for the church. All agreed to this, except for one board member. This member, John, sat off to the side, and was adamantly opposed to the purchase of a chandelier. So finally, after a great deal of discussion, he would not move, the pastor stopped and said, "Well, now John, why is it you're so opposed to buying a chandelier for the church?" And John said, "Well, I'll tell you -- in the first place we can't spell it, in the second place, I doubt if we have anyone that could play it, and in the third place, what we need is more light around here."

SOLUTIONS TO WATER PROBLEMS -- THE TIME IS NOW

Allen Agnew1/

I want to discuss briefly with you solutions to water problems, but first I want to compliment you on the recognition of the importance of water by Governor King through his proclamation of "Water for New Mexico Week".

Water problems are "people" problems, for without the demands of people -- new demands and changing demands -- we would have no water problems. And people are dynamic and changing. Therefore, water demand is dynamic and changing. However, people don't change in predictable ways, so it is difficult to project such demands with the accuracy we thought we could, just a few years ago. Moreover, the general public must be brought into the decision-making process at levels heretofore unattained -- in the establishment of water policy and in the planning for water management. In all of these matters, we should have had the answers yesterday -- the time is not only short, the time is now.

We've had a tremendous program this morning and look at what's coming up this afternoon -- a series of student papers that should be equally stimulating. For openers, now let's talk about pollution.

Pollution

"Pollution Rated Top Problem by Public" -- so said the headline in the newsletters and newspapers about a month ago, giving the results of a poll of 3,000 people across the nation last November by Louis Harris and Associates. Other problems, rated in decreasing order of seriousness by these 3,000, were crime, drugs, schools, housing and transportation, employment and taxes, and youth.

There's no question but that pollution *is* a problem, and water pollution is just as bad as some of the other forms of pollution. However, this isn't our only water problem -- or is it? Perhaps it is all in the way we look at it. Or talk about it.

For example, is a water shortage a matter of water pollution? A drought can be thought of as a physical or hydrologic drought, a meteorological drought, or an economic drought. What if we were to re-use more of the water than we do now? And don't let us forget the sociological drought -- caused by our increasing personal or sociological desires, because we are caught up in the affluence of our present-day society.

Perhaps it is all in the way we look at it. Or talk about it. Consider if you will, two views of geology -- my field -- as given in the February *Newsletter of the Council on Education in the Geological Sciences*.

1/ Chairman, Water Committee of National Association of State Universities and Land Grant Colleges and Direction, Washington State Water Research Institute

One view is that of Charles Maher, a columnist for the Los Angeles Times. On December 16 he said, "That's the trouble with getting too scientific about anything. The average guy will be out driving somewhere and come upon a massive rock formation and say, 'Hey, that's beautiful.' but show the same formation to a geologist and he may get all hung up over whether the rock is igneous or metamorphic. So while the average guy would be admiring the rocks, the geologist would be studying them, perhaps oblivious to the fact that they were beautiful."

The other view, by Thomas Henry Huxley in 1850 (On the Education Value of Natural History Sciences), is neatly counter to Maher's. "To a person uninstructed in natural history, his country or seaside stroll is a walk through a gallery filled with wonderful works of art, nine-tenths of which have their faces turned to the wall." Think about that -- their faces turned to the wall.

These two views, of the same thing, remind us that different people or people with different backgrounds, view things differently. They also tell us that beauty (or comprehension, or understanding) is in the eyes of the beholder. But then that is another story -- a geologist's story -- and I shall not bore you with it, today.

Now, let's talk about resources, water, and the environment.

Resources, Water, Environment

"The adequacy of resources stands with peace and population control among the crucial problems of our time and the future." So said Dr. Frederick Seitz, President of the National Academy of Sciences in 1968, in the foreword to the book Resources and Man.

One of our resources, whose adequacy Dr. Seitz says is such a crucial problem, is water.

And who says it with greater focus on water than Dr. Seitz, with even greater thrust? None other than Senator Frank Moss from our neighboring State of Utah. Senator Moss, who, like New Mexico's Senator Clinton Anderson and Washington's Senator Henry Jackson, has been a stalwart in water legislation. In his book, The Water Crisis, Senator Moss said in 1967 (p. ix), "I believe it is not an exaggeration to say that water -- its competing uses and the conflicts that arise out of these uses -- may be the most critical national problem."

Now that we have focused our attention on water, let's expand it again, for just a minute. Why? Because water problems are environmental problems. Therefore some of the most critical water problems possess the same elements -- and the same possibilities for solution -- as environmental problems. And they are both tied up in policy.

Policy enables man to manage his resources, and to do this one must consider several aspects -- technological, economic, legal, and political -- and don't forget philosophical. In his recent book, Environment: A Challenge to Modern Society, Dr. Lynton Keith Caldwell of Indiana University discusses how the politics intensify as the demands of men intensify. He points out (p. xiii) that

"First, social conflict forces government to allocate or mediate the uses of the environment," and "Second, the cumulative stress upon the environment forces public intervention to protect the life-support capabilities of the environment from impairment or destruction." These two factors, as you know, are often in conflict.

If you wish to substitute the term "water" for "environment" in the above quotation, then you will be talking about the same thing as I am.

Let's now turn to water problems that are national in scope.

Water Problems -- National

Are we running out of water? "No," Arthur M. Piper answered in 1965 (United States Geological Survey Water Supply Paper 1797, p. 22). However, he added that time is getting short to develop the competence to manage our water supplies "boldly, imaginatively, and with utmost efficiency." His colleague, Raymond L. Nace, agreed a couple of years later (United States Geological Survey Circular 536, p. 1) that the time is getting short to stem the waste of water before irreparable harm is done, and he continued that water pollution is mainly a problem of economics.

What are the water problems of the United States? Of the West? Of the Southwest? How effective are some of our current water programs in the Nation? What about current legislation that is being considered? And how pressing are these water problems, anyway? Well, back in 1959 the Senate Select Committee on National Water Resources, of which your Senator Anderson was a member, recognized (Com. Print 3, January 1960) six major water problems: (1) distribution, (2) long-term supply, (3) natural chemical and sediment, (4) man's pollution, (5) floods, and (6) short-term variability of supply. But these were all physical problems. What about the social, the economic, the legal side of the fence?

The latest word from the Federal Government on water research priorities -- and therefore on water problems that need to be solved -- was contained in the report of the Federal Council on Science and Technology in December, 1969. This publication listed the following five as being the most urgent:

1. Managing metropolitan area water systems

2. Improving regional planning and management of water resources

3. Controlling pollution caused by heated-water discharges, oil, and sediment

4. Protecting the public health

5. Predicting ecologic change.

These five represent a considerable revision from the priorities established by the FCST five years earlier as part of a 10-year program of federal water research (February 1966). Item No. 4 wasn't even recognized as a major problem in 1965 -- that's protecting the public health. Items No. 2 and 5 were repeated from the earlier list, and Item No. 3 was considerably restricted in scope and Item No. 1 enlarged in scope from the earlier list. In addition, you will note that in 1965 we thought of several other areas as problems which by 1969 were no longer on the new "Hit Parade." Let's take a look at that earlier list:

1. Methods and criteria for water-resource planning

2. Benefits and alternatives -- cost allocation, cost sharing, pricing, and repayment

3. Improved methods of waste treatment

4. Conservation of water in industrial and municipal uses

5. Conservation of water in agricultural use

6. Ecologic impact of water development

7. Undesirable effects of nonwater activities on water -- especially urbanization

8. Evaluating climatic changes -- significance of fluctuations from flood to drought

9. Assessment of extent and character of water-oriented problems, especially:

    a. Potential use of sea water and brackish water by desalting, or the

    b. Potential for improved water yield through land management, or the

    c. Potential for water conservation through better use of poor-quality water, or the

    d. Sources, quantities, and characteristics of pollutants in water sources, or

    e. Potential water recovery through waste-water purification, or the

    f. Possible impact of precipitation modification.

10. Consolidation of Federal laboratories, and <u>improvement of communication and coordination</u> among researchers

11. Review of current Federal program of experimental watersheds, and finally,

12. Increasing the efficacy and reducing the huge and mounting cost of engineering works of unprecedented magnitude and complexity.

Well! That shopping list should include just about everything but the kitchen sink! But does it? And, noticing how the priorities were changed after the first five years of this ten-year look ahead, do you think that we have important problems today that were not stated in the "top five" of only a year ago? Or is our perception of these problems changing?

If we stop and think about it for a moment, we'll have to admit that the answer to those last two questions has to be "yes -- it is changing." Society is dynamic -- constantly changing -- not only because of people-problems, but also because of unanticipated side effects of technological solutions that are proposed to answer those problems. Even if ZPG (Zero Population Growth) is achieved, the increasing or the changing desires of those of us who are already users of this resource will demand increases in both the quantity and quality of that resource -- water.

The National Water Commission was created in 1968, to study the Nation's water needs and problems, and to recommend improved national policies so that future needs can be met. The Commission is to report in 1973, so its life is half over. What does the Commission see as the major problems? Well, it has selected (Interim Report No. 2, December 1970) some twenty areas for study, as follows:

1. Technological developments that might substantially modify future needs for water and water development

2. Effect of changes in life style of the public on future water development

3. Forecasting regional and National water needs

4. Values of using water for various purposes in different regions

5. Methods of increasing water supplies

6. Not identified yet

7. Use of water resources to promote regional economic development

8. Effect of water development on the environment

9. Influence of water development on the growth of existing population centers, and of new towns.

10. Federal water programs, an analysis of policies, procedures, and institutions

11. Combines with No. 14

12. Cost-sharing and pricing as incentives for water development

13. Metropolitan water problems

14. Institutional arrangements for water development

15. Methods used and constraints inhibiting water planning with emphasis on comprehensive river basin plans.

16. Criteria for evaluating interbasin transfers

17. Economic evaluation of proposed water projects

18. Practices and procedures of organizations that authorize, program, and finance water projects

19. Legal studies

20. How future water policies can affect the Nation's reserves of trained manpower

21. Review of the Nation's water-pollution control program, and

22. Public participation in the formulation of water policies and plans.

Thinking about that shopping list will help you focus on problems that you feel need tackling in the State of New Mexico. And who is going to tackle these problems? Why, your New Mexico Water Resources Research Institute, which has marshalled the many talented people in your three institutions of higher education and is reaching out to embrace experts in other schools in the State -- that's who.

Now let's turn to water problems at the State level.

Water Problems -- State

In order to manage its water resource, a State needs first of all a water policy. As a result of this policy, and as a necessary second step, a plan for the development and wise use of this resource must be developed. And you in New Mexico already have taken steps in this direction, for you will recall that at last year's Conference, the Fifteenth, you had a session dealing with "Overall State Water Planning."

You will remember the talks, by Mr. Carl Slingerland of the Interstate Stream Commission and by Professor George R. Dawson of New Mexico State University. Mr. Slingerland described how the State Planning Office had authorized the Offices of the State Engineer -- Steve Reynolds (remember Mr. Reynolds' paper at the 13th Conference in 1968?) -- and the Interstate Stream Commission to plan for the water and related land resources. Mr. Slingerland continued that in 1967 the U. S. Bureau of Reclamation was requested to re-orient its studies of the Rio Grande and Pecos River Basins in New Mexico toward a State-wide approach to water-resource development (Proceedings of the 15th Annual New Mexico Water Conference, 1970, p. 102). The Bureau's New Mexico Basins Project (State Water Plan) was visualized as including four steps:

1. Inventory the natural resources and determine the current state of their development and use. This had been completed for water, Mr. Slingerland reported, by the two State agencies.

2. Develop projections of population distribution and economic activities, at mileposts 1980, 2000, and 2020.

3. Determine ways in which projected water requirements can be met with supplies currently available under existing interstate agreements and court decrees.

4. Determine the prospects for (A) importation of water (B) weather modifications, and (C) desalting.

No. 1, Mr. Slingerland told you, the inventory, had already been completed by the time of last year's conference, and the rest were well along toward completion of the report, which is scheduled in Fiscal Year 1973.

The other talk by Professor Dawson, focused on the real problem of preparing a "plan". He stated (p. 107) that "Our basic conflict arises out of not being able to specify our common objectives in resource allocation" -- particularly the social and economic objectives of a State Water Plan, and how they should be determined. He sagely noted that our plans have been mainly short-run ones, heavily influenced by political factors such as a four-year term of office. Professor Dawson selected the issue of "mining" of underground water as illustrating short-term objectives that are out of tune with desired social and economic goals in the long run.

I would say that this is one of the most important problems facing the people of the State of New Mexico -- the development of a State water policy and a State water plan that will identify goals and objectives first, and then go into the elements of what is normally considered a State water plan -- planning the physical structures and processes that will make the water available where and when it is needed.

As an illustration of what I mean, let us take a look at my State, Washington. Last summer, the State of Washington Water Research Center prepared a report entitled "A Water Planning Concept for the State of Washington" (Report No. 6) at the request of the Washington Department of Ecology. We considered four categories of goals or objectives: (1) net State income, (2) Environmental, (3) Regional, and (4) General well being. In doing so, we examined desirable characteristics of water planning, organization and procedure, recommendations for immediate action in developing a State Water Plan, and implementation of water planning.

We noted that, in the past, much of the resource planning and development that affects the people and the environment within the State of Washington had been done without reference to State policy and goals. We pointed out that one cannot establish objectives clearly in advance without evaluating their consequences, and that one must lay out alternatives toward achieving an objective before we really understand what that objective means. We emphasized the fact that much resource planning has been based on the assumption that ultimate solutions to our problems are technological, whereas actually, more permanent solutions are in general socially oriented.

We identified one of our major needs as being that of including the public in the planning process at every turn, for without public support the plan will fail.

And, we questioned the validity of long-range forecasts and therefore of planning based on those forecasts. You will recall the newspaper headline last November 29, "Slower Rate of Growth Projected for California." Subsequent news items told us that California may not need new dams for 20 years, according to a revised assessment from the California Department of Water Resources, which is said to have reported that projects already authorized will provide enough water to meet the demand until 1990.

A few years ago the State of Washington Water Research Center prepared an inventory of the State's water resources and made projections of our water needs at mileposts 1980, 2020, and 2065. Our neighbor, Oregon, published last year its estimate of Oregon's water needs at milepost 2070, and Idaho is currently preparing estimates for 1980, 2000, 2020, and 2070. The first national assessment of the Federal Water Resources Council likewise made projections to 1980, 2000, and 2020. We in Washington recognized that our 2065 projection was less solid than ours for 2020, and that the 1980 projection was best of all. The California experience just cited shows that our concern is well justified.

We in the State of Washington have identified two categories of water-research studies that we feel should be undertaken -- broad-gage and specific. Some in the broad-gage categories that would apply equally to New Mexico, it seems to me, include:

1. Regional policy guidelines, an extension of State Water Policy

2. Changes in land-use patterns -- for example, urbanization

3. Relationship of attitudes of people to success in implementation of water-planning and water-management decisions

4. Public awareness and communication between conflicting users

5. Relations between the State's lead water agency and other State agencies having an interest in water

6. Impact of the Bureau of Reclamation's Westwide Water Study on the State

7. Interstate and International problems

8. Interbasin water transfers -- within the State as well as from the outside -- considering both economic efficiency as well as engineering aspects

9. Exchange of information between the Universities, the State agencies, the State legislators, and the people

10. Two-State studies of a shared water resource such as a groundwater basin.

Those were the broad-gage ones. Now for the specific ones. Specific problems are numerous. Some that occur to me (and you can think of many more) are:

1. Use and re-use of water of poorer quality

2. Recreation and aesthetics

3. Sociological concerns -- people decisions

4. Shorelines of streams and lakes

5. Water quality of lakes

6. Irrigation potential in relation to changing land use

7. Instream uses of water -- the waste-assimilation properties

8. Integrated ground-water and surface-water management

Now, you may not agree with me that all of these eight are actually problems in New Mexico. You may feel that they are no longer problems because studies have already been made. However, at the risk of subjecting myself to criticism because I am asking for more studies and re-studies, let me remind you once again that our water problems are dynamic ones, and are changing as our demands and technology change. So I think we had better take another look at these items.

Finally, let's take another tack, with a brief look at current legislation and its effect on solving some of these problems that we have been discussing.

Current Legislation

In looking back over last year, we saw that the major emphasis in Federal water legislation was in the water quality, or pollution field. With the large hue and cry these days about our despoiling the environment, I certainly do not see any change in this emphasis. As an aside, you will recall that the Water Pollution Control authorization expires next June 30, and that legislation renewing it did not get through the Congress last year. I would guess that the authorization will not only be extended beyond next June, but that it will provide for more rigorous enforcement of pollution standards.

We who are seeking answers to water problems -- and that includes all of us who are here today -- should be interested in the fact that legislation was introduced last year in both the House and the Senate, to expand the authorization of the Water Resources Research Act under Title I. Several bills were introduced in the House (H.R. 15957 by Robison of New York; H. R. 16274 by Morse of Massachusetts; H. R. 16279 by Burton of Utah and Saylor of Pennsylvania; H. R. 16285 by Johnson of California) and in the Senate S.3553 by Moss of Utah and S.3721 by Hansen of Wyoming), which would have increased the annual allotment to the 51 University Water Research Centers in each State and Puerto Rico, from $100,000 to $250,000. This increase in funds would have permitted additional worthwhile research to be conducted on critical water problems, and it would have provided for a much better system of communicating these research results to the users -- governmental agencies, industry, and the public. Hearings were held in the Senate, and S.3553 (the Moss bill) was reported out with two major changes -- (1) the new allotment figure was lowered to $200,000, which is still double the present $100,000, and (2) a new section was incorporated in the bill (from Senator Bible's S.1051) to add the District of Columbia and the territories of the Virgin Islands and Guam to the 51 Centers already funded. The Senate passed the amended bill, but because the House Committee did not hold hearings on the legislation, it expired with the 91st Congress on January 2, 1971.

The legislation has been re-introduced in the new Congress by Congressman Johnson of California (H.R. 1400 on January 25), Senator Hansen of Wyoming (S.121 on January 26), Senators Moss of Utah and Hatfield of Oregon (S.219 on January 26), Congressman Morse of Massachusetts (H.R. 3835 on February 8), and Congressman Robison of New York (H.R. 5413 on March 2). We anticipate that hearings will be held in both houses of the Congress this time, and that a thorough review of the total program of the Water Resources Research Act of 1964 will be conducted. Such a review is welcome after six years of life of the program, with which New Mexico's Senator Anderson and Washington's Senator Jackson have been so thoroughly identified. Your State Water Resources Research Institute, under Ralph Stucky, is in the process of preparing material for the hearing.

The other area of legislation, besides water pollution control and water research, is land-use planning. Last year Senator Jackson proposed S. 3554, to establish a national policy regarding land-use planning and management; it was, he said, a "working draft," for comment, review, and analysis. This legislation would provide $50 million annually to develop and implement Statewide land-use plans. In 1970 only Hawaii had such a plan, although Colorado was in the process of developing one at mid-year.

The legislation provided, within three years, for an inventory of land areas and the development of comprehensive land-use plans. A year later each State must have authorized a planning agency to implement such a plan; this authority would include the power to acquire land, to control the kind of development according to area specified, and to ensure full public participation by conducting public hearings. Each State would have to comply with certain minimum standards before it could qualify for the grant-in-aid. Failure of a State to adopt an acceptable plan within four years would result in a reduction of Federal assistance to that State by as much as 20 percent per year until it did comply.

The Act would create a Federal Land and Water Resources Planning Council headed by the Secretary of the Interior; it was drafted as an amendment to the Water Resources Planning Act of 1965, said Senator Jackson, because the Federal Water Resources Council already administers similar programs concerning the use of water and related land resources.

Jackson stated that one of the Federal Government's basic problems was lack of coordination among Federal agencies that pursue separate single-purpose missions such as highway building, dam construction, and urban renewal. Thus, confrontations have pitted proponents of highways against parks, dams against wild rivers, open beaches against development, industry against scenery, and commerce against wilderness.

This legislation was reported out by the Senate Committee but died with the 91st Congress; Senator Jackson has re-introduced it in the new Congress as S.632. Congressman Aspinall, Chairman of the House Committee, stated last June (Congressional Quarterly Weekly Report, June 5, 1970, p. 1502) that his panel would wait until the Public Land Law Review Commission Report was available before holding any hearings. The PLLRC Report was published in mid 1970, and Congressman Aspinall introduced his bill, H.R.4332, on February 17 of this year.

Also, last August President Nixon urged a National land-use policy in his State-of-the-Environment address, and the administration has just introduced a package of legislation that includes land-use planning and coastal management.

I don't have to tell you how important this matter of land-use planning is to water people. The problem of the interrelations between water development or preservation, and other natural resources is a most significant one, and we should consider it as one deserving of our utmost attention.

Conclusion

Well, what have we said during the past 25 minutes or so?

1. Pollution is an important water problem, but there are others.

2. Water problems are intertwined with problems of other natural resources.

We have many technological problems, but more severe is the problem of decision-making. Why? Because decisions are made by people, and people are notoriously mercurial. (That word, you know, has a double meaning these days -- as a pollutant or, as Webster says, having "rapid and unpredictable changeableness of mood.") Therefore one of our problems is the decision-making process -- and the legal, and the political, and the economic framework in which those decisions are reached.

In order to provide a framework for good decision-making we must establish a policy, and plan for the wise management of the resource. Only in this way can goals and objectives be examined and changed, because the planning process, you'll recall, is a dynamic, changing one. Re-evaluation of the management plan, with continual participation by the public, is a must.

We are beset by problems. But the situation is no different today than it has been for the past 15 years, as you have met in your annual New Mexico Water Conference and discussed water problems and their solutions.

Geologist A. C. Lane challenged us half a century ago with the statement, "The larger the area of our knowledge, the greater the circumference of our ignorance."

Think about that for a minute. The unknown just beyond the periphery of what is known, is exciting to contemplate.

And Alfred North Whitehead consoled us a little when he said, "It is the business of the future to be dangerous."

If you add those two remarks together, you can see that we have some challenging times ahead of us, both in New Mexico and in the State of Washington. And there, Ladies and Gentlemen, is the challenge.

The Time Is Now!

Richard L. Thomas, Jr.1/

Biographical Sketch

Rick Thomas is president of the Associated Students of New Mexico State University. ASNMSU is the organization of the students of the university which is responsible for sponsoring many varied programs. In addition to the cultural programs, it brings name entertainers to campus and sponsors student publications.

Mr. Thomas, veteran of the armed forces, will graduate in May, 1971, with a major in agricultural economics.

His interests are in resources, anti-pollution laws and enforcement and state and local government finances.

He plans to attend Graduate School at New Mexico State University to study Economics.

Rick's activities include Aggie Rodeo Association, Sigma Chi National Fraternity, Student Senate, President of Associated Students, American Agricultural Economics Association and his honors include Who's Who in American Colleges and Universities.

Rick was born in Washington, D. C. and is now a resident of Los Alamos, New Mexico.

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This session will be devoted to University students speaking on water in a quality environment. the Sixteenth Annual New Mexico Water Conference Planning Committee has decided to make the student papers session a major part this year's conference. Their hopes are that the students can contribute to the theme in educational value of the overall conference.

The committee's reasons for including student papers are two-fold: (1) to give the students of the region an opportunity to become involved profession-

1/ President, NMSU Student Body

ally in working on the water problems of the southwest, and (2) to give an educational opportunity for the rest of the participants of the conference to gain a better understanding of what students may be thinking.

After the decision had been made to include students in the conference program, some 30 colleges and universities in the southwest were contacted. The students at each university were invited to submit papers to the student paper committee. The papers were invited from multidisciplinary subject matter areas. They were to include such disciplines as engineering, biological sciences, social sciences, law and ethics. However, the central theme of the papers were required to have dealt with some aspect of water resources.

The papers that were submitted were then screened by the student paper committee. The committee was composed of Professor Jesse Lunsford, Civil Engineering; Dr. Gary Cunningham, Biology; and the Chairman, Dr. James R. Gray, Agricultural Economics and Agricultural Business. Those papers being presented here today were chosen by the committee as being the most informative and educational, as well as the closest to the theme of the conference -- "Water, A Key to a Quality Environment."

SYSTEMS ANALYSIS IN NATURAL RESOURCES MANAGEMENT

E. T. Bartlett[1]/

Biographical Sketch

Mr. Bartlett is a native of New Mexico, where he obtained his high school education. His undergraduate work included courses at Ft. Lewis College in Durango, Colorado and Utah State University at Logan, Utah, where he was awarded a Bachelor of Science Degree in Range Management in 1965. During his undergraduate training, Mr. Bartlett worked for the Bureau of Land Management. To continue his education, the University of Arizona awarded him an assistantship in the Department of Watershed Management. He completed his Masters work in 1967. Research during this time was concerned with herbicidal effects on creosotebush and the relationship to carbohydrate levels of the plant. Mr. Bartlett is currently completing the requirements for a Ph.D. in Watershed Management at Tucson. His course work and interests have been in statistics, economics and systems analysis. He is currently Associate Coordinator of the Tucson Site of the Desert Biome Study, a part of the International Biological Program, and also works under an Agency for International Development grant for studying Systems analysis in Watershed Management.

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Forest, range, wildlife and watershed managers have based their decisions on an impirical interpretation of basic inventory data. While this method of decision making is used widely and has essentially been the only one available, researchers are now in the position to develop allocation models for natural resources using systems analysis. Systems analysis evolved during World War II when it was used as an aid in logistic decisions. After the war systems analysis was applied in the business world for allocating resources, products, or personnel to meet demands. However, only within the last ten years has systems analysis, through allocation models, been used in natural resource management; and this use has been primarily in water allocation and

1/ University of Arizona

reservoir operation (4, 6, 7, 9). Some allocation models have dealt with other natural resources such as range forage or timber. But these have either been extremely limited in the resource base considered (8), limited to a particular problem concerning one or more resources (1), or both.

Models are needed which will deal with a much broader range of resources and problems. Natural resource managers, faced with decisions concerning the allocation of funds in resource conservation and development efforts, must be able to predict specific benefits resulting from the investment or allocation of limited funds and manpower available to them from the basic data of resource condition and potential. Existing techniques can be adapted and new techniques developed to produce a meaningful transition from inventories to decisions which enable the manager to use past knowledge and experience, as well as economics, physical relationships of the natural system, and the ecological and social constraints. A resource allocation model would provide such a transition. A model can and should incorporate a larger number of alnatives than the typical manager would consider in the empirical process. It is not to be implied that such a resource allocation model would eliminate all empiricism from resource planning, but that the decisions will be based on a quantitative analysis. Because uncertainties will always be present and knowledge will never be perfect, final decisions will always be tempered by the manager's judgement.

In fact, such models will be linked to the manager's experience and expertise in three ways. First, the decision maker must specify his objectives and goals so that they can be incorporated in the systems analysis program. Second, the manager always has certain levels of production which he must meet, and these minimum levels of production can be incorporated into the model as constraints. Finally, after the management plan has been developed with the model, the manager must still make the decision of whether it should be implemented.

A Desired Model

In developing a model that would serve as an effective tool in managing natural resources for multiple objectives, a factor common to all objectives is needed. Two possible factors are the fundamental inputs to the natural system, water and energy. Since water, once it enters the system, is more amenable to management, it provides this factor. It is also convenient that the watershed basin is a natural ecological area where in a balance can be struck between inputs and outputs of water and energy. As such it provides the logical management area. Even though water can be used to relate the components and products of the ecosystem, monetary and social values will still be used to evaluate and compare alternatives to the decision maker.

What should a resource allocation model include to be an effective management tool? Certainly it should include the following submodels as components:

1. A stochastic submodel of rainfall.

2. A hydrologic submodel that will synthesize the effects of land treatment and management practices on water yield.

3. An operational submodel which will actually serve as the tool for managers.

Of the above components, the first two provide information and linkages for the last and will be very briefly covered.

Rainfall Submodel

Precipitation is a major input to the natural system, and one that the manager cannot control. Rainfall occurrence must be predicted in order for the model to predict future events. Stochastic models of rainfall such as the one developed by Fogel and Duckstein (3) are promising. Their model at present requires only two parameters, the mean number of storm events per year and the probability of having rain at a point given an event has occurred. It is necessary that this model or a similar one be expanded so that sequential events are generated over the long term.

Hydrologic Submodel

Several hydrologic models are in existence (2, 5), and it should be possible to adapt these for the needs of the allocation model. The hydrologic submodel will provide not only the results of an alternative, but will also give feedback to the operational model which may in fact alter the result of that model.

Operational Submodel

The operational submodel is actually the tool for the decision maker and incorporates the output from the other submodels of the system. This is where systems analysis methods will be used to guide resource managers. It combines technology and economics, subject to the constraints of the physical system, social patterns, politics, and money available. In the operational submodel, the wide range of treatments that can be imposed on a watershed are considered as alternatives to the manager. This does not mean that an unrealistic treatment would be considered for a particular management unit. The components of the area would be classified by some system and the model would only consider treatments amenable to a particular class. The resource allocation model is further explained in the following example.

Example

This example represents an extremely simplified representation of an allocation model concerning natural resource development and is illustrated in Figure 1. The model considers only two products of a water basin: water and forage. Forage is considered only as an on-site product while water can be used both on the site and down stream. Because this model is simplified and is a prototype for future model development, only a very limited number of management alternatives are considered, and those are manipulative treatments which increase forage yield.

The water basin is divided into subwatersheds or management areas. The subwatershed is then divided into management units. The management unit is an area which is sufficiently homogeneous to permit the decision maker to assume

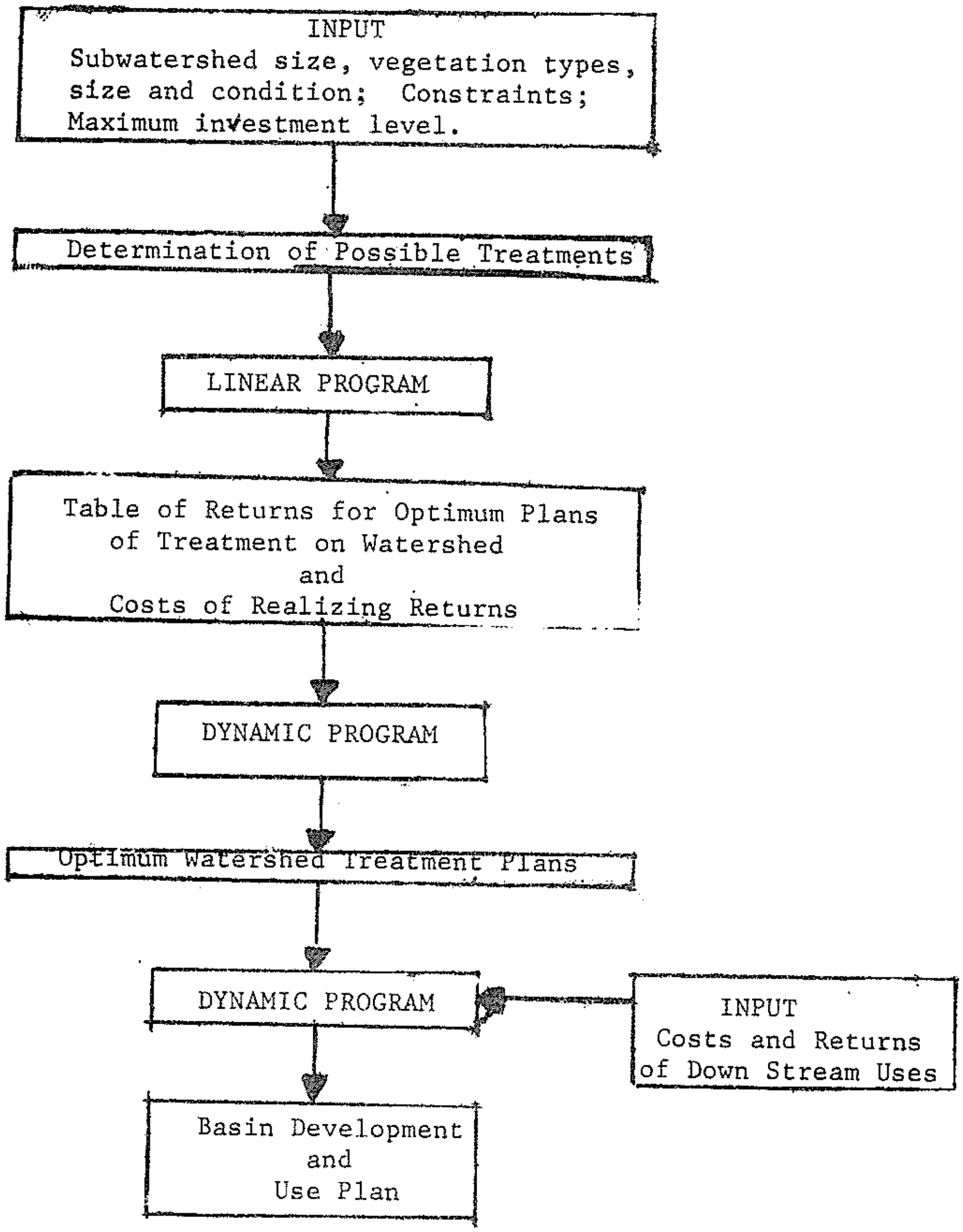


Figure 1: Simplified flow chart of the resource allocation model.

that each acre of that area will respond to treatment the same as every other acre. This assumption never completely holds in the real world, but is necessary because of the continuous manner in which the parameters governing treatment response occur. In this example the management unit was assumed to be a general vegetation type. However, this could be refined further to a more specific vegetation classification or even a vegetation-soil classification.

The model utilizes two techniques of systems analysis: linear programming and dynamic programming. From basic inventory data, constraints and the maximum level of investment, linear programming is used for each subwatershed to determine the optimal treatment or development plan for an array of investment levels. Both the costs and returns of the treatments are compared over a common planning horizon by discounting to present values. The results are then used for the dynamic program in which the subwatersheds are stages and the level of investment is the state variable.

By using the dynamic program, the manager is given a guide in allocating his investment among the subwatersheds for the investment levels. An additional cost to the alternatives is the requirement for water by livestock if the increased forage production is to be utilized, and the cost of supplying that water using small reservoirs. This is a realistic constraint within the model because the increase in income from increased forage is not realized unless that forage is utilized.

After an investment is made on the watershed, a basin decision must be made concerning the use of the water produced when the plan is implemented. Such a decision can again use dynamic programming as a tool. In this case, water may be used for agricultural purposes, by municipalities, or possibly for recreation. The different uses are the stages of the program while the state variable is the amount of water used by a stage. The basin benefits include on-site benefits and the down stream benefits of water use. Finally by combining the results of the two dynamic programs the manager is given a guide to watershed development and use of the water that would be produced.

It is hoped, through the development of this model as well as the development of other resource allocation models, managers will be provided a tool that will guide them in their decision making process. It is good to reiterate the idea that good common sense is the final step in decision making and that man has the last say. However, it is useful to note that even though the source of knowledge in computer models is man, the computer has the advantage of total recall and an unfailing memory.

REFERENCES

1. Bratten, Frederick W. 1970. Allocation models for firefighting resources ... a progress report. USDA For. Ser. Res. Note PSW-214. 6 pages.

2. Crawford, N. H. and R. K. Linsley. 1966. Digital simulation in hydrology: Stanford Watershed Model IV. Dept. of Civil Eng., Stanford Univ. Tech. Report No. 39. 309 pages.

3. Fogel, M. M. and L. Duckstein. 1969. Point rainfall frequencies in convective storms. Water Resources Research 5(6):1229-1237.

4. Hall, Warren A., William S. Butcher, and Austin Esogbue. 1968. Optimization of the operation of a multi-purpose reservoir by dynamic programming. Water Resources Research 4(3):471-477.

5. Huggins, L. F. and E. J. Monke. 1968. A mathematical model for simulating the hydrologic response of a watershed. Water Resources Research 4(3):529-539.

6. Mass, Arthur, et al. 1966. Design of Water-Resource Systems. Cambridge: Harvard Univ. Press, 620 pages.

7. Mobasheri, Fereiboun and Ricardo C. Harboe. 1970. A two-stage optimization model for design of a multi-purpose reservoir. Water Resources Research 6(1):22-31.

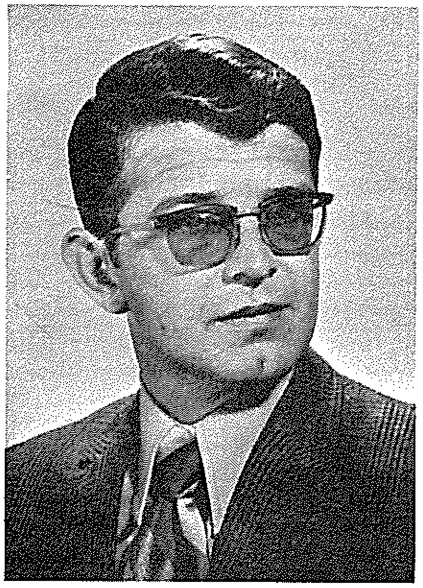
8. Nielson, Darwin B., et al. 1966. Economics of federal range use and improvement for livestock production. Oregon Agr. Exp. Sta. Tech. Bul. 92. 40 pages.

9. Young, George K. and Mark A. Pisano. 1970. Nonlinear programming applied to regional water resource planning. Water Resources Research 6(1):32-42.

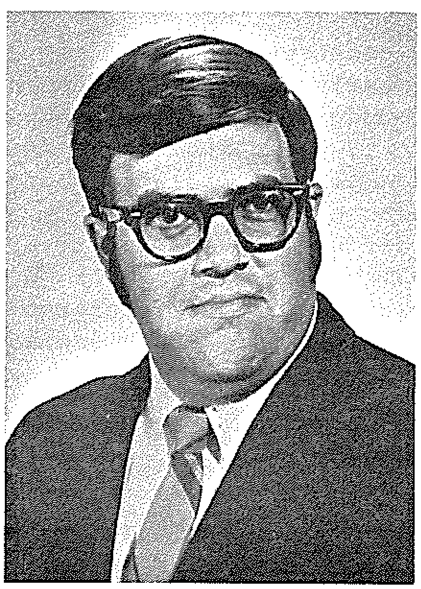
ARIZONA'S GROUNDWATER PROBLEM AND PROPOSED LEGISLATION

Dean Eldon Peterson and Larry L. Deason[1]

Biographical Sketch



Born in Scottsbluff, Nebraska. Graduated from Holdrege High School, Holdrege, Nebraska in 1955. Engaged in irrigated and dry land farming from 1955 to 1965. Graduated from Arizona State University in 1968. (B.S. - Accounting) Will graduate from Arizona State University College of Law in June, 1971. (J.D.)



Born in Yuma, Arizona. Graduated from Kofa High School, Yuma, Arizona in 1964. Graduated from Arizona Western (Junior) College in 1966. Graduated from Arizona State University in 1968. (B.S. - Management) Will graduate from Arizona State University College of Law in June 1971. (J.D.) Presently serving legislative internship in State Senate of Arizona.

1/ Arizona State University

Arizon's Groundwater Problem As It Stood In 1948

In 1947 almost all knowledgeable sources agreed that Arizona's groundwater problem had reached the critical point. The Legislature of Arizona was asked time and again by the Governor to consider the problem in special sessions. Irrigated acreage was at its highest point in history, and increasing steadily, without regard to declining groundwater levels. The surface waters had long since been put to maximum use. Day by day the feeling seemed to grow that there was a need for some kind of statewide groundwater control in Arizona.

Very little farming is accomplished in Arizona without irrigation. But in 1947 an extensive agricultural industry had been developed through a continuous expansion of irrigation projects for more than 50 years. Practically all early agricultural development resulted from the diversion of water from flowing streams and by constructing dams and storage reservoirs on the rivers. By 1930 the use of these surface waters for agricultural development was so complete that since that time no water has run out of the mouth of the Gila River, which drains most of the state (1).

Nearly all the agricultural development in Arizona since 1930 has resulted from an increasing use of underground water supplies made available by the installation of wells and pumping systems. Owing to the increased efficiency of pumps, higher prices for crops, and lower costs for power, groundwater began to play an important part in Arizona agriculture.

These developments made it possible for the irrigated acreage to increase from about 330,000 acres in 1910 to 950,000 acres of land in 1947 (2). It is easily seen that Arizona agriculturalists were quite proud of their efforts in developing elaborate irrigation systems.

It was during the 1930's that concern for the conservation of underground water supplies first developed. Some saw the early need for settlement of the legal and policy questions surrounding groundwater, but their hopes for settlement were in vain (3). However, between 1940 and 1947 it became increasingly apparent that there was not enough water available to support the increasing agricultural program. There had been no rain to speak of since the winter of 1940-1941. This situation rapidly used up surface reservoir supplies as well as underground supplies of water. Studies by the University of Arizona in 1946, showed clearly that practically all the underground water supplies had been developed. Also, it was felt that only a decreasing amount of underground water would be obtainable in the future (4).

Some experts were projecting that if something was not done about the situation, Arizona's irrigated acreage would have to be decreased by one-third (5).

During the early 1940's proposals were introduced into the legislature calling for the establishment of study committees for the writing of a code, but these proposals could not gain needed support (6). As early as 1942, the Arizona Farm Bureau Federation called for a code (7). In 1944, after five years of investigation by the U. S. Geological Survey, the State Land Commissioner informed the Governor, that without a groundwater code "The agricultural development of the state can never be safeguarded against over development that will always threaten the return of certain areas to the desert" (8).

In 1945 the pressure for enactment of some kind of code increased when the Governor warned the legislature that the long awaited Central Arizona Project would not receive Bureau of Reclamation support unless the state took action to control its groundwater depletion problem (9). The result was the Groundwater Act of 1945 (10). The primary purpose of this Act was that it be an information gathering device. Persons owning and operating wells were required to give certain information to the State Land Commissioner. No new wells could be drilled without first giving notice of intention to drill. However, the Act in no way placed any limitations on groundwater pumpage.

"Governor Osborne was an ardent supporter of a groundwater code and was determined to see one passed. He assailed what he called the 'forces of greed and destruction' who resisted passage of a code. Failing to obtain action from the regular session of the legislature in 1947, he called the legislature back into session three times for the specific purpose of writing a groundwater code and finally was successful" (11).

Groundwater Law In Arizona

A law which permits limited state regulation of the use of groundwater for irrigation in Arizona was enacted by the Sixth Special Session of the Eighteenth Arizona Legislature in March 1948. This code did not adopt any of the basic principals of water law but was an exercise of the general police power of the state in providing reasonable regulations for the designation and establishment of "critical groundwater areas".

Groundwater as defined in the Act, "means water under the surface of the earth regardless of the geologic structure in which it is standing or moving. It does not include water flowing in underground streams with acertainable beds and banks" (12). According to Arizona law, as developed by court decisions, there are two classes of underground waters, those flowing in definite underground channels, and percolating waters. The importance of this distinction by the courts will be discussed later. Suffice it for now to say that the Code applies only to percolating water.

Administration of the law is vested in the State Land Department (prior to 1950, the State Land Commissioner). The Code provides for the registration of all irrigation wells operating prior to the enactment of the 1945 Groundwater Act and in addition for the filing of "Notice of Intention to Drill" new wells for any use.

One of the duties of the State Land Department is the designation, on the basis of adequate factual data, of groundwater basins and their subdivisions, and the alteration of the boundaries thereof as future conditions require. The fact that an area is designated a groundwater basin does not give the department authority to regulate the drilling or operation of wells in the basin.

However, the Department is further empowered, after notice and hearing, to designate critical groundwater areas. A critical groundwater area, according to the law, is any basin or subdivision thereof "not having sufficient groundwater to provide a reasonably safe supply for irrigation of the cultivated lands in the basin at the then current rates of withdrawal." The designation of a groundwater basin or a critical groundwater area may be initiated either by the Department or on a petition signed by a given percentage of the groundwater users in the groundwater basin concerned (13). Maps of the present critical groundwater areas in Arizona are included as Appendix A.

The law does not place any restrictions on the drilling of wells for irrigation or otherwise in non-critical areas, nor does it limit the use of water from existing wells in critical areas. The main restriction that the Code imposes is upon the drilling of wells for the irrigation of new land within a critical area. In addition, replacing or deepening present irrigation wells will be allowed only upon a satisfactory showing that the well intended to be replaced or deepened will no longer yield sufficient water to irrigate the land normally supplied by it within the five years immediately prior to filing application for the permit. Otherwise, the only irrigation wells allowed to be drilled in critical groundwater areas are those for the irrigation of lands which were irrigated on the date the area was declared critical or had been cultivated within five years prior thereto.

Infractions of the law or of rules issued under it are classified as misdemeanors punishable by a fine of not less than $25 or more than $250 for each offense. Persons who persist in the violation of any provision of the Act or of regulations for its enforcement, after due notice and after the expiration of a reasonable period of time in which to comply are guilty of a separate offense for each day the violation continues. The law permits a person to appeal from orders and decisions of the Department to the County Superior Court, in which the case will be tried de novo and from the Superior Court to the State Supreme Court.

The constitutionality of the Act has been questioned on a number of grounds. In 1955 the case of Southwest Engineering Co. v. Ernst reached the State Supreme Court (14). Southwest Engineering Co. had applied to the State Land Commissioner for a permit to construct a well on land within a critical area which did not have a history of cultivation. The Commissioner denied the application and the company then sued to enjoin the Commissioner from preventing the construction of the well. The primary argument of the company was that the action of the Commissioner was an unreasonable and arbitrary use of the police power to interfere with private property without due process of law and without just compensation. In considering this argument the court said:

> "We are of the opinion that there is a preponderant public concern in the preservation of lands presently in cultivation as against lands potentially reclamable, and that whereas here the choice is unavoidable because a supply of water is not available for both, we cannot say that the exercise of such choice, controlled by considerations of social policy which are not unreasonable, involves a denial of due process (15).

In other words the police power can be exercised in any reasonable manner to meet the needs of the public.

The company further argued that the classifications involved in the Code were arbitrary and unreasonable and therefore violated the equal protection clause of the Fourteenth Amendment since the classification was not reasonably related to the purpose for which the Code was passed. The Code allegedly discriminated among persons in a single class, the distinction between present and potential users being unwarranted. Admitting that the distinction was an unusual one, the court said "this is not sufficient grounds to invalidate the Act if the classification has a rational basis. That the classification does have a rational basis is readily apparent." The court then stated that there were sound reasons for the distinction involving protection of the community against economic loss due to the water shortage in the state.

Finally, the company contended the Act was unconstitutional for want of definitness and gave to the Commissioner law making powers. The court accepted the argument that a law must not be so "vague, uncertain, and incomplete that reasonable men could not agree on the law's meaning and application," but found that there was sufficient certainty concerning the principals to be used in the determination of critical areas and the procedures to be followed. The court stated that since the groundwater problem is quite complex it is necessary that the determination of certain facts or conditions be delegated to an administrative body.

In 1960 the Supreme Court interpreted the Code in the case State ex rel Morrison v. Anway in which the court stated that a landowner could transfer the application of groundwater from a parcel of land having a history of cultivation to a parcel of land not having such a history. The court did not agree with the State Land Department's argument that the Code forbade expansion of the acreage developed by groundwater (16).

As stated previously, the courts in Arizona draw a distinction between underground percolating water and water flowing in defined underground streams. The importance of this distinction is realized when it is seen how an individual acquires rights in these different kinds of water. Water flowing in defined underground streams is subject to the same rules as surface water, the doctrine of prior appropriation. In essence this doctrine declares that the waters are public property, but may be appropriated and put to beneficial use. Claims to water depend not on the ownership of riparian land, but on the use to which the water is put, and the time at which the claim is established. In the event of conflict the earliest right takes precedence. This water right under prior Arizona law was issued for beneficial use on a specific parcel of land and could not be used elsewhere under most conditions although there were provisions for transferring the right if its use on the original land became impracticable for reasons beyond the control of the owner. However, under present Arizona law a right to surface water is no longer appurtenant to the land for which it was appropriated. The right is valid only so long as the water is actually used and may be forfeited if the right is not used for five successive years.

Percolating water in Arizona as decided in the case of Brister v. Cheatham, is subject to the doctrine of reasonable use (17). That is, the owner of the land has a right to take as much water as he can put to reasonable use on that land, without regard to the effect of the withdrawal on neighboring landowners. There is no priority of rights in this system.

In a recent Arizona case, Jarvis v. City of Tucson (18) the court held that the beneficial user of groundwater may transport the water off his land as long as that use of the water does no damage to other users. In that case, damage to others was presumed because the land in question fell within the boundaries of a designated critical groundwater area, and therefore, the City of Tucson was enjoined from transporting the water away from the land from which it was pumped.

Clearly the prior user of groundwater would rather fall under the doctrine of prior appropriation because he would be able to assert his prior right any time pumpage by his neighbors damages him. However, with the decision in Proctor v. Pima Farms Company (19) the court took a very restrictive view concerning what was necessary to prove the existence of an underground stream. It required clear evidence of a channel with well defined beds and banks, and current, and a certainty of location. The presumption is, without evidence to the contrary, that underground water is percolating and therefore subject to the reasonable use doctrine. The result of this decision by the court is that practically all underground water in Arizona is subject to the reasonable use doctrine.

Effect Of Present Law On Groundwater Problem

Since 1939 a planned program of groundwater studies has been conducted by the U. S. Geological Survey in cooperation with the State of Arizona. The results of these studies show a steady decline in the groundwater levels throughout the state. Although the rate of decline has leveled off somewhat in certain areas, there does not appear to be any relief in the near future. The following statistics will show that the 1948 Arizona Groundwater Code has not been effective in decreasing the groundwater overdraft. (Tables 1, 2, and 3 are included as Appendix B)

Table 1 shows that between 1940 and the effective date of the Code in 1948 groundwater pumpage in Arizona had more than doubled, increasing from 1.5 million acre feet to over 3 million acre feet. During the same period the state experienced a one-third increase in irrigated acreage. The large difference in the rates of increase is explained by the fact that there was a drought throughout the state during this period. Without surface water available the farmers naturally started pumping more groundwater. It is estimated that the annual recharge of groundwater in the state of Arizona is 1.0 million acre feet (20). According to this estimate, groundwater pumpage since before 1942 has been far greater than the annual recharge. The net result has been a general overdraft on the groundwater reservoir and a constant lowering of groundwater levels. On an annual basis it has been many years since water supply has exceeded water use, therefore much of the water being used to meet todays needs is being derived from stream flows stored in the groundwater reservoir many years ago. Groundwater pumpage continued to increase from the time the Code went into effect until 1953. The bulk of the increase seems to be explained by the fact that irrigated acreage was also increasing. However, it should be noted that there were very few critical groundwater areas under the Code until 1951. Therefore, increases in groundwater pumpage until that time cannot be blamed on the provisions of the Code, only its administration.

Since 1953, both groundwater pumpage and irrigated acreage have remained relatively stable. Groundwater pumpage is averaging approximately 5.0 million A.F. annually, while irrigated acreage has leveled off at about 1.2 million acres. Even though groundwater pumpage has been stabilized there still remains an acute overdraft of approximately 4.0 million acre feet annually (21). As long as this overdraft continues, groundwater levels will continue to decline. In addition, as water levels decline, pumping costs increase and the quality of the water is lowered.

To show the effect of the Code, Tables 2 and 3 show the average pumpage and depth to water in two areas which have been declared critical by the State Land Department.

Lower Santa Cruz Basin

This area was declared critical in three stages. The Gila-Santa Cruz area was created June 19, 1951, and the Eloy critical area was created April 4, 1949. Additions were made to both these areas on October 15, 1954.

From Table 2 it can be seen that since 1949 pumpage in the lower Santa Cruz Basin has remained at approximately 1 million A.F. While the Code may be credited with the stabilization of groundwater pumpage levels, it should be noted that since there was already an overdraft on the groundwater supply, groundwater levels have continued to fall. The decrease has been as much as 160 feet in some areas. It is estimated that pumping costs increase $.03 per acre foot, per foot of lift (22). Therefore, if the average decline in the water level has been 120 feet, this represents an increase of $3.60 per acre foot of water used.

Salt River Valley

The Salt River Valley critical area was created September 1, 1951 and additions were made August 14, 1956. From Table 3 it can be seen that pumpage levels in the Salt River Valley began to level off almost immediately after the area was declared critical and have remained stable at around 2 million A.F. annually. Again however, even though pumpage has remained stable, the water level has continued its rapid decline. Beginning in 1965 groundwater pumpage has shown a marked decrease due to the fact that more surface water has been available for irrigation. The additional surface waters and the decreased pumpage since 1965 has stopped this decline and even raised water levels in some areas.

From the above factors it is clear that although increases in pumpage may be stopped when an area is declared critical, the decline in the water level will continue as long as there is no actual cutback in the amount of water pumped. Under the present groundwater code there is no way that the State Land Department can effectively control decling water tables.

Comparison Of Groundwater Statutes In Other Western States

After having pointed out the deficiencies in the groundwater laws of Arizona it becomes necessary to investigate the groundwater laws of those western states whose groundwater situations are similar to that of Arizona before one can determine what future legislation is necessary in Arizona. At first glance it appears that each state has enacted groundwater legislation in light of its own particular problems which have been somewhat unique in each case.

However, upon deeper examination similarities can be found which allow division of the 17 western states into three groups. The first group, including North Dakota, South Dakota, Kansas, Oklahoma, Wyoming, Idaho, Utah, Nevada, Washington, Oregon, Colorado and New Mexico have statutes which bring the right to use percolating waters under the doctrine of prior appropriation. Two states, Arizona and Texas, extend regulation of groundwater to certain uses of such waters in areas in which it is particularly needed, but without basing restrictions on priority of appropriation. In three other states, California, Montana, and Nebraska, there are no statutory restrictions upon the diversion and use of percolating waters (23).

The appropriation group can be considered as a whole with note of some of the significant variations. A statute that makes adequate provision for the appropriation of groundwater must contain among other things, such features as: designation of waters affected, designation of public administrative agency, recordation of claims of preexisting water rights, procedure for acquiring new rights, determination or adjudication of groundwater rights, supervision of extractions of groundwater, changes in exercise of groundwater rights, and loss of rights.

1. Waters affected. Several of the original groundwater laws in specifying waters subject to appropriation set up elaborate classifications of groundwaters having reasonably ascertainable boundries, with seemingly no two states having the same classification system. The trend now is away from elaborate classifications and toward complete coverage of all groundwaters that are subject to practical administration.

2. Public administrative agencies. All of the statutes place some responsibility upon the State Engineer of other comparable state official. The tendency is to provide procedure for registering in the office of the administrative agency claims of preexisting rights and applications for the acquirement of new rights. The administration of all these rights is the responsibility of a single state agency.

3. Preexisting rights. Here we are worried about the claims of rights to the use of groundwater that are initiated prior to the enactment of the groundwater statute. These are sometimes called claims of vested rights or claims of existing rights. They relate to rights which are claimed to exist by reason of previous actual application of groundwater to beneficial use. Claims are made on forms furnished by the states and are filed in the state agency. When properly filed

and recorded these claims are usually prima facie evidence of the rights so described.

4. Acquiring new rights. The excess water in the source of supply above the quantities to which holders of preexisting rights are entitled is available for appropriation under the specific procedure prescribed in these statutes. The procedures usually parallel those provided for appropriations of surface waters with such variations as are caused by differences in the character of these water supplies and in methods of withdrawal.

5. Determination or adjudication of groundwater rights. The trend is toward including in the appropriation statutes provisions for administrative determinations of groundwater rights followed by court adjudications. Even though surface stream procedure is followed the different nature of groundwater supplies calls for special handling. The boundaries of each source of groundwater supply must be defined. Information is needed with respect to the depth and capacity of the groundwater reservoir, safe yield, extent and quality of the supply, and servicable methods of withdrawal. If two or more such reservoirs overlie one another wholly or in part, it is necessary to decide whether they are physically interconnected and whether they shall be adjudicated and administered separately or together.

6. Supervision of extractions of groundwater. Supervision over the extraction of groundwater begins when it appears that the water supply in a defined area is overdrawn, or is about to be overdrawn or dangerously polluted. Investigations and hearings are held by the state agency to determine whether corrective controls are required. Control of groundwater diversions in a critical area generally takes the form of closing the area to further appropriation while the critical condition persists, and of restricting current withdrawals in the reverse order of priority.

7. Changes in the exercise of groundwater rights. Most of the appropriation statutes allow a prior appropriator to abandon his original well or original use and transfer his rights to another well or use if no injury will result to the holders of other rights.

8. Loss of groundwater rights. Provision is generally made for loss of groundwater rights by forfeiture for non use over a prescribed period of years.

Other than Arizona, Texas is the only western state which has enacted extensive legislation controlling the diversion and use of groundwater not based upon the doctrine of prior appropriation. The Texas statute authorizes the creation of underground water conservation districts. The purposes of these districts are the conservation, preservation, protection, recharging, and the prevention of waste of groundwater. They may issue bonds and levy ad valorem taxes. Subject to the rules and regulations of the district, for the purpose of preventing waste, the English rule of ownership by the landowner is recognized and priorities and provisions of the surface water laws do not apply.

California's courts have held that the use of percolating groundwater in that state is subject to the "correlative rights" doctrine (24). Under this system, in times of shortage an individual user is entitled to "only his reasonable share" of available water. By statute, the state has declared that he will not lose his right to that share because he has been using some alternate supply of water (25). The statute also requires annual reports to be filed with the State Water Rights Board. The only Montana legislation requires filing of logs of all wells drilled. Nebraska merely provides for registration of irrigation wells, minimum spacing between irrigation wells, and preferential uses.

In this brief survey of the groundwater law of the other western states we are attempting to draw from the experience of those states in determining what future groundwater legislation is necessary in Arizona. In general 12 of the 17 western states have effective codes which are based on the appropriation doctrine and are continually being updated. The remainder of the western states place little control or regulation on the diversion or use of groundwater.

While the appropriation statutes are in effect in approximately 70% of the western jurisdictions with which we are concerned, the aggregate area irrigated with groundwater in these states is extremely small as compared with the total for the west. Considering relative irrigated acreage according to the Bureau of the Census the 12 states that have appropriation statutes governing percolating waters are included in the 13 states with the smallest total acreages of land irrigated from pumped wells (26). Therefore, it appears that the trend toward adoption of appropriation type statutes is effective in only those states which have enacted legislation prior to extensive development of agriculture. This trend may effect the other western states in the near future. However, it seems more likely at this time that groundwater legislation in those states will proceed along lines other than priority of appropriation.

Arizona's Projected Water Needs And Public Reaction

Before one can propose legislation to regulate groundwater two additional things must be considered. First, the projected water needs of the state of Arizona, and second, the reconciliation of the different public interests involved in this type of legislation.

Arizona has one of the highest rates of population growth in the United States. Estimated population in 1969 was 1,692,000. Future projections indicate that population will reach 2.1 million by 1980, 3.3 million by 2000, and 5.5 million by the year 2030 (27). The U. S. Geological Survey estimates that presently the total consumptive use of water in Arizona is 7.0 million A.F. annually. Of this amount an estimated 2 million A.F. is surface water. The remaining 5.0 million A.F. is pumped from groundwater sources. Since the estimated annual recharge is 1.0 million A.F., the overdraft on the groundwater reservoirs is 4.0 million A.F. per year (28). With the projected population increases stated above, it is easily seen that the water shortage in Arizona will reach crisis proportion unless remedial action is taken.

Of the 7.0 million A.F. of water consumed annually, 5.5 million A.F. is devoted to irrigation. It has become increasingly obvious that "...acre for acre, domestic uses consume less water than agricultural uses. However, as more presently unirrigated desert areas are developed, the demand for water in these more than compensates for any additional water released from agricultural use" (29). It should be noted at this point that demand for water is increasing not only in absolute terms but also in terms of per capita use. Perhaps the most important reason for this increase is the demand for more water for recreation purposes. While some might argue that recreation is not of primary importance, there can be no doubt that recreation is accepted as a legitimate use of water and that such use will increase in the future.

The most likely source of water from outside the state is the Colorado River. Congressional approval for the Central Arizona Project was finally given in 1968 (30). Present estimates are that this system will deliver approximately 1.2 million A.F. of water for use in Central Arizona (31). This amount is not nearly as much as the present overdraft of the groundwaters with no guarantee that groundwater pumping will actually be reduced. Also, assuming that the C.A.P. will be of great benefit to the state it should be realized that even the most optimistic projections show that the project will not be completed before 1980. Arizona's groundwater problem is an existing reality which should be dealt with as quickly as possible.

Of major importance is possible public reaction to any new legislation. Protection of private rights in property is unquestionably a matter of public concern. Constitutional guarantees are invoked in securing the individual's rights. However, the Arizona Supreme Court has held that a significant public interest such as the need for efficient use of a rapidly depleting groundwater supply takes precedence over the property interests of the individual (32). The water shortage in Arizona has reached such proportions that it is necessary for all the people of the state to began taking an overall look at the problem rather than focusing on their own individual needs. Not until this realization is made will the state be able to most efficiently balance the direct and indirect benefits to the community.

Conclusions And Proposed Legislation

Arizona's first solution to its groundwater problem was the Groundwater Code of 1948. It would be inaccurate to say that this Code was completely ineffective. The Code was effective in that it brought about the stabilization of irrigated acreage in Arizona and in so doing stopped the increasing rate of overdraft. This would have been fine except for the fact that in 1948 there was already a substantial overdraft on groundwater reservoirs. Although groundwater pumpage has remained relatively stable since the enactment of the Code, the then existing overdraft has sent pumping levels lower and lower.

The following statement by Dean E. Mann summarizes the problem:

> "With the legal issues apparently settled there is little interest in altering basically the existing legal and administrative arrangements involving groundwater. Farmers will continue to pump until it is economically no longer feasible to do so, or until they receive

offers sufficiently attractive to induce them to sell their water rights. Meanwhile, new lands are opened up without restriction and with the eventual danger of overdevelopment. Groundwater laws have perhaps prevented the expansion of agriculture and further overdevelopment of land dependent on groundwater, but they have not redressed the serious imbalance of withdrawal and supply that existed before the laws were put on the statute books" (33).

It is our conclusion that additional legislation relating to the groundwater problem is necessary. There are substantial areas in Arizona which, unless some change is made, will be out of water in the near future. Therefore, the remainder of our paper will be devoted to proposed legislation.

Initially it should be realized that new groundwater legislation will not necessarily have an immediate effect on all groundwater pumpers. There are some areas in the state that need immediate relief, but the main purpose of any additional legislation would be in its future effect. The primary failing of the Groundwater Code as it stands now is that there is no way to stop an overdraft once it begins. Future legislation should be aimed at stopping an overdraft problem before it becomes critical, in addition to regulating pumpage in those areas where there is already an overdraft. Ideally the goal is that groundwater pumpage in a particular area will be no greater than the amount of recharge.

Procedurally there are two ways that new groundwater legislation can be put into effect, either by amending the present Groundwater Code or by completely repealing the old Code and starting anew.

We feel that although the present Groundwater Code was not strong enough, it was satisfactory as far as it went. Therefore, it is believed that strengthening of the present code is all that is necessary.

There have been proposals before the legislature of Arizona providing for the centralized control of all matters dealing with water. We feel it is of primary importance that any future groundwater legislation be incorporated into this type of program.

The authors feel that there are two major alternatives available to the legislature of Arizona to meet both present and future groundwater problems. These alternatives are: 1) A system of prior appropriation, and 2) A system involving pro-rata cutbacks. These systems are similar in some respects and each involves advantages and disadvantages which must be considered. It should be pointed out that the two proposals are offered merely as individual frameworks upon which future legislation can be based. We do not purport to resolve all the minor technicalities that would be encountered in any such legislation. Instead, our proposal is to investigate the major difficulties involved in each system.

Prior Appropriation System

As stated in Section IV. by far the majority of western states control their groundwater pumpage through a system of prior appropriation. Therefore, it would seem appropriate that Arizona should consider this type of legislation for its own groundwater problems. However, it was also noted in Section IV. that the states which have enacted prior appropriation legislation in dealing with their groundwater problems are the states with the least amount of land irrigated with groundwater. In other words at the time those states adopted this system, their agricultural development dependant upon groundwater was practically non existant. Therefore, the prior appropriation system did not affect preexisting rights. Consequently, Arizona's problems in enacting this type of legislation would be quite different and more complex.

So, it appears that no state has ever applied prior appropriation retroactively. For such a system to effectively solve the groundwater problem in Arizona, it would have to be applied in that manner, because application to future users only would in no way eliminate present overdrafts.

There are constitutional problems which arise when this type of system is applied to rights already in existence. As the law now stands in Arizona a landowner has a right to the reasonable use of groundwater upon his land (34). However, in Southwest Engineering Co. v. Ernst the Supreme Court of Arizona held that the State could deny the landowner this right if his land lay within an established critical groundwater area, thereby upholding the constitutionality of the 1948 Code. It should be noted that the policy enumerated in that case was that there is sufficient public interest to allow the placement of the rights of present groundwater users above the rights of future users. In order for a prior appropriation system to have the needed effect on Arizona's groundwater shortage, it would be necessary that the court be willing to go even further and allow the rights of some present users to be subordinated to the rights of other present users, keeping in mind that under present law these rights are equal. In other words in Southwest Engineering the court was willing to divest an owner of rights not in use, whereas here the court would be required to discriminately take away rights that are being used.

Even assuming that these constitutional problems can be overcome, difficult administrative problems would remain. Due to the fact that agriculture in Arizona makes extensive use of groundwater it would appear that the initial determination of the prior appropriators and the extent of their rights would present an almost insurmountable problem of adjudication and administration. This is true even though all wells in the state are required to be registered under the Code. Adjudication would still be necessary because the Code did not require the dating of wells existing before 1945. This would have to be done before any priority of rights could be established.

Another problem in applying any groundwater legislation is the determination of how much water is actually available in a certain area. Unless this information is obtainable the decision of when to cut back junior appropriators will be difficult. However, if the advances of engineering and hydrology allow accurate determination of the available water supply, the prior appropriation system would offer a reasonably definite method for regulating groundwater pumpage. However, one should realize the difficulties encountered when trying to determine if pumpage by one party is actually damaging another party's well.

Arizona statutes already provide that all water, other than percolating water, are subject to prior appropriation. In order to enact this type of legislation an amendment to the present statute to include percolating water would be necessary. However, it should be made clear that appropriations of percolating water will not be affected by appropriations of other waters.

Recent litigation in Arizona has pointed out that it is necessary that some system be adopted which will allow municipalities to transport groundwater away from the land on which it is pumped. The "reasonable use" doctrine as it is now applied in Arizona does not allow this because it is said that the right to reasonable use of the water is appurtenant to the land. The advantage of the prior appropriation system is that it usually does not matter where the water is used as long as it is put to beneficial use. However, at least some states have added the further requirement that the water cannot be taken out of the groundwater basin from which it is pumped.

In concluding the discussion of this type of system, it is the opinion of the authors that, although prior appropriation might have been the most desirable method if it had been enacted earlier in Arizona's history, at this point in time the practical difficulties encountered make this system less desirable than the other proposal.

System Involving Pro-Rata Cut-Backs

This type of system would provide for an equal reduction on each irrigation pumper upon a finding by the state agency that the water shortage in a given area had reached sufficient proportions. In other words, if there is a critical overdraft in a given area the problem will never be solved by merely prohibiting the drilling of new wells. Once the amount of groundwater pumpage exceeds the amount of recharge the only way the situation can be remedied is by decreasing the amount of pumpage. Since, as we stated previously, the present groundwater code operates satisfactorily within its limits, there is no reason why such a cut-back system could not be implemented within the present setup.

At the present time if an area is declared a critical groundwater area, the state agency is given only the power to restrict the drilling of new irrigation wells. The critical groundwater area method would continue to be used, but this system would give the state agency additional steps to take where the present Code is ineffective. These additional steps would allow the agency, upon the creation of a critical groundwater area, to not only prohibit the drilling of new wells, but also to either, 1) require that all present pumpers maintain the status quo, or 2) require that all present irrigation pumpers in a critical area equally reduce their groundwater withdrawals.

Besides these additions to the Code we propose that it is also necessary that municipal and industrial users be exempted from only the cut-back provisions. However, all other prohibitions should be applied equally to all users. To meet the demands of a growing population provisions should be made for allowing M & I users to purchase groundwater rights. While the cut-back system offered will have its heaviest effect on the agricultural sector, we do not feel that the entire burden should be placed upon the farmers. In times of water shortage, if M & I users need more water it would be more beneficial to the state if they are required to purchase that water from present users, rather than taking more water out of the ground themselves. In order to implement these provisions it would be necessary for the legislature to declare groundwater rights severable from the land so that the M & I users would not have to begin speculating in land, but would be able to transport the water off the land from which it is pumped. This would be in line with the 1962 Surface Water Law Amendment A.R.S. SEC. 45-172 which provides that surface waters are no longer appurtenate to the lands for which they were originally appropriated.

In A.R.S. SEC. 45-301, "critical groundwater area" is defined as any area "not having sufficient groundwater to provide a reasonably safe supply" to meet the current demands for irrigation. Past history shows that this definition is too indefinite and does not provide a sufficient basis for action by the state agency. It is recommended that clear guidelines be set out by the legislature to enable quick and responsive action to groundwater shortages. Acting on this more detailed definition, the state agency will be able to act in the public interest and apply the prohibitions outlined before the groundwater withdrawals equal crisis proportions.

Not only must there be a sufficient public interest in utilizing the cut-back system, but also the cut-backs themselves must be reasonable and carried out in the least injurious manner possible. Therefore, we recommend that limitations be placed upon the severity of the cut-backs so that, for example, the maximum cut-back would be 10 percent of each individuals average amount of pumpage and no further cut-backs can be declared until five years had elapsed. Also, it should be provided that no cut-backs can be enforced until the individual has been given one year notice. The penalties provided in the present groundwater code are sufficient to bring about compliance with the proposed amendments.

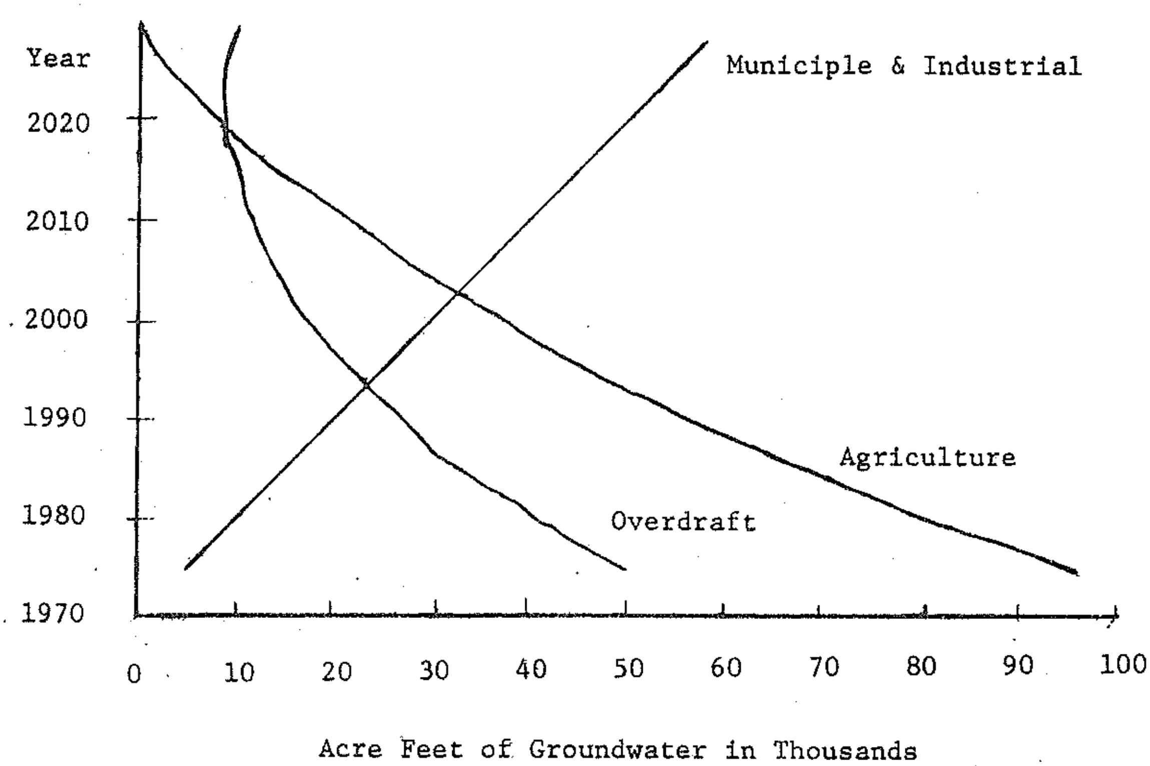
While it is conceded that a 10 percent cut-back on certain marginal farms would force the discontinuance of operations, the majority of farmers would be able to withstand the cut-backs by making more efficient use of the smaller amount of water. After the initial five-year period, if any additional cut-backs are necessary, the groundwater user will have sufficient warning to convert to lower use crops or take other steps if necessary.

Before a cut-back system can be effectively administered it will be necessary for all groundwater pumps to be accurately metered in one manner or another. This will enable the state agency to obtain the information necessary to both decide whether a cut-back is necessary and to enforce the cut-back once it has been declared. The metering of all pumps and the addition of personnel to read those meters would appear to be quite expensive. However, this expense would certainly be justified in light of the water saved and the additional accuracy of this type of information.

The following examples A and B, illustrate the use of the cut-back system:

A. This is a hypothetical area in which the groundwater shortage is such that in 1974 annual pumpage is 100,000 A.F. with only 50,000 A.F. annual recharge. This area has already been declared "critical" under the present code. Assuming a cut-back system has been enacted, the following table illustrates its effect on this hypothetical area

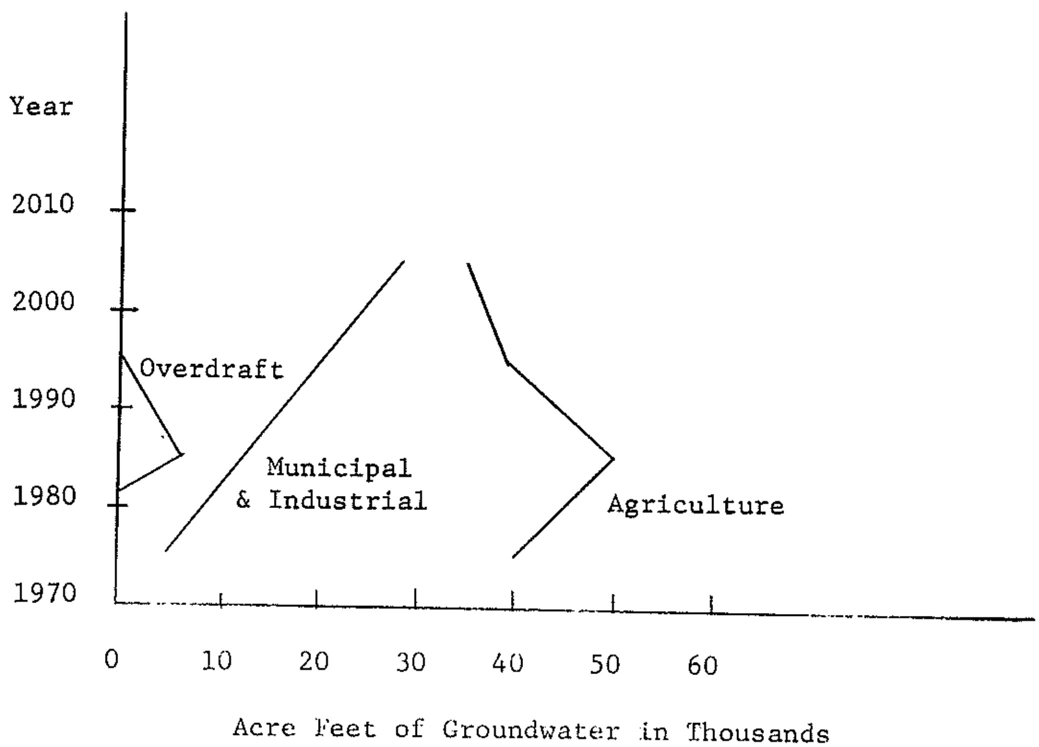
Year	M & I Pumpage	Agri. Pumpage*	Annual Amount of Cut-Back (10%)	Annual Overdraft
1970-74	5,000	95,000	---	50,000
1975-79	10,000	81,000	9,000	41,000
1980-84	15,000	68,400	7,600	33,400
1985-89	20,000	57,060	6,340	27,060
1990-94	25,000	46,854	5,206	21,854
1995-99	30,000	37,669	4,185	17,669
2000-04	35,000	29,402	3,267	14,402
2005-09	40,000	21,962	2,440	11,962
2010-14	45,000	15,266	1,696	10,266
2015-19	50,000	9,239	1,027	9,239
2020-24	55,000	3,816	423	8,816
2025-29	60,000	-	-	10,000



B. This is a hypothetical area in which the annual groundwater pumpage does not yet exceed the annual recharge of 50,000. The area has not yet been declared "critical".

Year	M & I Pumpage	Agri. Pumpage*	Amount of Cut-Back	Annual Overdraft
1970-74	2,000	40,000	-	-
1975-79	4,000	45,000	-	-
1980-84	6,000	50,000	-	6,000
1985-89	8,000	45,200	4,800	3,200
1990-94	10,000	38,880	4,320	-
1995-99	12,000	36,880	-	-
2000-04	14,000	34,880	-	-

* The figures in this column assume that after the designation as a critical groundwater area, all M & I pumpage increases result in an equal reduction of agricultural pumpage.



It can be seen from example A that in an area already experiencing an extreme groundwater shortage, cut-backs in this manner may never completely halt the overdraft. However, we don't believe this means the system is a failure. A major aim of any new groundwater law in Arizona is to gain time to plan and develop new sources of water. Also, it should be noted that we have assumed this area to be one in which there are rapidly increasing M & I uses. The system would be more effective in an area where M & I uses are relatively stable because in our proposal M & I uses are exempt from cut-backs.

Example B shows that this system would effectively control groundwater problems in areas which are not presently experiencing overdrafts. Although this system might seem overly harsh on agricultural users, it must be remembered than any increased uses of groundwater by M & I must be purchased from irrigators. Under the present Code M & I users are allowed to increase groundwater pumping without regard to the injury to agricultural users from lowering groundwater tables.

In the discussion of the proposed prior appropriation system it was noted that there are difficult constitutional questions raised when the state attempts to give priorities among agricultural water rights which were equal before passage of the act. In a system of pro-rata cut-backs these water rights are subordinated to the public interest on an equal basis, thereby eliminating the equal protection argument. As long as the guidelines set out by the legislature are reasonably calculated to bring about cut-backs only when there is a definite public need, any claims of denial of due process must fail. An individual's rights will be subordinated if there is sufficient public necessity.

In the case of a possible cut-back in an over-developed area the users of that area should be given some voice in the determination of the necessity for and the amount of that cut-back. This could be done by adopting provisions similar to A.R.S. SEC. 45-308 allowing initiation of proceedings by a certain percentage of the users in the area.

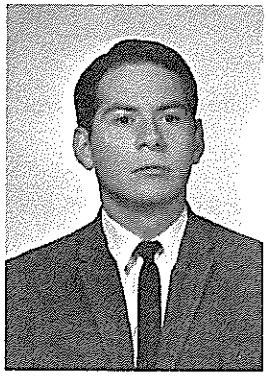
As under the present system, cut-backs would only be utilized as long as necessary. The rights of the groundwater user would not be permanently decreased. If at a later point in time, additional waters become available or other circumstances warrant it the cut-backs could be removed.

With the law and water rights in the state of Arizona as they are now, the authors feel that the pro-rata cut-back system is the most desirable method available to meet the groundwater problem. The equality of application is by far superior to that offered by the prior appropriation system. Under this system the difficult task of dating water rights would be eliminated. The current distinction between percolating waters and other groundwaters would be maintained thereby precluding inevitable litigation. To our knowledge, no other jurisdiction has attempted a pro-rata cut-back system and therefore, Arizona would be in the enviable position of being able to develop its own rules for its own problems.

IMPORTANCE OF THE IRRIGATION OF CORN (*Zea mays*, L.)
DURING ITS MAXIMUM RATE OF TRANSPIRATION PERIOD

Jose Macias Quintana and Jaime Leal Diaz[1/]

Biographical Sketch



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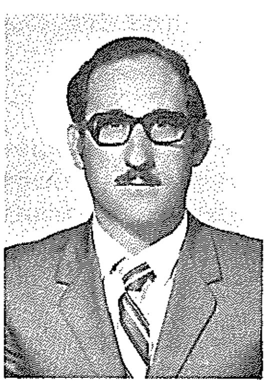

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Summary

Three different states of plant development were considered to apply irrigation during the maximum potential rate of transpiration period: Preflowering, flowering and postflowering, 70, 82 and 91 days after seeding respectively.

All the combination possibilities to apply irrigation were included. The treatments were distributed at random, replicated four times and the results were analyzed statistically.

It is presented data of soil properties, consumptive use, plant growth and grain production.

Preflowering irrigation did not affect plant growth or grain production; however, flowering and postflowering irrigation increased significantly grain production.

Apparently rainfall canceled preflowering irrigation need.

The consumptive use during the irrigation period studied was similar in all treatments, getting extreme values of 33.4 and 39.4 cms. It was obtained a linear correlation of 0.93 between grain production and water transpired from the upper 20 cms of soil, arriving to an apparent transpiration efficiency of about 2 cms per ton of grain.

Introduction

Grain production of corn can be increased avoiding water deficits during its maximum rate of growth period which corresponds in most of the cases, to its maximum rate of potential transpiration period.

In our local conditions, spring corn receives three applications of water during that period, independently of soil properties, atmospheric conditions and plant growth, and it is not known the real importance of every one of these irrigations. The objective of this research work was to find out the effectiveness of an irrigation program for the maximum rate of growth period in corn production.

Robins and Domingo (8) did not find significant difference in grain production between irrigated and not irrigated corn blocks when considering water application before flowering. The soil of the not irrigated blocks reaches 15% available moisture and the irrigated ones to a minimum of 60% available moisture. However, during and after flowering, water deficits were critical. It was observed a yield decrease of 22 to 50% by letting dry the soil once to wilting point. They arrived at the conclusion that the most critical period was flowering due to the effect on receptivity of the stigma and the reduction of corn ear size.

Howe and Rhoades (4) obtained yield of 9.94 tons/Ha with six water applications, keeping the soil moisture above 40% available moisture. The blocks receiving three irrigations from one week before flowering to one week after completion of flowering produced 9.36 tons/Ha of grain. When irrigation was reduced during that period the yield decreased significantly. Water deficit before flowering did not reduce grain production that much but delayed flowering.

Similar results had been reported by Cordner (1), Nelson (6), Hernandez and Laird (3), Rhoades and Nelson (7) and MacGillivray (5).

Haynes (2) observed that corn growth depends on soil moisture so much that there is a direct and linear relationship between dry matter produced and water transpired. Similarly Vega (9) reported that in sorghum grain production and foliage weight is related linearly to water transpired. On the other hand, root development and distribution is affected by soil moisture and in general it has been observed according to Rhoades and Nelson (7) that root explore mainly the upper levels of soil when grown in high moisture conditions.

Methods and Materials

The experiment was established in the Experimental Station of the Institute of Technology of Monterrey, in an area characterized by a calcareous soil, 3 ft. deep, underlayed by a caliche stratum, clay loam, with an apparent density of 1.3 g/ml at the surface to 1.76 g/ml at 3 ft. depth, 1 to 2% of organic matter and a changing pH from 7.2 to 8.3 (10).

The crop was corn of the variety Nuevo Leon VS-1, which is about 8 ft. high, and has 140 day cycle.

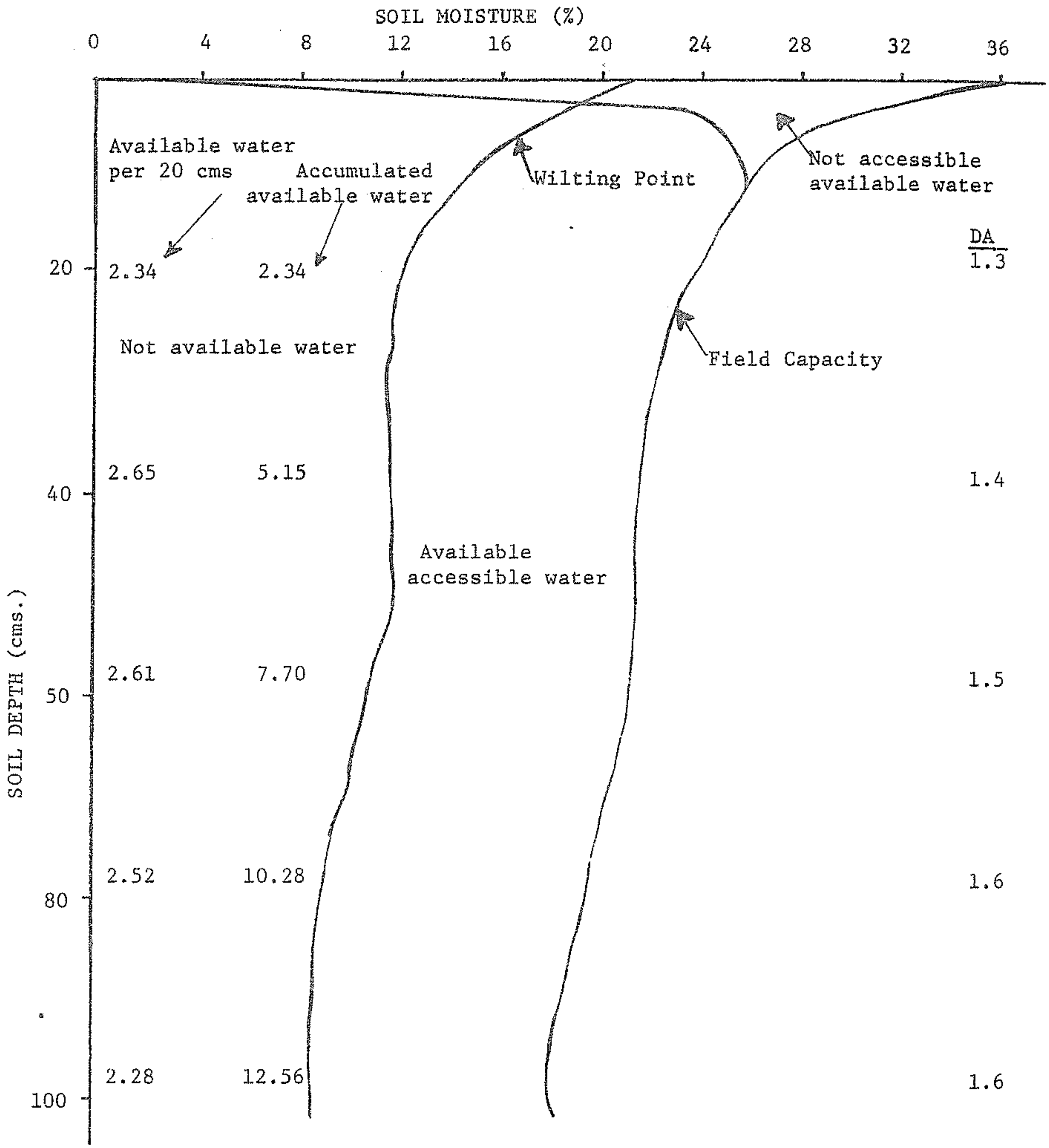
The treatments included consisted of applying irrigations at three different growth states: a) Preflowering (P), b) Flowering (F), and c) Postflowering (E) or 70, 82 and 91 days after seeding time. There were included all the combinations possible, that is 8 different treatments. Before the critical period studied, the field received 3 applications of water at seeding time and 14 and 56 days after respectively.

The experimental design was random block, included 4 replicates and the effective experimental unit was 3 rows of 25 ft. long.

The water retention characteristics of the soil are indicated in Figure 1.

The effects of the variable studied were determined by grain production and height of the plants and related to water evapotranspired, rainfall and air moisture and temperature.

Figure 1. Field Capacity, Wilting Point, Not Accessible Available Water, Available Accessible Water, Not Available Water and Apparent Density of the Soil.



Experimental Results

Grain production. The grain weights were calculated on 15% moisture bases. The effects of the treatments are expressed in the following table:

Table 1. Grain production in relation to the application of water at different states of growth.

Treatment	Grain Production Tons/Ha	Relative Grain Production %
P + F + E	5.57	121
P + F + O	5.12	112
O + F + E	5.40	118
P + O + E	5.32	116
P + O + O	4.42	96
O + F + O	5.19	113
O + O + E	5.11	111
O + O + O	4.59	100

P = Preflowering
F = Flowering
E = Postflowering
O = Without irrigation

D.M.S. 0.05 = 0.60 to 0.68 Tons/Ha

Plant height. To determine the irrigations effects on plant height, five plants at random were measured up to the tassel. It was found no significant difference between treatments and plant height oscillated between 10.3 to 10.6 ft.

Water evapotranspired. It was determined by soil sampling before and after irrigation and considering rainfall. The corresponding values during the total growth period were the following:

Table 2. Water applied expressed in centimeters considered to be evapotranspired and total rainfall occurred.

Treatment	Days After Seeding Time 14	56	70	82	91	118	Total a	Rainfall cms Total b	Total a + b
P + F + E	2.0	4.96	3.31	4.54	2.60	3.49	20.90	16.96	37.86
P + F + 0	2.0	4.96	3.31	4.54	-	6.03	20.84	16.96	37.80
0 + F + E	2.0	4.96	-	6.41	2.42	3.54	19.33	16.96	36.29
P + 0 + E	2.0	4.96	3.31	-	2.43	4.73	22.43	16.96	39.39
P + 0 + 0	2.0	4.96	3.31	-	-	6.13	16.40	16.96	33.36
0 + F + 0	2.0	4.96	-	6.41	-	6.57	19.94	16.96	36.90
0 + 0 + E	2.0	4.96	-	-	7.54	5.93	20.43	16.96	37.39
0 + 0 + 0	2.0	4.96	-	-	-	9.78	16.74	16.96	33.70

P = Preflowering
F = Flowering
E = Postflowering
0 = Without irrigation

No statistical analysis was possible since soil sampling was made only in one replicate.

Total irrigation varied from 16.40 to 22.43 cms and total rainfall was 16.96 cms. Rainfall occurred in 31 days during the 118 days of the growth period; however, only in 13 days occurred rainfall higher than 0.5 cms. The distribution of water applied artificially or received naturally is indicated in Figure 2.

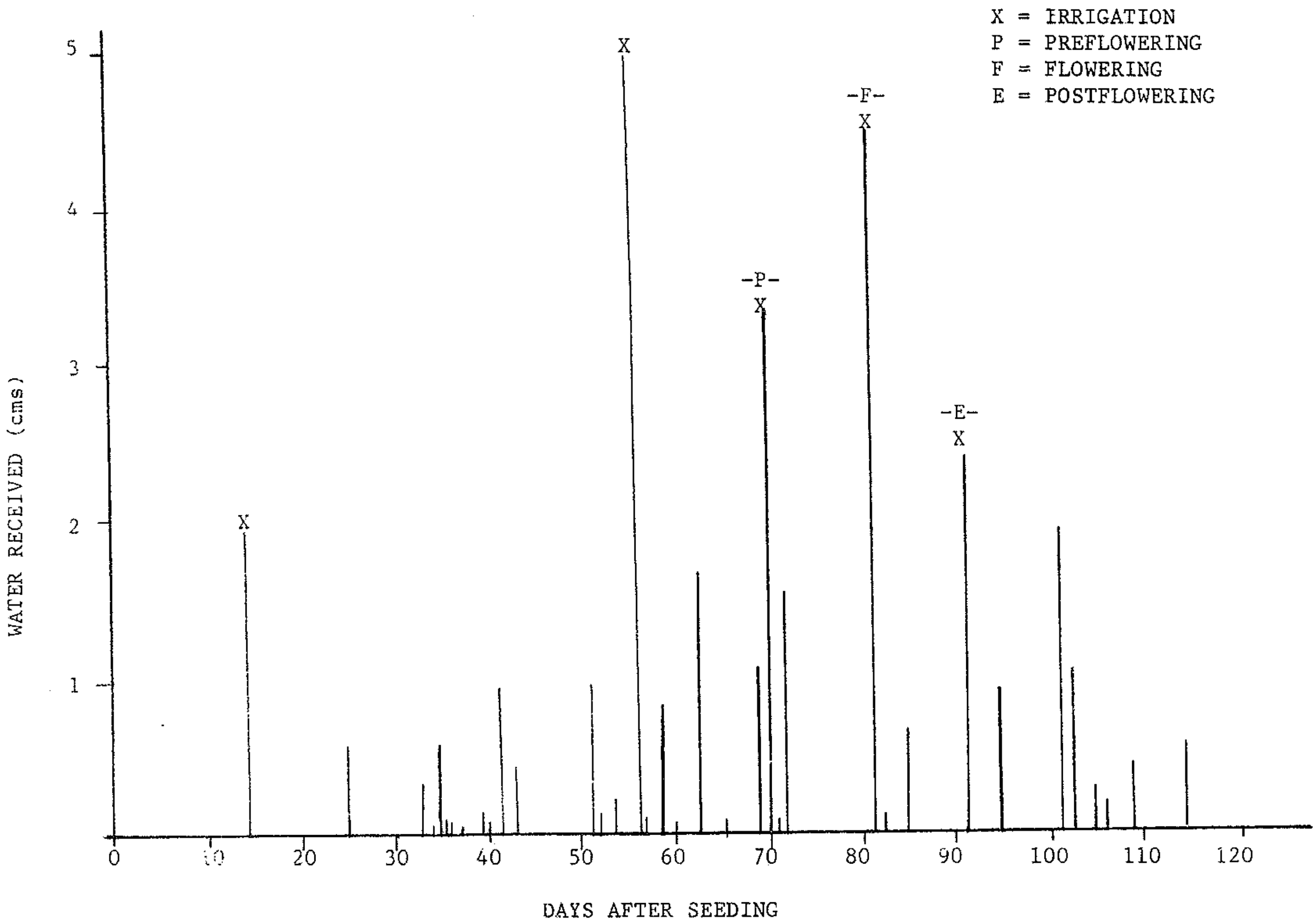


Figure 2. Rainfall and Irrigation Water Captured by the Soil During the Total Growth Period of Corn.

Discussion

Although soil water deficit never was lower than 60% of the available moisture, corn response to irrigation during the most intense transpiration period was significant. The referred influence on grain production is indicated in the following table:

Table 3. Grain production as related to irrigation during most intense transpiration period.

Irrigation	Treatments Compared	Increment Ton/Ha
Preflowering	P + F + E vs. F + E	0.17
	P + F vs. F	-0.07
	P + F vs. E	-0.21
	P vs O	-0.17
Flowering	P + F + E vs. P + E	0.25
	P + F vs. P	0.70 +
	F + E vs. E	0.29
	F vs. O	0.60 +
Postflowering	P + F + E vs. P + F	0.45
	F + E vs. F	0.21
	P + E vs. P	0.90
	E vs. O	0.52
Preflowering and flowering	P + F + E vs. E	0.46
	P + F vs. O	0.53
Preflowering and postflowering	P + F + E vs. F	0.38
	P + E vs. O	0.73 +
Flowering and postflowering	P + F + E vs. P	1.15 +
	F + E vs. O	0.81 +
Preflowering, flowering and postflowering	P + F + E vs. O	0.98 +

+Significantly different at 5% error level.

P = Preflowering
F = Flowering
E = Postflowering
O = Without irrigation

Preflowering irrigation. (P) It was not necessary since the differences observed never were significant, this is explained because soil available moisture deficit was 18%, rainfall occurred 6 days (3.98 cms), mean temperature was 26.1° C and when not applied in combination with the other two irrigations its effect is masked by the corresponding to the other irrigation.

Flowering irrigation. (F) This irrigation was considered important for grain production especially when preflowering irrigation was not applied and relatively less determinant of production when postflowering irrigation was excluded. This is probably a consequence of the strong influence of the postflowering irrigation on grain production and related to high air moisture influence period (Mean of 71.8%) and moderate temperature during the corresponding influence period (27.3°C).

Postflowering irrigation. (E) Highly determinant of grain production when flowering irrigation was not applied (900 Kgs/Ha) and preflowering irrigation occurred. When these two irrigations were excluded its influence is less (520 Kgs/Ha), since yield was limited by flowering irrigation, phenomena also observed by Howes and Rhoades (4) and Robins and Domingo (8).

According to the experimental results the highest yields were obtained when flowering and postflowering irrigations were applied.

Consumptive Use.

To study the relationship between water evapotranspired and grain production, water loss as vapor was separated in two fractions: water lost immediately after irrigation or after a rainfall, normally during the following 48 hours, called in this study as Not Accessible Available Moisture and water lost later named Accessible Available Moisture. The corresponding values are indicated in Table 4.

Table 4. Consumptive use, not accessible available moisture, accessible available moisture and water efficiency of corn when receiving preflowering, flowering or postflowering irrigations.

	C.U. cms a	Not Acc. Available Moisture cms	Acc. Available Moisture cms b	Grain Production Ton/Ha	Water Efficiency cms/Ton a	b
P + F + E	37.86	6.54	31.32	5.57	6.8	5.6
P + F + 0	37.80	5.45	32.35	5.12	7.4	6.3
0 + F + E	36.29	5.45	30.84	5.40	6.7	5.7
P + 0 + E	39.39	5.45	33.94	5.32	7.4	6.4
P + 0 + 0	33.36	4.36	29.00	4.42	7.5	6.6
0 + F + 0	36.90	4.36	32.54	5.19	7.1	6.3
0 + 0 + E	37.39	4.36	33.03	5.11	7.3	6.5
0 + 0 + 0	33.70	3.27	30.43	4.59	7.3	6.6

Highest efficiencies were observed when flowering and postflowering irrigations were applied, and practically constant efficiency is obtained in the rest of the treatments. From these two irrigations postflowering was especially important.

In order to explain the results from another point of view, it was determined the accessible available moisture consumed from the different depths of soil and related to grain production, finding an apparent relationship between water coming from the upper 20 cms of soil and grain production given by the regression = 3.85 + 0.51 X and a correlation of r = 0.93. This supports the idea that yield was determined mainly by the accessible available moisture lost by the crop mostly by transpiration from the upper layer of soil, observation referred for sorghum in the same soils by Vega (9).

Conclusions

Apparently the postflowering irrigation was the most important for an efficient grain production, followed by the flowering irrigation.

Grain production relates directly to consumptive use considering total evapotranspired water or only that accessible available moisture lost as vapor, probably most by transpiration.

From the total water evapotranspired that accessible available moisture coming from the upper 20 cms of soil relates directly to grain production with a slope value of 0.51 Tons/cms or 1.96 cms/Ton supporting that this is the most effective water.

REFERENCES

1. Cordner, H. B. 1942. The Influence of Irrigation Water on The Yield and Quality of Sweet Corn and Tomatoes With Special Reference to The Time and Number of Applications. Proc. Amer. Soc. Hort. Sci. 40:475-481.

2. Haynes, J. L. 1948. The Effect of Soil Moisture Upon Vegetative Growth and Water Use in Corn. J. Amer. Soc. Agr. 40:385-395.

3. Hernandez, S. R. and R. J. Laird. 1958. La Humedad del Suelo en la Primavera Parte del Ciclo en Relacion al Rendimiento del Maiz. S. A. G. Tech. Bull. 33, 1-16, Mexico.

4. Howe, O. W. and H. F. Rhoades. 1955. Irrigation Practice for Corn Production in Relation to Stage of Plant Development. Soil Sci. Soc. Amer. Proc. 17: 94-98.

5. MacGillivray, J. H. 1949. Effect of Irrigation on the Growth and Yield of Sweet Corn. Proc. Amer. Soc. Hort. Sci. 54: 330.

6. Nelson, L. B. 1956. The Mineral Nutrition of Corn as Related to Its Growth and Culture. Adv. of Agron. 8: 363-368.

7. Rhoades, H. F. and L. B. Nelson. 1955. Growing 100-Bushel Corn with Irrigation. The 1955 Yearbook of Agriculture. U. S. Dept. of Agric. Washington pp. 394, 400.

8. Robins, J. S. and E. E. Domingo. 1953. Some Effects of Severe Soil Moisture Deficits at Specific Growth Stages of Corn. Agr. Jour. 45: 618-621.

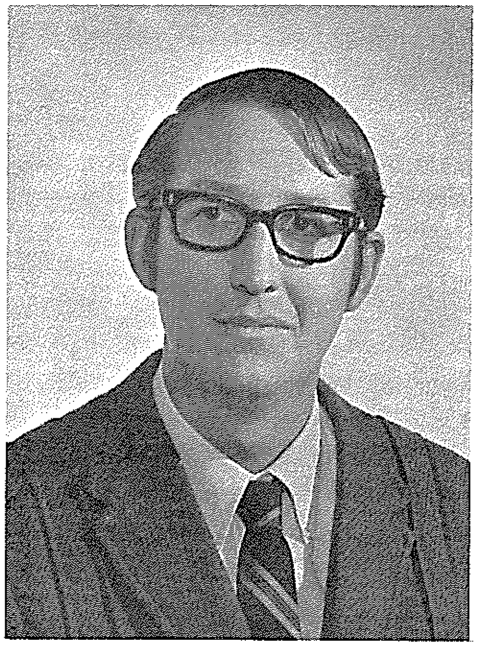
9. Vega-Gutierrez, J. D. 1968. Comportamiento del Sorgo (Sorghum vulgare, L.) en Funcion de la Humedad Disponible en el Suelo. Tesis sin Publicar. Inst. Tec. Est. Sup. de Mont. Monterrey, N. L., Mexico.

10. Villaverde Garcia de Leon, J. H. 1963. Estudio de Algunas Propiedades Quimicas del Suelo en El Campo Agricola Experimental de Apodaca del Inst. Tec. Est. Sup. de Mont. Monterrey, N. L., Mexico.

ANTITRANSPIRANTS: A POSSIBLE ALTERNATIVE TO THE ERADICATION OF SALTCEDAR THICKETS

Robert S. Cunningham[1/]
David B. Thorud[2/]

Biographical Sketch



In May, 1970, I graduated from the University of Arizona, with distinction, receiving a Bachelor of Science degree in Agriculture from the Department of Watershed Management under the Department's hydrology option. As an undergraduate assistant I was involved in data collection for two snow management studies as well as greenhouse and laboratory work with antitranspirants. My graduate studies are directed toward saltcedar antitranspirant investigations.

I am a member of Alpha Zeta national agricultural honorary, and a student member of the Society of American Foresters.

After completion of my graduate work at Arizona, I will be actively pursuing a career in land management.

Background

The demand for water in the arid West has resulted in various plans for increasing available supplies. One plan involves the eradication of phreatophyte vegetation adjacent to stream channels. Phreatophytes are often large water users because of their direct contact with shallow groundwater tables. Saltcedar (*Tamarix pentandra* Pall.) is a prime example, due to its vast areal extent and high water use which may exceed 180 cm per year (van Hylckama, 1970). Consequently, saltcedar is often the object of eradication management. This report presents a brief review of the motivations for and limitations of eradication, and proposes a possible management alternatives for situations where the retention of saltcedar communities may be desirable.

Tamarix is one of four genera of the *Tamaricaceae* family, native to Africa, Asia, and Europe. Although the taxonomy is somewhat uncertain, *T. pentandra* is believed to be the most common saltcedar throughout the West. *T. gallica* Linn. is another important species found mainly on saline soils near the Texas Gulf Coast. Saltcedar species have spread rapidly since their intro-

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duction into the United States during the early 19th century, and now occupy an estimated 1.3 million acres of river bottom land in the West (Robinson, 1965). In the following discussion, the term saltcedar refers to T. pentandra.

Saltcedar is ecologically adaptive for several reasons. It sprouts prolifically and is capable of producing thousands of seeds throughout its growing season, although the majority are produced during May and June (Horton and others, 1960). Seeds germinate well in saline solutions which would be unfavorable for some competing vegetation (Hulett and Tomanek, 1961). Rapid growth is another competitive attribute. Van Hylckama (1970) reported growth rates as high as 5 cm per day for young shoots in ideal environments. All of the above factors combine to make saltcedar tenacious and difficult to control in moist riparian environments.

The reduction of flood hazards is another motivation for saltcedar eradication, in addition to water salvage. Dense saltcedar thickets can impede bankfull and larger flows and block normal overflow channels. This daming effect causes water to spread over adjacent lowlands. Such flooding has damaged agricultural lands. Channel clearing would reduce this hazard.

Wildlife utilization of saltcedar thickets has become an important consideration in eradication plans; some wildlife organizations have even stopped eradication programs by legal means. White-winged dove, an important game species, and other creatures including some "endangered species" have adapted readily to saltcedar thickets (Manes, 1970). Shaw (1961) outlined the evolution of the white-winged dove's association with saltcedar in the Gila Valley of Arizona. The clearing of mesquite bosques for agriculture prior to 1940 in combination with hunting during nesting periods almost decimated the dove population. Consequently, a closed summer hunting season was imposed (Arnold, 1943). These events took place at about the time saltcedar thickets were developing into suitable nesting sites. The combination of a closed season, readily available food and water, and new nesting sites enabled a large, concentrated white-winged dove population to become established. The closeness of these areas to an urban center contributed to their excellent hunting characteristics. Regardless of the circumstances resulting in the use of saltcedar thickets by dove, the thicket can be an important habitat for wildlife values. A "green strip" may also have aesthetic value in arid environments.

The application of a harmless foliar spray to reduce plant water use, combined with a limited channelization program, could provide an alternative to eradication which may be agreeable to both wildlife and water interests. Such sprays, antitranspirants, have been used to prevent the wilting of transplants and floral arrangements and to decrease winter desiccation damage (Gale and Hagan, 1966). Antitranspirants that close or narrow stomate apertures have generally been the most successful. Growth rates may be adversely affected if stomate apertures are reduced by treatment, but theoretically transpiration should decrease more than photosynthesis (Zelitch and Waggoner, 1962).

Alkenylsuccinic acids and their derivatives have closed stomata at low concentrations. The unsaturated hydrocarbons of these compounds may affect the lipid layers in plant cells and thereby cause an increase in the cell wall permeability to water (Kuiper, 1964). If the permeability increases, the turgor of guard cells should decrease and this should narrow stomatal apertures. Eight-hydroxyquinoline sulfate (8-HQS), a fungicide and chelating compound, has also reduced transpiration rates. Eight-HQS affects stomate apertures, but its mode of operation is not clear (Zelitch, 1969).

Brooks and Thorud (1971) demonstrated the effectiveness of antitranspirant foliar sprays on saltcedar (T. pentandra) in Arizona. The most successful compounds were: 8-HQS at 0.01M; a combination of the monoglyceryl ester of n-decenylsuccinic acid (GDSA) at 150 ppm and the monomethyl ester of n-decenylsuccinic acid (MDSA) at 150 ppm; and MDSA at 350 ppm. The three compounds reduced transpiration for 20 days by 36, 28 and 29% of control, respectively. However, a growth reduction for treated plants possibly caused some of the decrease in transpiration. Before these antitranspirants can be considered as workable alternatives to eradication, several additional aspects should be investigated, including the effects of retreatment and rainfall.

Methods and Materials

In this study, two greenhouse experiments were performed with saltcedar to evaluate the effects of rainfall and retreatments on the transpiration rates of plants treated with 8-HQS (0.01M) and MDSA (350 ppm). Antitranspirants were mixed in distilled water with 0.5% Triton X-100, a wetting agent. The 1st experiment was done in August 1970 and the 2nd from October through November 1970 in a greenhouse at Tucson. Plants were grown from stem cuttings taken on the Gila and San Pedro river flood plains. The plants were potted in sandy soil and were watered with nutrient supplement (Mace, 1968) once each week. Soil water levels were maintained near field capacity by adding sufficient water each evening. The effects of soil water stress on transpiration were probably minimized by this procedure. The soil was sealed with plastic sheeting during the day to prevent evaporation, but the sheeting was opened at night to facilitate gas exchange. Transpiration was measured gravimetrically with a solution balance of 1 g accuracy. Plant-pot weights were measured in the morning and evening to determine daily transpiration.

Rainfall was simulated for both experiments by spraying distilled water on foliage from an overhead sprinkler. The duration and intensity of each simulated rainfall event were 15 minutes and 15 cm per hour, respectively.

In experiment 1, 72 plants were assigned permanent bench positions, and pretreatment transpiration rates were determined. These plants were 7-months-old and averaged 80 cm in height. The average pre-treatment transpiration rate was 293 g per day for 4 days. Of the 72 plants, 36 were selected for study and were grouped into 6 blocks of 6 plants each. Plants with similar transpiration rates were placed in the same block. Each block was then subdivided into 2 groups of 3 plants each. In each subgroup, 8-HQS was applied to 1 plant, MDSA to another and the 3rd was left untreated as a control. The antitranspirants were hand-sprayed on foliage outdoors at midmorning, under full sunlight and in still air. One subgroup in each block received the simulated rainfall 1 day after the antitranspirant treatments. Minimum and maximum daily air temperatures averaged 22° and 33° C during the post-treatment period. Minimum and maximum relative humidities averaged 39 and 73%.

The statistical design of the 2nd experiment was identical to that of the 1st; however, other factors differed. The plants for experiment 2 were obtained from the same locations, but were only 4-months-old and 50 cm in height. Thirty-six plants were selected from a total of 42. The average pre-treatment transpiration rate was 39 g per day. The greenhouse was artificially heated and sunlight was supplemented by 2 banks of florescent lights on 12-hour cycles. Antitranspirants were applied in the greenhouse at midmorning, under the florescent lights and in still air. A 2nd antitranspirant treatment was similarly applied 13 days after the initial treatment. Simulated rainfall was applied to 1 subgroup of each block 2 days after the initial treatment, and again 4 days after the 2nd treatment. Minimum and maximum daily air temperatures averaged 17° and 26° C during the post-treatment period. Minimum and maximum relative humidities averaged 29 and 56%. Transpiration measurements were terminated 31 days after the 2nd treatment when treated and untreated plants began to show signs of winter dormancy. Plants were cropped 17 days after transpiration measurements ended and oven-dry weights of foliage were determined.

The data for both experiments were analyzed for each sampling date by analysis of variance and the Duncan's new multiple range test at alpha levels of 0.05.

Results

Effects of Treatments Without Rainfall

The mean daily transpiration rates of plants receiving a single application of 8-HQS were 29 to 46% less than control for 5 to 7 days (Table 1). For 1 application of MDSA, the transpiration rates were 42 to 47% less than control for an additional 15 to 31 days (Table 1). Thus, the transpiration rates of plants receiving 2 treatments of 8-HQS and MDSA were 32 to 38% less than control for a total of 3 to 5 weeks (Figures 1 and 2).

Table 1. Summary of statistically significant responses for 8-HQS (0.01 M) and MDSA (350 ppm) treatments ($\alpha = 0.05$).

Experiment Identification	Anti-trans-pirant	Mean Reduction In Transpiration (%) rain	Mean Reduction In Transpiration (%) no rain	Treatment Duration (Days) rain	Treatment Duration (Days) no rain
Experiment 1	8-HQS	28	29	4	5
	MDSA	39	47	10	13
Experiment 2 1st treatment	8-HQS	27	46	5	7
	MDSA	37	42	7	7
Experiment 2 2nd treatment	8-HQS	28	35	3	31
	MDSA	37	27	3	15
Experiment 2 overall effect of the 1st and 2nd treatments	8-HQS	27	38	8	38
	MDSA	37	32	10	22

Effects of Treatments With Rainfall

Rainfall effects were also evaluated by considering both the magnitude and duration of transpiration change following treatment with antitranspirants. These analyses were inconclusive for both 8-HQS and MDSA.

A total of 27 post-treatment days were analyzed in experiments 1 and 2. The rained-on plants transpired significantly less than plants receiving no rain on only two days for 8-HQS. No differences were significant for MDSA.

Analyses of treatment duration gave more variable results. In experiment 1, the transpiration rates of rained-on plants treated with 8-HQS were less than control for four days; while the duration for plants receiving no rain was five days (Table 1). For MDSA these values were 10 and 13 days, respectively. After the initial treatment with 8-HQS and MDSA in experiment 2, the durations for rained-on plants and those receiving no rain varied from five to seven days. None of these differences are considered important. However, the effect of rain seemed to be more pronounced following retreatments with 8-HQS and MDSA in experiment 2. Transpiration rates of rained-on plants were lower than control for only three days following retreatment (Table 1). In contrast, plants receiving no rain transpired less than control for 15 to 31 days following retreatment (Figures 1 and 2).

Effects of Treatment on Growth and Appearance

The dry weights of foliage from treated and control plants were not significantly different 48 days after retreatment in experiment 2. However, these growth determinations were based on limited measurements and are therefore only a crude index. The treated plants in both experiments showed no significant color or form differences in comparison to untreated plants during or after the experiments.

Discussion

Antitranspirants should be effective in reducing plant water use, harmless to the environment and economical, to be useful as a water salvage tool. The antitranspirants tested in this study were effective in reducing plant water use, but simulated rainfall may have shortened the duration of treatment effectiveness in one case. Rain appeared to have no influence on treatment effectiveness in other tests. Consequently, questions concerning rainfall remain unanswered. Even if rainfall is important under field conditions, there may be times when antitranspirants could be used effectively. For example, rainfall is usually light and water use by saltcedar is high during late spring runoff periods and early summer in Arizona. Applications of antitranspirants at this time may increase available water supplies.

An important requirement is that antitranspirants be harmless in the environment. No damaging effects of 8-HQS or MDSA on saltcedar were detected in our experiments. The plants appeared to remain healthy even after two successive applications. But this analysis involves only one phase of the environment. Other factors including human health, wildlife and water quality should be thoroughly investigated before antitranspirants are applied operationally.

The total expected cost of an operational treatment program has not been estimated. Eight-HQS and MDSA are used in small quantities and are relatively inexpensive, but many other costs must also be considered.

The experiments with antitranspirants on saltcedar have progressed to the point where field studies should be performed in natural thickets. The experimental conditions should permit measurement of treatment effects on groundwater depletion, plant condition, water quality, particularly if surface water is present, and possibly other environmental factors.

Summary

Considerable controversy concerning the eradication of saltcedar thickets for water salvage and flood control indicates that a management alternative may be desirable for some situations. The application of antitranspirants to saltcedar foliage may provide such an alternative.

In this study, the antitranspirants 8-HQS (0.01 M) and MDSA (350 ppm) were sprayed on the foliage of potted saltcedar plants in a greenhouse at Tucson. The transpiration rates of treated plants were 29 to 47% below control for 5 to 13 days after single applications of the compounds. Following a retreatment, the treated plants transpired 27 to 35% less than control for an additional 15 to 31 days. Consequently, plants receiving two treatments transpired less than control for a minimum of three weeks. These are considered important treatment effects.

Conceivably, rainfall could diminish treatment effectiveness. To test for rainfall effects, simulated rain was sprayed on plants in the greenhouse on the 1st, 2nd or 4th day after treatment with antitranspirants. These studies were inconclusive. Generally, rain did not change the magnitude of transpiration reduction following treatment with antitranspirants. Likewise, rain did not cause important changes in the duration of transpiration reduction in two tests. In another test, however, plants receiving rain transpired less than control for three days, while plants receiving no rain transpired less than control for 15 to 31 days. A rain-no rain difference of this magnitude could be important in an operational treatment program.

The growth, color and form of plants that were treated with one and two applications of 8-HQS and MDSA were not noticeably different from control plants during or after the experiments.

Acknowledgements

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REFERENCES

1. Arnold, L. W. 1943. The western white-winged dove in Arizona. The Arizona Game and Fish Comm. Pittman-Robertson Project Arizona. 9-R, 103 pp.

2. Brooks, K. N. and D. B. Thorud. 1971. Antitranspirant effects on the transpiration and physiology of tamarisk. Water Resources Research (in press).

3. Friedman, J., Z. Shapira, and Y. Waisel. 1965. Tamarisk, a promising tree for fuel-break in Israel. Israel Journal Bot. 14: 208.

4. Gale, J. and R. M. Hagan. 1966. Plant antitranspirants. Ann. Rev. Plant Physiol. 17: 269-282.

5. Horton, J. S., F. C. Mounts, and J. M. Kraft. 1960. Seed germination and seedling establishment of phreatophyte species. U. S. Dept. Agr., Forest Service, Rocky Mtn. Forest and Range Exp. Sta., Sta. paper No. 48, 26 pp.

6. Hulett, G. K. and G. W. Tomanek. 1961. Effects of some environmental factors on germination of salt cedar (Tamarix pentandra Pall.) Trans., Kansas Acad. Science. 64 (2): 96-101.

7. Kuiper, P. J. C. 1964. Water transport across root cell membranes: effect of alkenylsuccinic acids. Science 143 (3607): 690-691

8. Mace, A. C., Jr. 1968. The influence of climatic, hydrologic, and soil factors on evapotranspiration rates of tamarisk (Tamarix pentandra Pall.). Ph.D. Dissertation, University of Arizona. 104 pp.

9. Manes, R. R. 1970. Threatened species doomed. In the Fatal Future, an Arizona Game and Fish Dept. publication. 25 pp.

10. Robinson, T. W. 1965. Introduction, spread and areal extent of salt cedar (Tamarix) in the Western States. U. S. Geol. Survey Prof. Paper 491-A. 12 pp.

11. Shaw, H. 1961. Influence of salt cedar on white-winged doves in the Gila Valley. Arizona Game and Fish Dept. Game Mgt. Div. Special Report. 9 pp.

12. van Hylckama, T. E. A. 1970. Water use by salt cedar. Water Resour. Res., 6 (3): 728-735.

13. Zelitch, I. 1969. Stomata control. Ann. Rev. Plant Physiol. 20: 329-350.

14. Zelitch, I. and P. E. Waggoner. 1962. Effect of chemical control of stomata on transpiration and photosynthesis. Proc. Natl. Acad. Sci. 48 (7): 1101-1108.

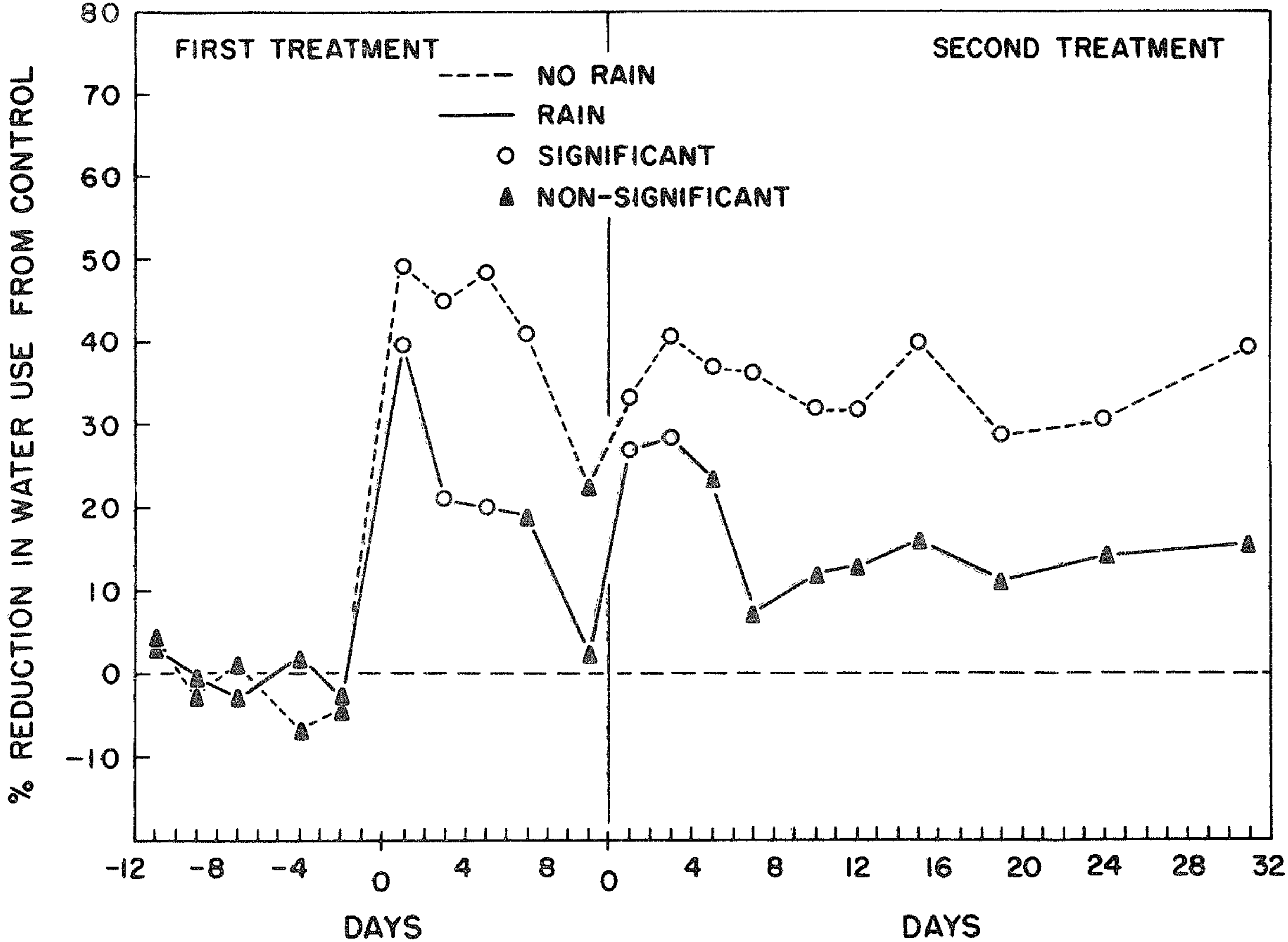


Figure I. Comparison of 8-HQS (.01 M) treatment and retreatment response. Treatments applied on days represented by zero.

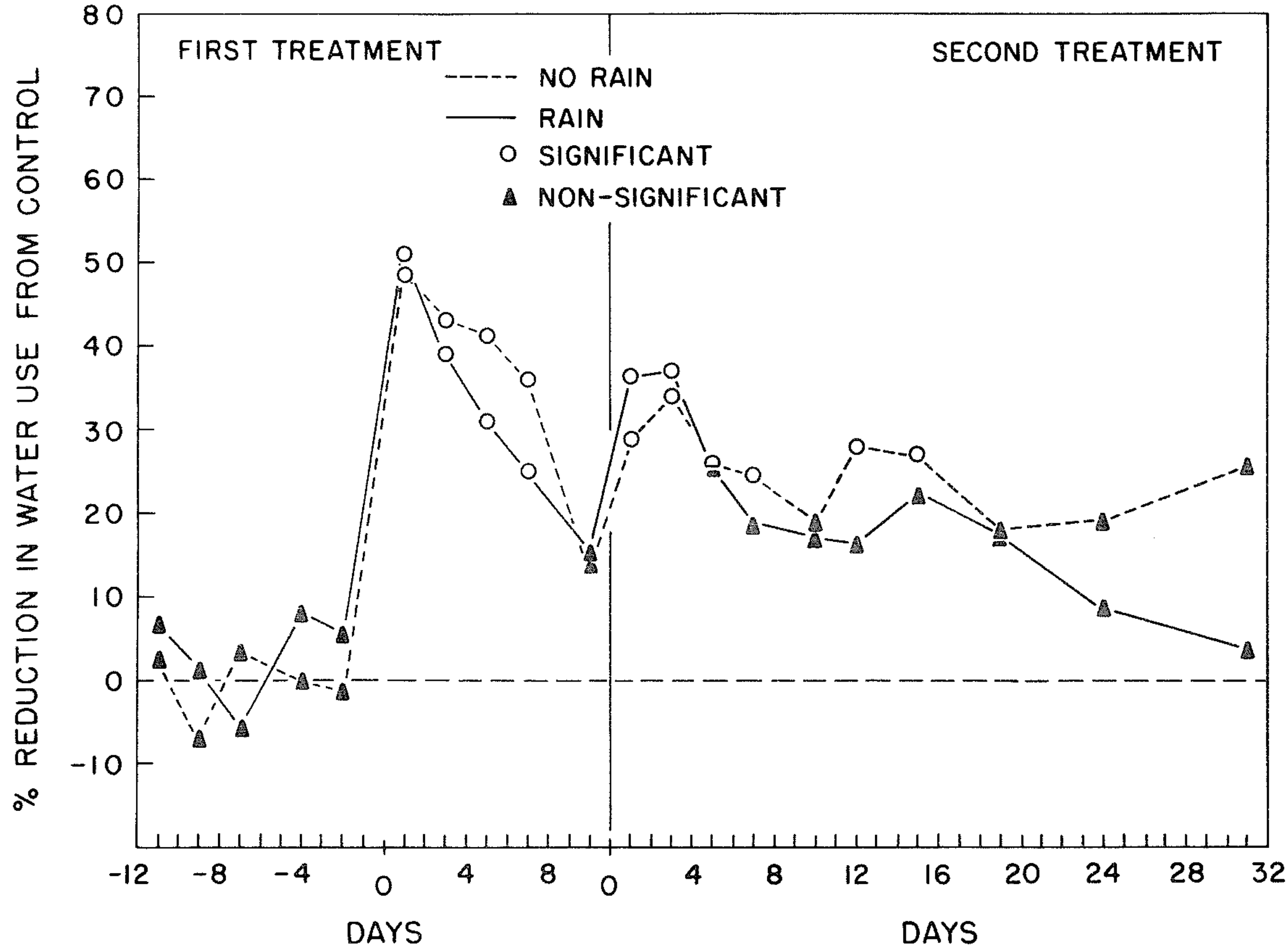
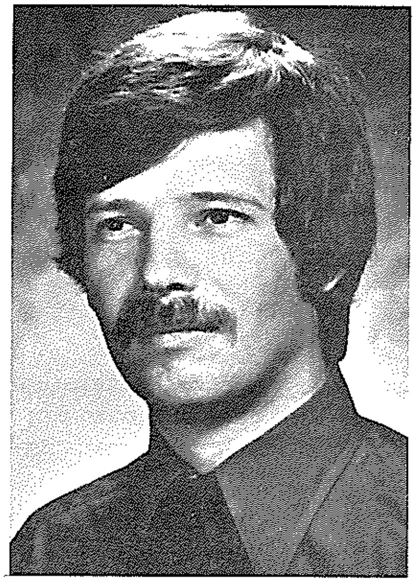


Figure 2. Comparison of MDSA (350 ppm) treatment and retreatment response. Treatments applied on days represented by zero.

SEDIMENT: THE CRITICAL ASPECT OF FUTURE WATER QUALITY IN THE ASPEN, COLORADO REGION

David Mann[1/]

Biographical Sketch



I am a senior, graduating in May from the University of Colorado. I will receive two degrees: a B.S. in Civil Engineering and a B.A. in Russian with a minor in political science. Concentrating on water pollution control, I plan work towards an M.S. in Sanitary Engineering at the University of Colorado starting in September, 1971. Army service, 1960-1963, Washington, D. C. Member of student chapters of Chi Epsilon, ASCE, FWPCA, and AWWA. Also a member of the Sierra Club, Trout Unlimited, and the Federation of Fly Fishermen. Single.

Abstract

The new development of resort and transportation facilities in the Aspen, Colorado area will raise the peak population of the Upper Roaring Fork Valley by over 300% by 1985. This development should avoid degrading the Roaring Fork River because of the river's unique importance for recreation.

This paper discusses possible indicators of environmental impact and assesses the present condition of the river based on available information and observations. It is concluded that the ability of the river to endure new development depends largely on the amount and timing of sediment discharges. Turbidity is proposed as an indicator of environmental impact with respect to the river.

The paper examines problems associated with turbidity from an engineering and and ecological point of view, and identifies the principle sources and causes of sedimentation in hilly terrain. Guidelines are given for earth moving and soil protection related to seasonal variations in the aquatic environment.

1/ University of Colorado

Finally, the paper explores the implications of the legal standard on turbidity, and concludes that the quality of the river is protected if the standard is enforced.

Scope of the paper

This paper discusses the environmental impact of the development in the upper drainage of the Roaring Fork River near Aspen, Colorado, from the standpoint of water quality. Concentrating on the turbidity of the river as one index of environmental impact on water quality, although not the only one, we shall examine the sources, effects, and control of sedimentation which development may produce. Finally, we shall compare the limits placed on the turbidity of the river by its ecology, recreational uses, and the law.

Indices of environmental impact

New development planned for the upper drainage of the Roaring Fork River will provide lodging and slopes for 84,000 more skiers by 1985, as a conservative estimate. This increase of about 300% will come from the development of several areas listed in Table 1.

Construction on this massive scale is reasonably expected to have an extensive impact on the local environment. The specifics of this impact, however, are a matter of guesswork unless we have factual comparisons with the environment that existed prior to construction. The task of halting or repairing environmental damage which careless development may cause will clearly limit the freedom of individuals in some respects, so that there is need for decisions to be as well-informed and equitable as possible.

The indices or indicators of environmental impact which may help to guide these decisions should ideally provide a continuous monitoring of conditions, so that adjustments need not wait until a project is completed. (In the case of Aspen development, that would be a waiting period of fifteen years.) The indicators should also meet four other criteria:

1. They should reveal the impact of development on the most important environmental assets and resources.

2. They should reveal this impact as directly and unambiguously as possible.

3. They should allow quantitative comparisons with the conditions before development, from which qualitative comparisons may be deduced.

4. They should be measurable by competent investigators.

The correct indicators would vary with the type of development and the local environmental resources which are to be conserved. In the Aspen region, these are mainly the resources which are used for public recreation. Table 2 lists the resources, some quality criteria related to use, and some of the impact indicators which seem most promising. Individuals rank them in different orders of importance, so that one should attach no significance to the order in which they are listed in Table 2.

Table 1. New Development Being Contemplated for the Upper Roaring Fork Valley, Colorado.

Area		Capacity
Aspen Snowmass	8,000	(now 7,000; total 15,000)
Aspen Haystack	15,000	to 25,000
Aspen Wildcat	26,000	(initially planned 35,000)
Hunter Creek	10,000	
Owl Creek	10,000	to 15,000
Smith Ranch	5,000	to 7,000
Upper Reudi	10,000	
Total:	84,000	to 101,000

Table 2. Vital Environmental Resources and Environmental Impact Indicators for the Aspen, Colorado Region.

Activity	Asset	Quality Criterion for Use	Impact Indicator
Skiing	Slopes; lifts	Lift lines less than 10 minutes long	Injuries per skier day; seasonal basis
Fishing	Roaring Fork River	Angler spacing over six per mile	Turbidity; B.O.D.; Dissolved Solids
Hiking, Camping	Wilderness trails	Hiker spacing over four per mile	Litter density per mile of trail
Touring	View from Highway 82	Visual amenity	Percent open land converted to motels, trailer courts, billboards

Note: To supply data for a Development Plan, an environmental inventory has been in progress since November, 1969, under the direction of Mr. Charles Wolcott of Aspen.

Table 2 lists only three parameters for evaluating water quality; this list may eventually need to be expanded, for the Roaring Fork River will carry three times its present load of sewage effluent. Certainly no single measurement will do for appraising overall water quality, particularly if the sewage treatment units installed are the package-plant type. Such plants typically operate at about 80% efficiency in removing pollutants, but often range from 50% down to 20% efficiency if neglected.

The ecological effects of sewage pollution are both well known and predictable. How severely turbidity affects an aquatic environment, however, depends on the river in question. We do not suggest that turbidity applies equally well to all rivers as an indicator of environmental impact. To learn whether it applies to the Roaring Fork River, we must consider the nature of the river itself, how sediment might enter it, and what effects the sediment would have.

Description of the Roaring Fork River

The upper reach of the river, some 18 miles between Aspen and Basalt and draining a basin of some 500 square miles, is perhaps most remarkable for its productivity. The unusually large fishery which it supports, over 84 pounds per acre, makes the river quite important to the tourist economies of Aspen and Basalt. Table 3 lists the main wildlife of the river. It is typical of mountain rivers in this region, although the Roaring Fork is perhaps better conserved than most other rivers of its size.

The chief uses of the river are now irrigation and fishing, although it once supplied water for gold refineries near Aspen. Drinking water comes from its tributaries, rather than from the river itself.

Table 3. Principal Wildlife of the Upper Roaring Fork River, Colorado.

Animals:	Muskrats Deer Beavers
Birds:	Ducks Herons Water Ouzels
Fish:	Trout Whitefish Sculpins
Aquatic Insects:	Mayflies Caddisflies (The peak biomass density of these organisms (April) is 30 to 35 grams per square meter; samples show even balance among the families down to the confluence with the Crystal River, where siltation has eliminated stoneflies, mayflies, and most of the caddisflies.

Table 4 summarizes the results of monthly tests conducted by the state health department, based on a three-year average. We may assume that the upper reach of the river is actually purer than shown in Table 4; because in the 44 miles from Aspen to Glenwood Springs where the samples were collected, the river passes three towns, swells from the accession of the Frying Pan and Crystal rivers, warms up, broadens out, and becomes considerably more turbid. Certainly the upper reach is clearer, as we see from Figure 2.

Figure 3 shows the mean flows of the upper reach at two points. First, at the Aspen gauging station. Second, at Basalt some 18 miles downstream. The point of this figure is that there is a large accession of tributary flow along the upper reach of the river. The volume of this accession allows us to predict that disturbed soils in the highlands drained by these tributaries will create a good amount of turbidity in the river below.

Table 4. Water Quality Characteristics of the Lower Roaring Fork River, Glenwood Springs, Colorado. Period 1968-1970.

Characteristic	Range	Mean
Temperature	32° to 69° F	43.9° F
pH	7.4 to 9.4	8.0
Dissolved solids	195 to 430 mg/L	273 mg/L
B.O.D.	0.6 to 2.0 mg/L	1.3 mg/L
Total coliform	17 to 3000 /100 ml	1116/100 ml
Dissolved oxygen	varies with temperature;	saturated
Turbidity	varies with flow; see Figure 2.	

We may conclude that the Roaring Fork is a relatively pure, or very mildly polluted mountain river[1/] in a good state of conservation and of much value as an environmental asset. It would make an interesting study to determine its economic worth, although some residents of Aspen regard it as priceless, and we have observed them to treat it as though it were.

Turbidity and environmental impact

We have proposed turbidity as one indicator of environmental impact and briefly described the Roaring Fork River. Let us next consider turbidity itself, from the standpoint of its effects, sources, and control.

A. Measurement of turbidity

Turbidity, the physical measure of light scattering through water, results from suspended solid particles. By far the greatest component of turbidity in natural waters is sediment.

1/ See Smades, 1969.

Turbidity may be measured with either the Jackson Candle, which measures the reduction of transmitted light; or with electronic turbidity meters, which measure the light scattered at some fixed angle. Both techniques are described in Standard Methods. The unit of measurement is the Jackson Turbidity Unit (JTU).

The size of particle transported by water varies roughly with the square of velocity (Leopold, *et al.*, 1964), so that it is not surprising to find that the fuller the river, the more turbid it is, particularly in undisturbed watersheds (Leaf, 1966; Weisel and Newell, 1970). Turbulence keeps most of the finer particles suspended; larger particles bounce and roll along the bottom as bed load when the river reaches about 3/4 bankful (Hynes, 1970).

The net effect is to move the riverbed continuously downstream, where it comes to rest in pools, behind dams, and finally forms deltas projecting into the sea. Our efforts to control this migration fly in the face of inevitable processes which have persisted over geologic time. One may not conclude from this, however, that no harm comes from accelerating these processes; or that attempting to halt them is a waste of money.

B. Prevalence and costs of sedimentation

Turbidity is a much greater pollutant than one might expect, considering the inert nature of most sediment. The cost of clarifying muddy drinking water to the tolerable level of 5 JTU is $15 million per year (NACRF, 1970). A loss of reservoir capacity from siltation of $50 million per year comes at a time when the demand for water supplies is expected to double by the year 2000. The annual volume of sediment transported by water in the United States may amount to about four billion cubic yards, the equivalent of the top 0.4 inch of New Mexico.

The damage to aquatic life is also considerable, although we have no idea what it is worth in dollars. Hynes (1970) and others have observed that silt blankets on stony riverbeds both decrease the fauna and alter it. Very short periods of siltation have reduced the aquatic life of the Oka River in Russia. One study measured a loss in overall productivity of 58% and a 70% decrease of aquatic insects caused by erosion from a highway construction site near the Red Cedar River, Michigan (King and Ball, 1964).

The ecological damage to rivers seems particularly untimely now, when the public demand for outdoor recreation is expected to triple within thirty years (NACRF, 1970). It is temporary, of course; for we know that sediment finally washes downstream, restoring the river to its original state. That is true in the long run only. In the short run, which is the time-scale of living organisms, including people, the sediment may appear to be permanent.

C. Sources and mechanics of sedimentation

There are basically two kinds of erosion: natural and accelerated. The acceleration may be very great. There is evidence, for example, that sediment yields from watersheds undergoing suburban development can be up to 500 times higher than in rural areas (NACRF, 1970). The most careful possible logging in an experimental forest raised the sediment yield about ninefold (Leaf, 1966).

Rainfall has enormous power to dislodge exposed soils. A basin which gets 15 inches of rainfall endures an impact of about one million tons per square mile. The sheet erosion caused by rainfall often comes when the river is low, which greatly aggravates blanketing, bacterial coagulation, and chemical adsorption problems.

Snowmelt, on the other hand, erodes chiefly by means of enlarging its own drainage channels; it also comes in the spring when aquatic organisms are the least vulnerable to turbidity (Hynes, 1970a).

The wash load of turbidity in a stream at any time depends on the rate at which fine particles become dislodged, entrained, and transported from the watershed (ASCE, 1965). This in turn depends mainly on rainfall intensity, ground cover, topographical relief, and the properties of the soil itself, including cohesiveness, size, and specific weight.

The result of all these considerations is that some soils are more erodible than others; but that any soil may be eroded into waterways if it is subjected to enough disturbance.

In summary, we have described briefly the Roaring Fork River, and we have discussed turbidity at some length. We have reviewed the measurement of turbidity; the extent of sediment problems; the damages it can inflict, particularly ecological damages to aquatic life; and last the main causes of accelerated erosion into rivers.

The discussion so far allows us to draw four basic conclusions:

1. That turbidity is sufficiently direct and unambiguous to meet our criteria for indicators of environmental impact. As we have seen, the logging of skiing slopes, clearing of lands for mountain lodgings, building of new roads, and widening of old ones may reasonably be expected to accelerate erosion in the Aspen region. Without a determined and perhaps expensive effort to control it, this acceleration may be great enough to inflict considerable harm on the river.

2. That the main mechanisms of sediment damage would be blanketing, reduction of photosynthesis, and lowering of overall productivity by impairment of sight feeding efficiency. In the presence of three times the current sewage effluent load, bacterial coagulation would heighten the blanketing effects.

3. That the ability of the river to endure extensive development in its drainage basin depends in part on the timing of sediment discharges. That is, the problems caused by sediment are most severe when the river is low, usually in the summer and fall. They are the least severe when the river is high with snowmelt in the spring, for the ecology of the river has evolved under conditions of natural turbidity which are normally prevalent at that time.

4. That turbidity is a central and, to the ecology of the river, a critical aspect of water quality. This is not to say that it alone is sufficient for evaluating the impact of development on the aquatic environment.

D. Control of sedimentation

With these conclusions in mind, let us next consider how engineering skills may serve to control sedimentation in waterways.

This topic has received extensive study since the 1930's from the point of view of conserving reservoir capacity and farmland (ASCE, 1969). Interest in the control of smaller amounts of sedimentation for the sake of water quality is relatively more recent. A 65-page guidebook published last year by the National Association of Counties Research Foundation (NACRF, 1970) gives a good introduction to the problem. A discussion here of the various legal, administrative, and engineering control measures would needlessly duplicate much of the valuable material in this guidebook. Instead, we shall consider briefly the signs of impending erosion problems, and some of the strategies for minimizing them.

1. Indications of sediment problems

The first sign of a problem is likely to be an increase in turbid or muddy runoff after a rainfall (ASCE, 1969). This runoff may be traced upstream to its source to determine whether it is natural or accelerated.

On the land, a first sign is the appearance of V-shaped rills over one inch deep in disturbed soils (Packer and Christiansen, 1964). Shallower rills often start at the tops of slopes but dwindle out; the rills deeper than one inch tend to widen and cut. Observation of various soils and slopes in Colorado shows considerable variation from the one-inch average (plus or minus 75%); but one may take as a rule of thumb that the runoff concentrates enough in rills one inch or deeper to exceed the infiltration capacity of most mountain soils in this region.

These are the two main signs of impending or active erosion, but an experienced eye can usually spot others. For example, any bare, loose embankment may be expected to erode; and whether or not this sediment will enter a watercourse depends on local conditions which one must judge individually, based on common sense and a knowledge of the terrain.

2. Control strategies

The structural measures used in practice to control erosion seek either to dissipate flow energy or to divert it from erodible material. The common structural devices include bench terraces, diversions, downspouts, outlet channels, drop structures, sedimentation dams, and storm drains (ASCE, 1969; NACRF, 1970; McCullough and Nicklen, 1971).

There are also at least six natural impediments to soil transport which are commonly available on construction sites but which are often not utilized.

The following guidelines for logging roads seem to be fully applicable to other earthwork in controlling sediment (Packer and Christiansen, 1964):

1. To minimize the chance for sediment to enter watercourses, avoid disturbing the adjacent soil and cover with equipment. Cuts and fills should be as far away as possible from natural drainage channels.

2. The low point of roads and other graded surfaces should not occur over deep fills.

3. Downspouts may be necessary to protect the face of unstable fills.

4. Logs and slash should be windrowed along the toe of fill areas to trap sediment and dissipate flow energy. Although the faces of fills often have protective rip-rap or vegetative cover, the worst erosion may occur where flows concentrate at the toe. There is no good reason for wasting the slash from right-of-way and cleared lots which could serve to obstruct sediment; yet it is common practice to do so.

Finally, in addition to structural measures, we have operational measures. The imaginative planning of construction phases may frequently take advantage of the seasons to ensure that sediment can only reach the river when it can do the least harm; that is, only during the high-water stages of snowmelt. Slopes should be stabilized with grasses or mulch, and control structures should be in place, before snowmelt ends and certainly before the advent of torrential summer rains.

This principle applies as well to work within live streams. It does not seem to be possible to perform this work during summer or fall without inflicting considerable damage to the river environment. This work should be performed during the late winter or early spring, when aquatic organisms are least vulnerable and before the snowmelt brings heavy ice flows to interfere with construction.

Conclusion: Turbidity and the Roaring Fork River

We have discussed the general problem of sedimentation and some of the control measures which may serve to minimize pollution from sedimentation in rivers. Let us turn finally to the specific case of the Roaring Fork River and the question of what safeguards it has. In other words, does the law protect the river against sediment damages? The whole controversy of pollution and effluent standards is currently receiving much thought, and we do not have a conclusive answer to this question. Instead, we shall briefly compare two ways of interpreting the standard, its implications, and the experience of other states.

The standard on turbidity for the Roaring Fork River reads as follows: (Colorado Water Quality Standards, Section II B, Paragraph 1, c):

> "No turbidity shall exist in concentrations that will impair natural or developed fisheries."

There are at least two ways to interpret the word "fishery" in this rule.

First, it may signify a recreational site; and its impairment would mean that the river is too turbid to be fishable.

Second, the word "fishery" may designate all the aquatic debris, algae, and organisms leading up to fish. Impairment of the fishery in this sense would follow from any increase in turbidity above the historical normal for that time. Significant and noticeable impairment, however, would be associated with the decrease in photosynthesis and sight feeding efficiency which occur at about 5 JTU in the Roaring Fork River.

Both interpretations seem logical, and perhaps both apply. We may conclude in either case that the standard is sufficiently stringent if it continues to be enforced.

There is little doubt that summer and fall turbidities will far exceed the upper safe limit of 5 JTU if the development contractors fail to employ the precautions available to them. In this season, there are enough fishermen on the river to provide continuous monitoring; one may expect that violations of the standard will be traced upstream, reported, and prosecuted. If so, project owners may protect themselves against work stoppages by using pollution abatement engineers (McCullough and Nicklen, 1971), or by otherwise ensuring that their contractors avoid violations of the standard. There is no question that the State Water Pollution Control Division of the health department intends to enforce the standard.

In conclusion, we have seen that turbidity is a significant factor in river ecology and that it may serve as an indicator of environmental impact under certain conditions. Turbidity, however, is only one aspect of water quality, and only one aspect of environmental quality. We should note that the Environmental Protection Agency, which is charged in Executive Order 11514 to develop various indicators of environmental quality, does not rely exclusively on turbidity, or even on water. It seems possible for the Aspen region to undergo considerable crowding, littering, and other forms of degradation without much harm to its river. There may be strips of motels and trailer courts, neon signs, traffic jams, crime, and winter smog without great damage to the river as a recreational asset.

Water, then, is like a key; but not the only key on the ring. To unlock the full potential for a quality environment in America, as we all desire to do, we must turn all of the keys together.

REFERENCES

1. ASCE, 1965. Anon. Sediment transport mechanics: the nature of sedimentation problems. Jour. Hydraulics Div., ASCE, 91, p. 251-266.

2. ASCE, 1969. Anon. Chapter V; sediment control methods. Jour. Hydraulics Div., ASCE, 95, p. 653, 662.

3. Cairns, J., Jr., 1967. Suspended solids standards for the protection of aquatic organisms. Industrial Waste Conference Proceedings, 22, pt. 1, 16-24.

4. Cordone, A. J. and Kelley, D. W., 1961. The influence of inorganic sediment on the aquatic life of streams. California Fish and Game, 47, No. 2, 189-223.

5. Dougal, M. D., 1970. Physical and Economic Factors Associated with the Establishment of Stream Water Quality Standards, V. I, Iowa State University Engineering Research Institute, p. I-103.

6. FWPCA, 1968. Federal Water Pollution Control Administration. Report of the Committee on Water Quality Criteria, p. 21, 34, 46.

7. Heimstra, N. W., Damkot, D. K., and Benson, N. G., 1969. Some effects of silt turbidity on behavior of juvenile largemouth bass and green sunfish. Technical Paper No. 20, Bureau of Sport Fisheries and Wildlife, p. 6.

8. Hynes, H. B. N., 1966. The Biology of Polluted Waters, Liverpool Univ. Press, Liverpool, p. 49-50.
   1970. The Ecology of Running Waters, Univ. of Toronto Press.
   1970a. The ecology of flowing waters in relation to management. Jour. Water Pollution Control Fed., 42, No. 3, p. 419.

9. Kemp, Imgram, and Mackenthun, eds. Biology of Water Pollution. Fed. Water Pollution Control Adm., 1967.

10. King, D. L. and Ball, R. C., 1964. The influence of highway construction on a stream. Research Report No. 19, Michigan State Univ. Agricult. Exp. Sta., East Lansing, Michigan.

11. Leaf, C. F., 1966. Sediment yields from high mountain watersheds, Central Colorado. Research Paper RM-23, Rocky Mtn. Forest and Range Exp. Stn., Fort Collins, Colo.

12. Leopold, L. B., Wolman, M. G., and Miller, J. P., 1964. Fluvial Processes in Geomorphology, Freeman, San Francisco.

13. McCullough, C. A. and Nicklen, R. R., 1971. Control of water pollution during dam construction. Jour. Sanitary Eng. Div., ASCE, 97, No. SA 1, p. 81-89.

14. McHarg, I. L., 1969. Design With Nature, Natural History Press, Garden City, N. J., p. 31.

15. NACRF, 1970. National Association of Counties Research Foundation, Urban Soil Erosion and Sediment Control, Fed. Water Quality Adm., p. G 52 - G 58.

16. Packer, P. E. and Christiansen, G. F., 1964. Guides for Controlling Sediment from Secondary Logging Roads. Intermountain Forest and Range Exp. Sta., Ogden, Utah.

17. Pennak, R. W. and Van Gerpen, E. D., 1947. Bottom fauna production and the physical nature of the substrate in a Northern Colorado trout stream. Ecology, 28.

18. Saunders, J. W. and Smith, M. W., 1965. Changes in a stream population of trout associated with increased silt. Jour. Fisheries Research Board of Canada, 22, No. 2, p. 397.

19. Smades, R. H., 1969. Pollution Investigation of the Roaring Fork River. Water Pollution Control Div., Colo. State Department of Health (mimeo).

20. Tarzwell, C. M., 1965, ed. Second Seminar on Biological Problems in Water Pollution. Taft Sanitary Engineering Center, Cincinnati, Ohio.

21. Tebo, L. B., 1955. Effects of siltation, resulting from improper logging, on the bottom fauna of a small trout stream in the Southern Appalachians. Progressive Fish Cult., 17, p. 64-70.

22. Weisel, G. F. and Newell, R. L., 1970. Quality and seasonal fluctuation of headwater streams in Western Montana. Montana School of Forestry Bulletin 38, Univ. of Montana, Missoula, Montana.

23. Van Beneden, G., and Van Beneden, P., 1966. Le desembouage des lits des rivieres par lait de craie et la lutte contre l'eutrophisation. Centre Belge d'Etude et de Documentation des Eaux, May, 1966, No. 270, p. 227-230.

THE POTENTIAL CONTAMINATION OF SURFACE WATERS BY HERBICIDES

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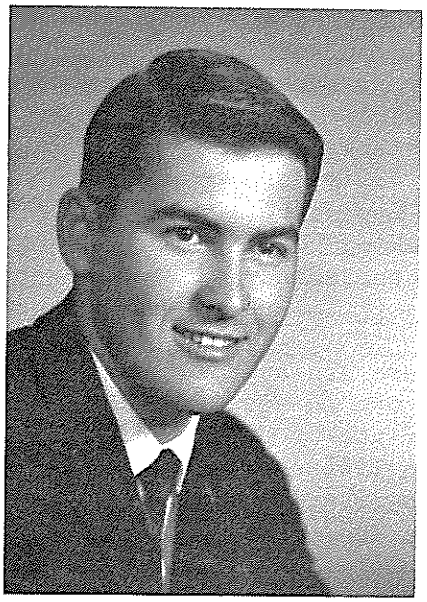
Biographical Sketch



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Abstract. The present demand for maintaining high quality water has created considerable interest in the role of pesticides in water pollution. In addition, there are increased pressures on farmers to return irrigation water without lowering its quality. Prior to 1940 few herbicides existed; at present, there are over 100 herbicides registered. With nearly 400,000,000 pounds of herbicides used annually on cropland and rangeland there is considerable potential for contamination of water sources with these materials. It is imperative that we understand the behavior of herbicides and their degradation products in the environment; particularly those herbicides have proven to be extremely toxic to plant or other living organisms in a water environment. Degradation products also may be more detrimental to aquatic life than the parent material. Picloram in extremely small quantities is toxic to most plants. The movement and the persistence of picloram and its degradation products in water has been studied over a two-year period. Photolytic decomposition occurs with picloram resulting in degradation products. An analytical and a quantitative procedure has been worked out for these products, and will be reported. In addition, the extension of these procedures to study the movement of other herbicides in the environment will be discussed.

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The demand for high quality water has created considerable interest in the role of pesticides in water quality. Although pesticides have increased food and fiber production enormously, there is an increasing concern of these compounds affecting the welfare of non-target organisms. Historically, there has not been a great deal of concern of the impact of pesticides on the environment except by a few individuals; at present we are experiencing the reverse trend, where many individuals or groups of individuals are involved in the decision making processes which may result in drastic and damaging curtailment of the use of agricultural chemicals. It is true that many of the most active opponents base their actions on personal emotion rather than on reputable data. In their opinion, agricultural chemicals are an uncontrollable detriment to the balance of nature and all the same, so consequently we should stop using them. Research has shown that each chemical behaves in the environment in a unique and predictable fashion. If we are to use them effectively and insure that we have control of their movement we must consider each new chemical independently from the rest. By taking this approach it is possible to use agricultural chemicals and to insure the safety of aquatic life, plants, animals and man.

Prior to 1940 few herbicides existed; at present, there are over 100 herbicides registered. Of these, many are registered for use in aquatic weed control including canal and ditchbank weed control. The use of herbicides during the period 1965-1968 increase by 54 percent (14). In 1965 thirteen states reported treatment of 84,000 acres of ponds, lakes, and reservoirs with herbicides, and they reported a need to treat considerable additional acres of waterways (2). As more effective herbicides are developed, it will increase the number of herbicides being used, and also increase the area treated. The potential for contamination is obvious unless we become aware of the conditions for movement and persistence of these chemicals into water and it might be impossible to use them without polluting our waterways. Canal and ditchbank weed control has also been increasing. Since these are applied very near the surface of water, the potential for contamination of water sources is very high. With nearly 170,000 miles of irrigation canals, 190,000 miles of drainage canals, and 21.5 million acres of small lakes and reservoirs in the United States, many of which are treated once, twice or three times annually, there exists a potential for contamination (12). In addition, about 400,000,000 pounds of herbicides are used annually on cropland and rangeland, some enters the irrigation waters and streams by surface runoff and erosion (2).

It is important that we understand the behavior of herbicides and their degradation products in the environment; particularly those herbicides that are used where they may get into water channels. Molecular structure, formulation and dosage rate play an important role in governing the movement of herbicides into water and their persistence. Recent research data has indicated that herbicides do not tend to accumulate in soil or water even under conditions of repeated applications. Frank and Comes (6) could not detect 2,4-D after 55 days when 1.33 ppm was placed in a pond and Faust and co-workers (5) were not capable of detecting 2,4-D within four days of applying a high rate of 20 lb/A to surface waters. Residues do exist for varying periods of time after treatment with most herbicides but are usually of little practical concern since they fall within the allowable tolerances set for the herbicides. Considerable effort is being made to insure that chemicals of high toxicity to aquatic life do not enter waterways. For example trifluralin in water is extremely toxic to fish, but it is applied to the soil and its movement is nearly non-existant because it is strongly adsorbed onto the soil colloid (11). The maximum allowable tolerances for herbicides in water are set by the federal government. A limit of 0.1 ppm has been established for 2,4-D, 2,4,5-T and Silvex (2,4,5-TP) in surface waters (15). Studies involving the control of aquatic weeds indicate that 2,4-D does not persist in high enough concentrations to cause injury to crops. In Oregon, Tarrant and Norris (13) after spraying forest land observed the detectable level of 2,4-D in surface runoff waters to drop to a level of 0.2 ppb in two days. It appears that herbicides do not seriously affect our municiple waters when applied at recommended rates.

Some herbicides have proven to be extremely toxic to plants but safe to most desirable aquatic organisms in a water environment. Diquat, an herbicide for aquatic weed control, is reported to persist in the hydrosoils for a number of years controlling the weeds, but having no affect on the fish (3). The herbicide 2,4-D is used extensively for the control of some undesirable aquatic plants. At recommended rates no serious affects from 2,4-D have been reported.

Picloram is an important herbicide because of its toxicity in small quantities to most plants. It is especially phytotoxic to most broadleaved plants and many natural weedy plants along ditchbanks or on range watersheds. The movement of picloram into water, however, may be especially undesirable due to its extreme toxicity to some plant life. There is also considerable concern in using water containing picloram for subsequent crop irrigation (1).

The movement and persistence of picloram has been studied over a two-year period in Utah. Two experimental watersheds were selected to study the surface movement of picloram (4-amino-3,5,6-trichloropicolinic acid) and 2,4-D (2,4-dichlorophenoxyacetic acid) in runoff waters. One watershed located in Wasatch county, Utah, consisting of a mixed grass sward on a loam soil, was divided into two half-acre plots. One plot was treated with ½ lb/A picloram (formulated as the potassium salt of picloram) and the remaining plot was treated with 2 lb/A (ai) 2,4-D (formulated as alkanolamine salt of 2,4-D).

The second watershed was located in Northern Utah in Cache county and consisted of a sparce cover of native grasses and woody shrubs with discontinuous infestations of perennial broadleaved weeds. The predominant soil at the site was a loam. The area was divided and treated in a manner described above for the Wasatch county site. Both watersheds had a slope of 15 to 25 percent and the areas were delineated so that no surface or subsurface flow waters entered the area.

The herbicides were applied to both areas in early May 1969 and the subsequent movement of the herbicides were followed during the succeeding 18-month period. Samples were collected four times during the season immediately following periods of natural precipitation. Each plot was equipped with a catchment device to monitor the movement of the herbicides. A Varian Aerograph Model 1800 gas chromatograph equipped with an electron capture detector was used to quantitate the movement of the compounds. Low limits of detection of picloram in water was 0.1 ppb; for 2,4-D the low limit was 1.0 ppb. Following the application of the herbicide, sampling stations were established at points 10, 100, 1,000 and 10,000 meters below the treated area. In each case the two most distant sampling locations were along a natural creek-bed being fed by the watersheds. Samples were acidified and refrigerated immediately after collection and were analyzed within two days after collection.

Only the results of the movement of picloram will be given in this report. A total of 32 water samples were collected and analyzed for picloram from the two sites. The average picloram context of the triplicate samples taken at each site are shown in Table 1.

Table 1. Average picloram concentration at various collection points during 1969.

Site	Collection date	Precipitation after treatment	Concentration (ppb) Location (Meters from treated Area)			
			10	100	1,000	10,000
Wasatch county	May 16	0.25	28	21	0	0
	June 26	2.32	3	10	0	0
	July 20	2.80	0	T	0	0
	Aug. 17	4.08	0	0	0	0
Cache county	May 15	0.20	10	8	T	0
	June 16	1.10	0	0	0	0
	June 27	3.55	0	0	0	0
	July 8	4.04	0	0	0	0

Table 1 indicates that there was no residue problem in water with picloram since movement from soil into surface waters was very limited. The Wasatch county study shows that as distance from treated area increases, the quantity of picloram in the water decreases. As time increases the amount of picloram also decreases. At the time of the first collection, picloram concentrations of 28 and 21 ppb at the 10 meter and 100 meter collection points respectively were obtained. The concentration at the collection site nearest the treated area was 28 ppb at the time the first samples were taken, but dropped to 3 ppb on the second date of collection.

In Cache county the concentrations of picloram were somewhat less than in Wasatch county, but the trends of picloram movement was similar. Detectable levels of picloram were observed in the water sample only at the time of the first collection. Subsequent samples taken from the collection devices did not reveal detectable levels. There were no detectable levels of picloram in the runoff waters from these sites during the 1970 collection period.

The results of the above study led to a further investigation of possible degradation products from picloram and their subsequent movement. In 1967 Merkle (10) suggested that photodecomposition may be responsible for the major loss of activity of picloram. He reported that the degradation product resulting from radiation of picloram at wavelengths of 220 mu and 280 mu was a molecule in which a chlorine atom had been lost (7). Studies have been made in our laboratory to determine what particular wavelengths are the most efficient in causing picloram to decompose. Studies have also been made on the stability of the degradation products in water and on their phytoxicity. A Baird-Atomic fluorospec Model SF 100 was used to radiate the samples at a concentration of 9 ppm picloram in water. The samples were radiated at wavelengths ranging from 300 mu to 350 mu in 10 angstrom increments, each for a one hour period. The radiated samples were then spotted and developed on thin layer chromatograms. The spots were removed with 1 ml of acetone and aliquots were injected into a gas chromatograph equipped with an electron capture detector to determine the amount that degraded. The location of the peaks were compared to the peaks of a standard solution of decarboxylated picloram (4-amino-2,3,5-trichloropyridine). The retention times were exactly equal for the two. Preliminary studies indicate that decarboxylated picloram is a major degradation product. This does not rule out the possibility of a product or decarboxylated molecule having lost a chlorine atom. Studies are now in progress to determine more precisely the molecular structure of the major products. A goal will be to see if the decarboxylated picloram has lost a chlorine atom. This study was greatly aided by an analytical technique developed by Evans (17) for the detection of minute quantities of either picloram or decarboxylated picloram in water.

The picloram was also decarboxylated with the aid of the sublimation unit illustrated on page 125. Water samples can be analyzed rapidly with this unit. A liter of water is collected, acidified with HCl to pH2 and extracted with two separate portions of diethyl ether in a separatory funnel. The picloram, now in solution in ether, is placed on the flash evaporator at 40°C. and taken to dryness. The flask is then placed in a heating mantle and the temperature is taken to 190° - 200°C. for 15 minutes with cold water circulating and vacuum being applied to the sublimation unit. After the apparatus cools the unit is removed from the flask and the decarboxylated picloram is washed from the unit with acetone. It can then be injected into the G.L.C. and quantitatively measured. A similar procedure as used for picloram may be used for other herbicides. The benzoic acid herbicides may also be quantitated by a similar procedure.

Following a study with 2,4-D Butler (4) concluded that herbicides are less toxic than most other pesticides. The literature does not produce any evidence that there is a biological magnification with herbicides. Government studies show very little residues in the water. Some parts of the year showed no residues. The report also indicates that no residues were found in excess of the permissible limits (9).

SUBLIMATION UNIT

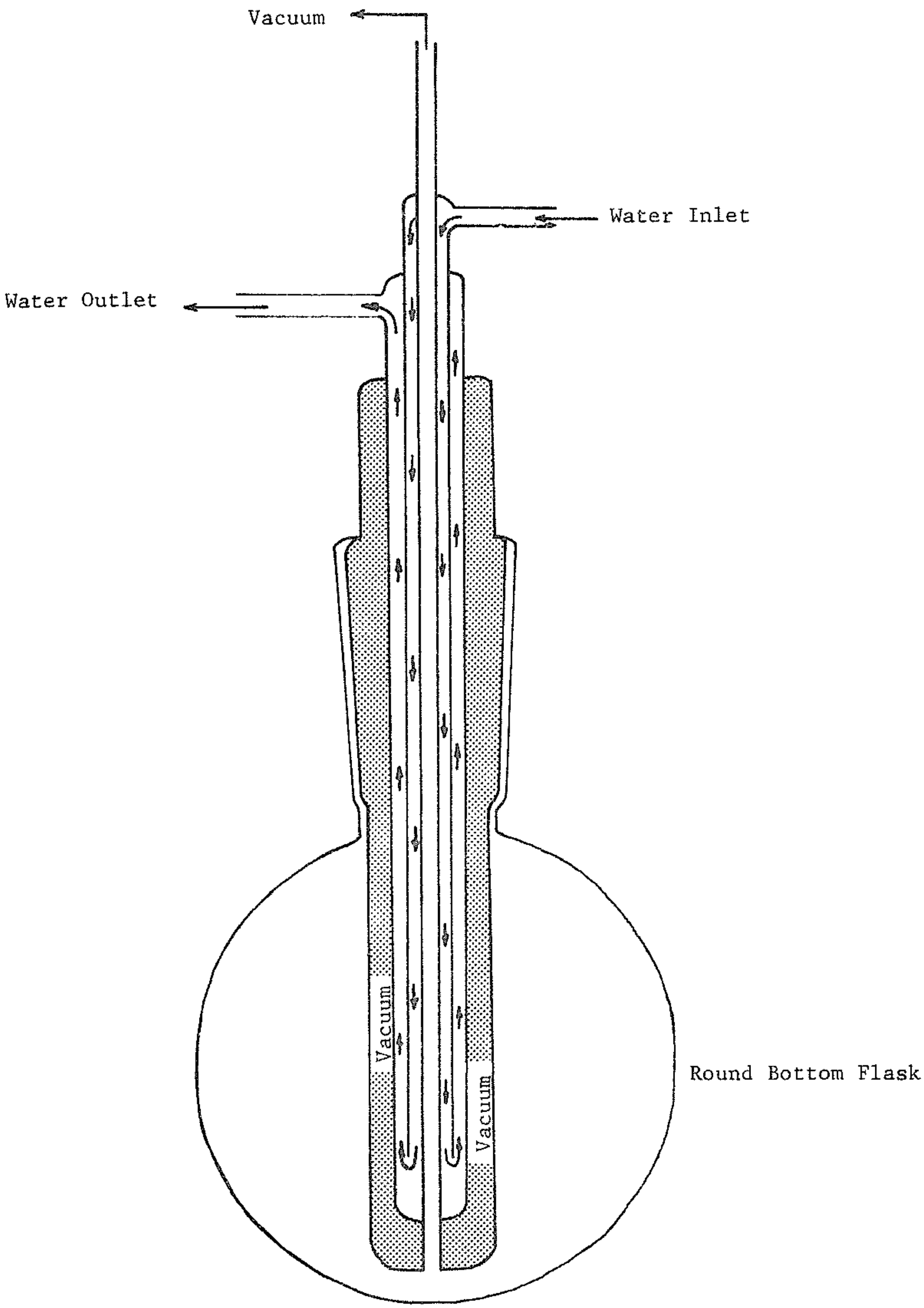


Figure 1. Schematic of Sublimation Unit for Degrading Picloram.

REFERENCES

1. Alley, H. P. 1965. A promising future for control of perennial weeds. Down to Earth 21(1-2): 8-10.

2. A Survey of Extent and Cost of Weed Control and Specific Weed Problems. 1965. (Joint Report) Agr. Res. Ser. and Fed. Ext. Ser. U.S.D.A. ARS 34-102. 70 pp.

3. Beasley, P. G., J. M. Lawrence, and H. H. Funderburk, Jr. 1965. The adsorption and distribution of C^{14}-labelled diquat in the goldfish (Carossius airratus L.). Proc. So. Weed Conf. 18: 581.

4. Butler, P. A. 1965. Effects of herbicides on estuarine fauna. Proc. So. Weed Conf. 18: 576-580.

5. Faust, S.D., R. R. Younger, J. T. Tucker, and O. M. Aly. 1962. Observations on the occurrence and persistence of 2,4-D and 2,4-dichlorophenol in Lake Water. Proc. No. East. Weed Contr. Conf. 16: 459-465.

6. Frank, P. A. and R. D. Comes. 1967. Herbicidal Residues in Pond Water and Hydrosoil Weeds 15: 210-213.

7. Hall, R. D., C. S. Giam, and M. G. Merkle. 1968. Photolytic decomposition of Picloram. Weed Res. 8: 293-297.

8. Herr, Donald A., E. W. Stroube, and D. A. Ray. 1966. Effect of Tordon residues on agronomic crops. Down to Earth 21 (4): 18-20.

9. Manigold, D. B. and J. A. Schulze. 1969. Pesticides in selected western streams. A Progress Report. Report Pest. Monit. J. 3:2.

10. Merkle, M. G., R. W. Bovey, F. S. Davis. 1967. Factors affecting the persistence of picloram in soils. Agron. J. 59:413-415.

11. Mullison, W. R. 1970. Effects of herbicides on water and its inhabitants. Weed Sci. 18: 738-747.

12. Principles of Plant and Animal Pest Control V. 2 - Weed Control. 1968. Nat. Academy of Sciences, Washington, D. C. 468 pp.

13. Tarrant, R. F. and L. A. Norris. 1967. Residues of herbicides and diesel oil carriers in forest water. Proc. Symp. Herb. in Veg. Mange. pp 81-88.

14. The Pesticide Review. 1969. U.S.D.A. Ag. Stabilization and Conservation Service Washington, D. C. 48 pp.

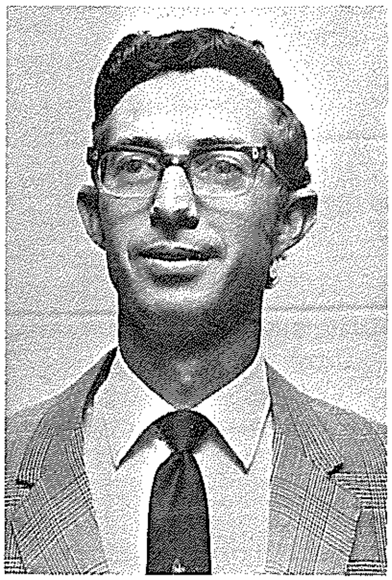
15. U. S. Dept. of Int. 1968. Report of the Committee on Water Quality Criteria. Fed. Water Poll. Contr. Admin., Washington, D. C. 234 pp.

16. Zimdahl, R. L. Pesticides - A Rational Analysis, Colorado State University, Dept. of Botany and Plant Pathology.

17. Evans, J. O. 1979. Analytical technique for the detection of Picloram and some Picloram degradation products in Water. Paper presented to the Technical Committee of the Regional Research Project W82. Dec. 2, 1970. Denver, Colorado.

MONTHLY CONSUMPTIVE IRRIGATION REQUIREMENTS AS A GUIDE TO EFFICIENT MANAGEMENT

Bobby J. Creel[1/]



Biographical Sketch

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Publications

Irrigation Water Requirements for Crop Production - Roswell Artesian Basin, An Economic Analysis and Basic Data; Water Resources Research Institute, WRRI Report 4 Part II, New Mexico State University, 1969.

Irrigation Water Requirements for Crop Production - Roswell Artesian Basin, Project Analysis and Summary; Water Resources Research Institute, WRRI Report 4 part IV, New Mexico State University, 1969.

Irrigation Water Requirements for Crop Production - Roswell Artesian Basin, Water Resources Research Institute, WRRI Report 5, New Mexico State University, 1969.

An Economic Land Classification of the Irrigated Cropland in the Pecos River Basin, New Mexico; Water Resources Research Institute, WRRI Report 7, New Mexico State University, 1970.

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Agriculture in New Mexico utilizes a major portion of the state's water resources. New Mexico presently diverts about 3,077,000 acre-feet of water annually for irrigation of about 1,000,000 acres of land (14). In 1965, slightly more than a million acres (1,046,600 acres) were irrigated from surface and groundwater sources. Irrigation of this acreage accounts for approximately 90 percent of the average annual depletion for beneficial uses of the state's surface and groundwater supplies (12).

The arid nature of New Mexico requires irrigation for successful crop production. The large use of water by irrigation, relative to other uses, is of prime importance in a state with limited water supplies.

Water problems are high on the list of public concern at present. Water supply and pollution problems have spread throughout the country and have become critical in many areas. Many of the problems are of a scope and nature requiring state and federal planning as well as large public investments in water development programs.

With a major portion of the water supply of New Mexico being used for the irrigation of agricultural crops, most of the problems dealing with water directly or indirectly concern the users of this water. Farmers are concerned not only with the utilization of a resource that is becoming increasingly scarce, but one in which the uses to which it is put and the results of this use are being scrutinized as never before.

Much interest has been directed to plans which would supply additional water to New Mexico and the Southwest. Importation plans appear to offer the only means of maintaining present levels of irrigation in some areas. Other plans would permit continued irrigation development in some areas. The uncertain future of irrigation should cause us to consider carefully these alternative plans.

Irrigation technology will almost certainly preclude the present practices such as furrow irrigation. It has been predicted that probably most crops will be solid planted and watered by subsurface irrigation systems or sprinklers in the not-so-distant future.

These are but two of the many ideas which have been presented and projected for the future concerning irrigated agriculture. The third, and primary topic of this paper, involves the idea of knowledge of irrigation requirements.

The primary purpose of this paper is to point out the need for knowledge of basic irrigation requirements which would allow for a more efficient utilization of the existing water supplies. It is recognized that improvements in irrigation technology will undoubtedly make substantial contributions to increased water-use efficiencies and in many respects pave-the-way for some of the water importation plans, desalination plans, and other such plans. However, before additional supplies are provided, those supplies presently available should be put to their fullest beneficial use. In this respect, the supplies of water currently available for irrigation should be used only to the extent that they satisfy the crops' minimum requirements.

This would be an ideal situation, but in the same respect an impossible task. Non-beneficial depletions in agriculture range from losses from canals to evapotranspiration by weeds on the farm ditches, which would not be eliminated without considerable expense and investments in time and energy.

In the opinion of the author, there is a potential for increasing the efficiency of water use in agriculture through the improvement of management knowledge relating to irrigation water requirements of the various crops. Before proceeding with this idea a review of the work and studies done in this area are in order.

Even though irrigation has been practiced in various parts of the world for centuries, only until about 70 years ago were intensive studies conducted to determine the basic water requirements of crops. This was primarily because actual measurements of consumptive use under each of the physical and climatic conditions of any large area were expensive in time and money.

Various methods have been used to measure the amount of water consumed by agricultural crops and native vegetation. The principal approaches have been tank experiments, studies of soil moisture, and observations of groundwater fluctuations -- and for larger areas, the inflow-outflow, effective heat, and integration methods (1). One of the more common methods of determining the use of water by individual crops was to grow them in tanks and measure the quantity of water necessary to maintain their growth satisfactorily. Another common method used employed soil-moisture depletion studies in which the change in the moisture content of the soil within the root zone of the crop was measured periodically.

Methods of estimating consumptive use of water by crops and other vegetation, for climatic factors, have been found to give reasonably accurate results. The Blaney-Criddle formula (U=KF) has been used extensively in many states. The procedure was developed by correlating measured consumptive-use data with monthly percentages of yearly daytime hours, precipitation and growing season. The coefficients developed allowed for the computation of consumptive use of each crop.

Actual measurements of consumptive use of water by plants have been conducted by a number of research agencies over the past 60-70 years. One of the first such studies was made in 1903 in California. Extensive studies of evaporation, evapotranspiration, temperature, humidity, and wind movement were conducted by Blaney in 1919 in Colorado. Several research studies have been conducted in New Mexico, one of the first being made in the Mesilla Valley in 1904 (13). Bloodgood (8) conducted experiments in 1924-25 on the irrigation requirements of alfalfa, barley, chile, sorghum, wheat, and other crops at the New Mexico Agricultural Experiment Station. The Rio Grande Joint Investigation in 1936 (4) and the Pecos River Joint Investigation in 1939-41 (5) conducted studies on consumptive use of water by irrigated crops and natural vegetation. More recently, Blaney and Hanson (7) reported in 1965 consumptive use and water requirements for crops in New Mexico using the Blaney-Criddle method, and Henderson and Sorensen (11) in 1968 published consumptive irrigation requirements for areas of New Mexico.

These studies were designed primarily to estimate the water requirements of irrigated crops as an aggregate for the individual states or areas under consideration. The knowledge of irrigation water requirements of crops were considered necessary in planning conservation projects, farm irrigation systems, water conservation, and full utilization of water in river basins. They were also considered as an important factor in the negotiation of compacts and treaties and in the litigation and adjudication of water rights (4,2).

The purpose of this paper is not to present the idea that these studies were limited in their usefulness. since in many large projects the construction costs chargeable against irrigation have been well above $500 per acre (1). With costs this high, large errors in estimating the acreage of land suitable for continued irrigation and the amount of water required for it must be avoided. If sufficient water is allowed for maximum production, the project lands will not produce properly and will not be able to pay the charges; but if the supply exceeds the needs, water costs may exceed the ability of the user to pay (1).

Most of these earlier studies on consumptive use of water were made only on a seasonal basis, with little consideration given for monthly, weekly, or daily use-rates. For most purposes, data on seasonal basis were sufficient. Certainly many storage reservoirs were safely and efficiently designed with a knowledge of only seasonal water requirements.

Most drainage systems were designed without detailed short-time use of water rates and determination of basin-wide water supplies, and water inventories hardly needed more than seasonal and annual consumptive use rates.

With growing use of sprinkler irrigation systems and need for better information on the most economical capacities of irrigation systems, there has been a growing need for monthly, weekly, and even daily consumptive use of water rates. Beginning about 1950, considerable effort had been directed by many agencies toward gathering such data. Several investigators have reported highly variable rates of use on a short-time basis, however. It was felt in most cases that considerably more research would be necessary before monthly or short-time consumptive use could be accurately predicted.

Studies dealing with the monthly or short-time consumptive water use recognized the greater variation in monthly coefficients than in the seasonal coefficients. This greater variation was thought to be due to the greater number of factors besides climate that might influence growth. Such factors as insect damage, cutting of alfalfa for hay, and actual solar radiation were thought to influence the consumptive use rates and probably accounted for the variation. Actual measurements indicated that water use varied widely throughout the season and such variation could not be explained by climatic data generally available.

Work in Texas (6) in the early 1950's suggested that the average consumptive use of water by grain sorghum started at about 0.06 inch per day during the emergence period, but increased rapidly to a peak of 0.30 inch per day, then continued to decrease to about 0.05 inch per day until harvest.

Blaney and Criddle (1) in the late 1950's reported results of studies in the United States and several foreign countries. In their report, the empirical formula for consumptive use, developed from the results of the various studies, was presented. They noted that the seasonal coefficient (K) for each crop appeared to be approximately constant for most areas where irrigation was practiced. However, the coefficients did not appear to be constant for consecutive short periods during the growing season. Adjustments could be made in areas where the data was available. For short periods and higher temperatures, the coefficients (k) appeared to be larger. They concluded that temperature was not the only factor affecting consumptive-use relations, and that each crop had its own particular growth and water-use pattern. Thus, for short periods, use coefficients varied, depending upon the temperature and stage of growth. Records of measured seasonal consumptive use of water by irrigated crops and calculated consumptive-use factors (F) and crop coefficients (K) were reported, as well as some suggested monthly crop coefficients (k) for selected locations.

More recent work in Arizona (10) presented consumptive-use curves for 30 different oil, hay, small grain, fruit, vegetable and green manure crops for various locations in the state. Without exception these curves suggested higher consumptive use over the periods of higher temperatures and periods of expected higher plant growth rates.

The consumptive-use curves included in this report were the averages of several years and did not show the short-time fluctuations in water use. The authors noted that they represented data from irrigation treatments which resulted in optimum crop production. Each figure contained estimates of seasonal use, semi-monthly use, and soil profile moisture depletion.

These curves also could be used for calculating irrigation schedules, thus allowing irrigations to coincide with needs of the plants. Inefficiencies of deep percolation resulting from over-irrigation and from crop damage or stress due to lack of sufficient water could thereby be reduced.

A direct transfer of this consumptive-use data to another area with widely different climatic conditions is not valid, but data from the study could be used for irrigation scheduling in areas having comparable growing seasons. Small differences in growing season length and planting dates could be taken care of by shifting the curves forward or backward on the time scale, as required.

Several methods of making such transfers have been proposed. One in wide use today is the method developed by Blaney and Criddle. If the consumptive use coefficient (K) was known for a specific crop at a certain location, it was this factor that was transposed to other areas, using the local area (F) factor, from which estimates of consumptive use were made (1).

Appendix Table 1 presents the seasonal and semi-monthly (k) factors as determined for crops grown in Arizona, to be used with the Blaney-Criddle formula in estimating consumptive use of water in other areas. When the 15-day (k) factors are used, the corresponding daytime sunshine hour percentages and the mean average temperature for the 15-day period at a particular location should be used.

For example, it might be desirable to estimate the consumptive use of cotton for the first half of July here at Las Cruces, using the developed (k) values. The (k) factor for cotton from appendix Table 1 is 1.10, and from the sunshine tables, the average daytime hour percentage for July at Las Cruces would be approximately 9.77. The first half daytime hour percentage would therefore be:

4.73, calculated as follows $(\frac{15}{31} \times 9.77 = 4.73)$.

The mean temperature for the first 15 days of July for Las Cruces (New Mexico State University Weather Station) in 1970 was 82° F (15). Thus the (f) factor for the first half of July would be:

3.88, calculated as follows $(\frac{82 \times 4.73}{100} = 3.88)$

and the estimated consumptive use for the first 15 days of July would be:

4.27, calculated as follows (1.10 x 3.88 = 4.27)

Applying the consumptive-use coefficients (k) from the Arizona study allowed an estimate of the semi-monthly consumptive use of a crop that otherwise was not available. These estimates could be made for all semi-monthly periods of the seasons for the necessary crops and used to construct irrigation requirements or irrigation schedules, where the seasonal values could not.

Transposing of the Arizona (k) factors into New Mexico provides a means of supplying information developed from actual consumptive-use studies. The Arizona consumptive-use data was computed from gravimetric soil moisture measurements on soil samples taken at depths and locations that could be expected to evaluate the average soil moisture distribution and depletion by the plants under study. The application of the consumptive-use data from Arizona to New Mexico has certain limitations which affect the validity and accuracy of the estimates. It may not be accurate in assuming that the (k) factor for Arizona was valid for use in New Mexico since some factors which were not accounted for in the local (f) values, such as length of growing season, humidity, differences in soil fertility, topography, wind movement, quality of irrigation water, and the types and varieties of crops produced may be somewhat different for the two areas in question.

Consumptive irrigation requirements1/ are dependent not only on the consumptive needs of the plants, but also on that contributed from such natural sources as usable summer precipitation, available soil moisture and any contribution from groundwater. Normally in semi-arid regions where water tables do not contribute to the crops, the precipitation which occurs during the season need only be considered. Thus, the calculated consumptive use minus the effective precipitation for the same period would give the consumptive irrigation requirement.

In the many areas of irrigated agriculture in New Mexico, climatic factors vary considerably. This fact alone would rule out the transfer of the Arizona consumptive use coefficients into many areas of New Mexico. Thus, it would seem that in order to obtain valid and accurate estimates of monthly consumptive use and monthly consumptive irrigation requirements for crops in New Mexico. There is a need for research which would develop basic water requirements for the various crops.

With the large portion of the water resources of New Mexico being used in irrigated agriculture, and with the present concern for our water resource in the state; it would seem to indicate that the necessary research should be implemented which would provide monthly consumptive use and monthly consumptive irrigation requirements for crops produced in New Mexico.

REFERENCES

1. Blaney, H. F., and Criddle, W. D., Determining Consumptive Use and Irrigation Water Requirements: USDA Technical Bulletin No. 1275., 1962, 59 pp.

2. ______________, Determining Water Requirements for Settling Water Disputes, Natural Resources Journal, University of New Mexico, V. 4 No. 1, 1964, p. 29-41.

3. ______________, Determining Water Requirements in Irrigated Areas From Climatological and Irrigation Data, USDA, Soil Conservation Service Technical Publication No. 96, 1950, 48 pp.

4. Blaney, H. F., Ewing, P. A., Israelsen, O. W., et al., "Regional Planning, pt. VI," The Rio Grande Joint Investigation, Upper Rio Grande, Natural Resources Committee, 1938, p. 293-616.

5. Blaney, H. F., Ewing, P. A., Morin, K. V., and Criddle, W. D., "Consumptive Water Use and Requirements," The Pecos River Joint Investigation, Reports of the Participating Agencies, Natural Resources Planning Board, 1942, p. 170-230.

1/ The equation for monthly consumptive irrigation requirements is: cir=u=r, where u=kf, the (r) values are the monthly precipitation considered available for consumptive water requirements of crops, and does not include deep percolation below the root zone nor surface runoff, and (f) values are the monthly consumptive-use factor (1).

6. Blaney, H. F., Haise, H. R., and Jensen, M. E., Consumptive Use By Irrigated Crops in Western United States, USDA Agricultural Research Service, 53 pp. (Processed.)

7. Blaney, H. F., and Hanson, E. G., Consumptive Use and Water Requirements In New Mexico, New Mexico State Engineer Technical Report No. 32, 1965, 82 pp.

8. Bloodgood, D. W., Net Requirements of Crops For Irrigation Water In The Mesilla Valley, New Mexico, Agricultural Experiment Station, New Mexico State University, Bulletin No. 149, 1925, 48 pp.

9. Criddle, W. D., Harris K., and Willardson, L. S., Consumptive Use and Water Requirements for Utah, Utah State Engineer Technical Publication No. 8 (revised), 1962, 47 pp.

10. Erie, L. J., Orrin, F. F., and Harris, K., Consumptive Use of Water By Crops in Arizona, Agricultural Experiment Station, University of Arizona, Technical Bulletin No. 169, 1965, 43 pp.

11. Henderson, D. C., and Sorensen, E. F., Consumptive Irrigation Requirements of Selected Irrigated Areas In New Mexico, Agricultural Experiment Station, New Mexico State University, Bulletin No. 531, 1968, 55 pp.

12. Henderson, D. C., and Stucky, H. R., Agricultural Land And Water in New Mexico, New Mexico State Planning Office, 1966, 62 pp.

13. Tinsley, J. D., and Vernon, J. J., Soil Moisture Investigations For 1904, Agricultural Experiment Station, New Mexico State University, Bulletin No. 54, 1905, 27 pp.

14. Water Resources of New Mexico: Occurrence, Development and Use, Compiled by New Mexico State Engineer Office in cooperation with New Mexico Interstate Stream Commission and United States Geological Survey, State Planning Office, Santa Fe, New Mexico, 1967, 321 pp.

15. Weather Bureau, Climatological Data, New Mexico, (July 1970), United States Department of Commerce, Vol. 74, No. 7, p. 101-127.

Appendix Table 1. Computed Seasonal "K" and Semi-monthly "k" Values for Use in the Blaney-Criddle Formula CU=KF or u=kf

Crop	Seasonal "K" Values	Semi-Monthly Values: January		February		March		April		May		June		July		August		September		October		November		December	
		1-15	16-31	1-14	15-28	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-30	1-15	16-31
Cash and Oil Crops																									
Castor Beans	0.84								.07	.21	.35	.58	.98	.95	.93	.86	1.08	1.44	1.56	1.23	.82	.48			
Cotton	0.79							.06	.11	.20	.34	.50	.79	1.10	1.30	1.43	1.36	1.23	1.00	.79	.47	.27			
Flax	0.78	.84	.86	.82	.85	.81	1.07	1.24	1.26	.79	.59	.38	.27									.68	.81	.87	.90
Safflower	1.21	.08	.20	.23	.44	.59	1.01	1.63	2.21	1.98	1.00	1.70	1.43	.34											
Soy Beans	0.68												.24	.38	.45	.71	.93	1.13	1.07	.86	.68				
Bermuda Lawn and Hay Crops																									
Alfalfa	1.20				.92	1.20	1.22	1.18	1.34	1.31	1.42	1.39	1.33	1.30	1.16	1.14	1.06	1.39	1.27	1.10	.87	.80	.80		
Bermuda Lawn	0.97								.66	.70	.88	1.00	1.12	1.19	1.15	1.16	1.05	.96	.82	.71					
Blue Panicum Grass	0.98							.83	1.03	1.03	1.11	1.07	1.03	1.11	1.11	1.10	1.01	.95	.89	.89	.75	.32			
Small Grain and Forage Crops																									
Barley	1.09	.25	.39	.79	.99	1.17	1.38	2.08	1.74	.99															.12
Sorghum Grain (Single crop)	0.87													.14	.74	1.29	1.67	1.34	.86	.51	.18				
Sorghum Grain (Double crop)	0.90							.03	.28	.71	1.37	1.61	1.60	.90	.71	.59	.96	1.66	1.18	.90	.67	.56	.44	.16	
Sorghum Forage (Double crop)	0.94							.02	.32	.80	1.42	1.49	1.42	1.05	.74	.59	1.15	1.79	1.39	1.10	.73	.56	.44	.10	
Wheat	0.99	.18	.25	.32	.40	.55	1.28	1.70	1.94	1.22	.51														
Fruits																									
Grapefruit	0.66	.45	.55	.48	.47	.47	.50	.49	.52	.55	.62	.67	.70	.76	.71	.80	.75	.79	.76	.83	.69	.72	.58	.63	.61
Grapes	0.70						.35	.33	.56	.78	1.06	.73	.77	.79											
Oranges	0.53	.34	.44	.43	.52	.39	.43	.42	.49	.47	.47	.55	.56	.58	.57	.66	.59	.63	.65	.69	.55	.59	.58	.46	.34
Vegetables																									
Broccoli	0.77	.95	1.09	1.08														.12	.27	.62	.85	1.29	1.09	1.08	.91
Cabbage (early)	0.72	.89	.80															.07	.23	.56	1.02	1.33	1.15	1.05	.94
Cabbage (late)	0.82	1.07	.95	.86	.89	.65												.12	.41	.81	1.02	1.29	1.21	1.14	1.04
Cantaloupe	0.74							.06	.20	.27	.78	1.32	1.34	.81											
Carrots	0.63	.89	.75	.66	.69	.40													.05	.25	.53	1.19	1.06	.94	.86
Cauliflower	0.78	1.07	.85															.11	.30	.51	.82	1.29	1.36	1.41	1.14
Lettuce	0.50																		.07	.27	.43	.59	.75	.98	.90
Onions (dry)	0.80	.30	.38	.46	.67	.95	1.50	1.66	1.81	.85												.02	.05	.11	.20
Onions (green)	0.88	.99	.85																.26	.38	1.06	1.38	1.28	1.17	1.03
Potatoes	1.01				.03	.09	.34	.93	1.65	1.78	1.53	.85													
Sweet Corn	0.98						.07	.26	.62	1.19	1.82	1.49													
Green Manure Crops																									
Guar	0.78													.38	.81	1.00	.93								
Papago Peas	1.01		.21	.47	.62	.91	1.29	1.54	1.42	1.08								.83	.81	.87	.64				
Sesbania	0.82														.11	.72	1.28	1.26							

BASIC SUMMARY OF STUDENT SECTION

Ralph Fegley[1]

Biographical Sketch

Ralph Fegley is president of the New Mexico State University Engineer's Council which has 1,400 members. This group sponsors activities in the College of Engineering and encourages professionalism among the engineering students.

Mr. Fegley is a veteran of the armed forces and will graduate with a B. S. degree in Civil Engineering in December, 1971.

GOALS: Engineering Management - Junior Executive in pollution control - overseas employment.

Mr. Fegley worked from July 1970 to present, State of New Mexico (part-time work), Pollution Engineer. In charge of air monitoring stations and public relations in the southwestern part of New Mexico.

He was born and raised on a farm in North Dakota, the second child in a family of five. After completion of high school, he was chosen as a representative of a farm organization to live on an English farm and tour European countries. He was married while in the Army. His wife is presently a high school English teacher.

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We have heard seven papers delivered by students from six universities in the Southwest and Mexico: The University of Arizona, Arizona State University, Instituto Tecnologico Y De Estudios Superiores De Monterrey, Utah State University, University of Colorado and New Mexico State University.

We appreciate the effort of these men in preparing and delivering these papers. In my view, they were excellent papers and were presented in a professional manner. We congratulate each of you for these fine presentations.

1/ Student Engineering Council, NMSU

Now, I would like to make a few comments concerning our views, our role here in this water conference. After discussion with a number of the students, we really appreciated this opportunity to participate in this Water Conference. Most of the students live quite a great distance from here, and they've gone to some personal expense to come here and present their papers. They've already received your general feelings and attitudes through your standing ovations, and through some comments by Dr. Agnew. We really can't find the best words to express our appreciation for considering us and letting us become a part of this Conference. Such a tremendous opportunity for us to, what you might say, "hone" our professionalism, and we hope that you will consider us again next year. Not necessarily in this way -- maybe in some smaller portion of the Conference. We'd also like to see a few of the ladies -- maybe there's some of the ladies that might have a paper that would be worthwhile -- you know, get the women into this thing too. I'd like to cap this by saying we appreciate the opportunity of coming here today and we thank you very much.

IMPACT OF WATER DEVELOPMENT FOR THE NAVAJOS

W. D. Gorman[1]/

The Navajo Indian Irrigation Project is a 110,630-acre development for the Navajo Indians. The lands to be irrigated are located on the mesa south of Farmington, New Mexico. The project has a diversion allocation of 508,000-acre feet from the San Juan River. It is anticipated that 360,000 to 400,000-acre feet of water will actually be delivered to the project lands.

The United States Congress has authorized 206-million dollars for the development of the Irrigation Project. Approximately 40-million dollars have been appropriated for the project development to date. The project is under the control of the Bureau of Indian Affairs, but construction is being supervised by the Bureau of Reclamation. The completed project will be under the ownership of the Navajo Tribe with no private ownership of the irrigated lands--either Navajo or non-Navajo.

Development Schedule

The idea of an irrigation project from the San Juan River evolved as part of a treaty with the Navajo Tribe in the late 19th century. As a part of the treaty, the United States Government promised to provide irrigated lands to the Navajos. Project planning, including survey work, has continued on an off-and on-basis since the signing of the treaty; but it was not until 1962 that Congress authorized the development. Construction began on a limited scale in 1964. The first water is expected to reach 10,000 acres of the project lands by 1975 or 1976. The scheduled completion date is 1986 to 1990, depending upon funding.

Site Factors

The soil on the project lands is predominately sandy to sandy loams. A large part of the land that is being brought in under irrigation has fairly shallow soil which makes it difficult to level the land for flood irrigation. The topography is generally rolling, and the elevation ranges from 5,500 feet to slightly over 6,000 feet. The region has a growing season of approximately 160 days on the average, but frequently ranges from 140 to 180 days. It is anticipated that the project will be mostly under sprinkler irrigation because of soil and topography conditions.

Navajo Economic Situation

It is estimated that 17,000 to 18,000 Navajos are presently unemployed. Underemployment is as much a problem on the reservation as unemployment. Because of small farms and ranches, most Navajos, particularly those engaged in agriculture, are underemployed. The average Navajo family annual income is about $800. The average Navajo family size is 5.6 persons; hence, the annual income per capita on the reservation is very low.

1/ Associate Professor of Agricultural Economics, New Mexico State University

The primary purpose of the Irrigation Project is to create income and employment opportunities for the Navajo in his native land. There is a critical need for additional income and employment opportunities on the reservation. Most Navajos, with the exception of a few highly trained individuals, have not been successful in relocating off the reservation. They find it very difficult to get satisfactory employment in the cities and even more difficult to have a satisfactory social life.

Role of New Mexico State University in the Project Development

New Mexico State University is assisting the Irrigation Project development in at least two ways. The University has located a branch Experiment Station directly on the project lands. This station is testing crops that are likely to be grown on the project lands. The Agricultural Experiment Station has also jointly funded with the Four Corners Regional Commission a multi-disciplinary team approach to study the project and assist in its planning. The project team consists of agricultural economists, agronomists, horticulturists, and engineers.1/ The primary objectives of the study are: (1) make recommendations on crop and livestock enterprises that will likely be most profitable, (2) evaluate agricultural processing and service industries and make recommendations on those that appear most profitable, (3) make suggestions and recommendations on how the Irrigation Project should be organized, and (4) specify employment opportunities and the training and education needed to meet the employment opportunities.

Major Issues

There are several major issues pertaining to the project development that will have to be resolved. One of the big issues is whether the land should be divided into individual entrepreneurship-size farms, possibly ranging from 160 to as much as 1,200 acres, or should it be organized as a tribal enterprise farms or farms ranging in size from 10,000 acres to one large 110,000-acre farm. Another alternative would be a combination of tribal enterprise farms and individual entrepreneurship-size farms. The ultimate decision on how the project lands will be organized must be made by the Navajos themselves. It is a very difficult and important issue.

The authorized 206-million dollars provides funding to deliver water to the project lands. It does not, however, provide capital for sprinkler irrigation systems, land development, farm equipment and buildings, and for operating expenses. The sources of this substantial additional capital requirement is another important issue. The Navajos do not have the needed capital, nor do they appear to have the potential basis for borrowing it from commercial sources without government assistance.

1/ William D. Gorman and Robert R. Lansford, Associate Professors, Agricultural Economics; Thomas S. Clevenger, Assistant Professor, Agricultural Economics; Joseph E. Williams, Research Associate, Agricultural Economics; E. J. Gregory, Assistant Professor, Agronomy, Jack M. Jordan, Assistant Professor, Horticulture; William H. Trego, Research Aide, Agricultural Economics; and Hector H. Ogaz and Robert K. Bull, Graduate Assistants, Agricultural Economics.

Other major issues are the educational and training requirements needed to make the project a success. The training and educational requirements, as well as the capital needs, are closely associated with the type of farm organizational structure selected. The educational and training requirements are substantially different for the tribal enterprise type of farm as compared with the individual entrepreneurship-size farms. One of the major deterrents to individual entrepreneurship farms is that there are relatively few Navajos who have the training and experience necessary to manage a commercial irrigated farm. A successful manager of a commercial farm is a highly skilled individual. It is anticipated that the level of management required will increase substantially for successful farming in the future.

Another factor to consider with the individual farm approach to project organization is that relatively few Navajos would get farms. A minimum size economic unit, given the types of crops that will likely be grown in the area, is likely to be about 320 acres. If the project were divided into 320-acre farms, there would be room for only 345 farms. Hence, as few as 345 Navajo families out of the estimated 23,000 families on the reservation would receive farms.

The tribal enterprise farm approach also has many inherent problems. Large farms are difficult to manage. There are relatively few farms in the world larger than 50,000 irrigated acres. Large farms, however, can be managed successfully and offer many opportunities, particularly from economies to be gained in purchasing, marketing, machinery efficiency, and integration into processing activities. It is also likely that capital would be easier to obtain under the tribal enterprise farm approach. The Navajo Tribe has had some experience in tribal enterprise activities having organized the tribal utilities and forest products' industries along these lines.

Potential Crops

The area is adaptable to a large number of crops. The research team concluded that the crops listed in Table 1, under the present production and marketing conditions, offer the most potential. A large number of other crops were considered but were eliminated for climatic, production costs, or market reasons.

Table 1. Budgeted crops

Field Crops	Vegetable Crops	Fruit Crops	Livestock Enterprises
Sugar beets	Asparagus	Apples	Dairy
Alfalfa hay (baled)	Beets		Warmup feedlot
Dry beans	Bell peppers		Finish feedlot
Soybeans	Cabbage		Swine
Grain sorghum	Carrots (fresh)		Laying hens
Corn silage	Carrots (processed)		
Winter barley	Cucumbers (processed)		
Winter wheat	Onions		
Irrigated pasture	Potatoes (fresh)		
Alfalfa seed	Snap beans		
	Sweet potatoes		

Potential Livestock Enterprises

The Navajo people have raised sheep and cattle for many years. Because of this experience and climatic and locational factors, it is reasonable to expect that many livestock enterprises will be associated with the project lands. If the project is developed along the individual farm entrepreneurship approach, the principal livestock enterprises will likely be cow-calf programs, sheep grazing, summer grazing of yearling beef animals, and possibly, swine production. If the project is developed along the enterprise farm approach, large scale livestock enterprises appear feasible. Among the most promising are dairy, backgrounding and finish beef feedlots, and large-scale egg production. Large-scale confinement and semi-confinement swine production operations might also prove profitable.

Under current cost and return figures developed by New Mexico State University, it is anticipated that if the project is developed along the individual farm approach, the cropping pattern and livestock produced or fed will likely be as shown in Table 2. It is predicted that the farms will be heavily committed to hay crops, cereals, feedgrains, and sugar beets. This assumes the project can get a sugar beet allotment. If a sugar beet allotment cannot be obtained, preliminary results indicate the land will be shifted to cereals and feedgrains. Markets and production seasons are the major limiting factors for fresh and processed vegetable production.

Table 2. Potential cropping pattern and livestock for individual farms

Cropping Pattern	Percent of Acreage
Cereals, feedgrains and sugar beets	35
Hay crops	50
Fresh vegetables	8
Processed vegetables	6
Seed crops	1
Livestock Enterprises	
Cow-calf	
Beef yearlings	

If the project is developed under the concept of the enterprise farm approach, a slightly different cropping pattern is expected as shown in Table 3. It is anticipated that fresh market and processed vegetable acreage will be about the same as under individual farms. The big change will likely be an increase in feedgrains relative to hay and silage crops. It is anticipated that because of the advantages of integration opportunities and capital availability for large-scale units, the enterprise farm development would have considerably more livestock enterprises, particularly feedlots and large-scale egg operations. These operations would provide a substantial market for feedgrains.

Table 3. Potential cropping pattern and livestock enterprise farm

Cropping Pattern	Percent of Acreage
Cereals, feedgrains and sugar beets	51
Hay and silage crops	37
Fresh market vegetables	6
Processed vegetables	5
Seed crops	1
Livestock Enterprises	
Laying hens	300,000 hens
Dairy	1,100 cows
Feedlot	60,000-head capacity
Backgrounding lot	30,000-head capacity
Cow-calf	Several thousand
Steers	Several thousand

Economic Impact

Because of the many unknowns as to how the project will be developed, it is difficult to estimate accurately the economic impact of the Irrigation Project. Coefficients indicating the relationship between off-farm income and employment relative to direct farm income are of questionable accuracy. Better estimates of income investment multipliers are also needed to measure the impact of the Irrigation Project development on the supply, processing and service industries in the general Four Corners Region. Allowing for uncertainties and using coefficients of questionable accuracy, the predicted number of jobs created if the project is developed on the basis of 320-acre farms is as follows:

Employment	Number of Full-Time Jobs
On-Farm Employment (Mostly operators and family labor)	400-500
Off-Farm Employment Directly Related Businesses	500-800
Impact on Other Industries and Services	1,800-2,300
Total	2,750-3,600

The number of jobs created if the project is developed on the basis of an enterprise farm approach is as follows:

	Number of Full-Time Jobs
Direct Enterprise	
December-March	500
April-May	1,100
June-August	2,100
September-November	1,400
Enterprise Service Industries	400-600
Impact on Other Industries and Services	1,800-2,300
Total	3,200-4,200

The estimated number of jobs created is likely to be larger for the tribal enterprise farm development approach. This is because more processing industries and livestock enterprises would be developed as an integrated part of the enterprise farm or farms. In general, the greater the degree a product is processed in a local region, the greater number of jobs will be created. This will be a very important consideration on the part of the Navajo people.

One of the primary difficulties of farm production and processing industries is the substantial variation in the number of jobs by seasons. It is anticipated that some of the seasonal peaks in the labor needs can be provided by students in the summer months and by homemakers who want to work only part of the year. Most livestock enterprises, as opposed to cropping activities, provide year-round employment. The addition of these enterprises to the development plan should assist, therefore, in balancing the employment requirements. The projected income generation and investment requirements for a typical 320-acre farm under the assumption of above average management are estimated in Table 4.

Table 4. Projected income per 320-acre farm under above-average management

Labor Income (Operator, Family, Hired)	$4,000 to $10,000
Returns to Management and Capital (Paying $20 per rent to the tribe)	$8,000 to $20,000
Investment Capital in Machinery and Equipment	$ 64,000
Investment Capital in Buildings, Farmstead, Fences	$ 30,000
Operating Capital	$ 40,000
Total Capital	$134,000
Return to Operator's Labor and Management (Assuming 8 percent interest on 50 percent of investment capital and 100 percent of working capital)	$4,000 to $20,000
Income to the Tribe (Land Rent)	Slightly over Two Million Dollars

It is estimated that labor income will range from $4,000 to $10,000 per year. This includes income to the operator for his own labor, as well as family labor and hired labor. The returns will vary depending upon crops grown and livestock raised or fed. Those farms having a sizeable acreage of vegetable crops will have increased labor needs as compared with those producing primarily hay and grain crops. Returns to management and capital are estimated to range from $8,000 to $20,000 per year, using the assumption that the Navajos would pay $20 an acre per year cash rent to the tribe for use of the land. The projected total capital requirements are estimated to be $134,000 per farm. The capital would be needed for construction of farmsteads, purchasing irrigation equipment, machinery and farm implements, and for operating capital. If an eight percent interest charge were made on capital, and the working capital was 50 percent of the investment capital, it is anticipated that an above average operator would have anywhere from a $4,000 to a $20,000 return for his labor and management. Farmers with successful livestock enterprises and growing a sizeable acreage of vegetable crops will have the greatest net returns.

If the tribe were able to collect $20 cash rent per acre for the use of the land, the total rental income should run slightly over two million dollars per year. Doubling the cash rent to $40 per acre would add slightly over $7,000 to the annual operating expenses. This would eliminate nearly all of the expected profit except from those farms with sizeable vegetable acreage. A summary of the expected investments and operating profits, assuming a 110,000-acre tribal enterprise farm, is presented in Table 5. Assuming the Navajo Tribe will be able to raise nearly 80-million dollars in investment and operating capital, and if they are able to develop or obtain superior management, the total operation should return a net operating profit of approximately 18-million dollars when it is totally developed. This return figure does not include any charges for capital. This net return figure is based on the assumption that the Navajos will use a cropping pattern and establish a livestock enterprise similar to that shown in Table 3. It is estimated a 41-million dollar investment in facilities and equipment and 38-million dollars in annual operating capital would be required. Assuming an interest charge of eight percent on one-half of the investment capital, and eight percent on the operating capital, the net income will be about 13-million dollars. If the public investment in the project is 206-million dollars, a 13-million dollar annual return amounts to nearly six-percent return on the public investment.

Table 5. Enterprise Farm Approach

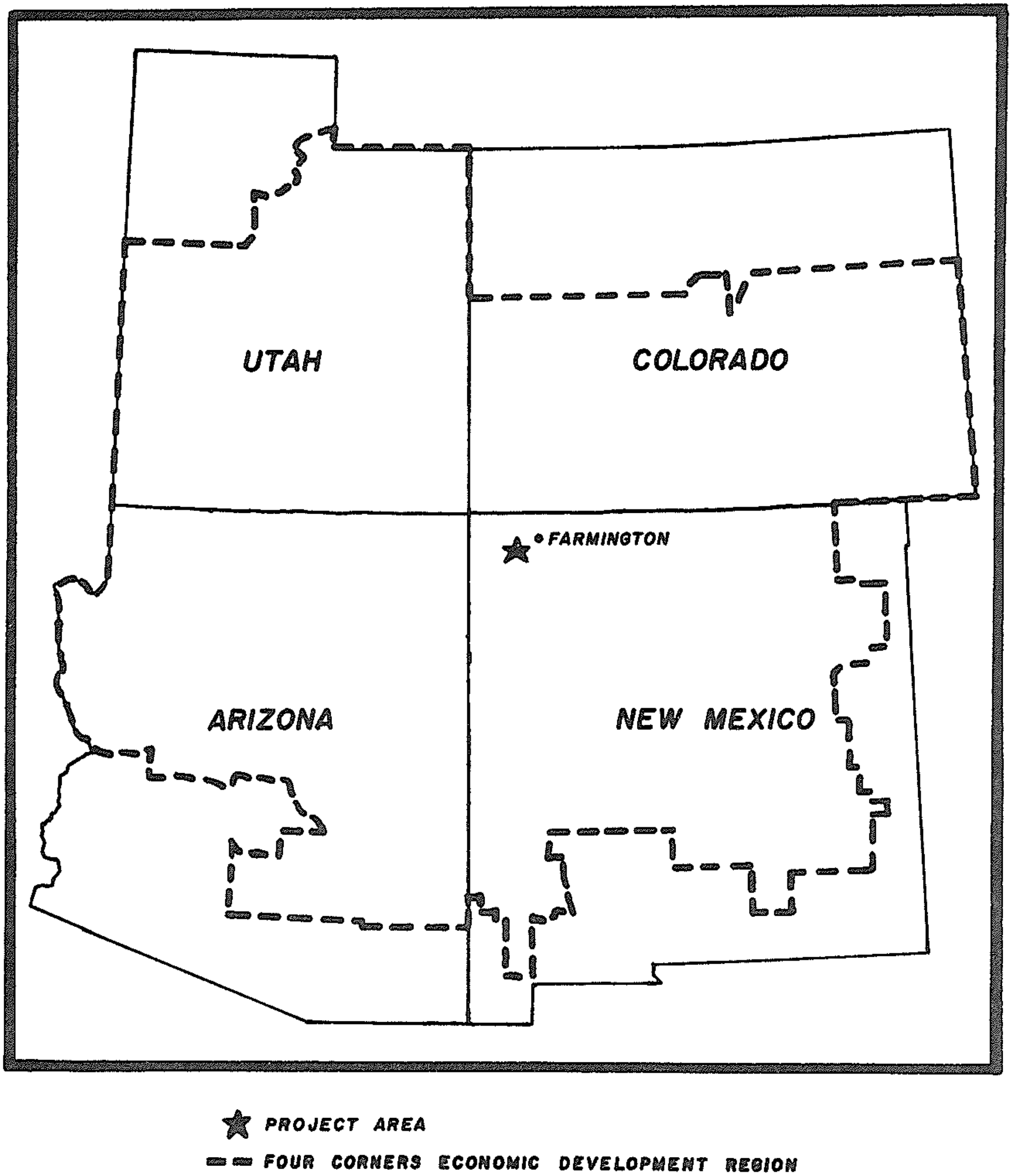
	Millions of Dollars	Percent
Expected Net Operating Profit	18	
Investment Capital	41	
Operating Capital	38	
Net Income (Less interest charge)	13	
Return to the Project (at 206 million) (Does not include any off-farm or secondary benefits)		6

Is the Project Worthwhile?

Many individuals have questioned the value of such a large undertaking. The past history of irrigation projects for Indians, and in particular the Navajos, has not been very encouraging. Most of these irrigation projects, however, were based on the concept of subsistence farming and not on the development of commercial agriculture. It is almost certain that the public investment will exceed 206-million dollars before the project is completed. These are direct appropriation funds and are not to be paid back. The value of the project should be measured by both the primary impact upon the Navajo Tribe as well as the secondary impact upon the general Four Corners Region. As indicated previously, the average Navajo family income is only $800 per year. If the project provides employment for approximetely 4,000 Navajo families, it could have the effect of removing these families from the poverty rolls. It is anticipated that at least 4,000 families would have an income exceeding $5,000 resulting from the project. Without this type of development or similar developments on the reservation, these families might have to be supported through public welfare transfer payments. If a minimum income level for a family of five to six people is $3,800, and the Navajo average is now $800, a public outlay of nearly twelve million dollars per year would be required to support 4,000 Navajo families. The project, viewed in this light, makes sense from an economic and a social viewpoint. From a purely agricultural production standpoint, the project does not appear to be economically rational. The present agricultural situation is excess production for many products. By the time the project is completed, there will be an average public investment of nearly $3,000 per acre of irrigated land. The land will not produce sufficient revenue to justify a $3,000 investment per acre needed to develop new land. Viewed in the broader economic-social perspective, however, the investment appears much more rational.

The Irrigation Project is extremely important to the Navajo people. It is imperative that the University, as well as all other public agencies, assist the Navajos in making this a successful project.

NAVAJO INDIAN IRRIGATION PROJECT



LAND AND WATER PROBLEM SOLVING ON THE UPPER RIO GRANDE

Ralph M. Bell[1]

"All water originates on or passes through watershed lands . . . Thus the condition of watershed lands constitutes an index of the quality of water yield from watersheds."

The author of this observation is lost in antiquity -- however, Dortignac[2] stated the watershed condition -- water quality relationship on the Rio Grande in a similar manner as follows:

"On much of the farmland irrigated below Elephant Butte Reservoir, crop yields are reduced 10 to 20 percent by an excess of soluble salts in the soil. Annual crop losses due to this salinity are estimated at more than half a million dollars. These monetary losses are but an index of overall losses caused by salinity. The initial investment in land development as well as both public and private improvements are endangered by loss in land productivity."

"The increase in salt content in going downriver is, no doubt, partially due to the high silt-laden surface runoff waters from woodland-sagebrush and semi-arid zones on soils derived from soft sedimentary rocks, particularly shales, in the New Mexico portion of the basin. The increase in salt content is concomitant with that of sediment. Most of the sediments and salts are contributed by drainages entering the river below Otowi Bridge."

The interrelationships of water supplies, water uses, and water quality with watershed lands are focused and "spot-lighted" by the preceeding comments, and the need for basic data and interpretations of these interrelationships has been the precipitator leading to present and prior studies on the Upper Rio Grande. Both the state of New Mexico and the Department of Agriculture (principally the Forest Service, Economic Research Service, and Soil Conservation Service) have an interest in learning the nature and magnitude of water and related land resource problems on the Upper Rio Grande; and to learn of alternative ways in which programs and activities, within the pervue of USDA, could aid local people and the state in attempting to deal with the problems. These mutual interests resulted in a "type 4" cooperative study on the Rio Grande. The study was initiated by the state in 1965 and was staffed for study by USDA in 1966. This multi-discipline, multi-USDA agency and state study has the following objectives:

1. Identify areas where watershed management efforts might improve the quantity and quality of surface water.

2. Provide a basis for coordinating U. S. Department of Agriculture program activity in watershed protection, flood prevention, and agricultural water management.

1/ Party Leader, River Basin Watershed Planning, SCS, Albuquerque, New Mexico

2/ Watershed Resources and Problems of the Upper Rio Grande Basin, E. J. Dortignac, Rocky Mountain Forest and Range Experiment Station

3. Identify opportunities for improving the agricultural economy through small watershed projects under Public Law 566.

4. Appraise opportunities for meeting local water and related land objectives with U. S. Department of Agriculture project-type programs.

5. Appraise development needs that contribute to a plan for coordination, regulation, and management of the water and related land resources.

6. Appraise the potential needs and desires of the human resource and indicate programs, procedures, and assistance possible and necessary to help the local people provide their full contribution to the economy and culture of the basin.

The importance of these objectives increases as one equates them to the tragedy taking place through the "death" of small towns and loss of rural population in parts of the Upper Rio Grande Basin. It is sobering and sad that seventeen of New Mexico's thirty-two counties lost population in the last census -- Catron, Socorro, and Torrance counties of the basin lost population.

As metropolitan areas such as Albuquerque and Santa Fe struggle with the problems and miseries of rapid growth and overcrowding, the proportion of New Mexico population still living in small towns and rural areas continues to decrease. In the basin, two-thirds of incorporated and unincorporated towns and villages of over 1,000 people lost populations. The rural outflow has been going on for a number of years, as the more efficient landowners and operators acquire or lease their neighbors' land, and as residents and young people of small towns and rural areas gravitate to job opportunities in the metropolitan areas. As the rural areas and small town lose population, social amenities diminish and economic survival and self-government becomes difficult for those who remain behind.

Throughout the study, the field party gave consideration to such necessities of life as adequate food, fiber, shelter, and raw materials for industry. The study has considered values such as the quality of life including attractive surroundings, space to live, outdoor recreation, suitable habitat for plants and animals, and aesthetic satisfaction. Also considered were the needs for safe and adequate water, clean air, and productive soil held in place.

The Upper Rio Grande is, indeed, a land of contrasts and presents the student or researcher many gradations of climate, topography, and circumstances from Elephant Butte Reservoir north to the Colorado-New Mexico state line. The variations provide one of the basin's greatest assets -- natural beauty illustrated by such views as the Sandia Mountains at sunset, Mount Taylor, or the Jurassic cliffs near Gallup. The New Mexico Tourist Bureau and Chambers of Commerce call attention to the Indian, Spanish, and Anglo heritage. This heritage is evidenced by such relics as the old abandoned church and abandoned residence at Engle, near T or C, and by the Laguna and Acoma Indian Pueblos west of Albuquerque.

A paramount problem of the basin is pollution -- sediment pollution which causes deterimental effects which can be traced from bare shale slopes and badlands areas, through the systems of arroyos, to areas of deposition on roads, railroads, in impoundments, or on farmlands. Of course, we find many other forms of pollution such as junk piles, animal waste, mine and mill waste, pollution of air from burning, and phreatophyte infestations where sediment inflows have created high water tables. These high water tables, in turn, allow invasion of phreatophytes or water-loving plants. Solutions are known for nearly all pollution problems. There are opportunities, for example, to curb bank-cutting erosion with rock and wire structures, or to substitute phreatophyte growth with improved irrigated pastures.

As the river basin study progressed, the basic data was developed for four subbasins which have been compiled to cover the entire basin. Results of the study are presented by maps designed to show a graphic story of the resources problems, needs, and possible solutions. Some of the maps provide basic data. Other maps are either complimentary or are interpretative.

Basic Information Maps

The land status map shows geographical distribution of specific land tenure.

The geology map is presented to show the basic geological features in the study area and their relationship to centers of population, stream systems, and transportation routes. It gives the reader an idea of the parent material in which the soils have formed.

The mean annual precipitation (climate) map is presented to show both high and low precipitation areas. This map indicates areas where attention should be focused for watershed management considerations to complement the quantity and quality of surface water.

The vegetation map shows the general kinds of vegetation and broad types of land uses. This map is helpful in locating areas where watershed management might be effective in improving quality and quantity of surface water.

A transportation routes and recreation map shows both present and planned access routes. Existing, planned, and potential recreation facilities may be used to assist in making many interpretations for land, water, and economic improvements.

Interpretative Maps

The land treatment map was developed through study of the geology, mean annual precipitation, soils, land resource area, temperature, present erosion, and vegetative maps. This map exhibits a broad framework of the types of land treatment and management needed in the study area.

A groundwater map shows geographical distribution of available subsurface water and estimated depths to the water-yielding aquifer.

The irrigable and non-irrigable land map presents the location of irrigable and non-irrigable soils in the basin. Irrigable areas shown on the map were determined from soil characteristics including slope, drainage, and extent of present erosion.

The present erosion status map was developed from soils, precipitation, and vegetative maps. When properly interpreted these factors indicate the severity of gross erosion on the land.

The map of areas of potential increased water yield due to land treatment delineates land areas with potential for increased water yield, The precipitation, vegetative, and land treatment maps provided the basic data from which this map was prepared.

A PL 566 projects map shows position and relationship of completed, planned, and potential project areas. The potential project areas are those where the watershed problems can be dealt with through the authorities of the Watershed Protection and Flood Prevention Act (PL 566).

The maps which were mentioned with accompanying tables, interpretations and analyses provide the basis for suggested alternative solutions to the problems. If the old adage holds true, "The proof of the pudding is in the eating" then let's compare one or two of the objectives with the findings and conclusions. Remember the objective "Identify areas where watershed management efforts might improve the quantity and quality of surface water," let's recall the map showing areas where watershed management practices have possibilities. Also, let's look at some statistics which are identified as having potential for development.

The study showed there is a total potential of increasing water harvest and yield by 2.0 million acre-feet in the basin! -- Perhaps only 1.0 million acre-feet of the total potential can be realized. The costs and returns of applying a "water harvest" land treatment and management program are generally as follows:

Land treatment systems applicable	Acres of need and opportunity	Estimated total cost of treatment $	Estimated annual dollar return of treatment* $	Value of additional av. annual employment
Snowpack management	4,000	348,000	25,000	70,000
Spruce-fir mgt.	143,000	5,720,000	1,448,000	172,000
Ponderosa pine mgt.	392,000	11,751,000	2,456,000	352,000
Aspen management	36,000	1,080,000	231,000	32,000
Phreatophyte control	19,000	1,800,000	2,247,000	54,000
Total	594,000	20,700,000	6,407,000	681,000

*Land treatment as applicable includes value of:

Increased water yield	$3,269,000
Sediment damage reduction	28,000
Increased red meat production	1,029,000
Timber and wood increase	2,081,000

The land abuse problems in the basin were determined (acres of land needing treatment). Alternatives were identified (the various land treatment systems) and a qualitative, quantitative, and monetary analysis developed. Actually, one might even note the "negative benefits" value of the obvious alternative of doing nothing or continuing a "status quo". The alternative to the public and private interests not making the $20,700,000 investment would be foregoing the future average annual benefits of $7,087,000. The choice must be the people's!

Remember the objective, "Identify opportunities for improving the agricultural economy through small watershed projects under Public Law 566?"

The field party looked at all watersheds in the Upper Rio Grande Basin. Where damages to cropland, urban areas, roads, or utilities appeared to justify needed measures, a "Watershed Investigation Report" was prepared. Let's look again at the interpretative PL 566 project map. This map shows watersheds where the watershed protection and flood prevention problems could be controlled through authorities of Public Law 566. For these 24 watersheds, there is opportunity to control 2,138 square miles of surface drainage with 132 floodwater retarding structures and 150 miles of floodwater diversions. Average annual costs for these structural measures would be $2,644,000 and average annual benefits would be $3,913,000.

As an "overview" of the nature and significance of the floodwater and sediment damage, the field party noted that three of the watersheds in the Grants area are interrelated in that the city of Grants is a common damage area to the three watersheds and will require a common disposal system. Also, there are many miles of canals and drains within the Middle Rio Grande Conservancy District in which arroyo flood flows are intercepted, and ten watersheds were found to be definitely interrelated with the conservancy district in that floodwater and sediment from any one of the watersheds may cause interruption of irrigation water delivery to substantial areas within the district. These two cases of interrelationships precipitated the field party's recommendation that local people seek basin-wide authorization to most effectively deal with the problems.

The field party first approached the problem of the agricultural economy on an "individual action or practice basis" but soon became mired down in a morass of actions and activities. A second attempt proved effective and usable. This was the "land treatment and management systems" approach. This approach groups applicable practices into an appropriate treatment and management system. In general, investment costs can be determined and economic returns assessed. Thus, in the basin study, a basic remedial program for the land evolved. The remedial program was essentially a qualitative, quantitative, and monetary assessment of land treatment and management needs for the basin. The watershed management aspects have been previously shown, and the following figures show the magnitude of the total land treatment program including watershed management:

Acres needing treatment	12,126,000
Total cost	$108,108,000

This cost when converted to annual equivalent is $10,788,000 as compared with annual returns of $28,667,000. This 1 to 2.65 cost return ratio certainly appears to be a good investment for the private and public dollar.

Applicable USDA project-type programs to the basin include the Watershed Protection and Flood Prevention Act (Public Law 566) with 24 opportunities identified. Other significant programs available include Public Law 46 which authorizes technical assistance to soil and water conservation districts, the Great Plains Conservation Program (Public Law 1021), and REAP (Rural Environmental Assistance Program). These programs provide technical and financial assistance in the installation of the needed land treatment and management systems. It is foreseeable that in the future, counties and cities may enter into joint efforts with landowners to accomplish needed land treatment in some watersheds. Other project-type programs available include the opportunity for water and sewerage developments through Public Law 660 administered by the Farmers Home Administration. In the Upper Rio Grande Basin, community water development is an acute need in 20 of 95 communities. Sewerage systems are needed in 63 of 95 communities. Another USDA project-type program especially well-adapted to accommodate water and related land problems on a project-type basis is the Resource Conservation and Development (RC&D) program. Experience in New Mexico has shown "RC&D" to be especially effective in bringing known sources of assistance to the attention of local decision makers and participants.

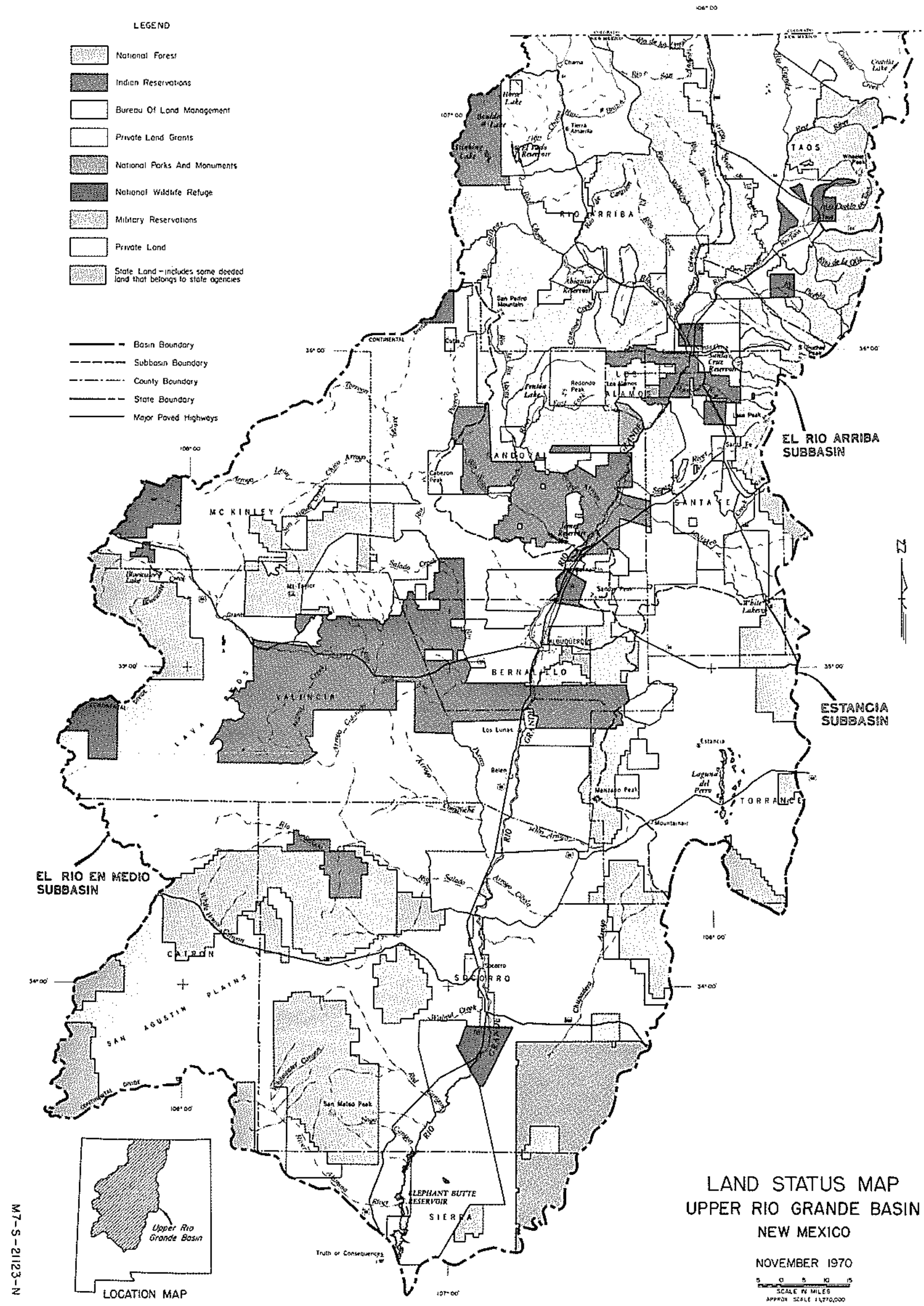
National forests in the basin are significant. The Multiple-Use Sustained Yield Act of 1960 states that national forests are to be administered for recreation, range, timber, watershed, and wildlife purposes. This philosophy of use has endured for 10 years, and the results of multiple uses of forest resources makes significant contributions to the basin economy.

The field party recognized that some legislative changes and enforcement will be required in order for the land and water resources in the basin to be developed and utilized efficiently and properly. Examples of needed changes include:

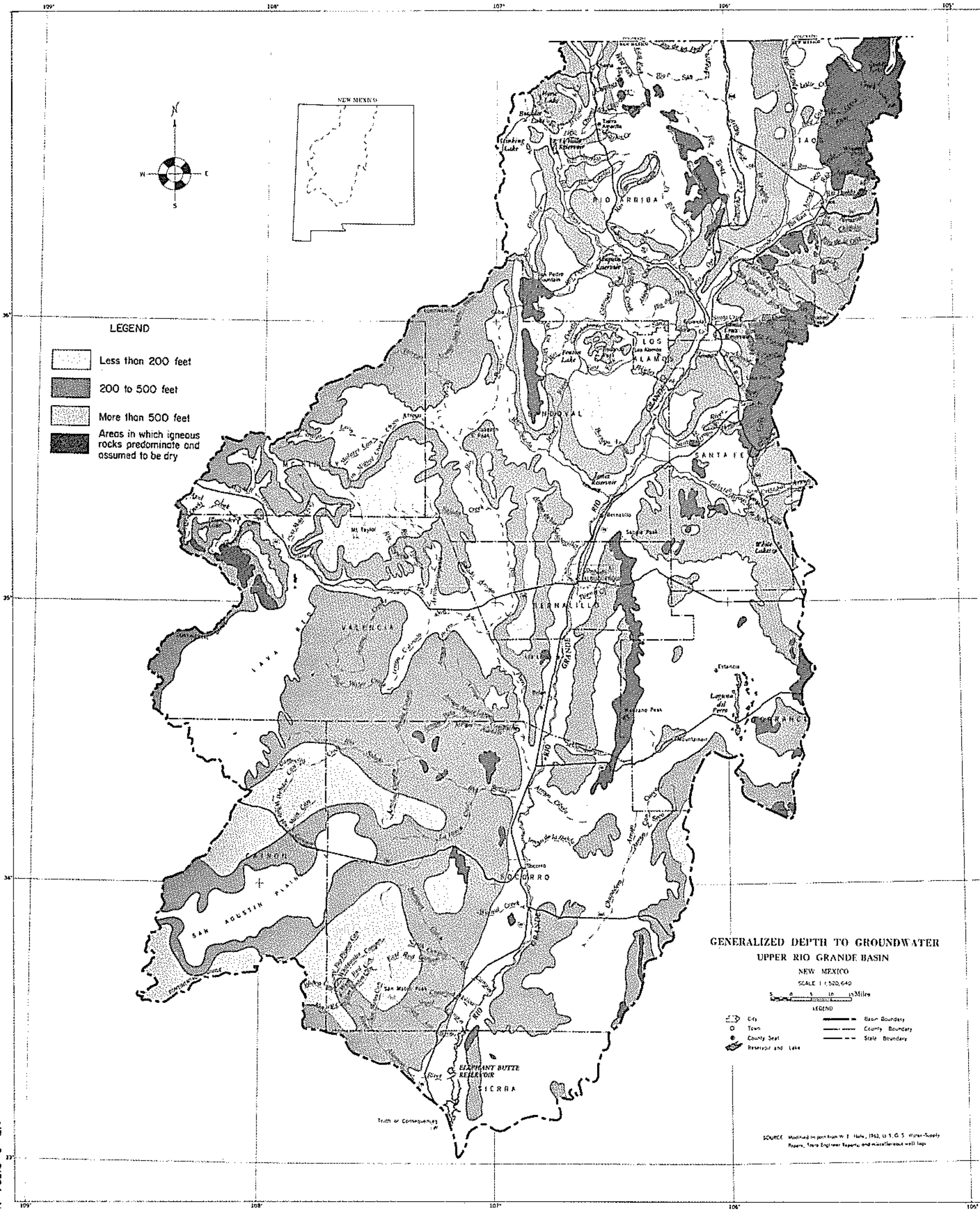
1. Water rights on Indian land need to be clarified.

2. Land zoning laws must be adopted and enforced. This is evident from the expenditures every year for flood damages and the cost for flood protection. Although millions of dollars have been spent on flood protection and prevention measures, flood damages increase every year. The public should demand that floodplains be marked and zoned. If floodplain areas are developed, they should be flood-proofed to a safe level of protection.

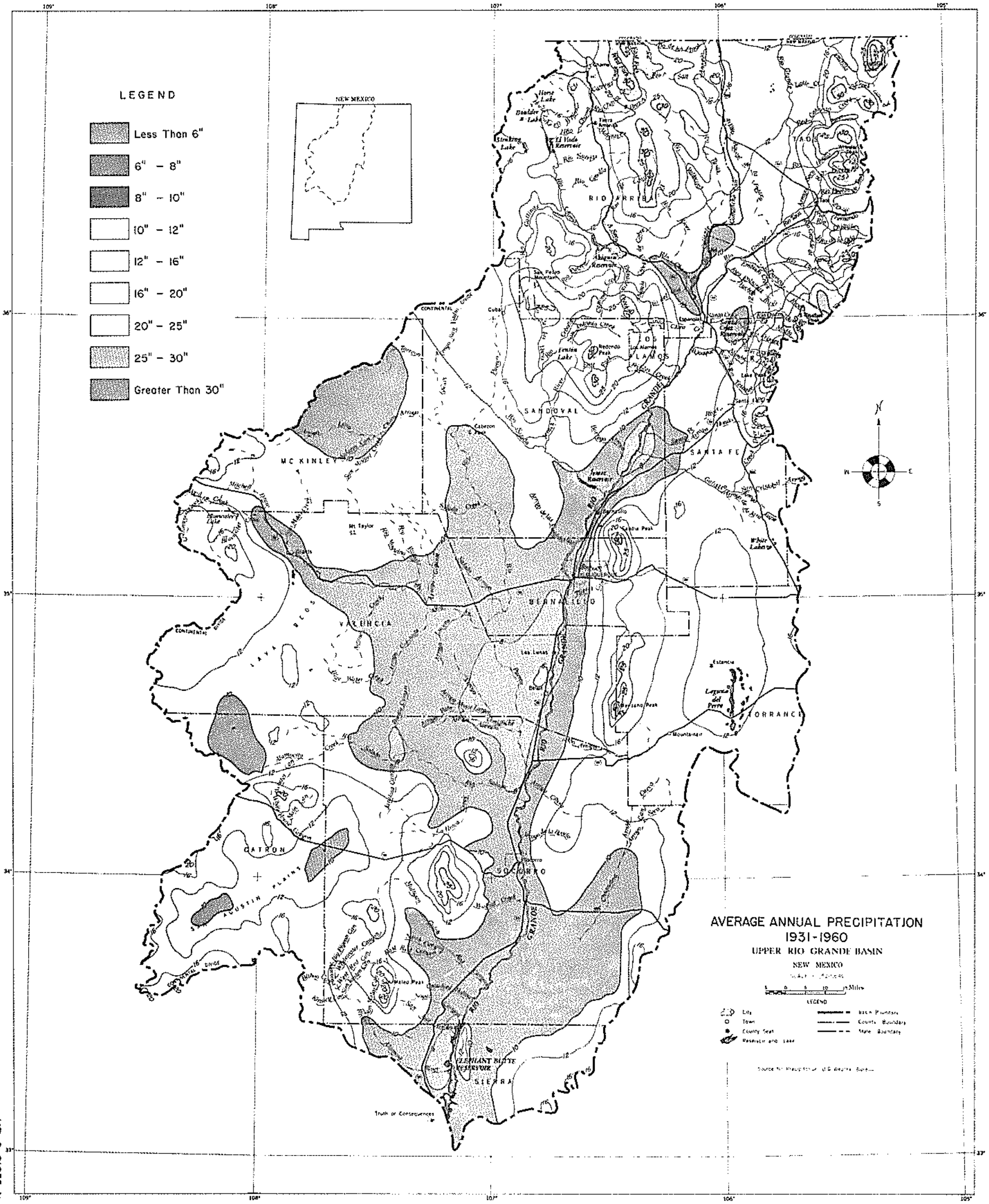
As previously mentioned, I've presented a few of the findings and conclusions of the study. The final basin report will include other suggested ways that local decision makers may deal with their resource development. I wish to close my presentation, however, with the reminder that "planners" per se have no authority to enact alternatives. This is how it should be in a democratic society. I hope it never changes. Action must come from motivated local decision makers who have a definite understanding of their benefits, costs, and responsibilities.



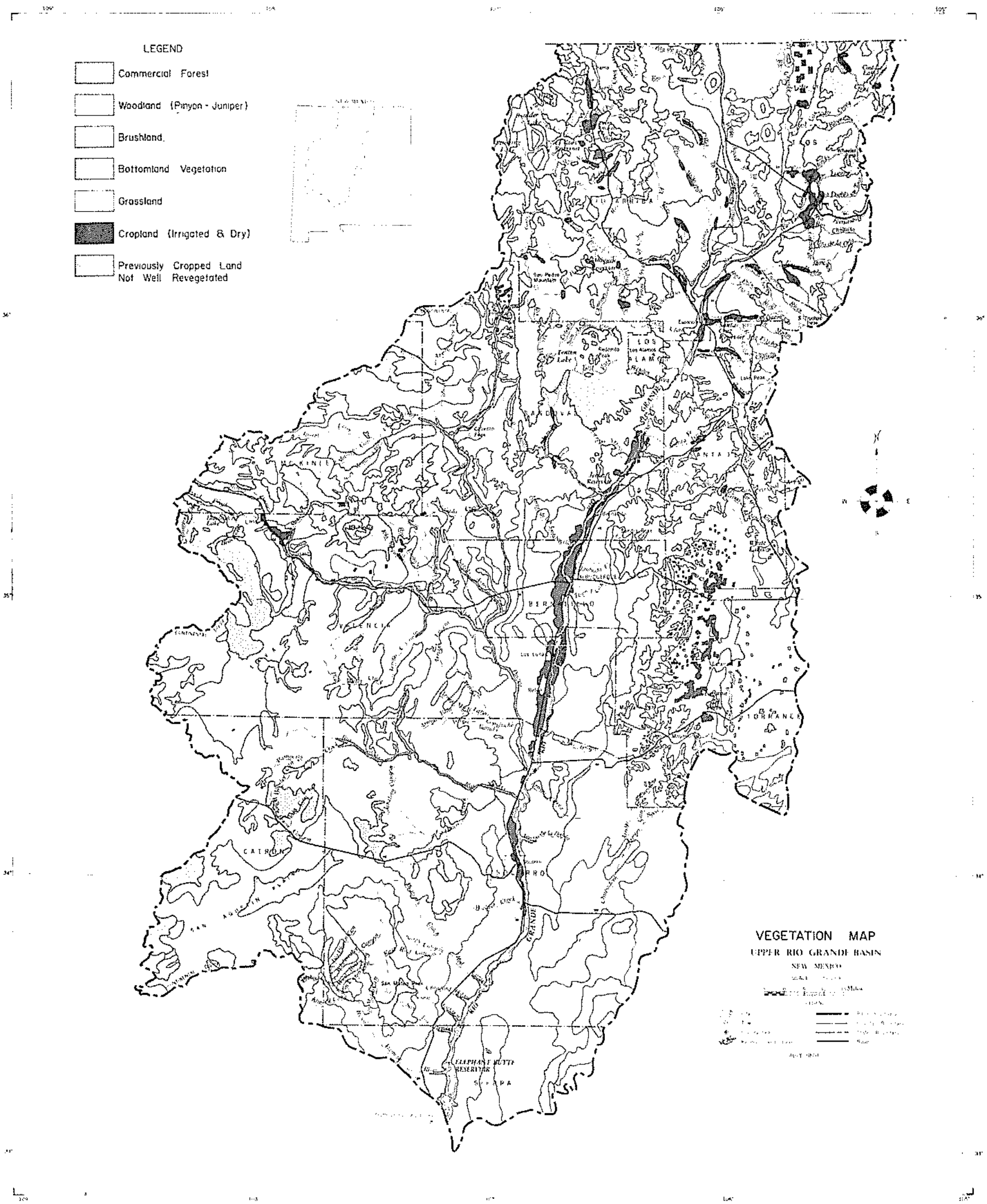
LAND STATUS MAP
UPPER RIO GRANDE BASIN
NEW MEXICO


NEW MEXICO
LEGEND
Less than 200 feet
200 to 500 feet
More than 500 feet
Areas in which igneous rocks predominate and assumed to be dry
GENERALIZED DEPTH TO GROUNDWATER
UPPER RIO GRANDE BASIN
NEW MEXICO
LEGEND
City
Town
County Seat
Reservoir and Lake
Basin Boundary
County Boundary
State Boundary
RIO ARRIBA
TAOS
LOS ALAMOS
SANDOVAL
SANTA FE
BERNALILLO
VALENCIA
TORRANCE
SOCORRO
CATRON
SIERRA
RIO GRANDE
SAN AGUSTIN PLAINS
LAVA
ELEPHANT BUTTE RESERVOIR
Truth or Consequences

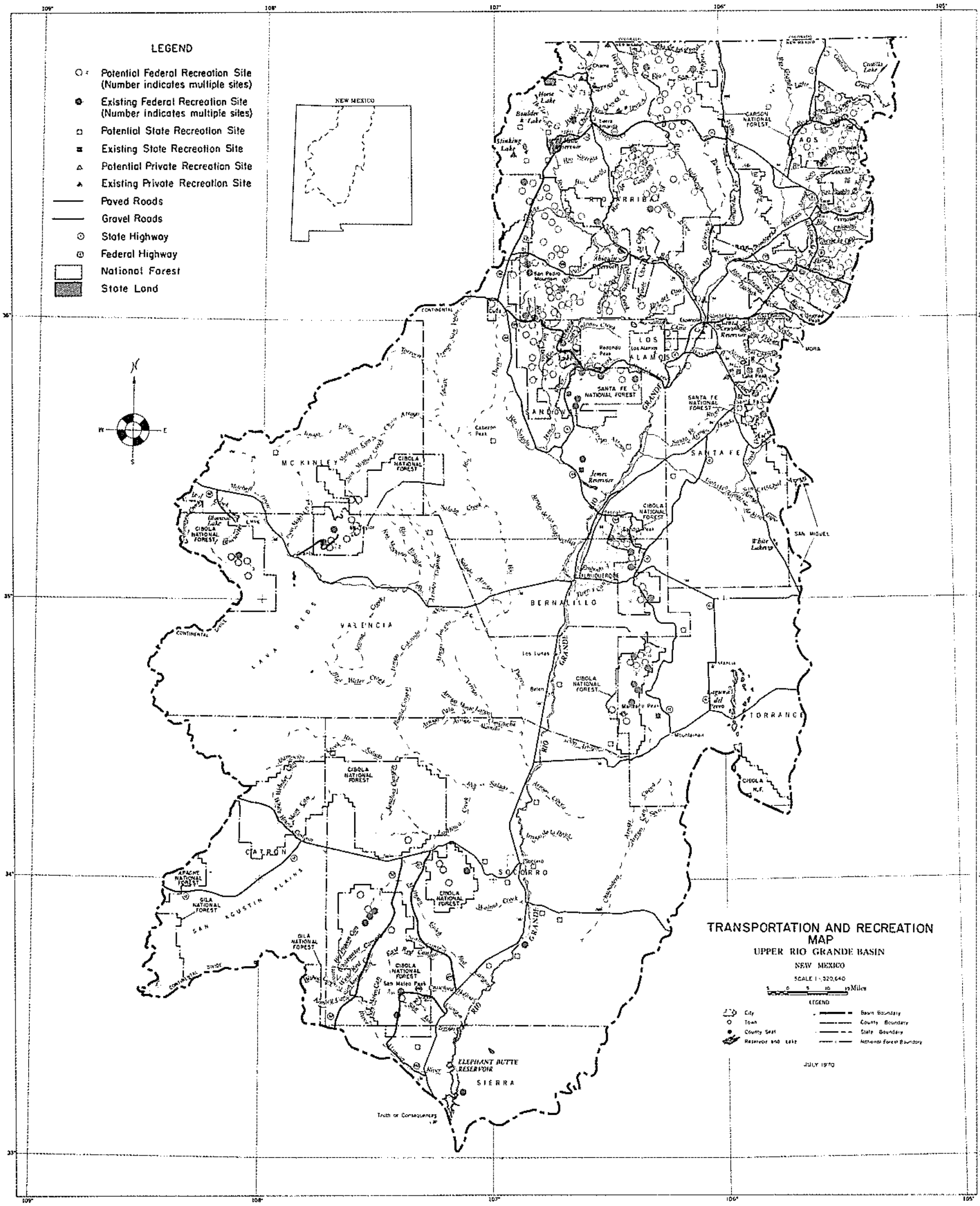
M7-S-21594-N


LEGEND
Less Than 6"
6" - 8"
8" - 10"
10" - 12"
12" - 16"
16" - 20"
20" - 25"
25" - 30"
Greater Than 30"
NEW MEXICO
AVERAGE ANNUAL PRECIPITATION
1931-1960
UPPER RIO GRANDE BASIN
NEW MEXICO
RIO ARRIBA
SANDOVAL
LOS ALAMOS
SANTA FE
MC KINLEY
BERNALILLO
VALENCIA
TORRANCE
CATRON
SOCORRO
SIERRA
ELEPHANT BUTTE RESERVOIR
Truth or Consequences

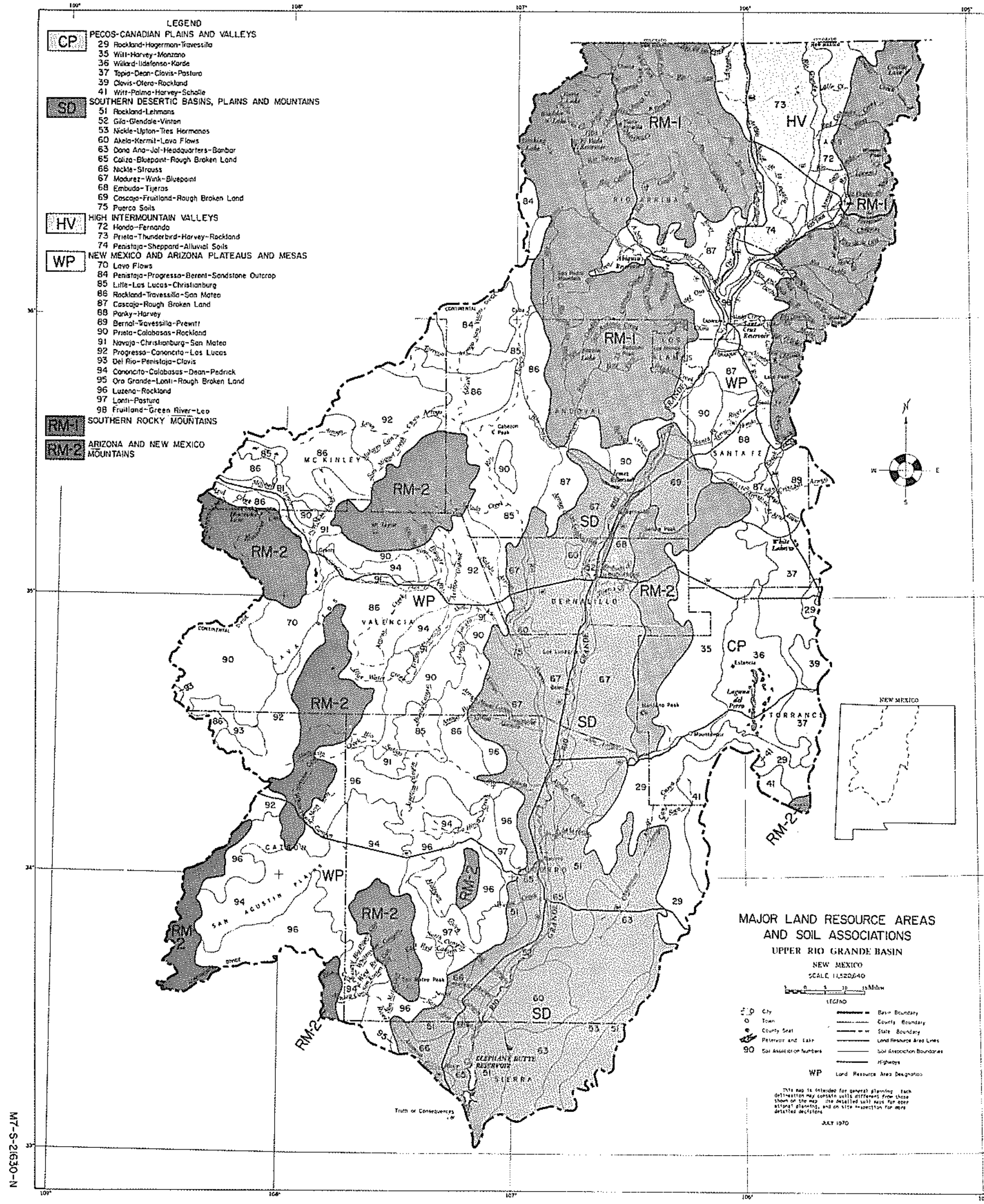
M7-S-21635-N

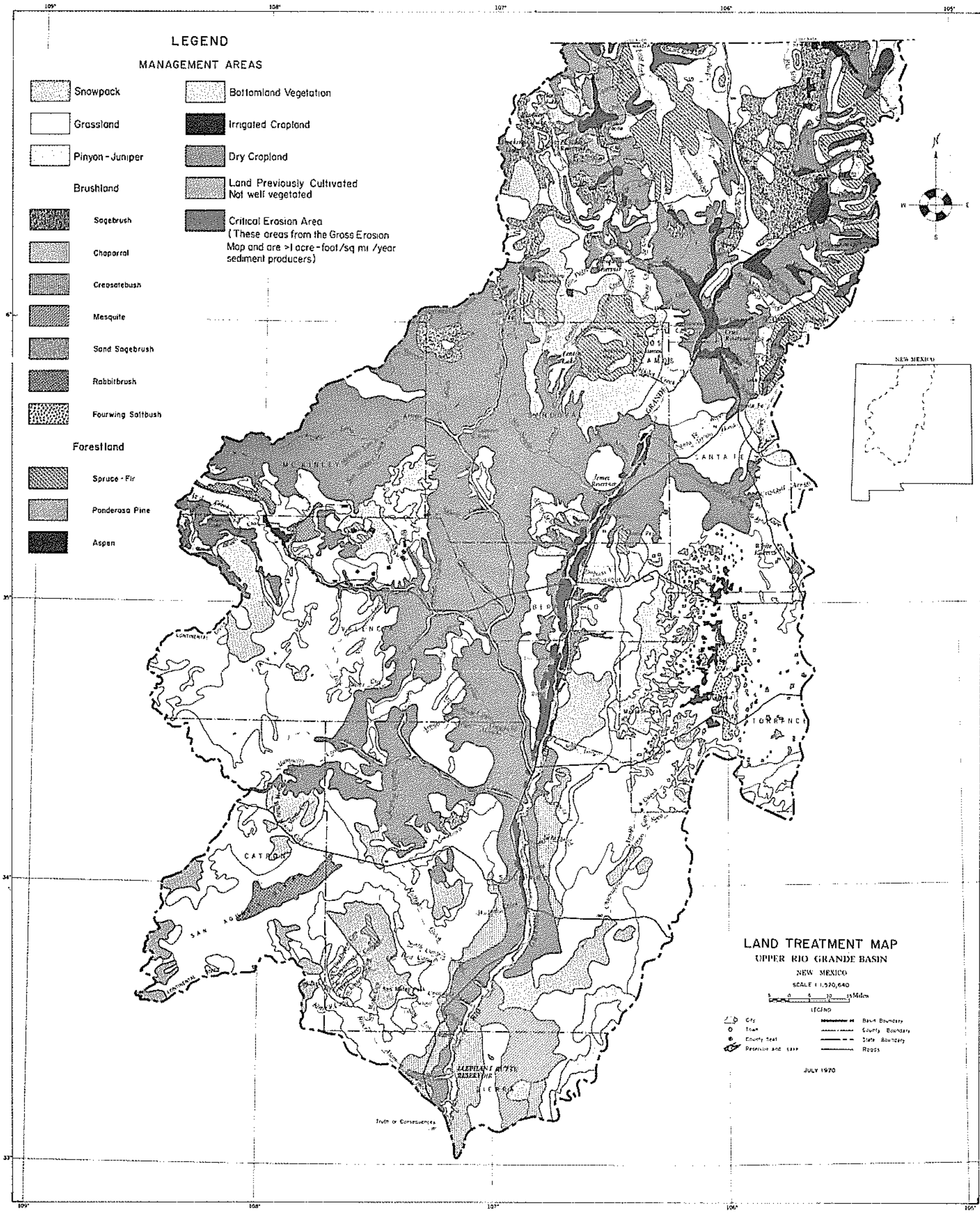

LEGEND
Commercial Forest
Woodland (Pinyon - Juniper)
Brushland
Bottomland Vegetation
Grassland
Cropland (Irrigated & Dry)
Previously Cropped Land Not Well Revegetated
VEGETATION MAP
UPPER RIO GRANDE BASIN
NEW MEXICO
GRANDE
CATRON
TORRANCE
ELEPHANT BUTTE RESERVOIR

M7-S-21631-N

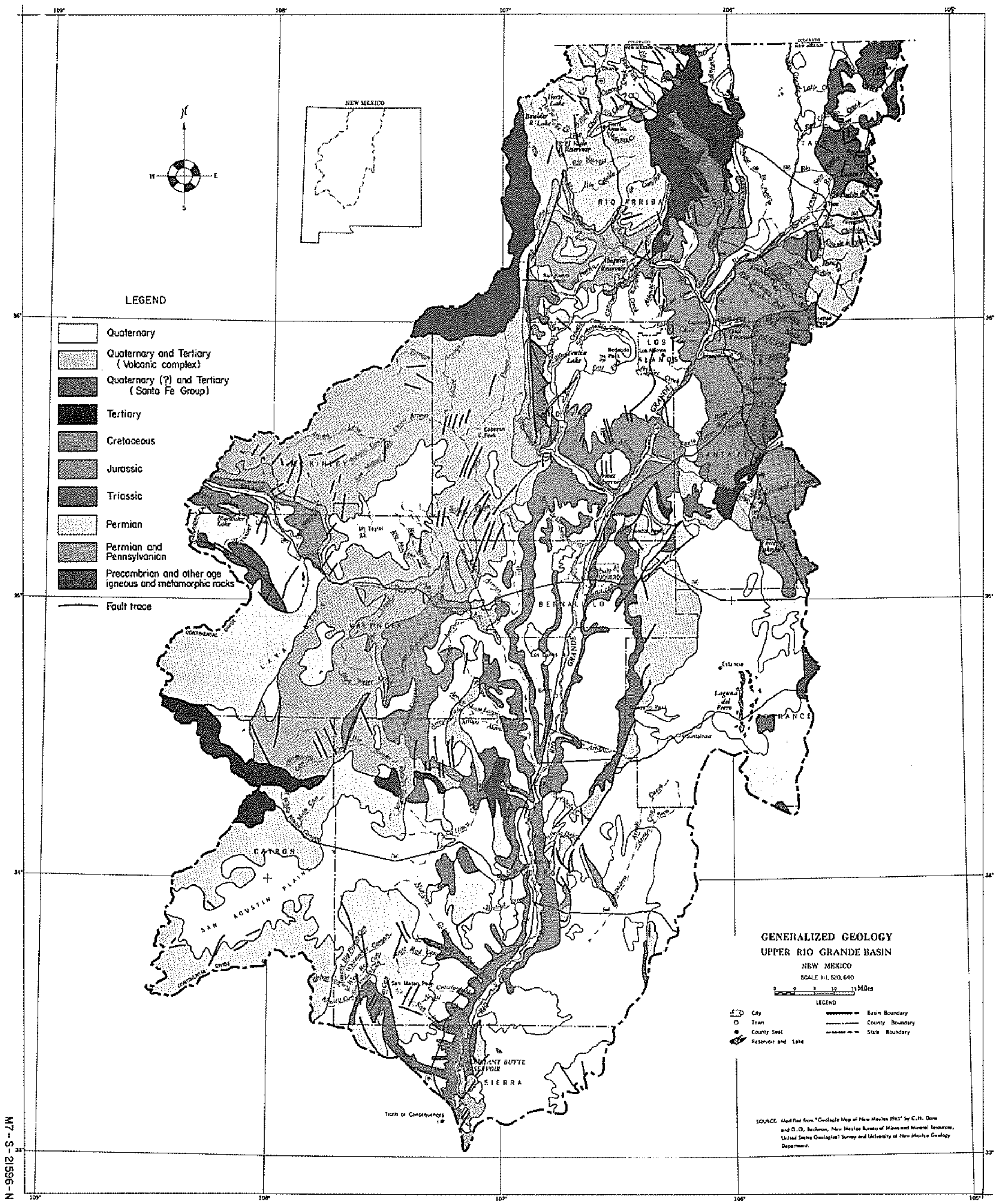

LEGEND
Potential Federal Recreation Site (Number indicates multiple sites)
Existing Federal Recreation Site (Number indicates multiple sites)
Potential State Recreation Site
Existing State Recreation Site
Potential Private Recreation Site
Existing Private Recreation Site
Paved Roads
Gravel Roads
State Highway
Federal Highway
National Forest
State Land
NEW MEXICO
TRANSPORTATION AND RECREATION MAP
UPPER RIO GRANDE BASIN
NEW MEXICO
JULY 1970
CARSON NATIONAL FOREST
SANTA FE NATIONAL FOREST
CIBOLA NATIONAL FOREST
APACHE NATIONAL FOREST
GILA NATIONAL FOREST
LOS ALAMOS
SANDOVAL
SANTA FE
McKINLEY
BERNALILLO
VALENCIA
TORRANCE
CATRON
SOCORRO
SIERRA
SAN MIGUEL
MORA
SAN AGUSTIN PLAINS
ELEPHANT BUTTE RESERVOIR
RIO GRANDE

M7-S-21629-N

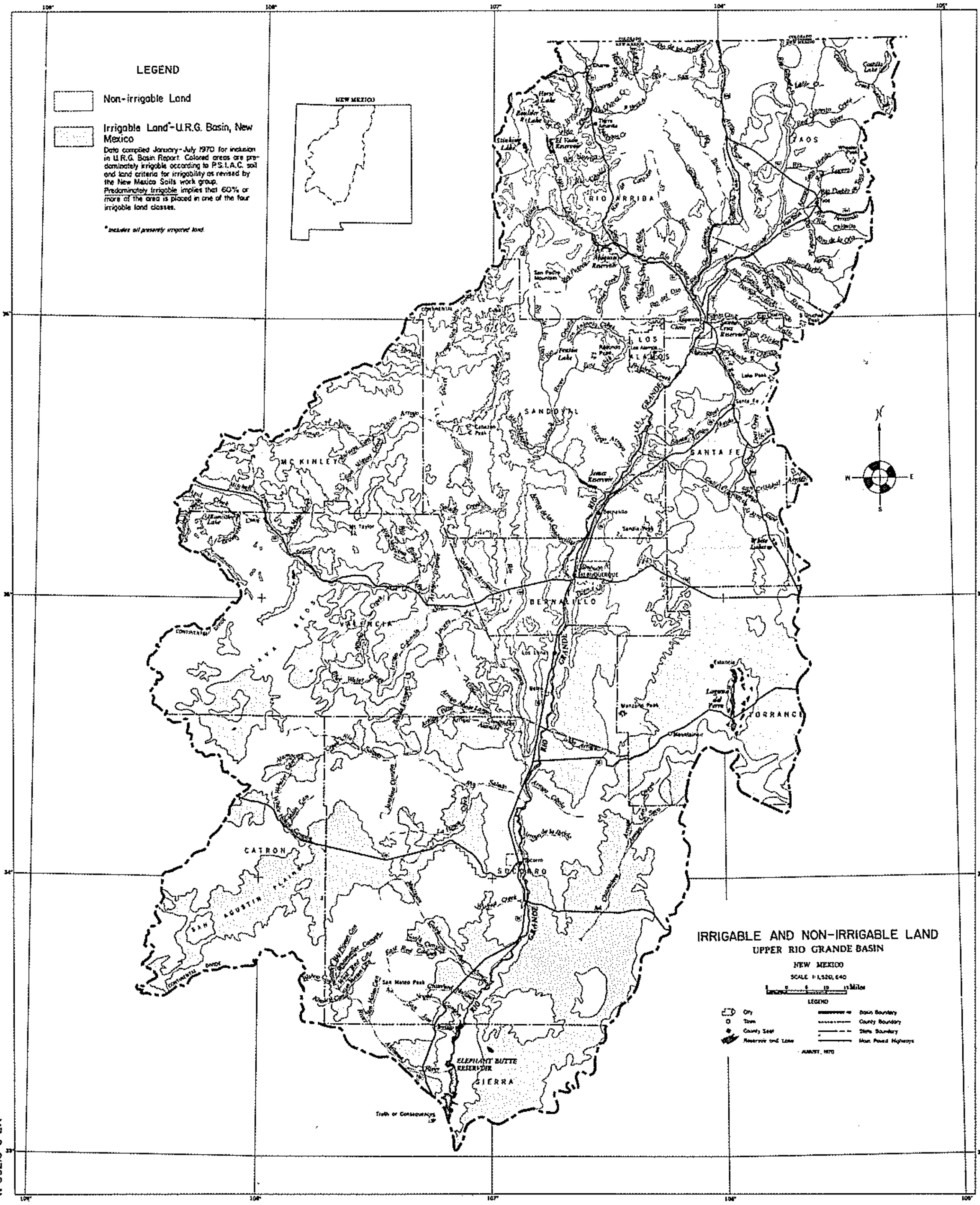

LEGEND
CP PECOS-CANADIAN PLAINS AND VALLEYS
29 Rockland-Hagerman-Travessilla
35 Witt-Harvey-Manzano
36 Willard-Ildefonso-Karde
37 Tapia-Dean-Clovis-Pastura
39 Clovis-Otero-Rockland
41 Witt-Palma-Harvey-Schalle
SD SOUTHERN DESERTIC BASINS, PLAINS AND MOUNTAINS
51 Rockland-Lehmans
52 Gila-Glendale-Vinton
53 Nickle-Upton-Tres Hermanos
60 Akela-Kermit-Lava Flows
63 Dona Ana-Jal-Headquarters-Bonbar
65 Caliza-Bluepoint-Rough Broken Land
66 Nickle-Strauss
67 Madurez-Wink-Bluepoint
68 Embudo-Tijeras
69 Cascajo-Fruitland-Rough Broken Land
75 Puerco Soils
HV HIGH INTERMOUNTAIN VALLEYS
72 Hondo-Fernando
73 Prieta-Thunderbird-Harvey-Rockland
74 Penistaja-Sheppard-Alluvial Soils
WP NEW MEXICO AND ARIZONA PLATEAUS AND MESAS
70 Lava Flows
84 Penistaja-Progresso-Berent-Sandstone Outcrop
85 Litle-Las Lucas-Christianburg
86 Rockland-Travessilla-San Mateo
87 Cascajo-Rough Broken Land
88 Panky-Harvey
89 Bernal-Travessilla-Prewitt
90 Prieta-Calabasas-Rockland
91 Navajo-Christianburg-San Mateo
92 Progresso-Canoncito-Los Lucas
93 Del Rio-Penistaja-Clovis
94 Canoncito-Calabasas-Dean-Pedrick
95 Oro Grande-Lonti-Rough Broken Land
96 Luzena-Rockland
97 Lonti-Pastura
98 Fruitland-Green River-Leo
RM-1 SOUTHERN ROCKY MOUNTAINS
RM-2 ARIZONA AND NEW MEXICO MOUNTAINS
MAJOR LAND RESOURCE AREAS AND SOIL ASSOCIATIONS
UPPER RIO GRANDE BASIN
NEW MEXICO
SCALE 1:1,520,640
LEGEND
City
Town
County Seat
Reservoir and Lake
Soil Association Numbers
Basin Boundary
County Boundary
State Boundary
Land Resource Area Lines
Soil Association Boundaries
Highways
WP Land Resource Area Designation
JULY 1970
M7-S-21630-N


LEGEND
MANAGEMENT AREAS
Snowpack
Grassland
Pinyon - Juniper
Brushland
Sagebrush
Chaparral
Creosotebush
Mesquite
Sand Sagebrush
Rabbitbrush
Fourwing Saltbush
Forestland
Spruce - Fir
Ponderosa Pine
Aspen
Bottomland Vegetation
Irrigated Cropland
Dry Cropland
Land Previously Cultivated
Not well vegetated
Critical Erosion Area
(These areas from the Gross Erosion Map and are >1 acre-foot/sq mi /year sediment producers)
NEW MEXICO
LAND TREATMENT MAP
UPPER RIO GRANDE BASIN
NEW MEXICO
JULY 1970
109°
108°
107°
106°
105°
36°
35°
34°
33°
SANTA FE
TORRANCE
CATRON
Elephant Butte Reservoir
Truth or Consequences

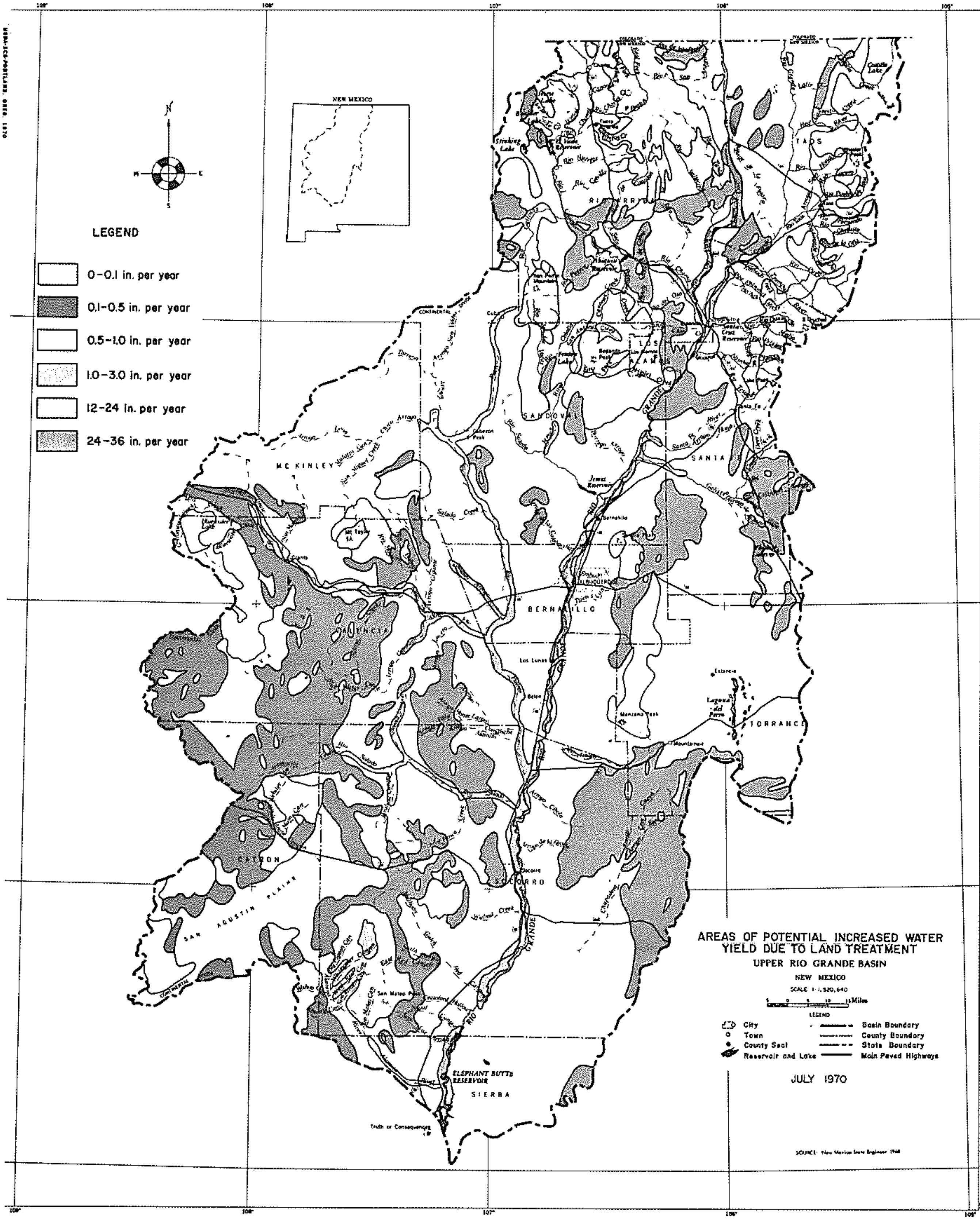
M7-S-21628-N



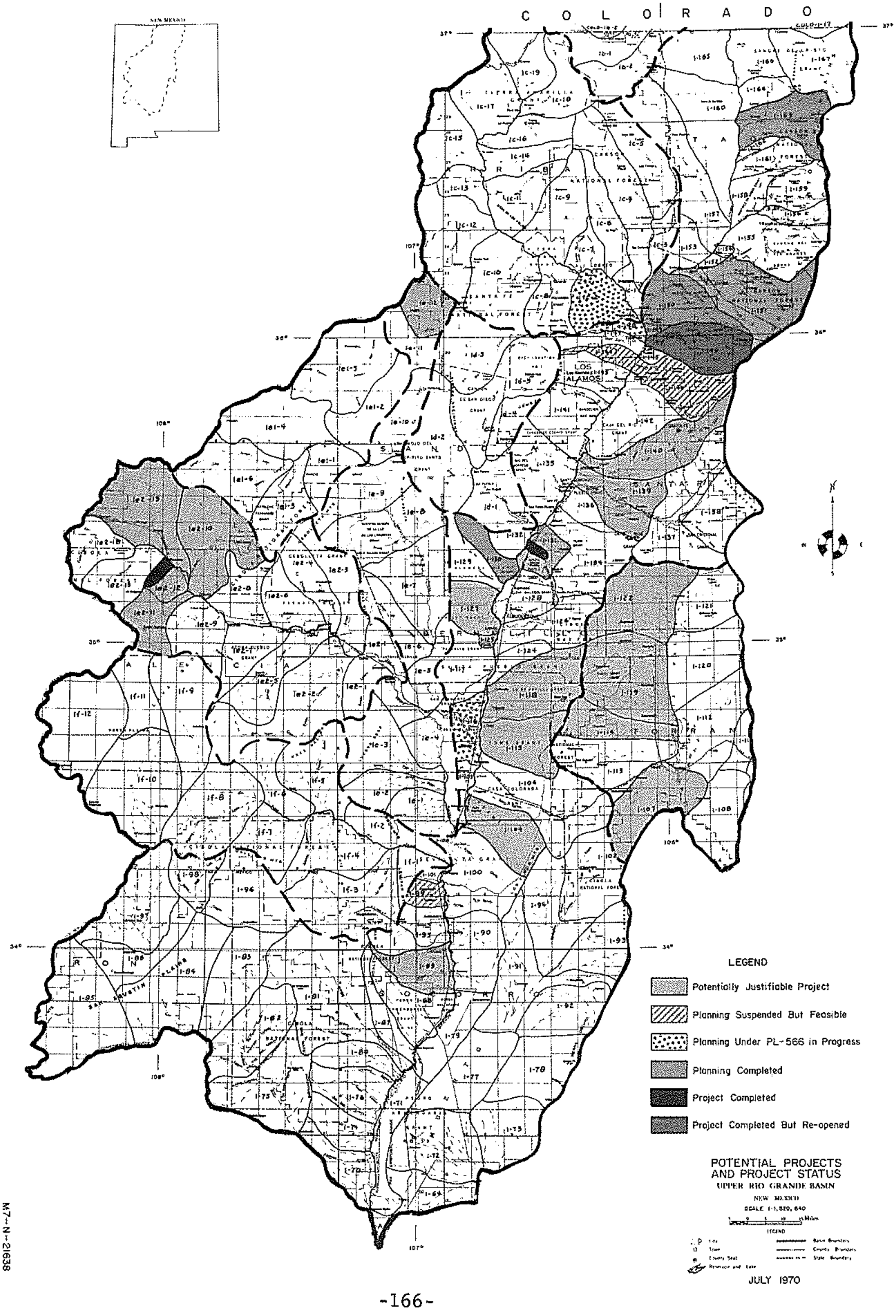
LEGEND
Quaternary
Quaternary and Tertiary (Volcanic complex)
Quaternary (?) and Tertiary (Santa Fe Group)
Tertiary
Cretaceous
Jurassic
Triassic
Permian
Permian and Pennsylvanian
Precambrian and other age igneous and metamorphic rocks
Fault trace
NEW MEXICO
GENERALIZED GEOLOGY
UPPER RIO GRANDE BASIN
NEW MEXICO
LEGEND
City
Town
County Seat
Reservoir and Lake
Basin Boundary
County Boundary
State Boundary
RIO ARRIBA
LOS ALAMOS
SANTA FE
BERNALILLO
VALENCIA
CATRON
SAN AUGUSTIN PLAINS
TORRANCE
SIERRA
RIO GRANDE
Truth or Consequences
M7-S-21596-N


LEGEND
Non-irrigable Land
Irrigable Land*-U.R.G. Basin, New Mexico
Data compiled January-July 1970 for inclusion in U.R.G. Basin Report. Colored areas are predominately irrigable according to P.S.I.A.C. soil and land criteria for irrigability as revised by the New Mexico Soils work group.
Predominately irrigable implies that 60% or more of the area is placed in one of the four irrigable land classes.
*Includes all presently irrigated land.
NEW MEXICO
TAOS
RIO ARRIBA
LOS ALAMOS
SANDOVAL
SANTA FE
MC KINLEY
BERNALILLO
VALENCIA
TORRANCE
CATRON
SOCORRO
SIERRA
RIO GRANDE
SAN AGUSTIN PLAINS
ELEPHANT BUTTE RESERVOIR
Truth or Consequences
IRRIGABLE AND NON-IRRIGABLE LAND
UPPER RIO GRANDE BASIN
NEW MEXICO
SCALE 1:1,520,640
Miles
LEGEND
City
Town
County Seat
Reservoir and Lake
Basin Boundary
County Boundary
State Boundary
Main Paved Highways
AUGUST, 1970

M7-S-21769-N


LEGEND
0–0.1 in. per year
0.1–0.5 in. per year
0.5–1.0 in. per year
1.0–3.0 in. per year
12–24 in. per year
24–36 in. per year
NEW MEXICO
AREAS OF POTENTIAL INCREASED WATER YIELD DUE TO LAND TREATMENT
UPPER RIO GRANDE BASIN
NEW MEXICO
City
Town
County Seat
Reservoir and Lake
Basin Boundary
County Boundary
State Boundary
Main Paved Highways
JULY 1970
BERNALILLO
SANDOVAL
TORRANCE
SOCORRO
CATRON
SIERRA
VALENCIA
MC KINLEY
SAN AGUSTIN PLAINS
ELEPHANT BUTTE RESERVOIR
RIO GRANDE

M7-N-21825


COLORADO
LOS ALAMOS
LEGEND
Potentially Justifiable Project
Planning Suspended But Feasible
Planning Under PL-566 in Progress
Planning Completed
Project Completed
Project Completed But Re-opened
POTENTIAL PROJECTS
AND PROJECT STATUS
UPPER RIO GRANDE BASIN
NEW MEXICO
JULY 1970

M7-N-21638

WATER IMPORT TO WEST TEXAS AND NEW MEXICO

Bill Clayton[1/]

One of the most urgent needs in the United States today is an expanded and accelerated program of comprehensive water resource development. This need must be met if we are to meet the pressing problems of the rising population and the growing economy. Here in this area, in Texas, and in New Mexico, we have recognized this need and are already pressing forward hand-in hand, together with the Bureau of Reclamation, U. S. Army Corps of Engineers, and state agencies in an effort to solve our problems.

In this day of almost instant communication and travel in jet planes at speeds that approach that of sound, no longer are arbitrary state lines realistic boundaries for planning and execution of water resource development projects. A good case in point is the Southern High Plains, which, you know, includes part of Western Texas and Eastern New Mexico. This vast expanse of fertile, level land is one of the nation's greatest assets; perhaps one of the greatest assets of the world. It is the largest contiguous area of high productive arable land in the world. Ever since man first tapped the clear, pure water lying beneath this great Southern Plains, the area's economy has flourished. The combination of fertile lands and underground water has resulted in one of the most productive areas in the world. Unfortunately, this vast reservoir of water underlying the Southern High Plains -- the reservoir we know as the Ogallala Aquifer -- is not inexhaustible. As you know, it is replenished only by percolation from the surface and at a rate infinitely lower than the rate of withdrawal. Recognizing this shortcoming, Texans and New Mexicans have united in a plan to provide supplemental water to the area.

The most likely source for this supplemental water in the immediate future -- and by the immediate future I mean within the next fifty years -- appears to be from the Lower Mississippi River. The U. S. Army Corps of Engineers, the Bureau of Reclamation, Texas and New Mexico are looking into the feasibility of such a major interbasin diversion of water. This joint undertaking is known by various names depending upon one's vantage point. Over in the area of the Lower Mississippi River, the venture is referred to as the Mississippi River Export Plan. In Texas, it's known as the Trans-Texas System of the Texas Water Plan, and here in New Mexico, the Bureau of Reclamation refers to the project as the West Texas-Eastern New Mexico Import Project. The basic question germane to the undertaking, regardless of which name you wish to use, is, "Is there, in fact, surplus water in the Mississippi River?" We cannot unequivocably answer that question today, but we are encouraged by preliminary reports.

Funds were included in the 1967 Public Works Appropriations Act to make it possible for the Bureau of Reclamation to make a preliminary appraisal of the best means of augmenting the natural water supply for the West Texas-Eastern New Mexico area. Early publicity on the Bureau's study stated that the Lower Mississippi River was considered a primary source for this supplemental supply.

1/ Executive Director, Water Inc., Lubbock, Texas

As this publicity reached the Mississippi Valley, a number of responsible leaders there, and here in New Mexico and in Texas, wanted to make sure that the present and future needs of the Valley were properly considered. As a result, through the efforts of Congressman George Mahon and others, resolutions were passed by the Committees on Public Works of the Senate on May 2, 1967, and the House of Representatives on October 19, 1967, directing the Secretary of the Army, acting through the Chief of Engineers and the Mississippi Valley Commission, to participate with concerned federal, state, and local agencies in studies to determine the feasibility for exporting any surplus water in the Mississippi River System to water deficient areas. Particular reference was made to the study by the Department of the Interior to supply water to West Texas and Eastern New Mexico. The keyword in these resolutions is "surplus." Funds were included in the Public Works Appropriations Act in fiscal 1968 to cover the initial requirements of the Corps of Engineers, and additional funds have been made available in subsequent years to continue the study. Although the Mississippi Valley Commission's final report is not due until 1973, early this year Commission officials began to disclose preliminary findings of the group. Fred H. Bayley, III, Assistant Chief of Planning Division, Mississippi River Commission, addressed the West Texas Water Institute in Lubbock on February 5. He made this comment, and I quote:

"Some Preliminary figures have been developed which indicate that there is a surplus above the fifty-year demands in some high-flow months, and that in many months, the flows will not be sufficient to meet the demands of the Mississippi River."

This, of course, is the word we have been waiting for. Simply stated, if the tentative findings stand up, during some months there is surplus water in the Mississippi River, hopefully for export.

In his budget, President Nixon has requested full funding for the continuation of these studies by the Bureau and by the Corps. These studies will, I am confident, continue to completion in 1973.

In Texas, our statewide water resource development program is referred to as the Texas Water Plan. There is one point about the Texas Water Plan that I would like to make clear. The Texas Water Plan was not -- repeating, was not -- defeated in the Constitutional Amendment Election in August, 1969. Voters were not, in fact, voting on the water plan, but on a constitutional amendment that would have provided 3 and one-half billion dollars for the state's cost-share for financing implementation of the water plan. As you will remember, this amendment failed passage by only about 6,000 votes in statewide balloting. The Texas Water Plan, which is flexible enough to adjust to changing demands, is statutory law regarding water resource development in the state. Even now, the Texas Water Development Board is perfecting plans to go ahead on a limited basis, limited only by available funds. Bonds totaling more than 300 million dollars and earmarked for water resource development projects have been authorized by Texas voters, however, an interest rate limitation has stymied efforts to market these bonds in the last three years with one single exception which has the sale of $15,100,000 sold last month A critical milestone in the Texas Water Development Program comes on May 18th when Texans will again be asked to amend their constitution. One proposed amendment on the ballot would raise this interest limitation ceiling, if approved by the voters. I am confident that an informed electorate will see fit to raise this interest limitation, making these bonds available for immediate use. Although implementation of these projects planned with the limited resources do not relate directly to construction of the Trans-Texas System, that portion of the Water Plan which provides the facilities for transporting water into the West Texas-Eastern New Mexico area. They are vital to the overall plan. Included are some reservoir projects in which storage space for water will be acquired by the state, and this water will be earmarked for future sale to users in Northeast Texas and to users who will be served through the Texas Water Plan including those in New Mexico. This is a small, but an extremely significant step toward realization of our joint goal -- supplemental water for West Texas and Eastern New Mexico.

The Corps of Engineers is also studying possible routes for the imported water across Louisiana and to points in Northeast Texas. The Bureau of Reclamation Office at Austin is making the same investigation from those points in Northeast Texas up to the Plains and to Bull Lake Reservoir, located just east of the New Mexico state line. The Bureau of Reclamation Office at Albuquerque concurrently is studying possible supply routes from Bull Lake into Eastern New Mexico and distribution routes in the Plains area of New Mexico. Incidentally, the initial possible supply routes from Bull Lake developed by the Albuquerque Office of the Bureau are shown on the map attached to this paper and will be published in the proceedings of this conference. I hope you will study this map, and I am sure that Mr. Rowland Fife, the Area Engineer in charge of the Bureau's Albuquerque Office, would be most happy to hear your reactions concerning the service areas and tentative supply routes. Needless to say, the New Mexico State Engineer's Office, along with other state agencies and your own water resources institute, are cooperating to the utmost with the federal agencies and other states involved in these studies. As a matter of fact, as we sit back and view the entire project, cooperation is the keyword. It is most gratifying that all petty jealousies have gone out the window and that all of the various state and federal agencies involved are cooperating to the fullest degree possible.

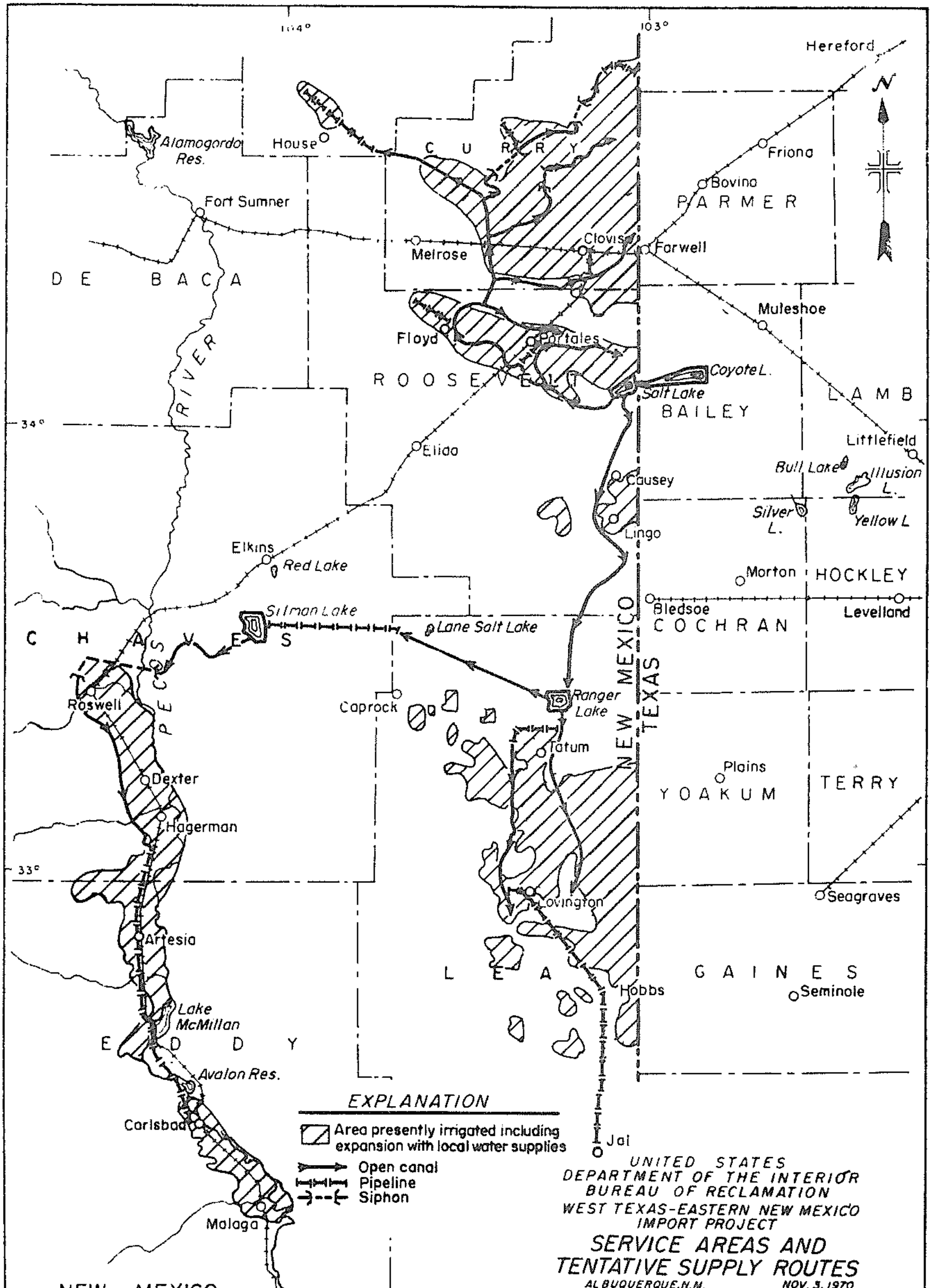
In Texas, our Legislature convenes every two years. We have been in session only since January and already state lawmakers have met the water challenge with virtually no opposition of note. The Texas Legislature passed the constitutional amendment voters will be voting on May 18th. This amendment would make available 100 million dollars through the sale of bonds and to be used as the state's matching share to local governmental entities so they may obtain additional federal funds for construction of waste water treatment facilities. The amendment also would raise the water development bond interest rate from four to six percent making these bonds marketable. This could be the most significant water legislation that will be passed by the Texas Legislature this year. Another significant piece of water legislation, with which I am intimately involved, is the recodification of all the state's water laws. A four-year project of rewording and organizing systematically all of the state's water laws into a state water code has been completed, and the recodification bill has now passed the House of Representatives and is under consideration by the Senate. I might add parenthetically that there is no significant opposition to this legislation either. Over 200 other bills have been introduced dealing with water resource development or the environment so we have plenty of work ahead of us for the remainder of the Texas Legislative Session.

Here in New Mexico, I am informed that more than 30 separate pieces of proposed legislation dealing with water in one way or another have been introduced during the 30th Legislature. Although I would certainly not present myself as an expert on New Mexico water law nor legislative activities, I think it would be a valid assumption in view of this legislative load, that your elected representatives in state government are facing up to their responsibilities in water law just as we are in Texas.

From an engineering standpoint, this water import program -- believed to be the largest water resource development program ever conceived in the mind of men and carried through the planning stages -- is, I am told, quite feasible. From an economic standpoint, the project can be justified. In the final analysis, our problems boil down to one thing -- people. There is a grassroots organization serving basically West Texas and Eastern New Mexico that is dealing with this "people" problem. I refer, of course, to Water, Inc., an organization that I am most delighted to represent. Water, Inc. is meeting head-on the challenge of the necessity for an informed people. Water, Inc. is the catalyst for public understanding. Its membership totals almost 3,000 and represents the broad spectrum of the West Texas-Eastern New Mexico economic life. Our members are farmers, ranchers, businessmen, educators, financeers -- the whole bit. At the risk of being called a "namedropper," let me list a few New Mexico leaders participating in Water, Inc. activities. First, the President of this great University, Dr. Thomas, was one of the organizers of our organization and has served faithfully as an Advisory Director since that time. Dr. Stucky, one of the most knowledgeable people in New Mexico in the field of water resources development currently serves on our Advisory Board, as does Steve Reynolds, John Shanklin of Albuquerque and Rogers Aston of Roswell. Lloyd Calhoun of Hobbs, whose dedicated service to this conference you know so well, is a member of our Board of Directors. Also serving on the Board are State Representative Hoyt Pattison from Clovis, Marion Foster of Lovington, Bill Bacon of Roswell and Eddie Harrington of Clovis. I could go on with the list, but I think that you get the point. In Water, Inc., your leaders have joined with their counterparts east of the border, and together they speak with one voice, a true voice of unity.

Information passes both ways through Water, Inc. First it is a vital instrument for informing the people, not only of the area, but the entire region, and our states, and neighboring states, providing all with information that is vital to their understanding the needs of water resource development and the problems appertaining thereto. On the other side of the street, the traffic moves in the other direction. Water, Inc. is a natural instrument for passing on to these governmental agencies the needs, the desires and the wishes of the people it serves. It is a unique organization. No other that I know of serves this purpose. Its goals are lofty, but obtainable. Our primary goal -- adequate water for all. We at Water, Inc. have been referred to as "dreamers." Perhaps so. I am reminded of a remark made at Water, Inc.'s third annual membership meeting last year in Lubbock by Assistant Secretary of the Interior, James R. Smith, and I quote:

"Men of small dreams accomplish very little, and men of great vision frequently accomplish more than they ever dreamed possible."



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THE HISTORICAL APPROACH TO WATER LAW -- Its Value and Its Problems

Ira G. Clark[1]

History adds a new dimension to the technological, sociological, and legal approaches to the study of the administration of our water resources. Had these resources been developed according to some broad preconceived plan, many present-day problems might well have been avoided. But this is not the way it did develop. The law governing water in the western states was born in conflict because there simply was not enough of that precious commodity to go around. It evolved through a multitude of adjustments growing out of specific situations which required immediate answers. The solutions were not arrived at philosophically nor did the lawmakers usually anticipate the effect of their action beyond the issue at hand. As a result, they frequently created as many or more difficulties than they resolved. Present-day water problems cannot be separated from their origins and development because that background remains a part of the problem. Today I would like to consider some of these relationships, concentrating particularly on the formative years. In a brief period, it is impossible to do more than sketch the general outline, omitting much which is properly a part of the story.

Any discussion of western water law must begin with federal lands, which have had a profound and continuing influence. With few exceptions, early controversies arose as the result of the occupation of the public domain; furthermore, much of the area of the sub humid states is still owned by the government and from these lands a preponderance of the surface water originates.

For all practical purposes, public land law beyond the one hundredth meridian (the eastern boundary of the Texas Panhandle) was water law, because the value of the land was almost wholly dependent upon its accessibility to water. Forty-niners who fought their way across the continent to get rich panning gold were not too concerned with legal niceties such as their right to occupy claims or to divert public streams in order to carry on their placer-mining operations. Since most of their activity was on the public domain, they were in point of fact illegally squatting, and their water diversions a violation of the common-law principle which guaranteed to each riparian owner an undiminished and unpolluted flow of water from above. In order to secure a shadow of legality, the miners turned to a frequently-used frontier device which went back to the extra-legal landing of the *Mayflower's* passengers at Plymouth: that of establishing a body politic to regulate and govern itself. The Californians then set up their own rules for determining the validity of mining claims; more important, from our standpoint, they recognized the right of the first appropriator of water to divert it elsewhere irrespective of downstream riparian settlers.

1/ Professor of History, New Mexico State University

Seventeen years later Congress belatedly took up the matter, and in the mining law of July 26, 1866, recognized local mining custom and, incidentally, the accompanying water rights doctrine. This simple, direct solution, the work of a body of legislators who had not the foggiest notion of conditions in California, supplied an answer which inherently raised problems which have never been resolved. Was it the intent of Congress to surrender jurisdiction over non-navigable waters of the public domain, to sever water rights from land rights in those regions in which the value of the land was wholly dependent upon water, and to recognize preferential use -- California's favoring of mining or New Mexico's protection of agriculture -- as limiting the operation of the doctrine, "first in time, first in right?"

In 1862, four years before it legalized local mining custom, Congress enacted the famous Homestead Law. By this time the frontier had passed beyond the region with which the vast majority of the nation's lawmakers were familiar. It was poised on the border of subhumid lands upon which it was impossible to survive on the traditional quarter-section but which, nonetheless, was designated as the size of a homestead. Paraphrasing Walter Prescott Webb, Congress innocently set up a system in which the United States bet 160 acres of land against an entry fee that the homesteader would starve before proving up -- and the government usually won. The timber-culture and desert-land acts were attempts to remedy some of the inadequacies, but the overall result was simply to encourage illegal land entries, usually for the purpose of securing water rights. Almost from the beginning these laws were under attack from their administrators, and this assault continued until they were repealed or drastically modified. The modifications themselves, however, opened loopholes which had not existed previously.

It was during this period, and while there was still a very considerable amount of unappropriated water, that Major John Wesley Powell presented a broad plan for future development of the arid public lands. It included a system of land classification, a dedication of the waters and the lands of each catchment basin to an organization of land-users within that basin, and a revamping of the Homestead Act in recognition of the completely different mode of land tenure necessary for the successful occupation of the dry region. Powell also advocated the storage of flood waters so that they would be available when needed. His plan never became operative because a combination of forces successfully resisted his crusade. Powerful western interests were hostile because Powell was critical of promotional schemes which would result in disastrous consequences by inviting settlement far in excess of the water resources. To follow his design would mean a slower and more limited growth than promoters were willing to accept. Many easterners, unacquainted with western conditions, were equally hostile to changing the traditional methods for occupying lands. The only other comprehensive scheme was that of Elwood Mead, the eminent state engineer of Wyoming and irrigation adviser in the Department of Agriculture, which, had it been adopted in its entirety, came too late to avert major conflicts which had already arisen.

The range-cattle industry dominated much of the arid country during the quarter-century following the Civil War, after which promoters became aware of the possibilities of irrigation. There was a flurry of activity in developing privately-financed projects in the late eighties and early nineties, but both the profits and the results were disappointingly meager. It was quite evident that private enterprise would be unwilling and unable to undertake the costly construction which would be necessary for extensive future development. Since the impetus would have to come from a public source, the question became one of how it could best be carried out. Many solutions were advanced: donating the arid lands to the state and territories in which they were located; ceding limited quantities of irrigable lands to state and territories which would guarantee their irrigation; and placing the responsibility on the federal government itself for reclaiming its arid domain. The Carey Act of 1894, granting up to one million acres of irrigable land in each of the western states which would assure its reclamation, enjoyed only limited success. The Newlands Act, or Reclamation Act, took its place alongside the Carey Act in 1902. It provided for the dedication of the proceeds from public land sales in sixteen western states and territories to a reclamation fund which would be used for building irrigation works for storing and diverting waters. Irrigable public lands within each approved project were open to homestead entry only, and on the condition that over a period of time the settler on each tract would pay his proportionate share of the estimated cost of construction. Once water rights had been paid on the majority of the acreage, the operation, management, and future financing would be turned over to local water-users' associations, but with title to, and operation and protection of the reservoir works and major canals remaining in the federal government. Although in theory the Newlands Act applied to the public domain, much of the land was already patented; therefore, provision had to be made for supplying water to bona fide landowners residing within the districts.

As was true of most public land legislation, the Newlands Act was controversial. Was it either feasible or just for the government to undertake the opening of new lands to compete with established eastern agriculture when there were agricultural surpluses? To what degree would the proposed reservoirs interfere with the flow and the navigability of interstate streams? Was the central government exceeding its delegated authority and, if not, was it nonetheless intruding into an area more properly reserved to the states? These were hardy perennials which were to surface time after time in the future. In actual operation, federal reclamation initially proved disappointing. Actual costs of construction ran far above estimates, the settlement of the land was usually much slower than had been anticipated, and entrymen were chronically in default in their payments. Engineering features were emphasized to the exclusion of educating newcomers in the art of irrigation farming, and scant attention was given to screening entrymen. There was much disillusionment, and the Reclamation Act required many amendments to remedy some of its obvious weaknesses.

The federal government was also struggling with other water problems. The desire to protect water sources resulted in legislation of 1891 providing for the creation of forest reserves, the primary purpose of which was to regulate water flow. There was general agreement in principle with this action; the problems arose when it came down to the specifics of what land should be reserved, whether it would be closed to future development, and what effect the withdrawals would have on those already enjoying the benefits of its use. Another issue which was becoming acute was that of dividing the waters of interstate and international waters as upstream diversions increased.

While this was going on in Washington, New Mexico's own water law was evolving. During the nineteenth century it was dominated by custom, inherited from Spain through Mexico, designed for simple direct diversion from streams through individual, partnership, or community ditches. This period was marked by an amazingly small amount of water litigation, due in part to the relatively static nature of a system with which the populace was acquainted and in part to the substantial body of law turned out by the territorial assembly for solving local problems.

New Mexico shared with other western states and territories the general evasion of the public land laws during the wild heyday of the range-cattle industry. At an earlier water conference, Robert Emmett Clark described this as the period in which water rights were often determined at the end of a gun barrel. The interest in irrigation, largely generated by droughts and the spectacular collapse of this phase of livestock growing, had a profound effect on the territory. New Mexico was particularly in need of some answers because most of the water of the Rio Grande Valley had been appropriated, and the idea of storing flood waters was appealing. Underdeveloped streams, particularly the Pecos, were beginning to attract outside capital, especially after the territorial assembly's action in 1887 providing for the incorporation of irrigation and colonization companies. As a matter of fact, the activities on the Pecos entered prominently into a debate at the nation's capital in 1890 over the restoration to entry of lands which had been temporarily withdrawn two years earlier. Proponents of the measure used the Pecos project to illustrate the beneficent effects of privately-financed companies; opponents, to demonstrate the potential dangers attending them. New Mexico's delegates to Congress consistently supported private projects and worked to liberalize those laws which limited the investment of capital in the territories. As the prospect for federal action brightened, however, the territorial assembly memorialized Congress in favor of that program. With the passage of the Newlands Act, the assembly responded immediately to the requirements of that measure which provided for the organizing of water-users' associations to assume responsibility for the administration of the irrigation districts.

New Mexico was also prominently involved in controversies attending the use of the waters from interstate and international streams. When the touring Senate Select Committee on Irrigation and Reclamation arrived in the El Paso-Las Cruces area in the summer of 1890, they saw a bone-dry river-bed and the resulting tragic loss of trees, vines, and crops in the valley. The cause of the severe shortages was a matter of dispute. Serious droughts were not unknown, but this time it was compounded by the enormous increase in diversions from the river in the Colorado's San Luis Valley. Mexico was demanding protection for the centuries-old appropriative rights enjoyed by Juarez residents. This particular problem was solved eventually by the building of the dam at Elephant Butte after a complicated chain of events beyond the scope of this paper. The dividing of such waters, however, has been a continuing source of friction only partially answered through interstate compacts and the cooperative effort of interstate stream commissions. Considering the delicacy of the situation both within and between the states, this is hardly surprising. I am reminded of something which I saw written on a blackboard in the Office of the State Engineer a couple of years ago. It went something like this: "Our problem for today: the water of the Rio Grande, Colorado has it; Texas is trying to get it. Where does that leave us?"

After 1900 there was increasing awareness in New Mexico that the Territory must modernize its water law. The general immaturity and inadequacy of this type of legislation throughout the West had been the subject of pointed comment at the national level, with some question of whether those states and territories were, indeed, capable of providing effective and just administration for their water resources. In New Mexico, despite the report of a governor's committee in 1897 which assured the chief executive that the existing rules were working satisfactorily, it was generally recognized that they could not serve the need for large-scale development. Finally in 1905, the assembly adopted a water code which it elaborated considerably in 1907. It incorporated much which had been customary or had been established by case law, but it followed the example of Wyoming in creating for its administration the office of territorial engineer. At the same time, the increased use of ground water led to establishing the posts of artesian well inspectors to guard against waste in those counties which depended heavily on that source. As might have been expected, these changes resulted in a substantial increase in litigation in order to interpret the meaning of things which were new and different.

The lack of uniformity among western water codes was and is another source of difficulty. This has been particularly evident in conflicts over the use of waters of interstate streams, but it has complicated many other domestic problems. In one field in which New Mexico pioneered, that of developing a ground water code, problems of its internal administration have been rendered more complex because of the impact of the code along the borders of adjoining states.

Returning to the national scene, a crusade was under way in the early twentieth century which in time was to take the name "the conservation movement." The Newlands Act had introduced the revolutionary concept of direct federal intervention in reclaiming semiarid lands, but this was simply a first step towards a recognition of the nation's responsibility for protecting and developing its natural resources. Water was one of the key factors in popularizing the interrelationship of all land resources, such as the effect of lumbering, grazing, and agricultural practices on water supply, flooding, and siltation of waterways and reservoirs. New agencies came into existence to administer various parts of the program. The Army Engineers, traditional guardians of the rivers, and the General Land Office, long-time administrator of the public lands, had already been joined by the United States Geological Survey, and now were forced to share their rights and responsibilities with the Reclamation, Forest and Park services. There was an interlude between the two Roosevelt's after which conservation again became a major issue, this time broadened to include privately as well as publicly-owned resources. In the case of dams, for example, they were no longer simply a means for creating storage for irrigation water but were multiple-purpose in nature. Conservation remained as controversial in the thirties as it had been earlier, with the arguments a rehash of those of the first decade of the century. Many new agencies came into existence, including such highly-publicized ones as the Civilian Conservation Corps, the Soil Conservation Service, the Grazing Service, and the National Resources Planning Board. Some were to disappear, others to merge, and yet others to expand. It was only natural that there would be conflict among them because inevitably there were overlapping functions, and each viewed its responsibilities as paramount to the others.

At the same time that conservation was becoming a great national concern, the competition for water was increasing. The number of traditional users was multiplying; they were joined by newcomers who were interested in using water for industrial and recreational purposes, or for producing hydroelectric power. Growing cities were demanding a greater share. As each was injected into the scene, it developed its entourage of advocates and lobbyists. Inherent in the situation was the necessity for making many difficult decisions. During World War II and immediately following, there was another interlude of relative quiet, followed by an awakening to the despoliation which was of critical importance to the entire nation. The greatest present national concern is one of trying to restore the environment, with attention being paid to dead bodies of water, and to streams incapable of sustaining animal life and dangerous for human or even economic use.

The history of water law is a story of controversy of battlegrounds on which were hammered out answers to specific issues. There was and is conflict over whether some programs are creeping socialism or prudent inventorying and husbanding of the natural resources; over the respective rights and duties of federal as opposed to state governments; over administrative control by specialists or by the legislative branch as directly representative of the people, with generous appeal to the judiciary based on due process. There are inter-agency and alternative-user rivalries, and sharp differences of opinion over the extent to which water should be developed to its full economic capability as balanced against the destruction of natural beauty and ecological balance. I would venture that there is in this room a wide variety of conflicting opinion on these subjects.

What can history contribute to the overall resolution of water problems? Its method is that of tracing the various strands of the story and showing their relationships. There is a common saying that history repeats itself; on the other hand history has been defined as the science of that which never happens twice. Quite obviously the first statement cannot be true because no situation is ever duplicated exactly; at the same time there are recurring situations which are similar to those in the past experience. The simplest answer would be to say that by studying the past we can correct the present, but that is not always easy or even possible. Quite possibly a greater value comes from studying the growth of water law -- its sources, its development, and the reasons why frictions and contradictions have crept in. It certainly shows that there are no perfect answers nor any which will satisfy everyone. Although it might not lead to a sympathetic understanding of an opposing point of view, it might establish the basis for a certain grudging respect for why that view persists.

COCHITI - A KEY WATER RESOURCE DEVELOPMENT FOR NEW MEXICO

Colonel R. L. West[1]

My subject is Cochiti Lake, the dam and reservoir currently under construction by the Corps of Engineers on the Rio Grande, 50 miles north of Albuquerque, New Mexico. It is the largest project ever undertaken by the Corps of Engineers in New Mexico and is the last of four dams on the Rio Grande basin in New Mexico designed for flood control. When completed, it will not only ensure a high level of protection for the Middle Rio Grande Valley from flooding on the main stem, but will also provide a strategically located permanent lake for recreation.

In this presentation I plan to cover background leading to the project, significant design considerations, main structural features, current status, and recreational development.

History of Flooding on Rio Grande

Flood flows on the Rio Grande are erratic but can be very devastating. In the early days it was reported that entire vallages were washed away. In 1828, records left by a Catholic priest indicate a flow of about 100,000 cubic feet per second just below Albuquerque. High level water marks left by a mid Rio Grande Valley flood in 1874 indicate an estimated flow of 125,000 cfs. When compared with a normal spring runoff which can be expected to produce a little over 5,000 cubic feet per second at Albuquerque, this gives us a conception as to the order of magnitude of floods which have occurred and could occur on the middle Rio Grande without special flood control measures.

Survey Report and Authorization History

In 1956, the Committee on Public Works, United States Senate, by resolution, requested the Corps of Engineers to make a study. The resulting survey report, published in 1960, recommended construction of Cochiti Lake and Galisteo Dam. This was subsequently authorized in the same year as Public Law 86-645.

Initial authorization of the Cochiti Lake project in 1960 was prior to the San Juan-Chama Transmountain Diversion Project and did not provide for a permanent pool. Any pool for recreation would, of necessity, have to be provided by water obtained entirely outside the drainage basin of the Rio Grande. The San Juan-Chama Diversion provided this opportunity, and Public Law 88-293 in 1964 authorized the use of 50,000 acre feet of storage in Cochiti for "Conservation and Development of Fish and Wildlife Resources and for Recreation," provided that the water for the per-

1/ Corps of Army Engineers, Albuquerque, New Mexico

manent pool be made available from water diverted into the Rio Grande from the Colorado Basin via the San Juan-Chama Transmountain Diversion.

Site Location (Figure 1)

Site selection studies completed in 1961 fixed the Cochiti Dam, immediately upstream of Cochiti Pueblo, about 50 miles north of Albuquerque, New Mexico, and about 25 miles southwest of Santa Fe, New Mexico. Project structures and a large portion of the reservoir area are on Cochiti Pueblo lands. The embankment was aligned to intercept flows from the Santa Fe River and Canada de Cochiti as well as the Rio Grande.

Galisteo Dam, authorized concurrently with Cochiti, was designed to control flows on Galisteo Creek at a location about 12 miles upstream from its confluence with the Rio Grande. Galisteo was completed in September 1970.

Geology of the Site

From the Geologist's standpoint the selected site is an exciting one.

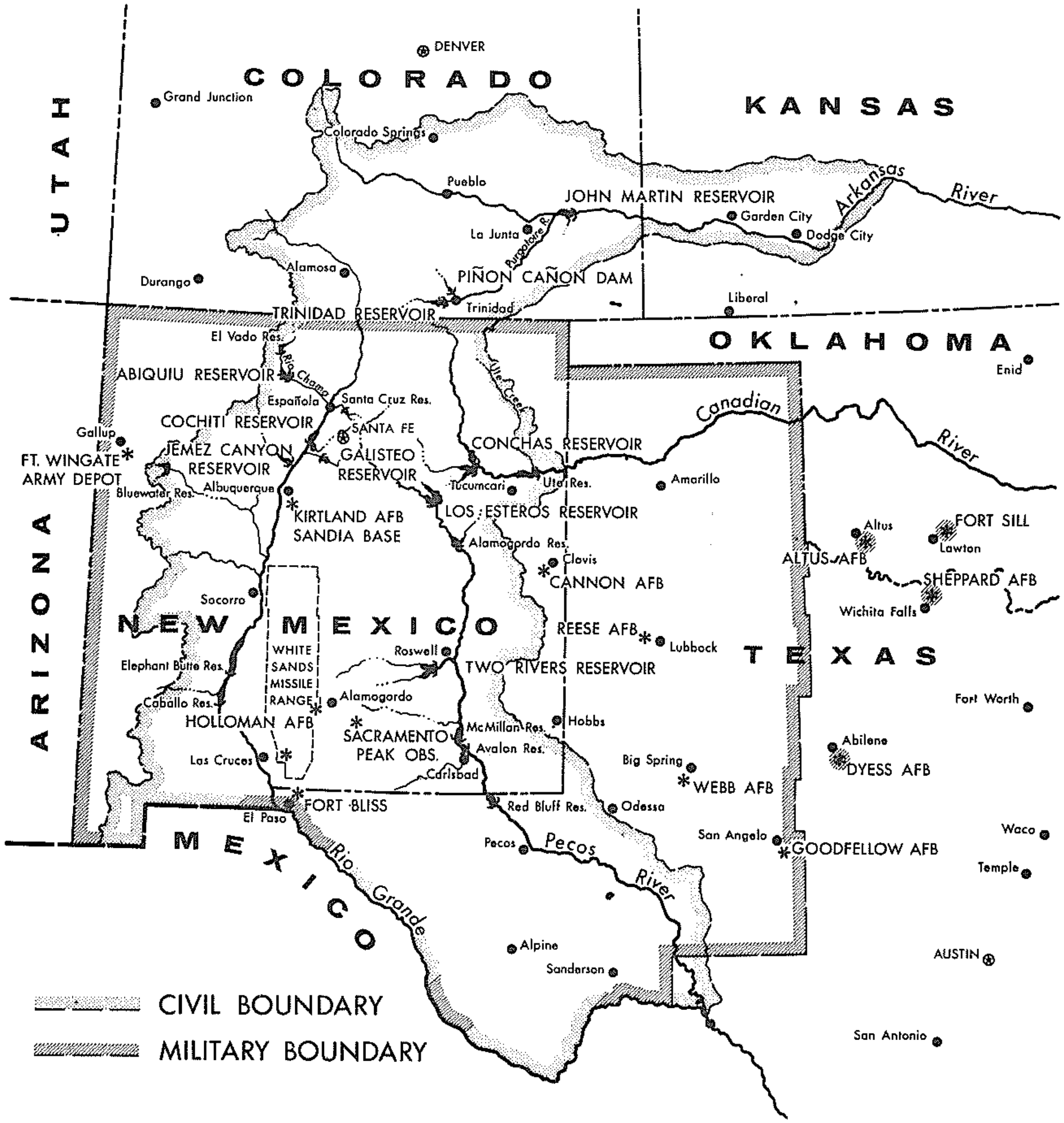
What today is called the Rio Grande valley was at one time in geologic history a series of isolated bowl shaped depressions called basins. These basins formed along a large fault zone extending from the San Luis valley in South Central Colorado to the vicinity of El Paso, Texas. Drainage in these basins was trapped and probably each one had its own ephemeral lake. As the basins filled with sediments, the drainage became integrated from one to another and formed a through flowing stream, the Rio Grande.

The Cochiti Dam is being constructed in one of these historical bowl shaped depressions known as the Santo Domingo Basin. The basin is bounded by volcanoes and has been partially filled with sand, gravel, silt, and clay deposits. This material can be found to depths in excess of 400 feet. Drilling in the Rio Grande valley downstream of the Santo Domingo basin has shown that unconsolidated sediments, fine and coarse grained sandstone and conglomerate also occur in this vicinity. In the past, lava or basalt flows have covered much of the area.

Geologic materials on or near the ground surface and within the area of construction for the dam and other structures consist of sandstone, sand, gravel, cobbles, boulders, silt, clay, and pumice deposited in step-like benches or terraces. Intermittent flows of lava or basalt have contributed to the accumulation of materials found at the site.

Coarse grained sandstone is the oldest rock exposed in the project area. This rock has been exposed by faulting in the area of the outlet works and in the Canada de Cochiti. This sandstone is the foundation rock for the outlet works and for portions of the earth dam. Lava flows up to 200 feet thick are present in the Santa Fe River portions of the dam and form the foundation rock for the dam and spillway structure in this area.

Foundation conditions along the 5.4 mile long earth dam are extremely varied and complex. Depth of overburden or alluvial material over sand-



ALBUQUERQUE DISTRICT

SCALE IN MILES

0 30 60 120 180 240

stone or basalt bedrock varies from zero on the left abutment of the Rio Grande and in the Santa Fe River Canyon to more than 200 feet in other areas of the dam foundation. Much of the dam will be founded on overburden or alluvial materials. In four foundation areas along the dam alignment, deposits of low strength fat clay were found above bedrock level, necessitating special design and construction procedures.

Project Features (Figure 2)

The project consists of a major earth dam; a conveyance channel to connect the Rio Grande, Canada de Cochiti, and Santa Fe River arms of the reservoir; an uncontrolled overflow type, mass concrete spillway structure; an outlet works equipped with hydraulically operated slide gates to control discharges from the lake; recreational development; and necessary operation facilities, roads, and utilities. The project also requires revision to the existing Sile Irrigation Canal on the west side of the river, and the Cochiti main irrigation canal on the east side of the river.

Land Acquisition

Land acquisition was somewhat unique in the case of the Cochiti project, because a large portion of this project is located on lands belonging to the Cochiti Indians. The Cochitis stated a willingness to agree to conveying the necessary land to the U. S. Government if recreational rights could be preserved to them. After a period of negotiation, an "Easement Grant and Agreement" was entered into in November 1965. A "Memorandum of Understanding" with the Pueblo governing the construction, operation, and maintenance of the public use facilities of the project was executed at the same time. Basically, the memorandum describes the responsibilities of the Corps of Engineers and the Cochiti Pueblo as they relate to constructing various public use facilities and concession facilities. It further defines responsibilities for and maintaining the facilities. The memorandum allows the Cochiti Pueblo to charge for admission to these facilities to the extent necessary to finance operating and maintenance costs.

Other lands and easements were acquired through agreements with the U. S. Forest Service, Atomic Energy Commission, National Park Service, and the University of New Mexico.

Design

1. Reservoir Storage Allocations:

Capacity of the reservoir at maximum pool elevation will be 736,000 acre feet. Capacity at maximum flood control pool will be 602,000 acre feet. Storage allocations are: Recreation (Permanent pool) - 50,000 acre feet; Sediment Reserve - 110,000 acre feet; and flood control - 442,000 acre feet. The permanent pool was authorized for conservation, development of fish and wildlife resources, and recreation.

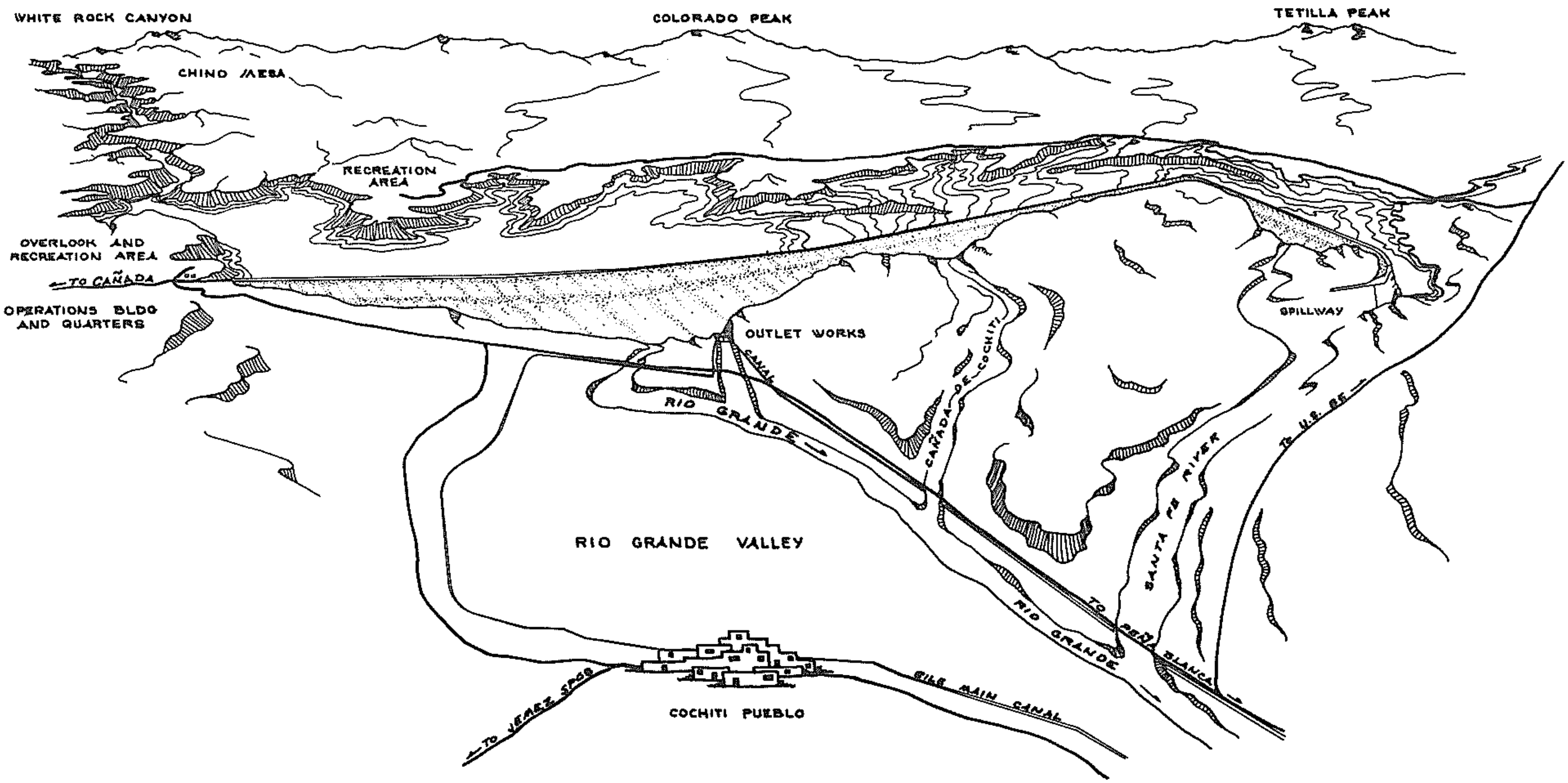


Figure 2. **COCHITI DAM & RESERVOIR**

2. Embankment: (Figure 3)

The design calls for a rolled earth fill dam, 5.4 miles long, maximum height 251 feet above Rio Grande streambed level. The earth dam, after crossing the Rio Grande, extends southward across Canada de Cochiti and the Santa Fe River, both left bank tributaries to the Rio Grande. A conveyance channel connects the Santa Fe River and Canada de Cochiti reservoir arms with the main Rio Grande reservoir area. The dam will be founded on material ranging from overburden to sandstone or basalt bedrock. The grout curtain, 125 feet into bedrock, will be provided to limit underseepage losses through bedrock. Zoned sections designed for the earth dam utilize the earth and rock materials locally available at the site. The zoned section will have a centrally located impervious fill core zone supported by upstream and downstream shells of higher strength granular fill. Internal drainage blankets of pervious fill and processed drain material, both having a high permeability or the ability to convey water, are provided downstream of the central core zone to collect, convey or otherwise care for any through seepage or underseepage waters or pressures.

3. Outlet Works:

The outlet works is located on the left abutment of the Rio Grande adjacent to the present river channel. The outlet works consists of an approach structure, gated intake structure, a triple conduit, and terminal stilling basin. The conduit is 1,286 feet long. Dimension of each rectangular conduit is 6.5 x 12 feet. The control tower is 261 feet in height. Pairs of service and emergency hydraulically operated slide gates are provided for each conduit opening. The control tower is a circular shaft, 25 feet inside diameter, containing an elevator, stairs, air vent pipes, and other installed equipment and utilities. A control house is provided at the top of the tower. Access to the control house will be by a bridge from the top of the earth fill dam to the intake structure. Total length of the bridge is 474 feet. A two-level stilling basin at the end of the conduit is required to dissipate the energy of the water discharged through the outlet works. The higher level is required for gravity deliveries of irrigation water to the downstream existing canal systems. The lower level is required for dissipation of energy of flows from the upper basin before returning releases to the river. Irrigation takeoffs are provided on both sides of the upper basin complete with control gates and sluices for delivery of irrigation water to the downstream Sile and Cochiti main canals.

4. Spillway:

The uncontrolled concrete gravity spillway structure is located at the south (left) end of the dam. Spillway flows discharge into the natural Santa Fe River channel. The structure is founded on multiple lava or basalt flows having a thickness in excess of 100 feet. Its total length is 650 feet. Principal features are an ogee overflow section, 460 feet wide, and non-overflow end sections for connection to the dam. Maximum height of the overflow sections above bedrock is about 84 feet.

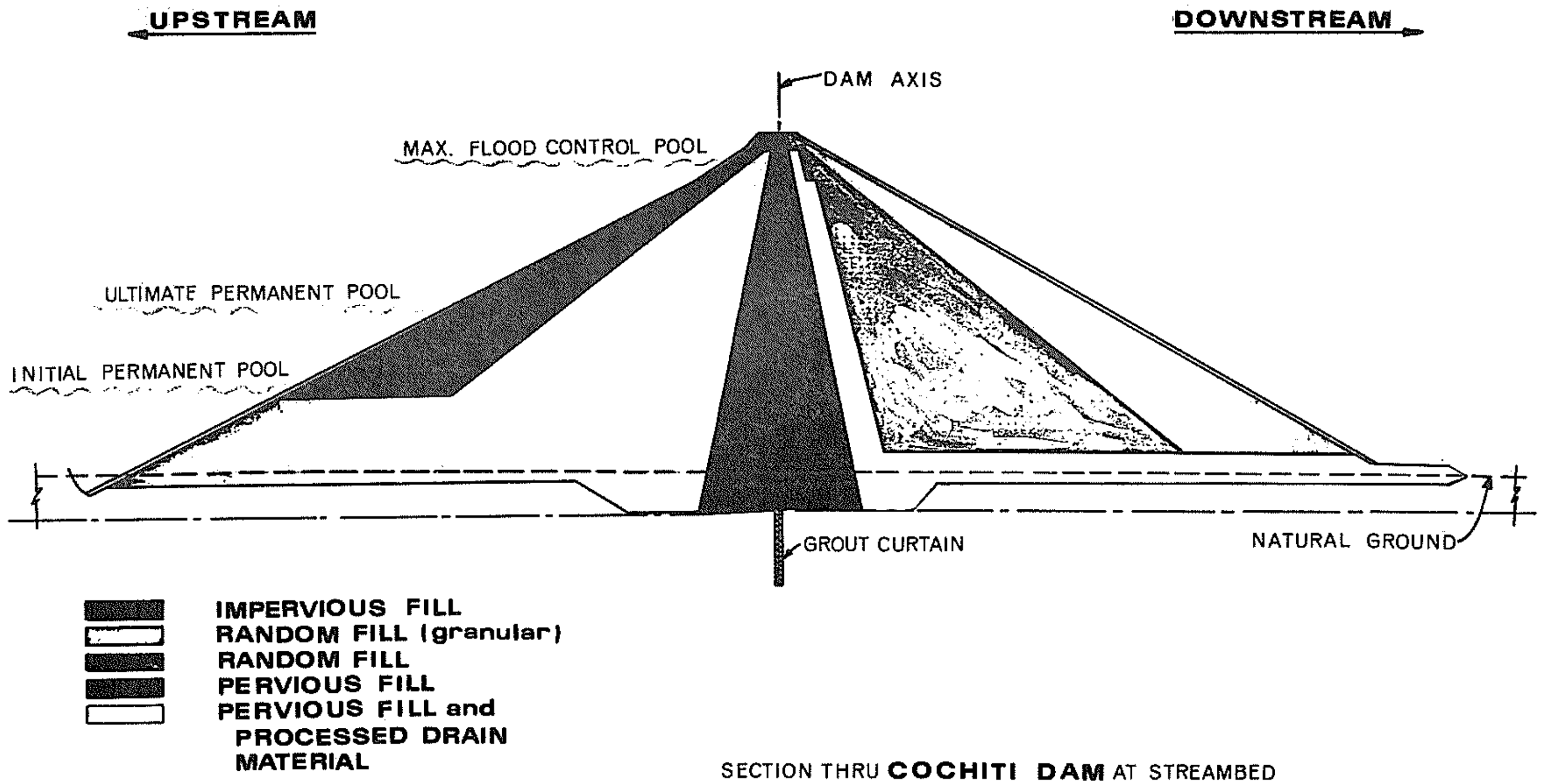

UPSTREAM
DOWNSTREAM
DAM AXIS
MAX. FLOOD CONTROL POOL
ULTIMATE PERMANENT POOL
INITIAL PERMANENT POOL
GROUT CURTAIN
NATURAL GROUND
IMPERVIOUS FILL
RANDOM FILL (granular)
RANDOM FILL
PERVIOUS FILL
PERVIOUS FILL and PROCESSED DRAIN MATERIAL
SECTION THRU COCHITI DAM AT STREAMBED

Figure 3.

Construction of the spillway structure was completed in August 1967.

Construction

Phases

The total project was broken down into parcels for purposes of construction in the following order:

1. Access Road and Operations Building. Constructed by Universal Constructors, Inc., in 1965 at a cost of $473,000.

2. Spillway. Constructed by Universal Constructors, Inc., from January 1966 to August 1967 at a cost of $2,500,000.

3. Outlet Works. Constructed by Nolan Brothers from 1967 to 1970 at a cost of $5,600,000.

4. Embankment. Bids for construction of the 63 million cubic yard Cochiti Dam were solicited on 6 March 1970 and opened on 13 May 1970. There were four bidders for the job. Two bidders based their estimates on a belt-conveyor operation and the other two based theirs on conventional hauling methods, which the successful bidder is using. The low bid of $61.7 million was submitted by Guy F. Atkinson Construction Company, South San Francisco, California. The contract was awarded on 1 June 1970.

The scheduled construction period of the earth dam is five years, assuming proper continuity of funding.

Quality Control System

In 1967, the Corps of Engineers adopted a quality control system for large projects requiring contractors to inspect their own work. This procedure greatly increases the contractor's responsibility to perform quality production. An earth fill dam such as Cochiti requires very close surveillance and much highly technical testing through all phases of construction. The contractor currently has a special organization for this purpose.

Interesting Construction Operations

Here again, the geology and water conditions play an important role in the contractor's scheduling sequence. During construction, it is necessary to consider and control the river water for three reasons. First, the water must be diverted so that the foundation can be cleaned, inspected, grouting performed, and prepared for earth fill. Second, adequate protection must be made to accomodate the river flow under both normal and flood conditions during the construction period. Third, irrigation water which flows in two canals adjacent to the river must not be interrupted.

During the first stages of work, the contractor constructed a cofferdam to protect his work area from the river, including needed de-watering operations to protect his work from underground water. One irrigation canal has been relocated to flow on the side of the cofferdam; the other canal required no work. Next winter, when the irrigation water is not required, the contractor will remove the cofferdam and construct two dikes to contain the river within a new channel. The river will actually flow across a part of the completed work, but it will remain at its present elevation. During the closure operation, between the end of the irrigation season and the start of the spring floods (April), the contractor will complete the earth embankment across the Rio Grande and the Canada de Cochiti to a predetermined elevation. Normal flows and irrigation water will pass through the outlet works.

The following winter, when the chance of flood flow is at a minimum, the contractor will make closure of the Santa Fe River. He will also be completing the embankment to full height throughout its length.

Recreation

The recreational aspects of Cochiti Lake are most exciting from the public standpoint.

The project area is in an attractive foothill and valley region surrounded by scenic mountains possessing clear streams, extensive forests, fish, and game. The history and culture of this region are unique. Several ancient but still active indian pueblos are situated in the Rio Grande valley upstream and downstream from the lake. Cochiti, Santo Domingo, and San Ildefonso pueblos are in close proximity to the lake site. Nationally famous Taos Pueblo is located about 70 miles northeast of the dam. Bandelier National Monument lies about four miles north of the dam site. This monument contains many ancient indian ruins in a scenic mountainous area.

The public will have fully developed recreational areas on the lands adjacent to the lake. These will consist of picnic areas, overnight camping facilities, comfort stations, boat launching ramps, overlooks, access roads, water supply, and sanitation facilities. The Pueblo de Cochiti, through its agent[1/], will provide additional facilities.

A recreation area is also being planned for the White Rock Canyon area on Forest Service lands approximately 4.5 miles upstream from the embankment.

The lake, 1,200 surface acres at permanent pool level, will provide a well balanced water-oriented recreational program. The New Mexico Department of Game and Fish plans to assume responsibility for the development and management of a warm-water fishery. The fishery will include such species as largemouth bass, white crappie, bluegill, channel catfish, northern pike, and walleye. Sailboating, canoeing, swimming, and some water skiing will be available. Because of the small surface acreage that can safely sustain water skiing (approximately 320 of the 1,200 surface acres), area and time zoning restrictions will be required. Therefore, the Cochiti

1/ The Pueblo de Cochiti has contracted Great Western Cities, Inc., to provide and manage facilities that include a marina, swimming pool, restaurant-motel complex, riding stables, and concessions including a store and gas station.

Lake project will not only serve as a major recreational center in New Mexico, but will also complement other recreational activities such as wilderness outings, snow skiing, hunting, and fishing now available in the adjacent Carson and Santa Fe National Forests. It is strategically located within a 50-mile radius of forty percent of the New Mexico population.

Summary

The Cochiti Lake project is significant from three aspects.

First, it is particularly interesting from a technical engineering viewpoint; an outstanding example of a massive earth fill embankment and the largest structure of its kind to be built in New Mexico.

Secondly, it's the last and largest of the major flood control structures for protection of the Middle Rio Grande Valley. When completed, the valley will have a high degree of protection from flooding along the main stem of the Rio Grande.

And, finally, it will be a unique recreational asset in northern New Mexico, providing a variety of water-oriented activities in an area where this has not previously existed.

REFERENCES

1. French, James A., First Report of the State Engineer, State Engineer, December 1, 1914.

2. Bryan, Kirk, Geology and Ground Water Conditions of the Rio Grande Depression in Colorado and New Mexico, in Regional Planning, Part 6, The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-37 (U. S.) National Resources Committee, V. 1, Pt. 2, Sec. 1, pp. 197-225.

3. Public Act No. 96, May 31, 1939 (Covers Congressional Ratification of Rio Grande Compact between Colorado, New Mexico, and Texas as agreed 18 March 1938).

4. Resolution adopted June 28, 1956, the Committee on Public Works, United States Senate (Requested the Corps of Engineers to review House Document 243, 81st Congress).

5. Public Law 86-645, 14 July 1960 (authorized the construction of the Cochiti Lake Project).

6. Northrop, Stuart A., (Editor), Albuquerque Country, New Mexico Geological Society Guidebook, Twelfth Field Conference, October, 1961.

7. Public Law 87-483, June 13, 1962 (Authorized the construction of the San Juan-Chama Transmountain Diversion Project).

8. Cochiti Dam and Reservoir, Rio Grande, New Mexico, Design Memorandum on Geology, Soils and Construction Materials, Design Memorandum No. 4, August 1963.

9. Public Law 88-293, approved 26 March 1964 (Authorized the storage of 50,000 acre feet of imported water).

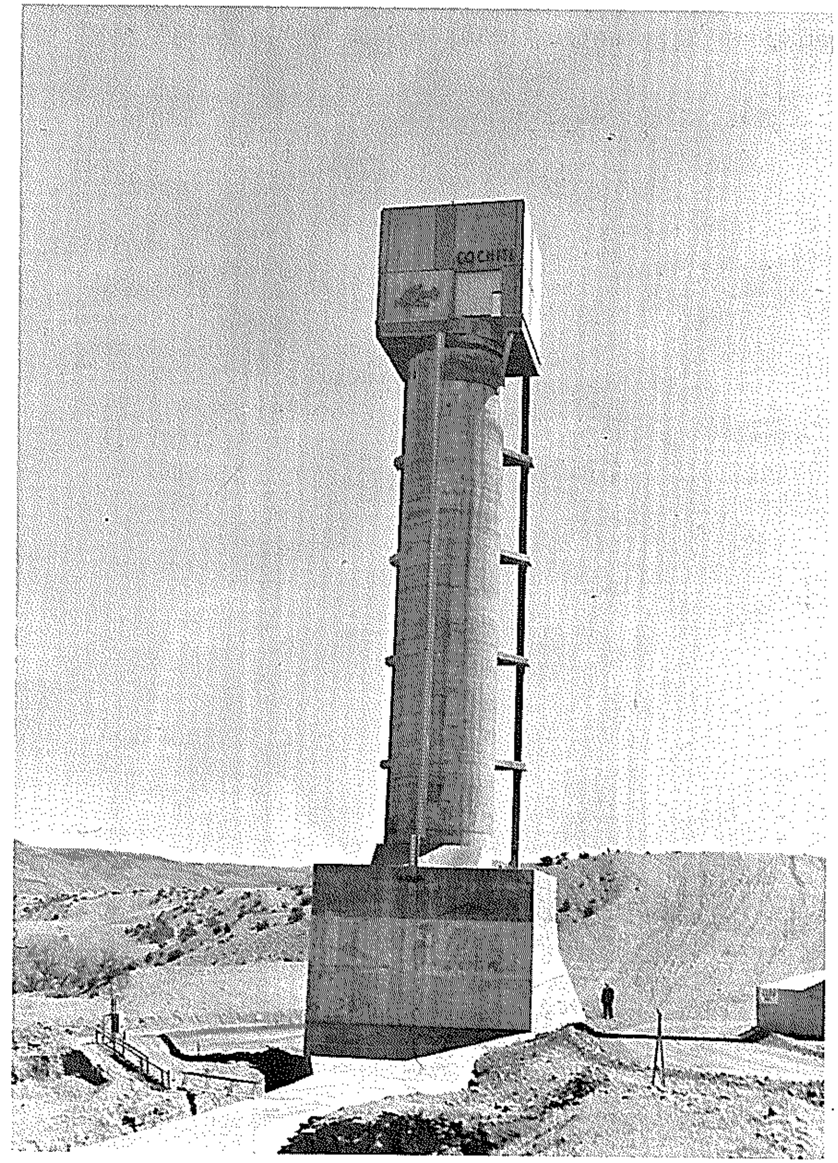
10. Cochiti Dam and Reservoir, General Design Memorandum, U. S. Army Engineer District, Albuquerque, Corps of Engineers, Albuquerque, New Mexico, approved 20 April 1964.

11. Easement Grant and Agreement, Cochiti Pueblo and Department of the Army, 16 November 1965 (99-year lease covering the project).

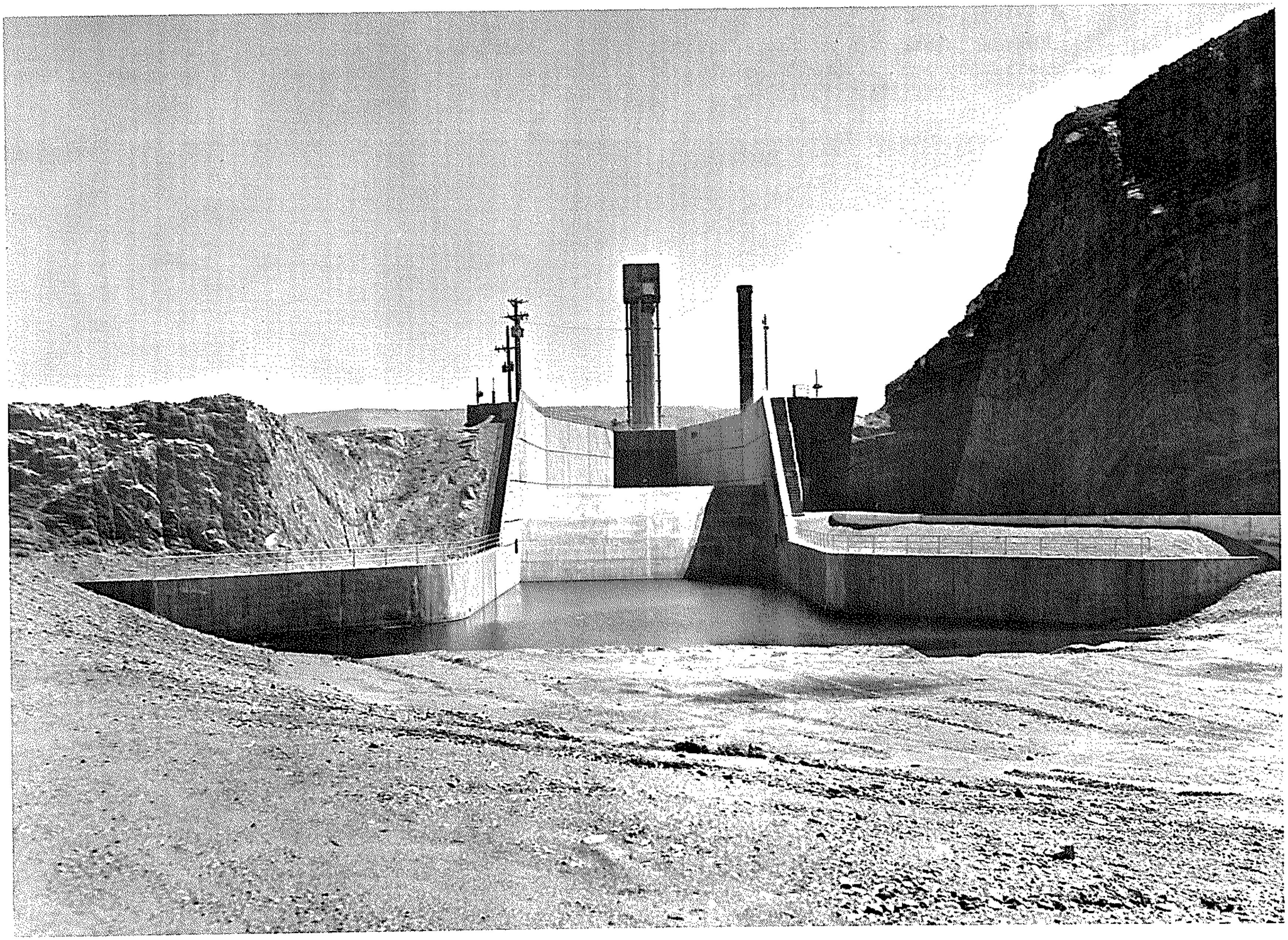
12. Memorandum of Understanding, Cochiti Pueblo and Department of the Army, 16 November 1965 (Agreement covering recreation facilities).

13. Lange, Charles H., Cochiti - A New Mexico Pueblo Past and Present, Southern Illinois University Press, Carbondale and Edwardsville, 1968.

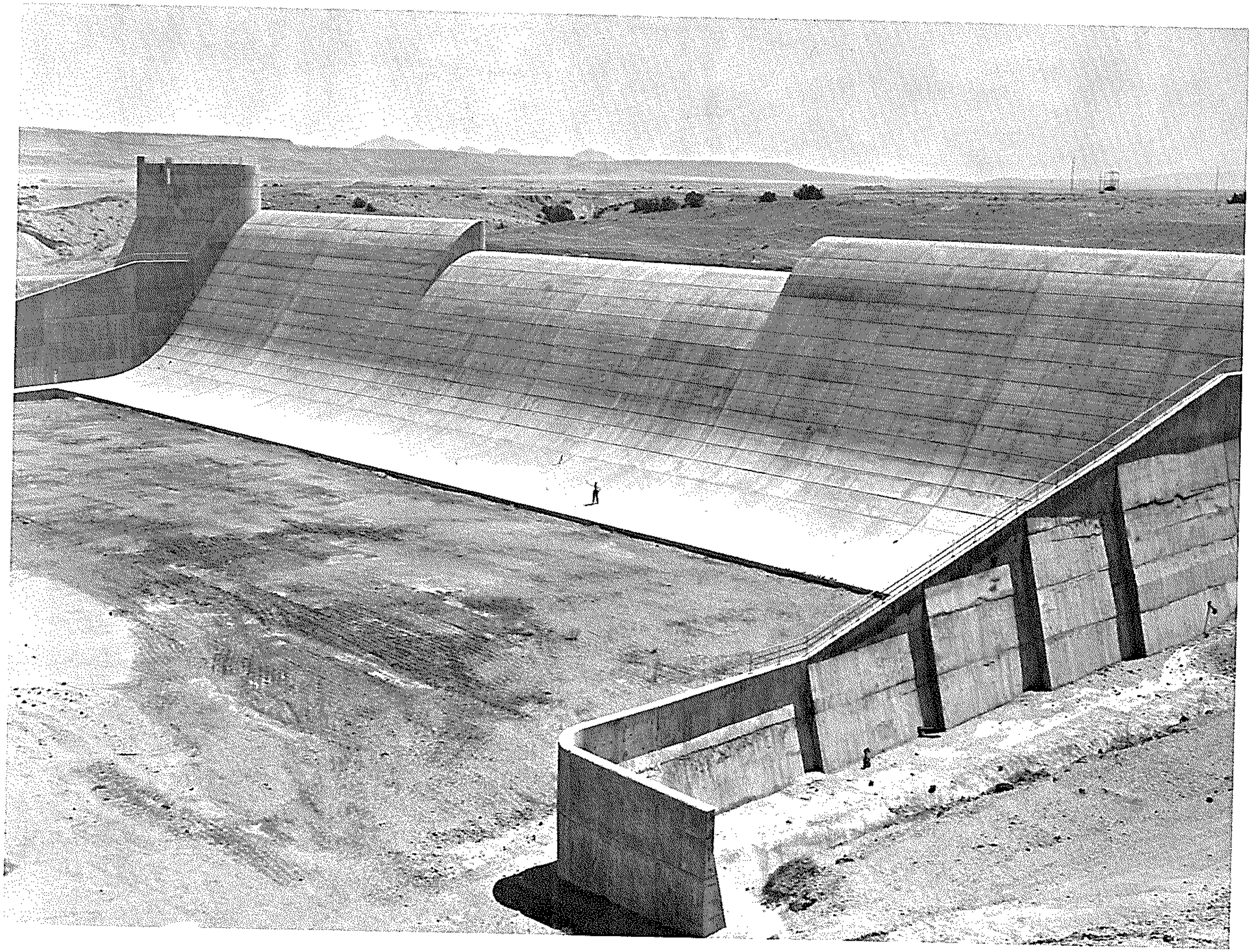
View of the intake structure of the outlet works. If you look very closely - you can see a man standing next to the trash rack on the concrete floor of the intake.



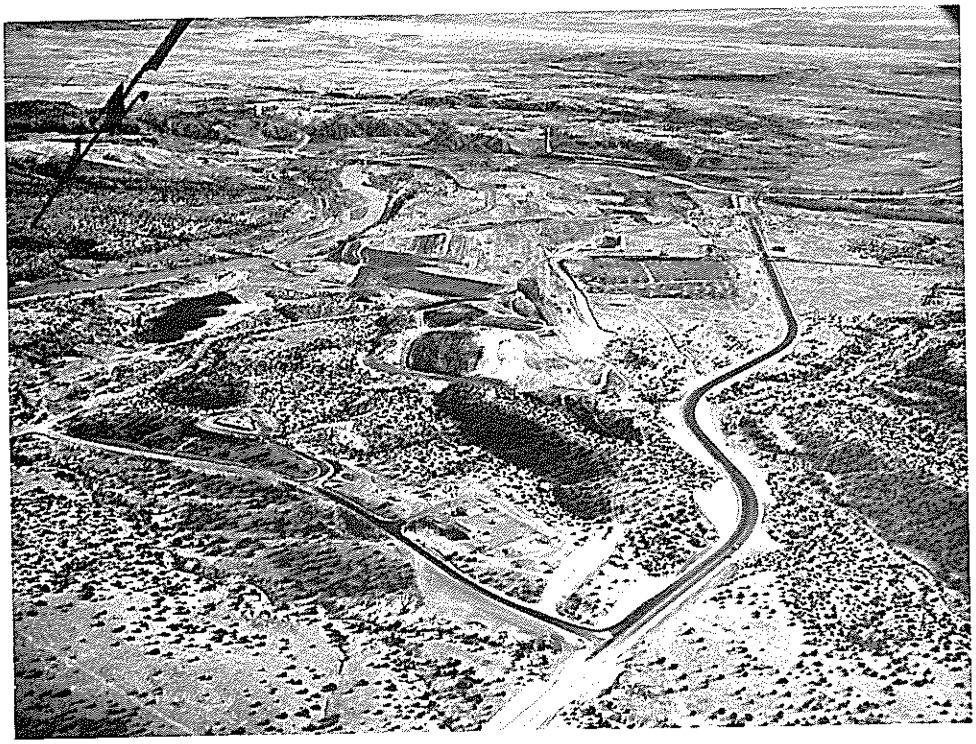
This is a view of the downstream side of the intake tower of the outlet works.



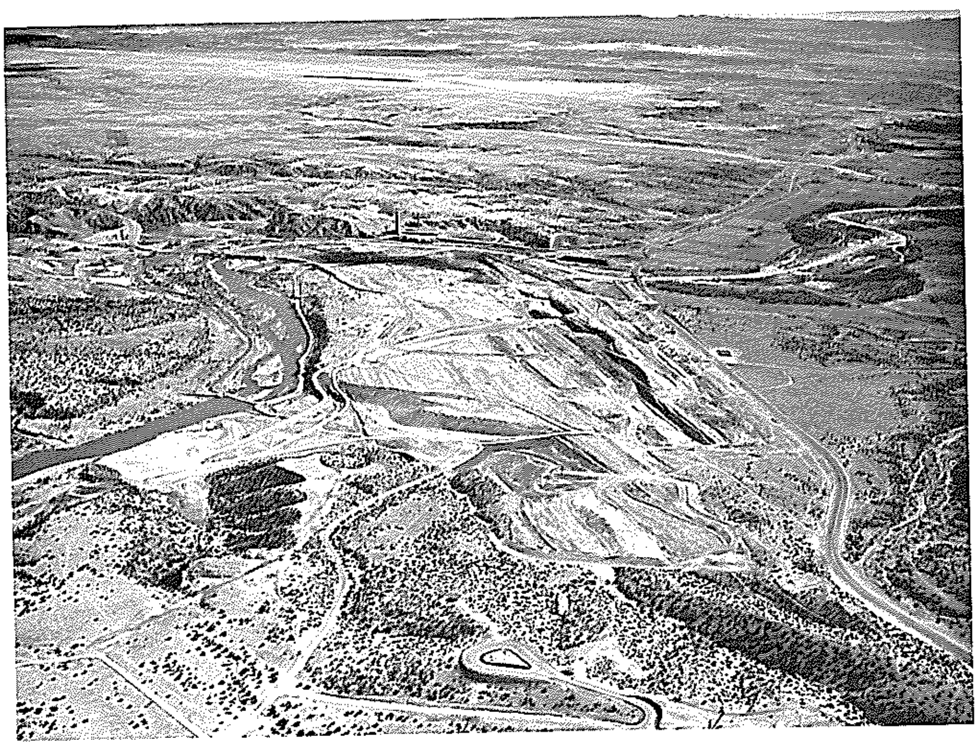
A graphic view of the downstream end of the outlet works. This photo shows the unique double weir designed into the outlet works.



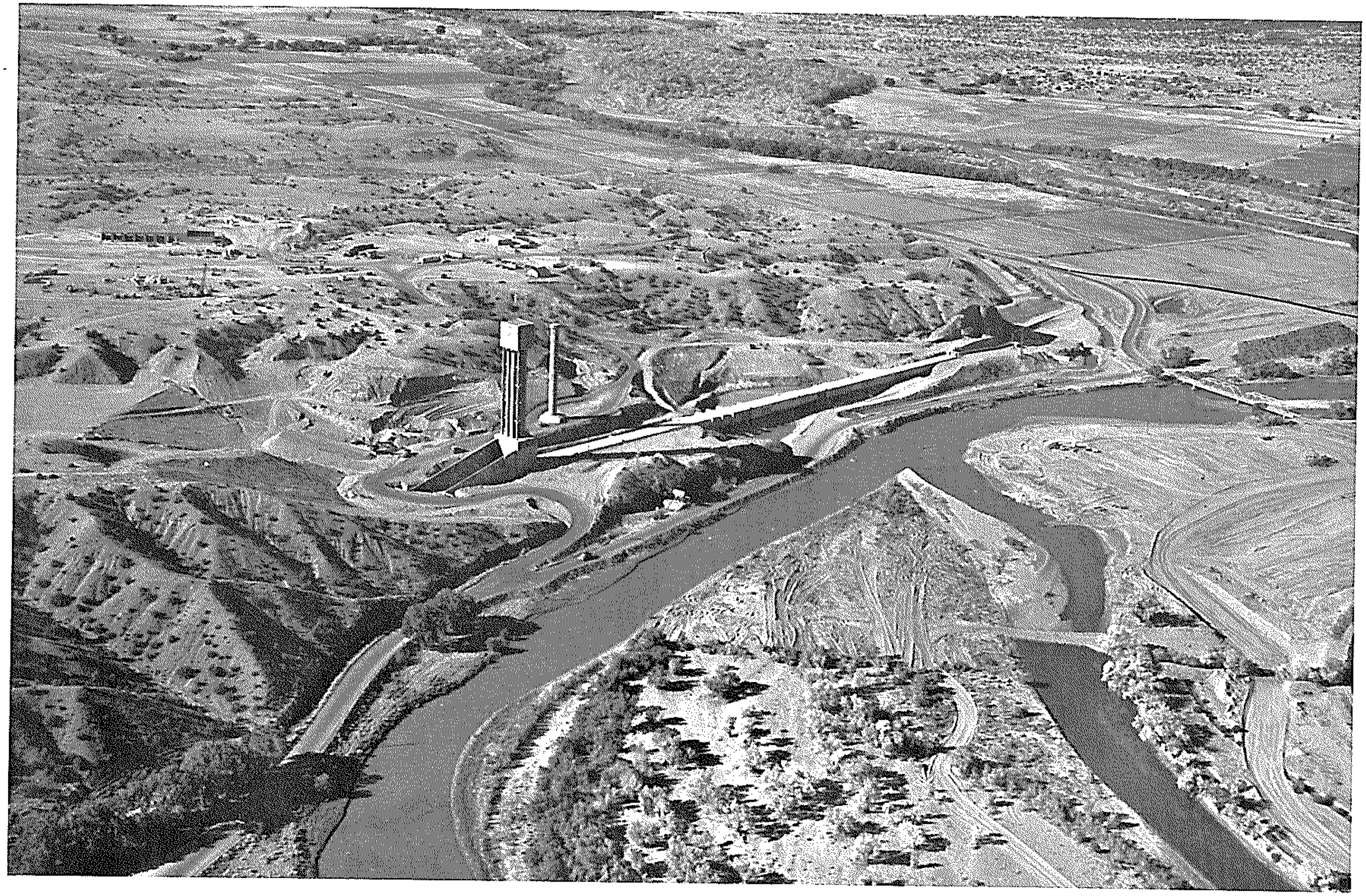
Spillway - already completed.



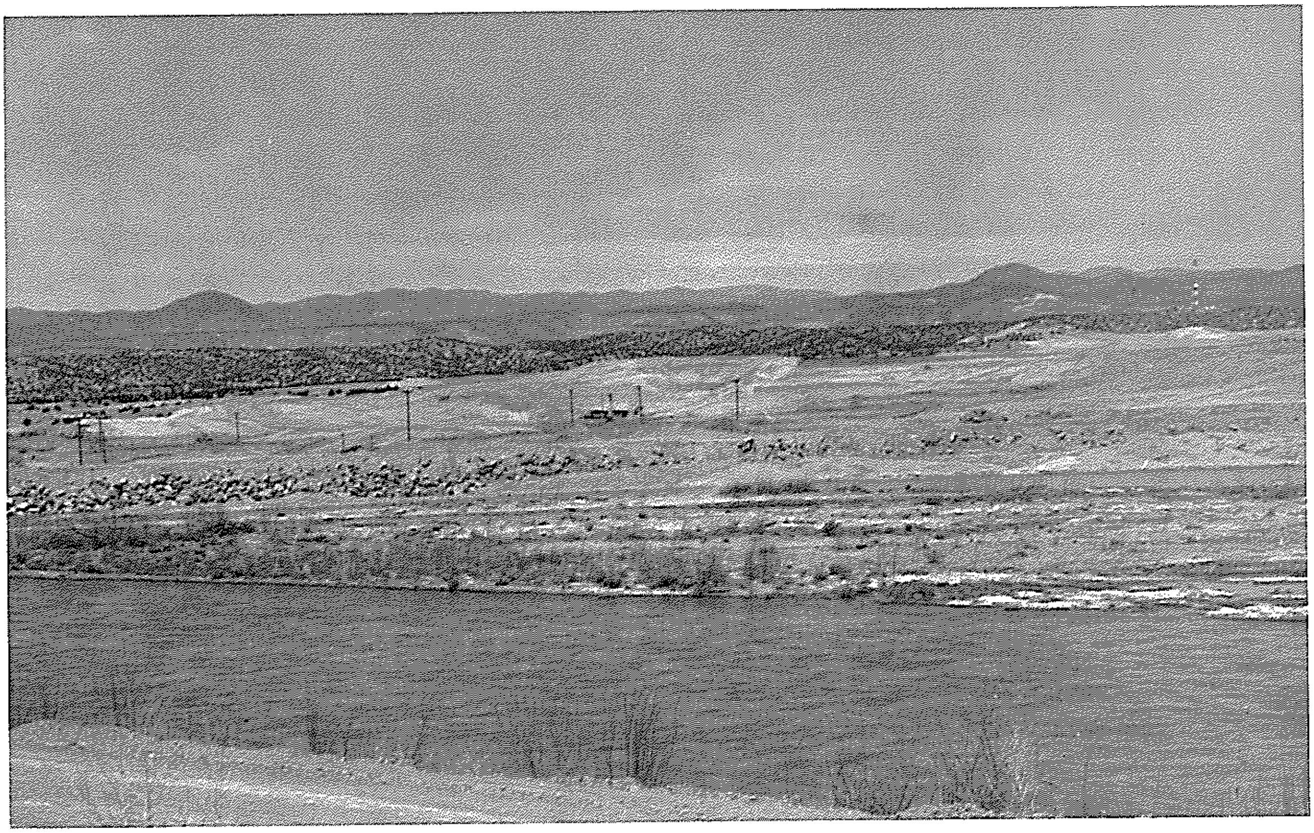
Aerial Photo - Embankment, Cochiti Dam and Reservoir (December 8, 1970)
This photo shows the overall project and particularly is a good example of the terrain.



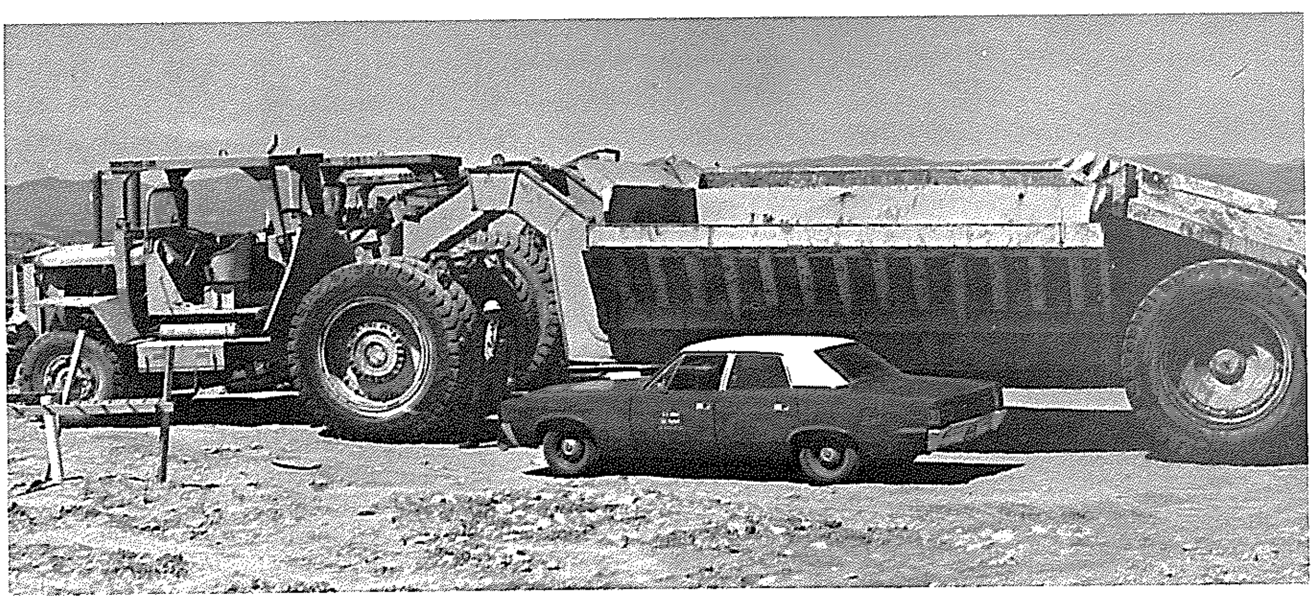
Aerial Photo - Embankment, Cochiti Dam and Reservoir (March 16, 1971)



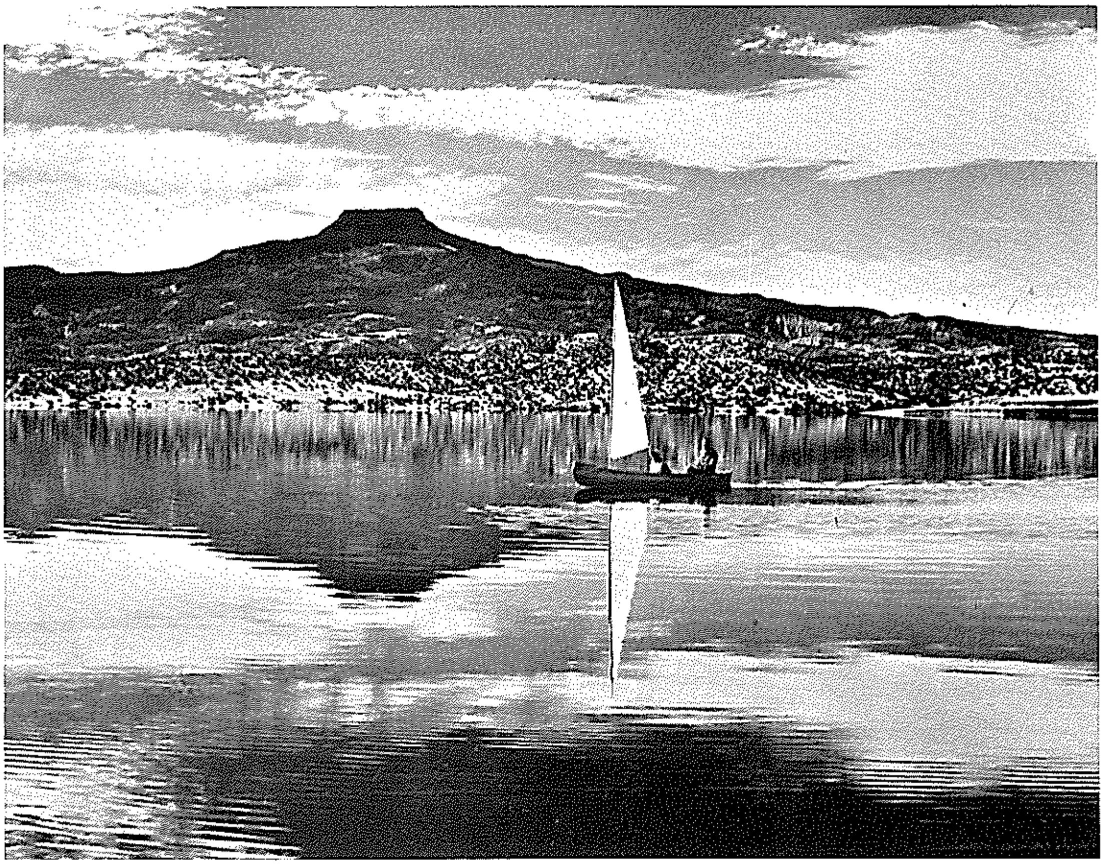
The completed outlet works at Cochiti Dam stands out against the broken terrain on the Rio Grande. This view looking downstream in a southwesterly direction shows the intake structure which will become a part of the embankment now under construction. The outlet works contains three 6.5 x 12 ft conduits about 1300 ft long. The control tower is 270 ft high and the pillar shown to the right of it will support a 430 ft bridge from the control house on top of the intake structure to the top of the 5.2 mile dam embankment. Steel bridge shown at right will be relocated and a new permanent bridge and road will be built later. A temporary bridge (not shown) has been built for use during construction. Completion date of this $85.5 million Corps of Engineers project is June 1975. The Cochiti Pueblo is visible in the upper right hand corner.



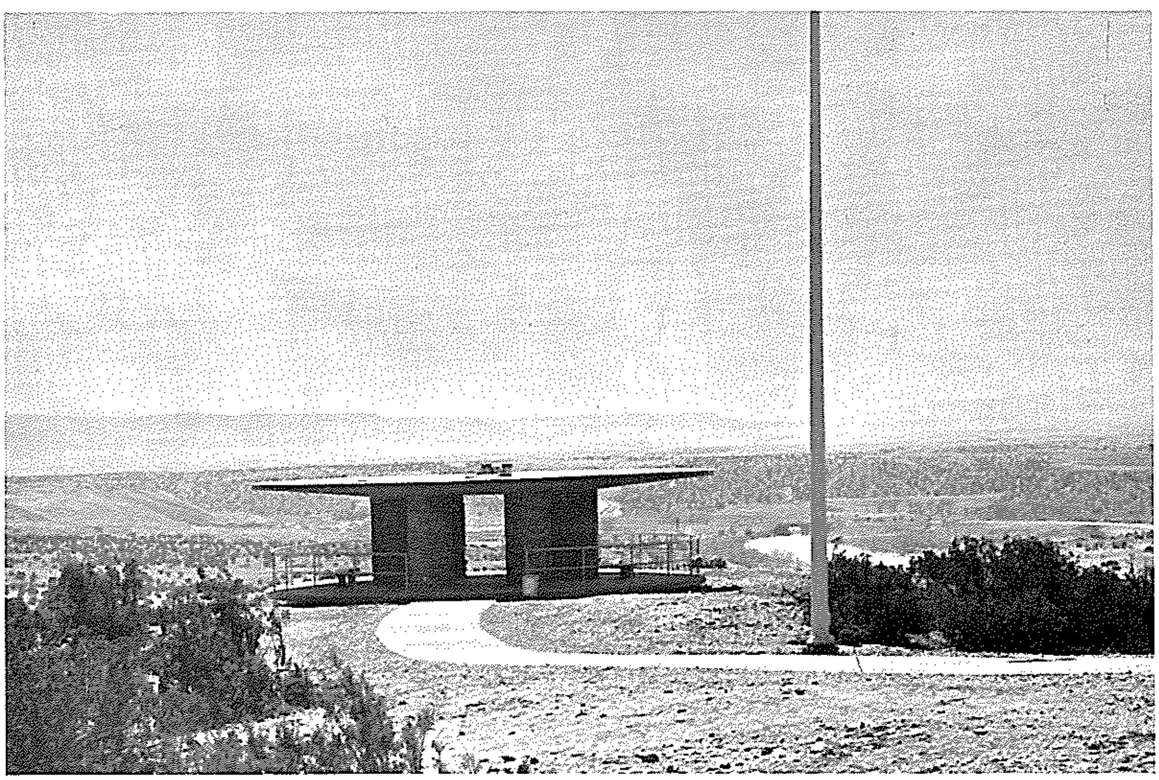
A good view of the cofferdam surrounding the contractors work area to insure the area remains dry while excavating to bedrock.



An illustration of the gigantic size of some of the contractors equipment. As a note, this is not the largest equipment of this type being used on this project.



Abiquiu



Recently completed overlook at Cochiti.

Close-up view of the recently completed Cochiti Overlook.