WATER RESOURCES RESEARCH INSTITUTE

FOURTEENTH ANNUAL
MARCH 27-28, 1969

NEW MEXICO WATER CONFERENCE

THEME:

Water Research And Development

New Mexico State University, Las Cruces, New Mexico

NEW MEXICO WATER CONFERENCE
Sponsored By
NEW MEXICO STATE UNIVERSITY DIVISIONS
of

Agricultural Experiment Station	College of Engineering
Agricultural Extension Service	Engineering Experiment Station
College of Agriculture	Cooperative Agent, USDA-ARS, SCS

Water Resources Research Institute
and the
WATER CONFERENCE ADVISORY COMMITTEE

Membership New Mexico State University

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New Mexico Department of Game & Fish
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Production Credit Association
Roswell, New Mexico

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Ralph Charles
Middle Rio Grande Conservancy District
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U. S. Bureau of Reclamation
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Wm. E. Hale, District Chief
U. S. Geological Survey
Albuquerque, New Mexico

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Farmers Home Administration
Albuquerque, New Mexico

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New Mexico Electric Service Co.
Hobbs, New Mexico

Wm. D. Hurst, Regional Forester
Forest Service, USDA
Albuquerque, New Mexico

Kenneth Williams, State Conservationist
Soil Conservation Service
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New Mexico Oil & Gas Association
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New Mexico Municipal League
Santa Fe, New Mexico

Hoyt Pattison
Representative, Curry County
Clovis, New Mexico

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Los Alamos Scientific Laboratory
Los Alamos, New Mexico

Arthur L. Ortiz
Department of Development
Santa Fe, New Mexico

STATE OF NEW MEXICO

EXECUTIVE OFFICE

SANTA FE, NEW MEXICO

PROCLAMATION

WHEREAS, THE FUTURE SOCIAL, ECONOMIC AND CULTURAL GROWTH AND DEVELOPMENT OF THE STATE OF NEW MEXICO DEPEND UPON A CONTINUING ABUNDANT SUPPLY OF WATER OF GOOD QUALITY; AND

WHEREAS, TO ASSURE MAXIMUM CONSERVATION THE WATER RESOURCES OF NEW MEXICO MUST ONLY BE USED IN THE MOST EFFICIENT AND ECONOMIC MANNER; AND

WHEREAS, FUTURE WATER REQUIREMENTS OF THE STATE MUST BE SUPPLEMENTED THROUGH RESEARCH AND DEVELOPMENT OF LARGE SCALE IMPORTATION PROJECTS, RETREATMENT AND REUSE OF WATER, DESALINIZATION, WEATHER MODIFICATION, AND ALL OTHER FEASIBLE MEANS; AND

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

NOW, THEREFORE, I, DAVID F. CARGO, GOVERNOR OF NEW MEXICO, BY VIRTUE OF THE AUTHORITY IN ME VESTED, DO HEREBY PROCLAIM THE WEEK OF MARCH 24, 1969, AS

WATER FOR NEW MEXICO WEEK

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

ATTEST:

Ernestine D. Evans

SECRETARY OF STATE

DONE AT THE EXECUTIVE OFFICE THIS 17TH DAY OF FEBRUARY, 1969

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

David F. Cargo

GOVERNOR

FOREWORD

Water research and development should go hand in hand in any consideration for the present and future use of New Mexico's most valuable and definitely limited resource. The many excellent papers in the proceedings of the Fourteenth Annual Conference indicate the importance of careful research and planning in our water development programs.

Governor David F. Cargo proclaimed the week of March 24-28 as Water for New Mexico Week. This recognition by the Governor and by the people of New Mexico brought many people to consider our water resources and caused a few more to participate in the entire Fourteenth Annual Conference, which was held during the water emphasis week.

The statewide Water Conference Advisory Committee, whose names appear on the inside of the front cover, have contributed much to the success of this and all of the previous water conferences. They meet with the University Water Conference Committee in a luncheon session immediately following the end of each conference to take stock of the conference just concluded and to start to discuss topics, select dates and make recommendations for the next one. A second joint meeting of the committees is held in the fall to consider the type of conference to be held and to pinpoint the subject areas. This permits the program for each conference to be directed toward important current problems and toward securing outstanding speakers. The Fifteenth Conference will be held on March 19-20, 1970.

Part of the funds required for the publication of this proceedings report were provided by the United States Department of the 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

Mr. W. H. Gary

The Fourteenth Annual New Mexico Water Conference was dedicated to the honor of this outstanding leader. His many positions of leadership in the water field in New Mexico are outlined in the Memorial Resolution.

MEMORIAL RESOLUTION

WHEREAS, Mr. W. H. Gary, of Rincon, New Mexico, passed away on the 19th day of July, 1968, and

WHEREAS, Mr. Gary was a faithful and productive member of the New Mexico Water Conference Advisory Committee, contributing in planning and serving on programs and participating in group discussions in the Annual Conferences, and

WHEREAS, his life was dedicated to the conservation and efficient use of water, as evidenced by service on the New Mexico Interstate Streams Commission, as Chairman of the Board of Directors of the Elephant Butte Irrigation District, and in support of measures effecting good water use and conservation as a member of the New Mexico Legislature, and

WHEREAS, he gave of his time generously in other public services --in the New Mexico Crop Improvement Association, the New Mexico Farm and Livestock Bureau, the 1517 Cotton Association, as a member of the Board of Directors of the Hatch Co-operative Gin Association, and as a County Commissioner of Dona Ana County, and

WHEREAS, his passing deprives the New Mexico Water Conference of wise and valuable counsel,

NOW THEREFORE BE IT RESOLVED, that those attending the Fourteenth Annual New Mexico Water Conference express their appreciation and gratitude for the faithful service which Mr. Gary rendered through the years toward the success of the conferences.

BE IT FURTHER RESOLVED, that the members of the New Mexico Water Conference Advisory Committee, the University Water Conference Committee and those attending this conference express their sincere sympathy to Mrs. Gary and her family.

BE IT FURTHER RESOLVED, that this, the Fourteenth Annual New Mexico Water Conference meeting at New Mexico State University, be dedicated to the memory of Mr. Gary in recognition of his services and contributions.

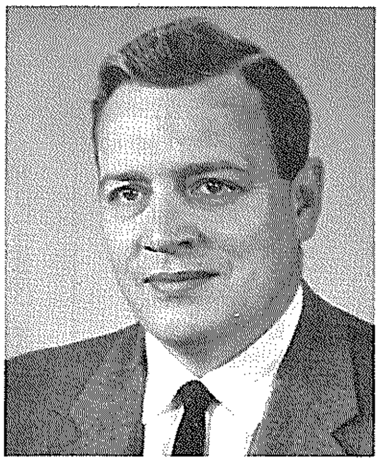
AND BE IT FURTHER RESOLVED, that the Chairman of the Conference transmit a copy of this memorial resolution to Mrs. Gary and his sons Edwin and Woodrow.

Resolution presented
March 27, 1969, by:

K. A. Valentine, Member
University Water Conference Committee

R. B. Corbett, President
New Mexico State University

H. R. Stucky, Chairman
Annual New Mexico Water Conference



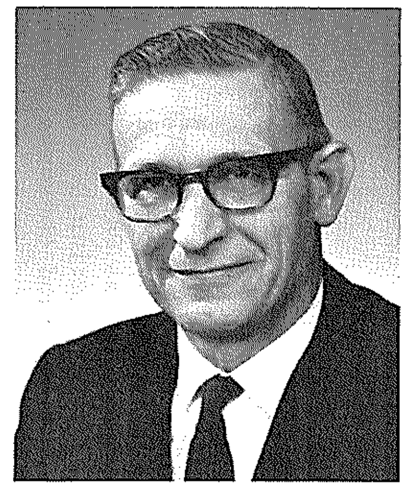
Fred Hennighausen,
District Engineer, State
Engineer Office - Roswell

Earl Cannon, Project Engineer
San Juan-Chama Diversion Project
Bureau of Reclamation

Dr. Wm. B. O'Donnell
State Representative
Dona Ana County

Bert Levine, Project Engr.
Bureau of Reclamation
Navajo Indian Irrigation
Project

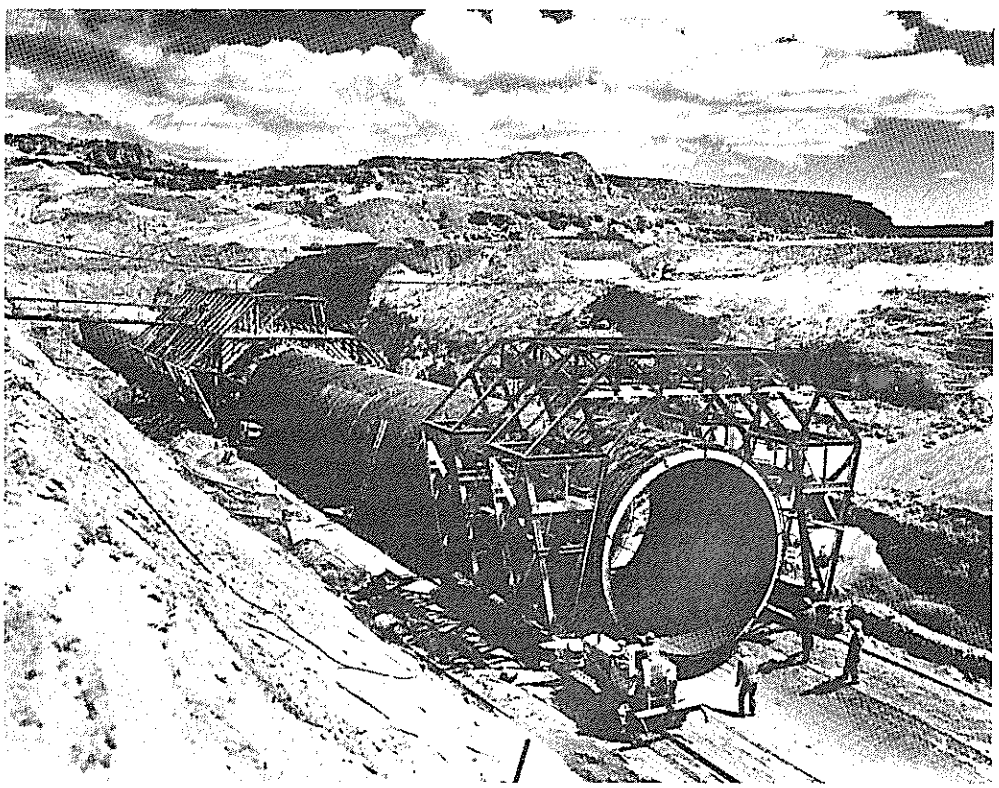
Harvey O. Banks, Consulting Engr.
Leeds, Hill & Jewett, L.A.
San Francisco, Cal.



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

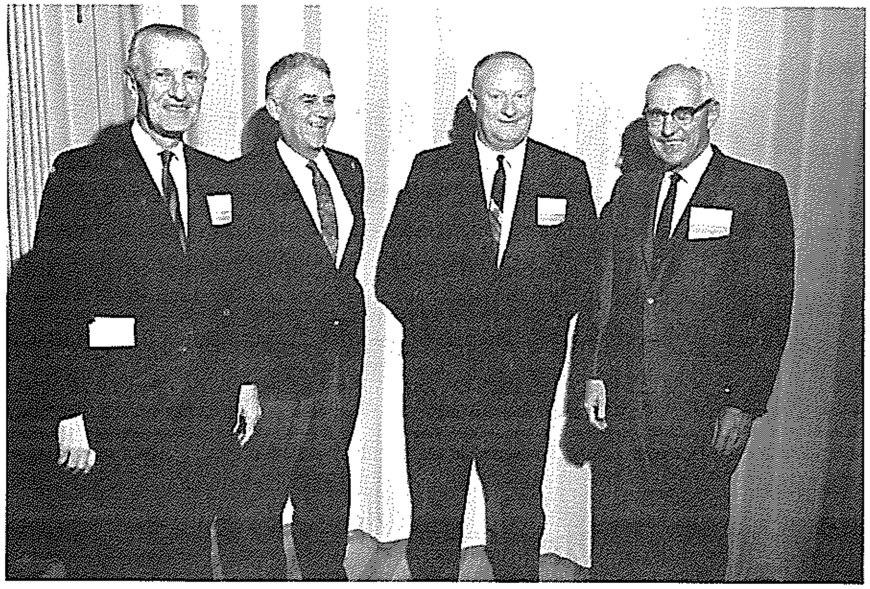
A group of speakers who contributed greatly to the fund of information presented by all of the speakers at the Conference.

NAVAJO INDIAN IRRIGATION PROJECT

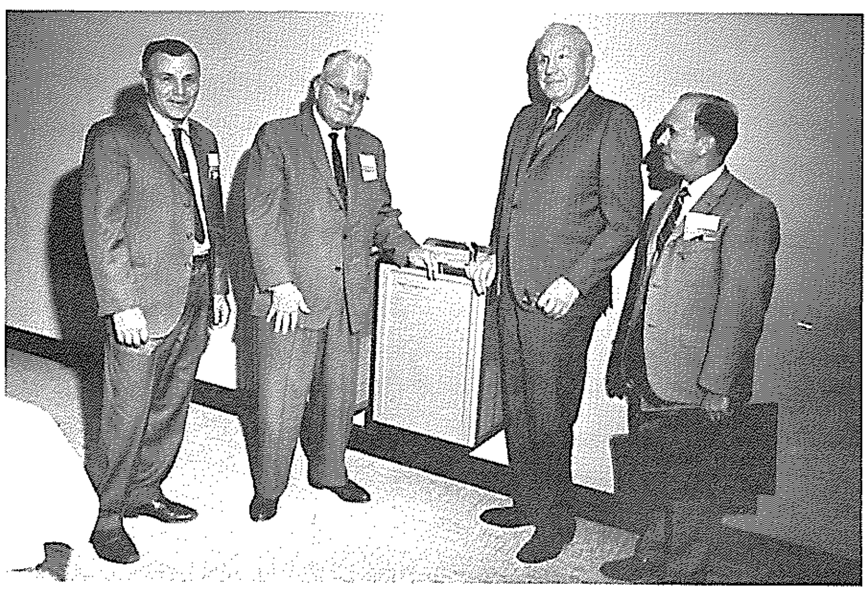


LARGO SIPHON

FARMINGTON, NEW MEXICO

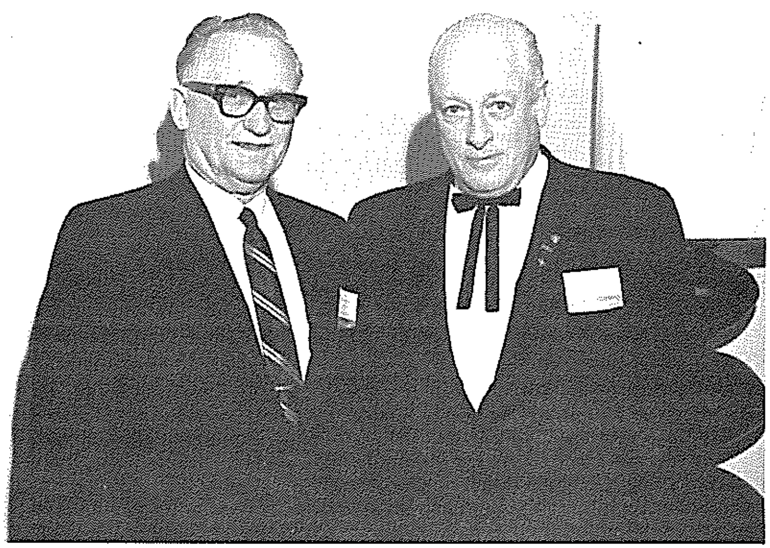


I. J. Coury, Chairman New Mexico Interstate Stream Commission, Farmington, David Hale, Interstate Stream Engineer, Santa Fe, Hilton Dickson, Jr., Attorney and Commission Member, H. Ralph Stucky, Director Water Resources Research Institute, and Water Conference Chairman.

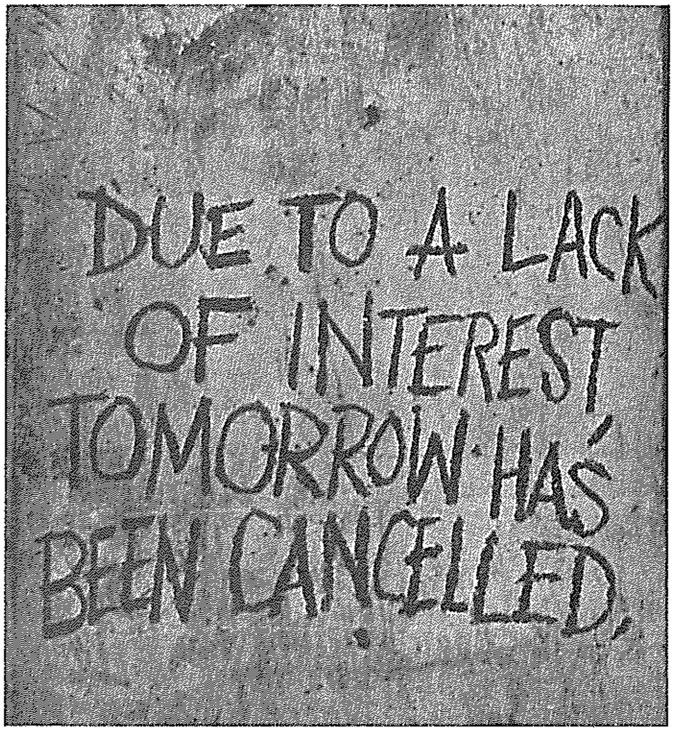


Sinecio Torres, Bureau of Reclamation, Albuquerque, Boyd Turbeville, El Paso Electric Company, Las Cruces, Senator Frank O. Papen, First National Bank, Las Cruces, and Jay Bingham, Executive Director Western States Water Council, Salt Lake City, discuss water problems as they prepare to get a refreshing drink.

U.S. Senator Joseph M. Montoya, Conference Speaker registering at the Conference with Dr. Paul Rader, NMSU Vice-President for development, and Mrs. Helen Hudson, Water Institute Secretary, as interested observers.



New Mexico's former Governor Tom Bolack of Farmington, with President Roger B. Corbett, New Mexico State University. Governor Bolack outlined his interest in New Mexico's water programs and the work on his B-Square experimental farm and ranch to the Conference.



Sounds ridiculous, doesn't it?
But what if everybody in this country were to throw their hands up in despair and say they don't give a hoot.
Indeed, there would be no tomorrow.
But fortunately, Americans have a way of solving their problems.
And that's just what's going to happen in these troubled times. Simply because it's always been an American tradition.

Source - A clipping from a U.S. Savings Bond Advertisement.

. . . . . This statement could almost come to pass in New Mexico over the next 100 years if our water resources are not properly developed and used.

Research and development activities must be linked together so there may be a brighter tomorrow.

PROGRAM

NEW MEXICO WATER CONFERENCE

March 27 - 28, 1969

THEME OF THE CONFERENCE - WATER RESEARCH AND DEVELOPMENT

WATER RESEARCH AND DEVELOPMENT IN NEW MEXICO

Dr. R. B. Corbett[1/]

You know we are pleased that you are here for this Fourteenth Annual New Mexico Water Conference. It has been my pleasure to welcome those attending most of these fourteen conferences. My only wish is that many more were here than this approximately 250 present this morning. You are always welcome to New Mexico State University and we hope you may have time to visit with some of our faculty and students and to see the campus and the several new buildings opened since last year.

Dr. Stucky's invitation to appear on this program reminded me that, following my first trip around the state after joining NMSU, I had placed water as New Mexico's chief problem. I plead guilty to having made that statement and I repeat it now, water still is New Mexico's chief problem.

The U. S. Senate Select Committee, in its 1961 report on the 20 major river basins in the Continental United States, pointed out that the Rio Grande-Pecos Basin had less water in relation to projected needs of any of the 20 U. S. river basins. The Colorado River Basin was listed as second shortest of water. Eighty percent or more of New Mexico is located in these two basins.

Much water research and development have occurred in New Mexico in these past fourteen years, but much more needs to be done. This water conference has been continued under the leadership of the excellent Statewide and University Water Conference Committee with Ralph Stucky as the chairman. Several of these committee members have attended most all of the annual conferences and the planning meetings held for each conference. Two statewide committee members who have no connection with any official agency and who have attended practically every conference and every planning meeting are Rogers Aston of Roswell and Lloyd Calhoun of Hobbs. Three other state committee members who have contributed much, both in attendance and contribution of information, are E. O. Moore of Roswell, Fred Thompson and Steve Reynolds, both of Santa Fe. To these men and all the others on the Statewide Committee and the University Committee we offer our thanks.

I will just look at the "forest" of important water resources problems and/or opportunities and comment on them briefly: some of the "trees" may be considered here today by men who know the details of these subjects. Their analysis will be expert. You should believe them. Mine will be from a layman's view.

1/ President, New Mexico State University

Water Conference - One of the big steps in New Mexico water development through the past fourteen years has been the continuation of this conference. It has supplied a continuing forum for the discussion of the water issues, developments and accomplishments within this state. The annual proceedings of this conference have become a highly useful reference for many in New Mexico, the United States and even in other countries around the world. The establishment of the desalting plant at Roswell by the Office of Saline Water received support from this conference by the passage of a resolution which requested the location of one of the five U. S. demonstration plants in this state.

Water Research - Another significant accomplishment is the establishment of the Water Resources Research Institute. The New Mexico Institute was the first of the 50 state institutes established in the nation under the Water Resources Research Act of 1964. These Water Research Institutes were established to greatly increase the U. S. and state research effort in all water resource areas and to train students to take their place in forwarding the research and development in these areas. Much credit must go to Senator Clinton P. Anderson for his leadership both in the original writing and in the final passage of the Water Resources Research Act. The New Mexico Water Research Institute is officially a part of New Mexico State University. However, three higher educational institutions, The University of New Mexico, Institute of Mining and Technology and New Mexico State University are cooperating in the research effort through memoranda of agreement. We hope that others of our state higher educational units may soon join this research effort in their special fields of competence.

The Tularosa Basin has always interested me because of its potential as an important water resource area. Large quantities of saline water are in storage there. A research project involving the State Engineer Office, the U. S. Geological Survey, the Institute of Mining and Technology, and New Mexico State University, is now under way in cooperation with the Federal Office of Saline Water. Many persons predict that this research will help make some of this vast water resource available for human consumption and economic development.

Further development of the Roswell saline water plant is now under way with the recent announcement that about one million dollars will be used to install test facilities at Roswell where companies can test desalting machinery. The earlier demonstration plant has not been successful, partly because the Roswell water is the toughest in the U. S. to process. These new commercial tests may make it possible to greatly advance our knowledge on desalting and to develop machines so potable water will be much more available and cheaper than is now possible.

Cloud seeding - Our Civil Engineering Department and the Physical Science Laboratory on this campus are conducting research and development work in cooperation with the Bureau of Reclamation and other agencies to increase snow fall in the higher elevations near Cuba, New Mexico. There is much promise in this particular project. Increased snow fall in the higher elevations would result in higher water runoff which would be available for all uses.

Water importation has been discussed in this conference in previous years. Importation of water into New Mexico and West Texas is vital to the economy of these areas. Unless water is imported from some source before 1980 or 1985, some important reductions in irrigated land and total income of that area will result. More and more leaders are beginning to believe that massive water importations can be and probably will be accomplished. The engineering work is now under way to determine the feasibility of tapping Mississippi river water. Many of the real important considerations, however, will be in the social, political and economic areas. These, along with the engineering, will be factors in whether or not large transfers will be approved by the people involved.

Evaporation control has been tried. To date it has not been highly successful but is deserving of further research.

Excessive non-beneficial uses - Phreatophyte control is now being attempted on quite a large scale in both the Middle Rio Grande and Pecos watersheds. Control or elimination of the salt cedar would add much to our present available water supply. Much progress is possible in returning some of this non-beneficially used water to productive uses.

Irrigation efficiency - Lined ditches, underground pipes and sprinkler irrigation methods are all being developed and installed to reduce water losses and lower costs. Plant research is being proposed and some is actually under way to develop plants which require less water per unit of production. Similar breeding and selection in cattle and sheep has resulted in real gain in pounds produced per unit of feed both on the range and in the feed lot. Reducing the water to produce a unit of product would stretch our total water supply and reduce costs.

Save water - Our present water is the cheapest water we will ever have. Every effort should be made to conserve this resource and to improve the income from the use of our present supplies.

Research - Funds spent in research produce very high returns per dollar of expenditure. Since water is vital to New Mexico, the west and the nation, we need to make greater investments in research than is being done at present. Investments now would produce results in time for use by decision makers in the future resource developments.

Again, I want to say we are glad you are here to consider our vital water issues. We are looking forward to seeing all of you, and hopefully many more, here for the conference next year.

Thank you.

"THE WESTERN STATES WATER COUNCIL"

Jay R. Bingham[1/]

It is a privilege to take part in this New Mexico Water Conference. I have a three-fold reason to welcome this assignment. First, the reputation of this annual meeting entices me. Secondly, this is a pleasant time to visit southern New Mexico. Thirdly, I have been reunited with an old friend Eldon Hanson after a 28-year separation.

My comments will be in the nature of a progress report to the people of New Mexico. Perhaps we can begin with some background information.

HISTORICAL DIVERGENCE

The eleven western states were formed from the expanse of the western frontier. This area has a varied political as well as a varied physiographic setting. The entry of the western states into the union spanned a 62-year period (1850-California, 1912-Arizona) and the eleven states were in the last group of 18 states to be admitted into the union. There is a common bond in the west that gives the states cohesiveness but there is also diversity. Climate, topography, and the inevitable competition for development; these are but a few. In some ways it is amazing that there has been the degree of harmony that now prevails.

MAN-MADE BARRIERS

Man has introduced unnecessary complications in resource development. I refer to the unnatural and unfortunate barriers created when the boundaries of the states were fixed. In the eleven contiguous western states, we have eight major drainage basins that subdivide into 39 separate river basins. Of the 39 river basins there are 190 instances where the streams cross state boundaries. There are 42 streams that cross international boundaries. The Bear River is a case in point. This stream arises in the High Uintas 90 miles from its point of discharge into Great Salt Lake. Between these two points the Bear River makes a circuitous 500 mile loop that brings it into three states and crosses state boundaries five times.

To help alleviate the complications of the unfortunate and unnatural boundaries, interstate compacts have come into being. In the eleven western states 20 interstate water compacts have been negotiated to make possible simpler administration of present water uses and to permit future development.

1/ Executive Director, Western States Water Council

VARIABILITY OF PRECIPITATION

Using mean annual precipitation as the measure, Nevada with 9 inches is the driest state in the nation while Louisiana with 55 inches is the wettest. The 11 western states include the first 7 driest and the 11 are in the 21 driest. Admittedly this is a dubious honor.

As is generally true the variations of precipitation in an arid area are greater than humid zones. The variations of precipitation are magnified in terms of runoff. Considering the 8 major drainage basins in the 11 western states, two of these basins have five times the runoff of the other six combined.

POPULATION PROBLEMS

A projection of the 48 contiguous states' population to the year 2000 indicates that we will approach a total of 300 million. The population of the 11 western states is estimated to reach 60 million by the year 2000.

A tabulation of the projected population of the 48 states, the 11 western states and the percent of the 48 states' population residing in the 11 western states is of special interest. Note that in 1900 the west had 5.4% of the 48 state population and by the year 2000 it is estimated that 20.0% will reside in the west.

With a 48-state population of 300 million by the year 2000 and a corresponding 11-state population of 60 million it follows that the western states population is doubling each 36 years whereas the 48 contiguous states doubles each 50 years.

With this increased growth the 11 western states will achieve a population density by the year 2000 equal to the population density the 37 midwest and eastern states had in 1950. Stating this another way, the west is one-half century behind in terms of population density.

Population 1900-2000 (For 48 states and the 11 western states)

Year	48 States Millions	11 States Millions	%
1900	76.0	4.1	5.4
1910	92.0	6.8	7.4
1920	105.7	8.9	8.4
1930	122.8	11.9	9.7
1940	131.7	13.9	10.6
1950	150.7	19.6	13.0
1960	178.5	27.2	14.7
1970	(205.0)	(34.0)	(16.5)
1980	(234.0)	(42.0)	(18.0)
1990	(267.0)	(51.0)	(19.0)
2000	(300.0)	(60.0)	(20.0)

( ) Projected

REASONS FOR COOPERATING

Some of the challenging problems facing the western states are: (1) state boundaries drawn without regard for natural drainage basins; (2) scanty and uneven precipitation; (3) the necessity to double the water supply each 36 years; and (4) a scattered relatively low density population.

Add to the list other problems such as: our growing economic interdependence, the problems of resource development occasioned by the large federal domain; and the competition for federal appropriations to support water development.

These are all compelling reasons for the states to band together but these reasons collectively or individually did not trigger the creation of the Council.

In my opinion it was the repercussion of Arizona v. California that was responsible for the decision to organize the Western States Water Council. When the legal recourse was completed and the final decree was issued it appeared that the state of Arizona was the victor. The court had rendered its verdict but it still remained for Arizona to get congressional authorization before development could proceed. This necessitated negotiations with the very states who were parties to the suit as well as others in and out of the Colorado River Basin.

The lesson to be drawn from Arizona v. California is that the west can no longer afford the expenditure of time, money, and energy in legal contests over water.

GENESIS OF THE COUNCIL

In 1957 the Western Governors Conference in Las Vegas, Nevada took a cautious step toward regional cooperation in water matters. The Governors of the Colorado River States at this time endorsed the organization of the Southwest Water Council. Articles and bylaws were prepared and leadership was provided by state officials involved in water matters. This organization served to lessen the tensions then existing between the Upper and Lower Basins of the Colorado and set the stage for later cooperative moves.

Again in 1964, the Governors recognized the need for cooperation on a broader scale between the states of the west. By resolution they initiated a committee study of the possibilities. This initiatory action by the governors provided the impetus for staging a Western Interstate Water Conference. The Conference was sponsored by Utah State University, University of Nevada and the University of California.

Introductory paragraphs from the resolution unanimously adopted by the Conference are of interest.

> "WHEREAS, the future growth, prosperity and well-being of the West depend upon the maintenance of a strong vigorous economy throughout the Western states; and
>
> "WHEREAS, the economy and well-being of the people throughout much of the West are threatened by critical water shortages; and
>
> "WHEREAS, there is need for an accurate appraisal of present and future water requirements as recognized by each state of the West, and for development of comprehensive plan for equitably resolving the problems of supply and distribution of water resources in the West."

The resolution resolved . . . . . .

> ". . . that the Governors of the Western States be urged to establish a task force composed of representatives of each of the Western states as soon as possible to work with the Council of State Governments, in considering the formation of a permanent regional water commission, and in the making of recommendations concerning the role, organization, and authority of a regional water commission."

The Western Governors responded on June 12, 1965 at Portland, Oregon.

At that time the Governors created the "Council" and announced its purpose to foster cooperation among the states of Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming in the development of their water resources.

There were the usual side comments. It was said that some states had joined to get water while it was averred that others had agreed to join the Council for an opposite reason to protect their water.

RULES OF ORGANIZATION

Lofty principles were to guide the Council's operations. The list included:

> One vote for each state,
> Equal sharing of costs,
> No surprises,
> No power plays,
> Unanimous action on external matters, and
> No domination by Federal interests.

SIGN OF STRAIN

After a valiant first effort signs of strain developed. The rigors of spelling out principles-standards-guidelines brought into the open points of difference and tempers warmed.

A new complication arose. The northwestern states argued for time to complete studies of future water needs. The southwest countered with proposals for area of origin protection. Arizona insisted because of her long wait that her project to use Colorado River water be authorized immediately. The other states of the Colorado River Basin with unused allocations insisted that their future rights be protected by initiating studies to augment the shrinking Colorado River.

Caught in this crunch, the deliberations went painfully slow and were held up on fine but sensitive points.

The Council reluctantly decided to reduce the staff while looking for a means of improving relations and finding a better means of resolving problems.

One lone but able stenographer carried on, keeping the delicate communication lines open. Hope and great expectation was replaced by uncertainty. A reappraisal by each of the states began.

NEW HOPE

To a degree all of the states realized that if the Council were to be dissolved the time was at hand. There were strong differences and the staff was greatly reduced. If the effort were to be abandoned now was the time.

Seemingly each state came to quite similar conclusions. The need was still present. Water problems would continue and differing viewpoints would persist, but the states should strive to reach agreement among themselves and not have it done for them.

It was recognized that out of the initial effort some gains had been made and there was value in frank discussion and better understanding of each others' problems.

On March 7, 1968, at Tucson, Arizona, a reconciliation began and uncertainty was replaced by positive action. After nearly a year without a director, the position was filled and on May 15, 1968, headquarters were transferred to Salt Lake City.

The Council adopted an "Activities Program" vowing to give strong voice to areas of common interest where heretofore no such action had been taken. Momentarily the regional planning problem would rest and Council attention would accentuate westwide interests in:

Activities of the Public Land Law Review Commission
State-Federal Water Rights Jurisdiction
Wild and Scenic Rivers
160 Acre Limitation on Federal Reclamation Projects.

THE FUTURE

The Western States Water Council is the best evidence that the states are determined to assert their role in state and regional development. The Council demonstrates that the states want a voice in preparing and promulgating new procedures and not as in the past, be forced to react.

The states have expressed their intention to support and strengthen each other so that more uniform and equitable application of national legislation will result. Through a unified organization the Congress and others can be advised that the problems relating to water in the west are different than other more humid areas and because of this difference, the western states cannot be conformed to general mold.

The Council has taken an active part in securing uniform and more moderate non-degradation provisions. A position has been unanimously adopted on the 160 acre limitation, State-Federal Water Rights, the Discount Rate and adequate appropriations for water development.

The Council has made a review of inter-regional and international Water Transfer Proposals.

The economic well-being of the states is at stake. The reasons for the states to work together are more compelling than ever.

The Western States Water Council is here today to help the states meet their responsibilities for tomorrow.

THE TEXAS WATER PLAN--
IMPORTS TO WEST TEXAS AND NEW MEXICO

Lewis B. Seward1/

It is almost impossible to view water planning in Texas without first looking at some of the contrasts of our State which produce the complexities that compound our water problems.

Some of these contrasts---I will not attempt to recite all of them---are our land elevation, rising from sea level to 8,750 feet near El Paso; our annual rainfall ranges from 56 inches in Southeast Texas to 8 inches in far West Texas, where most of it may come in a single storm or two---we've had some years when East Texas stations measured more than 100 inches while West Texas recorded only two inches during the year.

Our contrasts have produced subfreezing weather on the High Plains, while the Lower Rio Grande Valley basked in semitropical warmth. Our farming and ranching have reversed their geographic bases, adding to our water problems. The large cattle ranges of West Texas have given way to cotton and grain, while East Texas' cotton and corn fields have gone to grass---changes induced by the lush pastures of East Texas and the development of irrigation in the West.

Texas' economy is no longer geared to cotton, cattle, and corn. We have moved from an agricultural state to one of industrial importance. Yet, agriculture continues to have a major role in our economy.

Despite more than 150 major surface reservoirs having a conservation storage capacity---not yield---in excess of 27 million acre-feet, 85 percent of all water used in Texas comes from our ground water resources. In some areas of Texas, ground water is essentially the only source of water supply.

We have 23 river basins, ranging in size from small basins encompassing only a few counties to those such as the Brazos which spans the State from the New Mexico border to the Gulf of Mexico.

Our rivers generally flow from northwest to southeast---from water-deficient to water-sufficient areas. This adds to our complexities in the development of our water resources.

Depleting ground water resources in major parts of our State and a growing population---the U. S. Census Bureau recently released its population projections for 1975, pointing out that Texas would only be outranked in population by California and New York at that time ---have caused us to realize the necessity of planning the full development and management of our water resources.

1/ Assistant Chief Engineer, Texas Water Development Board.

Three and a half months ago we presented the Texas Water Plan to the people of our State. Its completion climaxed some four years of intensive study and planning, including more than 27 public hearings on our preliminary Plan in all sections of Texas.

The Texas Water Plan will be the flexible guide for the development and management of our water resources---and if we are fortunate---an imported supply of surplus water from the lower Mississippi River to meet our needs and some of the requirements of Eastern New Mexico into the next century.

We learned early in our studies that Texas does not have within its borders enough water to meet our growing needs beyond the last decade of this century. We expect to pass from water sufficiency to water deficiency during that period.

According to what we believe to be realistic and conservative projections, Texas will require in 2020 about 32 million acre feet of ground and surface water annually for municipal and industrial uses, for the maintenance of our irrigated agriculture, and for other essential and beneficial purposes.

We will need more than 12 million acre-feet of water annually for municipal and industrial requirements. We will need more than 16 million acre-feet annually to maintain our irrigated agriculture at levels necessary to provide the food and fiber we will need to help sustain our growth and to share in supplying the needs of a growing nation.

To provide the amounts of water we will need means we must fully develop all of our in-state water resources. Even so, we will still be short.

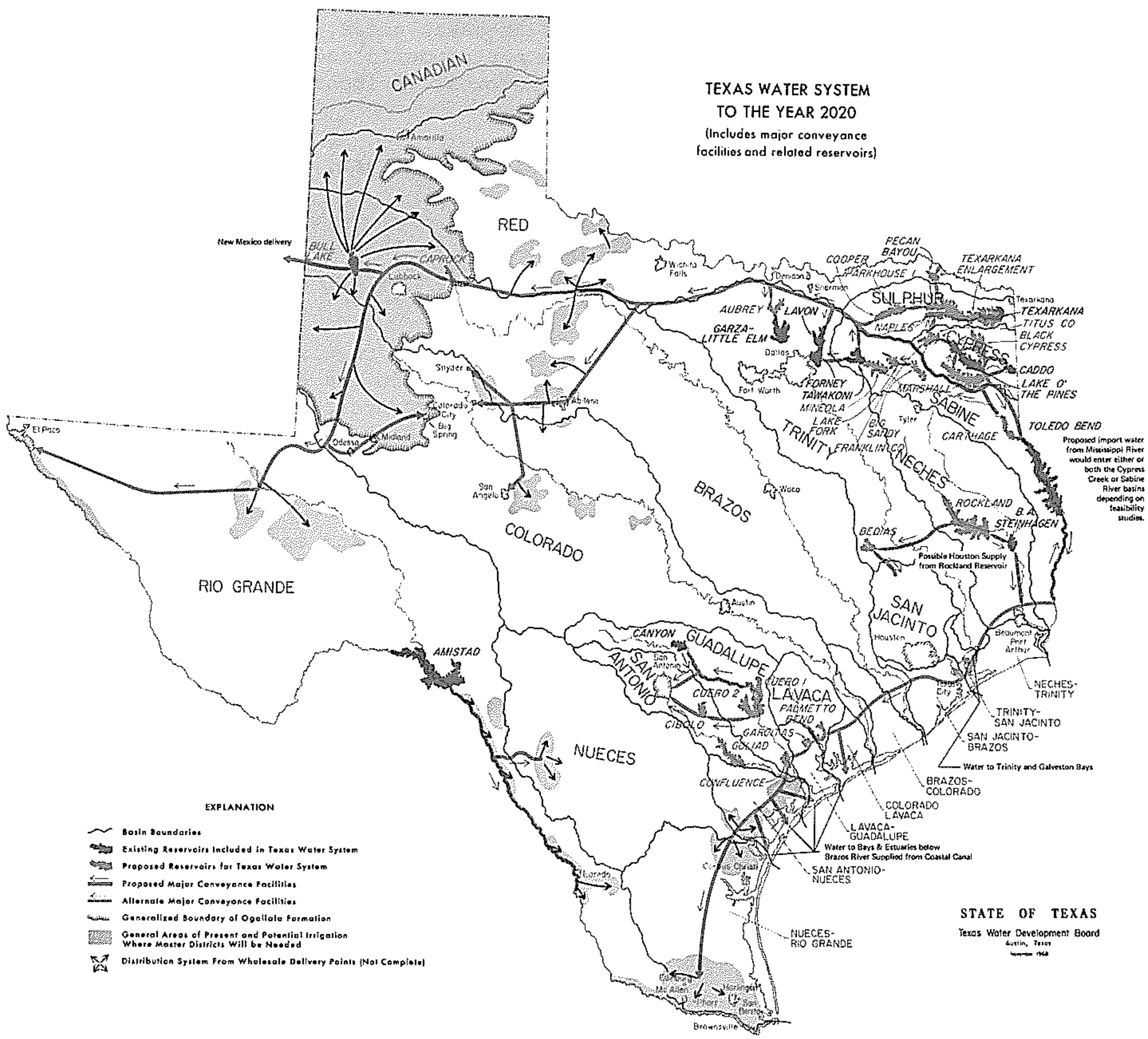
We have based the Texas Water Plan on the premise that the State's water resources will be fully committed by 2020 and that 12 to 13 million acre-feet of surplus water will be available from the lower Mississippi River for import into Texas, with 1.5 million acre-feet of this water annually scheduled for export to Eastern New Mexico.

Texas today has 157 major reservoirs, each having a conservation storage capacity of 5,000 or more acre-feet, existing or under construction. Sixty-seven reservoirs or alternate reservoirs for water supply, flood control, recreation, navigation, and other beneficial uses are proposed in the Texas Water Plan.

With the full development of our in-state water resources and an imported supply of some 13 million acre-feet of water annually, we feel we can meet our water requirements into the next century.

We hope to accomplish this goal with the Texas Water Plan.

I would like to take a few minutes to give you a brief description of the elements of the Texas Water Plan.


TEXAS WATER SYSTEM
TO THE YEAR 2020
(Includes major conveyance facilities and related reservoirs)
CANADIAN
RED
RIO GRANDE
COLORADO
BRAZOS
TRINITY
SULPHUR
CYPRESS
SABINE
NECHES
SAN JACINTO
GUADALUPE
SAN ANTONIO
LAVACA
NUECES
Amarillo
Lubbock
BULL LAKE
CAPROCK
New Mexico delivery
Wichita Falls
Snyder
Abilene
Colorado City
Big Spring
Odessa
Midland
El Paso
San Angelo
Waco
Austin
Houston
Dallas
Fort Worth
Denison
Sherman
Tyler
Texarkana
Beaumont
Port Arthur
Texas City
San Antonio
Laredo
Corpus Christi
McAllen
Harlingen
Brownsville
PECAN BAYOU
COOPER
PARKHOUSE I
TEXARKANA ENLARGEMENT
TEXARKANA
TITUS CO
BLACK CYPRESS
CADDO
LAKE O' THE PINES
NAPLES
AUBREY
LAVON
GARZA-LITTLE ELM
FORNEY
TAWAKONI
MINEOLA
LAKE FORK
BIG SANDY
FRANKLIN CO
MARSHALL
CARTHAGE
TOLEDO BEND
Proposed import water from Mississippi River would enter either or both the Cypress Creek or Sabine River basins depending on feasibility studies.
ROCKLAND
B. A. STEINHAGEN
BEDIAS
Possible Houston Supply from Rockland Reservoir
AMISTAD
CANYON
CUERO I
CUERO 2
PALMETTO BEND
CIBOLO
GOLIAD
CONFLUENCE
NECHES-TRINITY
TRINITY-SAN JACINTO
SAN JACINTO-BRAZOS
Water to Trinity and Galveston Bays
BRAZOS-COLORADO
COLORADO LAVACA
LAVACA-GUADALUPE
Water to Bays & Estuaries below Brazos River Supplied from Coastal Canal
SAN ANTONIO-NUECES
NUECES-RIO GRANDE
EXPLANATION
Basin Boundaries
Existing Reservoirs Included in Texas Water System
Proposed Reservoirs for Texas Water System
Proposed Major Conveyance Facilities
Alternate Major Conveyance Facilities
Generalized Boundary of Ogallala Formation
General Areas of Present and Potential Irrigation Where Master Districts Will be Needed
Distribution System From Wholesale Delivery Points (Not Complete)
STATE OF TEXAS
Texas Water Development Board
Austin, Texas

A major portion of the Plan is what we call the Texas Water System. It is comprised of reservoirs, canals and pipelines, pump stations and other facilities necessary to manage an imported water supply and the water resources of Texas' river basins having interim or long-term surpluses needed to meet in-basin needs, and for the movement of surpluses available to our semiarid and arid areas---about half of Texas---and for the movement of imported water to Eastern New Mexico.

The System includes three divisions: the Eastern, Trans-Texas, and Coastal.

The Eastern Division includes facilities in the State's eastern basins necessary to move imported water from points of delivery to the Trans-Texas and Coastal Divisions.

The Trans-Texas Division includes storage and regulating reservoirs, interconnecting conduits, and pump stations in the Northeast Texas basins; the Trans-Texas Canal extending westward from the Dallas-Fort Worth area to terminal storage on the High Plains near Lubbock, then south and west to serve the Trans-Pecos region, and a connecting pipeline for movement of water to El Paso.

The Division would provide water for municipal and industrial purposes to Dallas-Fort Worth and some of the other cities and towns within the Division and water to maintain irrigation in North Central Texas, the High Plains, and the Trans-Pecos. Eastern New Mexico water---1.5 million acre-feet---would be picked up at Bull Lake Reservoir northwest of Lubbock and moved to the Texas-New Mexico border on a "share-the-cost" basis between Texas and New Mexico.

The Trans-Texas Canal would be a man-made river stretching some 400 miles from Dallas-Fort Worth to Lubbock.

The Coastal Division would transport water for municipal and industrial uses, for irrigation, and for our bays and estuaries from the Sabine River on the eastern border of Texas to the lower Rio Grande Valley.

Other "works" proposed by the Plan include the Interstate System for moving surplus water across Louisiana to the Texas border; projects not associated with the Texas Water System but which will be needed to meet local water requirements; and facilities designed for purposes other than water supply---flood control, water quality, protection of water supplies from salt-water intrusion, and for hurricane protection.

The development of Texas' water resources and the importation of water will be costly. Our estimates of the cost of the Plan---in today's dollars---is some $9 billion, with the State's share to be between $2.5 and $3.5 billion.

The Plan has been formulated on the concept that its financing would be based on full repayment by water users of reimbursable costs under Federal and State policies.

The Water Development Board has made recommendations for local, State, and Federal actions which we feel are essential for the successful implementation of the Plan.

The Texas Legislature, now in session, is moving ahead in its deliberations on the legislative actions we feel are needed to implement the Plan. There is much to be done. All the problems ahead are not those of engineering. Our major problems are people and money.

We have first to convince the people of Texas of the need to move massive quantities of water to our metropolitan areas and to our arid and semiarid sections of Texas. We must convince the people of Louisiana and the other Delta States that we are not trying to "raid" their water, and want only to share that which is surplus to their needs and requirements.

The Congress must be convinced of the need to allocate the large sums necessary to make the Texas Water Plan a regional water plan, serving Louisiana, Texas, and a part of New Mexico.

These problems are not insurmountable, but they must be overcome if we are to continue moving forward with the nation into the 21st Century and to meet our responsibilities to generations yet unborn.

NEW MEXICO AND SOUTHWEST WATER

Joseph M. Montoya[1/]

With a thin crust of earth, a scant few inches of rain, and a layer of air, life for man on this planet has been made possible.

Vigorous action is needed if we are to continue.

Earthquakes fracture our land, human activities foul the air, and man posts signs around his water sources reading, "Unfit for Human Consumption!", "No Swimming, Beach Closed".

We react to these quakes, the dirty air, the vile water and the ugliness with disgust - and we demand changes.

But, as the users - consumers - of an ever-increasing supply of goods and services, we are the ones who contribute on a rising basis to the very things we protest.

We treat our land, air and water as disposable products - the no-deposit, no-return six pack of beer - with the complacency that if this store - our earth - runs out - we'll simply buy from another merchant, in this case move to a new frontier of some other planet.

I do not subscribe to this "disposable society" idea - nor do any of you here today. I am an optimist - I believe that with action now we can renovate, rejuvenate and recapture our environment.

I did not come here today before the Fourteenth Annual New Mexico Water Conference to talk in terms of population growth rate, economic growth rate, gross national product, or billions of gallons a day run-off of our water supply. You know those figures too well for me to review at 11:30 A. M. I came, rather, to talk about people - because that's what our concern is all about - and to talk of participatory politics - for that is where the solutions to our fouled air, ruined water and torn earth rest.

Of the people, it is sufficient for me to say now that we have 200 million, and it is projected the United States will see a population of 468 million in the year 2020. You know what this means in terms of human air needs, water supply and land usage.

If the trends of increasing demand for water and the decreasing supply are allowed to continue unchecked we will have a crisis of extreme scarcity, widespread hardship and economic stagnation.

Fortunately, this nation possesses the means to avert this crisis - if we convert our courage and intelligence into action.

1/ United States Senator from New Mexico.

Our water problems can be solved by four keys:

1. Capital
2. Scientific-technological know-how
3. Proper organization - and -
4. Genuine concern for public welfare.

We are "brim-full" with the first three - capital, technology and organization - but I fear we shall come home with an "empty cup" under the current Republican Administration unless we take the action now to stimulate participatory politics - people at every level in our nation actively participating in the decisions made by government affecting our environment.

We have the laws on the books today to assure public participation in these policy decisions - a good example is the first stage of the Water Quality Program, when states were required to hold public hearings on what kind of water quality the public wanted.

Those who have benefitted from the lack of statutes will, however, come to these hearings better prepared, better financed, and spend more time.

The individual citizen - the people most concerned with their own survival - tend to only join the fray on a crisis-to-crisis basis and to fight in an unorganized way.

This is where we, today, - public and water officials of the State of New Mexico - can take a key action role. The consumer concern must be translated by state and local environmental control agencies into meaningful standards which will meet the tests of time and usage and enhance our environmental quality.

The creative people of our state and nation deserve a creative government. This is where I fear for the public interest in water under the current Republican Administration if the record of the past becomes the fact of the future.

In the years of the administration - of which Mr. Nixon was a part - there was an indifference to, and betrayal of the public welfare in the water area. Capital was refused, attempts were made to shift Federal responsibility to local interests and the private sector, the well-established and successful multiple-purpose river basin development principle was discarded for the proven useless single-purpose approach.

That Republication Administration - which was the training ground for Mr. Nixon - failed to support a comprehensive development program of such closely related activities as soil conservation, scientific forestry, land - use management, small water-shed protection, wildlife management, and pollution control.

Not content with simply this do-nothing position, that Administration aggressively sought to shut the faucet of public water rights by the giveaways, grants of privilege and subsidies to private monopolistic corporations.

I do not charge here that Mr. Nixon will follow these policies - I simply say that I have seen no firm indication of where he stands on the historic, constitutional responsibility of the Federal Government in this crucial area and I do call upon him today to come forth with a program so that we may get on with the business of "human survival" in this world of polluted air, water and land.

Our challenge is clear - too frequently that which is destroyed today cannot be recovered tomorrow.

We must undertake an action program now - whether it be from the Administration or from participatory politics.

Our capital, technology and organization skills must be blended with a genuine concern for the people - we must initiate and move with bold programs of technical assistance and grants-in-aid to support the efforts of state and local governments and farmer cooperatives to develop water projects.

Our natural resources are a national birthright - and our national goal must be to maximize the general welfare of this nation by a complete, total, scientific development of our water resources for all beneficial purposes.

METERS AND THEIR EFFECTS IN THE ROSWELL ARTESIAN BASIN IN CHAVES AND EDDY COUNTIES, NEW MEXICO

Fred H. Hennighausen[1/]

INTRODUCTION

The Roswell Artesian basin, located adjacent to the west side of the Pecos River in Chaves and Eddy Counties, New Mexico is a rechargeable basin with two principal aquifers: the artesian limestone aquifer which produces water from depths of 250 feet to 1200 feet, and the shallow alluvial aquifer which produces water from depths of 10 to 300 feet. These aquifers, in most of the area, are separated by semi-permeable beds that range from a few feet in thickness in the northern part of the basin to about 500 feet in the southern part of the basin. Recharge to the artesian aquifer is derived primarily from infiltration of precipitation and runoff into outcrops of limestone west of the basin and recharge to the shallow aquifer is derived primarily from return flows of applied irrigation water, leakage from the underlying artesian aquifer, and local precipitation. Recharge to the artesian and shallow aquifers from precipitation has been estimated to average about 235,000 acre feet per year and about 35,000 acre feet per year, respectively. The basin was declared and closed to further appropriations of artesian water in 1931. The shallow ground water supply of the basin was closed to further appropriations in 1937. The administrative boundaries of the basin have been extended on several occasions.

BACKGROUND FOR METERING

It has been apparent for many years that pumpage in the basin has greatly exceeded recharge. Evidence of this fact has been reflected in diminishing artesian pressures, an almost continuous decline of the shallow water table, diminishing flow to the Pecos River, and saline water encroachment in the vicinity of Roswell. Pumpage for irrigation increased from less than 3 acre feet per acre in the 1930's to an average in excess of 4 acre feet per acre in the early 1960's.

As a move to help stabilize the basin by curtailing gradually increasing overpumpage, which had been estimated to exceed recharge by over 120,000 acre feet, all water rights in the basin were adjudicated by court decree with the order of the court being entered February 10, 1966. In addition to defining the extent and priorities of rights, the court also set the duty of water at 3 acre feet per acre per annum at the well, with a 5-year averaging provision, and ordered that all wells be equipped with meters as of January 1, 1967.

1/ District Supervisor, State Engineer Office, Roswell, New Mexico.

METER INSTALLATION AND PROBLEMS

The installation of meters commenced in the early part of 1966 and continued into 1967. Approximately 1,575 meters were installed. Many of the meters installed during the 1966 season were installed early in that year and then used by their owner to obtain an idea of the quantities of water required for their farming operations. All meter installations were inspected and approved by the watermaster. Some wells, owned in partnership, were equipped with as many as 5 meters.

The initiation of the use of meters brought some problems, but these were soon resolved, due primarily to the excellent cooperation of the meter servicing companies. These problems included mechanical failures due to the highly corrosive action of artesian waters on aluminum parts, the freezing of water between the plastic propellers and shafts, the accumulation of the sand between the propeller and the shaft, the seepage of water into the recording head and the entrainment of air in the water which caused the meters to race. Four different brands of meters were used in the basin; three of these have a right angle gear drive between the meter head and the propeller shaft and the fourth has an encased flexible-drive shaft between the meter head and the propeller. All four brands of meters, with appropriate corrections, have been relatively trouble-free. About 5 percent of the meters were found to be inoperative during 1967 but this percentage dropped considerably during 1968.

FIRST USE UNDER METERING

In 1966 it appeared from various indications that the overall use of water was less than in 1965 due to an increase in rainfall and in preparation for the mandatory decrease the following year. It was noted, however, in December 1966, immediately prior to mandatory metering, that the majority of water users pumped large quantities of water on their lands to obtain a buildup of soil moisture before metering actually began. This pumpage was reflected markedly on water-level hydrographs, in pumpage records and in increases in some drainline flows.

During 1967 many farmers, apprehensive as to whether or not they would have enough water, left some of their acreage fallow in order that they might utilize their allowed water supply for cotton and alfalfa production. Approximately 15 percent of the irrigated acreage was believed to be fallow during the first year (1967) of compulsory metering. Most of the "bugs" in the meters, and in the use of meters, were pretty well ironed out by the end of 1967.

SECOND YEAR OF METERING

During the second year of metering (1968) pumpage was reduced 12 percent from the previous year even though less acreage was fallow than in 1967. Although much of this decrease must be attributed to the increased precipitation during the 1968 growing season, a large part undoubtedly occurred in response to increased efficiency of application. Although many farmers who had previously opposed metering now recognized its benefits to both the basin and their farm operations, many contended that the decreed duty of water should be increased to more than 3 acre feet per acre per annum.

QUANTITIES USED

Quantitative figures show that, under the Decree, and during the first year of metering, 387,361.5 acre feet of water was diverted within the basin of which 373,290.8 acre feet was diverted from wells, and 14,070.4 acre feet was diverted from the surface streams and Hagerman Canal. Water used for irrigation purposes accounted for 95.8 percent of the total; the use for municipal purposes, primarily by the Cities of Roswell and Artesia, was 3.8 percent of the total; and the use for commercial and industrial purposes was 0.4 percent of the total. The total irrigation use of 371,250.6 acre feet on 128,245 equivalent water-right acres was equal to an average diversion of approximately 2.9 acre feet per acre for the basin as a whole. Approximately 30 percent of the users exceeded 3 acre foot per acre duty. In 1968 there was a further reduction in fallow acreage but in consequence of more experience, and increased precipitation the total pumpage was reduced by 12.45 percent to 339,124.5 acre feet of which 328,985.5 acre feet was diverted from wells and 10,139 acre feet was diverted from surface water sources. The total irrigation use in 1968 of 323,917.1 acre feet on equivalent water-right acres was equal to an average diversion of 2.53 acre feet per acre for the basin as a whole. Approximately 22.6 percent of the users exceeded the decreed annual duty of 3 acre feet per acre. The quantity of water diverted during each of these two years was less than in any year since 1958 and 1944, respectively, compared to estimates of diversion for previous years.

The use of water per water-right acre by individual users during both of these years varied considerably. These differences were due to differences in crops grown, differences in soil, quality of water, types of irrigation systems, and differences in rainfall. One of the greatest differences appears to be the difference in water management.

EFFECTS OF METERED USE

Some of the effects of metered use were readily apparent. Winter irrigation, which had rapidly increased since the late 1950's, particularly in areas of large capacity and flowing artesian wells, was drastically curtailed. No complaints of water waste to borrow pits and similar areas have been received since metering began in 1967. Crops are not generally irrigated during rains and irrigation pumps are usually shut down at those times in contrast to previous practice. The irrigator has become one of the most important persons on the farm. The resulting decrease in pumping costs have in turn reduced farm operating costs.

One of the items most notable to the farmers was that with metering and reduced withdrawals of water from the basin, pumps did not have to be lowered as had been the almost annual practice in many areas for the preceding 10 years. Service companies which specialize in this work reported a very large decrease in business.

In some ways metering has brought less rigid controls on the use of water, for with metering, emphasis is placed upon the quantity of water diverted, rather than on detailed surveys of irrigated acreage. Many farmers have elected to spread their water rights over larger areas to attain greater flexibility in farming.

OTHER RESULTS

Other less obvious results of the large reduction in pumpage enforced by the metering are indeed evident. Hydrographs on recorder wells and reports of farmers show that artesian pressures have increased considerably. Wells which had not flowed for many years flowed during the winter of 1967-1968. In the eastern part of the irrigated area near the Pecos River, drainlines were installed prior to the development of the shallow aquifer to alleviate subbing of the land due to return flow from artesian irrigation. An analyses of flow from these drainlines indicates that since 1966, in the area near Roswell where the shallow ground water supply is more directly related to artesian pressures, the flow of several drainlines has increased. In areas further south where the semipermeable beds separating the aquifers are thicker, however, the flow of drainlines has decreased markedly, particularly during the winter months when return flow from irrigation is at a minimum. An analysis of the flow in the upper reaches of Cottonwood Creek, which reportedly did not have perennial flow prior to the development of the basin, discloses a similar trend. The measured flow in the creek has been decreasing since the early part of 1967 with the greatest decreases in flow occurring during the winter months when return flow from irrigation is at a minimum.

Effects of the decreased pumpage brought about by the enforcement of a per acre limitation through the use of meters have also been noted in the area of saline water encroachment into the artesian aquifer north and east of Roswell. In this area an increase in the salinity of the artesian water had accompanied the progressive increase in overall pumpage prior to 1966. Since 1966 the quality of water produced by 67 sampled "high chloride wells" (1,000 to 2,000 parts per million) has progressively improved and the quality in 31 of the 53 low chloride wells (100 to 1,000 ppm chloride) has also improved. The salinity of the water produced by the remaining 22 sampled wells either has remained essentially unchanged or has increased slightly. Saline water encroachment has been further deterred by the lessening of severe summer declines of artesian head which in turn have reduced the upward movement of saline water from the basal part of the artesian aquifer.

Metering has resulted in continued emphasis on conservation measures such as land leveling and the installation of impervious conduits to transport water supplies, and has practially eliminated the uncontrolled use of water from flowing artesian wells. The practice of winter irrigation, which many agronomists believe unnecessary, has also decreased.

SUMMARY

It is recognized that it is still too early to draw definite conclusions regarding changes in conditions of the ground water basin resulting from the use of meters, and that all of the beneficial results in the basin noted within the past 2 or 3 years cannot be attributed solely to the metering of produced water. Some credit must certainly be given to improved conservation practices as well as phreatophyte eradication, stream channelization, and a somewhat improved situation in annual precipitation. The meters, however, did accelerate many of the other improvements and in my opinion, is the most important and beneficial measure that has been initiated in the Roswell ground water basin since the appropriation of water was first controlled in 1931.

COLORADO RIVER BASIN PROJECT ACT
AS IT AFFECTS NEW MEXICO

S. E. Reynolds[1/]

The Colorado River Basin Project Act became law on September 30, 1968. Full appreciation of the significance of this Act to New Mexico requires a brief review of the history of the "law of the river."

By the turn of the century, it had become evident that control of the Colorado River to prevent floods and to apply its waters to beneficial use was essential. This need was emphasized by the 1905 flood in which the Colorado River left its course to the Gulf of California and flowed into the Imperial Valley for 16 months to create havoc and the Salton Sea.

The works needed to control the Colorado River obviously could not be designed and constructed with the resources available to the people of the lower Colorado River valley and Southern California. Federal assistance was needed. The seven states of the Colorado River system -- Arizona, California and Nevada in the Lower Basin and Utah, Wyoming, Colorado and New Mexico in the Upper Basin -- all managed their water under the doctrine of prior appropriation in one form or another. Under that doctrine, the person who first controls the water of a stream and applies it to beneficial use has the better right to the use of the water. Thus, the states of the Upper Basin were reluctant to support construction of works which would put the Lower Basin states in a position to acquire a first right in the waters of the Colorado River before the Upper Basin states would have had an opportunity to establish a right to a reasonable share of the waters of the Colorado River system.

To make it possible for all of the Colorado River states to support the development needed, the seven states undertook the negotiation of the Colorado River Compact of 1922. Herbert Hoover, later to become President of the United States, was appointed to represent the federal government and served as chairman of the negotiating commission. The goal of the commission at the outset was to apportion to each of the basin states a share of the waters of the Colorado River system. This goal was never fully achieved.

Article III(a) of the 1922 agreement apportioned from the Colorado River system in perpetuity to the Upper Basin and to the Lower Basin, respectively, the exclusive beneficial consumptive use of 7.5 million acre feet of water per year. Article III(b) permits the Lower Basin to increase its beneficial consumptive use of the waters of the system by 1 million acre feet per year over and above the apportionment of Article III(a).

1/ State Engineer of New Mexico

Article III(c) of the compact provides that if the United States should ever recognize in Mexico a right to the use of any waters of the Colorado River system those rights would be supplied first from water surplus to the quantities allocated to the Upper Basin and to the Lower Basin. If that surplus proved insufficient to meet the Mexican rights recognized, then the burden of the deficiency is to be equally borne by the Upper Basin and the Lower Basin.

Paragraph III(d) of the compact provides that the states of the Upper Division will not cause the flow of the river at Lee Ferry to be depleted below an aggregate of 75 million acre feet in any period of 10 consecutive years. Lee Ferry is a point about 30 miles downstream from the Utah-Arizona state line.

The compact agreed to by the commissioners for each of the seven Colorado River states and the federal government could not become effective until ratified by the legislature of each of the states and consented to by the Congress of the United States.

By 1928, Arizona had not ratified the Colorado River Compact and the agreement was not yet effective. The negotiators' initial goal of apportioning a certain amount to each of the states had not been achieved in the agreement and Arizona was concerned that if works to control and use the waters of the Colorado River were built, California would establish rights to a disproportionate share of the allocation that would be made to the Lower Basin by the 1922 compact.

To overcome the impasse, the Congress enacted the Boulder Canyon Project Act. This law authorized the construction and operation of the Hoover Dam and Reservoir project and authorized the Secretary of the Interior to contract the delivery of water from Lake Mead for consumptive uses totalling 7.5 million acre feet annually -- 4.4 million acre feet to California; 2.8 million acre feet to Arizona and 0.3 million acre feet to Nevada. The act also authorized the Secretary to contract any surplus water one-half to California and one-half to Arizona.

The interests of the other states were protected by a provision giving the consent of the Congress to the 1922 compact on the condition that six of the seven Colorado River states ratified the compact and the California legislature enacted a law limiting the beneficial consumptive use of Colorado River water in California to 4.4 million acre feet annually plus one-half of any surplus. The authority to proceed with the construction of Hoover Dam was conditioned upon the compact becoming effective under the terms of the legislation. The California Limitation Act was adopted by the California legislature and the President of the United States proclaimed the Colorado River Compact effective in 1929. The construction of Hoover Dam was then undertaken.

The Arizona legislature finally did ratify the 1922 compact in 1944.

Although efforts continued, the Lower Basin states were never able to agree upon an apportionment of the allocation made to the Lower Basin by the Colorado River Compact. The Upper Basin states were more fortunate. The Upper Colorado River Basin Compact of 1948 allocated among the Upper Basin states the apportionment made to the Upper Basin by the 1922 compact. The Upper Basin compact alloted to Arizona the consumptive use of 50,000 acre feet of the 7.5 million acre feet apportioned to the Upper Basin. Of the remainder, Colorado is apportioned 51 3/4%, Wyoming 14%, Utah 23% and New Mexico 11 1/4%. New Mexico's 11 1/4% of 7.5 million less 50,000 computes out to 838,000 acre feet annually. But because Article III(d) of the 1922 compact enjoins the Upper Basin from causing the flow of the river at Lee Ferry to fall below 75 million acre feet in any period of 10 consecutive years and because recent records suggest that the flow of the river may not be as abundant as the 1922 negotiators thought, we estimate that New Mexico's share of the Upper Basin supply will amount to only about 770,000 acre feet annually.

By the mid-1940's the need for the Central Arizona Project was apparent. The municipal-industry economy in the Phoenix-Tucson area of Central Arizona was sky-rocketing. There was already a heavy overdraft on the ground water resources of the area for the lucrative irrigation economy. Water levels were declining, pump lifts were increasing and salt encroachment was deteriorating the quality of what had been fresh water.

The Central Arizona Project would bring an average of 1.2 million acre feet annually of Colorado River mainstream water from Lake Havasu to the Phoenix area through about 200 miles of aqueduct system.

In 1945, legislation was introduced to authorize the Central Arizona Project. This proposal initiated bitter controversy. The Colorado River Aqueduct had been completed in 1941 to take mainstream water to Los Angeles, San Diego and other Southern California communities. California had completed works capable of using a total of about 5.4 million acre feet of water annually. The Mexican Treaty, by which the United States recognized Mexico's right to 1.5 million acre feet annually of Colorado River Water, was agreed to in 1944. Recent records of streamflow had made it clear that the production of the Colorado River system was not sufficient to serve contracts for 7.5 million acre feet annually of consumptive use from Lake Mead after the Upper Basin put its share of the river to use. Faced with these facts, California contended that her completed works had first call on the river and that there simply was not enough water to justify authorization and construction of the Central Arizona Project.

In 1951, the House Interior and Insular Affairs Committee reporting on the legislation to authorize the Central Arizona Project said that further consideration of such legislation should be deferred until Arizona's right to the water had been adjudicated by the courts or established firmly by a compact between the states.

In 1952, Arizona filed in the Supreme Court of the United States a suit against the State of California seeking an adjudication of rights to the waters of the Colorado River.

In 1955, New Mexico was impleaded in the suit on a motion of the State of California. New Mexico resisted the California motion with partial success. We were made a party only in respect to our Lower Basin interests. These interests include the Little Colorado River system and the Gila River system which are lower basin Colorado River tributaries rising in New Mexico.

In 1955, the Congress was considering authorization of the great Colorado River Storage Project in the Upper Basin. Had we been required to defend and establish our Upper Basin rights in the suit, Congressional consideration of the Colorado River Storage Project Act almost certainly would have ended and we would not have Glen Canyon Dam and the other now completed works which were authorized in 1956.

In Arizona vs. California, et al., New Mexico contended for water from the Gila River system sufficient for all of our present uses. We also contended for additional amounts of water to permit the development of new uses in New Mexico. We attempted to show how, with good management of the Gila River system including a system of dams and reservoirs in New Mexico and Arizona, New Mexico could increase its consumptive use of water by 38,000 acre feet annually without decreasing the supply available to users in Arizona.

The Special Master appointed by the Supreme Court to hear the evidence in the case agreed that New Mexico should be decreed an amount of water sufficient for the uses then being made. He acknowledged that it had been demonstrated that there were shortages for those using water from the Gila River system and that the rights in Arizona generally are senior to the rights in New Mexico but nonetheless recommended that an equitable apportionment of the waters of the stream system should not require New Mexico to reduce present uses. At the Special Master's strong suggestion, New Mexico and Arizona ultimately stipulated that the amount of water required for New Mexico's uses from the Gila River system, including the San Simon Basin, amounted to 31,000 acre feet annually and the Supreme Court adopted that stipulation in its decree.

The Special Master recommended against permitting New Mexico to increase its consumptive use of water because there were already shortages for users in Arizona and because there was no assurance that the system of reservoirs that we proposed could or would be constructed. However, the Special Master did recommend that the decree be left open at its foot so that if circumstances changed

New Mexico would have the opportunity to ask the court to review its decree with respect to new uses in New Mexico. This recommendation was adopted by the court and ultimately proved important to our cause.

With respect to the Little Colorado River system, the Special Master found that there was no substantial conflict on the present use of the water of that system and recommended that the Supreme Court not undertake to apportion those waters between the states. The Court adopted that recommendation.

In the suit California contended for a first priority for works already completed with shortages to be taken by works which might be constructed later such as the Central Arizona Project. The Special Master in his report recommended that the available water supply be prorated among the states in accordance with the Boulder Dam Project Act -- i.e., 4.4 to California, 2.8 to Arizona and 0.3 to Nevada.

The Court did not accept this recommendation of the Special Master and ruled that the Secretary had the authority to distribute the shortages in accordance with his own good judgment and that in the alternative the Congress of the United States could direct the Secretary to distribute the shortages as he saw fit.

Arizona saw the Supreme Court decision as a great victory. Immediately after the decision was handed down in 1963, Arizona's Congressional delegation introduced legislation to authorize the Central Arizona Project. There followed five years of intense and often acrimonious negotiations among the 11 western states.

California insisted on first priority for its 4.4 million acre feet and contended that there was not enough water left for the Central Arizona Project.

The Upper Basin states were concerned that with a large federal investment in the Central Arizona Project the Congress would be reluctant to authorize the construction of water projects in the Upper Basin that would have the effect of reducing the supply for the Central Arizona Project. The Upper Basin states asked among other things that the legislation authorize studies of projects to import as much as 8.5 million acre feet annually from the Columbia River system to the Colorado. This suggestion gave rise to bitter opposition from the northwest states.

The bill as introduced would have authorized the Bridge and Marble Canyon Dam and Reservoir units in the Grand Canyon reach of the Colorado River. The purpose of these units was to have been the generation of power for Central Arizona Project pumping and power for sale to produce revenues to assist in the repayment of the project costs allocated to irrigation. This proposal brought on the opposition of the Sierra Club and other groups and individuals interested in preserving the Colorado River as nearly as possible in its natural condition.

The bill as introduced in 1963 would have authorized the Hooker Dam and Reservoir on the Gila River in New Mexico as a unit of the Central Arizona Project, but it contained no provision that would have permitted New Mexico to increase its consumptive use above the amount set forth in the Supreme Court decree. Had the Hooker unit been constructed under the terms of that bill, the reservoir evaporation alone would have put us in violation of the Supreme Court decree. New Mexico insisted on agreement by Arizona and the United States to an amendment of the Supreme Court decree or legislative provisions that would authorize increased uses in New Mexico.

Accommodation of these conflicting interests seemed impossible -- but it was done. The bill ultimately passed was S. 1004, introduced by Senator Carl Hayden of Arizona.

The act makes diversions for the Central Arizona Project subordinate to a first priority for California's 4.4 million acre feet.

The Bridge Canyon and Marble Canyon power units in the Grand Canyon were rejected and the Federal Power Commission is prohibited from licensing the construction of hydroelectric units in the reach of the river from Glen Canyon Dam to Hoover Dam. To furnish pumping energy for the Central Arizona Project, the Secretary of the Interior is authorized to participate in the construction of a thermalpower unit in partnership with public and private utilities.

To provide the assistance needed in the repayment of costs allocated to irrigation purposes a development fund is created. This fund draws principally on power revenues from the existing Hoover-Parker-Davis units after about 1985 when the cost of constructing these units will have been repaid and on the revenues that will become available from the Pacific Northwest-Pacific Southwest high-voltage transmission intertie.

The act recognizes the Mexican Treaty of 1944 as a federal obligation. If and when means are found to augment the supply of the Colorado River in an amount sufficient to meet the treaty obligation, the works will be constructed at federal expense and the cost will be nonreimbursable.

The act prohibits the Secretary of the Interior from undertaking studies of projects to augment the supply of the Colorado River by importation from any source other than northern California for a period of 10 years. This provision mollified the northwest states by giving them ample time to determine their own ultimate requirements from the abundant water supplies available to them.

The act authorizes the construction of five Bureau of Reclamation projects in the Upper Basin. Four of these are in Colorado and one - the Animas LaPlata Project - is to be constructed in Colorado and New Mexico.

One project in Utah, the Uintah unit, was conditionally authorized. The Dixie Project in Utah was reauthorized at higher cost with the provision that it may share in the financial assistance available from the development fund.

Last but not least the act authorizes the construction of a dam and reservoir on the Gila River in New Mexico as a unit of the Central Arizona Project. Construction is authorized at the Hooker site or a suitable alternative site. The Secretary is authorized, when the Central Arizona Project aqueduct system has been completed, to contract with water users in New Mexico in amounts sufficient to permit 18,000 acre feet of consumptive use annually in excess of the limit set in the decree in Arizona vs. California. The effects of these additional uses in New Mexico on Gila River water users in the Phoenix area are to be offset by mainstream water imported to the Phoenix area by the Central Arizona Project. The Secretary is further authorized to contract with New Mexico users for additional amounts of water sufficient to permit another 30,000 acre feet annually of consumptive use when the water supply of the mainstream of the Colorado River has been augmented sufficiently to give Arizona 2.8 million acre feet annually plus the amounts needed for the exchange of mainstream water for Gila River water authorized by the act.

These new uses in New Mexico are subject to all existing rights from the Gila River system in New Mexico and Arizona and must be made without adverse effect on those existing rights. New uses can be made in New Mexico under these terms by constructing reservoir capacity in New Mexico and making the exchange of mainstream water for Gila River water in the Phoenix area.

It seems worthwhile to note in passing that the exchange arrangement authorized in the Colorado River Basin Project Act makes it unnecessary to ask the Supreme Court for an amendment of its decree to permit uses in New Mexico in excess of the limits set in the 1963 decision. However, the fact that the Supreme Court left its decree open at the foot so that New Mexico could seek a relaxation of the decree limits should a change in circumstances warrant was a key factor in establishing the equity of the provisions of the act permitting new uses in New Mexico.

The Sierra Club and the Wilderness Society bitterly opposed authorization of construction at the Hooker site for the reason that water would be backed into the Gila Wilderness Area. Constructed to a capacity of 265,000 acre feet, the reservoir at normal water surface would extend for 13 miles above the dam site; seven miles of this length would be in the Wilderness Area. The lake would cover 480 acres of the total of 438,000 acres in the Wilderness Area -- that is, about 1/10th of 1% of the Wilderness Area would be under the lake. According to the Forest Service, there are about 500 visitor days of usage in the project area under present conditions. According to the Department of the Interior, there would be with the project 184,500 visitor days of usage annually.

It does not seem that construction at the Hooker site would have more than a negligible effect on wilderness values and could have a tremendously important effect on the welfare and economy of the people of southwestern New Mexico. Nonetheless, we acknowledged that feasibility grade studies of works in New Mexico had not been completed and that it would be reasonable in bringing the reconnaissance studies to feasibility grade to consider possible alternative sites, taking into account all factors, including construction costs, water supply and wilderness and recreation values, to achieve the best possible project. With this thought in mind, it was not difficult to agree to the compromise language that authorized construction at the Hooker site or a suitable alternative site.

The Upper Basin authorizations are also of great importance to New Mexico. The Animas-LaPlata Project will bring water from the Animas River in Colorado to the La Plata River Valley in Colorado and New Mexico. It will provide an irrigation water supply for 16,700 acres in New Mexico and will furnish 13,500 acre feet annually for municipal and industrial uses for Aztec, Farmington and other smaller communities in northwestern New Mexico. The total cost of this project is estimated at $109 million; $26 million of this amount is attributable to works to be constructed for the benefit of New Mexico. The project will deplete 34,100 acre feet annually of New Mexico's Upper Colorado River Basin allocation.

The total cost of the Central Arizona Project, including distribution and drainage facilities, is estimated at $932 million. In the neighborhood of $25 million of this amount will be needed for the construction of the Hooker unit in New Mexico. The total cost of the five Upper Basin projects authorized is estimated at $392 million. Thus, the total authorized by the Colorado River Basin Project Act is about $1.3 billion.

It may be worthwhile for me to recapitulate at this point what has transpired with respect to our entitlement from the Gila River system since New Mexico was impleaded in Arizona vs. California, et al. in 1955. In that suit, New Mexico claimed the right to irrigate the 19,039 acres then estimated to be under irrigation using the waters of Gila River, San Francisco River and San Simon Creek. We claimed the right to deplete the flow of the Gila River system by 34,800 acre feet annually in the exercise of all existing rights. We also asked for an additional 38,000 acre feet of consumptive use annually for new developments in New Mexico. The Special Master after considering the evidence which included the permits, declarations and notices of intention on file in the office of the State Engineer and the depositions of New Mexico witnesses taken in extended sessions in Silver City and Reserve, recommended in his draft report that New Mexico be decreed the right to irrigate 13,747 acres and to deplete the flow of the stream system by 27,500 acre feet annually with no allowance for new uses. New Mexico vigorously protested this recommendation and the Special Master acknowledged that he might have been a little stingy in his treatment of New Mexico. He strongly suggested that Arizona and New Mexico sit down at the conference table and attempt to stipulate the acreage and consumptive use that should be decreed to New Mexico. This was done and the stipulation adopted and ultimately incorporated in the final decree of the Supreme Court gave New Mexico 15,476 acres and a consumptive use of 31,000 acre feet annually for present use.

The test of how this stipulation fit the facts came in the recently completed adjudications of water rights in our state district court. We found that we were able to increase the irrigated acreage by 430 acres and the annual consumptive use by 2900 acre feet in the San Simon Basin without exceeding the limitations set in the Supreme Court decree. In 1966 the State Engineer issued new permits for the irrigation of 430 acres with ground water in the San Simon Basin.

Our district court adjudication showed that we could increase irrigation from the Gila River by about 600 acres and thus increase consumptive use by about 1,000 acre feet annually without exceeding the limits of the Supreme Court decree. Permits to effect this increase were issued earlier this month.

The result of the state district court adjudication of water rights on the San Francisco River showed that we cannot increase our uses from that river. The Supreme Court decree allows us to make a consumptive use averaging 3,187 acre feet annually from the San Francisco River. Tabulating the rights adjudicated by our district court and taking into account average annual shortages to the requirements of those rights and the acreage normally left fallow, we estimate the annual consumptive use by the adjudicated rights to be 3,300 acre feet annually. Thus, the amount decreed to us by the Supremem Court for the San Francisco River represents about 96 1/2% of what is needed for the rights found by our district court on that stream.

Although we resisted the provision with our best efforts, the Arizona-New Mexico stipulation limited the acreage that could be irrigated in each of four areas along the San Francisco River and there is some mismatch between the Supreme Court decree and the district court adjudication in this respect. The total irrigated acreage allowed us by the Supreme Court on the San Francisco River is 2,269 acres and the rights found by our district court total 2,393 acres. The Supreme Court decree limits us to the irrigation of 225 acres in the Luna area while the district court found 462 acres of irrigation water rights in that area. The limitations of the Supreme Court decree do not have the effect of depriving the owners of rights adjudicated to them by the district court. The more junior rights can be irrigated in any year in which a sufficient amount of the more senior rights are left fallow so that the total irrigated acreage does not exceed the Supreme Court limit. Furthermore, the irrigation rights outside the Supreme Court acreage limitation can be transferred in accordance with our state law to stock, domestic, municipal and industrial uses so that the right could be exercised without regard to the acreage limitation.

To summarize this recapitulation -- there is a good match between what the Supreme Court decreed to New Mexico and what is needed to satisfy the existing rights found by our own district court. The Supreme Court decree did not give us water for new uses from the Gila River system in New Mexico. But the Colorado River Basin Project Act gives us reasonable assurance of water for new consumptive uses amounting to 18,000 acre feet annually and reasonable hope for water for additional new consumptive uses amounting to 30,000 acre feet annually.

CONCLUSION

The Colorado River Basin Project Act was an extremely important step forward in more than a half a century of dissension, negotiation and accommodation related to the waters of the Colorado River system. The Act contains authorizations of tremendous importance to New Mexico's water supply, economy and welfare.

WATER CONSERVATION AND DEVELOPMENT IN THE FARMINGTON AREA AND IN THE STATE

Governor Tom Bolack[1/]

Thank you Mr. Chairman. I think after that introduction I should just say - thank you, it is nice to be here, and return to my seat. I do appreciate the introduction.

Very little of what I have to say will be on the technical side, as is the tone of most of this conference. I will discuss some observations I have made in many of the places I have been and many of the things I have had contact with, both in this state and abroad. In view of some questions which may be asked later, I will leave the door open in several spots. I will try to summarize a few thoughts that are most important to me and might leave a little food for thought, and perhaps give another reason of why you dedicated people are here for this conference.

I do feel very keenly about multiple use of land and water, of course, because I think too often we have gotten on to one version or the other without any thought of what the other needs might be. Certainly in our operation at Farmington we are trying to prove the compatibility of production as well as having a recreational benefit, together with game animals, fish and wild birds. We have considered the impact created on the public domain lands and the federal parks, state parks, and the need for space. Most everything we hear about space today is about the moon and all of the outer space, but actually there is a great need for space for people to move about and enjoy life. I think this particular situation is going to increase. There is greater push to the outdoors, and a greater demand on nature and a greater demand on what we do with our lands. In New Mexico we do little with our land without connecting it with water. So, maybe I will talk about land more than water, but I mean one and the same because we do have to keep them together. I think one mistake that has been made in this state, a very serious mistake, is that many people who are speculating on our lands, even our state land, have done nothing to preserve or improve or even keep those lands the same. I am not against the free enterprise system, which I have evidenced in several ways, but I think that people should be encouraged to do something with the land to better it, whether they plant trees, or whether they plant legumes, or grass, or something else to keep it from eroding away, filling our rivers and lakes with silt and not really benefiting anybody. I definitely think we have a long way to go in this respect. Unfortunately many of those speculators don't even live in our state much less contribute anything to the beauty or future of it. I think we have a great ceiling over our head, which we might say is the amount of available water, especially in the West

1/ Former Governor of New Mexico and owner and operator of B-Square Experimental Farm and Ranch, Farmington, New Mexico

and certainly our great state of New Mexico. Today we talk about the irrigation and we talk about the water used for crops and that is the battle of today. Tomorrow we will have this plus how good the quality is and how much will be available for people to actually drink. I think that shortage will be most serious. I think there is a great deal of merit in going to northern basins for transfers, and even into Canada to look for additional water. It might well be Canada, because they have such a surplus of water that one day through a greater compact may be made available. The expense at this time seems completely astronomical and out of reach. However, when people are thirsty enough, certainly those equations will change.

I cannot give you the exact figure but no one can deny that the whole and total use of the land will create an economic boost to New Mexico's economy. This is particularly true in the north. We hear lots about the north's problems. The main reason is that most of those little fields that grew chili and beans some decades ago are growing up to weeds now and the owners are on welfare, or somewhere else. This has had a great impact on our state's economy. If that land was all put back even as it was two decades ago, it would solve a lot of our problems up north. The true value of the land is a great question. We can get hundreds of dollars,and in some cases thousands of dollars for land in New Mexico, but what is the true value? What if we were to accumulate the amount of revenue or resource, or food, or way of life, however you want to weigh it, that has been produced say from one acre of land in the Holy Land over the last 2,000 years, what is the accumulated value? Perhaps we should think of that sometimes. Sometimes we might be a bit short-sighted when some present promoter or subdivider comes along with a price that seems too good to turn down. A subdivider has been sort of a target of mine. Living in a stream valley in San Juan Basin is much the same as it is around Albuquerque and the Rio Grande. The presently developed land and water is a little closer in and easier to build a mass subdivision, or an industrial subdivision, or building any other development. The very fertile land has been taken out of cultivation, when adjacent to these developed lands are rolling hills which actually once landscaped would probably make a more beautiful city and certainly a better place for many people to live and operate. Yet, for a little bit of short-sightedness, or perhaps other reasons I am not in a position to discuss, many of our fertile lands are now completely gone from any contributing factor as far as land use is concerned in producing crops. We may well regret that before it is all over, because there are millions of acres lost to highways, airports and subdivisions with no consideration of the land use, or the land needs on down the road. We talk about our surpluses which are nonexistent any more and certainly with the population explosion throughout the world we may well starve before we are blown off the face of the earth with bombs.

I speak from many of the things I have seen in Africa and India where the soil is gone, completely gone to bedrock. No atomic energy or irrigation projects, or anything else will bring that land back. This scorched earth policy of burning off all the brush, grass and humus year by year, plus overgrazing, plus poor management, has completely left the land devoid of any fertility and in turn when the vegetation was gone it was only a few short years until the soil eroded away into the existing lakes, rivers, or to the ocean.

Certainly, water development is something that is hard to sell. Steve Reynolds touched on it previously. I well remember the Upper Colorado River project. By some chance I was representing the four states, the four upper basin states, Colorado, Utah, Wyoming and New Mexico. We had a real fine project. We were all convinced it was a great thing. We went to Washington with a couple of movies, a few bushel baskets of folders and maps and thought there was really nothing to it, and it would be a very fine thing and everybody would be for it. We had barely unpacked our bags when we found out that half of the people in San Juan County and a lot of the people in the state of New Mexico - and this was true of other states - right back home in our own backyards were against the very project we were trying to sell. We then came back home to complete the home work. We went back again and after a great deal of effort the Upper Colorado River, the first project, was finally authorized. But it is amazing how little the average layman in the state, even as important as water is to New Mexico, can really comprehend or appreciate, in the beginning at least. I am certainly not here as an expert. I have not attended one of these meetings before. During the time spent back there in Washington I continued to find out a lot more about the water question and to realize how deep and technical it really is and how many facets there really are. Many people did not understand how important it was then, and I wonder if they do now.

While I am on the subject, I would have to say that if I had to list two men in this nation who had anything to do with our state's position, at least on the water problem, I would have to say in all fairness that General Dwight D. Eisenhower was one and our senior senator, Clinton P. Anderson, was the other. I know of no reclamation project that was the doing of either side of the political aisle alone. Unquestionably, it was a joint effort -- people from all walks of life and from both sides of the aisle. I can only speak very highly of Senator Clinton P. Anderson because I was there some 24 months out of a three-year period and saw what actually went on.

I would like to talk a little about our actual operation at Farmington. Again I am not in a position to give you the actual second-feet or the acre-feet. We feel that some three acre-feet per acre per year is probably sufficient in our area, but we do not have the growing season that you have down here. We probably accomplished proving a lot of things that it is not wise to do, and hopefully a few that are wise to do with irrigation in our project up there. We certainly made our share of mistakes. One thing that I would say, and I am sure is well known by most of you people, is the fact that irrigation methods are very important, particularly with vegetables; we grow a hundred non-surplus crops, which puts us into all of the squash and pumpkins, and every kind of vegetable except cotton and peanuts. A former governor takes care of that. We have found that because of the shallow root limitation of many of the vegetables, and because of our sandy and even more sandy subsoil, that if we irrigate twice as often and half as much, we seem to get a lot better yield.

We have had a surplus of water available in the San Juan area for years. It seems to me, and God love them all, and I am not picking on my neighbors, but it seems that many operate on the old theory that "if a little water is good a whole lot is better". I believe of any place in our state San Juan probably claims the record of over-irrigation. Most of the well-meaning people over-irrigate and leach the fertility beyond the reach of the shallow roots and the result is that our carrots seem to be always a little bit bigger and our pumpkins produce higher yields. We irrigate often and not much at one time. Just enough to get it across the land, and again not leach our fertility beyond the reach of the roots. We made a lot of mistakes and as I say we probably could tell you a lot of the things not to do rather than so many of what you should do. We have made a real effort in trying to help the Navajos be prepared for their project when it becomes a reality.

Our seasons vary a great deal. We have tried as many as 21 varieties of one particular onion strain. We thought we had the answer, but with all respect to our college here and to other research, the season changed and what we thought was so good was terrible. We do have an erratic season which many times throws off what we think is a conclusion. Our management of crops, reforesting, game management, even to predator control, we feel has contributed a great deal to the beauty and still maintained the productivity of the land and land use. Again, it goes back to the fact that it doesn't hurt for anyone to look at it or enjoy it. It doesn't hurt for a lake to be full of fish, either, or for people to enjoy it. There is a lot that can be done - leaving the fence rows and improving game cover and feed. Of course, as you concentrate game - we very dearly learned a lesson that it will concentrate the predators, some of them two-legged, too. This is just something you learn the hard way. We shot the hoot owls because they were eating the pheasants and guinea fowls and others off the roosts; then the field mice girdled many of the trees in the orchard and I lost some fruit trees that were 30 years old. You cannot interfere with nature without paying the price and sometimes it is pretty dear.

I do believe that a lesson of life can be learned by all of us from nature and the out-of-doors. I also feel very keenly that very few of our world problems today actually stem from people who have had, or still have, their feet in the soil. You will find few of those creating our serious problems and making the adverse headlines in the world, either now or ever, who had their feet in the soil for very long.

I do want to extend each and every one of you an invitation to come to Farmington and see our operation. If you have been there before, you will certainly be welcome again. We keep trying to build on, and prove some things right and some other things wrong.

It has been a pleasure for me to be before this group. I realize I have rambled a great deal but hope I have left a few thoughts with you that are important. I do congratulate you for your interest in water, and your part in making this occasion possible, and your feeling about water which I think is one of the greatest and most important problems which faces our state and the whole southwest at this time.

Thank you.

NAVAJO INDIAN IRRIGATION PROJECT

Bert Levine[1/]

PEOPLE

The transition of 25 percent of the Navajo Indian population from the pastoral age to one based on agricultural food production can be accomplished by the agricultural potential provided by the Navajo Indian Irrigation Project. During the past years, a number of small irrigation projects have been constructed for the Navajo. However, many of these have proved unsuccessful while the others have been only partially successful. Basically, today the Navajo lives in the pastoral era as his forefathers had since their return to the Navajo Reservation in the northwest part of New Mexico and northeast Arizona some 100 years ago. The 100,000 Navajo Indians live on a reservation, comparable to the size of West Virginia, with several small towns, the largest of which is only 5,000 population. The opportunity for advancement from their sheepherding environment has been quite limited throughout the years and has been recognized by the Government to be one of the necessary early needs to achieve a higher economic standard of living for these people. Several industrial plants have been established on the reservation which offer limited employment opportunities for the Navajos.

The irrigation of lands by Indians is not new to this country. In the period between 500 and 600 A. D. the Hohokums Indians, who were living at that time in the Gila and Salt River areas of southern Arizona, constructed more than 200 miles of ditches and canals. The creation of irrigation works of such large magnitude required inter-village cooperation and regional control. Yet the Hohokums did not reach a level of social cultural complexity comparable to the early civilizations to the south. This may have been a major factor in the ultimate failure of this project.

Historically, from ancient civilizations to the present, the construction of irrigation works has been associated with the desire for national wealth and power. But today, with the expenditure of public funds, borad social goals are also included, which incorporate a balanced concern for the welfare of the farmer and the region in which he lives. These social goals incorporate the notion of combination of best use of water and land resources. The success of irrigation enterprises is the product of careful use of a well designed system by well trained and equipped farmers. To assure that the investment in physical resources will be properly managed, it is becoming increasingly common to select, train, and provide assistance to project settlers.

1/ Project Engineer, Navajo Irrigation Project

The degree of assistance given to settlers varies as widely as the criteria for selection of the settlers. In the United States, services available to irrigation farmers are similar to those available to all farmers, including assistance of farm advisers, cooperative credit and cooperative markets; however, special assistance may be available in certain irrigation developments.

To develop the Navajo Indian Irrigation Project, the assistance offered the Navajo will be more extensive. Colonizing families may be provided with credit for the purchase of homes and farm equipment. An education program is especially important. In this project, the colonists will have been subsistent farmers who lived in almost totally isolated communities. When these people become a part of the developmental project, they will be thrust into the market economy, and are expected to become participants in the national economy and culture. To accomplish these ends, the colonists are encouraged to develop new desires and will be provided with the means to achieve these desires through the improvement of farm techniques and commercialization of agriculture. The type of educational program that becomes an integral part of this scheme must be administered with great care and patience. Such changes come as a shock to colonists from traditional societies and require cultural adjustments on their part. Changes of this magnitude have taken centuries to accomplish through the normal evolution to more advanced economies.

Yet, in the desires for results from national investment in irrigation projects, the time element required for cultural changes may seem extensive. The evolution of the Navajo from the pastoral to the agricultural production era will be a complex procedure, but must be recognized as an essential element of the development of the irrigation project.

WATER

The San Juan River which runs through the northwest corner of New Mexico and west of the Continental Divide contains the only large quantity of undeveloped water in New Mexico. This river now has been tamed and the water stored and available for use behind the Bureau of Reclamation's Navajo Dam. Based on the apportionment under the Upper Colorado River Compact, the State of New Mexico obtains 11.25 percent of Colorado River water available to the Upper Basin States. On the basis of long-term records, this compact allocation is expected to average about 838,000 acre-feet annually. A diversion of approximately 508,000 acre-feet is estimated to be required for the Navajo Indian Irrigation Project. The remaining water will be used for prior rights irrigation, industrial, and municipal usages, as well as for the potential Animas-LaPlata Irrigation Project. In addition to the excellent water supply available for the Project, the quality is outstanding for water in the western United States. The total dissolved solids in the water from Navajo Dam will be approximately 161 parts per million containing about 27 percent sodium with a low salinity hazard and a low alkalinity hazard. This should provide water for the project that would be suitable for continued use for irrigation of the crops expected to be grown on the project. It will further assure that the full range of adaptable crops can be grown on the project.

LANDS

The lands to be irrigated by the development of the Navajo Indian Irrigation Project are located on the high mesa south of Farmington, ranging from 5,400 feet in the northwest to 6,480 feet in the southeast part of the project, and lying 200 to 800 feet above the entrenched San Juan River. Vegetation of sagebrush, Galleta, Indian Rice, Blue Grams, ring Muhly and Morman tea are sufficient for year-round grazing; however, the carrying capacity is low, permitting one sheep unit per 22 acres.

The soils, formed from sandstone and shale, are typical of semi-desert soils occupying high plateaus and mesas of the intermountain West. Sand and gravel underlying the soil vary in depth from 8 to 70 feet. The irrigable soils are predominantly sandy loams with loamy sands occurring on the steeper slopes and loams and clay loams in flatter areas. Low in organic matter because of the sparse vegetation and low rainfall, the soil has good water holding capacity, moderate to moderately high infiltration rates, and is well drained. Water movement and root development are not limited, the soil is well aerated, and can be worked under a wide range of moisture conditions. These conditions allow a wide variety of adaptable crops, especially root-type crops and fruits.

Surface and subsurface drainage conditions are quite favorable for most of the project lands. Excess surface water will be diverted to natural or constructed collector drains. Deep collector drains will be provided in areas where the substrata material is not capable of carrying the excess groundwater to the natural outlets. Land will not be irrigated where subsurface drains are not feasible.

CLIMATE

The climate in San Juan Basin is conducive to successful agricultural production. The area enjoys abundant sunshine, low humidity, and considerable differentials between day and nighttime temperatures. Severe weather conditions, such as tornadoes, hurricanes, flooding, snowstorms, smog and hail are rare in the Four Corners area.

Winds present a problem in late winter and early spring. Short afternoon thunderstorms account for almost 50% of the annual rainfall of approximately 8 inches.

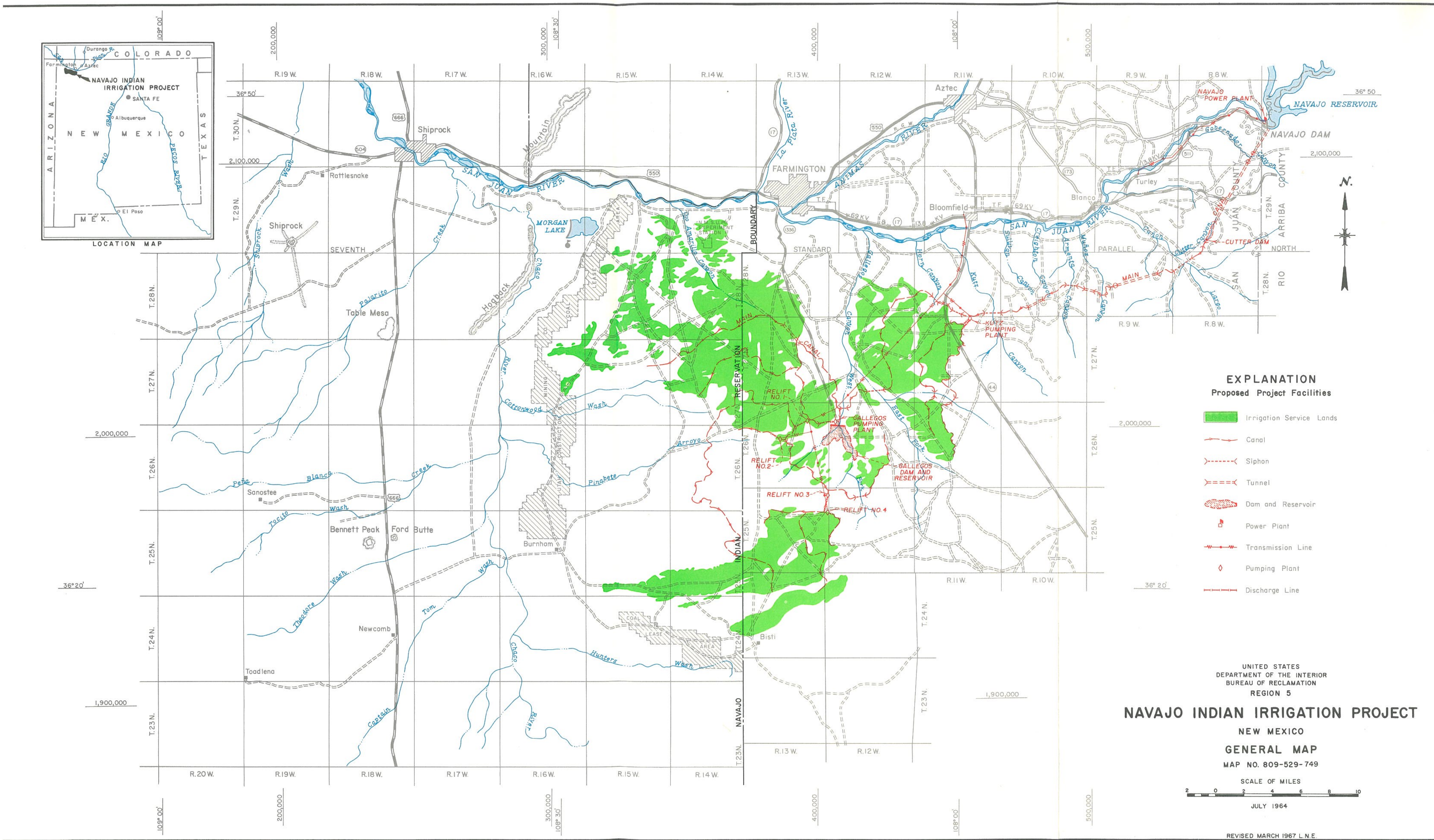
Mid-June through August, the daytime temperatures frequently exceed 90° F, but rarely are over 100°. However, the summer evenings are generally cool. The area experiences about 75 percent of possible sunshine throughout the year. Humidity normally ranges from less than 30 percent during the warmer portion of the day to 60 percent during the cooler early morning hours. The mean annual temperature of nearly 52° permits a growing season of from 146 to 166 days depending upon the elevation and location of the land.

PROJECT DEVELOPMENT

The need for irrigation of lands to provide farming operations for the Navajos was realized 100 years ago. In signing the historic Treaty of 1868 between the Navajos and the Federal Government, one of the provisions stated that productive land would be provided for each Navajo farmer. The application of water to the lands is the major barrier to making the lands productive. The Congress, in passing the project's authorization, recognized this prior commitment of the Government. On June 13, 1962, with the construction of Navajo Dam under way, which is the water supply for the irrigation project, the 87th Congress authorized the construction of a 110,630-acre irrigation project for the primary use of the Navajos. In the legislative history it was stated that the construction of the irrigation project facilities would be performed by the Bureau of Reclamation and the land development facilities by the Bureau of Indian Affairs.

Early in 1963, the Bureau of Reclamation started preconstruction activities, including surveys, land classification and drainage studies, location and design of project works. One of the initial steps was the awarding of two aerial photogrammetric contracts, at a cost of approximately $400,000, to obtain topographic maps on a scale of 1" = 400' with a 2-foot contour interval. Approximately 188,000 acres were mapped, providing maps for land classification, field layouts, structure locations, and design purposes.

Land classification and drainage studies were initiated on the project areas. These investigations determined drainage requirements, equilibrium salinity, and exchangeable sodium percentage levels, water requirements, soil productivity following land development, anticipated land use and management practices, and chemical suitability of irrigation soil and water erosion. Based on this data, farm layout investigations were also initiated on the project. Between Navajo Reservoir and the first lands there are 25 miles of very rugged country to be traversed with the irrigation facilities. Numerous tunnels, siphons and open canal sections are required to be constructed so that water could be delivered to the irrigable acreages. The diversion requirement is 1,800 c.f.s. of water by the main canal headworks, thus the tunnels are 18 feet in diameter, the siphons 17 feet 6 inches in diameter, and the open canal has a bottom width of 23 feet with 1-1/2 to 1 side slopes. Works of this magnitude width are expensive to


UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
REGION 5
NAVAJO INDIAN IRRIGATION PROJECT
NEW MEXICO
GENERAL MAP
MAP NO. 809-529-749
SCALE OF MILES
JULY 1964
REVISED MARCH 1967 L.N.E.
EXPLANATION
Proposed Project Facilities
Irrigation Service Lands
Canal
Siphon
Tunnel
Dam and Reservoir
Power Plant
Transmission Line
Pumping Plant
Discharge Line
LOCATION MAP
COLORADO
ARIZONA
NEW MEXICO
TEXAS
MEX.
NAVAJO INDIAN IRRIGATION PROJECT
SANTA FE
Albuquerque
El Paso
Durango
Farmington
Aztec
NAVAJO RESERVOIR
NAVAJO DAM
NAVAJO POWER PLANT
CUTTER DAM
KUTZ PUMPING PLANT
GALLEGOS PUMPING PLANT
GALLEGOS DAM AND RESERVOIR
RELIFT NO. 1
RELIFT NO. 2
RELIFT NO. 3
RELIFT NO. 4
MAIN CANAL
FARMINGTON
Bloomfield
Aztec
Shiprock
Blanco
Turley
Burnham
Bisti
Newcomb
Toadlena
Sanostee
Rattlesnake
Table Mesa
Bennett Peak
Ford Butte
MORGAN LAKE
SAN JUAN RIVER
ANIMAS RIVER
La Plata River
Chaco River
NAVAJO INDIAN RESERVATION BOUNDARY
SAN JUAN COUNTY
RIO ARRIBA COUNTY
SEVENTH STANDARD PARALLEL NORTH
COAL LEASE AREA
UTAH CONSTRUCTION & MINING CO. COAL LEASE
N.M.S.U. EXPERIMENT STATION
Hogback
Shiprock Mountain

GPO 834-250

construct and it is estimated that it will require approximately $66 million for the construction of the first 25 miles of works.

Utilizing the maps previously obtained, it is possible to lay out the lateral distribution system so that the individual farms can be readily served. At the present, it is planned to construct an all pressure-pipe distribution system for the first block of 10,000 acres, thereby permitting sprinkler irrigation of these lands.

PROJECT CONSTRUCTION

To date, project works under construction extend from Navajo Dam to approximately midway to the first lands. The works completed consist of two tunnels, one 2 miles in length and the other 5 miles in length. In addition, work on three siphons and 2.7 miles of canal is practically completed. It will be necessary that five additional contracts be awarded and completed before water can be delivered to the first block of lands. Had funds been appropriated in accordance with the original schedule, it would have permitted irrigation of the first project lands seven years earlier than the now scheduled 1977. Since the first appropriation in 1963, a total of $28,598,000 has been appropriated for use through June 30, 1969. This is only 16.3 percent of the total required to complete the project while the project has been under construction 39 percent of the original time scheduled for completion.

CONCLUSION

The four basic requirements for an irrigation project; namely, the people, the land, the water and the climate, are available in the project area. Upon completion of the irrigation project, estimated employment of 6,600 Navajos on the project farms, and related industries, will affect the standard of living for approximately 30,000 Navajos. The tremendous effect on the entire Navajo population, and the urgent need for early completion of the project is apparent. Although this project is only one of numerous projects and other items of cost to the Federal Government and must be evaluated in the overall Federal scheme, it appears that the economic evaluation of the benefits to the Navajos should lead to continuous efficient progress and early acquisition of the project benefits.

SAN JUAN-CHAMA PROJECT

D. E. Cannon[1/]

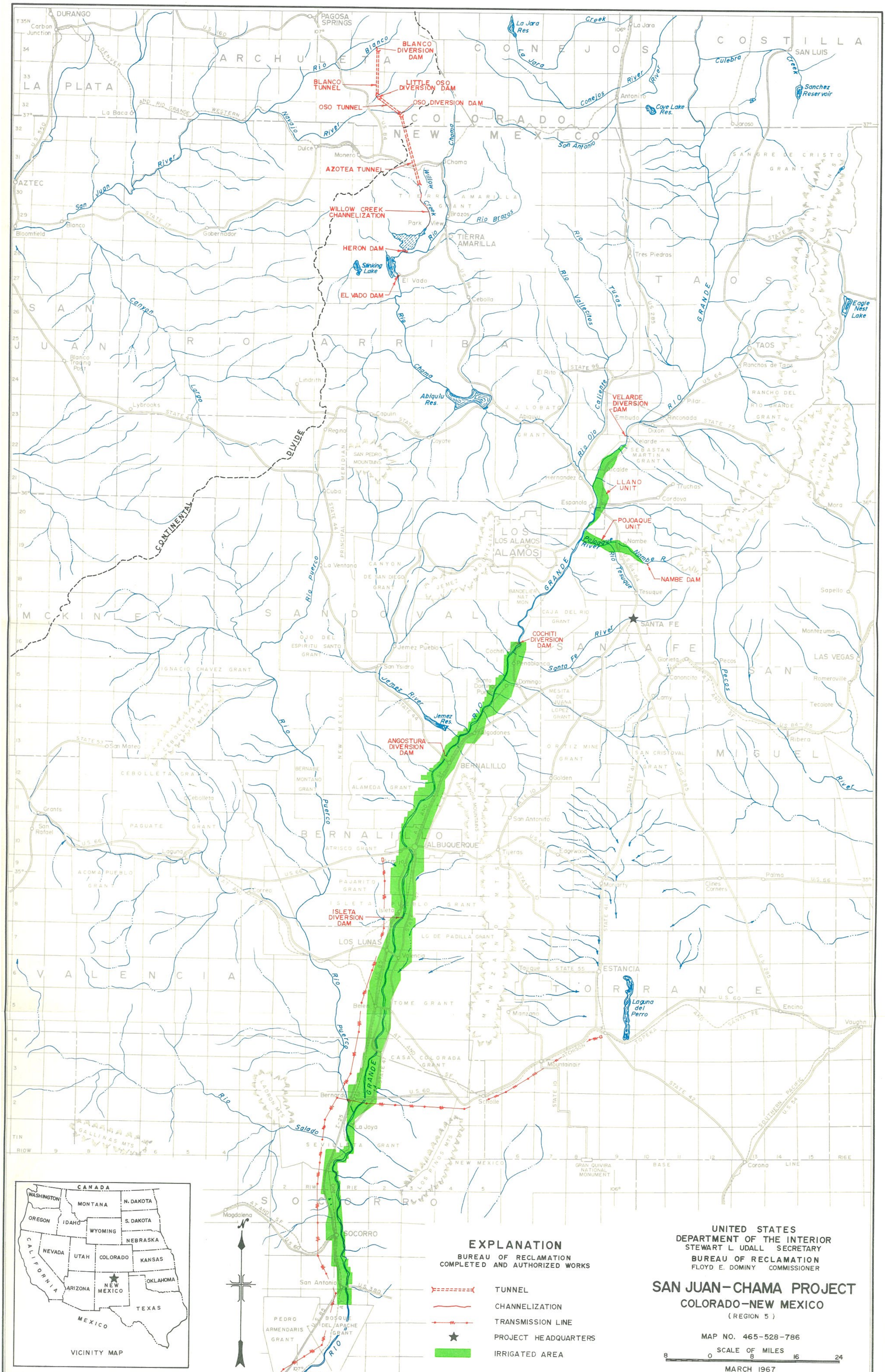
I am happy to tell you that construction progress on the San Juan-Chama Project is excellent and that in the spring of 1971 the State of New Mexico will have a new source of water available for its use. For those who may not be familiar with the project I will give you some background information, a description of the project, the present status of construction, and the allocation of water. And should you have any questions, I will attempt to answer them in the discussion period.

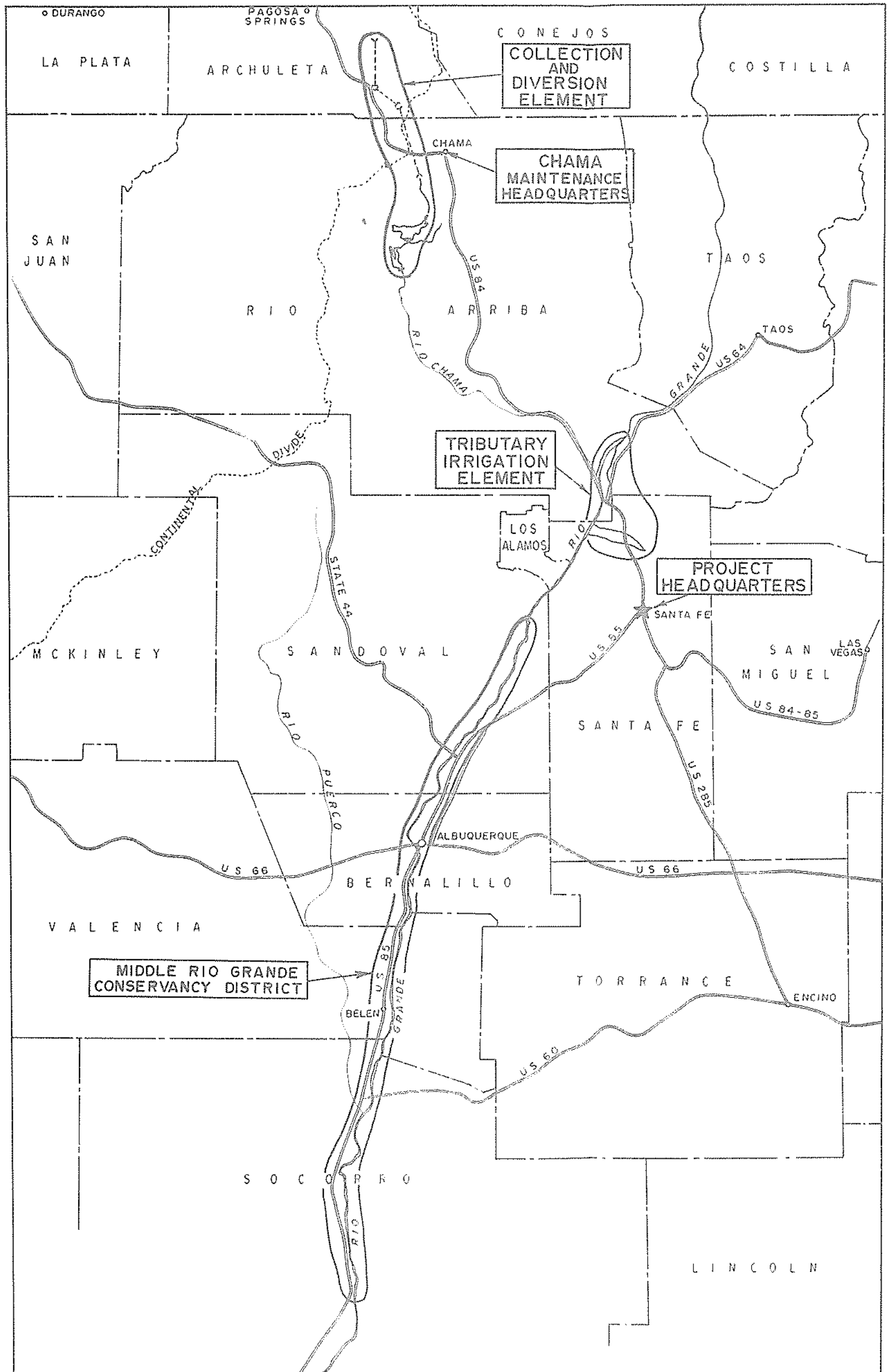
The first in a series of events that are of prime importance to New Mexico was the Upper Colorado River Compact of 1949, which allocated to the State a portion of the waters of the Colorado River. Most of you are aware, I am sure, that this water is the only sizeable block of undeveloped water remaining in the State. As a practical matter, all other waters are fully appropriated.

The second event in this series was authorization of the Colorado River Storage Project in 1956. This Project consists of the Glen Canyon, Flaming Gorge, Curicanti, and Navajo Reservoirs, all of which, except the Navajo, produce hydro-electric power. The purpose of this project is to provide the upstream storage that will control the river flows, so that the required deliveries can be made to downstream users, and, in addition, will provide power revenues. The power revenues, in excess of those required to repay power costs with interest, are used to assist projects such as the San Juan-Chama where in some instances the payment ability is little more than enough to cover annual operation and maintenance costs. Consequently, the storage project not only makes it possible for New Mexico to use its allocated share of Colorado River water, but provides part of the funds required to make the State's project financially feasible.

The third event was the authorization of the San Juan-Chama Project under a bill passed by Congress and signed by the President in June 1962. The project will import, through the Continental Divide, an average of 110,000 acre-feet of water annually from the Upper San Juan River tributaries for use in the Rio Grande. The water is allocated by law, 52,500 acre-feet for Albuquerque; 29,900 acre-feet for the four tributary units; 22,600 acre-feet for the Middle Rio Grande Conservancy District; and 5,000 acre-feet for a recreation pool in the planned Cochiti Reservoir. The State of New Mexico has wisely planned use of its water and put in a lot of hard work in developing its entitlement of Colorado River water. Our state's water authorities are to be highly commended for their part in bringing about the project.

1/ Project Construction Engineer


BLANCO DIVERSION DAM
BLANCO TUNNEL
LITTLE OSO DIVERSION DAM
OSO TUNNEL
OSO DIVERSION DAM
AZOTEA TUNNEL
WILLOW CREEK CHANNELIZATION
HERON DAM
EL VADO DAM
VELARDE DIVERSION DAM
LLANO UNIT
POJOAQUE UNIT
NAMBE DAM
COCHITI DIVERSION DAM
ANGOSTURA DIVERSION DAM
ISLETA DIVERSION DAM
CONTINENTAL DIVIDE
COLORADO
NEW MEXICO
LA PLATA
ARCHULETA
CONEJOS
COSTILLA
SAN JUAN
RIO ARRIBA
TAOS
LOS ALAMOS
SANDOVAL
SANTA FE
MCKINLEY
SAN MIGUEL
BERNALILLO
VALENCIA
TORRANCE
SOCORRO
DURANGO
PAGOSA SPRINGS
AZTEC
TIERRA AMARILLA
TAOS
SANTA FE
BERNALILLO
ALBUQUERQUE
LOS LUNAS
ESTANCIA
LAS VEGAS
SOCORRO
RIO GRANDE
Rio Chama
Rio Puerco
Jemez River
Santa Fe River
San Juan River
Navajo River
Rio Blanco
Abiquiu Res.
Jemez Res.
Laguna del Perro
Stinking Lake
Eagle Nest Lake
VICINITY MAP
CANADA
WASHINGTON
MONTANA
N. DAKOTA
OREGON
IDAHO
S. DAKOTA
WYOMING
NEBRASKA
NEVADA
UTAH
COLORADO
KANSAS
CALIFORNIA
ARIZONA
NEW MEXICO
OKLAHOMA
TEXAS
MEXICO
EXPLANATION
BUREAU OF RECLAMATION
COMPLETED AND AUTHORIZED WORKS
TUNNEL
CHANNELIZATION
TRANSMISSION LINE
PROJECT HEADQUARTERS
IRRIGATED AREA
UNITED STATES
DEPARTMENT OF THE INTERIOR
STEWART L. UDALL SECRETARY
BUREAU OF RECLAMATION
FLOYD E. DOMINY COMMISSIONER
SAN JUAN-CHAMA PROJECT
COLORADO-NEW MEXICO
(REGION 5)
MAP NO. 465-528-786
SCALE OF MILES
8 0 8 16 24
MARCH 1967



FACTUAL DATA—SAN JUAN-CHAMA PROJECT—COLORADO-NEW MEXICO

HISTORY

The upper San Juan River area was long considered Indian territory. Because of its inaccessibility and the proximity of hostile tribes, it was not settled until shortly before the turn of the present century. The population within the San Juan area and immediately south is sparse. Pagosa Springs, Colorado, the only major town in the vicinity, has a population of about 1,500. Much of the land in the San Juan River Basin in New Mexico is still inhabited by Indian tribes. The Navajo, Southern Ute, and Jicarilla Apache Indian Reservations occupy a considerable portion of the basin, and Navajo Indian allotments control the greatest part of the remaining watershed lands.

In contrast, the Rio Grande Valley is the oldest continuously occupied area in the United States, and the site of the first Spanish settlement. Ethnically, it contains three groups—the native Indians, the descendants of the Spanish settlers, and people of Anglo extraction who came after the American occupation.

The first Spanish exploration into the area was made in 1540 by Coronado in search of the Seven Cities of Cibola. Colonization was started in 1598, and by the middle of the 18th century Spanish settlements were scattered throughout the basin. More than 900 years ago the Pueblo Indians of the Rio Grande Valley had used simple irrigation systems and methods to supply irrigation water to their lands. The early Spanish colonists adopted the same type irrigation methods practiced by the Indians. Each community constructed and maintained its own ditches, diverting water directly from the river without benefit of storage.

The Indians revolted in 1680 and drove the Spaniards as far south as the present site of Juarez, Mexico. In 1692 De Vargas reconquered the region for Spain and again Spanish colonists entered the area. Settlement spread gradually along the Rio Grande and its tributaries.

In 1821 Mexico, which included most of the project area, declared her independence from Spain. Trade with the United States began in 1823, and by 1840 American merchants were firmly established in the basin. Actual occupation by Americans did not occur until after 1848 when the Rio Grande Valley lands were ceded to the United States by the treaty of Guadalupe Hidalgo.

The population of the Rio Grande Basin in New Mexico has shown a marked increase in the last three decades with most of the growth in the counties containing the larger cities and towns. Important cities and towns include Santa Fe, the state capitol; Albuquerque, the largest city; Las Cruces; Los Alamos; Taos; Espanola; Bernalillo; Belen; Socorro; and Truth or Consequences. From 1930 to 1960 the population of these cities and towns increased more than fivefold, and the present tempo of growth indicates continued population increase.

PURPOSE OF THE PROJECT

In the State of New Mexico, with its arid climate, water is the most precious natural resource and a limiting factor in its development. Throughout the Rio Grande, the uses of water have been developed to the extent that they far exceed the available supplies and there is a pressing need for additional supplies. Serious droughts and general decreased river flows have characterized the period since 1942 and have accentuated the widespread problem of water shortages.

The initial stage of the San Juan-Chama Project was authorized for construction under a bill passed by Congress and signed into law by the President on June 13, 1962. The project, authorized as a participating project of the Upper Colorado River Storage Project, will make possible an average annual diversion of about 110,000 acre feet from the upper tributaries of the San Juan River in the Upper Colorado River Basin, through the Continental Divide, for utilization in the Rio Grande Basin in New Mexico.

The imported waters are used to serve the city of Albuquerque with urgently needed additional water for municipal and industrial purposes (48,200 acre feet annually), provide supplemental water for irrigation of lands in the 81,610-acre Middle Rio Grande Conservancy District, and replace depletion in the Rio Grande Basin caused by furnishing a firm water supply to 6,960 acres of land in the Llano and Pojoaque tributary irrigation units in the Rio Grande Basin. Recreation and the preservation and propogation of fish and wildlife are also purposes served by the project. An annual allocation of 5,000 acre feet of water is made available for fish and wildlife and recreation purposes at Cochiti Reservoir.

WATER SUPPLY

The project water supply comes from the share of Colorado River water allocated to New Mexico by the Upper Colorado River Basin Compact. Water is obtained by diversion of part of the flows of the Rio Blanco, Little Navajo, and Navajo Rivers, all of which are tributaries of the San Juan River. The total mean annual flow of the streams at the proposed diversion sites for the period 1935 through 1957 was 167,500 acre feet.

Criteria for determination of stream flows to be reserved for downstream uses and not available for project diversion were established by representatives of the States of Colorado and New Mexico. These uses included prior water rights, maintenance of sufficient flows to preserve fish and wildlife values, and maintenance of sanitary conditions. The water bypassed averages 45,800 acre-feet per year, leaving for diversion a total of 121,700 acre-feet annually. After subtraction of the various losses due to transportation, evaporation, and capacity of the siphons, a net amount of 110,500 acre-feet is divertable to the Rio Grande Basin.

COLLECTION, DIVERSION AND STORAGE FEATURES

The collection and diversion facilities, located in the San Juan River Basin above Navajo Reservoir, consist of three diversion dams, two siphons, and a tunnel system to bring San Juan River Basin water through the Continental Divide. The imported water will be stored and held for release in Heron Reservoir, located on Willow Creek, a tributary of the Rio Chama. The outlet works of El Vado Dam on the Rio Chama has been enlarged to permit passing project water without interfering with the normal operation of El Vado Reservoir and to permit compliance with the Rio Grande Compact. Deliveries of San Juan-Chama Project water will be made in accordance with the provisions of the Rio Grande Compact.

The three diversion dams have concrete, ogee-type overflow sections, appropriate gates and headworks to divert water, and a sluicing facility to permit passing sediment downstream. The dams are the Blanco on the Rio Blanco, the Little Oso on the Little Navajo River, and the Oso on the Navajo River. Bypasses of water will be made as necessary at each diversion point to maintain a live stream for fishing and to furnish water to downstream water users who have prior water rights.

The conduit system consists of three concrete-lined tunnels, varying in size from 8-feet 7-inches to 10-feet 11-inches in diameter, and two siphons with 8-foot diameters. The Blanco Tunnel extends from the Rio Blanco to the Little Navajo River, a distance of about 9 miles, and has a capacity of 520 cubic feet per second. Oso Tunnel extends from the Little Navajo River to the Navajo River, a distance of about 5 miles and has a capacity of 550 cubic feet per second. Azotea Tunnel lies under the Continental Divide and extends from the Navajo River to Azotea Creek in the Rio Grande Basin, a distance of about 13 miles. Azotea Tunnel has a capacity of 950 cubic feet per second.

Approximately 7.25 miles of stream channel on Azotea Creek and Willow Creek between the outlet portal of Azotea Tunnel and the headwaters of Heron Reservoir were included under the heading of channelization. Prevention of erosion due to the increased flow in these streams was accomplished by channel re-alinement; installation of concrete drop structures; and riprap bank protection.

Heron Dam is located on Willow Creek just above its confluence with the Chama River and provides a regulating and storage reservoir with a capacity of about 400,000 acre-feet. The dam is an earthfill structure rising 263 feet above the streambed.

Heron Dike, also a rolled earthfill structure, contains the uncontrolled concrete spillway and is located approximately 1 mile northwest of Heron Dam. The dike has a height of about 75 feet and a crest length of 2,400 feet. The outlet works and the spillway have a combined capacity of about 4,700 cubic feet per second at maximum water surface.

The outlet works at El Vado Dam was enlarged to permit passing of the imported water through the reservoir without interfering with prior releases. The existing outlet works was plugged and a new outlet works having a capacity of 4,000 cubic feet per second was constructed. The new outlet works consists of a concrete-lined tunnel, four high pressure control gates and new intake structure.

TRIBUTARY IRRIGATION ELEMENTS

Llano Unit

The Llano Unit is located along a relatively narrow bench adjacent to the Rio Grande, extending from about 12 miles north to some 4 miles south of the town of Espanola. Supplemental water provided by the project insures an adequate supply of water for 4,669 acres of irrigable land of which 1,922 acres are Indian land. The average elevation of the irrigated area is approximately 5,700 feet above sea level.

The project works consist of Velarde Diversion Dam, located on the Rio Grande about 15 miles north of Espanola, about 19 miles of main canal, and the necessary appurtenant works to effect efficient water delivery. The average annual diversion requirement is about 2.37 acre-feet per acre of irrigable land in the Llano Unit, including only the supplemental supply of those lands receiving supplemental waters.

Pojoaque Unit

The Pojoaque Unit, about 16 miles north of Santa Fe, is located in the bottom lands of the Pojoaque and Nambe Rivers, extending about 14 miles upstream from the confluence of the Pojoaque River and the Rio Grande. Supplemental water provided by the project insures an adequate supply of water for 2,300 acres of irrigated land. Both Indian and non-Indian lands are included. The average elevation of the irrigated area is approximately 5,800 feet above sea level.

The storage feature of the unit is the Nambe Falls Dam and Reservoir located immediately above Nambe Falls on Nambe Creek. The dam is an earthfill and concrete structure rising about 120 feet above streambed. The reservoir has a conservation capacity of 1,500 acre-feet at the end of 50 years and a surface area of 49 acres at normal water surface elevation. Two diversion dams are used in water distribution, an existing dam on Nambe Creek at the upper end of the area, and a new concrete structure below the village of Pojoaque. The canal system has been enlarged and the ditches have been consolidated. The average annual diversion requirement is about 3.80 acre-feet per acre of irrigated land in the Pojoaque Unit.

Principal crops grown in the Pojoaque and Llano Units include apples, hay, corn, small grains, and a variety of vegetables.

The average annual precipitation at Espanola, New Mexico, is 10.11 inches. Temperature extremes range from −23°F. to a maximum of 106°F. The average frost-free period of 164 days occurs between April 29 and October 10.

Inquiries for additional information may be addressed to:

Regional Director, Region 5
Bureau of Reclamation
Post Office Box 1609
Amarillo, Texas 79105

GPO 836-074

The overall cost of the San Juan-Chama Project is expected to be $75.5 million. The joint use facilities which consist of the storage and diversion elements are estimated to cost $56.5 million, of which about $24.5 million is allocated to Albuquerque's water supply; $25.7 million to irrigation, and $6.2 million is a non-reimbursable allocation to recreation and fish and wildlife. Thus, some 90 percent of the joint costs will be repaid by water users or by power revenues. I should like to add that on all Reclamation projects constructed, an average of 90 cents out of every dollar is repaid to the Federal Treasury by the beneficiaries of the project. Repayment contracts have been signed with the City of Albuquerque and the Middle Rio Grande Conservancy District for their proportionate share of the project costs.

These joint use facilities originate in southern Colorado. The diversion works consist of three long tunnels starting on the Rio Blanco in Colorado, siphoning under the Little Navajo and Navajo Rivers, and discharging into a tributary of Willow Creek in New Mexico. Diversion dams and feeder conduits at all three streams will divert the available water into the tunnel system. The first two tunnels, designated Blanco and Oso, will be 8 feet 7 inches in diameter with capacities of 520 and 550 cubic feet per second. Azotea, the third tunnel, will be 10 feet 11 inches in diameter with a capacity of 950 cubic feet per second. All tunnels will be circular in shape and lined with concrete. Tunnel lengths are approximately: Blanco -- 9 miles; Oso -- 5 miles; and Azotea -- 13 miles. Other features in the element are a new outlet works for the existing El Vado Dam and Reservoir, Channelization for Willow Creek, and Heron Dam and Reservoir. The imported water will flow into Heron Reservoir where it will be stored and regulated. The dam will be an earth and rockfill structure about 270 feet in height constructed in a canyon on Willow Creek at its confluence with the Chama River. The reservoir will have a capacity of 400,000 acre feet. Recreational development on the reservoir will be constructed by the National Park Service.

Water purchased by Albuquerque and the Middle Rio Grande Conservancy District will be released from Heron Reservoir as needed and will flow down the Chama River and Rio Grande to the point of use. Delivery of Albuquerque's water will be in the river, and the Conservancy District's water will be diverted from the Rio Grande through its existing irrigation system.

Also authorized under the San Juan-Chama Project were four tributary units -- Pojoaque, Llano, Taos, and Cerro. The additional water for these units is Rio Grande water already appropriated by downstream users. As Rio Grande water or water from tributaries of the Rio Grande is stored or diverted for use, equivalent amounts of imported water will be released from Heron Reservoir. It will flow down the Rio Chama into the Rio Grande and, in effect, will restore the Rio Grande flows at the Otowi gage, and give downstream users the same water supply by exchange that they would have received if the San Juan-Chama Project had not been built. I will discuss the tributary units more in detail later.

The status of construction of the various features is as follows:

The Blanco Diversion Dam and the 9-mile long Blanco Tunnel are completed and ready for use. The 5-mile long Oso Tunnel is complete except for backfill grout behind the concrete tunnel lining. This should be finished in about 2 months. The two diversion dams located at the Little Navajo and Navajo Rivers are each about 75 percent complete. The siphons under the rivers and feeder conduits are yet to be constructed. The 13-mile long Azotea Tunnel which crosses under the state line and through the Continental Divide is about 85 percent complete. Excavation of the tunnel was completed in May 1968 and the placement of concrete lining is now in progress. About 6 miles of the concrete lining remain to be placed. A contract has recently been awarded to complete the channelization between Azotea Tunnel and the headwaters of Heron Reservoir. At the Heron damsite the diversion tunnel under the left abutment and operating shaft are practically completed. Progress on the excavation for the dam abutments and foundation grouting is such that diversion of Willow Creek should be accomplished about June 1 which in turn will permit start of embankment placing for the dam. Clearing of Heron Reservoir will be started this spring. The construction of a new and larger outlet works for the existing El Vado Dam has been completed. Overall the storage and diversion element is about 78 percent complete and the total project is 61 percent complete.

Perhaps one of the more interesting facets in the construction of the project was the use of a mechanical boring machine or mole for tunnel construction. Prior to this project a mole had never been used on a Bureau of Reclamation project. Geology reports indicated the rock to be encountered in the tunnels -- shale and sandstone -- could be economically excavated by a mole. An extensive exploration program was then undertaken consisting of geophysical investigations and subsurface drilling. The results of this program were then made available to all prospective bidders on the tunnels. When bids were opened on the first tunnel in March 1964, it was obvious that our exploration program had paid good dividends. Of the ten bids received, seven indicated a preference for the mole-driven tunnel and only three indicated performance by conventional methods. The difference between the low bids received for the mole tunnel and for the conventionally driven tunnel were in excess of $6.5 million. On bids received for the other two long tunnels, all indicated use of moles.

When I refer to conventional tunneling, I am speaking of the method used for many years which involves drilling a series of holes in the tunnel face, loading the holes with explosives, detonating the explosives, loading the loosened rock into muck cars, hauling the materials from the tunnel, and then repeating the cycle. Utilizing this method an average of about 50 feet of tunnel can be excavated in 24 hours, dependent somewhat on the size of tunnel, and in one month about 1,000 feet. As a comparison in the Blanco Tunnel on one 8-hour shift 135 feet of tunnel were excavated, in one day 375 feet, and in one month 6,713 feet. And not to be outdone, the contractor on Oso Tunnel excavated 156 feet in one 8-hour shift, 403 feet in one day, and 6851 feet in one month. From the above statistics it is plain that use of the mole has been very successful and that the San Juan-Chama Project has materially contributed to the improvement of tunneling technology. Projects such as the San Juan-Chama are complex and expensive. The many water laws, compacts, and other contractual agreements which must be complied with make the planning, development, and operation of such projects difficult. Projects in the future will be even more complicated and expensive. However, I am sure with the added technology available to our planners, engineers, and scientists these new projects will be feasible and ways will be found to economically bring water to areas in short supply.

The other element of the San Juan-Chama Project consists of four tributary irrigation units -- Cerro, Taos, Llano and Pojoaque -- which were authorized under the project. Further investigation showed that the two larger units -- Cerro and Taos which are located north of and in the vicinity of Taos -- were infeasible due to unsound geological conditions at the proposed reservoir and dam sites. However, additional planning work is being done on a reduced size Taos unit. The two smaller units -- Llano and Pojoaque which are located in the vicinity of Espanola -- are programmed for future construction. As a result of the infeasibility of the two units 12,000 acre feet of water remains unallocated. On January 30 and 31, 1969, the Interstate Streams Commission conducted a public hearing and entertained requests for allocation of the surplus water. To show you what demand exists for water, some 30 applications were received from practically every city and town located adjacent to the Rio Grande or its tributaries, from potential and existing irrigation districts, from recreational organizations, and from military installations and these applications totaled about 170,000 acre feet. Your water is valuable. Conserve it and use it wisely.

WATER BILLS INTRODUCED IN HOUSE AND SENATE
TWENTY-NINTH NEW MEXICO LEGISLATURE
First Session 1969

Dr. Wm. B. O'Donnell - Representative, Dona Ana County
Lt. Col. James Kirkpatrick - Senator, Dona Ana County

Representative O'Donnell reported on the bills which were considered by the 1969 Legislature. These bills may be of the most interest to this Conference:

Passed

H 231 - Act, to ratify Animas-La Plata Project Compact between New Mexico and Colorado. Passed House and Senate. Signed: Chapter 57.

HJM 8 - Relating to the urgent need for a series of dams on the Pecos River and the Tecolote Creek. Passed and Signed.

S 43 - Administrative Procedures Act providing for standardization of practice and procedure in the conduct of administrative hearings. Amended and Passed Senate and House. Signed: Chapter 252.

S 180 - Repealing Section 75-11-26 through 36 NMSA 1953 relating to rights in underground waters prior to inclusion in an underground basin. Passed the Senate and House. Signed: Chapter 51.

S 219 - Relating to the procedure to be used before the state engineer in regard to public waters. Amended and passed Senate and House. Signed: Chapter 250.

S 59 - Making an appropriation for recreational facilities at Running Water Draw. Amended and passed Senate and House, Signed, Partial Veto: Chapter 135.

SM 8 - Requesting action to provide for channelization of the Gallinas River within the limits of Las Vegas Town and City. Passed and Signed.

Not Passed

H 309 - Water Basin Appropriation to allow owners of water rights to appropriate water from underground basin. Do Not Pass House Committee.

H 329 - Providing for the banking of unused water and subsequent use within 5 years. Died in House Committee.

H 406 - Providing for the regulation of water disposal which is not contaminated. Died in House Committee.

H 407 - Creating a state water commission who would appoint the state engineer. Died in House Committee.

HM 25 - Water Rights Moratorium Action Postponed Indefinitely.

S 9 - Amending Section 75-11-7 NMSA 1953 dealing with the permanent or temporary change in well location and the use of the water. Passed Senate. Died in House Committee.

S 109 - Repealing Section 75-11-30 NMSA 1953 relating to the procurement of a permit to complete an appropriation commenced before a water right basin was declared. Died in Senate Committee.

S 117 - Authorizing the sale of $7,151,000 severance tax lands to build additional dams and spillway gates on the Canadian River. Do Not Pass Senate Committee.

S 174 - Providing for mandatory adjudication of water rights in areas lying outside adjudicated water basins. Died in Senate Committee.

S 218 - Amending Section 75-11-3, 7, 24 and 25 NMSA 1953 to allow the state engineer to deny water applications. Do Not Pass Senate Committee.

S 261 - Requiring water rights to be held in suspense in certain situations where a change in use is made. Died in Senate Committee.

H 284 - Providing for financing of state park and recreation project in the Eagle Nest Lake Area. Do Not Pass Senate Committee.

Several other bills relating to water problems were introduced but they were of limited statewide importance or applied to administrative details.

Representative O'Donnell pointed out that when looking at all of the water bills which were included, there was relatively no consistency in the legislative proposals. Many of the bills seemed designed to pass a law as it applied to an individual, or to review some present law or court action as it applies to certain restricted subject areas. There is virtually no way for a legislator at the present time to consider these bills in relationship to the needs of the state or in relation to a forward-looking, statewide or community-wide water development objective.

It was suggested that the Annual Water Conference or the Water Resources Research Institute might consider ways by which the legislative needs of New Mexico and of the several areas of the state could be developed. This would permit the legislature to be more consistent and constructive in its action. As it is now, the legislators have no idea what kinds of water legislation may be presented or whether that which is introduced may be constructive in its application even to those proposing it. It was pointed out, also, that there is no citizens' group in the state which has considered the needs for legislation in relation to the conservation and development of the water resources of New Mexico.

Senator Kirkpatrick in his discussion on the general legislative procedures, stated that a 60-day session did not allow the senators and representatives adequate time to study the proposed legislation and to investigate the possible impact of a certain bill on the state or area involved. He suggested that a 90-day session is needed and he hoped the Constitutional Convention, to be convened in 1969, would establish a 90-day session.

Also, he stated that (1) due to lack of time and (2) lack of any developed water legislation program, the senators generally had to depend for guidance from either the man who proposed the majority of water legislation this year, or the State Engineer Office. This, he felt was not a satisfactory arrangement but about the only alternative available during the 1969 session of the Legislature.

Senator Kirkpatrick concurred with Representative O'Donnell on the need for some type of a developed state water plan which would also include a guide to water legislation to which the Senate and the House of Representatives might refer in their deliberations on water legislation.

POTENTIALS FOR WATER DEVELOPMENT

WITH ATOMIC POWER

L. P. Reinig1/

Nuclear reactors and nuclear explosives both have potential applications to water resource development. I'd like to begin with reactors and proceed to peaceful uses of nuclear explosives.

Nuclear reactor construction is increasing. In 1965 less than 1 percent of the electricity in the United States was generated by nuclear plants. By January 1969, 91 central station nuclear power reactors, with a net capacity of 65,482 MWe, approximately 20% of the nation's generating capacity in 1969, were either under contract, under construction, or in operation (1). In 1968 alone, electric utilities contracted for 17 nuclear power stations in the United States. By 1980 it is estimated that the nuclear share of our American electricity generating capacity will have risen above 25%, and by the year 2000 about half our generating plants will be nuclear.

Figure 1 shows a forecast of electric utility generating capacity, prepared by the Joint Committee on Atomic Energy, Congress of the United States (2). The steep slope of the curve marked "nuclear" is not surprising in view of the fact that nuclear power plant "starts" already exceed fossil fuel "starts" in this country, and will increase their lead from now on. The economic reason for this is indicated by the following table (based on Reference 2) of comparative costs for a 600 MWe2/ power station:

	Capital Costs $/kWe	Operation Maintenance & Insurance Mills/kWh	Fuel Mills/kWh	Total Energy Cost Mills/kWh
Nuclear Plant	135	.3	1.5	4.5
Fossil Plant	120	.2	2.55	5.15

Current estimates project capital costs at $150 per MWe and bus bar electricity costs at 4.5 mills per KWH from a 1000 MWe nuclear reactor.

The term thermal reactor refers to the energy of the neutrons causing fission. It is sometimes used to refer to the type of reactor which merely consumes uranium and produces thermal energy since all commercial power producing thermal reactors are of this type.

1/ Head Engineering Department, Los Alamos Scientific Laboratory.
2/ According to W. Kenneth Davis of Bechtel Corporation, quoted in Nucleonics Week, March 13, 1969, there will be much wider use of nuclear power world-wide as countries reach the point where their utility systems can utilize economically large nuclear units of 500 MWe or more.

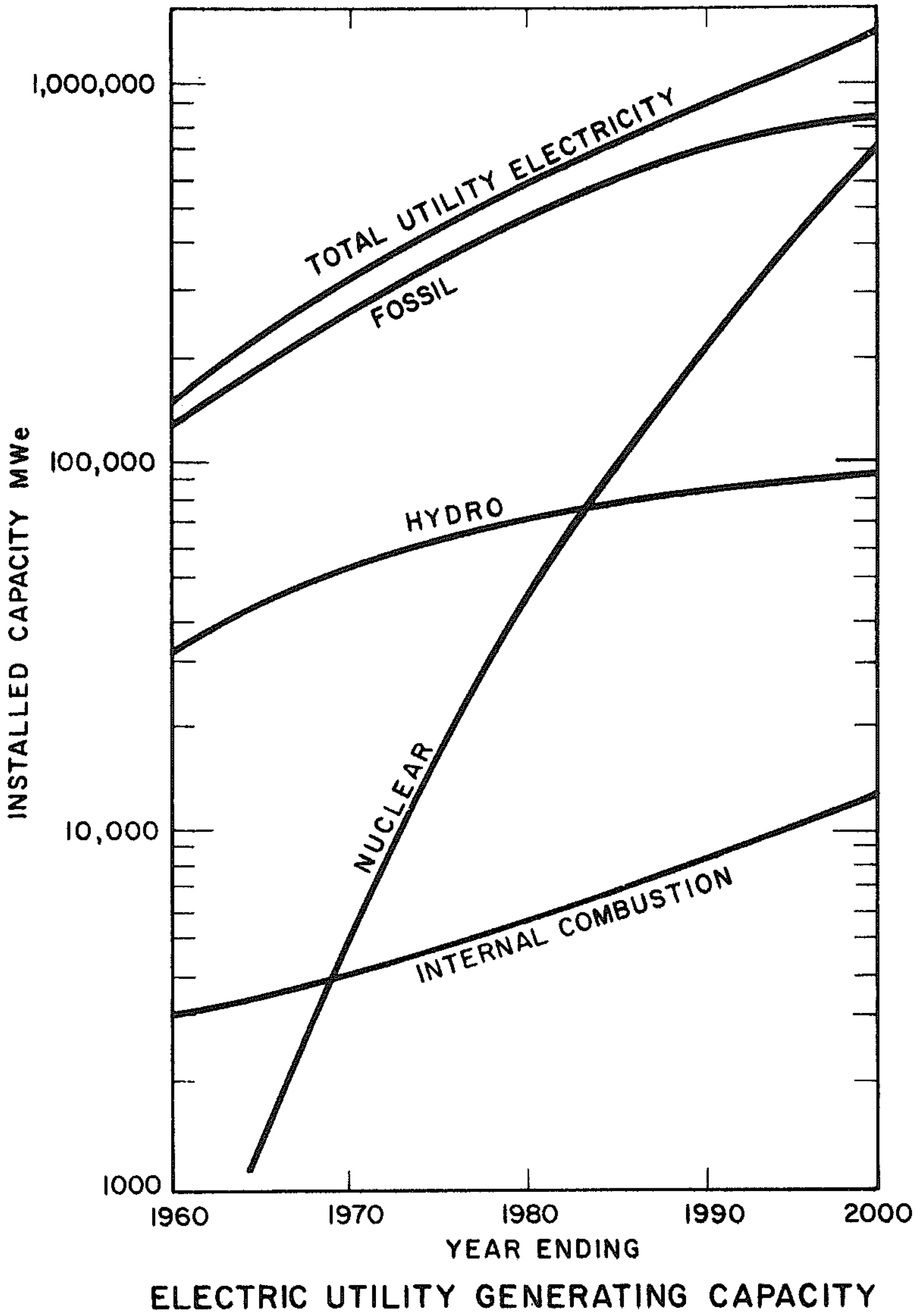

1,000,000
100,000
10,000
1000
INSTALLED CAPACITY MWe
TOTAL UTILITY ELECTRICITY
FOSSIL
HYDRO
NUCLEAR
INTERNAL COMBUSTION
1960
1970
1980
1990
2000
YEAR ENDING
ELECTRIC UTILITY GENERATING CAPACITY

Figure 1

A breeder reactor refers to the type of reactor which, in addition to producing thermal energy, also produces additional fuel by, for example, the capture of neutrons in uranium 238 thereby creating plutonium 239. Since the supply of ^{238}U is very large (natural uranium is 99.3% ^{238}U, .7% ^{235}U), and it is actually possible to produce more fuel than is consumed, this concept promises a system with very low fuel costs. Since most concepts for breeder reactors utilize fast or high energy neutrons they are usually referred to as Fast Breeder reactors.

The AEC budget for Fast Breeder reactors has ranged from $48.3 million in fiscal 1967 to $88.3 million in 1969. In the private enterprise sector, more than $100 million had been invested, by January 1969, in Fast Breeder research, development and construction. Westinghouse plans a $50 million corporate investment in liquid-metal Fast Breeder reactor work during the next three years, and General Electric and Babcock and Wilcox are also expanding their interest in Fast Breeders (1).

The problem with Fast Breeder reactors is one of solving the many engineering difficulties facing the construction of an economic power producing reactor.

With a limited budget, the United States program has moved rather slowly at first in order to avoid wasted effort on uneconomical systems. The approach now being emphasized is the liquid metal cooled Fast Breeder. Much effort has gone into the selection and testing of possible fuel systems, and into the development of testing facilities such as the Fast Flux Test Facility (FFTF) at Hanford, which will cost almost $100 million. We are nearing the time when, in conjunction with the testing facilities now under construction, a demonstration project would provide much of the remaining information necessary for the commercial exploitation of the Fast Breeder concept.

Breeder reactors are very likely to be the answer to the earth's shortage of energy sources after fossil fuels (mainly petroleum products and coal) become less plentiful. Even with Breeders, however, the shortage of fertile material from which fissionable material can be bred may some day force us to develop machinery for extracting nuclear energy from more abundant material, such as water. In theory, the way to do so is by exploiting the nuclear fusion reaction, the principle of the hydrogen bomb.

Research and development has been underway for several years to find ways in which nuclear fusion can be controlled and harnessed for useful work, such as water desalination and pumping. The AEC budget for controlled fusion research has ranged from $21.7 million dollars in fiscal 1966 to a projected $28.3 million in 1969. It is worthwhile to note that the Russians are spending twice this amount on fusion research.

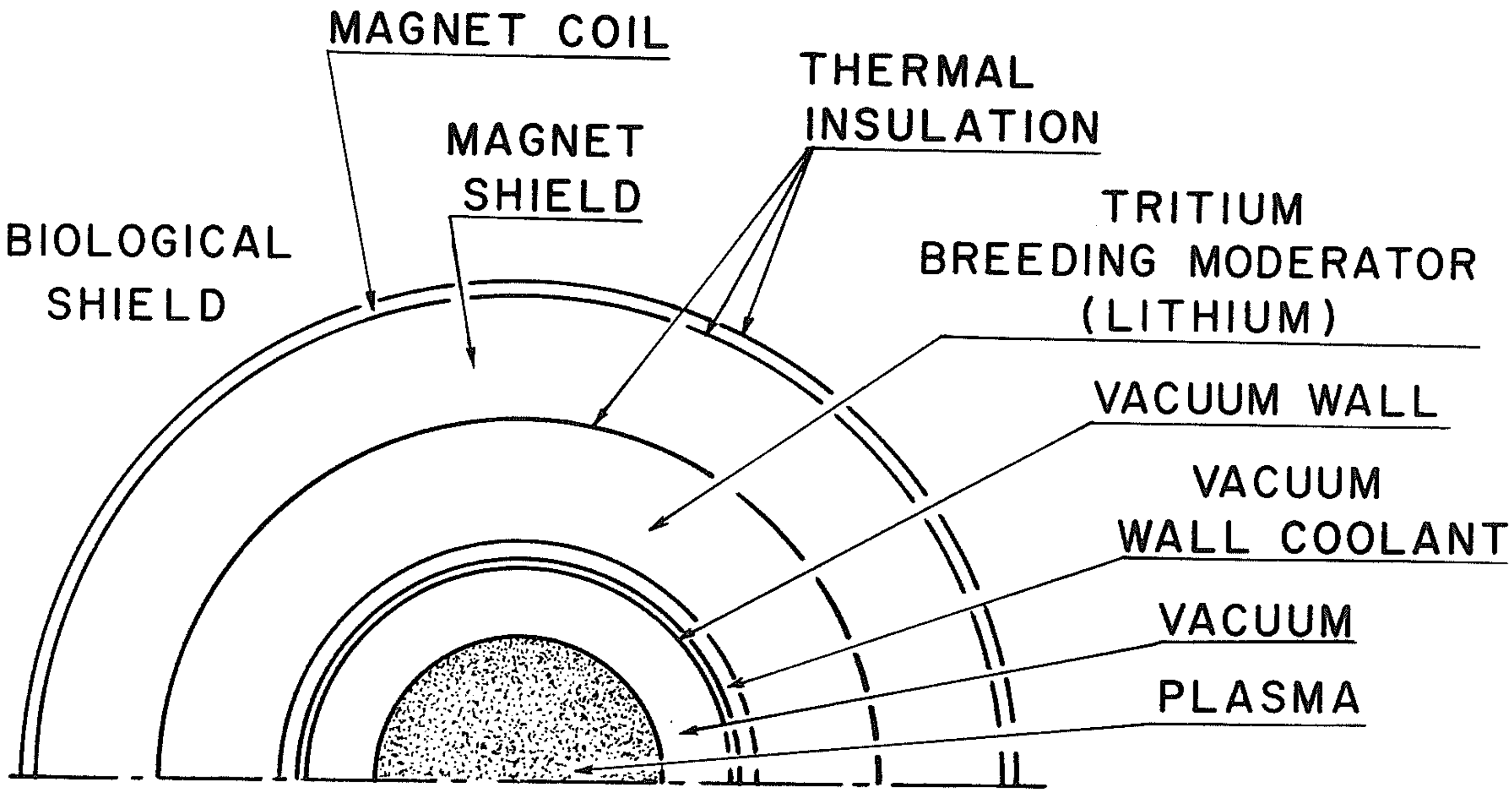
As an example of interest from the private sector, private support for similar research at the University of Texas is running at $400,000 per year (3) --evidence that the utilities consider controlled fusion a good potential energy source.

The problem with fusion research, as with so many areas of science, is not with the science itself but with its application. The reactions are known; the problems involve maintaining the required high temperatures and pressures necessary to sustain the reactions. The approach which seems most promising is to heat and compress the deuterium-tritium plasma with a strong magnetic field. So far this has been successful only on a laboratory scale, for short periods of time. Research directed toward extending the reaction times so that power can be extracted ultimately on a commercial scale is being carried out at several laboratories in the United States, including Los Alamos. Factors involved in this effort are as follows:

> The basic physics problem is to demonstrate a process for extracting energy from a plasma of deuterium gas. A plasma is an ionized gas where all of the electrons have been stripped away from the nucleus.
>
> Deuterium is "heavy oxygen", or an isotope of hydrogen, having one extra neutron in the nucleus. To extract the energy, the deuterium must be heated to approximately 400 million degrees Kelvin. (The interior temperature of the sun is estimated to be 15 million degrees Kelvin). At this temperature, the only known way of containing the plasma is in a magnetic field and this has been done for brief periods.
>
> Deuterium exists in nature: for every 6500 atoms of regular hydrogen in water, there is 1 atom of deuterium.
>
> Each gallon of water (fresh or salt) will yield about 1/8 gram of deuterium. This amount of deuterium can be extracted for a cost of about 5 cents.
>
> The energy present in the 1/8 gram of deuterium is equal to the energy content of 300 gallons of gasoline.
>
> At the world's current rate of consumption of power, there is enough energy in the deuterium in the world's oceans to supply our energy needs for over 1 billion years.

Dr. Fred Ribe, a leader in fusion research at the Los Alamos Scientific Laboratory, predicts it will take 10 to 15 years to solve the physics problems involved in controlled fusion. Engineering problems, says Dr. Ribe, may perhaps be solved by the turn of the century. However, the expenditures for such engineering development will far exceed those involved in the physics research now under way.

One interesting fusion reactor concept (Figure 2) includes a lithium moderator in which tritium reactor fuel will be "bred" in a way roughly parallel to the breeding of fissionable fuel in fission



CONFIGURATION OF A CONCEPTUAL STEADY—STATE D-T FUSION SYSTEM

Figure 2

Fast Breeders. Neutrons from the fusion reaction will bombard the lithium, producing both useful heat and new tritium.

There is little room for doubt about the economic feasibility of desalting sea water in evaporators heated with nuclear energy, whether from fission or fusion reactions. Dr. R. P. Hammond, Director of the Nuclear Desalination Program, Oak Ridge National Laboratory, predicts that sea water can be desalinated for as little as 22 cents per thousand gallons (4). But there is great need for further study devoted to optimizing such factors as plant location and the proper proportion between desalting and electric power production. These are largely economic, rather than technological problems, but they are large. They deserve the close attention they are being given at the Oak Ridge National Laboratory and elsewhere. Figure 3 shows an artist's concept of a dual-purpose plant for desalting sea water and for power. The large building near the sea water intake houses a 250 million gallon per day evaporator. The sphere contains the nuclear reactor steam supply, and the other buildings house the power station and the sulfuric acid plant used for pretreatment of the sea water feed stream.

The economics of such plants has been studied intensively, and the conclusion most usually drawn has been that dual-purpose nuclear desalting and power plants will pay their way, especially if they are large.

In October 1965, an agreement was signed between Mexico, the United States, and the International Atomic Energy Agency, IAEA, which established the framework for the first study in which two emerging technologies, nuclear energy and desalting, were to be analyzed for the benefit of an arid region common to the two countries. Several cases were considered in the three-year study effort, including a case in which design and cost features were as follows: Water capacity, one billion gallons per day; electrical power capacity, 2,000 MWe; reactor size, 10,000 MWth; all costs to be based on a 1966-67 cost index; escalation beyond this cost base not included; nine to ten years required to plan, design, construct and place in operation after authorization to proceed.

Estimated capital operating and product costs are as follows, based on fixed charge rates of four and ten percent, thirty-year life: Capital cost range - approximately $850 million to $1 billion with present technology; advanced technology system 1990 (breeder reactor) - 20 percent less. Annual costs vary from $80 to $180 million. Water costs in 1980, 16 cents to 33 cents per thousand gallons; in 1990 6 cents to 10 cents per thousand gallons due to technology improvements. Electricity costs excluding transmission vary from 1.8 to 3.1 mills per KW hour. Breeder reactors projected for advanced plants in the 1990 period are expected to reduce electricity cost by .5 mills per KW hour (5).

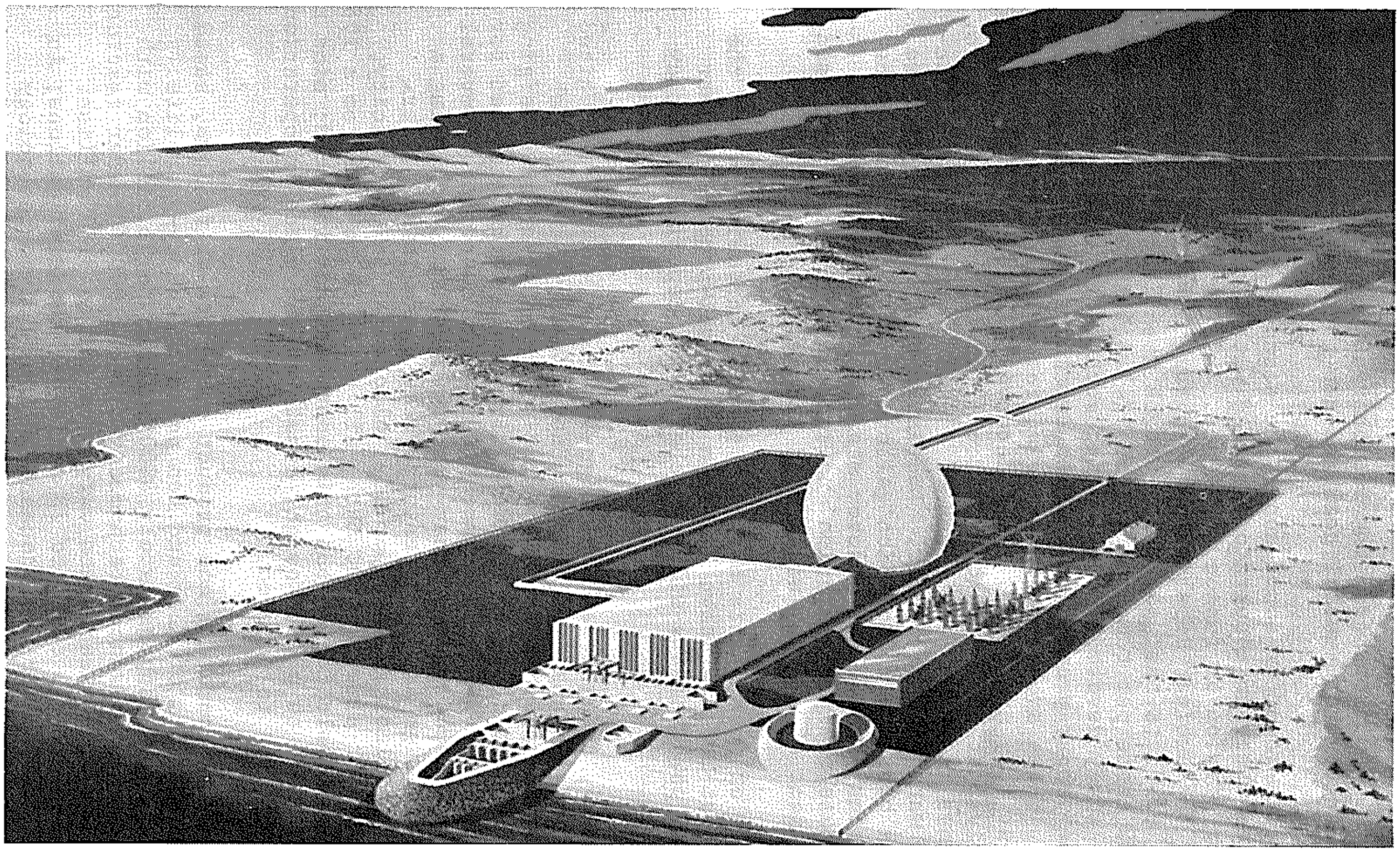


Figure 3

According to U. S. Atomic Energy Commissioner Wilfred E. Johnson, "Nuclear fuel when used in a light-water reactor produces heat in the boiler at a cost of about 14 cents to 20 cents per million Btu. . . Coal prices have tended to run higher than this and fall into the range of 25 cents to 35 cents per million Btu's." It is hoped that Fast Breeder technology will provide fuel costs in the order of 5 cents to 7 cents per million Btu's. Mr. Johnson continues, "The availability of low-cost nuclear energy will permit us to conserve our fossil fuels and reserve them for more vitally needed functions, such as transportation and the production of chemicals and plastics. Low-cost nuclear energy can also provide us with the process heat required for desalination and for the purification and recycling of water" (6).

So much for the usefulness of nuclear reactors, with their rather slow release of atomic energy. Is there any hope that their more violent cousins, the atomic and hydrogen bombs, can be made useful in equally peaceful ways? There certainly is.

The technology of peaceful nuclear explosives (PNE) is advancing rapidly. Project Gasbuggy in the recent past and Project Rulison in the near future were both designed to stimulate natural gas flow underground. Gasbuggy was a 26 kiloton explosion at a depth of 4240 feet. If it lives up to expectations (7), Gasbuggy will multiply the well's total yield by a factor of seven. Rulison will be 40 kt at 8500 feet. Project Sloop is scheduled to fracture underground copper ore beds in southeastern Arizona, and will pioneer PNE application for the mining industry. Once an underground chimney is formed and partially filled with copper ore rubble, dilute sulfuric acid will be added to the rubble to leach the copper from the rock. The pregnant liquor will then be pumped to the surface for extraction of the copper.

Certain PNE applications are exceedingly attractive from the economic point of view. A ton of TNT costs something like $1000, as against the AEC projected charge of 35 cents for the equivalent potential in thermonuclear explosives --if one buys the explosives in megaton amounts. Figure 4 shows the AEC projected prices, which include the services of an arming and firing team. The price of 35 cents per ton of explosive yield is based on the $500,000 price for two megatons. At that end of the scale, nuclear explosive is about 3600 times cheaper than TNT. As the figure shows, however, the nuclear advantage decreases for smaller shots. For half a megaton, nuclear explosive is only a thousand times cheaper, and for 20 kilotons, only fifty times cheaper. Even in such small sizes, however, the nuclear advantage over conventional explosives is large enough to make it seem very likely that PNE will find many applications in water supply development.

One interesting study of such applications is sponsored by the Arizona Atomic Energy Commission in cooperation with the University of Arizona. Its preliminary report (8) describes a potential site investigation for the following projects:

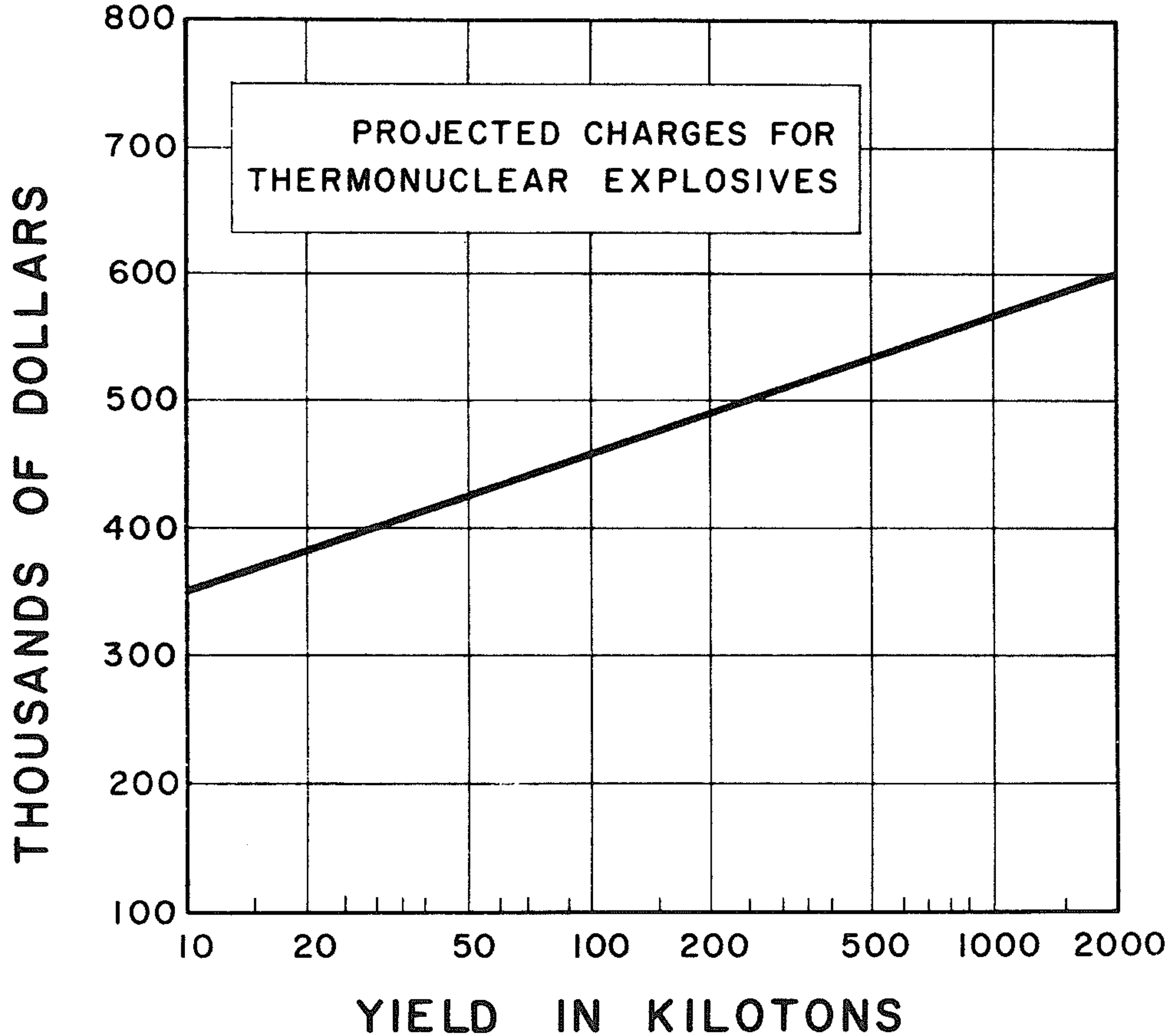

PROJECTED CHARGES FOR
THERMONUCLEAR EXPLOSIVES
THOUSANDS OF DOLLARS
800
700
600
500
400
300
200
100
10
20
50
100
200
500
1000
2000
YIELD IN KILOTONS

Figure 4

1. Development of ground water reservoirs and conservation of streamflow.

2. Development of ground water from low yield aquifers.

3. Combination system --recharge of streamflow and low yield aquifers.

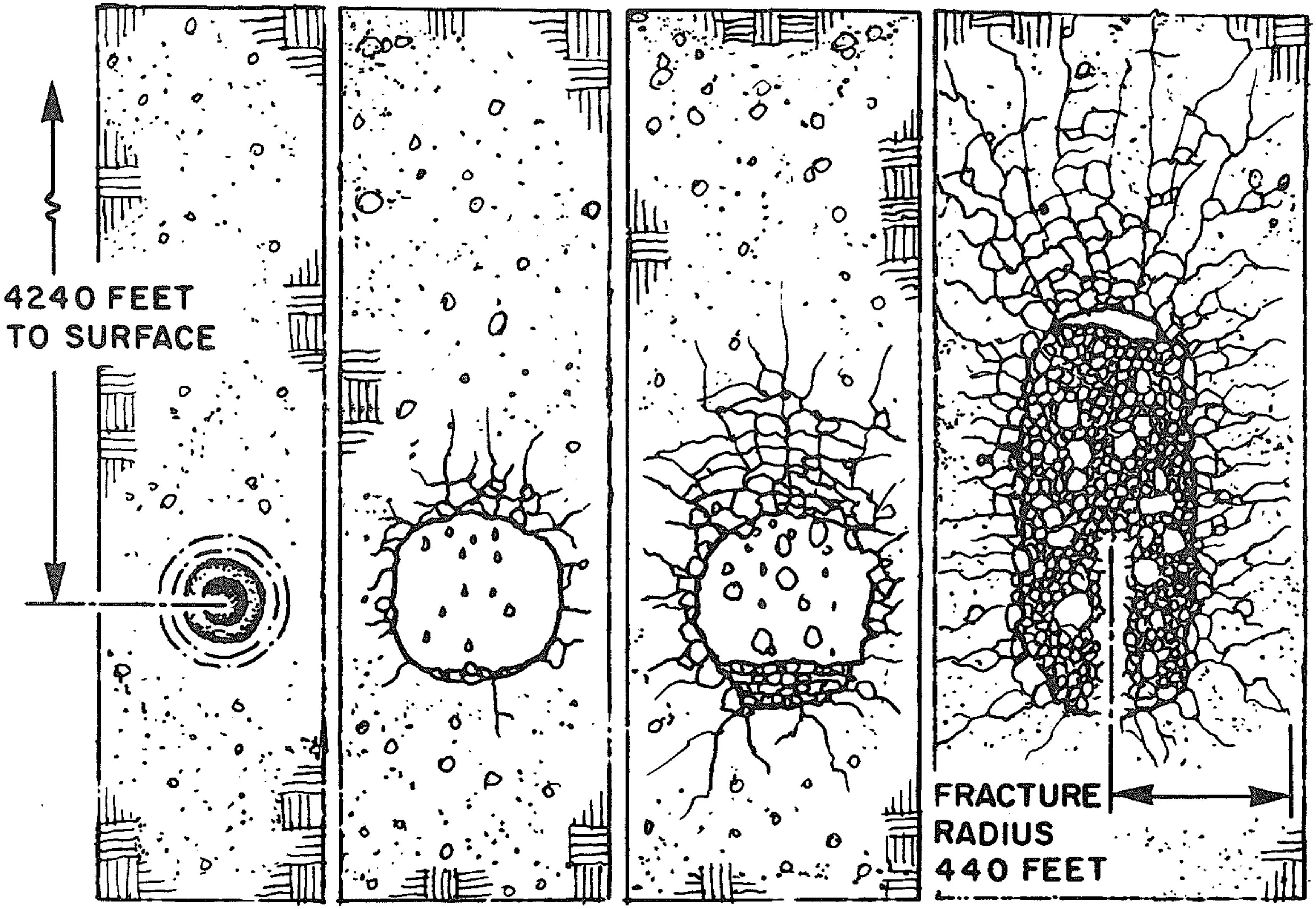
4. Development of surface reservoirs for water storage.

Figure 5 demonstrates a possible application for PNE. This shows what happens at four successive stages after the underground detonation of a nuclear charge -- specifically a charge of the same yield and depth used in Project Gasbuggy. The first stage, shown three microseconds after firing, is the one in which an expanding sphere of high-temperature gas --mainly vaporized rock-- creates a spherical cavity underground. The second stage, 500 microseconds later, shows condensed material (molten rock) falling to the bottom of the cavity. (Note the fracture lines in the surrounding rock; these fractures can be useful.) The third stage, a few seconds to a few hours after the blast, is a time of collapse, when the weakened rock forming the ceiling of the cavity breaks loose and falls. This falling process goes on (depending on the nature of the rock, the size of the charge, and other factors) until the final configuration, or chimney, shown at right in the figure, has been reached. It is easy to imagine situations in which underground fracturing like this, especially with the creation of a large chimney of highly permeable rock fragments, might serve purposes related to improved water supplies.

On the earth's surface as well, when the several political, social, and ecological problems are solved, PNE will become quite useful. Figure 6 shows how a row of craters, created by nuclear detonations, can form a vast canal, useful for navigation or water transport or both.

A year ago this month, at the Nevada Test Site, five nuclear charges of 1 kiloton each were used to dig a ditch 65 feet deep, 255 feet wide, and 855 feet long. Several single cratering experiments were also made, including Project Schooner, last December 8, in which a 35 kiloton charge created a crater 270 feet deep and 800 feet across. Such experiments have amply demonstrated that nuclear explosives can be handled safely.

Nuclear energy, both from reactors and from explosives, can become an important tool in the achievement of water abundance. By means of the proper use of this tool, many arid regions of the world can eventually acquire the water they need.



FOUR STAGES OF CHIMNEY FORMATION

Figure 5

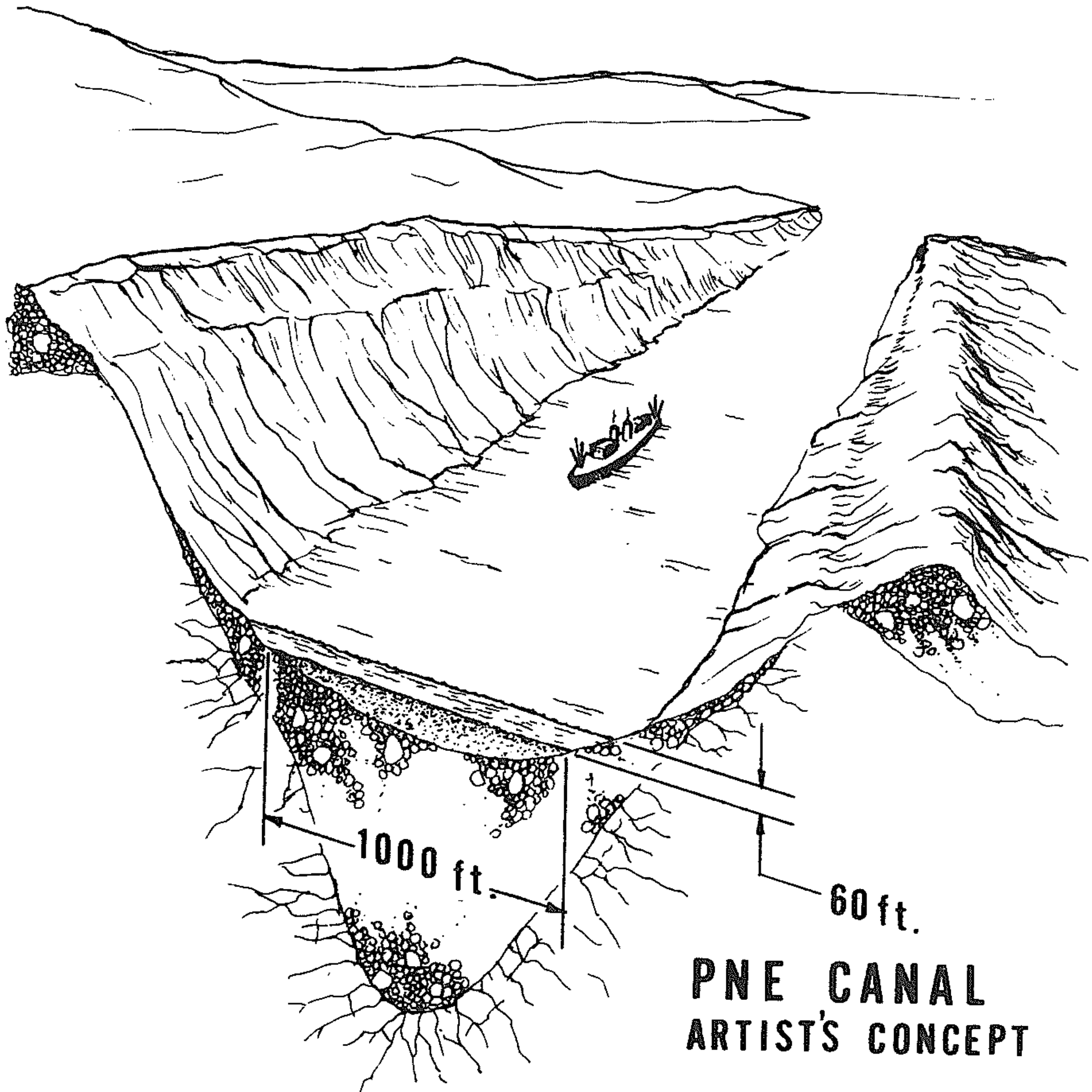


Figure 6

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3. Nucleonics Week, Vol. 10, No. 10, March 6, 1969.

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5. Nuclear Power and Water Desalting Plants for Southwest United States and Northwest Mexico, TID-24681, U. S. Department of Commerce, September 1968.

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WATER POTENTIALS OF WEATHER MODIFICATION

Jesse V. Lunsford[1/]

INTRODUCTION

Weather modification is a term that refers to the alterations of any of several physical dynamic processes that occur naturally in the atmosphere. It includes hail suppression, cyclone deterioration, fog dissipation and precipitation augmentation. It is the latter that will be discussed in this paper.

Vincent J. Schaefer (1) and Irving Langmuir at the General Electric Laboratories in Schenectady, New York, demonstrated that certain types of storm systems produced more rainfall when seeded with dry ice. Bernard Vonnegut (2) used silver iodide crystals in his studies and concluded that they were more effective nucleants than soil particulates normally found in the atmosphere. Tor Bergeron (3), a Swedish meteorologist, and Walter Findeisen, a German physicist, determined that clouds would begin precipitation if they contained the right mixture of ice crystals and super-cooled water drops. The exact mechanism by which raindrops or snowflakes are produced from tiny cloud droplets or ice particles is not fully understood.

Cloud Physics

The clouds that produce appreciable precipitation are formed when moist storm systems are forced to rise either by topographical features or by interaction with a colder air mass. The rising system is cooled by expansion and billions of tiny water droplets are formed.

These droplets are extremely small, their diameters ranging from 1×10^{-5} to 1×10^{-3} centimeters, and are too light to be effectively removed from the clouds as precipitation. The buoyancy force due to air turbulance and the gravity force are approximately equal. Thus an additional process must occur to form water drops large enough to fall from the cloud and reach the ground without evaporating.

In the ice crystal process the cloud must exist in a temperature regime colder than freezing so both ice crystals and super-cooled water drops will be present. The vapor pressure over the ice crystal is less than over water, so the ice crystals will grow at the expense of the water drops.

Extensive laboratory research has conclusively shown that water vapor requires a nucleus of solid matter about which to freeze if the temperature is warmer than -40°C. The freezing nuclei are quite

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variable in their behavior and their numbers may vary a thousandfold or more from day to day and from place to place. The natural nuclei are dusts,or combustion particulates. The particulates are unable to serve as freezing nuclei until the temperature has fallen to some value much colder than freezing. Each type of particulate has its own specific freezing value.

Precipitation augmentation depends upon using artificial nuclei such as silver iodide to provide the proper nuclei concentration and a warmer freezing temperature. Figure one (4) indicates the theoretical relationships between elevation, temperature and type of freezing nuclei. Water content of Zone A can be affected by silver iodide nucleation while water in Zone B will remain unaffected.

Practical Application

In 1952, Dr. Irving P. Krick, (5) a meteorologist, initiated a contract with the City of Dallas, Texas to augment their municipal water supplies. He used ground based silver iodide generators and claimed a 40% increase over a period of two years. In 1953 and 1954 he claimed an increase of 23,000 acre feet for Oklahoma City at a cost of fifty cents per acre foot.

In 1961 the U. S. Congress (6) appropriated $100,000 and commissioned the U. S. Bureau of Reclamation to initiate concentrated laboratory research in the physical processes of precipitation. In 1964 the Bureau of Reclamation started a series of research programs in outdoor laboratories. Contracts were made with several universities and private corporations for the actual research programs. New Mexico State University (7) presented a proposal to the Bureau of Reclamation for a feasibility study within the Rio Grande Basin in 1965. The study indicated the Jemez and Sierra Nacimiento mountain ranges near Cuba, New Mexico were suitable as an outdoor experimental project. The Bureau of Reclamation requested, received and funded a three-year research proposal for study, design, establishment, operation and evaluation of the precipitation augmentation program in New Mexico.

The research area is bounded on the west near Cuba, on the north by Coyote, on the east by the Baca Location and on the south by Jemez Springs (Figure 2).

The primary purpose of the New Mexico engineering research program is to develop and use precipitation augmentation and management procedures to increase the quantity of celestial waters that can be contained and used for beneficial purposes within the Rio Grande Basin. In addition, the technology developed in this specific basin can be integrated with the technologies developed from other research projects within "Project Skywater" to allow the creation of a national program to enhance the nation's total water resources. The region offers the opportunity to develop techniques for precipitation augmentation where water supplies are very critical and where the physical constraints enhance the probability of a successful program.

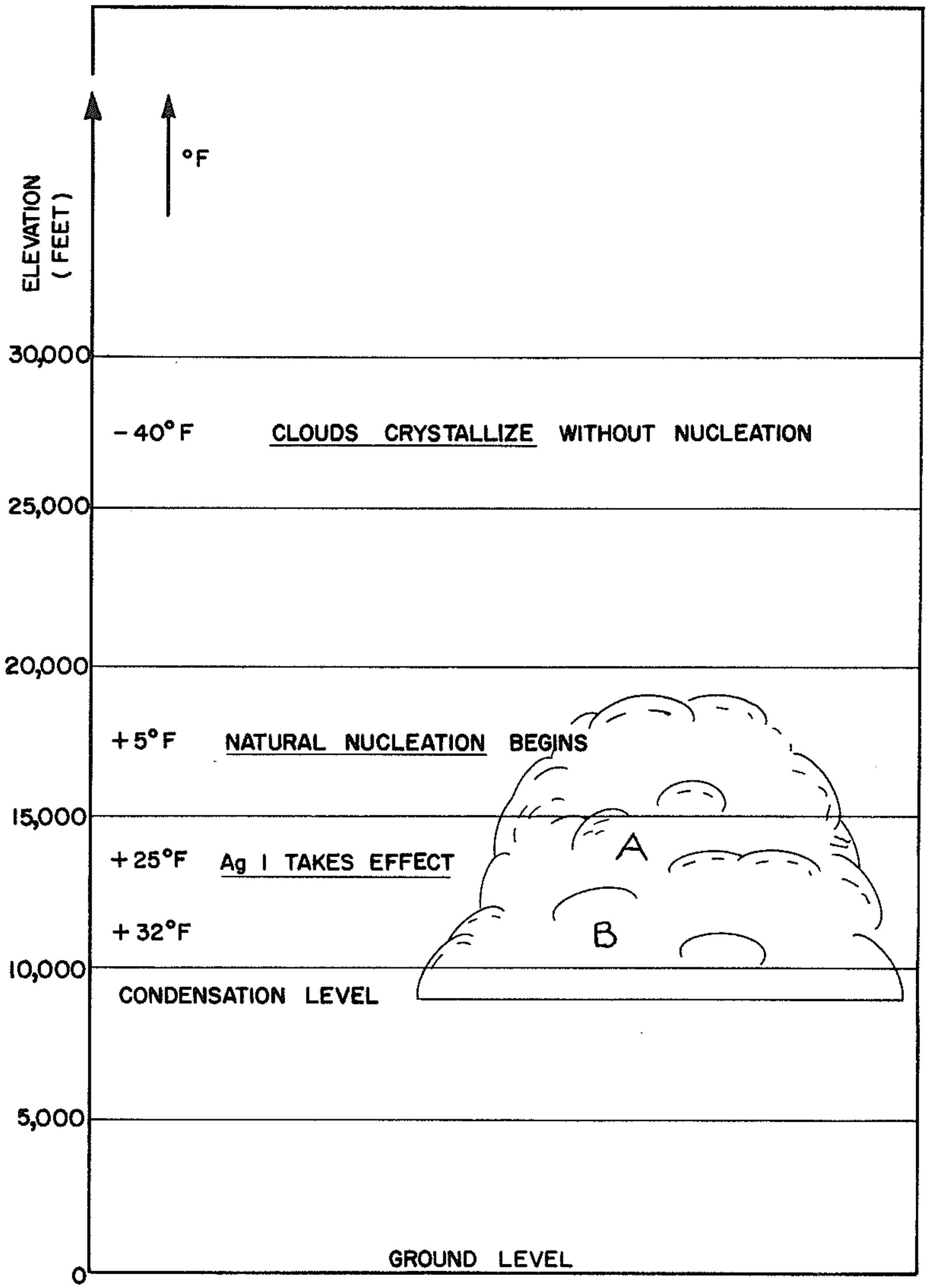

FIGURE 1 NUCLEI TYPE AND TEMPERATURE INTERACTION (4)

The drainage basin is very well defined and contains approximately 350 square miles. The climate, hydrology, geology, and logistics are very unique in the New Mexico program.

A research and experimental program to objectively manage precipitation augmentation from winter orographic snow storms must include the following components:

A. A statistical design that will determine the experimental units, and procedures for data collection and analysis.

B. A scientific study of the meteorological parameters to determine treatability of natural storm systems.

C. An adequate treatment delivery and measurement system.

D. An adequate terrestrial precipitation measurement system.

E. Adequate support facilities, such as, transportation, communications, radar, radiosonde releasing and tracking, and emergency shelters.

F. Cooperative work agreements with other state and governmental agencies (U. S. Forest Service, U. S. Soil Conservation Service, U. S. Atomic Energy Corporation, U. S. Geological Survey, New Mexico Engineer Office, New Mexico Fish and Game Department).

G. A good public relationship with the citizens of the experimental area and its environs.

H. A comprehensive analysis system to evaluate data within a reasonable time.

I. Sufficient funds and personnel to adequately complete the experimental program within a reasonable time.

The New Mexico Project has been involved in the development and implementation of each of these components. The amount of effort expended has been limited by a lack of scientific personnel (Meteorologists), transportation facilities, precipitation and ice nuclei measuring equipment, and finances.

Each of the components of the program will be discussed briefly to enhance clarity of purposes and procedures.

The statistical model is completely randomized and employs separate target and control areas. Differences between precipitation effects produced naturally and artificially are analyzed. This model has been used by the research group at Colorado State University and has been proven to be very efficient.

The primary objectives of the statistical evaluations have been directed towards the following:

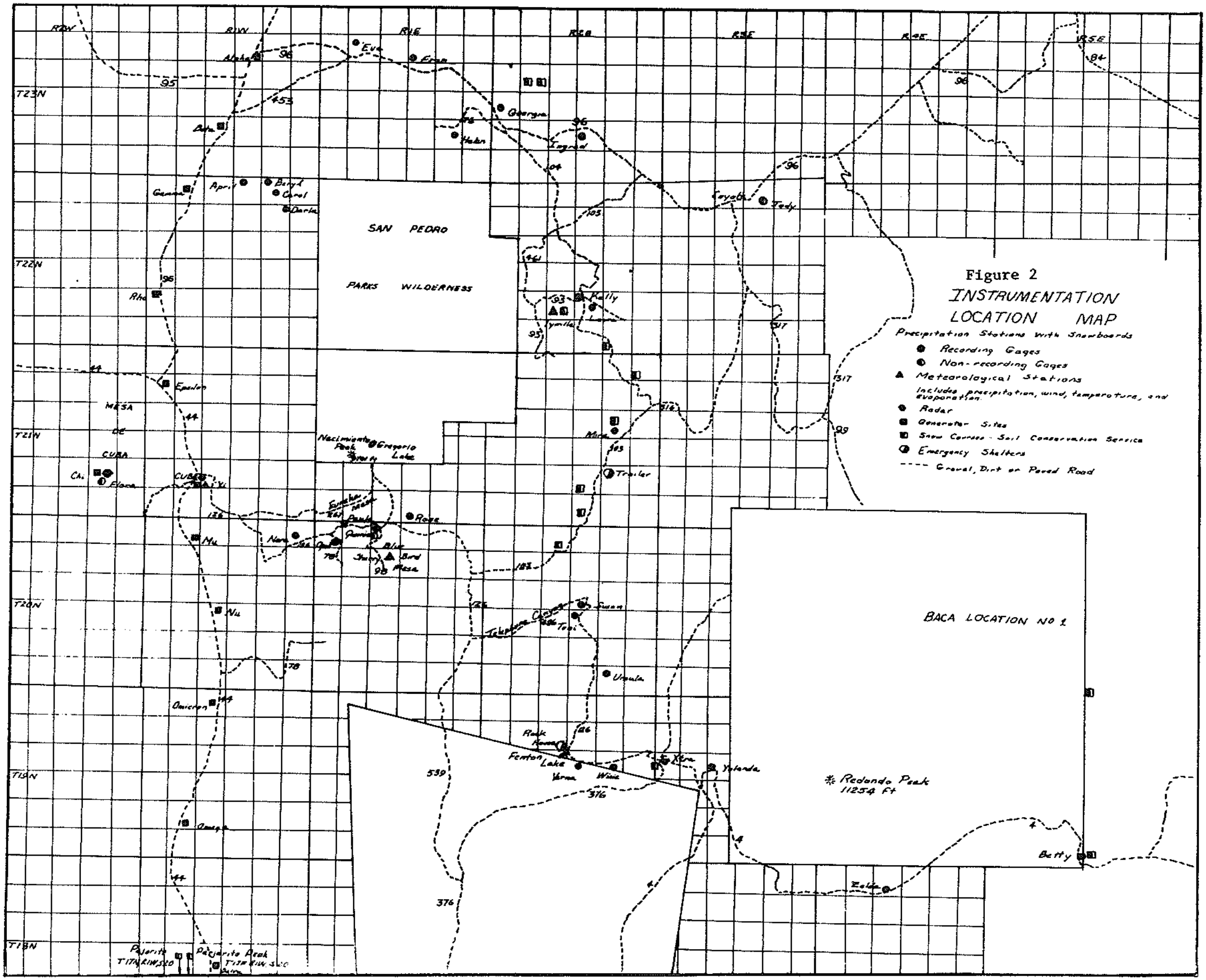

Figure 2
INSTRUMENTATION
LOCATION MAP

1. To determine if there is an increase in the winter snow precipitation as a result of cloud seeding operations in the Jemez and Sierra Nacimiento Mountain Ranges. If so, what is its magnitude?

2. To determine if there is an increase in the flows of the Jemez Springs River as a result of cloud seeding in the watershed.

3. To determine if secondary effects have been initiated "down wind" from the cloud seeding operation in the target area. (Sangre de Christo Range).

Other evaluation methods will also be considered and investigated as the program progresses. Some of the methods are listed below in brief qualitative form:

1. Correlation between average precipitation (day, week, month, storm period, etc.) on the target and control areas.

2. Precipitation patterns in the target area will be correlated as a percent of normal of the adjacent areas.

3. Steamflow correlation studies.

4. Times Series Analysis.

A research and field experimental program just include a continued analysis of the types and classes of storm systems. Experimental prediction models must be developed for reliability and accuracy of weather forecasts. The New Mexico Project has personnel and equipment for locating and tracking storm systems as they approach and pass over the experimental area. Measurement of specific meteorological parameters are made to determine suitability for modification. These parameters are: winds aloft, temperature, relative humidity, pressure, natural nuclei concentrations and elevations of top and bottom of cloud system.

The nuclei delivery and measurement system is one of the most difficult components of the program. Five artificial (CSU Modified Skyfire) nuclei generators and one (NCAR) portable and acoustical nuclei counter are being used. Twelve generator sites and one mobile generator unit have been used near Cuba, New Mexico on Highways 44 and 96 as shown in Figure 2. The generators operate on a variable pressure system and can deliver from 0.2 to 0.4 gallons per hour of a 2% solution of AG I in acetone. A series of diffusion studies have been made to determine the longitudinal axis and band spread of the Ag I plume from each generator site. Vertical movement of plume has to be measured by kites or airplanes. Figure 3 indicates the ground level diffusion pattern for generator sites and wind direction shown. The winds aloft that accompany snow storm systems for our project usually come from $270 \pm 20^{\circ}$.

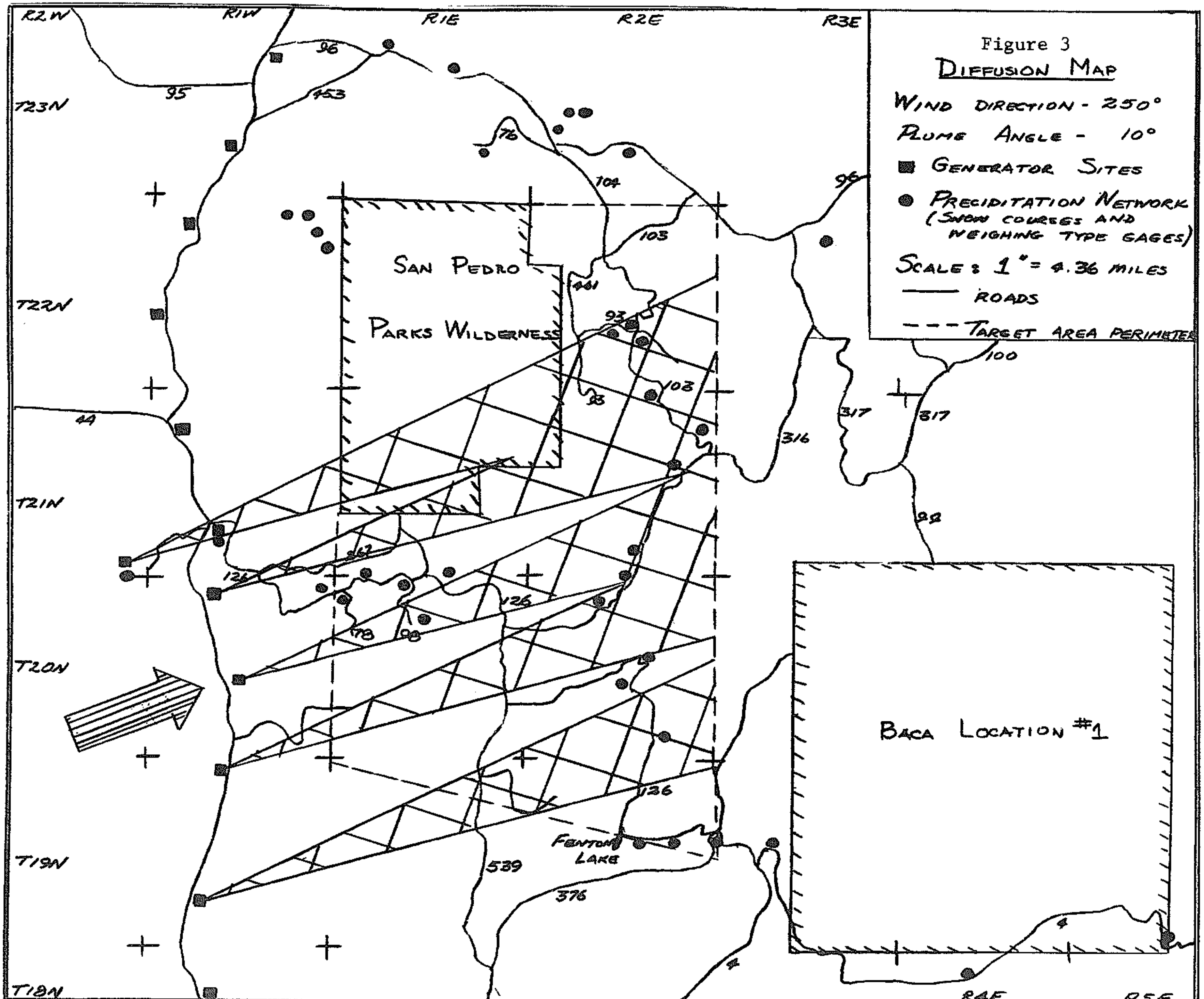
Figure 3
Diffusion Map
Wind direction - 250°
Plume Angle - 10°
Generator Sites
Precipitation Network (Snow courses and weighing type gages)
Scale: 1" = 4.36 miles
Roads
Target Area Perimeter
San Pedro Parks Wilderness
Baca Location #1
Fenton Lake
R2W
R1W
R1E
R2E
R3E
R4E
R5E
T23N
T22N
T21N
T20N
T19N
T18N
96
95
453
76
104
103
461
93
100
317
316
44
126
98
539
376
4

Precipitation on the ground is measured and used as the criteria to evaluate the efficiency of the project. Twenty-five recording snow precipitation gages have been installed to create a grid pattern within specific drainage basins and to present a spectrum of elevations. The locations are shown on Figure 2. A snow board and a snow pole are located adjacent to each recording precipitation station. They are used to provide additional independent measurements of total precipitation and precipitation per storm period.

The Soil Conservation Service has completed the installation of 12 snow courses within the target area and environs. Information received will be autocorrelated to provide an independent method of determining effects of seeding select storm systems. A snow pillow and attendant instrumentation has been located near an emergency trailer house on Road 103 to provide a secondary method of measuring precipitation rate and accumulated snow fall.

Adequate support facilities of radars, transportation, communications, living quarters and office facilities have been provided to assure an effective and safe operation.

A Wilcox 890 Series Radar is located on Cuba Mesa to locate intense storm cels (50Km), to track same, to measure antenna elevation angle, and to record time of day and day of month. A time-lapse camera has been mounted on the PPI scope for post-time analysis of storm systems.

A T9 Tracking radar unit is located at the Cuba highway yard and is used to track balloons and tin foils in special diffusion studies.

A contract has been made with the Director of the Physical Plant Facilities to lease two 4-wheel drive and one 2-wheel drive trucks. These vehicles have been fitted with wenches, special tires, canopies and emergency supplies. Road 103 and the interior of Road 126 are passable with a 4-wheel drive truck except for the period of January through March. A snow-kat is available on a cooperative basis from the U.S. Conservation Service, Snow Survey group. Two ski-doos and a portable trailer have been purchased and are used for servicing gages located off the main roads.

A complete radio communication system has been purchased and a unit has been installed in each vehicle and at the main office in Cuba. A relay station has been installed on Blue Bird Mesa. Two portable radios of the same receiving and sending frequencies are used in the ski-doos. All personnel make contact with the main office each hour on the hour. Safety of the personnel is of primary interest to all.

Two trailers have been located on the Cuba highway yard for personnel living quarters. Bunk beds, showers, refrigerators and cooking facilities are provided. The radar van on Cuba Mesa, a trailer on Road 103 and a rock house on Blue Bird Mesa have all been provided with emergency supplies, bunk beds and a stove.

In November 1968 the project personnel put the program into full operation. Fifty randomized yes-no envelopes were prepared and placed into the custody of the project engineer. The actual field seeding program has been initiated. The precipitation data can be analyzed on a year to year basis to determine snow fall rates, quantities and distribution on a storm and seasonal basis, however the determination of seed-no-seed snow fall differences require an accumulation of precipitation records for four to five years.

The project personnel were able to clearly define how many storm systems passed over the project area, how many of the units were seedable, the location of how many generators were needed, determination of plume axis and concentration of artificial nuclei in the storm systems were made, communications, transportation and all other systems performed quite well. As a qualitative measurement of artificial nuclei distribution, personnel have driven through seeded storms at ground level and have been able to detect a "concentration gradient wall" by eye and to confirm it by using the NCAR Nuclei Detector. Analysis of precipitation stations have also indicated the gradient effect.

The potential for increasing snow pack in selected areas by using artificial nuclei intelligently looks very promising. Dr. Lewis Grant (8) of Colorado State University has reported that he has augmented precipitation in the Climax Project by 10-80% in selected cases where temperature, pressure, relative humidity and winds were just right. Negative values were also obtained when seeding occurred during undesirable storm systems.

The scientific approach to precipitation augmentation will succeed, however, a total environmental analysis will have to be completed to determine its actual benefit to mankind. The long range plans of the New Mexico Project include ecological and sociological as well as economic studies of net benefits.

THE FUTURE OF SUBSURFACE IRRIGATION: A METHOD OF SAVING WATER

Eldon G. Hanson[1/]

Research with subsurface irrigation at New Mexico State University has been accomplished under a Water Resources Research Institute project in cooperation with the New Mexico Agricultural Experiment Station. The research has been conducted jointly by the Agronomy Department and the Agricultural Engineering Department. Dr. Boyce Williams of the Agronomy Department has been studying mainly the influence of subsurface irrigation on cotton yield and fiber quality, and I have been working mainly with the engineering aspects of design and management of the system, and consumptive use of water by cotton.

For three years cotton was grown on a field containing eight sub-surface-irrigated plots which were interspaced with eight surface irrigated plots. All plots were 158 feet long and each plot contained half-inch perforated plastic pipe which was buried under each row to a depth of about 12 inches. These pipes were connected to a two-inch manifold header for each plot. A two-inch pipe with a meter was used to connect the headers to the main line of two-inch plastic pipe. The perforations in the half-inch pipe were 0.030 inch in diameter. They were made by a 0.030 drill in preference to a punch since previous tests in the laboratory showed that drilled holes produced more uniformity of flow.

The surface-irrigated plots were irrigated from alfalfa valves at the head of each plot. These valves received water from a 10-inch under-ground pipeline. Alfalfa valves were also installed for each sub-surface-irrigated plot to permit surface irrigation and leaching in the event that salt accumulated in these plots. A salt buildup near the ground surface was considered possible due to evaporation of capillary water flowing upward from the perforated pipe.

During the first two years there was no appreciable buildup of salt in the soil. Measurements for the third year have not been completed to date.

Figure 1 which was taken from a magazine shows an artist's concept of what subsurface irrigation looks like. It shows water squirting out of all the little holes in the perforated pipe. Actually, the pipe buried in the ground has soil pressed up against the holes and as the water comes out it flows through the pores in the soil. The flow pattern is approximately spherical as shown by the circular lines in Figure 2 if flow rates from perforations are low and water moves

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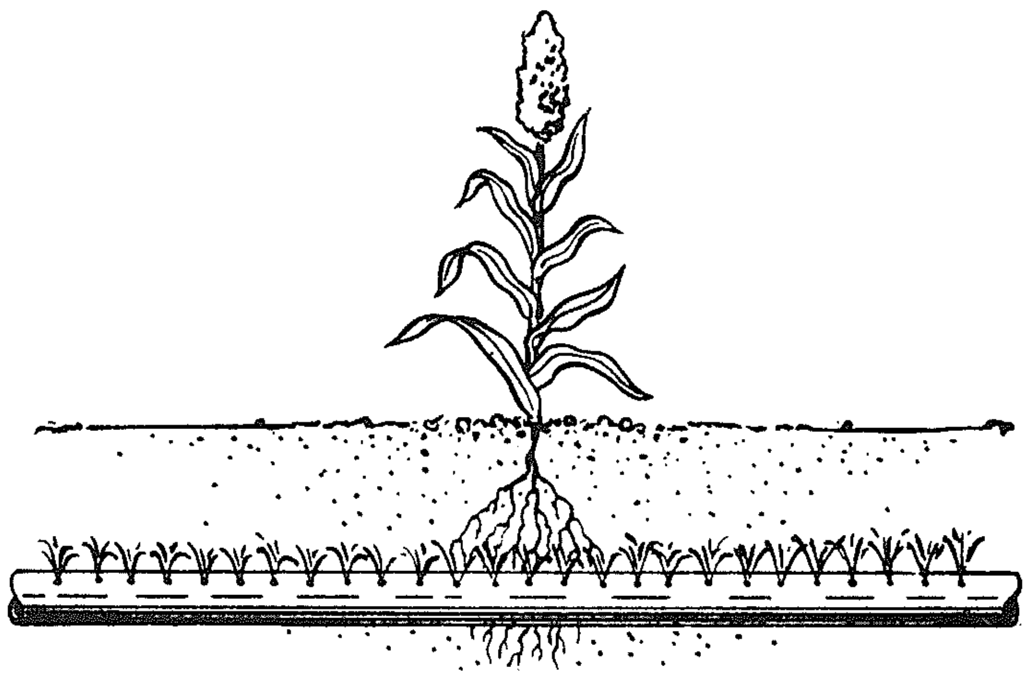

FIG. 1 ARTIST'S CONCEPT OF SUBSURFACE IRRIGATION.

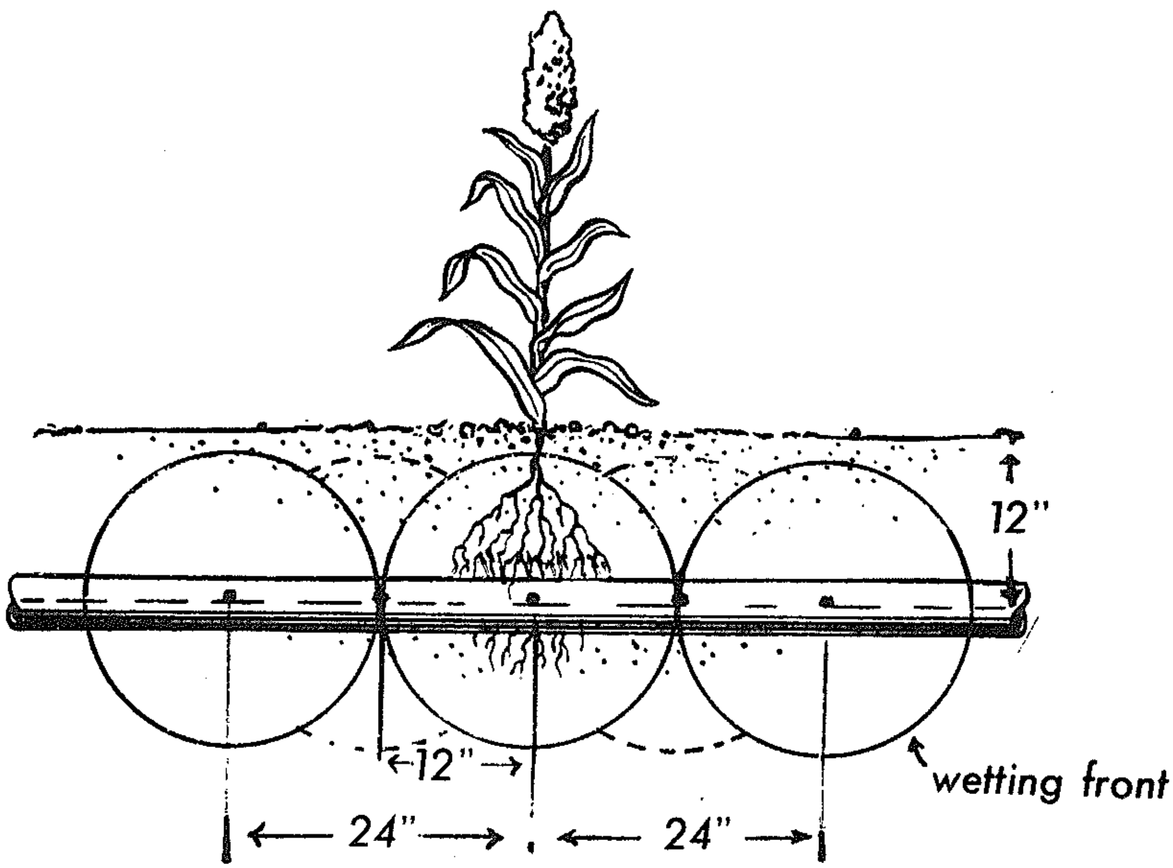

FIG. 2 WETTING FRONT OF SOIL MOISTURE MOVING BY CAPILLARY FLOW FROM PERFORATED PIPE.

through the soil by capillary flow. When flow rates through the perforations are in excess of the capillary flow capacity of the soil, the excess is pulled downward by gravity and may be lost below the root zone by deep percolation. To keep the soil surface as warm as possible at planting time and to minimize weed growth and salt accumulation at the surface it is desirable to keep the ground surface dry when irrigating with a subsurface irrigation system. With the perforations spaced 24 inches apart on a pipe placed 12 inches below the ground surface the moisture pattern would be somewhat as shown by the full circular lines in Figure 2 if capillary flow conditions prevail. There would be some unduly dry zones at the seed planting depth if the ground surface above each hole was kept dry. Because of this the spacing was reduced to 12 inches to provide more uniformity of wetting front at the planting depth near the ground surface as indicated by the broken circular lines in the figure.

This research was done on one of the slowest subbing soils in this area. In the area near Lubbock, Texas some subsurface systems have holes 40 inches apart and capillary movement appears to be satisfactory. However, that area is more humid and rains have helped to provide uniform moisture conditions near the soil surface at planting time. With the slow-subbing soil used in the local project, there have been problems of getting a complete and uniform stand on the subsurface plots each year. In order to have stands which were comparable to the uniform cotton stands on the surface-irrigated plots, surface irrigation water was applied to the subsurface plots to prevent skips. By putting some surface water on subsurface plots the differential between the treatments was somewhat reduced; but despite this, the yield for the first two years from subsurface-irrigated plots was significantly greater than that from the surface-irrigated plots. This third year it was decided to let the crop grow with the skips to see how the fields compared. The skips in the cotton on the subsurface plots are shown in Figure 3 and the cotton with complete stands on the surface irrigated plots is shown in Figure 4.

Each year the plants on the subsurface irrigated plots grew faster and the squares and boles developed earlier. This was particularly noticeable during the first year. By the time that the surface-irrigated plots had two squares the subsurface-irrigated plots had six squares. Table 1 shows cotton yields and inches of water applied for 1967 and 1968. The 1967 yields are also quite representative of the 1966 yields in that there was a significant increase in yield from subsurface-irrigation. The raw data for 1968 shows that 150 pounds more seed cotton was picked from the subsurface-irrigated plots despite the skips than was picked from the surface-irrigated plots. These data have not been analyzed for significance to date.

Measuring of water to the subsurface plots was accomplished by positive displacement meters on the lead-in pipe to the header of each plot. The meter is the type that is commonly used by cities to measure water to homes. Periodic tests have shown that these test meters have an error of

Fig 3 . Cotton stand with skips on sub-
surface irrigated plot. July 24, 1968

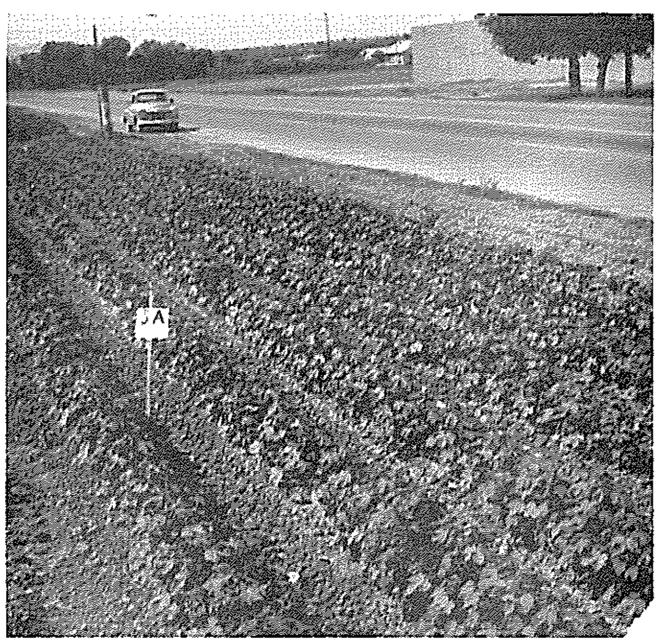

Fig. 4 Cotton stand with no skips on sur-
face irrigated plot. July 24, 1968

TABLE 1. COTTON YIELDS AND IRRIGATION WATER APPLIED TO SURFACE AND SUBSURFACE PLOTS DURING 1967 AND 1968

	1967 Treatments			
	Surface Irrigation		Subsurface Irrigation	
	Heavy	Light	Heavy	Light
Water applied, inches	33.7	28.7	33.2	29.6
Seed cotton, lbs/acre	3337 bc	3272 c	3906 a	3409 b 1/

	1968 Treatments			
	Surface Irrigation		Subsurface Irrigation	
	Heavy	Light	Heavy	Light
Water applied, inches	27.6	23.4	21.9	18.8
Seed cotton, lbs/acre	3339 2/		3494 2/	

1/ Treatments not followed by the same letter are significantly different at the five percent level of probability.

2/ Average yields by irrigation method. Data have not been analyzed by Heavy and Light treatments to date.

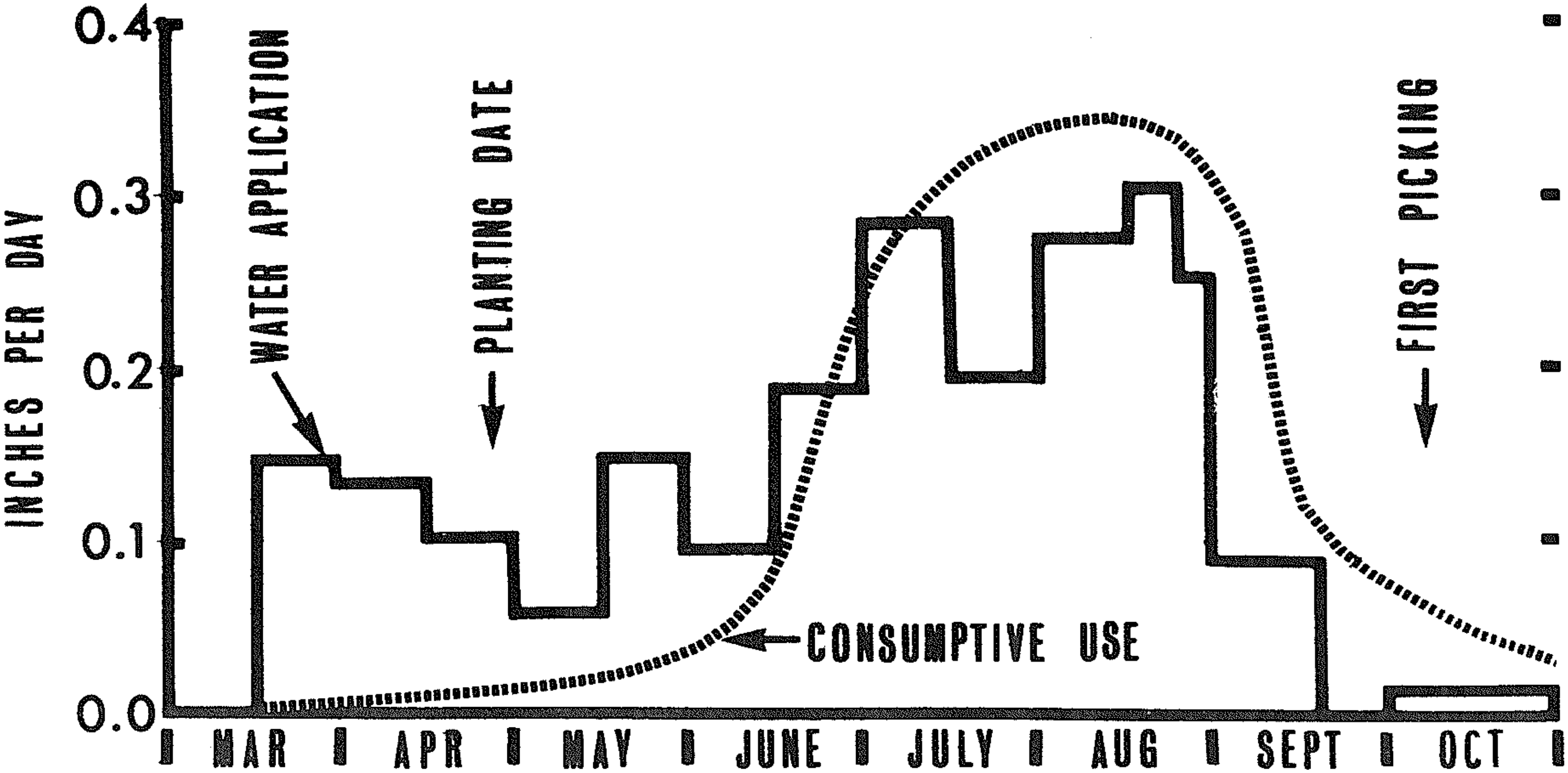

FIG. 5, CONSUMPTIVE USE BY COTTON AND RATES OF WATER APPLICATION INCLUDING PRECIPITATION, 1968 (SUBSURFACE, HEAVY TREATMENT)

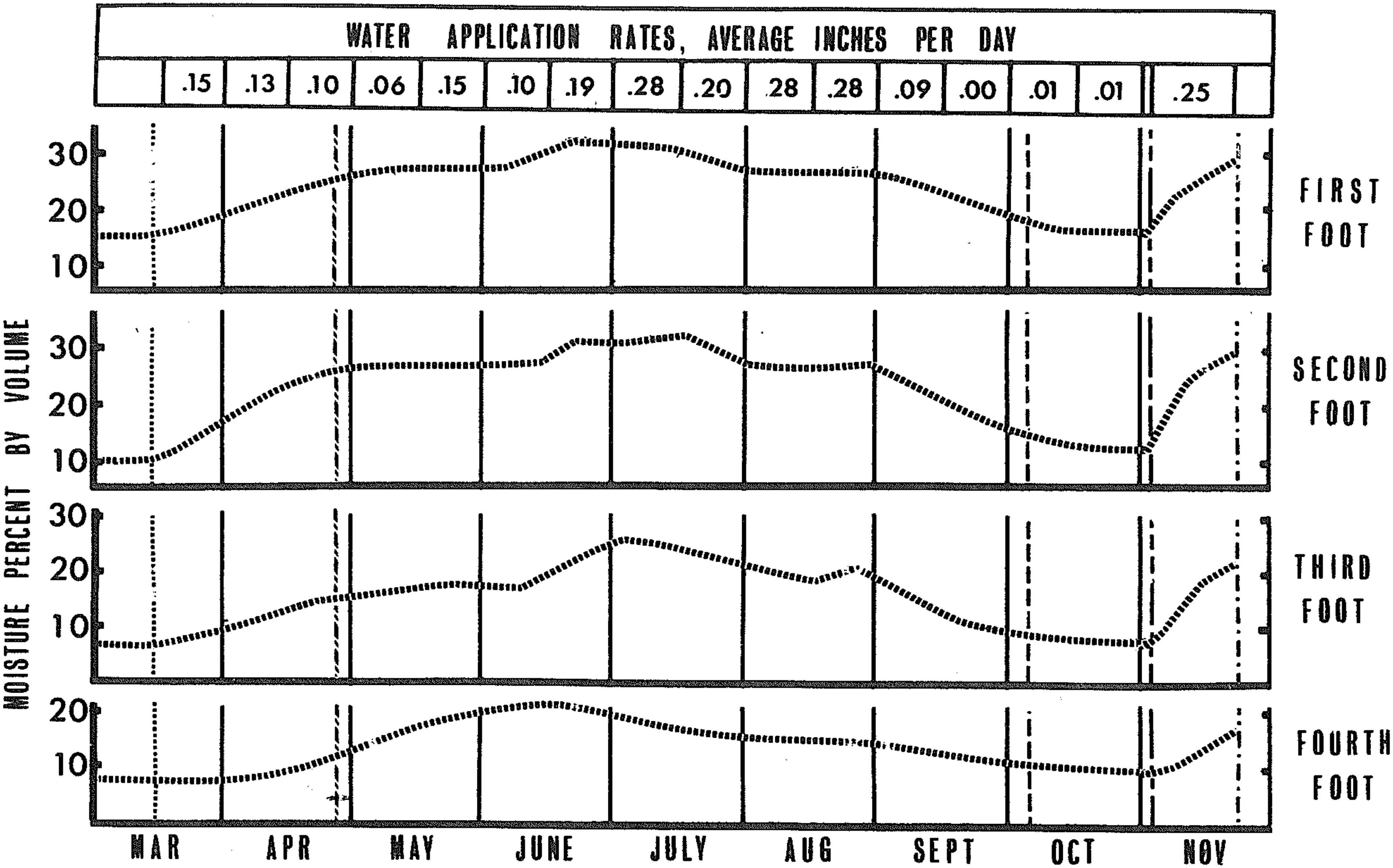

FIG. 6. SOIL MOISTURE VARIATION UNDER SUBSURFACE IRRIGATED COTTON, 1968

LEGEND: IRRIGATION STARTED ·········· PLANTING DATE
FIRST PICKING ———— LAST PICKING —·—·—
PRACTICE IRRIGATION ———

less than two percent. A Sparling meter in the 10-inch underground line was used to measure the water on the surface plots. The moisture levels in the soil were measured throughout the season with a neutron probe.

Dr. Williams will probably describe the fertilizer and irrigation treatments later, but I will briefly preview two irrigation treatments which are the "Light" Treatment and the "Heavy" Treatment. The plots designated for the light treatment had water applied in quantity sufficient to satisfy consumptive use. The plots designated for the heavy treatment received 25 percent more water than the place with the light treatment. See Table 1.

Figure 5 shows application rates to the subsurface plots in comparison to consumptive use. The preplanting irrigation commenced on March 15, about five weeks before planting. Water was applied at approximately 0.15 inches per day at the beginning of the season. The low application rate was selected to allow time for the water to sub up to the planting depth without having excessive deep percolation losses. A time clock was used to operate the pump for the subsurface system. Subsurface irrigation water was applied to the soil with the system operating 15 minutes during each hour or two throughout the day and night. The rate of flow was adjusted as needed during the season.

Figure 6 shows typical soil moisture levels in the upper four feet of soil in the subsurface irrigated plots throughout the 1968 irrigation season. Since water was being lost below the upper foot soon after March 15 as shown by the rise in the curves below the first foot, the application rates were reduced during April and early May to minimize deep percolation losses. The slow drainage downward continued until the consumptive use rate increased in June sufficiently to use the water as it was applied. Application rates shown in Figure 5 were maintained early in the season at rates higher than consumptive use until the latter part of June to assure that adequate moisture would be available in the upper foot while the small plants were extending their roots and becoming well established. After July 1 the application rate was held slightly below the consumptive use rate to permit the plants to draw slightly on stored soil moisture. Since the July - August period is the major time of fruiting, moisture levels were held high during these months. Only a slight lowering of moisture levels was permitted during August.

Figure 7 shows how soil moisture levels varied with surface irrigation during 1968. The solid black vertical lines represent dates of irrigation. Immediately before each irrigation the moisture level was low. The difference in moisture levels before and after irrigations represents the quantity of moisture stored in the soil during irrigations, and the difference in moisture levels between irrigations represents the quantity of moisture depleted.

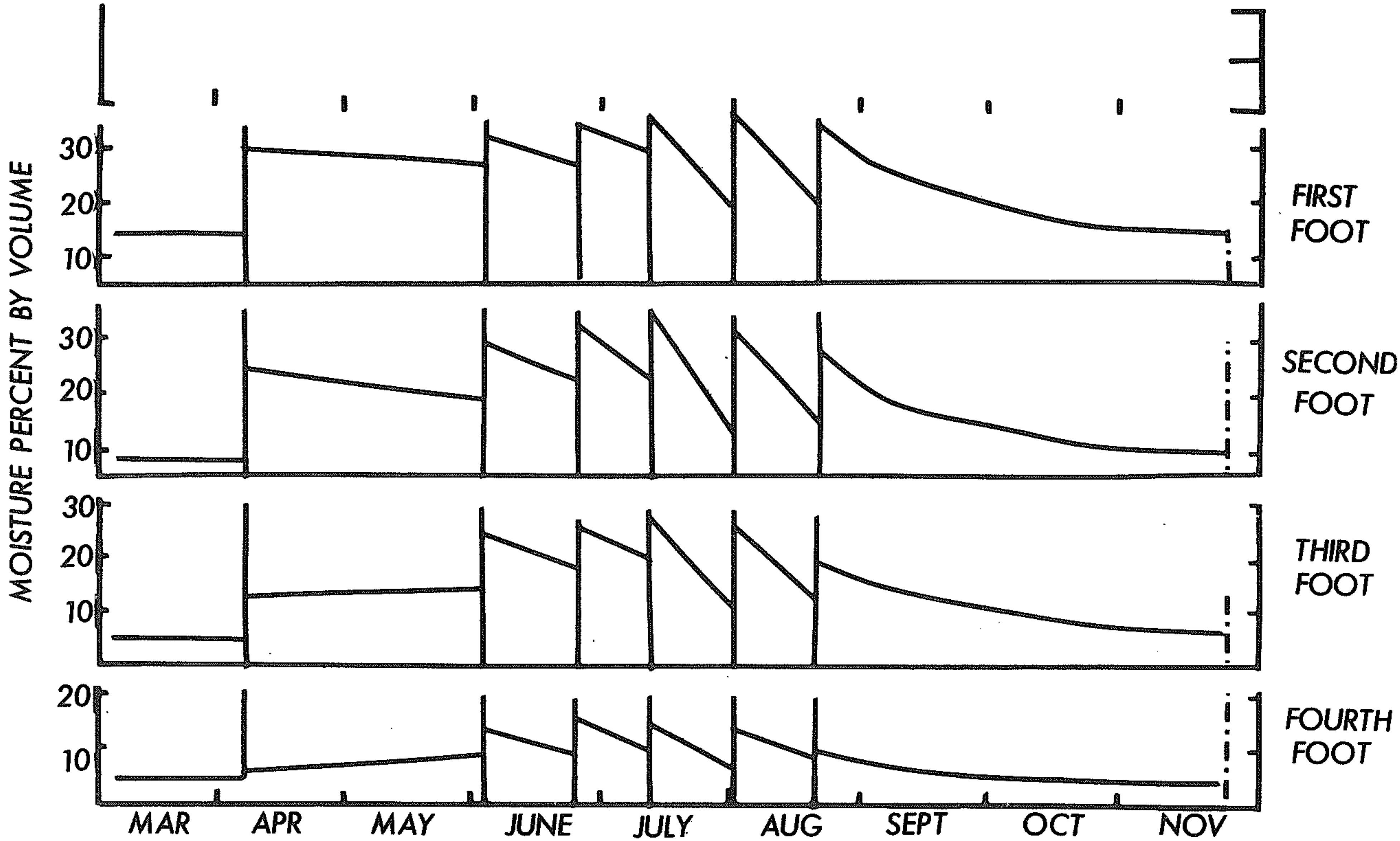

FIG. 7. SOIL MOISTURE VARIATION UNDER SURFACE IRRIGATED COTTON, 1968

Yesterday Governor Bolack mentioned that he learned from his research work that it was better to irrigate with one-half as much twice as often. One of the reasons for this is the up and down variation of the moisture percentage in the soil with ordinary surface irrigation. As the moisture level lowers between irrigations the soil moisture tension increases and more energy must be expended to remove the moisture from the soil. This condition is usually more pronounced in the upper part of the root zone where there are more roots, more organic matter and fertilizer and better aeration. These and other factors cause moisture depletion to be greater in the upper part of the root zone. Therefore a continuous supply of available moisture in the upper and most import part of the root zone is essential for high yield for most crops. By increasing the frequency of irrigations and applying less water each time, a buildup of soil moisture tension in the upper part of the root zone may be minimized.

When plants are wilting severely before an irrigation there is usually an ample supply of available moisture in the lower half of the root zone. Since the root growth in this zone is relatively sparse, the moisture cannot be moved sufficiently fast from the soil to the plant to retain plant turgidity. Moisture in the lower part of the root zone has some benefits to crop yield and will keep the plant from dying but it is not as effective for high crop production as the available moisture in the upper part of the root zone.

Subsurface irrigation as used in the project is somewhat of an extension of Governor Bolack's statement - "irrigate with half as much, twice as often." The subsurface plots have been irrigated a hundred times more often with less than one-hundredth as much each irrigation. These plots have had very light irrigations every hour or two, day and night.

Subsurface irrigation practices in the project have prevented almost completely up and down fluctuations of soil moisture as shown in Figure 6 during the months of June, July and August, when the consumptive use of water by the crop is the greatest.

Subsurface irrigation has other benefits besides those which have been presented. Weed growth on subsurface-irrigated plots has been considerably less than that on the surface irrigated plots. Subsurface irrigation also lends itself to automation. With the development of ways to make perforations or slits in pipe or other orifices with which clogging may be minimized, farmers will be able to irrigate extensive acreages by automatic controls at the pump. Sensors in the soil to measure tension may be used to turn the pumps on and off to maintain optimum moisture conditions.

Subsurface irrigation systems may be designed to apply water efficiently and place the water when and where it will be best utilized. The peak consumptive use rate for most crops in this area ranges from 0.30 to 0.40 acre-inches per acre per day. This represents slightly less than seven gallons per minute of water per acre. With subsurface pipes under rows 1000 feet long there would be approximately 13 lines per acre if rows are spaced at 38 inches. With continuous flow to satisfy consumptive use each line would carry seven-thirteenths of a gallon per minute with a pressure head loss of less than two feet of water. By using ori ices with an appropriate size to have the subsurface lines operate with 20 feet of head at the upper end and about 18 feet at the lower end, there would only be about five percent difference in the rates of discharge in the soil at the extreme ends. By using smaller pipe orifices and higher operating pressure heads the water application efficiency could be even higher than 95 percent.

During three years of operation of the subsurface irrigation system the operating pressure has gradually built up from five feet to slightly more than 14 feet of water. The increase has been unimportant with respect to the amount of pressure, but it is important in that it represents clogging in the perforations. Samples of pipe removed from the field have shown that about two holes in sixteen have become completely clogged and some of the remaining holes have been partially clogged. It is unlikely that these systems could be installed to operate for 10 to 20 years without unusual filtering requirements. In recent research by Davis in California with subsurface irrigation of potatoes, machinery has been developed with which half-inch plastic pipe can be planted and harvested with the potatoes. Under this practice the perforated pipe could be cleaned each fall for use during the next season.

POTENTIALS OF SUBSURFACE IRRIGATION

In the opinion of the leaders in this project subsurface irrigation has more potential for automated and efficient application of irrigation water than any other irrigation system now operable (7). The appended references represent recent and current research work which increases confidence that solutions will be found for the problems that have been holding back subsurface irrigation.

Subsurface irrigation opens the door for a new means of applying fertilizer, fungicide, pesticide, and air directly in the root zone. No other system offers such potential as a means for balancing plant growth factors. It is easy to envision benefits from pumping air through the system into the root zone during periods of extended rainfall or flooding which ordinarily may damage crop production by preventing adequate aeration.

With continued research on filters and on the development of slits (2), orifices, or other openings which will minimize clogging or which will be self-cleansing under intermittent application of extra water pressure, it is expected that subsurface irrigation will become one of the most important methods of automated irrigation in the future.

SUMMARY

Yields from cotton grown with subsurface irrigation were significantly greater than yields obtained with surface irrigation. Potential water savings with subsurface irrigation as compared to surface irrigation appear to be in excess of 30 percent. Difficulty was experienced in obtaining a complete stand of cotton due to slow rate of capillary flow from the subsurface perforated pipe to the shallow planting depth. The subsurface irrigation system consisted of perforated half-inch plastic pipe which was placed 10 to 12 inches deep under each row. Suspended particles in filtered water partially obstructed the flow from the pipes to the soil and required an increase in pressure head to apply design rates of flow through the system. Water application rates with the subsurface irrigation system ranged mainly between 0.10 and 0.30 inches per day. Water was measured with positive displacement meters and application was programmed with a time clock.

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FUTURE OF SUB-SURFACE IRRIGATION:

INFLUENCE ON COTTON YIELDS AND QUALITY

B. C. Williams[1/]

Four years ago, under the auspices of the Water Resource Research Institute, Professor Hanson and I initiated the first cooperative study on irrigation and fertility at this station as it affects growth, development, yields, and quality of cotton. Our choice of irrigation methods and rates have been reported by Hanson. He has discussed the installation, operation, and maintenance of the system and now let us discuss the effects upon yield and quality of cotton produced.

First, it is best to point out that no crop, commonly used by man, grows at its optimum or anywhere near optimum genetic potential when it is stressed for either nutrient, water, or any of the other factors for growth. In spite of all the problems that we have encountered in the past four seasons as pointed out in the previous paper by Hanson, we have effectively increased yields, and we have maintained quality of the product produced. There are potentials in the use of this system that have not yet been touched, some of which I hope to mention later. There is only one system of irrigation that I know of in the world that equals the potential of this system. It is a trickle irrigation system that is being used by the Israelis in part of the desert region that they are having to put under cultivation. Some combination of these two systems working together could show us possibly even further water savings from the standpoint of increasing the efficiency in the use of our water for agricultural production.

Buildup of salt in our system as mentioned by Hanson has been remarkably low over the years of operation, the final year's data are presently being analyzed. This salt buildup was checked by patterned sampling across the rows of crop at the end of each growing season in a manner worked out by Dr. Harold Dregne and myself. The work of sampling and analysis for salt was accomplished by one of Dr. Dregne's graduate students. These results and those from trickle irrigation in Israel are quite similar and both indicate that we can use waters of relatively poor quality for crop production without obtaining a large salt buildup for a relatively long period of time. I have not put an actual number of years on this salt buildup but it is my opinion that occasionally some leaching will be necessary to remove excess salts. The frequency of such leaching in the sub-surface irrigation system where surface evaporation is negligible will have to be determined over a long period of time. It is highly possible that this system through maintenance of

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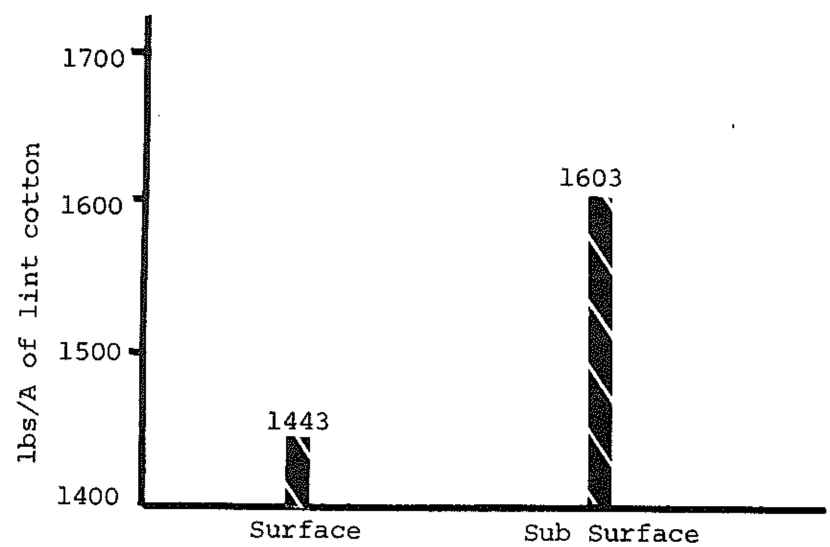


Figure 1. Lint cotton yields per acre for methods of irrigation

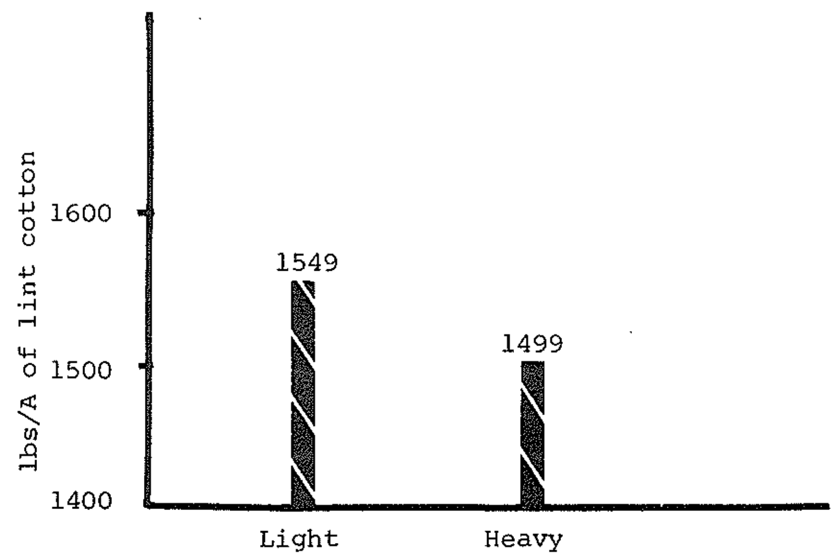


Figure 2. Lint cotton yields per acre for rates of irrigation

relatively constant low hydraulic tensions in the root zone of the plant may allow for a much more precise evaluation of detrimental salt concentrations and specific salt effects upon plant growth, development, and yield. On the irrigation experiment reported here, we have superimposed five fertility levels utilizing that fertility level in the field as a check and imposing a 4:1:1 NPK starting at 120 pounds of nitrogen, then going to 160, 200, 240 and 480 with the comparable ratios of phosphorus and potassium as the elements.[1] These fertilizers were sidedressed to the plant, one-half applied at planting and one-half applied at the time of first fruit forms. The soils from each plot were sampled for fertility analysis because this, as far as my part of it is concerned, must be taken into account when we evaluate the use of water. Over the years, we have gone back on the same plot every year with the same treatment. This has resulted in some buildup of fertility within these plots which has maintained an increased yield. Over the three-year period, we have had one relatively good year, we've had two relatively poor years, one of which was very poor from the standpoint of the normal climatic pattern. One thing that we have observed throughout the experiment is that on the average the maintenance of a continuous water level within the soil from the standpoint of the sub-surface system has given us from observation some slight increase in the temperature of the soil. This has meant to us on the average for the three years as much as two days earlier emergence of the cotton crop. It has meant that our fruit has set earlier and that the crop matured earlier. We picked what the geneticists have put in the crop for us to pick.

Here in the first figure we can see the effect that the method of irrigation had on lint cotton yield, these figures being the average for two years. I did not average in the raw data from the third year yield. If they are averaged in, however, it will only drop this difference slightly, with respect to the lint cotton yield. Here you see a difference of 160 pounds of lint cotton per acre in favor of the sub-surface system of irrigation. This, I believe, can be attributed to a continuous feeding where effects of detrimental changes in temperature in the root zone are at a minimum. The plant exhibits no great expenditure of energy for the uptake of water or nutrients. Therefore, the energy could be used for growth, and for maturing out the crop.

In figure 2 the differences we had between the light and the heavy irrigation rates can be seen. You note that heavy irrigation rates are not needed for good cotton yields. We had a fifty-pound differential in yield of lint cotton in favor of the light irrigation system -- the one that was adequate to keep the plant from showing any evidence of stress from moisture. This supports previous work by Hanson on effects of frequent light irrigations for crop production.

[1]To convert P and K to the oxide base (P_2O_5 and K_2O) multiply the pounds of element by 2.27 and 1.17 respectively.

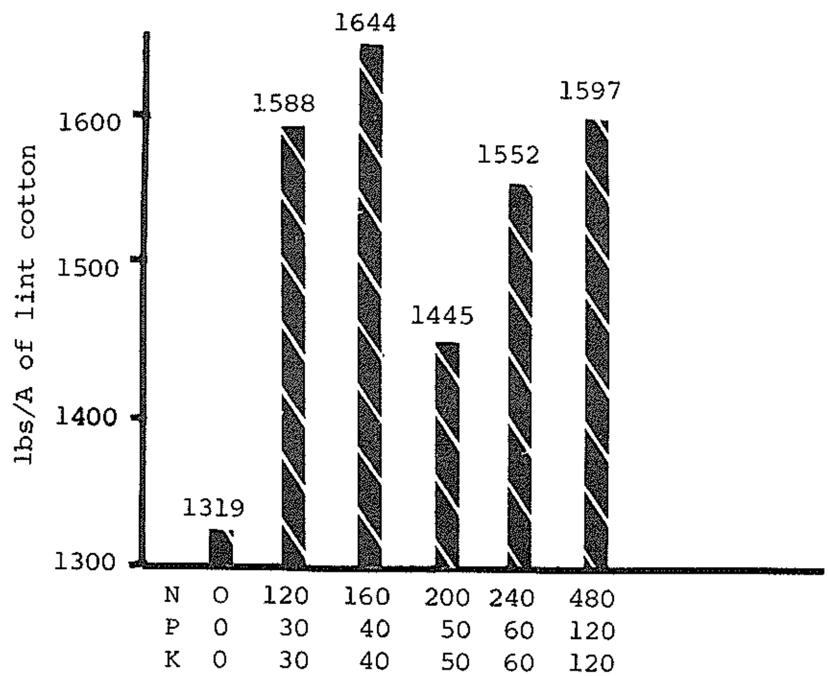


Figure 3. Lint cotton yield per acre for 6 fertility levels

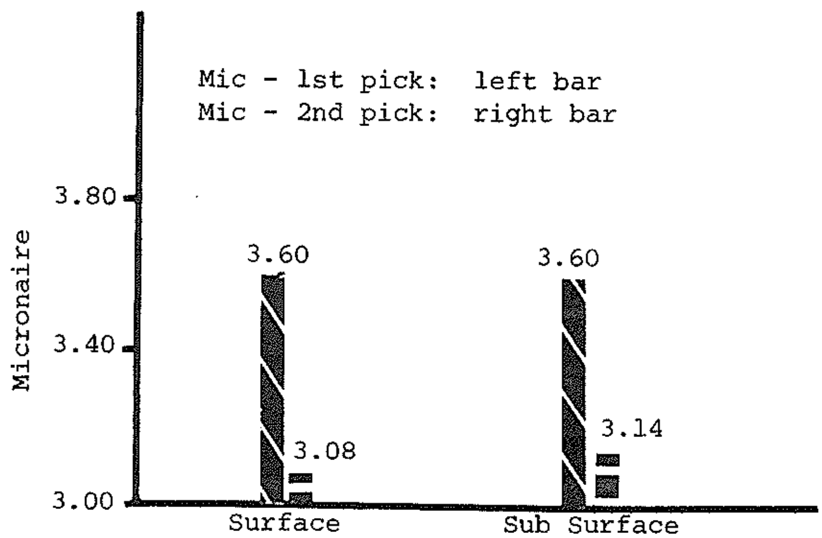


Figure 4. Micronaire values for methods of irrigation

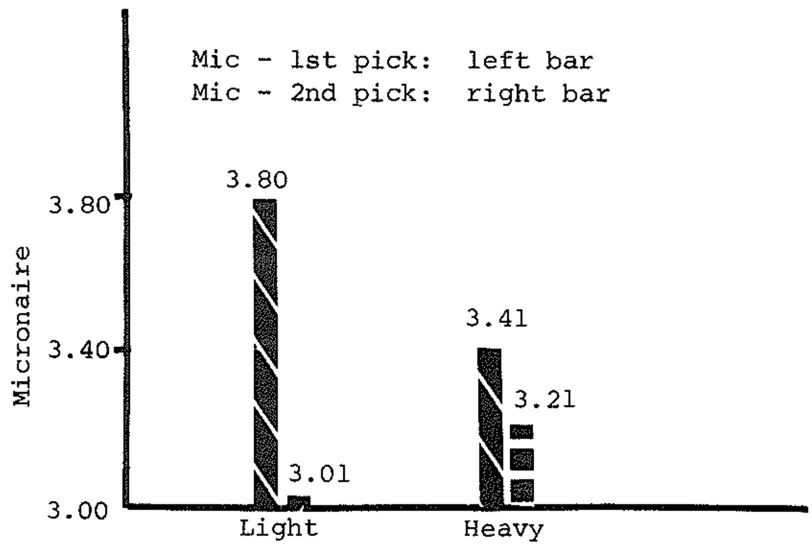


Figure 5. Micronaire values for rates of irrigation

One point here is that my use of the term "stress" is not limited to a deficiency. An excess of anything, water, nutrient, or any other factor affecting growth, can be as much of a stress upon the plant as the lack of that particular factor. The effect of low stress as indicated by this yield was shown in the plant growth during the season.

Since there was no interaction between fertility levels and irrigation methods and levels as determined in the individual statistical analyses as yet, the fertility levels have been separated out. In Figure 3 it can be seen that there is an increase in yield with increasing fertility levels. You will note that there is a 325 pound of lint cotton yield increase from the check, or no fertilizer application, to the rate of 160:40:40 of NPK per acre. This is a rate that has stood out in over ten years of fertility rate studies on cotton and the following drop that we note in yield with recovery at the higher rate is a common thing. I have no explanation as to why this occurs, I wish I did. Some day when we have a couple more good graduate students, maybe it will be possible to find out exactly what is happening in the system at this point. These yields are good yields as we can see that we are getting approximately three bales of lint cotton. These yields are especially good since these were occurring at the same time that the state average yield of lint cotton was decreasing rather rapidly and steadily. We have maintained and increased our yield of cotton by proper use of fertilizers and water. Either one, if improperly used, will give us poor yields and poor results. Good yields are what we want, but at the same time we want a product that is marketable. Therefore, we must look at the quality of the crop produced.

As one knows who has worked with cotton, the micronaire value for the cotton fiber is an estimate of maturity and fineness of the cotton produced within a variety of cotton. In other words, it is a measure of quality of product. So, I have restricted the presentation for this paper to the micronaire values. In Figure 4 we can see that the method of irrigation had no effect on the first picked cotton quality. The first picked cotton quality turned out a 3.6 micronaire value. In the second pick, you will note that the surface irrigated cotton dropped slightly lower than did the sub-surface irrigated cotton, and statistically it does not show a difference. The potential for better micronaire on sub-surface irrigated cotton is indicated.

A somewhat different effect is seen, Figure 5, with respect to rates of irrigation water applied. From the standpoint of the rates of water applied, you noted that we only needed the light rate from the standpoint of yield. We only need the light rate from the standpoint of quality of the fiber produced. Here we have an average micronaire for the first picked cotton in the light irrigation treatment of 3.8. This is a good quality cotton. We note that there is a very decided drop, however, into the second pick cotton

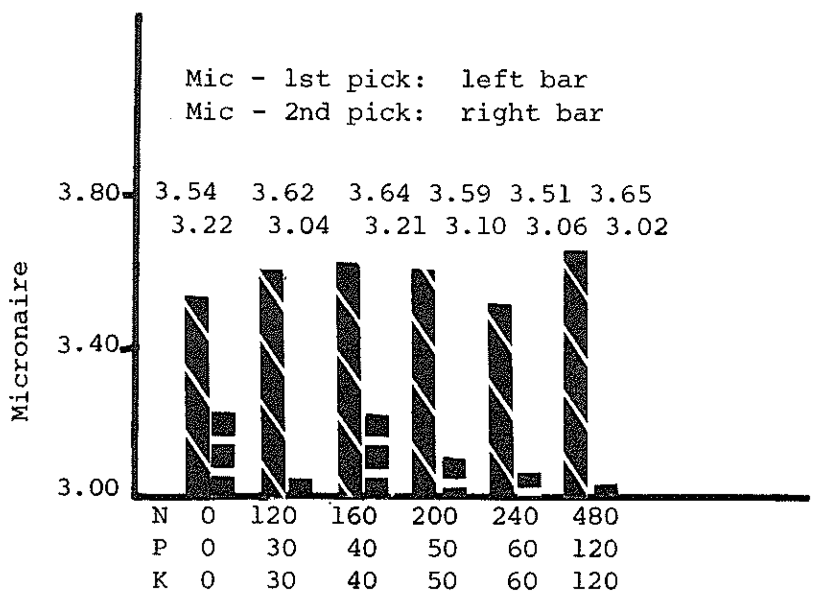
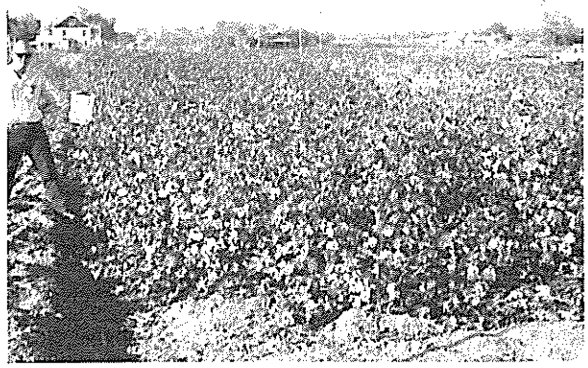
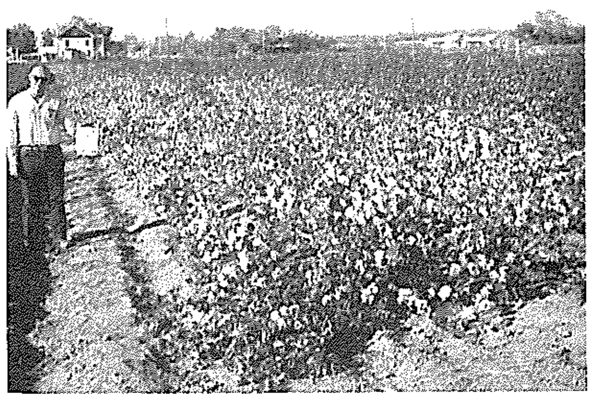


Figure 6. Micronaire values for 6 fertility levels



(a) Surface irrigated cotton that is not open well.



(b) Subsurface irrigated cotton that is well opened for first pick.

Figure 7. Effect of irrigation method upon open cotton, October 17, 1967.

where the micronaire value goes down to almost 3.0. There is one thing, however, that I would like to point out to you. Practically all of the cotton on this particular treatment was picked at the first pick. We picked less than twenty percent of our cotton in the second pick. So, therefore, we still had a real good marketable cotton crop. On the heavy irrigation treatment, micronaire values are poorer from the standpoint of the light versus the heavy on the first pick. It did not drop as much on the second. But we picked more cotton on the second pick. This indicates less crop maturity since more cotton was picked later in the season and a less acceptable crop for the market place as indicated by the lower crop micronaire value.

Now, with respect to fertility, we can see in Figure 6 that there is very little difference in the first picked cotton micronaire values. However, statistically, there is a difference between the 120, 160, and 480 levels and the other three levels of fertility. In the second pick cotton, you will note that the check, or no fertilizer treatment, and the 160 pound rate of nigrogen coupled with phosphorus and potassium gave us the best second pick micronaire cotton. These rates had the highest first pick yields and the best quality of cotton. Of course, I would prefer that which we got off the 160:40:40 NPK simply because of the fact that we got the best yields as well as the best micronaire values for the crop. I would not sacrifice the yield to obtain the micronaire value on the second pick crop on the checks. What this comes down to as far as we can see within our work, is the fact that if we utilize the water on the basis of consumptive use at the light irrigation rate, which we have proven can be done in the third year of experimentation without any surface irrigation water application, and with the proper fertility, we get a cotton crop that has good yield and good quality for the market place.

The surface irrigated cotton shown in Figure 7a is not open too well, it is late. These pictures were made on October 17.

Figure 7b shows the sub-surface irrigated plots. Practically all of the cotton opened for the first picking. We get back that which the breeder has put in the crop, if we manage our water and our soil with respect to fertility so that we can have an opportunity for the factors of the normal environment other than these two to be effective. With this combination of factors, we can obtain our yields and our quality while we are saving water and using water that we otherwise could not utilize.

The potential of saving of water in these studies ranges from 25 to 30 percent plus as indicated in the data for the first two years and confirmed in the third year of operation. As to the future of this particular system, we see many uses. Professor Hanson, at the end of his paper, mentioned a few. There are other potentials that we have not touched. There is one definitely that I feel that we must think of and have work on and that is the temperature effect. The effect of temperature upon crop growth, development, and yield is by far one of the greatest that we know. If we can reduce the fluctuations with respect to soil temperatures, by the maintenance of high moisture without detrimental effects upon aeration, or by the introduction of warm waters within the soil system, we cannot only further increase our yield but we should have a much greater effect upon the favorable quality of the product produced than we have yet shown. This should be effective because of a more constant rate of both water and nutrient uptake which should give a more nearly optimum condition for growth and development of the crop. This becomes even more important when coupled with feeding the fertilizer through these lines in relation to the uptake potential of the plant, day by day, the same as for the water. Higher yields with less amounts of fertilizer then become common because of an increase in efficiency in use of water and fertilizers greater than we have ever imagined.