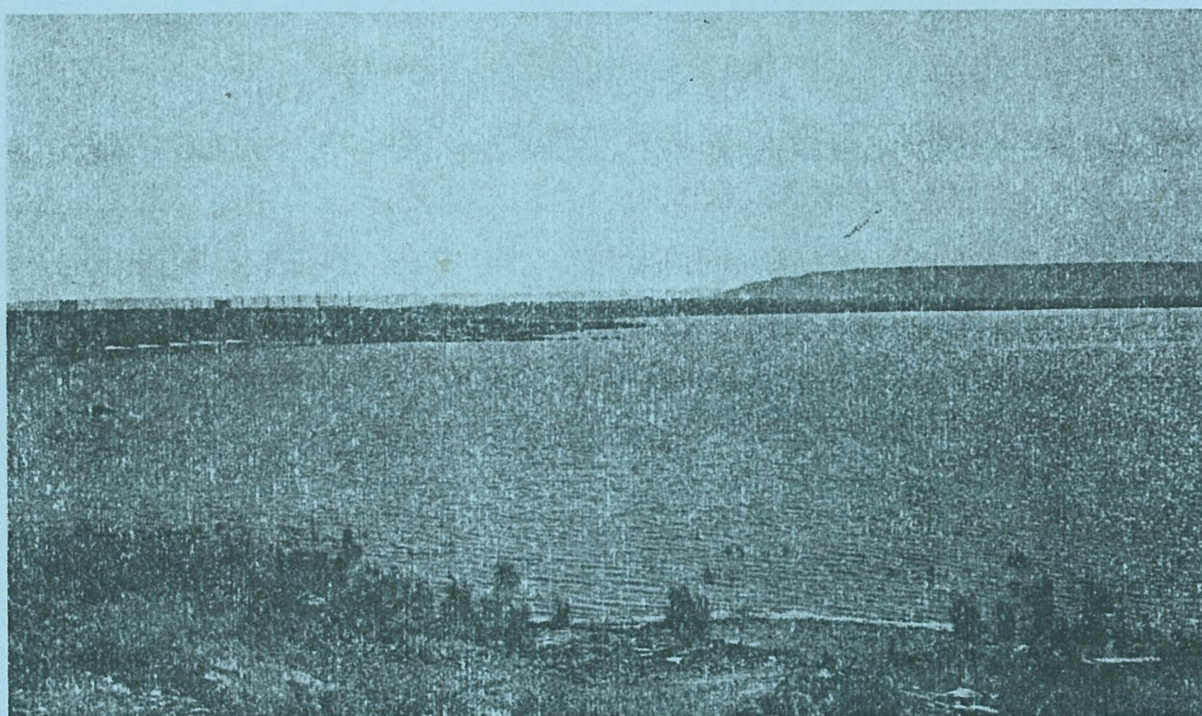
New Mexico Water Conference

NEW MEXICO COLLEGE OF AGRICULTURE AND MECHANIC ARTS

Oct. 31, Nov. 1-2, 1956



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AGRICULTURAL EXTENSION SERVICE

OF

NEW MEXICO COLLEGE OF AGRICULTURE AND MECHANIC ARTS

STATE COLLEGE, NEW MEXICO

FOREWORD

Water is vital to New Mexico, both for industrial development and for the development and maintenance of agriculture. The water problem is becoming more important as the population of New Mexico increases and as the drought continues. Recognizing these facts, a state-wide Water Conference was arranged by New Mexico College of Agriculture and Mechanic Arts to discuss this important problem. The Conference was held in Milton Hall on the A & M Campus on October 31 and November 1 and 2, 1956.

Outstanding leaders in the State of New Mexico and in the West presented papers during this conference. Several of those leaders took part in panel discussions to help emphasize the interests of the various areas of the state and the problems and programs in those areas.

The Conference was attended by leaders in business, agriculture and government from many areas of New Mexico. The exchange of ideas and the bringing together of this set of papers has helped focus the attention of all people of the state to the need for a definite program of water development and conservation. New Mexico is becoming more aware that water is one of the most valuable and scarce resources and that conservation and use of our limited water is vital to all of the people of the State.

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

The Conference was sponsored by New Mexico College of Agriculture and Mechanic Arts through the Engineering Experiment Station, the Agricultural Experiment Station, the Agricultural Extension Service and the Agricultural Research Service U.S.D.A. The committee was J. W. Clark, Civil Engineering; Ross Leamer, A.R.S., U.S.D.A.; Eldon Hanson, Agricultural Engineering; K. A. Valentine, Animal Husbandry; John Gaume, Agricultural Extension Service; and W. P. Stephens, Morris Evans and the general chairman, Agricultural Economics.

A limited number of copies of this Conference Report are being processed for distribution primarily for reference purposes.

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

NEW MEXICO WATER CONFERENCE PROGRAM

New Mexico College of Agriculture and Mechanic Arts
Sate College, New Mexico

October 31 and November 1-2, 1956

Milton Hall (Student Union Building)
New Mexico College of Agriculture and Mechanic Arts Campus

Wednesday Morning - October 31

8:00 - 9:45 Registration - Milton Hall

General Conference Chairman - H. R. Stucky

9:45 - 10:00 Invocation - Rev. Nelson Wurgler

10:00 - 10:30 Welcome and Address on Water and Its Economic and Social Influences in New Mexico

Dr. Roger B. Corbett
President of New Mexico College of A & M A

Page Number

10:30 - 11:30 Water Resources of New Mexico

Steve Reynolds - 6
New Mexico State Engineer

Afternoon UNDERGROUND WATER

Chairman - Morris Evans

1:15 - 2:00 Underground Water Laws of New Mexico

* Charles B. Harris
Special Assistant Attorney General
Roswell, New Mexico

2:00 - 2:45 Economics of the Use of Underground Water

Wm. P. Stephens - 18
Agricultural Economics Department
New Mexico College of A & M A

3:00 **Panel Subject - Underground Water Problems in New Mexico (8-10 minutes opening statements for each area)**

2:00 - 2:45	Instruments for Measuring and Controlling Water for Efficient Use	Page Number
	Dwight Davenport, Field Representative - - - - - - - - Sparling Meter Co., Engineer, Los Angeles, California	66
	WATERSHED MANAGEMENT	
	Chairman - K. A. Valentine	
3:00 - 4:00	Water Yields Through Watershed Management	
	E. J. Dortignac, Research Leader - - - - - - - - - - - Forest Service, Albuquerque, New Mexico	69
6:30 P.M.	Banquet Subject: Industrial Development Possibilities in New Mexico and the Need for Water	
	Chairman: Dr. R. H. Black, Dean and Director of Agriculture and Home Economics, New Mexico College of A & M A	
	* Speaker: Mr. Burl Huffman, Director New Mexico Economic Development Commission Santa Fe, New Mexico	

Friday Morning - November 2

	RIO GRANDE WATER	
	Chairman - A. S. Curry	
8:30 - 9:15	Water Use and Water Control Planning on the Rio Grande	
	Harold B. Elmendorf - Chairman, USDA Field Advisory - - - - Committee, Upper Colorado River Basin	98
9:15 - 10:30	Panel Subject - Rio Grande Water - With Possible Additions by San Juan Diversion (8 - 10 minutes opening statements for each area)	
	Mesilla Valley - James F. Cole, Berino, N. M. - - - -	106
	* Middle Valley - Rufus Stroud, Albuquerque, N. M.	
	Upper Valley - Ernest Martinez, Taos, N. M. - - - -	109
	* San Juan - I. J. Coury, Farmington, N. M.	
	City and Industry Representation - Carl Meriwether, Las Cruces, N. M. -	112
11:45	Summary of Conference - H. R. Stucky	
12:00 noon	Adjourn	

*Papers not received for inclusion in this report.

C. W. LAURITZEN, Project Supervisor, Soil and Water Conservation Research Branch, Agricultural Research Service, U.S.D.A., Logan, Utah.

ERNEST MARTINEZ, Manager, Taos Municipal Water and Sewage System, Taos, New Mexico.

CARL MERIWETHER, Manager, Western Cottonoil Company and President, Mesilla Valley Chamber of Commerce, Las Cruces, New Mexico.

E. J. MINTON, Supervisor of the Lea County Water Conservation Office, Lovington, New Mexico.

JOHN ALLEN PHINIZY, Farmer and Secretary and Treasurer of Pecos Valley Artesian Conservancy District, Roswell, New Mexico.

STEVE REYNOLDS, State Engineer of New Mexico, Commissioner of Rio Grande, Canadian and Costilla River Compact Commissions, Santa Fe, New Mexico.

JESSE U. RICHARDSON, Farmer and President of Board of Regents, New Mexico College of A & M A, Mesilla Park, New Mexico.

WILLIAM P. STEPHENS, Assistant Professor, Agricultural Economics Department, New Mexico College of A & M A.

RUFUS STROUD, Farmer, Albuquerque, New Mexico.

DR. H. R. STUCKY, Professor and Head, Agricultural Economics Department, New Mexico College of A & M A.

E. J. UMBENHAUER, Superintendent, Water and Sewage Departments, El Paso, Texas.

K. A. VALENTINE, Associate Professor, Animal Husbandry and Range Management, New Mexico College of A & M A.

REV. NELSON WURGLER, Pastor, St. Paul's Methodist Church, Las Cruces, New Mexico.

COMMITTEE ON ARRANGEMENTS FOR CONFERENCE

New Mexico College of Agriculture and Mechanic Arts

John Clark - Civil Engineering Department
Ross W. Leamer - Agricultural Research Service, U.S.D.A.
Eldon G. Hanson - Agricultural Engineering Department
K. A. Valentine - Range Management - A. H. Department
John Gaume - Agricultural Extension Service
Wm. P. Stephens - Agricultural Economics Department
Morris Evans - Agricultural Economics Department
H. R. Stucky - Agricultural Economics Department, Chairman

KNOW YOUR SPEAKERS

New Mexico Water Conference
New Mexico College of A & M A
State College, New Mexico
October 31, November 1-2, 1956

DR. BUEL W. BEADLE, Chairman, Department of Chemistry and Chemical Engineering, Southwest Research Institute, San Antonio, Texas.

DR. ROBERT H. BLACK, Dean and Director of Agriculture and Home Economics, New Mexico College of A & M A.

FRANK BROMILOW, Professor and Head, Civil Engineering Department, New Mexico College of A & M A.

J. W. CLARK, Associate Professor of Civil Engineering, New Mexico College of A & M A.

JAMES F. COLE, Farmer and Secretary of Dona Ana County Farm Bureau, Berino, New Mexico.

DR. ROGER B. CORBETT, President, New Mexico College of A & M A.

I. J. COURY, Member, Interstate Stream Compact Commission, and Member, Upper Colorado River Commission, Farmington, New Mexico.

A. S. CURRY, Associate Director, Agricultural Experiment Station, New Mexico College of A & M A.

DWIGHT DAVENPORT, Field Representative, Sparling Meter Company, Engineers; Los Angeles, California.

E. J. DORTIGNAC, Research Leader, Rocky Mountain Forest and Range Experiment Station, U. S. Forest Service, Albuquerque, New Mexico.

HAROLD B. ELMENDORF, Chairman, U.S.D.A. Field Advisory Committee, Upper Colorado River Basin, Mesilla Park, New Mexico.

MORRIS EVANS, Associate Professor, Agricultural Economics Department, New Mexico College of A & M A.

CHARLES B. HARRIS, Special Assistant Attorney General to State Engineer's Office, Roswell, New Mexico.

G. D. HATFIELD, Farmer and Member State Highway Commission, Deming, New Mexico.

BURL HUFFMAN, Director, New Mexico Economic Development Commission, Santa Fe, New Mexico.

NEW MEXICO WATER RESOURCES

By

S. E. Reynolds*

Introduction

New Mexico's-surface and ground-water resources are derived primarily from two sources: precipitation within the boundaries of this enchanting land and runoff from the State of Colorado. The latter source makes most of its contribution through the San Juan River and the Rio Grande.

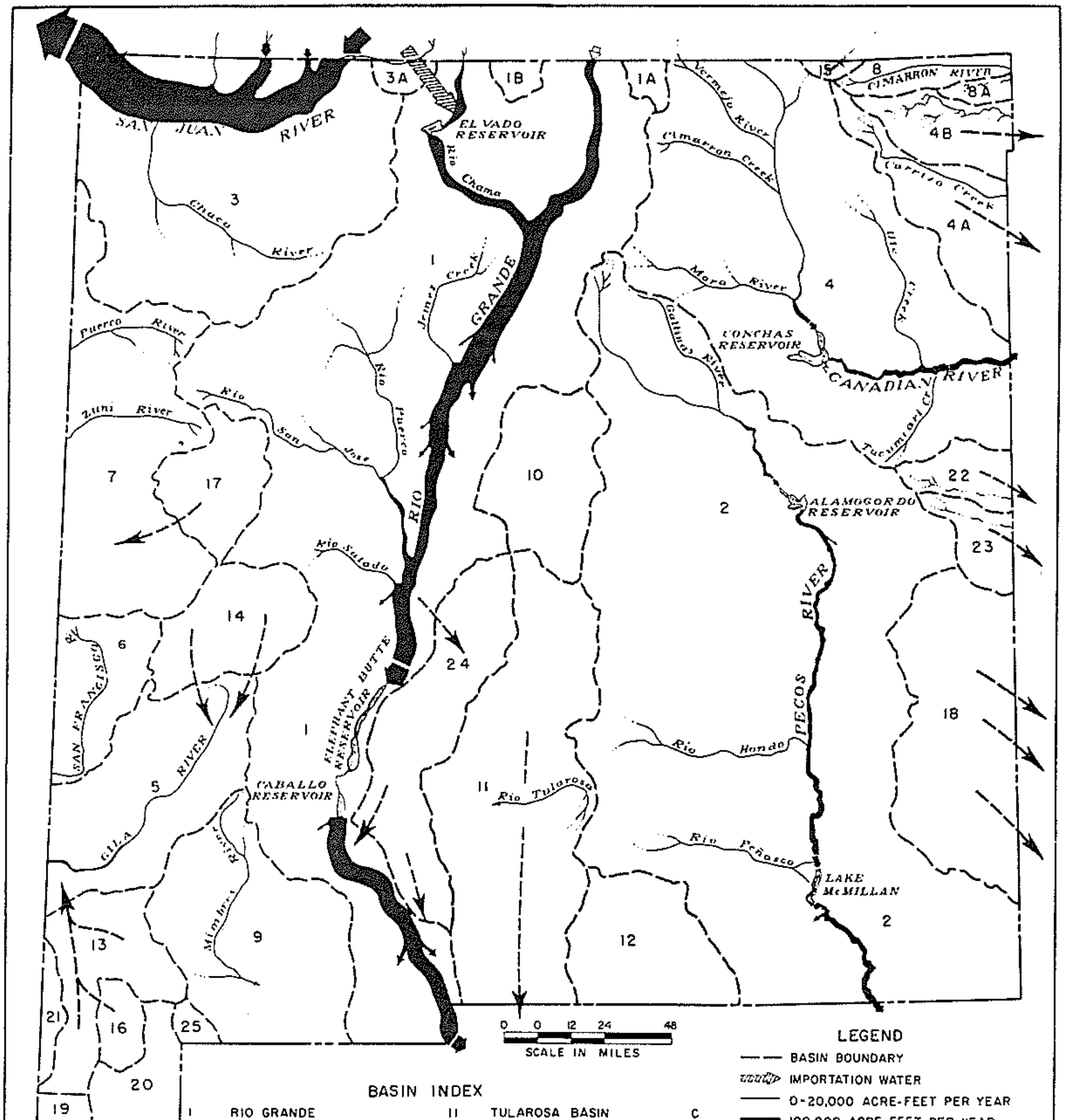
The total annual precipitation on New Mexico amounts to about 100 million acre-feet each year. However, only about 5% of this becomes divertible as surface or ground water -- thus the annual contribution of 2,500,000 acre-feet from our sister state to the north constitutes a substantial portion of our annual divertible supply.

The irrigator is inclined to rue the "loss" of the 95% of our precipitation which never reaches our streams or ground-water basins, but the contribution which that water makes to our grazing and forestry industries as it goes up in smoke is substantial and must not go unappreciated. Furthermore, to avoid the clogging of our streams and reservoirs with silt, a certain amount of precipitation must be consumed by plants at the point of fall.

Our meteorologic system is a metastable machine and relatively small changes in the synoptic pattern can result in wide variations in precipitation from day to day and from year to year -- and, as is forcefully demonstrated by the records of the ten or more years just past, wide variations on the deficiency side can persist for extended periods. These wide variations in precipitation make the utilization of reservoirs -- either man-made or natural underground reservoirs -- essential to the effective use of our water resources. These reservoirs explain the paradox of agricultural land in a region of variable and deficient rainfall being more valuable than the fertile land of our humid Middle West.

New Mexico contains portions of the headwaters of three of the principal river systems of the United States: the Mississippi, Colorado, and Rio Grande. Figure 1 shows the various natural surface drainage basins in the State. Basins 4, 4A, 4B, 8, 8A, 15, 18, 22, and 23 are

*State Engineer and Secretary, Interstate Stream Commission.



BASIN INDEX

1	RIO GRANDE		11	TULAROSA BASIN	C
1A	COSTILLA CREEK		12	SACRAMENTO RIVER	C
1B	RIO SAN ANTONIO		13	ANIMAS VALLEY	C
2	PECOS RIVER		14	SAN AGUSTIN BASIN	C
3	SAN JUAN RIVER		15	PURGATOIRE RIVER	
3A	NAVAJO RIVER		16	PLAYAS VALLEY	C
4	CANADIAN RIVER		17	LAVA BED VALLEY	C
4A	CARRIZO CREEK		18	LEA PLATEAU (COLORADO RIVER OF TEXAS)	
4B	NORTH CANADIAN RIVER				
5	GILA RIVER		19	SAN LUIS BASIN	C
6	SAN FRANCISCO RIVER		20	HACHITA	C
7	LITTLE COLORADO RIVER		21	SAN SIMON	
8	CIMARRON RIVER		22	RED RIVER	
8A	CARRIZOZO CREEK		23	BRAZOS	
9	MIMBRES RIVER	C	24	JORNADA DEL MUERTO	C
10	ESTANCIA VALLEY	C	25	WAMEL BASIN	C

LEGEND

- BASIN BOUNDARY
- IMPORTATION WATER
- 0-20,000 ACRE-FEET PER YEAR
- 100,000 ACRE-FEET PER YEAR
- 500,000 ACRE-FEET PER YEAR
- 1,000,000 ACRE-FEET PER YEAR
- 2,000,000 ACRE-FEET PER YEAR
- C CLOSED DRAINAGE-BASINS
- DIVERSIONS
- MOVEMENT-UNDERGROUND WATER

FIGURE I
DRAINAGE BASINS AND STREAM FLOW MAP OF NEW MEXICO

tributary to the Mississippi River; basins 3, 3A, 5, 6, 7, and 21 are tributary to the Colorado River, basins 5, 6, and 21 draining to the Gila River on the Lower Colorado River system; basins 1, 1A, and 1B are parts of the Rio Grande drainage; basin 2 drains to the Pecos River, a principal tributary of the Rio Grande. Basins 9, 10, 11, 12, 13, 14, 16, 17, 19, 20, 24, and 25 are areas from which surface water does not discharge to principal streams within the State.

All of our significant surface streams are involved in interstate water compacts -- in fact one of them, the La Plata River, is subject to three compacts, the Colorado River Compact of 1922, the Upper Colorado River Compact, and the La Plata River Compact.

All too commonly our interstate water compacts are viewed as oppressive agreements under which we have given up much more than we have received. A quick assessment of that notion can be made from the following figures: Under present conditions the approximate average annual flow of surface water into the state is 2,500,000 acre-feet and the average annual outflow is 3,500,000 acre-feet; when we have fully developed, within the limits of economic feasibility, the rights guaranteed us in the various compacts our average annual outflow will be about 2,600,000 acre-feet. As water becomes more valuable this outflow might be reduced slightly more. Thus, even though we are largely a headwater state, our receipts under the compacts nearly equal our disbursements.

Administration

All surface waters in New Mexico belong to the public and may be used in accordance with the doctrine of prior appropriation. The office of the State Engineer (originally known as the Territorial Engineer) was created by the Legislature in 1907. The office is charged with the general supervision, including measurement, appropriation, and distribution, of all the waters of the State. Beneficial use is the basis, the measure, and the limit of the right to the use of the water, and priority in time of appropriation gives the better right. The State Engineer must supervise the apportionment of the water according to licenses issued by him and his predecessors and according to the adjudication of the courts.

Relation of Surface- and Ground-Water Basins

Ground water is derived from the portion of the precipitation that penetrates below the soil and root zone of the ground. In addition to being the source of water for wells, ground water moves underground to reappear as the springs and invisible accretions that furnish the perennial base flow for all New Mexico streams.

The relations of natural ground-water basins in New Mexico to surface- water basins can be illustrated by referring again to Figure 1. Ground-water in Estancia Valley (number 10) and Playas Valley (number 16) is discharged by evapo-transpiration from playa lakes within these respective valleys. The ground water of the Crow Flats area, the Sacramento River Basin (number 12), is discharged into playa lakes in Texas, and ground water from four surface drainage basins in southwestern New Mexico (numbers 19, 20, 25, 9) discharges into playa lakes in northern Chihuahua, Mexico. Most of the ground water in the four other closed drainage basins discharges to the valleys of the principal streams in adjacent drainage basins, as shown by the arrows on the figure. Ground water in the San Augustin Plains (basin 14) probably discharges to the Upper Gila River. Ground water in Lava Bed Valley (basin 17) discharges to the Zuni River, a tributary of the Colorado River, and to the Rio San Jose, a tributary of the Rio Grande. Ground water in the Jornada del Muerto (basin 24) discharges to the Rio Grande. The Tularosa Valley ground water discharges to the Rio Grande although a large portion of the natural discharge in this valley occurs in the playa lakes near the White Sands.

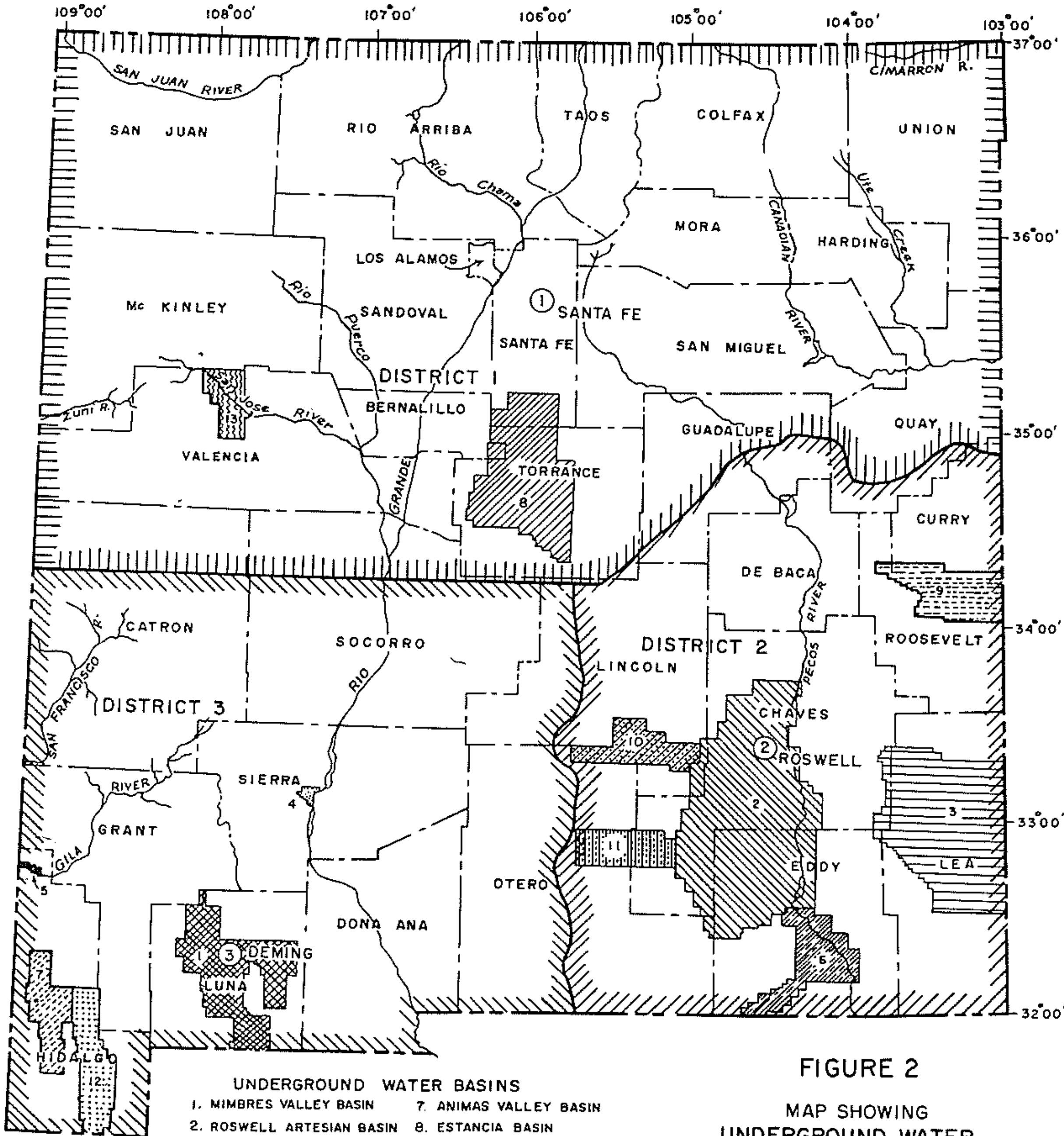
Ground water in the Animas Valley (basin 13) and the northern part of Playas Valley (basin 16) discharges to the Gila River near the Arizona-New Mexico line. Ground water in the northeastern part of the State discharges to numerous stream valleys within the area, ultimately reaching Mississippi River tributaries in Texas. The ground water in the Ogallala formation in eastern New Mexico below the Canadian River watershed discharges into tributaries of the Colorado and Brazos rivers in Texas. Ground water in the Pecos River Basin discharges naturally to the Pecos River.

Ground Water Administration

In the past 15 years there has been a great upsurge in the use of ground water in New Mexico. This increased usage results from several factors: favorable farm markets in the 1940's and early 1950's increased population and industry in the State, and the reduced availability of surface water in these drouth years.

Here are some data that the U. S. Geological Survey has provided me:

In 1940 there were 1,558 irrigation pumps in New Mexico; in 1950, 3,942; and in 1955, 7,500. In 1955 ground water was applied to 576,000 of a total of about 873,000 acres under irrigation. Much of this pumpage was to supplement the surface water normally used on these lands. Ground water now contributes 79% of the water used for industry and 92% of that used for municipal purposes.



UNDERGROUND WATER BASINS

1. MIMBRES VALLEY BASIN
2. ROSWELL ARTESIAN BASIN
3. LEA COUNTY BASIN
4. HOT SPRINGS BASIN
5. VIRDEN VALLEY BASIN
6. CARLSBAD BASIN
7. ANIMAS VALLEY BASIN
8. ESTANCIA BASIN
9. PORTALES BASIN
10. HONDO BASIN
11. PENASCO BASIN
12. PLAYAS VALLEY BASIN
13. BLUEWATER BASIN

DISTRICT OFFICES

(1) SANTA FE
(2) ROSWELL
(3) DEMING

FIGURE 2

MAP SHOWING
UNDERGROUND WATER DISTRICTS OF THE STATE ENGINEER OFFICE

10 0 10 30 50 70 90
SCALE IN MILES

COMPILED BY: F. E. IRBY
DRAWN BY: J. J. FOX
JUNE 30, 1956

A law declaring that ground water occurring in underground basins having boundaries that are reasonably ascertainable is public water and subject to use in accordance with the doctrine of prior appropriation was enacted in 1931. In 1953 the State Legislature declared that all underground waters of the State are public waters, but that permits to appropriate are required only in basins declared by the State Engineer.

Since establishment of the ground-water law in 1931 the State Engineer has declared the 13 underground water basins shown on Figure 2.

The Roswell, Mimbres, and Animas Basins are closed to all new appropriations except for domestic and stock use; in limited areas of the Lea County, Portales, Estancia, and Hot Springs Basins ground-water appropriations may still be made. In the Playas Basin the applications on file in our office more than fully appropriate the available water supply. These applications are in litigation and have not yet been granted.

In the Hot Springs, Hondo, Penasco, Carlsbad, Bluewater, and Virden Valley Basins, ground water is closely related to surface-water supplies, and ground-water withdrawals are nearly in equilibrium with the long-term recharge in these areas. New appropriations in these areas are permitted only to supplement existing surface-water rights or for stock and domestic use.

Ground water in the Animas, Mimbres, Playas, Portales, Lea County, and Estancia Basins is being withdrawn primarily from storage and water levels will continue to decline in those basins. The time limit for irrigation in the Portales, Lea County, and Estancia areas is set by the thickness of the saturated aquifer whereas the thickness of the aquifer in most of the Animas, Mimbres, and Playas Basins is so great that pumping costs will probably limit withdrawals of water for agriculture long before the water supply is actually exhausted. The policy of the State Engineer Office is, insofar as possible, to limit withdrawal in these areas to that which can be sustained for a reasonable pay-out period, usually about 40 years.

The wisdom of mining the ground-water resources in some of our basins is not infrequently questioned since many feel that these resources should be available to future generations in perpetuity. It seems to me that the mining of water might be justified as readily as the mining of any of our other mineral resources such as gold, oil, or coal. The impracticality of operating all basins on a continuous-yield basis can be more readily appreciated when it is realized that in the Lea County Basin, for example, the average annual recharge is 29,000 acre-feet per annum while the permitted withdrawal averages about 500,000 acre-feet per year. To justify the marketing, storage, and transportation facilities essential to a competent agricultural economy in the area, it is necessary for the withdrawals to exceed the recharge.

Roswell Basin

The Roswell Basin is susceptible to operation on a continuous yield basis, but the present withdrawals considerably exceed the average annual recharge, especially in recent years, and ground water is being mined in that area also. The average recharge to the basin, including irrigation return flow, has been computed by Hantush to be about 336,000 acre-feet; approximately 116,000 acre-feet of this amount is natural discharge that cannot be intercepted by the pumps. The average withdrawals of both shallow and artesian water is about 420,000 acre-feet; thus the appropriation amounts to 190% of the safe yield.

Reduction in total water consumed from the Roswell Basin would probably alleviate the rapid decline of water levels in the shallow aquifer as well as in the artesian aquifer since the two are hydraulically related. Otherwise, water levels will probably continue to decline rapidly. A series of wet years would probably only alleviate the situation temporarily.

While the annual safe yield in the Roswell Basin is adequate for a competent agricultural economy, it might be possible to justify ground-water mining in that basin during the war years; however, it is essential that we are fully aware of the course being pursued. The pinch is already being felt in some areas of the Roswell Basin in terms or artesian head lowering, salt encroachment in the artesian aquifer, and depletion of water in storage in the shallow water aquifer. Remedial measures are being sought by the State Engineer and the Pecos Valley Artesian Conservancy District with a sense of urgency.

The decline of artesian pressures and consequent salt encroachment and early depletion of the shallow water supply will be staved off to some degree by the adjudication of water rights in the Roswell Basin which is now in progress. It is estimated that 15,000 to 20,000 acres of a total of 140,000 acres now being irrigated in the basin do not have valid water rights.

The Pecos Valley Artesian Conservancy District in cooperation with the U. S. Geological Survey is studying the salt-encroachment problem. There is some hope that partial relief may be had by selectively sealing off strata in the artesian aquifer that are producing more concentrated salts.

Some reduction in withdrawals will result as the farmers avail themselves of the advantages of the Federal Soil Bank plan. We are considering legislation that will hold in abeyance the forfeiture statute to enable the farmer to take full advantage of the Soil Bank without risking abandonment of his water right.

The situation might be further alleviated by the purchase and drying up of valid ground-water rights, and I am informally advised that the Pecos Valley Artesian Conservancy District is giving consideration to this recourse. There is a remote possibility that artificial recharge or water-salvage measures might be employed without impairing existing surface-water rights, and this possibility is being studied by our office and the U. S. Geological Survey.

The Future

A. Upper Colorado River Project

Contrary to much public opinion New Mexico is still far from the maximum utilization of her water resources. However, several great steps toward this end, long strived for and long awaited, are about to be taken.

The Upper Colorado River Storage Project was authorized last spring by Public Law 485. This project will permit New Mexico to utilize fully the 838,000 acre-feet of consumptive use allotted us by the Upper Colorado River Compact. We currently are using only about 100,000 acre-feet of our share of the water of the Upper Colorado River System.

Public Law 485 provides for three large reservoirs on the Upper Colorado system which will ensure deliveries to the Lower Colorado Basin in accordance with the 1922 Compact, provide a regulated supply for uses in the Upper Basin, and produce power revenues which will be used first to repay the costs of the main storage reservoirs and then to repay a large share of the construction costs of irrigation projects in the Upper Basin States. All construction costs allocable to municipal and industrial uses must be fully repaid, with interest, by the user.

Public Law 485 also authorized the construction of Navajo Dam on the San Juan River above Farmington in New Mexico; the construction costs of this dam and reservoir are to be paid from power revenues. The primary purpose of this structure is to regulate the flow of the San Juan River for the 115,000-acre Navajo Irrigation Project. The legislation did not authorize this project but did give priority to its study and set forth that when authorized the project should be constructed with nonreimbursable Federal funds.

This latter concession is in recognition of a national responsibility to the Navajo Indians which should not be met entirely with the water and power resources of the Upper Basin states.

The legislation also authorized construction of the Hammond Project -- a 3,700-acre irrigation project on the San Juan River near Farmington -- and gave priority to the study of the Animas-LaPlata Irrigation Project and the San Juan-Chama Diversion Project.

The San Juan-Chama Diversion Project will bring from the San Juan Basin water urgently needed in the Rio Grande Basin for municipal and industrial purposes and supplemental irrigation. The project provides, by exchange, supplemental water for tributary irrigation units in northern New Mexico, and also provides for $22,000,000 worth of construction and rehabilitation work on these units. This work should do much to revitalize the economy of these depressed areas in New Mexico.

The provisions of the Upper Colorado River Storage Project make it possible for about $240,000,000 worth of water development work to be undertaken in New Mexico in the next few years, with over $200,000,000 of this being financed by power revenue credits or nonreimbursable Federal funds. This may sound like "something for nothing" of which we are always suspicious, but it should be remembered that the power revenue credits are no more a gift than any of our God-given natural resources.

With the exception of the Navajo Irrigation Project, essentially all of the Federal investment in the Upper Colorado River Storage Project will be repaid -- most of it with interest.

B. Canadian River

The Canadian River Compact gives New Mexico the unrestricted use of all of the waters of the Canadian River below Conchas Dam, but limits us in that reach to a conservation storage capacity not to exceed 200,000 acre-feet. The Interstate Stream Commission has authorized the expenditure of $20,000 from the New Mexico Irrigation Works Construction Fund for the purpose of investigating the construction of works to utilize the waters of the Canadian below Conchas Dam.

The studies made thus far are quite preliminary, but they indicate that there is a dam site on the Canadian below Logan which would provide a reservoir of about 200,000 acre-feet capacity. The studies indicate that this reservoir would develop a firm supply of about 80,000 acre-feet from the average of 240,000 acre-feet per annum that currently leaves New Mexico at the Texas line.

There is little possibility of using this water supply for irrigation, principally because the river there flows in a deeply incised canyon, and prohibitive pumping lifts would be required. However, the potentialities for industrial use of this water supply seem good because of the proximity of rail and truck transportation, and because our preliminary estimates show that the water can be made available in the reservoir for as little as 0.2 of a cent per 1000 gallons.

C. Gila River

We are currently using only about 20,000 acre-feet of the waters of the Gila River and its tributaries in New Mexico and about 270,000 acre-feet annually flows from New Mexico into Arizona. The Colorado River Compact of 1922 did not apportion the waters of the Lower Basin among the states involved, and while several attempts have been made the Lower Basin States have never succeeded in reaching an agreement allocating the waters of the Lower Colorado among themselves. Because of uncertainity about her share, New Mexico has had little incentive to prepare plans for a greater utilization of the waters of the Gila River.

We are now engaged in a Supreme Court contest to establish our rights to the waters of the Gila River. The Interstate Stream Commission staff is conducting hydrologic studies which it is hoped will provide the basis for a stipulation that will save us the expense of full participation in this Supreme Court litigation. I feel that under any equitable stipulation, or court decree, New Mexico will be able to substantially increase her uses of the waters of the Gila River. Embryonic plans for this increased utilization envision some increased irrigation along with the development of municipal and industrial usage.

D. Water Salvage

Water lost to noncommercial vegetation along our streams represents a potential source of water for beneficial uses of considerable magnitude, and steps are already being taken to recover this water for man's activities. The Bureau of Reclamation's Middle Rio Grande Project, which will rehabilitate the Middle Rio Grande Conservancy District and channelize many miles of the Rio Grande from Espanola to Elephant Butte Reservoir, is already salvaging an estimated 80,000 acre-feet per year, and will salvage considerably more when construction is complete. A major element of this project is the already constructed low-flow channel and floodway through the delta of the Elephant Butte Reservoir. The fact that the unofficial Rio Grande Compact computations for the last year showed New Mexico with a credit of about 20,000 acre-feet for the year can be attributed in considerable measure to the water salvaged by these works.

One hundred thousand dollars of the proceeds of a land grant fund known as the Fund for the Improvement of the Channel of the Rio Grande were appropriated by the legislature to implement the Middle Rio Grande Project over the past two fiscal years. In May of 1956 the Interstate Stream Commission authorized the expenditure of an additional $36,000 for this purpose.

The Interstate Stream Commission at its last meeting authorized the expenditure of an additional $150,000 to be spent in this and the next fiscal year on a program of water-salvage works which, it is estimated, will save about 9,000 acre-feet of water per year. The Bureau of Reclamation and the Middle Rio Grande Conservancy District are cooperators and a total of $360,000 will be spent in the program.

The Pecos River Commission and the Bureau of Reclamation have planned works similar to those constructed in the Elephant Butte delta for the McMillan Reservoir delta on the Pecos River above Carlsbad. It is estimated that these works, which will cost about $2,000,000, will be capable of salvaging about 26,000 acre-feet per annum.

Planning for work in the McMillan delta is complicated by the fact that the clearing of a floodway might lead to the rapid siltation of the already seriously depleted capacity of McMillan Reservoir, which provides terminal storage for the Carlsbad Irrigation District. For this reason the floodway will not be cleared and water salvaged will be limited to an approximate 16,000 acre-feet to be saved by the low-flow channel and spur drains until such time as provision for replacing the terminal storage for the Carlsbad Irrigation District can be made.

The natural discharge of the Roswell ground-water basin to the Pecos River amounts to about 116,000 acre-feet per year and somewhere between 30,000 and 60,000 acre-feet of this natural discharge is lost to evapo-transpiration before it reaches the river. Our Technical Division and the U. S. Geological Survey are cooperating in a study to determine the actual amount of water lost and what steps might be taken to salvage this water. This study is to cost $30,000 in this fiscal year; it is financed by expenditures from the New Mexico Irrigation Works Construction Fund, authorized by the Interstate Stream Commission, and matching funds furnished by the U. S. Geological Survey.

The water-salvage programs mentioned will fall far short of salvaging all of the approximately 600,000 acre-feet of water that is being non-beneficially consumed in New Mexico; but the State, with the cooperation of the Bureau of Reclamation and the Geological Survey, will continue to study this problem intensively and to work toward the salvage of the maximum that is economically feasible.

The amount of water that remains unsalvaged may be viewed as a resource that we can tap as the demand for water and its value increase.

E. Small Projects

I have made allusion at least twice to the New Mexico Irrigation Works Construction Fund. This fund was established by the 1955 Legislature to make feasibility studies of water-development projects and derives its monies from the income from a Federal land grant. The 1955 legislation authorized the Interstate Stream Commission to make expenditures from the Irrigation Works Construction Fund for feasibility studies, and to issue revenue bonds to finance the construction of feasible water utilization projects. The income from these projects would be used to retire the revenue bonds, with interest, and to repay the cost of the feasibility study. This legislation was passed to enable the State and local interests to take full advantage of an anticipated Federal Small Reclamation Projects Law.

A very preliminary survey conducted by the Technical Division in 1954 showed a need for 34 small construction or rehabilitation projects to improve water utilization in the State. However, it was apparent that few if any of these could show feasibility if it were necessary to repay construction costs with interest.

The Federal Small Reclamation Projects Act, Public Law 984, was passed in the last session of Congress, and since this law provides for 50-year interest-free loans of up to $5,000,000, we feel that a number of the small projects in New Mexico will be feasible under its provisions. The Interstate Stream Commission has authorized three feasibility studies at a total cost of $31,500 and has authorized the expenditure of $20,000 for reconnaissance studies of other small projects over the State to determine whether feasibility studies of these projects are warranted.

John Bliss, my predecessor as State Engineer and now New Mexico's Upper Colorado River Commissioner, was chairman of the National Reclamation Association's Small Projects Committee, and in the latter capacity he played a role of leadership in bringing about the passage of the Federal Small Reclamation Projects Act. He has been of great service to his State in this matter.

It is my belief that the Federal Small Reclamation Projects Law and the Department of Agriculture Small Watersheds Act operating in conjunction with the State's water development act can accomplish a great deal toward increasing the beneficial use of water in New Mexico, particularly where there are involved small irrigation districts in which financial restrictions have led to serious deterioration of the project's works.

F. Rain Making

I cannot close without commenting on at least two somewhat more visionary prospects for water resources development. The first of these is rainmaking, in which I have some personal experience. The President's Advisory Committee for Weather Control has recently released a report in which it is stated that their statistical analyses have given good evidence of precipitation increases of from 9% to 17% resulting from the use of ground-operated silver-iodide generators under the relatively ideal conditions presented by orographic storms on the west coast of the United States.

Most statisticians feel that while the analyses provide some evidence of precipitation increases, they fall far short of conclusive proof to this effect. It is my opinion that there is as yet little reliable evidence that precipitation in the Southwest can be significantly increased by rain-making techniques, but that the picture is by no means clear as yet and further research in this field is warranted.

The present state of the art, as I know it, is such that we cannot expect increases in our water supply from rainmaking for a number of years, and in one sense I am grateful for this -- I am appalled by the water-rights controversies that might arise from widespread application of rainmaking techniques in the Southwest.

G. Evaporation Control

A second proposition which stimulates my imagination is the use of monomolecular films to inhibit evaporation from reservoirs. The basic discovery of the effects of monomolecular layers as evaporation suppressants apparently belongs to Drs. Langmuir and Schaefer, as do many of the basic discoveries in rainmaking. W. W. Mansfield of the Commonwealth Scientific and Industrial Research Organization apparently deserves credit for suggesting the use of monomolecular films on water storage reservoirs. Hexadecanol, or cetyl alcohol, is the material that Manfield has worked with most. He has calculated that a monolayer should reduce natural evaporation by about 70% but, because of the temperature increase resulting from reduced evaporation rate, he predicts a mean reduction of about 45% for normal summer conditions in Australia. He believes that about 300 pounds per square mile is an adequate dosage to achieve this effect.

Mansfield's tests thus far indicate that the monolayer does not materially affect the rate at which oxygen and sunlight are absorbed by the water, and that, therefore, it does not impair aquatic life. He finds the material nontoxic to plant or animal life.

It is my understanding from a more or less cursory reading of Mansfield's work that the primary problem is that of dispensing the material. However, despite crude techniques which he described as quite unsatisfactory, he has measured evaporation reductions of from 23% to 73% in field tests on reservoirs of surface areas up to 11 acres. If a reasonably satisfactory method for dispensing the material can be achieved, the costs are expected to amount to about $1 per acre-foot of water salvaged.

The estimated annual evaporation from New Mexico's major impoundments, including the proposed Navajo Reservoir, and including New Mexico's share of evaporation losses from storage reservoirs on the Upper Colorado River, is about 440,000 acre-feet per year. Thus, if evaporation reduction of 45% could be achieved by the use of monolayers, our water resources would be enhanced by 200,000 acre-feet per year, or an amount sufficient to irrigate more than 66,000 acres.

The Bureau of Reclamation, the Southwest Research Institute, and I suppose other agencies in the United States, have become active in this field of research. At the present stage of progress these agencies are probably discovering only unanswered questions, but there does appear to be some reason to hope that Yankee ingenuity may be able to develop a practical technique that will increase our water resources by hundreds of thousands of acre-feet per year.

ECONOMICS OF THE USE OF UNDERGROUND WATER

W. P. Stephens 1/

Economics means different things to different people, but I think for most of us when the word economics is mentioned we think of our pocket book or in terms of dollars and cents. I am sure we all know that there is a cost side and an income side when we speak of dollars. There are people here that are not directly connected with agriculture, however, my job deals with the economics of agriculture, so my remarks and examples will be in terms of agriculture. Many of the basic principles will apply to any use that might be made of the water whether it is domestic, industrial or agricultural.

I do not want to be-labor the point of our need and lack of water, and I am sure other speakers will touch on this point, but I would like to make a few general observations along this line. The relationship between the supply and demand of water is becoming a topic for discussion and consideration in all sections of the United States. An indication of the seriousness of the problem is contained in the report issued in December 1955, by the Presidential Advisory Committee on Water Resource Policy. This report points out that the estimated combined municipal, rural, direct industrial, and irrigation water consumption in 1975 will be 350 million gallons per day, an increase of 90 percent over that of 1950. This water demand in 1975 will represent approximately 1/3 of the rainfall available for capture and use.

In New Mexico our major increase in water use has come from ground water sources. For example, acres of irrigated farm land receiving the water from wells increased about 200,000 from 1940 to 1950. By 1955 the irrigated land receiving water from wells had increased to about 576,000 acres or about 2/3 of the total. The State Engineer's Office reports that 91 percent of the ground water pumped is used for irrigation.

Another indication of the increased use of ground water is the number of irrigation wells on farms. In 1940 there were 1,558 irrigation wells in the state, by 1950, the number had increased to 3,942 or more than doubled. From 1950 to 1955 or a five year period, the number of wells almost doubled again, or there were about 7,500 wells in 1955. Most of you are familiar with what has happened in the Mesilla Valley and in Curry County. In 1950 the Mesilla Valley had about 46 wells, by 1956 there were about 1,200. Curry County reported about 16 wells in 1950 and at present there are probably over 400 wells.

Most of our urban areas depend on deep wells for their water supply and as you know our urban population is on the increase.

1/ Assistant Professor, Agricultural Economics Department, New Mexico College of A & M A.

Our ground water areas in New Mexico differ widely as to their physical characteristics, recharge, etc. For example the Lea County basin has just about zero net recharge, as far as New Mexico is concerned. The movement of water from the New Mexico portion of the basin into Texas is just about equal to the recharge from rainfall.

We might contrast this situation with the Mesilla Valley, where the principal recharge of the ground water comes from the river. Any time there is surface water in the river channel, the ground water reservoir is, we might say, automatically recharged.

In the Lea County basin any water that is pumped out might be referred to as "mining". There is basically little difference between the water stored there and a mineral such as copper. It is simply another resource stored, and once it is withdrawn, it is not being replaced, in other words it's gone. I like to think of it as a big pail of water and when we use it that's all. Theoretically if we put one farm and one pump in that area it would eventually drain the basin. So we can say that under present conditions, the Lea County area will not support farming indefinitely. At some time in the future we will be out of water.

Economics begins to come into the picture when we try to determine:

1. The point in time the water should be used.

2. At what rate it should be used.

3. For what purpose it should be used.

Let us consider each of these points separately. When the question is raised as to when the Lea County area should have been developed it can get pretty complicated and involved.

The interests of society and the individual are not always the same. For example, to the individual a dollar today is worth a lot more than a dollar in 20 years, but to society as a whole it makes little difference because someone in the society will receive that dollar whether it is 1956 or 1976.

We are all familiar with the terms boom and depressions, inflation and deflation, in our overall economy this goes on in a mild form all the time. We are seldom at a standstill. Now as far as our total economy is concerned it would be better if an area were brought into development during a down swing in business activity, because this would help to halt the downswing. If it were brought into development during an upswing it would tend to add to the inflationary trend.

But, if we consider this from an individual's point of view we find that when business is slow, that funds for investment are much harder to come by. It is much easier to borrow money in good times than in bad.

The second point mentioned was the rate at which the water in Lea County should be used. Should development in the area be limited until it will last 50 years, 40 years or 20 years? I think we can say that it should be used at a rate that will give the greatest net social product. Or we might say at a rate that will give the most people the most satisfaction. At this point we must realize that people have different wants and desires and derive different degrees of utility or satisfaction from the same thing. As yet we have no way to measure the utility or satisfaction an individual derives say from eating an apple, wearing a new suit, or listening to the Grande Old Opera. So, value judgments enter into the picture.

Some of these things are difficult to measure, but must be considered. For example, if there were enough farms in Lea County to deplete the basin in 15 years you can imagine some of the complications. This would require additional schools, churches, roads and other public institutions. We think of most of these as being constructed to last over a much longer period of time than 15 years. Most of the costs of this type are amortized over a much longer period than 15 years.

These are some of the things the administrator of our state ground water has to consider when making decisions regarding the development of a basin.

The third point I mentioned was for what purpose the water should be used. Should it be used for industrial, domestic or agricultural purposes and what proportion should be used for each. I think we can use the same principle we did for the rate of development. It should be divided among the various uses so as to return the greatest net social product.

The same principle applies when we ask how it should be used within agriculture, what crops should be grown and which land should be irrigated. If we think about it for a minute we find that much of this problem will be solved over time. This matter of price does a pretty good job of allocating our resources. In other words if the use of water in industry gives a greater net return than in agriculture, then industry can afford to pay a higher price, and in a free economy will get the water simply by bidding a higher price than farmers can afford to pay.

So we see that this matter of when, at what rate, and for what purpose the water should be used, is very complicated and many things have to be considered before a decision can be made. However, there are guide posts and these should be used when decisions are being made.

Up to now we have been talking in terms of areas and their development; I would now like to turn to the individual or the farm level. In discussing the economics of water at the farm level, it is well to limit ourselves to factors over which the farmer has some control. For example, in this highly competative game of farming, the individual has almost no control over the prices he will receive for a given grade of a commodity.

However, a farmer can exert considerable control over his costs by selection of efficient equipment and good management.

Since this conference is to deal with water, my topic is ground water and to be useful it has to be pumped. Let us examine some of the factors that effect the cost of pumping water.

As I see it, there are five basic factors:

1. Lift, or from what depth is the water being pumped.

2. The efficiency of the pump and motor. By efficiency, I mean the relationship between the input (which might be butane) and the out-put, which would be horsepower, if we are considering the efficiency of the motor.

3. Hours the pump is operated over a given period of time, say an irrigation season.

4. The gallons per minute discharge of the well.

5. The type of power and fuel used, such as electric motors, industrial engines, or automobile engines.

These 5 factors affect primarily the cash costs. There is one important item I should mention as affecting fixed cost and that is the useful life of the equipment and machinery.

The following is a more detail discussion of these factors. The energy required, whether it comes from butane, gasoline, or electricity, to pump a given amount of water increases as the depth (or lift) from which the water is being pumped increases. However, a study of some 60 wells in Lea County in 1952 showed no relation ship between the cost of pumping and lift.1/ At first thought that seems quite unusual. By closer examination we find that there was a relatively small variation in pumping lift. Sixty percent of the wells studied were lifting water between 70 and 80 feet and 86 percent between 65 and 85 feet.

Several other factors tended to obscure the effect of lift on cost. One was the similarity in size of power plant, regardless of the lift and discharge in gallons per minute. Another was the hours the pump operated per season, and the amount of water the well discharged, these two factors varied greatly between wells.

Other studies bear out my earlier statement that it cost more to pump water from greater depths. A recent study made in Pinal County, Arizona where the water is pumped from much greater depths than in most areas in New Mexico, shows some definite relationships between lift and cost. (2) For example, a 50 percent increase in lift, from 200 feet to 300 feet, increased the cash costs per acre-foot from $3.95 to $5.20 or 32 percent. The fact that cash costs did not increase in proportion to lift was largely the result of the decrease in the cost per cubic foot of natural gas as the monthly gas consumption increased.

On the electrically-operated wells in Arizona an increase in lift from 150 to 300 feet increased the cash cost per acre-foot from $4.50 to $9.50. Thus a 100 percent increase in lift increased cost by 111 percent.

In California an increase in lift from 70 feet to 220 feet or 150 feet greater lift, increased the cash cost from $2.75 to $5.25 or the lift was about three times greater and the cash cost about double. (3) Again in California an increase in lift from 220 feet to 475 feet or 255 feet more lift increased the cash costs from $5.25 to $7.25 per ac/ft. The total cost per acre-foot per foot of lift was 5.5 cents at 70 feet, about 4.5 cents at 220 feet and about 2.5 cents at 475 feet.

The next item to be considered, the efficiency of the pumping plant, is an important factor affecting the cost of water. Again from the Arizona study it was found that on the natural gas-operated wells a decrease in efficiency, of 2 percentage points or a drop in efficiency from 10 percent to 8 percent increased the cost of pumping water by 18 percent. An increase in efficiency of 3 percentage points or from 10 percent to 13 percent decreased pumping costs by about 13 percent.

The relationship was similar for electrically-operated wells. Comparing one group of wells with an overall efficiency of 46 percent to another group with 39 percent efficiency, the cost increased by about 16 percent. Increasing the efficiency from 46 to 54 percent or 8 percentage points decreased the cost by about 19 percent.

A study of 68 engine driven pumping plants in Nebraska showed that the plants were using 32 percent more fuel than would have been used by properly engineered plants operated at their designated capacity. (4) So, proper selection, installation and operation can materially affect the cost of pumping.

The third item mentioned earlier as affecting cost of pumping was the hours the pump was operated during the season. Several items of total annual expense, such as depreciation, interest, and taxes are not affected very much by the number of hours operated. Pumps operating a large number of hours per season should be expected to have a smaller per unit cost than those operating a small number of hours. In the Lea County study, the pumps were divided into three groups according to the number of hours operated. The first group, which operated an average of 641 hours had a total cost of $6.21 per acre-foot of water pumped. The second group, which operated an average of 1076 hours had a total cost of $4.64 per acre-foot. The total cost per acre-foot for the third group which operated an average of 1665 hours was $4.11 or only about two-thirds of the total cost for the group operating an average of 641 hours.

The gallons per minute discharge was another factor mentioned earlier as affecting the cost of pumping. In the Lea County study the wells were divided into four groups according to gallons per minute (gpm) discharge. The cost per acre-foot for the different groups was $7.54 for welling pumping 750 gpm and less, $5.60 for those pumping 751 to 1150 gpm, $4.19 for the 1151 to 1550 gpm group and $3.16 for the group pumping over 1550 gpm. The cost per acre-foot for the group of wells pumping 750 gpm and less was $4.38 more than the cost for wells pumping over 1550 gpm.

It was found that high cost per acre-foot was associated with a weak well, regardless of the type of power or kind of fuel used. As the rate of yield or gpm increased, there was a marked tendency for the cost per acre-foot to decrease. The hourly pumping cost for wells with low gpm discharge was about the same as those with high gpm discharge. Little difference was found either in the investment or the rate of depreciation for wells of different gpm discharge.

In most cases, there is very little that can be done to increase the yield or gpm of a well that is in a low water-yielding formation. It is important with any well that the pump operate efficiently in order to obtain the optimum yield the well is capable of producing.

The last item mentioned as affecting the cost of pumping was the type of power used. In the Lea County study there were three basic types of power units used.

Auto-type engines using butane had a total cost of $4.05 per acre-foot.

Industrial type engines using butane had a total cost of $4.65 per acre-foot.

Electric motors had a total cost of $3.63 per acre-foot.

The wells with electric motors had a cost of about $1.00 less per acre-foot than the wells with industrial type engines.

In addition to the specific type of power unit, there is the type of fuel. For example, it might be a choice between electric motors and an industrial type engine with either butane, natural gas, gasoline, or diesel fuel. The units powered by electricity have some advantages. In most areas charges for electricity are on a sliding scale, the more kilowatt hours (KWH) used per month, the less the cost per unit. This is true to a certain extent for natural gas, however, there is usually only one reduction in price per unit. For example, natural gas may be 31 cents per MCF (1000 cu. ft.)

up to 500,000 then 27 cents per MCF. This is not usually the case for butane- propane, gasoline, or diesel fuel. This would mean for pumps powered by electricity, that as the number of acre-feet pumped increased the cost per unit would decrease.

Another factor in favor of electric motors is, that the cost of repairs, lubricants and attendance is less. One objection some farmers give to the electric motor is the fact that you cannot adjust the speed of the motor when only a small ditch of water is wanted.

Useful Life of the Pumping Equipment.

How long a pump, well and motor will last has a definite effect on the long run cost of pumping. We usually think of this as depreciation costs and it is not considered as a cash cost or normal operating cost. However, in the final analysis the cost is just as real as that for fuel or repairs.

There are several factors that affect the useful life of the pumping plant. In my opinion the most important one is the number of hours it operates. Others are, the well drilling methods, quality of underground water, and the amount of sediments such as abrasive sands in the water. The life of the motor would depend more on how well it was fitted to the job to be done; overload and underload may reduce the life. The useful life of any piece of machinery or equipment can be extended by proper care and maintanance.

ECONOMIC LIMITS FOR PUMPING GROUND WATER

Theoretical the amount you can afford to spend for water can be forecast quite accurately, but the practical limit is much harder to arrive at. To determine the maximum water cost, or maximum amount you can pay for water, all that needs be done is:

1. To specify the minimum desired management income per acre.

2. Hold all other factors constant.

3. Allow pumping costs to increase until the management income limit is reached.

Now if we assume an 80 acre farm all in cotton(which is not very realistic under present acreage allotments but will serve to make the point), with a net return per acre of $100. If we allow the farmer $50.00 per acre of this net or $4,000 per year to buy groceries, etc., this would leave a balance of $50.00 per acre. If we can make a cotton crop on 2.5 acre-feet of water, divide 2.5 into $50.00 and we find that we could afford to pay an additional $20.00 per acre foot for water. For example, if the cost of pumping an acre-foot of water is presently $5.00, then you could spend up to $26.00 per acre-foot before you would cut into the

$4,000 set aside to buy groceries. If this is converted into depth of pumping it would mean that you could lift the water about 400 feet. Now if we carry this one step farther, it means that we could pump the water from a depth of 700 to 800 feet before we would reach the point of of no net income.

This concept of economic limits of pumping, or the limiting water cost, is not as simple as was indicated in the example just given. It depends on several factors, pumping cost per acre-foot, intensity of water application and crop grown, government acreage allotments, and the relative price of different commodities. In an area where the water table is lowering we must take into consideration the cost of lowering the well and perhaps a larger power unit. The economic limit of pumping does not exist as a fixed concept, it is dynamic or a changing concept over time depending on cost-price relationships. An advance in technology, (and by an advance in technology I mean that after the new technology is applied you get more output for the same quantity of input than you did before the new technology was applied) could change this concept. For example a new pump 25 percent more efficient, could reduce the cost of water and make it possible to pump from greater depths. The turbine deep well pump, which is of relatively recent development, compared with the old centrificual pump is an example.

Summary

1. Demand for water is increasing.

2. In New Mexico the big increase in water use in recent years has been from ground water sources.

3. There are 3 main points to be considered in the development of an underground water area:

    a. The point in time the water should be used.
    b. At what rate the water should be used.
    c. For what purpose the water should be used.

4. There are about 5 factors affecting the cost of pumping; lift, efficiency of pumping plant, hours the pump operates per season, yield of the well in g.p.m., and the type of power or fuel used.

5. The economic limits of pumping depend on:

    a. Pumping cost per acre foot
    b. Type of crops grown
    c. Government acreage allotments
    d. Relative price of different commodities.

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UNDERGROUND WATER USE AND PROBLEMS IN LUNA COUNTY

G. D. Hatfield [1/]

LUNA COUNTY

The Mimbres Valley Underground Water Basin is located in Luna County and comprises an area of approximately 2,500 square miles.

Underground water, which is the principle source of irrigation water, is found in a thick body of sand and gravel underlying the wide bolsons of the Mimbres Valley. The water derived for pumping comes chiefly from storage, and is evidenced by declining water levels in all areas of irrigational pumpage.

Pump irrigation began in the Mimbres Valley between 1908 and 1911 until by 1914 nearly 200 pumping plants were in operation. The pump irrigation economy suffered a severe slump so that in 1918 there were only 25 pumping plants still in operation. This can be attributed to high production costs, farming crops which were not suited to the land, and inexperience of the operators. In 1923 there began a gradual renewal in irrigation from underground waters and gradually increased ever since so that in 1956 there were 640 pumping plants, irrigated 32,000 acres.

The irrigated area in the Mimbres Basin can be considered as being divided into six districts, for a discussion of ground water level declines.

1. MAIN IRRIGATED AREA (Deming and vicinity and South approximately 12 miles). In 1914 the water level in this area averaged 40 feet below land surface. In 1956 the water level had declined to 100 feet. Large scale withdrawals of ground water commenced around 1940 and the water level decline has averaged 2-4 feet per year. This area contains 20,000 acres of irrigated land at present.

2. LEWIS FLATS (10-15 miles East of Deming)

   Water levels 1914 averaged 40 feet below land surface and 1956 averaged 90 feet, a decline of 50 feet. Acreage irrigated in 1956 was 2,700 acres.

3. FRANKLIN AREA (15 miles East and 5 miles South of Deming)

   Development of this area commenced in 1952 at which time water level was 70 feet below land surface, as of 1956 this level had declined 10 feet. In 1956 there were 1,100 acres being irrigated.

1/ Farmer, member of State Highway Commission, Member of Las Cruces Production Credit Association Board. Has operated a pump irrigated farm for many years in Deming area.

4. WEST OF RED MOUNTAIN (12 Miles West of Deming)

Development of this area commenced in 1950, at which time the water level was 90 feet below land surface. In 1956 the water level was 120 feet or a decline of 30 feet in six years. At the present time 2,500 acres are being irrigated in this area.

5. COLUMBUS AREA

Development in this area commenced in the early 1900's and has been spasmodic ever since. In 1950 approximately 200 acres were being irrigated, whereas in 1956 the irrigation had increased so that 3,900 acres were being irrigated. Water levels in this area remained fairly constant until 1950 at which time a gradual decline in water levels was noted. The depth to water in 1950 varied from 30 to 90 feet below the surface and the water levels have declined 10 feet in the past 6 years.

6. HERMANAS (15 miles West of Columbus)

Development commenced in this area in 1953 and at the present time 2,000 acres are being irrigated. Depth to water averages from 200 to 240 feet below land surface. No significant declines in water levels have been noted.

Pumping lifts at the height of the irrigation season, in the Mimbres Valley, average from 100 feet to a maximum of 280 feet in Hermanas area.

With the greater pumping depth the yields in most of the wells has been greatly reduced as the aquifer has proven to be less permeable at the greater depths. This has necessitated the construction of more supplemental wells in order to develop the required amount of water. For the past 8 years wells have had to be deepened or replaced due to the receeding water table.

HIDALGO COUNTY

In Hidalgo County there are three principal areas in which underground water is used for irrigation, namely the Animas, Virden, and Playas Valleys.

1. ANIMAS VALLEY is located Southwest of Lordsburg. In 1947 approximately 1,000 acres of land was irrigated, by using wells. In 1948 there was a large scale development of this valley so that at the present time approximately 15,000 acres are being irrigated by using 165 wells. The declines in water levels for the period 1948 through 1956 have been 28 feet at center of pumping, to 10 feet at the edge of the pumped area.

Since 1948 it has been necessary to either deepen or replace all of the original wells, the average depth in 1948 being 130 feet, whereas the average depth in 1956 is 300 feet. The pumping lifts average approximately 130 feet.

2. VIRDEN VALLEY is located on the Gila River at the New Mexico-Arizona line. Up until the last 5 years the irrigation in this valley was mainly surface water, with ground water used as a supplement. In the last five years ground water has become the principal source of supply with surface water being used as a supplement. In 1956 approximately 2,600 acres were irrigated with 50 wells in operation.

3. THE PLAYAS VALLEY UNDERGROUND WATER BASIN is located in the Southeastern portion of Hidalgo County, joining Mexico to the South.

The surface drainage covers an area of approximately 1,000 square miles, with the valley floor being approximately 500 square miles in area.

The area contains no permanent streams and practically its only certain source of water is underground. Water derived for irrigation is pumped from storage as in other valleys of this region.

The depth of the saturated valley fill has not been determined to date. A well drilled to a depth of 836 feet failed to reach the bedrocks.

The water table varies from flowing artesian wells to approximately 200 feet in depth. The slope of the land and water table is to the North.

Irrigation of any extent commenced in 1948 and has steadily increased to approximately 2,000 acres, using 20 wells.

In Hidalgo County, as is true for a large part of Southwestern New Mexico, ground water available for irrigation comes mainly from storage. In most of developed areas ground water is being mined resulting in declining water levels.

Underground Water Problems in the Mesilla Valley

Jesse U. Richardson[1/]

Information regarding ground water in the Mesilla Valley is not too plentiful. Hence, in a discussion of this type, it is necessary to rely upon observation, experience in other ground water areas, as well as upon available data. Some conclusions that now appear to be valid may later be subject to modification. This paper, therefore, does not pretend to express a technical viewpoint based upon the analysis of adequate data.

Underground water problems in the Mesilla Valley revolve mainly around the questions of quantity and quality of ground water, as is the case in practically all other ground water areas. Insofar as we know, there is nothing particularly unusual about the ground water situation in this area.

Due to a severe reduction in surface water supplies available to lands in the Mesilla Valley during the past several years, it has been necessary to make extensive use of ground water in this area. Under normal surface water conditions, the average amount of water per acre required by crops approaches three and one half acre feet. Allotments of surface water have been as follows during the past three years:

1954	6 inches per acre
1955	5 inches per acre
1956	4.7 inches per acre

The difference between the normal requirement of around three and one half acre feet, and the actual delivery of surface water, has consisted of ground water.

There are approximately 850 irrigation wells in, and adjacent to, the Mesilla Valley, the vast majority of them being located on the valley floor. These wells vary in size and output, but most of them are capable of pumping at least three cubic feet per second. The wells represent an average investment of around $7000 each, or a total investment of nearly six million dollars. Operation costs are estimated to be about $10.00 per acre foot of water pumped when adequate allowances are made for depreciation, repairs, fuel and interest on investment.

Most irrigation wells in the Mesilla Valley are comparatively shallow. Maximum depth, at present, does not appear to exceed 250

1/ Jess U. Richardson, Farmer and President of Board of Regents at New Mexico College of A & M A.

feet. Apparently the principal water strata now being tapped lie within 100 feet of the surface of the ground. During the early days of extensive well drilling in the Mesilla Valley, many wells were drilled to a depth of only 75 to 125 feet. So far, it has not been necessary to deepen existing wells to any considerable extent in an attempt to tap additional supplies of ground water.

The use of irrigation wells in the Mesilla Valley is presumably a temporary practice, designed solely to meet a serious situation caused by the shortage of surface water. It is assumed that, when surface water conditions improve, the use of irrigation wells will decline substantially, although some pumping will undoubtedly continue, particularly during the winter months. One factor favoring a reduction in pumping is its high cost in comparison with the cost of surface water. Another factor is the decline in the quality of ground water, particularly in some areas.

The Mesilla Valley is not located in a declared ground water district, hence the drilling of irrigation wells is not subject to control by the office of the State Engineer. This lack of control has not operated to the detriment of owners of water right land in the Mesilla Valley for the reason that there is comparatively little new land adjacent to the floor of the valley that is capable of being successfully cultivated. Also, due to the cost of drilling, equipping and operating irrigation wells, water users limit the number of wells, and the extent of their operation, to what is absolutely necessary to irrigate the acreage in cultivation.

Because of its extensive use in the Mesilla Valley, the questions of quantity and quality of ground water are of great importance. The quantity of ground water that underlies the Mesilla Valley has not been estimated. It is known, however, that the water tale extends outward underneath the adjoining mesas for varying distances. Depths to which recoverable ground water is available are not known with any degree of accuracy, but there are some indications that ground water strata may be found below present levels from which water is pumped. There appears to be some variation in occurrence of ground water beneath the valley floor, since occasional dry holes have been reported. There also appears to be considerable variation in materials encountered in drilling, as would be natural in a valley fill. Gravel and coarse sand strata containing recoverable ground water seem to alternate with layers of clay and other materials.

Prior to the extensive drilling of irrigation wells in the Mesilla Valley, the ground water table averaged about nine feet below the surface of the ground, based on Bureau of Reclamation test well data. It now averages about fourteen and one half feet below the surface of the ground, based on the same source of information. This indicates an average drop of approximately five and one half feet since the period immediately prior to 1951 when extensive pumping in the Mesilla Valley began. This does not appear to be particularly bad in view of experience elsewhere. These figures are based upon readings taken from 39 Bureau of Reclamation test wells located in the Mesilla Valley. Because the wells are comparatively few in number, and are not evenly distributed throughout the valley the data should be taken as indicative of a general trend rather than an a precise measurement of ground water levels in the area. There is considerable variation in the extent to which the water table has dropped in various parts of the valley, the difference between minimum and maximum fluctuations being about thirteen feet.

It was estimated some years ago that, beneath each township in the Middle Rio Grande Valley, there were 500,000 acre feet of ground water within 100 feet of the surface. On this basis, there would be around a million and a half acre feet beneath the New Mexico portion of the Mesilla Valley minus withdrawals to date. However, this estimate does not include ground water beneath the adjoining mesas which, in time, would become at least partially available to the wells in the valley and the effect of recharge of ground water from various sources.

There has been considerable discussion from time to time regarding the origin and movement of ground water beneath the Mesilla Valley. It undoubtedly originates from several sources such as precipitation on the valley floor; surface, and below surface, inflow from the adjoining mesas; seepage from the river and from the irrigation distribution system; and from the application of water to valley lands. It is impossible to define with any degree of accuracy how much ground water originates from each source. Positive statements are occasionally made that ground water originates mainly from a single source, but accurate proof of such statements has not been forthcoming. It is known that, prior to the construction of the present irrigation distribution system in the Mesilla Valley, and the furnishing of water from storage, there were no extensive seepage problems in the area. However, soon after the distribution system was extended and irrigation with stored water became possible, the ground water table rose rapidly and it became necessary to construct an extensive system of open drains in the valley. This might be interpreted to mean that the extensive application of water to the land is an important source of recharge to the ground water table; or that seepage from an extensive distribution system is an important contributor. There is some evidence that impervious material has sealed off portions of the river bed from the water table, thereby decreasing seepage loss. At any rate, an extensive study would be required to estimate the contributions from the various sources of ground water underlying the Mesilla Valley and the accuracy of such an estimate would be subject to question.

As to the movement of ground water underneath the Mesilla Valley, there is evidence to indicate a flow from north to south following the gradient of the valley floor. It is known that there is an undergraduate barrier at the lower end of the Mesilla Valley in the vicinity of the cement plant. During times of normal water supply the extreme lower end of the Mesilla Valley, located mostly in Texas, is troubled with a high water table, which is not the case elsewhere, indicating that free flow of ground water from the valley may be obstructed. Drains in the lower portion of the Mesilla Valley have continued to flow slightly, whereas drains in the upper end have been completely dry for a considerable period of time. This situation may also be indicative of a north to south flow of ground water with an obstructed outflow at the lower end. Whether there is any substantial permanent loss of ground water through outflow at points along the edges of the valley has not been determined. There is at least one unconfirmed report of such a situation.

The quality of ground water beneath the Mesilla Valley is generally satisfactory for irrigation purposes. There is considerable variation in quality, however, from place to place. Very few wells in the Mesilla Valley have had to be abandoned because of poor quality water up to the present time, and a relatively small number of wells may be approaching this situation. There is a tendency for total salts, as well as harmful salts, in irrigation well water to increase as pumping continues. This appears to be a natural situation that has also occurred in other areas irrigated by pumping. There is no evidence, as yet, of an accumulation of harmful salts in the soil, caused by the application of pumped water, to an extent that would permanently injure the soil. Water users are aware, however, of the advisability of making full use of available surface water supplies as a means of counteracting a decline in the quality of water.

To summarize and to conclude, it might be said that pumping in the Mesilla Valley is considered to be a temporary measure made necessary by a severely diminished surface water supply. It has been the principal factor in maintaining farm production at a normal level during the past six years in the face of an adverse water situation. It has made possible the transfer of sufficient surface water to small tracts that do not have wells to make it possible to keep such tracts in production. The use of ground water has been economical and has been largely confined to valley lands. The quantity of ground water available has been adequate since 1951, when pumping first began on a large scale, and there is not indication, as yet, of approaching exhaustion of ground water. In general, the quality of the water has been satisfactory for irrigation purposes and there appears to be no immeditate danger of a serious character caused by a deterioration in the quality of ground water.

UNDERGROUND WATER PROBLEMS IN PECOS VALLEY

John Allen Phinizy[1/]

We in the Pecos Valley only have one problem, just not enough water to go around. We have about 132,300 acres in cultivation, of that about 14,000 to 18,000 are watered illegally. Part of this or all will be taken care of in the adjudication of water rights, which is now in progress.

Our recharge is about 210,000 acre feet and withdrawal about 400,000 acre feet per year from both sources shallow and artesian.

By an order from the State Engineer the basin was closed August 1, 1937 to further developments in the Roswell Artesian Basin.

In 1925-1927 Fiedler and Nye reported a total withdrawal from the Artesian Basin as being 150,000 acre feet. C. V. Theis in 1939 estimated the withdrawal from the artesian basin to be 153.249 acre feet plus 97.400 acre feet from shallow wells or a total of 250,649 acre feet from both sources. The figure of 250,649 acre feet is some 40,649 acre feet over the annual recharge at this time.

In Dr. Hontush' report 1955, he states the safe withdrawal to be 130,000 acre feet from the artesian source and from the shallow source 116,000 acre feet. Part of the recharge to the shallow basin comes from return irrigation from the artesian aquifer. Using both figures a total of 246,000 acre feet being the safe withdrawal in the basin.

In 1947, there were lots of new farms developed to the North and West of the Pecos Valley Artesian Conservancy District. April 19, 1947, the Pecos Valley Artesian Conservancy District wrote Mr. John Bliss, State Engineer, to close this area to the North and West. It was not until 1953 that all of this was closed by the State Engineer.

By this time there were 16,000 acres and 141 wells added to the basin, which was closed in 1937. Since 1947 all of our recorder wells show a sharpe decline in water levels.

The Berrendo recorder, which is in the north of the District dropped 19.75 feet from 1927 to 1955.

The Berrendo-Smith recorder well dropped 19.19 feet from 1941 to 1955.

The Mountain-View recorder well dropped 21.41 feet from 1941 to 1955.

1/ Farmer and Secretary-Treasurer of the Pecos Valley Artesian Conservancy District.

The Greenfield Recorder well dropped 41.15 feet from 1941 to 1955.

The Orchard Park recorder well dropped 40 feet from 1926 to 1955.

The Artesian recorder well which is in the south end of the District dropped 71.55 feet from 1932 to 1955.

In the early part of 1956 the Board of Directors of the Pecos Valley Artesian Conservancy District wrote this letter:

Dear Sir:

The Board of Directors of the Pecos Valley Artesian Conservancy District are making a survey to find the thinking of all well and farm owners in the Valley as to what possible steps should be taken to stop the lowering of the water table.

The Board of Directors would appreciate if you would answer the questions below either yes or no. If you feel these are not the solution to our water problems, please feel free to express your idea as to what you feel would solve the problem.

1. Do you think by each farmer in the Valley laying out 5% or 10% of his land would be fair toward the solution? 71 Yes 276 No.

2. Would you volunteer to lay out 5% or 10% of your land? 79 Yes 269 No.

3. Do you think that metering all wells would help solve the problem? 111 Yes 254 No.

4. Would you be in favor of the Conservancy District raising their levy to buy up water rights in marginal areas and retiring the water rights? The additional levy to be set aside for this program only. 132 Yes 222 No.

5. Would you be in favor of metering all wells? 88 Yes 272 No.

6. What is your opinon of correcting this problem?

We had 394 or 39% that replied to these letters. The remarks were many and some were very good.

The adjudication suit will first take care of illegal land and second waste of water.

We flew the Roswell Basin this year locating waste from the air and making personal contact with the farmers, who were in violation. In most cases we found the farmers are not aware of wasting water, and places waste accured were readily repaired. Usually the farmer thanked us for calling to his attention the loss of the water. We found many who were very interested in helping to cooperate with us in this program. Eight farmers were contacted during the summer in regard to wasting water.

We find through measurements that from 25% to 30% of water used in earthern ditches is lost to seepage evaporation and transpiration. An estimated 3000 miles of earthern ditches are in use today in the Roswell Basin. In the past few years farmers are becoming aware of the water being lost in earthern ditches and through the Gpvernment A.S.C. program, the farmers of the Roswell Basin have installed about 100 miles of concrete ditch lining and 200 miles of underground pipe. One can see that we have a long way to go.

RESERVOIRS: I know of a reservoir that is losing one acre foot a day, through seepage evaporation and transpiration. The lost is more than this farmer uses.

Plugged Artesian wells in the Roswell Basin: The Pecos Valley Artesian Conservancy District has plugged some 1036 wells since 1934 to date. At a Cots of $2000.00 a well in 1934 to $850.00 in 1955 and 1956.

METERS: We have seven farmers who have agreed to meter their wells this year. Of these seven I will give you the records taken from three meters.

The first well is located in the northern part of the district. The soil condition is very sandy and the farm hasn't very much underground irrigation tile. This 72.3 acre farm used 3.76 acre feet of water during the irrigation season.

Another metered well is located in the East Grand Plains area in what is considered the center of the pumping area in the Roswell District. This 162.2 acre farm has some two miles of underground tile. The duty of water used on this farm during the crop year of 1956 was 3.76 acre feet.

The last farm was a 75 acre farm below Artesia in the Southern part of the District. The use of the sprinkler system was applied to this farm with the exception of one irrigation, and the total amount of water used was 3.24 acre feet during the crop year.

Underground Water Problems in New Mexico and Specifically in the High Plains Area

E. G. Minton, Jr.

It is certainly not my intention to attempt to compete with Mr. Charles Harris, who gave us such a fine paper this afternoon, but I do believe that some of the ground water problems of New Mexico are most assuredly relative to the water laws of New Mexico and I can hardly mention one without the other. Although the High Plains of New Mexico are specifically absent of almost any flowing streams, relationship between surface water and ground water, in so far as the history and development, must be mentioned for purposes of obtaining a more clear picture.

The type of waters which were used generally in the western states were from streams and the oldest rights are therefore in the base flow of these streams. The flow sustained largely by ground water, thus any surface water rights have higher priority than the rights to wells in the same basin. The priorities as set up by nature in the hydrologic cycle are just the opposite, as the replenishment to ground water reservoirs takes precedence over maintenance of stream flow. To date, relative water conflicts have arisen between users of water from wells and from streams, except possibly in the Roswell Artesian Basin of the Pecos River Valley, where possible serious conflicts may arise between these two users. It is inevitable that complex problems will arise as water levels in ground water basins and the flow of streams continue to decline. It is my personal opinion that these problems can be settled only by an adjudication of all water rights based on full recognition of the physical principles governing the movement of water throughout the hydrologic cycle under natural conditions and the changes that have been affected by development of the waters.

The actual administration of the use of water, whether it be surface or underground, has been impaired in recent years by the courts and the general public showing a lack of thorough understanding of the implications of the hydrologic cycle of ground water and consequently its first cousin, surface water. I believe that many of our water laws were developed in days when knowledge of water, both surface and underground, was very meager. In fact, some of these interpretations have been carried down into recent decisions and can not be valid any longer in the light of our present knowledge.

One ground water problem and one which I certainly consider to be the most serious water problem of all, is the perennial overdraft from a

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1/ Supervisor, Lea County Conservation Office ground water reservoir. In such reservoirs as the one which we have in Lea County, wells year after year, draw water in excess of the annual replenishment and the excess must therefore come from storage. Several of the problems of ground water mining under the appropriative doctrine of New Mexico were clearly brought out in the district court trial of Luther Cooper against the State Engineer's denials of his applications for wells in Lea County. Findings by the State Engineer indicated in the hearing, that pumping of ground water in Lea County since 1948, had been far in excess of recharge and that the excess had come from storage. Further information introduced, indicated that while large excesses of water had been removed from the ground water basin, large volumes remained in storage and much of it could not be removed by the existing wells at that time. The court, having to rely on information introduced, due to the absence of protest from existing well owners, stated that apparently public opinion was not hostile to drilling additional wells for mining of additional water and that apparently no one seemed to favor a reduction in pumpage. Consequently, the State Engineer, following additional studies, extended the boundaries of the Lea County underground basin and set 40 years as a period for reasonable depletion of the ground water reservoir. He further approved applications for new wells in areas where existing wells would not dewater the reservoir within that period and encouraged the change of location of water usage from concentrated areas to less developed areas. A new factor, therefore, has apparently extended the administration of the ground water law and the area has become a criterion in appropriative water rights. History of development in most western ground water includes declining water levels and in the following order, installation of shallow well pumps, installation of deep well pumps, deepening of wells and general over-all increased cost of operation. After decline in water levels become more serious, court suits become more common; such as interference created between wells and eventually on a broader aspect, interference and law suits between between areas of use. These are all the natural follow-up of the efforts on the parts of individuals or districts to maintain a status quo which they enjoyed prior to the mining operations. I most sincerely believe that our present existing ground water laws, as well as our antiquated surface water laws should most certainly be modernized to include the additional hydrologic facts which we have learned within the past 25 years.

I am of the opinion that not only in Lea County but throughout the entire arid southwest, low in precipitation, that we should make every available effort to protect and to conserve all of our nonconsumptive use waters. This could be return flow from irrigation, sewage, waste and precipitation. Many of our western states and including New Mexico, permit the appropriation of water which has been used but not consumed under other rights. There are many such practices of this within New Mexico which I deem most wasteful, in that a large majority of this nonconsumptive water could, by various means, be returned as recharge for further consumptive use based on approved water rights. Many thousands of acre feet of nonconsumed ground water are wasted each year by disposal plants, irrigation companies, industry and individual earthen ditches by evaporation and transpiration. The best storage reservoir available is the ground water basin itself. Water which is lost by seepage is in a large part lost to use by man. It is common knowledge that only a small part is returned to the ground water system for future use, while the major portion is evaporated or transpired.

As our ground water basins become more depleted each year, water on a whole becomes more and more precious and more and more money, whether public or private, will be spent for the protection and conservation as the preciousness increases.

We in Lea County are being faced with a most important problem which, while not too readily recognizable at this time, will no doubt grow into an increasingly cancerous growth as time progresses. Little has been thought of, regarding the salt water being produced by oil wells all over Lea County at the present time. It has, until very recently, been the common practice by the oil producers to get rid of this highly undesirable liquid at the least amount of cost. The highly mineralized salt water has been separated from the oil and dumped into natural dry lakes, into man made surface reservoirs or spread out upon the ground and allowed to flow where it might. From the May, 1956 Oil and Gas Report, there was a reported daily salt water production in Lea County alone of 118,123 barrels, or .362 acre feet per day. Having talked with various oil company operators over the past two years, at which time I became acquainted and personally concerned with the problem, it is agreed that these figures are on the order of 30% low of the actual production figures. More accurate figures of this salt water production would then be on the order of 154,000 barrels per day. This means then, that based on May, 1956, reports there is a total of approximately 172 acre feet per annum being spread upon the surface of the land in Lea County, New Mexico. This further indicates that there is a great deal of this produced salt water being allowed to percolate downward into the fresh ground water system which will time and ultimately, pollute all of the fresh water in the Lea County underground basin. I am happy to report that through the combined efforts of the State Engineer, the New Mexico Oil and Gas Commission and the oil companies themselves, already much has been done to alleviate this problem by the setting up of machinery in order to inject this salt water underground below any oil or fresh water horizons. Much needs to be done and rapidly, and it is my sincere opinion that efforts be made in major proportions to alleviate this problem within the very, very near future. The damage already suffered by the ground water system is yet unmeasurable and will be virtually unknown for some period of time until after levels have declined further, requiring the necessity of deepening the existing wells. This problem of salt water pollution, I believe, to be the major problem of importance that we have today in Lea County.

NEW SOURCES OF WATER FOR IRRIGATION, MUNICIPAL AND INDUSTRIAL USES

John W. Clark, Jr.*

Across our great Nation, from New York to California, in the steel mills and on the farms, there is a growing concern over the increasing thirst of our ever expanding economy. Some people have expressed fear that we are facing widespread bankruptcy of our water supplies. This may be true, but according to the U. S. Geological Survey, 3/4 of the earth's surface is water, and that if all the land were leveled off, water would stand 1½ miles deep over the entire earth. This leads one to believe that water is still one of our most abundant substances and that the principal problems are treatment and distribution of nature's most valuable resource.

Why then, is there a water shorgage in a land of plenty? True, our population is increasing, but the principal reason is the rising standard of living. We require far more water per person per day here in the United States than any place else in the world. To maintain the average U. S. citizen in this high standard of living requires about 1,500 tons of fresh water per year, and this does not include the water for hydroelectric power. Most of this 1,500 tons of water, required by each of us, cost less than 5¢ per ton and even this is a high price for farmers and ranchers as that amounts to $68 per acre foot. Certainly water for irrigation must be less than dirt cheap. Any old fill dirt at $1 per ton is a bargain and still 5¢ per ton is too much for water.

In the past we have depended upon nature for treatment and distribution of water, and we will probably continue to do so for many years to come. It is possible, and in some cases it might be economically feasible, to take small amounts of water from nature's normal process and transport and treat so that it might be available as needed for domestic, industrial and agricultural purposes.

Diversion of Missouri River Water to New Mexico

One such project has been mentioned many times as the solution to our water problems in New Mexico. The piping of a portion of the flow of the Missouri River into Elephant Butte Reservoir. For the sake of discussion, let us assume that we would take water from the Missouri River at Kansas City and pipe it to Elephant Butte Reservoir, a distance of about 800 miles.

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*Associate Professor. Civil Engineering Department, New Mexico College of Agriculture and Mechanic Arts

This envolves pumping the water up for about 4,000 feet. Taking a flow of about 3,450 cubic feet per second for economical design--this is quite a volume of water and amounts to 6,850 acre feet per day or 2½ million acre feet per year. This large volume of water is used to arrive at the minimum cost per acre ft. and would require a conduit around 20 ft. in diameter and 3,900,000 H.P. -- This horse power would be distributed in 50 pumping stations along the line. A project of this type would involve an expenditure of around 2.6 billion dollars. With capital recovery at 3% interest, operation and maintenance and power costs, this would amount to an annual cost of a little over 373 million dollars a year. This would be $149 per acre foot at Elephant Butte Reservoir or around $306 per acre foot delivered to the farms in the Mesilla Valley.

One acre foot of water here in the Mesilla Valley at $306 would have a cost breakdown something like this.

$91	Capital Recovery
$105	Operation and Maintenance
$102	Power cost
$8	Operation of Elephant Butte Distribution system

This pipe line could be built with some modifications of present heavy construction equipment and procedure. The principal difference of this project would be its size. Should this plan be considered feasible, there would still be two major problems to overcome, and their solutions might prove to be the most difficult.

1. Farm lands and cities in the areas of the pipe line would claim a portion of the flow and the 2½ million acre feet would never reach the Panhandle of Texas.

2. It is felt by many, that the Missouri River is being taxed to its utmost to supply the population of its basin. There is no unappropriated water at Kansas City during periods of low flow and the storm flow has been cut to a minimum by the large dams upstream.

During the low flows of the Mississippi River in 1953 and 54, there was low water trouble at New Orleans. Salt water intrusion was creeping up the Mississippi River towards the water intakes at New Orleans. It was necessary to let water out of Fort Peck Reservoir--2,500 miles away on the Upper Missouri River in order to force this salt water back. It has also been necessary to increase the flow of the Upper Missouri River in the last 2 years by letting water out of the dams to help water pollution at Kansas City intakes.

Based on these assumptions and calculations, it appears that the piping of water from the Missouri River at Kansas City to New Mexico is highly unprobable at this time.

Fresh Water from the Ocean

Many people dream of great new supplies of fresh water from the ocean. Considerable interest is being centered on research and development sponsored by agencies of the Federal Government, principally the Department of Interior and the Navy Department. Many of the schemes brought out this far are technically sound, but they cost too much.

One of the most common methods used commerically to produce fresh water from saline water is by distillation. A portion of the salt water is boiled and the vapor which is slat free, is condensed. This process is more efficient fuelwise, if multiple stage stills are placed together in a series so that the condenser of the first, forms the heat exchange for the next stage, which is operated at a slightly lower pressure than the proceeding stage. Too many stages make the process uneconomic and about three is presently considered to be the limit. One such plant using Westinghouse triple effect evaporators is supplying the water needs for over 170,000 people in the port of Kuwait, on the Persian Gulf. This water is being distilled with natural gas as the fuel. It takes only 5¢ worth of natural gas to produce 1,000 gallons of fresh water in Kuwait, but it is estimated that the cost would be over 50¢ in Texas or New Mexico for the same amount of fuel. The total cost of Kuwait's water is about 65¢ per 1,000 gallons and that is using the 5¢ gas and cheap labor. This amounts to $212 per Acre feet in Kuwait and at least $358 acre feet using New Mexico gas. (Labor at the same price as at Kuwait).

Another method for reclaiming sea water is by the ion exchange process. This is the method used by many of our home water softeners. The big problem is the large quantity of total solids that needs to be taken out of sea water. It will vary from 30 to 40 thousand parts per million over the world (30,000# in 1,000,000), but averages around 34,000 pp.m. The present economic limit for ion exchange equipment is around 2,500 ppm total solids. Fresh water could probably be produced from sea water by ion exchange in a large plant for about $325 per acre foot of fresh water.

Another method, and one we hear a lot about in the southwest, is Solar distillation. This is the same process by which nature provides us with our fresh water. This isn't a new idea and scientist have been working with the principal for years. An instillation in Chile in 1883 gave one gallon per day of fresh water for every 9 sq. ft. of surface. Present equipment will yield about one gallon per day of fresh water for every 4 sq. ft. of surface, under ideal conditions. It has been estimated that it would require 215 square miles of equipment to supply the Colorado River Aqueduct. The high cost of initial equipment makes this process uneconomic at present.

One of the most promising methods for obtaining fresh water from sea water is the electrodialysis process. In this method a plastic membrane is an electric field separates the fresh water from the salty brine.

These permeable membranes are reduced in efficiency as calcium and magnesium salts are precipitated on them, and of course, these are found in sea water. At present this electrodialysis method is considered as the most efficient process cost wise. The estimated cost is around 50¢ per 1,000 gallons of fresh water. This process is new and much remains to be seen. This 50¢ per 1,000 gallon is about $162 per acre foot, so we will have to wait for cotton to go up a little before we put that kind of water in our irrigation system. It is not yet possible to recover fresh wate from sea water at costs competitive with ordinary treatment and supply methods. Then too, the ocean is about 400 miles horizontal and 4,000 feet below us here in the Mesilla Valley, and it costs a lot of money to pump water that distance, especially up hill.

One suggestion has been made, that if you can't economically take the salt out of ocean water for irrigation, work from the other direction and develop plants that can use salt water.

Water from Sewage Effluent

A practical source of untapped water lies in our back yards, sewage effluent. The water that you drank today may have once been in Cleopatra's swimming pool! Science believes that the same water has existed on earth for ages, and that there is virtually no more or less than there ever was.

The use or reclaimed sewage effluent has definite possibilities as a dependable water supply for municipal industrial use. The costs can be expected to compare favorable with those of other sources of supply with the exception of irrigation water. Sewage water is a more dependable source of supply than are many others. Sewage flow in a stable community has a rather definite pattern and the amount of flow can usually be predicted with considerable accuracy for any future point in time.

A few years ago when television first became popular, an eastern city noticed a change in their sewage flow pattern. The flows were below normal expectancy for about one hour, and then about nine o'clock in the evening a heavy surge of sewage flow would take place. Upon investigation, they found that there were two popular television shows in a row and then a lengthy commercial. When the commerical would come on, the women would wash the dishes and bathe the children.

Psychological reasons make it unlikely that sewage water will be used for drinking purposes in the near future, but there isn't any logical reason why the major portion of our sewage flows couldn't be put to industrial use.

The idea of reclaiming sewage water isn't new, as several industrial firms have been doing it for some time. The Bethlehem Steel Company is taking Baltimore sewage effluent and piping it 7½ miles through a 60 inch reinforced concrete pipe and paying a fair price for this waste water.

The sludge (digested solid material taken out of raw sewage) might prove to be a profitable by-product in complete sewage treatment. It is estimated that $36 million a year is paid out for sludge disposal. Most of this sludge is dumped in the ocean or in our rivers to eventually reach the ocean floor. If sold, this sludge would bring in $400 million a year and it would return to the land the precious organic food elements now being leached from our soil. The sale of sludge wouldn't pay the cost of sewage treatment, but the total benefits, sludge as fertilizer, fresh usable water in our streams plus increased recreational benefits would more than pay the bill.

Our psychological attitudes that we possess regarding sewage water for personal use will have to be overcome if we are to be space travelers or live for a while on a stallite circling the earth. It seems improbably that we will be able to carry along the huge amounts of water necessary to our persons on a trip lasting days, months or even years. In the absence of other available supplies, it might be necessary to treat and reuse the same water many times.

The reclamation of sewage effluent certainly is not the solution to our farm water problem here in the southwest. This could solve the water problem for most all of our city and industrial users. By proper treatment of our sewage flows, most cities in the Southwest could expand at their present rate for a hundred years with their present water supplies.

In general, the city and industrial water users constitute a non-consumptive use of water. The water is taken into the homes and factories and used for cooling, washing and the conveyance of waste material. This same water can be used over and over as long as it is properly treated between each use.

On the other hand, water applied on fields for irrigation is by in large evaporated and transpired into the atmosphere and completely lost to that area.

A small percentage of this water infiltrates into the ground to the river, to drains, or to groundwater. Therefore, agriculture is a high consumptive user of water and all new sources of water to be beneficial to our area, must be produced in large quantities and cheap enough to be used for irrigation.

The domestic sewage and industrial waste could be treated or delayed in such a way that the public would accept it sooner. Industry doesn't possess the physological barrier and will readily take the reclaimed sewage effluent. Business decisions are usually made on an economical basis. The dependance of supply and known cost versus many unpredictable natural water supplies, will attract many additional industrial users in the immediate future. Several things could lessen the public attitude towards sewage effluent. A time lag would help, then a person wouldn't have the feeling of drinking the same water for dinner that they had for breakfast.

One method for providing a time lag would lagooning the effluent for a month or so before picking it up for treatment. The lagoon could be a natural lake or reservoir or series of park ponds. These bodies of water should have a maximum of beauty and recreational use. Public contact with this water would go a long way to prove that it is just like any other water and maybe a lot cleaner than some.

Another method to provide a delay and help some in lean water years, especially in heavily pumped areas, would be ground water recharge. Ground water recharge is being practiced on other waters in many areas. Mr. E. J. Umbanhauer mentioned the other day that the city of El Paso has studied the possibilities of recharge during the irrigation season with river water. This same water could be repumped at some later date with little loss. There would be no evaporation or transpiration loss and little movement in a perched table. Why not use treated sewage effluent for recharge and pump it out at some later date. There are other possibilities, but they all reduce to a particular situation.

In general, there is an ample water supply over the United States for many years to come. Under present conditions, it doesn't appear economical to bring water in from the Missouri River at Kansas City or to make fresh water out of sea water. Industry has proved that it is economical in certain instances to use sewage effluent as a raw water supply.

Remember, water is neither created or destroyed, nor is it changed in form, it merely becomes dirty and all we have to do is wash it.

WATER CONSERVATION THROUGH
CONTROL OF EVAPORATION

B. W. Beadle[1/]

Necessity for Water Conservation

The old saying: "You never miss the water 'til the well runs dry", has never been more to the point than it is now. The demand for water for municipal, industrial, and agricultural purposes in the United States has increased tremendously in recent years. Critical shortages of water in several major areas have resulted, especially in the Southwestern United States. In Texas, the state is experiencing a severe drouth, which has been termed a "major disaster" by John White, Texas Commissioner of Agriculture. Many counties in South Central, North Central, and West Texas have been declared disaster areas, eligible for federal relief measures. Other states, also, have recently experienced the same general situation with regard to water shortages.

Adding to the burden imposed by drouth conditions on our water supplies, we have a constantly increasing expansion of our population, industries and the use of irrigation on our farms and ranches. Consequently, the increased demands for water are more and more pronounced. The report by the Presidential Advisory Committee of Water Reserve Policy (issued in 1955) estimated that by 1975 the water requirements of the United States would reach 350 bgd. This is an increase of 90% over the requirements of 1950.

Our municipalities, as well as farm and ranch areas, have suffered shortages and, at times, have allocated and curtailed their water usage. An example of critical municipal water shortages is that experienced in New York City in 1950. In other instances, industries have refrained from moving into, or expanding in, locations where water shortages had developed, or appeared imminent.

Means of Conserving Water

There are a number of methods of conservation of water, including recycling, repurification and reuse; and, in rural areas, soil conservation techniques such as small reservoirs and catch basins, cover crops, contour plowing and other anti-erosion methods. A major conservation of water would be possible if evaporation from large reservoirs and lakes could be retarded by any of several control methods or combinations of these. For example, the State of Texas has natural and artificial reservoirs with a surface area of 3800 square miles. The total estimated gross loss by evaporation,

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based on records of the evaporation stations of the Texas Agricultural Experiment Station, is about 18 million acre-feet per year, of which about 10,500,000 acre-feet are replaced in a year of average rainfall. The net loss by evaporation, in excess of the rainfall, from the reservoirs of Texas, therefore, is about 7,500,000 acre-feet. Since the present annual consumption of water in Texas for all purposes -- municipal, industrial, and agricultural, is 8,000,000 acre-feet per year, the size of the evaporation losses, both gross and net, becomes apparent. Since these figures are based on a year of average rainfall, the situation existing under drouth conditions takes on an added significance. Even under normal conditions net losses by evaporation are nearly as great as the total consumption, while gross evaporation losses are over twice as much as consumption.

The States of Louisiana, Missouri, Arkansas, Texas, Kansas, Colorado, Oklahoma and New Mexico have a combined reservoir area of 9600 square miles. This area represents a total yearly evaporation loss of over 39 million acre feet of water (See Appendix A attached.)

Evaporation from reservoirs, especially in hot, arid climates, represents a very significant loss -- in some cases, as much as ten vertical feet of water depth per year. Thus, the full significance of the value of evaporation loss control is apparent. Methods and techniques, once developed, could be utilized throughout the United States and, indeed, world-wide.

The problem of evaporation in the United States has been studied since just before the turn of the century. Studies in Nebraska running from 1895 to 1910 [1] showed that the daily evaporation during the period from April to October was in excess of the rainfall.

Control of Water Evaporation Losses

Losses of water by evaporation can be retarded in several ways. These include [2]:

1. Monomulecular film applied to the water surface.
2. Construction of reservoirs with maximum average depth (minimum exposed surface area).
3. Concentration of water into single reservoirs.
4. Elimination of marine growths.
5. Elimination of shallow water areas.
6. Storing of water in ground water reservoirs (recharge of underground aquifers).
7. Reservoir roofs, floating covers, and sealants.
8. Wind breaks.

It is believed that the methods listed are, in general, self-explanatory. Basically, they serve either to reduce the amount of exposed surface of the reservoir, or to moderate conditions which favor or effect evaporation. The monomolecular film method, we believe, has considerable possibilities as a practical means of reducing evaporation. Consequently, this discussion will concentrate on this method of control, and on the research project now under way on this method, at Southwest Research Institute.

Theory of Action of Monomolecular Films

Certain types of organic compounds -- fatty acids, fatty amids, fatty alcohols, fatty amines, fatty nitriles, and certain special organic materials -- posses the property of forming a film one molecule in thickness when applied to a water surface. These molecules have in their molecular structure a hydrophilic portion, which is attracted by the water (e. g. the --COOH, $-CH_2OH$, $\_CONH_2$, $-CH_2NH_2$, CH_2CN groups, etc.) and a hydrophobic portion (the long carbon chain - 12 or more carbon atoms) attached to one of the above hydrophilic radicals, which is repelled by the water. Thus, when packed together, the molecules stand on end closely packed, and form a resistance to evaporation of the water thus covered. Chemical materials of this type applied to the surface of water will, by their own special nature, spread continuously unless confined by physical barriers such as shore lines, reservoir walls, etc. At any time that a material is present in excess over that amount necessary to form a compressed film one molecule deep, the film-forming material may function as an effective evaporation retardant[2].

History of the Monomolecular Film Technique

As has been previously mentioned, the study of evaporation of water from reservoirs in the United States goes back as far as 1895[1]. Records kept over a period of fifteen years showed that evaporation, even then, was in excess of local precipitation.

Certain effects of thin films of oil have been known for at least 2,000 years (oil has been used by mariners to calm the actions of stormy seas since ancient times). It was not until 1917, however, that Langmuir[3] reported his work on monomolecular films and their use in determining molecular size and shape. Langmuir's work introduced new concepts and experimental methods, and was the first to utilize fatty acids and alcohols. The first attempts to use the monofilm technique to reduce evaporation rates were reported in 1924[4]. These were not successful. The first successful results of the use of a monofilm to reduce evaporation were reported by Langmuir in 1927[5]. The use of a hexandecanol film gave a 50% reduction in the rate of evaporation. The use of an alkylphenol, or cresol, and mineral oil film was patented in 1939[6], but the process did not appear promising for such water bodies as lakes and reservoirs used for drinking water and recreational purposes.

More recently, large scale work utilizing hexadecanol was started in 1952 in Melbourne, Australia[7], with the express idea of reducing evaporation losses in large bodies of water. Although the information reported is incomplete, and somewhat preliminary, the technique and the material used are claimed to be both practical and effective. For normal summer condition in inland Southern Australia, a mean reduction of about 45% of the water loss is predicted.

The Australian research people have not reached definite conclusions, and plan to treat a number of large bodies of water and have an evaluation of the methods within two years.

In Kenya, East Africa, some work has been in progress in the form of field trials on reservoirs of one to ten acres in size.

In the United States, work is being conducted by the U. S. Bureau of Reclamation, the State Water Survey Division of Illinois, and by the Southwest Research Institute.

On a laboratory scale, La Mer and co-workers at Columbia University have recently published their studies [8, 9] on the action of fatty acids, esters and alcohols in reducing evaporation of water. Under the best available laboratory conditions, rate reductions of up to 99.99% were obtained.

Even if the best methods developed do not produce an evaporation reduction of over 45%, this saving is highly significant to the water economy of the United States.

It has been calculated that, on a basis of an application rate of 2.2 pounds of material per acre, a reduction of evaporation of 45%, and a film life of 30 days, the cost of saving (or producing) an acre-foot of water by this process is $1.60, or approximately one-half cent per 1,000 gallons.

The Southwest Research Institute Program

The results from practical tests in Australia may not be applicable to the United States due to differences in climatology, soil, and water conditions. It is therefore desirable to conduct laboratory and field trials here.

The Southwest Research Institute first became interested in the subject of water evaporation control in July 1954, when Dr. Ian W. Wark, of Australia addressed the San Antonio Section of the American Chemical Society on the Australian work on the utilization of the monofilm technique. The plan evolved that experimental work should be done here to develop water evaporation control measures as expecially adapted to our general and climatic conditions.

A full-day meeting was held among persons representing thirteen organizations in Texas interested in water control, and Southwest Research Institute representatives, at the Institute offices in San Antonio on December 1, 1955.

This meeting resulted in a plan for the organization, financing, and management of the water evaporation control program. The tentative project was called "The Southwest Cooperative Project on Control of Evaporation from Reservoirs." The program was set up for a research period of eighteen months, and at an estimated cost of $25,000. Colonel E. V. Spence, General Manager, Colorado River Municipal Water District, Big Spring, Texas, was named Chairman and Mr. Uel Stephens, Manager, Fort Worth Water District, Fort Worth, Texas, was named Secretary-Treasurer of the sponsoring group. The Texas State Board of Water Engineers agreed to act as the contracting agency for the sponsors. The current list of sponsors is shown in Appendix B attached.

The Southwest Research Institute has hoped that research and development of water evaporation control can be a cooperative venture on a wide - even international - basis. Workers in foreign countries and co-workers in the United States have been contacted in a spirit of cooperation, such as the U. S. Bureau of Reclamation, the U. S. Corps of Engineers, the Illinois State Water Survey Board and others. Industries, such as petroleum and chemical companies, who have a major interest in water have been invited to share in this program, and some have done so.

The Program

The proposed research program was designed to give information on the following pertinent subjects:

1. The present status of development by others.
2. The best compound to be used.
3. The best methods of application.
4. Explanations of how the films work.
5. The coverage and life of a film.

6. The biological effects.
7. The effect on physical objects in the water.
8. The effect of pysical factors such as water, temperature, rain, dust, freezing and wave action.
9. The general effectiveness of the treatment.
10. The cost of treatment in terms of acre feet of water saved.

Program - Phase I

A complete bibliography is to be compiled on all subjects relative to water evaporation and its control. This will include theory, methods suitable, means of application, techniques for water evaporation measurement, and all obtainable results of work to date.

Program - Phase II

Phase II concerns the preliminary laboratory work in the screening of organic chemical samples that may be applicable in water evaporation control. As a result of publicity, over one hundred forty-six different samples have been submitted by individual companies for testing, some of them at our request and others offered voluntarily. These are of a great variety of materials, such as alkanols, organic acides, amines, amides, ketones, silicones, diols, etc. Some of the samples are not pure compounds but are mixtures, such as preparations from the treatments of oils and fats (tallow). Inert materials such as ground plastics, plastic bubbles, ground cork, plastic air pillows and membranes, are also on hand for testing.

A fundamental study will be made of the physical chemistry of monomolecular films and chemical substances that are suitable, with the objective of correlating molecular structor or physical properties with their effectiveness as water evaporation retardants.

The major part of the biological work will be done by the U.S. Public Health Service. This will include tests for toxicity of the chemical compounds to be used, their effect on marine animal and plant life, their effect on oxygen and CO_2 transfer rates between air and water, and similar studies. Under the direction of Mr. Bernard B. Berger, work is under way at the Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio.

Program Phase III

Concurrently with the laboratory screening tests, evaluation of hexadecanol and other materials showing promise in the screening work is being investigated in ten-foot stock tanks. This phase will evaluate in a preliminary way the performance of the film under field conditions. In addition to providing a further screening of evaporation retardants showing promise in the laboratory, this phase is also expected to provide a technique which can be used on similar tanks on ranches and farms, after the toxicological effects of the material or materials used have been investigated. Climatic effects, methods of application, life expectancy, etc., can be explored further during this phase.

Program - Phase IV

This phase of the work is similar to Phase III, except that the work will be performed on a larger scale, such as swimming pools, and ponds and reservoirs up to five acres in size. Those compounds showing the most promise in Phase II and III will be further evaluated. At this stage the cost and economics of the process can be calculated with some reality. A large part of the work of this phase will be conducted in cooperation with the U. S. Geological Survey, Denver, Colorado under the direction of Mr. G. Earl Harbeck.

Program - Phase V

As the final step in the program, as now outlined, it is planned to present a schedule of tests and a program for treating large reservoirs (several hundred acres to several square miles). This will be done only after full clearance has been obtained from local, state, and U. S. Government Agencies, such as the local health departments, Fish and Game Commission, State Health Department, U. S. Public Health Service, Food and Drug Administrations, etc., including assistance from the U. S. Bureau of Reclamation and the U. S. Geological Survey. Thus, large bodies of water, particularly those used by animals or humans as drinking water sources, will not be used in the testing program until all possible deleterious effects have been eliminated.

Tests Currently in Progress at Southwest Research Institute

In the Chemistry and Chemical Engineering laboratories at Southwest Research Institute, the screening tests are near completion. One hundred thirty-six samples have been evaluated as of September 1, 1956.

The screening apparatus consist of an insulated constant temperature bath, containing water maintained at about 30°C. Battery jars placed in the trough contain the water under test. Sweep air is dried by being passed over silica gel. It then flows over the water surface at 0.3 mph. Water levels are maintained automatically by means of inverted, closed top cylinders (similar to a chicken-watering device).

Test dosage has been one pound of material per acre. Twelve samples and two control tests make up each test bank.

The fatty alkanols have shown up best to date. Although the fatty acids and fatty amides are known to form monofilms, and the former, under most precise laboratory conditions gave over 99% reduction of evaporation, neither type of compound has shown up well under conditions here. It is felt that the test conditions at Southwest Research Institute give a fair indication of preformance to be expected, at least for a short time, in the larger field tests. Tests which have been conducted in the ten-foot stock tanks tend to confirm this.

Four of the best materials produced by the screening program have been evaluated in the ten-foot tanks. Excellent reduction of evaporation has been achieved but only for a short time - five to eight days. Ways and means to increase the film life are being studied.

The basic evaporation and seepage characteristics of a four-acre lake located on the Essar Ranch, about six miles from Southwest Research Institute, have been determined in cooperation with the U. S. Geological Survey in Denver, Colorado. Two sets of tests have been conducted, one with hexadecanol and one with octadecanol. The technique of application was apparently faulty, as little, if any, evaporation reduction was effected. Our work will be continued as rapidly as possible.

The U. S. Public Health Service indicates some bacterial attack on hexadecanol. Results are preliminary, however, and investigations are continuing.

Summary

It has generally been found that long straight-chain primary compounds appear to show the most promise as evaporation retardants, which is in agreement with published theories. These have one disadvantage in that they may be subject to biochemical oxidation. This is especially true of the alkanols, although these materials form a film having a more sustained reduction of evaporation than acids, amides, or amines of various types.

Small, hard lumps of materials not over 2 mm diameter are believed to be the most desirable physical form of the solid film-forming material. The film does not generate rapidly from particles one-fourth inch and larger. Liquid materials offer the problem of how best to store the necessary reserve material to replace that consumed by shore losses and adherence to piers, boats and other objects in the water, and other losses.

The best evaporation retardants have shown savings of evaporation of as high as 93% for short periods of time, and 45-50% for as long as fifteen days in the laboratory and 5-8 days in the field. This short life in the field indicates the need for refinements in techniques of' application. Some of these are presently under consideration.

In addition to the increased water supplies to be made available by reducing the amount of water lost by evaporation, the same technique may make usable some water reservoirs now brackish or saline. Inasmuch as it is water only that evaporates, reduction of evaporation may save enough water to render usable some borderline water sources.

The ultimate objective will be to develop a practical and economic method for reservoir evaporation control - one that will be of maximum benefit to water users in the Southwest and other portions of the United States, and, indeed, the world.

APPENDIX A

WATER EVAPORATION LOSSES BY STATES*

State	Inland Water Surface	Annual Evap. Depth	Annual Evap. Loss, Acre Ft.	Loss Cubic Miles
Louisiana	3361 square miles	52 inches	9,321,000	2.76
Missouri	448 " "	85 "	2,031,000	.60
Arkansas	429 " "	69 "	1,579,000	.47
Texas	3826 " "	89 "	18,160,000	5.37
Kansas	168 " "	85 "	762,000	.23
Colorado	325 " "	100 "	1,733,000	.51
Oklahoma	888 " "	102 "	4,830,000	1.43
New Mexico	155 " "	114 "	942,000	.28
			39,358,000	11.65

*Taken from the 1956 World Almanac. (Bureau of Census Information)

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APPENDIX B

RESERVOIR EVAPORATION CONTROL SPONSORS AS OF AUGUST 11, 1956

Freese and Nichols
City of Weatherford
Pioneer Natural Gas Co.
Central Power & Light Co.
City of Abilene
Empire Southern Gas Co.
Houston Lighting & Power Co.
City of Waco
General Telephone Co.
City of Dallas
City of Fort Worth
Cosden Petroleum Corp.
Colorado River Municipal Water Dist.
Tarrant County Water Control & I.D. #1
Southwestern Bell Telephone Co.
W. S. Dickey Clay Manufacturing Co.
Texas Vitrified Pipe Co.
Powell and Powell, Engineers
Forrest and Cotton, Consulting Engrs
Lone Star Steel Company
Texas Electric Service Co.
Gulf States Asphalt Company
Dallas Power & Light Co.
Gifford - Hill - American, Inc.
James B. Clow & Sons, Inc.
Texas Water Conservation Assoc.
U. S. Pipe & Foundry
West Texas Chamber of Commerce
Wyatt B. Hendrick, Lawton, Okla.
El Paso Natural Gas Co.
United Gas Pipeline Co.
Sabine River Authority
West Texas Utilities Co.
Brown County Water Impvt. Dist.
American Cast Iron Pipe Co.
Allis-Chalmbers Mfg. Co.
City of San Angelo
Ambursen Engr. Co.
Texas Gulf Sulphur Co.
Humble Oil & Refining Co.
Fairbanks, Morse, & Co.
American Water Works Assoc.
Rockwell Manufacturing Co.
Continental Oil Co.
City of Houston
City of Wichita Falls
Rohm & Haas Co.
Lower Colorado River Authority
Gulf States Utilities Co.
Archer-Daniels-Midland Co.

CANAL AND RESERVOIR LINING

C. W. Lauritzen[1]

Lining of irrigation canals and reservoirs offers one of the best opportunities to extend limited water supplies. Not only is lining effective in controlling seepage losses, but it provides insurance against breaks, reduces maintenance costs, and constitutes a good weed-control measure.

Many materials have been used successfully for linings. In the United States, earth, asphalt, and concrete are the materials most commonly used. Recently a number of new materials have been investigated; among these are butyl rubber, plastic film, and soil stabilizers. The material best adapted for a given lining will depend upon site conditions and the choice determined by the labor involved and the relative cost of material, equipment, and labor.

Earth linings

Earth linings are not new, but in recent years the use of earth for controlling seepage is being investigated with renewed interest. Several types of earth linings are being investigated and utilized to some extent. A lining which has attracted considerable attention is the thick, rolled, earth lining. This lining is about 8 feet thick in the horizontal plane and 3 feet thick normal to the side slope. The U.S. Bureau of Reclamation reports[2] seepage in the order of 0.07 cubic foot per square foot of wetted area per 24 hours from properly constructed heavy compacted earth-lined canals. This is comparable to seepage losses from good concrete-lined canals. There are indications that these thick earth linings will become more permeable with use. Some investigations to determine the increase in permeability which accompanies use are in progress currently by the U.S. Bureau of Reclamation.

The earth linings at our River Laboratory, with one exception, have all tended to deteriorate with time. This includes natural earth materials and soil bentonite mixes. However, none of these

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1/ Soil Scientist, Western Soil and Water Management Section, Soil and Water Conservation Research Branch, Agricultural Research Service, U.S. Department of Agriculture.

2/ Canal Linings and Methods of Reducing Costs. Bulletin U.S. Bureau of Reclamation.

linings are of the thick, rolled type, but are composed of relatively thin earth blankets covered with gravel. The thin blanket-type linings, if compacted when installed, gradually decrease in apparent specific weight. Likewise, uncompacted earth linings have tended to increase in apparent specific weight until both the compacted and the uncompacted linings have about the same apparent specific weight and exhibit similar seepage losses. It has been concluded from our studies, therefore, that thin-blanket-type linings, to be effective, must be constructed of earth material having a low permeability independent of compaction. Apparently, material such as gravelly and sandy clay in which the clay does not exhibit extreme volume change upon wetting and drying is better adapted to the thick compacted earth lining. While frequently employed without a cover, the life of the thick compacted earth lining will be extended appreciably by the addition of an erosion-resistant topping such as gravel.

Treatment of canals and reservoirs with fine sediment has long been employed to control seepage. The cost is extremely low, but the benefits of this type of lining were generally of short duration and limited effectiveness depending upon the penetration of the sediment into the porous structure of the subgrade. An extensive study on the development and use of sediment linings is in progress at present under the direction of R. D. Dirmeyer.[3/] It has been reasoned that, if by some method the sediment can be held in suspension until penetration can be accomplished, the amount of material deposited in the canal subsurface will be proportional to the extent of the seepage--since the most water will be moving through the bed material at these locations. Various dispersing agents have been used and the results obtained to date are encouraging. Because of the cheapness of the method, it has great possibilities even if the treatment must be repeated at fairly frequent intervals.

The use of dispersing agents, such as polyphosphates, to reduce the permeability of soil, and thereby control seepage, is another promising cheap method which may be effective under certain conditions. Good seepage control from polyphosphate treatment in eastern United States has been reported by Lambe.[4/] Only small quantities of the chemical are required and the treatment is cheap by comparison with other materials. The effectiveness of the treatment, however, is limited by the character of the earth to be treated,

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3/ Dirmeyer, R. D. Colorado Agricultural and Mechanical College, Fort Collins, Colorado.

4/ Lambe, T. William. Impermeabilization of the Lagoon at the International Paper Co., Technical Association of the Pulp and Paper Industry, January 1955, Vol. 38, No. 1.

and therefore, the use of polyphosphates should be preceded by an investigation of site conditions and materials.

Asphalt linings

The water-repellent and adhesive properties of asphalt early attracted attention to it for canal and reservoir lining. Its resistance to biological deterioration and the action of acids, bases, and salts is another property of asphalt which is favorable to its use as a lining material. These properties and the availability of asphalt in this country led to numerous attempts to employ it in irrigation canals and reservoirs for seepage control and channel stabilization. Linings for these purposes have varied widely and many types of asphalt products have been used.

While numerous variations of asphaltic linings have been tested, the types most studied or successful fall into six categories; asphaltic-concrete linings, prime-membrane linings, buried-membrane linings, prefabricated liners, built-up linings, asphalt-emulsion linings and underseals. The general characteristics of the lining in the first four categories are outlined in a publication of the Asphalt Institute 5/ and a series of publications by Benson. 6/, 7/

The renewed interest and development work in the use of asphalt for controlling seepage losses in irrigation canals and reservoirs has been due to greater awareness of the need for water conservation and recognition that cost of the lining is a governing factor in its choice. Both the asphalt industry and public agencies have contributed to these studies. The search for lower-cost linings and linings adapted to varying site conditions goes on; nevertheless, some progress has been made. The cost of standard linings, such as concrete and earth, has been reduced through improved design and mechanization to less than it was 10 years ago, despite the general rise in construction costs during this period. The acceptance and wide usage of asphalt in this period was largely the result of the development of the buried-asphalt membrane (BAM) lining by the U.S. Bureau of Reclamation under the direction of J. R. Benson.

The BAM lining is the product of early failures, failures of exposed asphaltic linings, and adjustments to overcome these difficulties. The cracking and hardening of the asphalt from

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5/ The Asphalt Institute, 801 2nd Ave., New York 17, New York Asphaltic Canal Linings, Construction Series No. 86, February 1949.

6/ Benson, J. R. Buried Asphalt Membrane Lining Developed to Give Canal Seepage Control at Low Cost. Western Construction News, Sept. 15, 1949.

7/ --------------. Test of Prefabricated Canal Lining. Western Construction News, April 15, 1950.

exposure and mechanical damage was found to be sufficient to destroy the effectiveness of prime-membrane linings in about one year's time. In an attempt to improve the durability of these exposed membranes, fillers such as diatamaceous earth were added to the asphalt which extended their life but did little to improve the resistance to mechanical damage. Development work on prime-membrane linings has been largely discontinued or redirected.

The most common of the BAM linings is the sprayed type. Since the asphalt used in this type of lining has a high-softening point, special equipment and experienced contractors are required. This and practical difficulties led to the prefabrication of asphaltic liners for canals and reservoirs. These liners look and are handled much like roofing felts. The first were nothing more than a layer of asphalt on a paper backing to facilitate handling. Since then, a number of types have been produced, all containing supporting structures or fillers, such as fiberglass, asbestos felt, and aluminum foil. These liners are about 1/8 inch in thickness, and because of the weakness of the structure and susceptibility to deterioration upon exposure, are intended and employed primarily as buried membranes. Recently, prefabricated asphalt liners about 1/2 inch in thickness have become available commercially. These liners have a high percentage of filler and are semi-rigid and supplied in plank form. They are sufficiently flexible, however, that they can be fitted to the shape of a canal and can be employed as exposed linings. They are moderately resistant to mechanical damage but time alone will determine how long this type of lining will last.

The built-up lining is an exposed lining which consists of alternate layers of asphalt and a supporting fabric, such as jute, cotton, or fiberglass. Such linings have considerable resistance to mechanical damage and the supporting fabrics reduce the deterioration resulting from exposure. Toppings of gravel or other material imbedded or bonded to the surface may be employed to provide further protection from the elements and thereby materially reduce the deterioration of the asphalt.

The possibilities of this type of lining have not been fully explored, and further tests using such materials as fiberglass and jute are being made at the Utah Station. This work is new, and consequently no conclusion can be drawn concerning the effective life of these linings. It does appear, however, that they can be constructed somewhat cheaper than the heavy prefabricated type and should exhibit equal or better durability.

Another lining which has received considerable attention is asphaltic concrete. It consists of sand and gravel aggregate, stabilized with asphaltic cement. Linings of this type have performed reasonably well, and at one time, were being promoted rather extensively. The hot mixes have proven most satisfactory. The cost of this lining is about the same as portland cement concrete lining but appears to be considerably less durable under most conditions.

The use of emulsions for surface applications and as underseals is currently being investigated, but this work has not progressed far enough to draw any general conclusions.

The development of the catalytically-blown asphalt by the Lion Oil Company of El Dorado, Arkansas, likely can be considered largely responsible for the success of the BAM lining. Catalytically-blown asphalt is flexible over a wide range of temperatures without becoming liquid. It is tough and retains these properties over a considerable period of time, if protected from the sun's radiation. Experience with this liner indicates it will give reasonably good service, if properly installed, but unless certain minimum requirements are met, BAM linings will not be effective and will be more costly than other types of lining.[8/] The subgrade should be smooth, firm, and fine-textured and the cover material should consist first of a fine-textured layer topped with material sufficiently coarse to be stable at the velocities for which the canal is designed. Although it has been demonstrated that these BAM linings effectively control seepage where properly constructed and maintained, they have serious disadvantages as do all buried linings. In the first place, if they are damaged, it is very difficult to make repairs. Where cleaning is necessary, it is a problem to carry out the operation without damaging the lining. There is more of a cleaning and weed problem, and a much larger ditch is required to provide the same capacity, because of the less favorable hydraulic properties associated with these liners. Because of these unfavorable properties, we are continually searching for some means to avoid covering. The use of asphaltic concrete accomplishes this, and the thick prefabricated and built-up linings are attempts to do the same thing. The most serious difficulty encountered with these linings is the deterioration inherently associated with asphalt when exposed. Much progress would be made, if an asphalt could be developed which had better weathering properties. Some attempts have been made to accomplish this. Probably the poor stability upon exposure is associated with the unsaturated condition of the constituent hydrocarbons and saturation or partial saturation would improve the aging properties upon exposure. Some work has been done along this line with evidence of some success. Shielding the asphalt provides another approach.

Concrete linings

Mention canal lining to a water user in the United States and the chances are good he will think in terms of portland cement concrete. Portland cement concrete has long been used, and under conditions favorable to its use, it is hard to beat. The only reason other

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8/ Lauritzen, C. W. Site Conditions Increase Cost and Problems of Canal Lining Maintenance in Utah. Western Construction News, May 1953.

of lining are considered by many people is the high cost of concrete lining. Concrete linings have good hydraulic properties, they resist damage, and minimize cleaning and weed problems. Considering the durability and limited maintenance required for concrete linings, there is considerable doubt about the annual cost of concrete linings being greater than some other so-called lower-cost linings. Advances during the past 10 years have made it necessary to revaluate relative cost. As previously mentioned, although construction costs have more than doubled during this period, the cost of lining with concrete is lower now than it was 10 years ago. Costs as low as $2.20 per square yard for 3 1/2 inch concrete are reported by the USBR for the Friant-Kern Canal in California, a canal with a capacity of 2,500 to 5,000 cfs. A small canal in the vicinity of Ogden, Utah, was lined at a cost of $2.62 per square yard with 3-inch unreinforced concrete and $2.25 with 2-inch. The cost of the concrete for 1 square yard delivered to the site of the job ready for use was $1.02 and $0.62, respectively. Not only have construction costs been reduced, but new developments such as the use of air entraining agents have resulted in better concrete.

Butly rubber and plastic film linings

Plastic is becoming a universal material. Among some of the newer uses is its use for conveying water and controlling seepage losses. Butyl[9] has been found to be highly resistant to aging and appears to be well adapted to use as buried lining in the form of unsupported sheeting and to tubing in the form of coated fabrics. Plastic film of certain types also looks promising for buried linings, and plastic tubing offers possibilities for use in farm distribution systems. Information on long-time tests is not available, but short-term tests and artificial-aging studies indicate that film linings[10] of polyethylene, and polyvinyl chloride will effectively control seepage when employed as buried liners. When these films are employed as barriers to seepage, it is necessary to take special precautions against damage to the film during installation. If this is done, it appears that these materials will provide effective seepage control over a considerable period of time. Because of the weakness of the film and the ease with which it is punctured, it is necessary to use a cushion course of fine-textured material, both above and below the film. To protect the cover from erosion, a

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9/ Lauritzen, C. W. and Peterson, W. H. Butyl Fabrics as Canal Lining Materials, Utah Agricultural Experiment Station Bulletin No. 363.

10/ Lauritzen, C. W., Haws, Frank W., and Humpherys, Allan S. Plastic Film for Controlling Seepage Losses in Farm Reservoirs. Utah Agricultural Experiment Station Bulletin No. 391

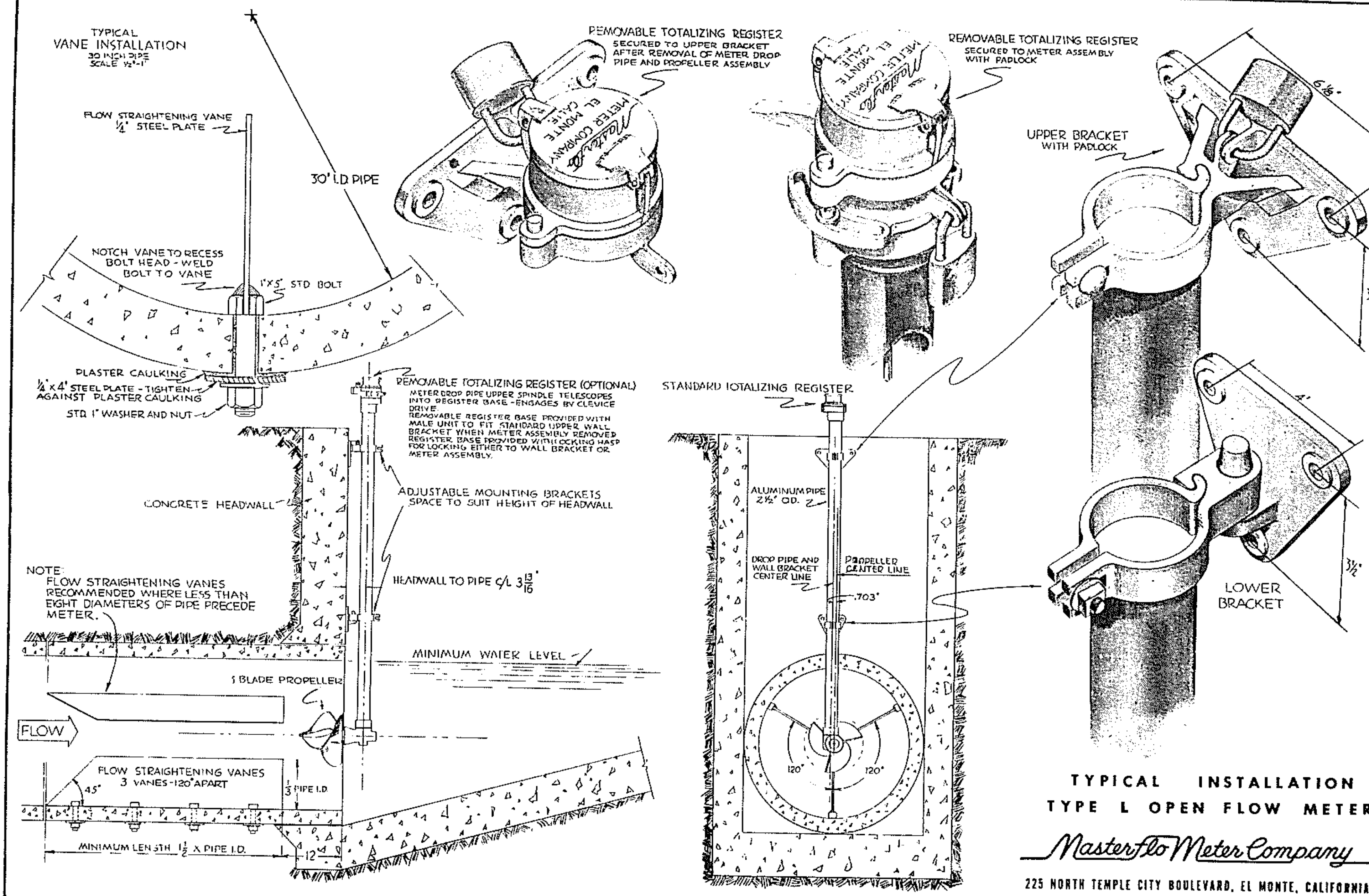
topping of gravel or other erosion resistant material will be required. Buried plastic films, like other buried liners, have certain disadvantages particularly for canal linings as previosuly mentioned. When employed for reservoir lining, the reduced capacity factor vanishes. Because of this, buried liners compete more favorably for reservoir lining than canal linings.

Plastic film for buried linings has one important advantage over other types. Because of its light weight, it can be fabricated in large units, minimizing field joints. It also eliminates the necessity for careful trimming of the canal prism in an effort to avoid fish mouths along the joints. Since the material is extremely flexible, if a little slack is allowed, it will adjust to subgrade irregularities without difficulties or impairment to the effectiveness of the material as a liner. The same advantage applies to butyl rubber to a lesser degree.

Stabilized earth linings

Concrete is not always the answer. In some areas, suitable concrete aggregate is not available locally, and because of this, other types of lining must be resorted to, if lining is to be economically feasible. In certain areas, buried membranes might be used, but since some type of gravel will be required to stabilize the cover, there are areas where something else must be used. Soil cement is a promising possibility in sandy areas. Soil cement consists of a mixture of portland cement and soil, the soil replacing the sand and gravel used in concrete. There are two types of soil cement--the plastic and standard. The plastic is mixed and placed similar to concrete. The standard, on the other hand, is mixed at optimum moisture for maximum compaction as determined by the Proctor method. Compaction is necessary to obtain the desired density. One of the problems encountered in the use of standard soil cement in canals has been the problem of compaction on the side slopes. Where good compaction can be obtained, the standard soil cement is more durable than the plastic type. Many methods have been employed to secure compaction on the side slope but a successful method has yet to be developed. The use of a traveling vibrator is being investigated, and the results obtained are promising, particularly for small canals. There seems to be no reason why the method cannot be adapted to larger canals.

The use of soil chemical stabilizers is another possibility for controlling seepage in canals and reservoirs. The one with which we have done the most work is water soluble, and when a catalyst system is added to a monomer solution, it polymerizes. When mixed with the soil, the gel forms around the solid particles and in this way binds the soil particles together and effects stabilization. The resulting mass is tough, yet slightly flexible when wet. The stabilized soil becomes hard when dry, but upon rewetting, assumes its original semiflexible characteristics. The character of the gel formed can be varied by varying the concentration of the monomer--a stiffer gel being produced with more concentrated solutions. The



TYPICAL INSTALLATION

TYPE L OPEN FLOW METER

Masterflo Meter Company

225 NORTH TEMPLE CITY BOULEVARD, EL MONTE, CALIFORNIA

DATA SHEET 234

JAN. 1955

time required for polymerization or gelling is governed by several factors, among which are the concentration of the catalyst and activator in the catalyst system and the temperature. Preliminary studies indicate that better stabilization is obtained when the soil contains some fines. The use of the stabilizer, therefore, might well be used in areas where the silt and clay content of the soil is too great for good soil cement. While encouraging results have been obtained, additional work will be required before the use of this stabilizer to line canals and reservoirs is practical. In the laboratory, we have been able to secure stabilization with both plastic mixes and mixes with the moisture content optimum for maximum compaction. Although several field tests have been conducted, we have yet to install a successful lining employing the dry mix.

Summary

Frequently the question is asked, "What is the best lining?" The answer to such a question obviously cannot be a generalization. Site conditions, relative cost, and availability of materials are governing factors. A canal located on a hillside presents a different problem than one through a broad valley, for at least one important reason. It is costly, if not next to impossible, to construct a canal on a steep sidehill with flat side slopes. Because of this, generally linings requiring flat slopes are not adapted to these locations. It is inviting trouble to use earth and membrane linings in canals and reservoirs where the material is subject to piping unless special precautions are taken to limit the hazard. It would be folly, on the other hand, to employ concrete linings in areas subject to high groundwater tables during periods of freezing weather. Frequently, in the design of a canal, there is a choice of reducing the gradient through drops to provide low stream velocity, or employing a lining material which will tolerate higher velocities. The most satisfactory and least costly method will depend upon the situation. The sediment content of water, the cleaning problem, and the importance of weed control are other factors which bear on the choice and effectiveness of a lining. Other factors might be enumerated.

We have made progress in the past in improving and adapting materials and methods employed for lining, and I feel sure the future holds promise of further progress. An encouraging development of our time has been the joining of industry with research organizations to solve problems and adapt materials to new uses. Such a combination should speed progress.

Meters for More Efficient Use and Conservation of Irrigation Water

Dwight Davenport[1/]

The use of meters in irrigation operations, to obtain more efficient use and conservation, is becoming almost as standard practice as the use of meters to measure the gasoline we put into the tanks of our automobiles. In New Mexico, as elsewhere, water is not only scarce, it is expensive. Therefore it behooves everyone to try to attain the highest possible efficiency of operation. The use of meters to tell accurately how much water is being used is of great importance. I think none of us would be satisfied to drive into a service station, have the attendant stick the nozzle into the tank, count verbally to twelve then say "OK, you owe four dollars." Yet, I have seen some methods of arriving at quantities of irrigation water which are just about as accurate as that.

My remarks here will deal with two basic types of propeller actuated meters. The Open Flow type meter is used at gate structures, siphons, turnouts, etc., where the water flows into an open ditch or canal. The Tube Type meter is used where the flow is through a tube, pipe, penstock, or pump discharge. Meters can be supplied to register in any standard unit of measurement, i.e. gallons, cubic feet, miners inches, acre feet, etc. The shape of the flow conveyance can be round, square, rectangular or any other, so long as a definite cross section area is maintained. And the conveyance must run full at all times. Meters can be equipped with Indicator Heads to show the Rate of Flow. Also, available are instruments for remote indication, totalization, and recording of flows at any distance from the meter location.

Now rather than try to expound a lot of theories or ideas about the use of meters, I would prefer to tell about a few places where meters are installed and operating, their purpose, and results obtained. There have been cases where the saving of water has resulted as a sort of secondary consideration. Some of the primary purposes for which meters are installed can be ordinary measurement, efficient control of flows, equitable distribution, basis of allocation, etc. The proper use of the information supplied by the meters does, in nearly all cases, result in the saving of water.

A few installations are -

U. S. Bureau of Reclamation, Albuquerque.

Large Type S Open Flow meters are installed on two siphons under the Rio Grande River. The Corrales Siphon, 60" in diameter and Atrisco

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1/ Sparling Meter Company, El Monte, California

Siphon, 78" in diameter. Here the meters serve to tell how much water is diverted from the east side to the west side of the river and also indicate the rate of this flow in cubic feet per second.

Salt River Valley Water Users Association, Phoenix, Arizona.

Here Type R Open Flow meters are installed in the Cross Cut Canal and are used to control the flow so that the flow into this canal can be held equal to the amount of water ordered by the users farther down the canal. The meters can also totalize the amount of water passed in any given period.

Buckeye Irrigation Company, Buckeye, Arizona.

On this project the Type L Meter is used to check the accuracy of farm deliveries at the farmer's turnout.

Arlington Canal Company, Arlington, Arizona.

Here irrigation water was in such short supply that frequently there was not sufficient water in the lower end of the canals to give the adjacent farms any delivery at all. By using meters to give accurate deliveries and make judicious allocation of the available water all the farmers were enabled to stay in business.

Wellton-Mohawk Irrigation and Drainage District, Wellton, Arizona.

This project has about 700 individual farm turnouts, all 30" in diameter, and all equipped for measurement with Type L Open Flow meters. The farmer pays in advance for a specified number of acre feet of water, then each irrigation delivery is deducted from his credit balance in exactly the same manner that money is withdrawn from a balance in the bank. Meters are also used at various points in the canal system and now consideration is being given to installation of meters in the discharges of the big pumps at the lift stations. These meters would serve to promote more efficient pumping operations and to check the pump efficiency as to kilowatts of power consumed, in addition to providing accurate records of the amounts of water delivered into the canals. In this project where every inch of water is charged against him the farmer naturally strives for the best possible use of his water and goes all out to prevent waste.

Orange County, California.

In Orange County every well is required by law to be equipped with a meter on the discharge. These are the Tube Type Low Pressure Line Meters. Water is taken from the All American Canal and put into the underground water strata, then pumped out by the farmers. On the basis of the amount of water pumped the farmer is assessed for his pro rata share of the cost of operation of the project. Because of this cost he naturally tries to conserve water. Mr. Dick Lindsey, University of California Farm Adviser, was quoted in the Los Angeles Times as saying that only a 5% to 10% improvement in irrigation practices will save 10,000 acre feet of water a year.

U. S. Indian Irrigation Service, San Carlos Project, Arizona.

Because of the shortage of water in San Carlos Reservoir all irrigation water is pumped from wells. Tube Type Low Pressure Line Meters are used on the discharges of pumps and because power costs are very high they serve to give a good check on pumping efficiency. Also when the time comes to establish water rights based on past usage the meter records will be of inestimable value.

In closing let me emphasize the fact that a meter cannot produce a drop of water. Nor can it, by itself, save a drop of water. But proper use and application of the information supplied by the meter can result in more efficient operating practices and consequent conservation of the water available today.

WATER YIELDS THROUGH WATERSHED MANAGEMENT IN NEW MEXICO

by

E. J. Dortignac 1/

Climate and water supply have exerted a powerful influence in the settlement and development of New Mexico. The high mountains have adequate precipitation for agriculture and the lower plains and valleys with deep fertile alluvial soils, long growing seasons and high temperatures are favorable for growing crops. Yet, precipitation is wholly deficient in these lower-lying lands. Thus, the problem in this state has been and will continue to be -- how best to manage, conserve, protect, store and deliver the mountain water supplies to the lower water-using areas.

The recent upsurge in population with its increased water-use and the prolonged drought starting in 1943 have resulted in an increased demand for water. This increased demand is causing a diligent search for new supplies and for an answer to the age-old question of how much more water can be obtained from existing sources. It is, therefore, natural that we should look to the mountains and wildlands with its myriad of small watersheds and ask the question, "How can these lands provide more usable and dependable water for downstream use?"

Our knowledge of the relation of climate, topography, geology and soil on streamflow, water yield and soil erosion as affected by type, condition and use of vegetation is mostly dependent on research findings outside of New Mexico. The most pertinent study areas are shown in figure 1. These are briefly described.

EXPERIMENTAL STUDY AREAS

The Sierra Ancha Experimental area is a group of variable-sized watersheds that form part of the Salt River drainage. It is located in the Sierra Ancha Mountains above Roosevelt Reservoir in central Arizona. This is an outdoor laboratory with facilities available for measuring individual plant and soil changes under controlled conditions as well as changes taking

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1/ Research Center Leader, Albuquerque Research Center, Rocky Mountain Forest and Range Experiment Station, Albuquerque, New Mexico.

place through different methods of management on natural watersheds. Small plots and lysimeters range in size from a few feet to 1000 square feet. Findings obtained from lysimeters and plots are progressively applied to small and then large natural watersheds (*38*). 2/

The Fraser Experimental Forest lies west and north of Denver near the Continental Divide (*25*). Water supply is the most important subject of research. About half of the annual precipitation is water yield from these forested watersheds in lodgepole pine and spruce-fir. Since 70 percent of the water yield comes from melting snow, research in watershed management has dealt mainly with the hydrology of snow and the influence of vegetation on snow accumulation and disappearance. Plots and natural watersheds are used in going studies.

At Manitou Experimental Forest in the Colorado Front Range, west of Colorado Springs, research has been concerned with water yield from ponderosa pine watersheds and the influence of grazing in parks and grassy openings on runoff and erosion (*26*).

The San Luis watersheds in New Mexico are to be used in a study designed to evaluate the effect of grazing and land treatment on surface runoff and sediment production in the high silt producing zone of the Rio Puerco. The U. S. Geological Survey, Bureau of Land Management and the Rocky Mountain Forest and Range Experiment Station are cooperating in this endeavor. The Geological Survey Cornfield Wash study is located 6 miles to the west and includes measurement of precipitation, surface runoff and sediment.

The Pine Flat study area involves the measurement of soil moisture depletion and accretion under pinyon trees, in an opening mostly blue grama and on a plot in this same opening kept bared of vegetation.

On Montano Grant, west of Albuquerque, precipitation and surface runoff have been measured continuously from 3 small semidesert watersheds for a period of about 15 years. The study was started and maintained by the Soil Conservation Service until recent years, when it was transferred to the Agricultural Research Service.

The first important watershed investigation in the United States was started during 1909 at Wagon Wheel Gap, Colorado in our own Rio Grande Basin. It was concluded in 1926. The final report (*2*) has now become a classic in watershed literature.

2/ Italic numbers in parentheses refer to literature cited.

Streamflow, precipitation, sediment and other related factors were continuously measured for 15 years on two small (212 and 222 acre) watersheds near Wagon Wheel Gap in the San Luis section of the Rio Grande. Both watersheds were left undisturbed for the first eight year period, then, one of the watersheds was cut of practically all woody vegetation and records continued for another seven years. The publication of the basic data affords the fullest opportunity to make independent analyses. This has been done by other investigators (19) and although some controversy was raised, it added to the validity of the interpretation and conclusions reached in the original report.

WATER PRODUCTION ZONES

New Mexico may be divided into three main water yielding zones on the basis of precipitation and evapo-transpiration potential. Fletcher and Rich (14) using the method developed by Thornthwaite (35) classified New Mexico lands according to this water yielding potential, figure 1. The high water yielding zone is in the mountains and is mostly forested while the low water yielding zone comprises grassland and shrub in the lowlands. An intermediate water yielding zone, mainly, ponderosa pine and pinyon-juniper woodland, lies between these other 2 extremes.

The graphic relation of precipitation to maximum water use by vegetation for high, intermediate and low elevations has been presented for 3 stations (Wagon Wheel Gap, Colo.; Santa Fe and Albuquerque, New Mexico) in the Upper Rio Grande Basin (11). The Wagon Wheel Gap station represents conditions in the high mountains of north-central and northwestern New Mexico. Water surplus exists during the seven month period, October through April, while in Albuquerque, a lowland station, there is a surplus of water only during the two coldest months -- December and January. The station at Santa Fe represents the lower-elevation pinyon-juniper woodland, an intermediate point. At this location, water surplus is insufficient to satisfy soil moisture deficit and water yield is low. Precipitation distribution is similar at all 3 locations with the exception that March and April receive appreciable quantities at Wagon Wheel Gap. The times of water use are also similar, highest in the summer and lowest in the winter. Fletcher and Rich (14) have shown there are four distinct periods: water surplus, water deficiency, soil moisture utilization and soil moisture recharge. Only at Wagon Wheel Gap can we expect a water surplus in excess of soil and watershed storage.

This method of classifying water yielding zones compares favorably with the direct method of mapping water yields from streamflow and runoff measurements as correlated with precipitation (11). A maximum of 30 inches of water is yielded annually, on the average, from the high mountains of the Rio Grande Basin in Colorado, while less than 0.1 inch of the annual precipitation falling in the Middle Rio Grande Valley reaches the stream channel. An idea of the actual contribution of water production from each vegetation zone in the Upper Rio Grande is given in table 1. The spruce-fir-aspen contributes most of the flow in Colorado and over 30 percent of that in New Mexico. Ponderosa pine in the New Mexico portion of the basin yields the most water -- about 40 percent of the total -- mostly because it occurs over extensive mountain areas. But, considering the entire Upper Rio Grande Basin, 87 percent of the total water yield comes from the spruce-fir-aspen, ponderosa pine, and mountain grassland which represents only 28 percent of the land area.

PRECIPITATION-RUNOFF RELATION

To understand this divergent runoff contribution, one must be cognizant of the differences in the precipitation pattern and hydrology of small and large watersheds from the highest mountains to the lowlands. In New Mexico, precipitation occurs principally during two seasons -- one in winter and the other in summer. Winter precipitation is mostly snow at the higher elevations and to the north, whereas summer rainfall is received at high intensities below 8000 feet elevation.

LOWLAND SEMI-ARID AND ARID REGION

The monthly precipitation-runoff distribution for a lowland semi-arid grassland watershed is shown in figure 2. On this experimental 40 acre basin only one half inch or 5 percent of the 9 inches of average annual precipitation was yielded as runoff. Waterflow was surface runoff -- a result of high intensity storms. There was no runoff between November 1 and May 1. This represents about the maximum runoff that can be expected from similar small lowland watersheds, for this basin has a narrow, barren and rocky channel with low retention capacity. The other 2 contiguous experimental watersheds on Montano Grant contributed only 4 and 2 percent of the annual precipitation as runoff. These latter watersheds are larger and have greater channel storage capacity in the wider main channels which support deep alluvium and heavy shrub growth. An idea of the opportunity for channel storage and losses of water is given in figure 3. Surface runoff per unit-area decreased with increased watershed size. The larger the watershed, the greater the opportunity for water losses, particularly during the warm season when evaporation-transpiration potential is high and rainstorms are localized.

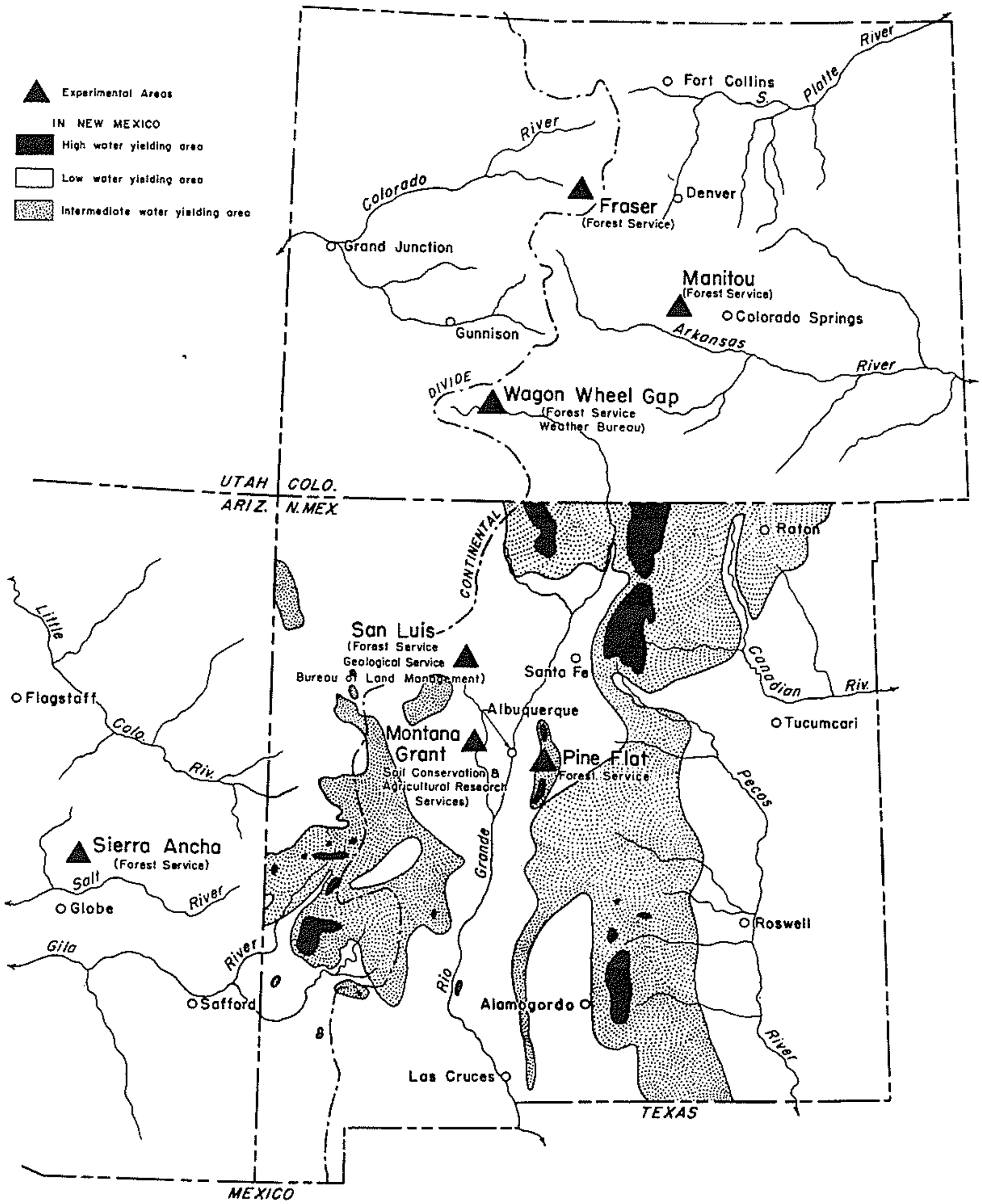

Figure 1.--Experimental areas in and adjacent to New Mexico and water production zones in New Mexico.

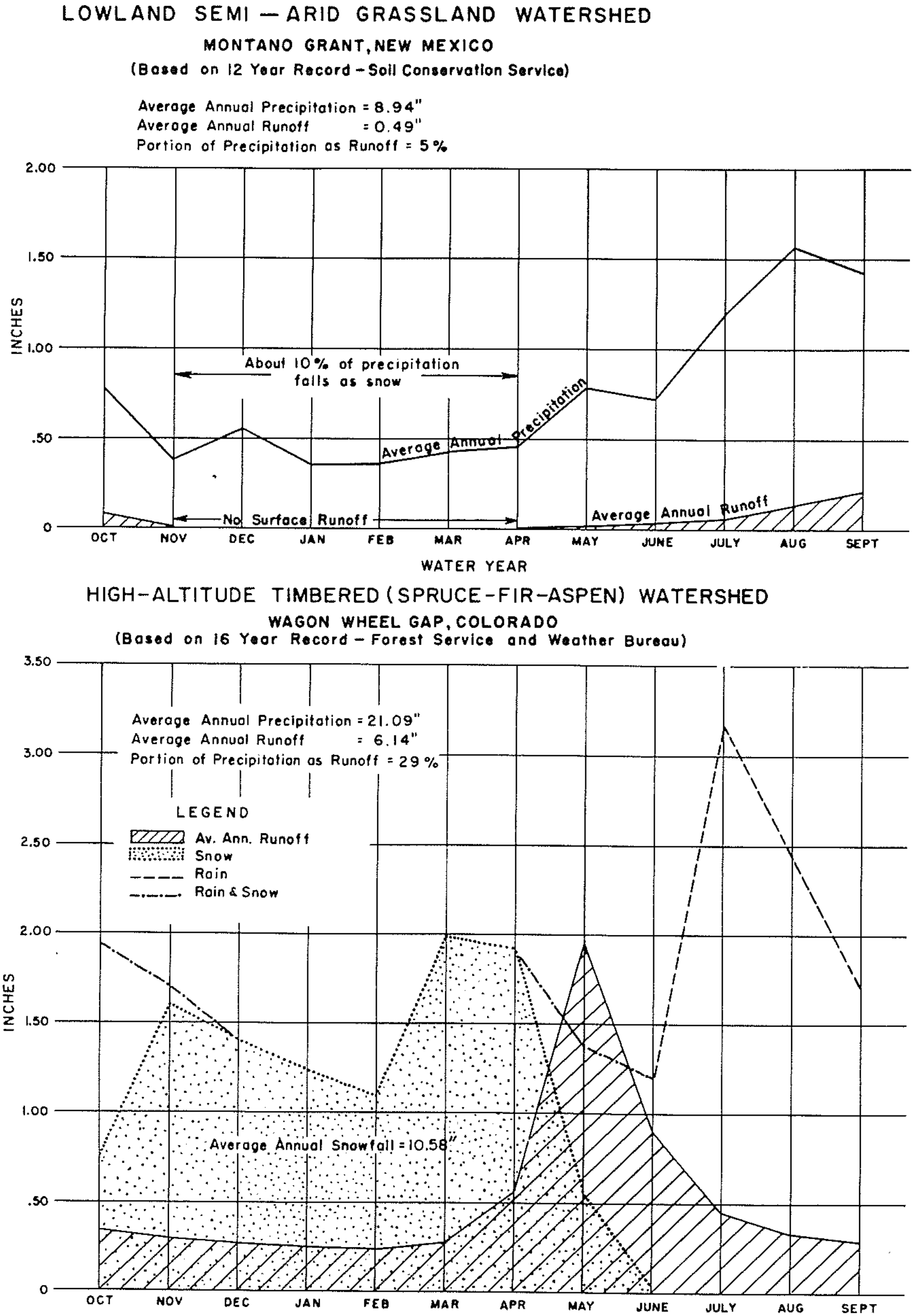

Figure 2.--Monthly precipitation and runoff pattern for a lowland semi-arid grassland watershed and a high-altitude forested watershed.

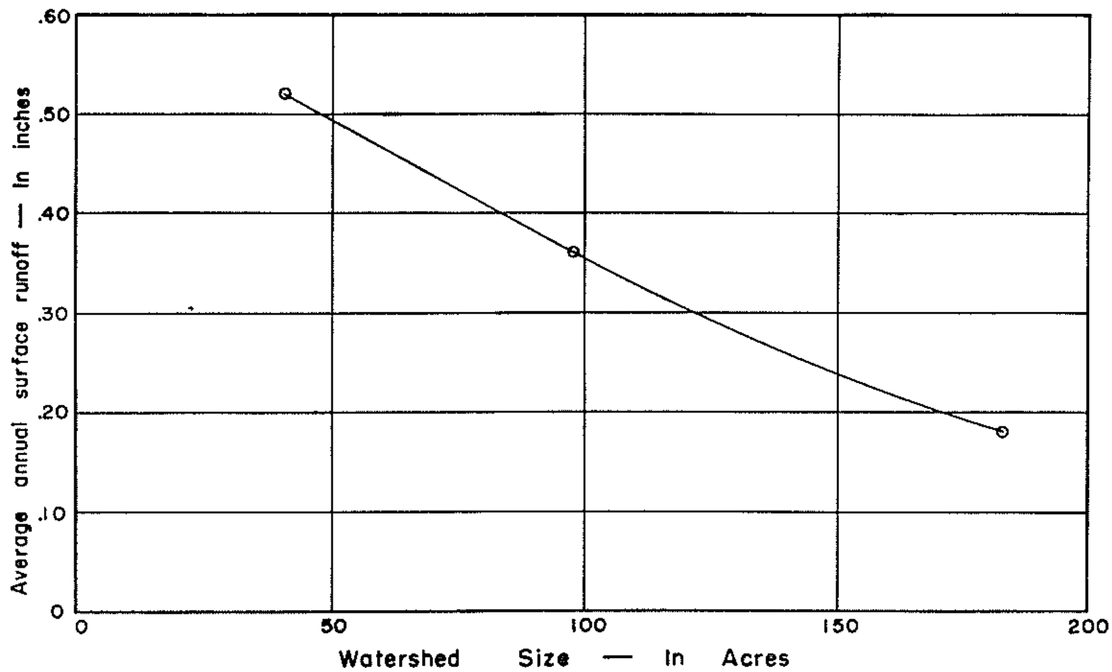

Figure 3.--Relation of runoff to watershed size on Montano Grant in the lowlands.

Table 1.--Sources of water yield to streamflow in the Rio Grande Basin above Elephant Butte Reservoir (11). 1/

Vegetation Zone	Water Yield Contribution	
	Colorado	New Mexico
	Percent	Percent
Spruce-fir-aspen	85.8	31.8
Ponderosa pine	--	40.4
Mountain grassland	11.0	12.1
Pinyon-juniper	2.3	10.8
Sagebrush	0.6	2.4
Semi-arid grassland	0.2	1.4
Greasewood-saltbush	2/	0.6
Cultivated	0.1	0.3
Creosote bush	--	0.1
Dalea brush (Dalea scoparia)	--	0.1

1/ Closed basins excluded.

2/ Less than 0.1 percent.

Thus, we see that water yield from the lowlands is entirely surface runoff contributed from high intensity storms during the high potential evapo-transpiration growing season. As these storms are seldom widespread and mainly localized in character, the rainfall that does not infiltrate the hot, dry slopes is mostly absorbed in the temporary-flow drainage ways connecting the land area with permanent streams. Runoff water leaving localized storm areas must roll down long-dry canyons, washes and gullies and is mostly lost long before reaching the permanent water courses. For example, on the U. S. Geological Survey experimental Cornfield Wash watersheds, runoff averaged 38 acre-feet per square mile during the five year period through 1955. 3/ The average runoff for the Rio Puerco at the downstream Cabezon Station was only 13 acre-feet per square mile for the same five year period. A study of hydrographs of several floods on the reach from Cabezon to Bernardo indicates channel losses may vary from 3 to 8 acre-feet per mile of channel. The lack of permanent streams makes local surface runoff from summer storms an ineffective source of streamflow over most of New Mexico. Yet, surface runoff may attain considerable volume on storm areas and cause much damage through flash floods, erosion and sediment.

MOUNTAINOUS REGION

The precipitation-runoff pattern of the mountains is in sharp contrast to that of the lowlands. Here, a large portion of the precipitation is received when low temperatures prevail. Much of the winter precipitation falls as snow and is slowly released to streamflow during the following spring. An illustration is given in figure 2 for the Wagon Wheel Gap experimental uncut watershed "A". Annual runoff was almost 30 percent of annual precipitation. Though Wagon Wheel Gap is in a rain shadow and does not represent the highest precipitation zone, it does illustrate a region of low evaporation-transpiration potential.

Peak streamflow occurred in May, a result of snowmelting, and continued at a decreasing rate until February, with the exception of a slight increase in October brought about by the cool weather and a drastic reduction in evapo-transpiration. It will be noted that the high summer rainfall had no apparent influence on streamflow which decreased gradually throughout the summer. Surface runoff from land slopes was not noted during the 15 years of study. This is further substantiated in figure 4 which fails to show a relation between summer rainfall and summer runoff, or even fall and winter runoff. Thus, summer rainfall

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3/ Kennon, F. W. and Peterson, H. V.
1956. Runoff and sediment yield in Cornfield Wash, Sandoval County, New Mexico, 37 pp., illus. Typewritten. [Proposed as a water supply paper].

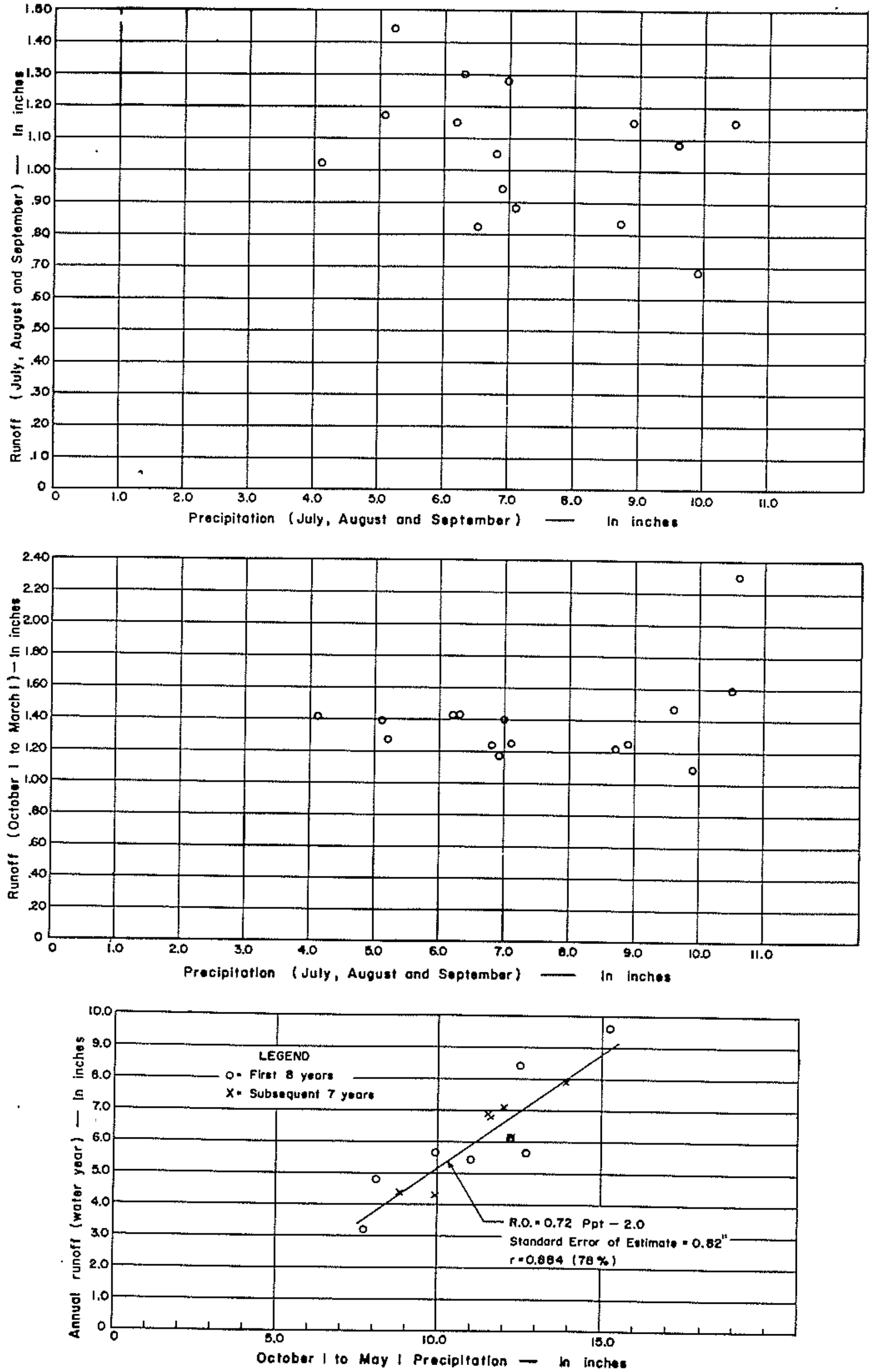

Figure 4.--Relation of runoff to precipitation. Uncut watershed "A", Wagon Wheel Gap, Colorado.

did not flow overland nor did it percolate through the soil. The strong relation between mean seasonal (October 1 to May 1) precipitation and annual runoff shown in figure 4 is in sharp contrast. Over-winter precipitation accounted for 78 percent of the variation in annual runoff. Apparently, melting snow infiltrated into and percolated through the soil before appearing as runoff in the stream channel, accounting for the lag in flow.

The reason for the high correlation between mean seasonal precipitation and annual runoff is that year after year the soil mantle dried out to about wilting point during the growing season. With the advent of cool weather in October, a lowered evapo-transpiration potential, dropping of leaves and curtailment of growth, the first precipitation was used in recharging the soil mantle. Subsequent precipitation and snow melting contributed directly to streamflow as percolation water. The need for satisfying the soil's capillary capacity for water before any appreciable snowmelt water is available to streams has been shown in Utah (7, 10). The amount of water required for soil recharge depends upon the quantity of water remaining in the soil at the end of the dry season. Apparently, summer rains failed to wet the soil completely and most of the soil water added by them was consumed by evapo-transpiration within a relatively short time. The principal effect of summer storms was to provide additional water for the use of plants and for evaporation within the watershed.

A reasonably similar hydrology has been observed on Parker Creek, an experimental watershed, in the Sierra Ancha study area (14). On this 700 acre watershed, slopes are steep and soils shallow so that percolation water drains out rapidly. Surface runoff is negligible from both ponderosa pine on north-facing slopes and mixed grass-chaparral on south-facing slopes. The average annual precipitation of 27 to 28 inches is related to annual runoff but winter precipitation, mostly rain, contributes most of the streamflow. Rainfall from October 1 through May averages about two-thirds of the precipitation, yet contributes 92 percent of the total streamflow. In contrast, only 8 percent of the annual streamflow comes from summer rainfall and more than 80 percent of this streamflow was a result of two large-size winter type storms. These rains occurred in mid-September 1946 and late August 1951 and were sufficient in quantity to satisfy soil moisture deficit.

Even with these 2 storms, summer runoff amounted to only 5.5 percent of summer rainfall while winter runoff averaged 34 percent of winter precipitation. A much higher water yield is obtained at Wagon Wheel Gap where about half of the seasonal (October 1 to May 1) precipitation is soil water runoff.

An attempt has been made to present a picture of the widely divergent water yield hydrology for 2 distinctly different watershed conditions. Yet, this by no means represents the extremes, for many small watersheds produce much less water than the experimental basins on Montano Grant, while on the other hand, small high-altitude watersheds in the Sangre de Cristo range and the southern extension of the San Juan mountains produce considerably more water than those at Wagon Wheel Gap.

Between these extremes lie many conditions depending on elevation, latitude, and position in regard to direction of moist air masses. Water yield from pinyon-juniper lands, though higher than from semi-arid grasslands, is still relatively low. Most of the water production is surface runoff from summer storms, although during wet years, percolation from winter precipitation contributes some water from the higher elevation watersheds and from those with shallow soils. But an important consideration is that during the dormant season, runoff originating almost anywhere on a drainage has a much better chance of reaching perennial streams.

Water production from the ponderosa pine zone is mostly soil water though some surface runoff is contributed from grassland openings and parks in deteriorated condition or where surface soil has been compacted by livestock trampling. The vegetation-soil erosion balance is much more delicate and the erosion hazard is much higher in ponderosa pine than in vegetation zones at higher elevation.

Thus far, our discussion has covered water production zones and how this water is delivered to the main streams. But, how can land managers successfully handle vegetation and soil for maximum production of usable water? The answer to this lies in two basic attributes of vegetation to water. First, a dense cover of trees, grass or even brush is effective in retarding surface runoff and holding soil in place. Secondly, vegetation consumes water through transpiration, interception and evaporation. Obviously, these basic relationships must be balanced properly if vegetation is to serve its highest purpose in controlling surface runoff and erosion and still produce optimum water yields. The main task is then to reduce erosion to safe limits and at the same time reduce water consumption to a practical minimum 4/. How can this be accomplished? It may be fallacious to expect to attain these objectives on each acre of land. We should be able to classify watershed lands according to water or sediment production. In general, lower-lying arid and semi-arid lands are high sediment and low water production areas in contrast to the low sediment and high water production mountainous region. This broad classification gives us a basis on which to operate. Soil stabilization through reduction in surface runoff may need to be practiced on these lowlands, even at the expense of some possible losses in net water production, while clear water may need to be "squeezed out" of the mountain watersheds.

PROBLEMS IN WATER-YIELD CONTROL

Problems of water-yield control vary from place to place, dependent on the attitudes of the water users as well as on the condition of the watersheds. The upstream user -- the one using the water-yielding lands -- whether concerned with growing farm, forage or tree crops, has a considerably different attitude than that of the downstream user. The upstream dryland grower is concerned with controlling water reaching the land so that it will do the least damage and also provide the greatest benefit to his crop. Water flowing off the soil surface is lost in regard to plant growth and presents the threat of erosion. Therefore, in attempting to produce the maximum quantity of plant material, the grower may actually reduce the amount of water yielded from the land, for surface runoff may be induced to enter the soil. But, reducing surface runoff will also reduce erosion and sediment and this improvement may outweigh the reduction in water yield.

On the other hand, the attitude of people downstream from the water-yielding lands is quite different. They are consumers of water coming from the upper watersheds and in the case of floods, the sufferers. Loss according to the down-stream

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4/ Assuming water production is in greater demand and of higher value than forage, wood, wildlife, and recreation.

attitude includes loss in opportunity of use by damaging floods or high flows occurring when waterflow cannot be utilized, loss in quality by sediment and salts and loss in quantity of flow caused by evapo-transpiration.

FLOODS

Floods in New Mexico are of two general types; spring floods resulting primarily from melting snow or rain falling on snow, and flash floods from high intensity summer rainstorms. In the Upper Rio Grande, future annual flood damages from spring flows is estimated at about 1 million dollars (11). Most everyone is familiar with the extensive damages resulting from flash floods in recent years. Some of the communities that have suffered considerable damage are Albuquerque, Bernalillo, Roswell, Artesia, Carlsbad, Las Cruces, Hondo and Pojoaque. Flash floods have also caused considerable damage to farmlands and other improvements. These damages have occurred during a prolonged period of drought when annual precipitation was much less than the long-time average.

SEDIMENT

Associated with flash floods is the problem of sediment transportation and deposition. Sediment damage in the Upper Rio Grande Basin is estimated at 2 million dollars annually (11) caused by depletion of reservoir capacities, aggradation of river channels, detrimental deposition on lands and crops and increased maintenance of irrigation facilities. The water wasted by non-beneficial vegetation (phreatophytes) occupying sediment deposits and the contamination of clear mountain water in transit to lower-lying, water-use areas are additional damages not included in the above estimate.

WATER QUALITY

The increase in salt content in going down the Rio Grande is associated with the increase in sediment. Annual crop losses due to salinity are considerable in the Rio Grande.

PHREATOPHYTES

Losses of water by phreatophytic vegetation (plants tapping the water table or capillary fringe) were estimated at about 240,000 acre-feet annually in the Upper Rio Grande before the rehabilitation project was started by the Bureau of Reclamation in recent years. Lowry (27) presented evidence that channel rectification, reservoir storage, drainage of bottomlands and by-passing water around phreatophyte areas appreciably reduced evaporation waste in the Rio Grande. The quantity of water saved by removing phreatophytes is still questionable and must await later evaluation. Poisoning plants or clearing land is only a temporary measure, as eventually, regrowth or other vegetation will occupy the site.

RESEARCH FINDINGS

GRAZING LANDS

Most of the problems dealing with the control of water yield (floods, sediment, salinity and wasteful evapo-transpiration) originate on lands lying below 8000 feet elevation. As these lands are used primarily for grazing, a review of investigations and research results covering the influence of grazing on water runoff and erosion appears necessary.

The effect of heavy grazing upon both plant cover and erosion has been clearly shown by the historical study and field survey reported in 1937 by Cooperrider and Hendricks (5) and by subsequent Soil Conservation Service studies in the Rio Grande Basin (37, 39). According to these studies, range deterioration resulted in increased surface runoff and erosion. Plot studies in Colorado, Arizona, Utah and elsewhere in the west, have shown that heavily grazed as well as deteriorated rangelands contribute considerably more surface runoff and erosion than protected or lightly grazed ranges or those in good condition (4, 6, 12, 31, 36, 43). Heavy grazing results in a reduction in the infiltration capacity of the soil by reducing the amount of vegetation and litter covering the ground as well as by compacting surface soil through trampling 5/ (32). Too heavy grazing also reduces the vigor of perennial grasses and eventually allows the site to be occupied by less desirable annuals, half shrubs and woody plants (38). These plants are a poor substitute for a good cover of perennial grasses in regard to infiltration and erosion.

Composition and density of herbaceous cover can be improved by control of grazing animals and by mechanical means. Improvement through animal control can be attained in a reasonable time in the moist mountain grassland zone. But in the semi-arid and arid zones, recovery of vegetation vigor, density and composition is extremely slow. For example, in the semi-desert portion of the Salt River watershed, exclusion of livestock for about 20 years resulted in a very small increase in grass density and no curtailment of erosion (38). The same has been observed by other investigators (15, 16, 30) studying vegetation in New Mexico. Research

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5/ Dortignac, E. J. and Love, L. D.
1957. Infiltration as affected by vegetation, soil and cattle grazing in Colorado ponderosa pine ranges. 122 pp., illus. Typewritten. [Proposed as a U. S. Dept. of Agr. Tech. Bull.].

has not shown how to satisfactorily rehabilitate deteriorated ranges with less than 14 inches annual precipitation under continued livestock use, particularly during drought years. Most reseeding efforts on these dry ranges have thus far been failures.

A start has been made in Idaho and Utah toward evaluating the density of range cover needed to reduce surface runoff and erosion to safe limits (28, 31). These studies have been made in the moist zones and it appears that at least 65 to 70 percent of the soil should be covered with vegetation and litter. Maintenance of this quantity of cover may be impossible in the arid and semi-arid zones.

An idea of how grazing may influence the yield of water was reported by Martin and Rich (29) utilizing a lysimeter study in grassland on the Sierra Ancha Experimental Forest. Three lysimeters of undisturbed soil underlain with impervious quartzite bedrock were used in this study. At the time of installation, plant cover was sparse, a result of previous heavy grazing. Grass seeding, fertilizing and watering were used to increase cover density. Then, under no other treatment, surface flow and drainage were measured for seven years and no significant differences were observed. Starting in 1942, one lysimeter was grazed heavily each year by sheep, one left untouched and one grazed moderately. Recognizing that these treatments which involved grazing by two mature ewes for 4 days, annually, is not comparable to grazing by a large number of sheep on rangeland, yet, the results are noteworthy. Ground-cover density decreased on both grazed lysimeters, the decrease being greater on the heavily grazed plot. Surface runoff was small during the low intensity, long-duration winter storms and percolation or drainage through them was about the same regardless of treatment. During the high-intensity summer rainstorms, the quantity of surface runoff and erosion increased with increased intensity of grazing. Yet, total water yield (surface plus subsurface runoff) was the same from all three plant-soil conditions, amounting to about one-third of the precipitation. Grazing use greatly influenced the proportion of surface runoff to percolation flow, but total quantity of yield remained about the same. Since the entire watershed was wetted by this general-type storm during a period of low evapo-transpiration potential, it is probable that most runoff reached the perennial stream channels.

Another lysimeter study at Sierra Ancha has shown there is a considerable difference between the times of year when different kinds of vegetation draw heavily on soil moisture (33). In comparing grass-cover with shrub-cover and bare soil it was found that during the summer there was no significant difference in evaporative losses. Nearly all of the water added by summer rains was lost so that no water was yielded as drainage. Important differences in evapo-transpiration were found during the winter and spring when appreciable quantities of water drained out of the lysimeters. During this period, grass cover lost between 70 and 81 percent, shrubs between 74 and 86 percent and bare soil between 52 and 72 percent of the precipitation. Ruling out the bare soil as undesirable from the standpoint of erosion, these results suggest that water yield might be increased in this area if lightly grazed grass replaced a cover of shrubs.

FORESTED LANDS

Since the mountain lands contribute an extremely large portion of the water yield in New Mexico, it follows that these lands should be managed, if possible, to contribute optimum yields of usable water. The most promising method for increasing water yields without damaging the watersheds appears to be that of improved management of the mountain snowpack. Snow accumulation and the time and amount of water yield from snowmelt are definitely subject to control by harvesting the tree crop. High altitude alpine areas offer some opportunity for management but in view of the extensiveness of the forested region in New Mexico, intensive but careful forest-watershed management in this zone appears most fruitful.

Snow Water

Many studies covering conditions in Colorado, Arizona, California and Idaho have shown that forests favor the evaporation of snow, primarily through their ability to intercept a portion of the snowfall and expose it to higher rates of evaporation than in the snowpack. All of these studies have indicated an inverse relation between tree density and snow accumulation. Cutting trees reduced interception losses approximately in proportion to the reduction in crown cover.

At Fraser, removal of all sawlogs from a mature lodgepole pine stand increased the water equivalent of the snowpack by about 30 percent (42), while clear cutting alternate narrow strips in an old and dense spruce forest resulted in a somewhat lower increase. Thinning young lodgepole pine stands increased the water equivalent of snow accumulation by 23 percent when 85 percent of original trees were cut and 17 percent when only half of the trees were cut (17). Similar results differing only in quantities were obtained in Arizona, California and Idaho (4, 20, 23). Generally, these investigations have indicated the greatest accumulation of snow in small openings in the forest and the least under dense forest canopy while tree stands opened up by logging had snowpacks of intermediate water content.

These studies have been empirical and provided results for certain conditions and localities. We need to know much more about the influence of topography and trees on microclimate and about wind, vapor pressure and temperature differences on various slope exposures, stand densities and variable-sized openings. The effect of heat radiation to the snowpack (by trees to the north of openings) on accumulation and melting is not known. Likewise, little information is available on reduction in evapoation from snow by retardation of air movement near the snow surface; on the effect of interception of diffuse sky radiation by trees; and on the relation of the snow crust and other surface conditions on the reflection of sunlight. Studies concerned with the relation of tree-cover to the physics of snowpack accumulation are needed before widespread forest-watershed management can be effectively practiced.

The effect of trees on trapping drifting snow from bare ridge tops and other exposed locations should be evaluated. The practicability of piling snow into deep drifts in the shade of trees, on north slopes and in shaded ravines as a means of reducing evaporation losses and delaying melt to prolong streamflow should be determined. Snow accumulation is usually greater on north aspects and least on slopes facing south. Aspect has been found to affect spring snowmelt in a similar manner (7, 41).

On the basis of present knowledge, logging high altitude timber such as spruce-fir in an alternate pattern of clear cut strips about equal to the height of trees seems desirable from the viewpoint of water yield. But how should strips be oriented? Should maximum protection from wind or solar radiation be the objective or should strips be on a contour? Studies in the central Sierra-Nevada mountains in California showed that evaporation losses from the snowpack, under eleven conditions of cover were small -- averaging less than 1.5 inches from December 1 to June 1 and less than 0.5 inch in any one month (23). Cutover mixed conifer, open logged and open meadow had the highest evaporation losses while mature red fir, mature ponderosa pine and a large opening near the river had the lowest evaporation losses. Yet, when comparing evaporation from snow under crowns with small openings between crowns, 5 out of 7 forested conditions had less evaporation from the snowpack in the small openings.

The rate of snowmelting as affected by cutting of trees is important in regard to spring flood flows and maintaining perennial flow during the late season. Maintenance of a dense forest cover tends to delay the rate of snow melting and reduce the contribution to flood flows, particularly, when rain occurs. According to Kittredge (23), the daily rate of melting might be as much as 0.1 inch of water lower in forested than in open areas. He found that snowmelt in a white fir stand was about half that in a large clearing and this quantity compared favorably with Anderson's recent analysis (1). According to Goodell (17), thinning dense young lodgepole pine stands accelerated snowmelt, amounting to more than 2 inches additional melt during the first 3 weeks of the melting period.

To retard melting of snow and prolong its contribution to streamflow later into the summer involves both the amount of snow in storage and its rate of release by melting. In creating small openings less than twice the height of trees in width by clear-cutting, where ecologically and silviculturally feasible, one might expect the most water under prolonged flow. Strip cutting might give almost as good results providing clear cut zones are narrow -- about half the height of the trees. The proportion of the total area to be clear cut in small groups or narrow strips should be based on the need for providing belts of uncut timber for wind protection and shading. Anderson (1) recently suggested that maximum accumulation of the snowpack might be obtained by cutting the forest so as to retain the most shade but at the same time reducing the height of trees to the north. His analysis indicated that shade from trees to the south was twice as effective in increasing snow accumulation by April 1 as radiation from trees to the north was in reducing the snowpack. He proposed harvesting trees in successive narrow strips at right angles to maximum solar radiation to produce a "wall-and step" pattern with the wall to the south.

Although a considerable number of plot studies have been made on the effect of vegetation on snow accumulation and melting, this type of information is not available on a watershed basis.

Water Yield as Affected by Vegetation Changes

Love's (24) recent analysis indicates a reduction in evapotranspiration and interception by beetle-killed spruce and pine was associated with increased streamflow in the 206 square mile White River drainage in Colorado. Preliminary data on the effect of timber cutting on streamflow should be forthcoming in the near future from Fool Creek in the Fraser Experimental Forest and from Workman Creek at Sierra Ancha. Until then, we must draw upon the results of cutting and tree removal from the Wagon Wheel Gap watersheds.

Results of this study are adequately shown in figure 5, which relates annual runoff of watershed "A", the control to the treated watershed "B", both before and after tree cutting. In the 8 years prior to tree cutting, a highly significant straight-line relationship was found. The straight-line fit by the method of least squares accounts for 98 percent of the variation. Under such conditions, there is no need to introduce the factor of precipitation, which was very similar on the 2 watersheds. The points for years subsequent to deforestation show that the full effect of treatment was not felt until the third year after tree cutting and removal and there was a gradual decrease to the seventh year. The increased runoff by years is given in table 3. The average annual increase in streamflow amounted to about 0.94 inch or 15 percent. Bates and Henry (2), the original authors, and Hoyt and Troxell (19) in 1932, using an entirely different approach obtained almost the same result; that is, 0.96 inch. Hoyt and Troxell, by correlating daily discharges, showed the same relative yearly increases but by the seventh year the increase had dwindled to .04 percent.

A partial explanation for the delay in maximum increase in streamflow occurring in the third year may be gained by review of the treatment procedure. Although most of Watershed B was cut over during the summer of 1919, a strip was purposely left along the stream channel until 1920. Slash from the larger conifers and entire stems and tops of smaller evergreens and aspens were piled in windrows and not burned until September 1920, just prior to the start of the second year of treatment. Plot studies in Colorado have shown that dense young lodgepole pine trees felled in thinning operations were as effective in intercepting rainfall as when standing, as long as they held their needles (17). Snow accumulation would be expected to be influenced in a similar manner.

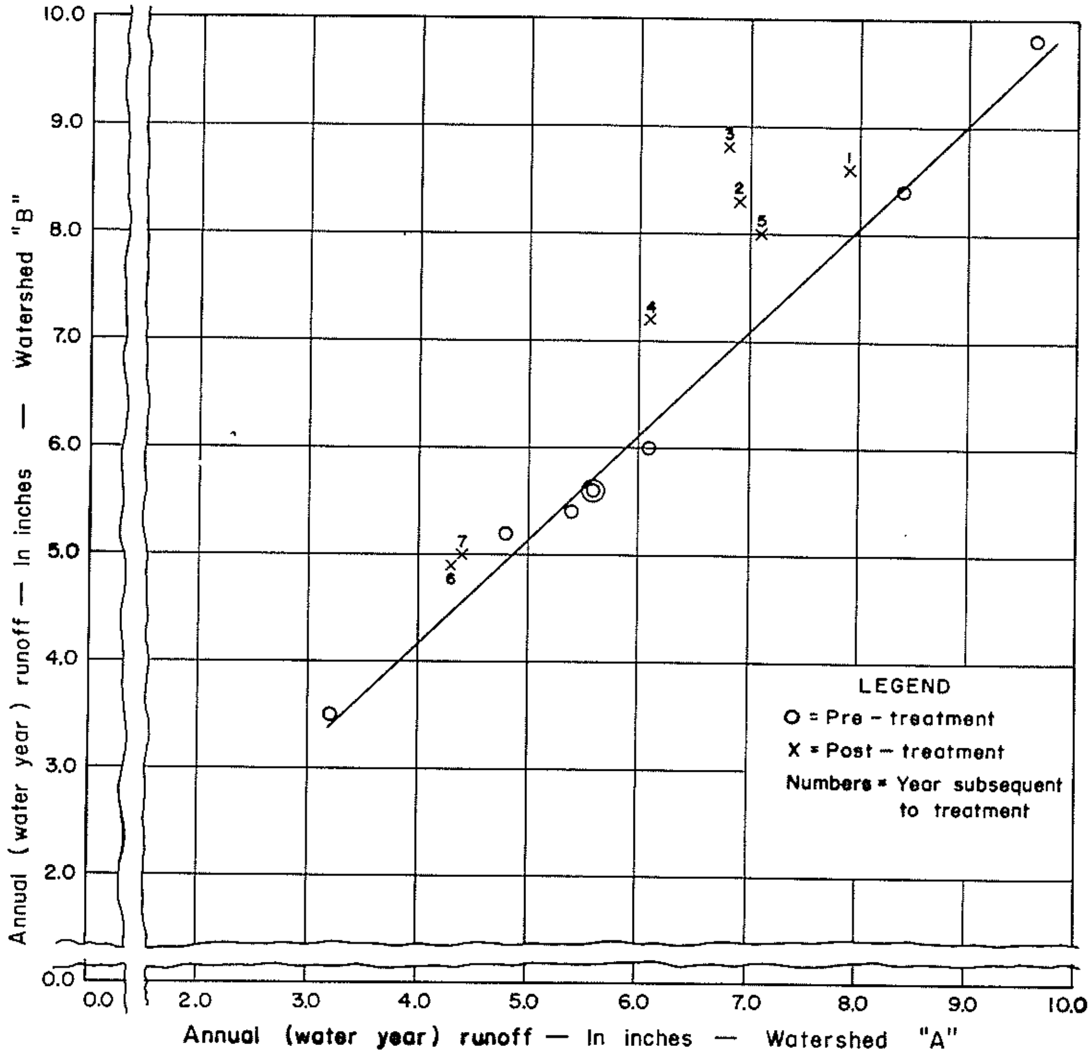

Figure 5.--Relation of annual (water year) runoff of "A" (uncut) to "B" (cut) watershed, Wagon Wheel Gap, Colorado.

Table 3.--Increased runoff of watershed "B" after tree cutting and removal. Wagon Wheel Gap, Colorado.

Time subsequent to treatment	Increased runoff of "B" (from regression line)	
Year	Inches	Percent
1	0.65	8.2
2	1.30	18.6
3	1.95	28.3
4	1.00	16.1
5	0.82	11.4
6	0.45	9.9
7	0.42	9.4
Average	0.94	14.9

The increase in spring flood runoff after deforestation was much greater than during the balance of the year. According to the analysis by Bates and Henry the annual increase in flow was distributed as follows:

	Increase in flow	
	Inches	Percent
Before flood crest	0.68	71
Decline of flood	0.12	12.5
Summer months	0.09	9.5
Winter months	0.07	7
Annual	0.96	100.0

In other words, 83.5 percent of the increase occurred during the flood or high flow period and only 10 percent during the summer months. The evaluation by Hoyt and Troxell did not differ greatly, for example, they concluded that the increase in summer runoff amounted to a little less than 0.15 inch for a 12 percent summer flow increase or about 15 percent of the annual increase.

There is no certainty as to the exact causes of these increases in runoff. Bates and Henry deduced that most of the increase was caused by a reduction in tree interception losses of snow and that decreased evapo-transpiration during the summer was much less important. In view of the relation previously shown between over-winter precipitation and annual streamflow, these conclusions appear sound for this study.

Other important results of deforestation were that flood crests were advanced three days -- a result of earlier melting and erosion increased 5 to 15 fold but averaged only 17 pounds per acre -- an unimportant soil loss.

One of the reasons for such small soil losses is that cutting and removal of woody vegetation was carefully done avoiding exposure of bare soil. Another is that soils were very porous.

The vegetation cover on watershed B prior to treatment was as follows:

Type of cover	Area percentage
Aspen without conifers	43.8
Aspen with conifers	17.1
Conifers	23.4
Barren, grass and burned-over spruce	15.7

A greater proportion of watershed A was in conifers than on watershed B prior to treatment. A field examination of these watersheds in the summer of 1953 indicated that little change in composition of vegetation cover occurred in the intervening period on the uncut watershed. Watershed B supported a thick stand of aspen which apparently is denser than the original stand. Since the period of evaluation showed the maximum streamflow increase during the third year and a steady decline thereafter, one may wonder whether less water is now produced on B than before treatment. Only a small amount of information on the relative merits of aspen versus conifers in regard to water yield is available. Plot studies in Colorado indicated that aspen and open grassland intercepted smaller amounts of precipitation than a dense stand of young lodgepole pine (13). In this study, winter snow storage plus net precipitation reaching the ground during snowmelting was highest under aspen:

	Net precipitation Inches
Aspen	14.8
Grass (open fields)	13.3
Lodgepole pine	11.6

But, on the other hand, aspen, a broad-leaved and deep-rooted tree, would be expected to use greater quantities of soil moisture during the active growing season (May to October) than spruce or fir.

Results obtained on a study plot in northern Utah indicate the possibility of reducing evaporative soil moisture losses by altering vegetation (9). No surface runoff nor erosion occurred on three plots in an aspen grove during a fifteen year period. Grazing was excluded. In 1947, all aspen trees were removed from one plot, all vegetation removed from another, and the third left untreated. In regard to summer evaporative losses of soil moisture, Croft found that by the end of the season field capacity deficits were:

Bare soil	--	3 inches
Herbaceous (trees removed)	--	8 inches
Aspen	--	11 inches

Removal of aspen brought about a saving of 3 inches of water and removal of all vegetation, 8 inches. But removal of all vegetation unleashed erosion at the rate of 10 tons per acre during 3 summers of rain, less intense than prior to treatment.

Another factor which may have affected water yields at Wagon Wheel Gap is that of evapo-transpiration by riparian vegetation.

RIPARIAN VEGETATION

Only a limited amount of research data is now available on evapo-transpiration along stream channels in the mountains of the west. Two studies, one in Utah and one in southern California, provide some preliminary leads. Croft (8) estimated from analysis of diurnal and seasonal fluctuations of Farmington Creek in the Wasatch mountains in Utah that riparian water losses equalled one-third of the total streamflow between August and October. The canyon bottom vegetation consisted of willow, alder, cottonwood, mixed shrub, a few fir and herbaceous vegetation including grasses. Young and Blaney (44) used 3 stream gaging stations along 8000 feet of channel in Cold Water Canyon in the southern California mountains to evaluate riparian losses. Calculations indicated that over the riparian zone about 45 feet wide that channel losses varied from an average of about 6 to 11.5 inches during the summer months.

But this information is too meager to apply directly to New Mexico conditions. Apparently, removal of certain tree species, mainly broad leaves, along stream courses may appreciably reduce water losses but when this saving is spread over an entire watershed the increase may be relatively small. Other considerations from the water yield standpoint need to be mentioned here. If trees were removed along certain perennial stream courses then some other type of low-water using vegetation such as grass would need to replace them. Often stream margins are more severely damaged by livestock and big-game trampling than land more distant from the water courses. Damage is partly due to the heavy trampling but mostly because soils are trampled when wet. As a consequence, streambanks are often beaten down and eroded during high waterflow stages. Such damage can be observed on the high-altitude grassy meadows in New Mexico where livestock and big game concentrate. Another factor which needs study and evaluation is the influence of trees in overcoming the compacting effects exerted on soil by trampling animals. The only information available on this subject is the Emmenthal study in Switzerland which indicated trees in pastures were beneficial in maintaining porous soils (3).

ALTERNATIVE TYPES OF VEGETATION

Although vegetation type conversion may have considerable appeal to the layman it is covered last because present opportunity for successful application appears limited. Moreover, little information is available on how to change and maintain a particular vegetation type without damaging the watershed. Research at hand, based solely on small plot studies indicates herbaceous cover may use less water than woody plants. Likewise, certain annuals, with limited root systems may use less water than perennial grasses with more extensive root systems for a comparable growth period. But, water use by plants varies considerably according to species, time of year and available soil water. For example, crested wheatgrass grows most actively during the cool spring period in contrast to blue grama, a summer grower. At Sierra Ancha (38) it was found that perennial grasses (summer growers) used less water during the water-yielding period (October 1 to June 1) than a deteriorated watershed cover consisting of winter annuals mostly filaree, snakeweed and evergreen shrubs. Thus, from the standpoint of water yield alone, under similar situations, a perennial grass cover might be the goal. Likewise, in New Mexico, from the standpoint of water yield, one might favor reseeding deteriorated high-elevation mountain meadows and parks with summer growing perennial bunchgrasses such as mountain muhly, Arizona and sheep fescue, rather than using cool-season growers such as wheatgrasses.

The opportunity for alternative kinds of vegetation is much greater in the more humid east than in New Mexico where precipitation is deficient. In the moist region at the higher elevations in New Mexico, the cool temperatures and the short growing season limit the type of vegetation that can be grown. In general, the greatest opportunity for change in cover type is along the fringe or transition zones but the areal extent is limited. However, some conversion of vegetation types has occurred in New Mexico. These are:

1. Grassland, woodland and sagebrush to cropland and vice versa.
2. Grassland to sagebrush -- probably through over-use by animals -- sagebrush to grassland through reseeding.
3. Encroachment of juniper and pinyon into grassland -- possibly a result of over-use. Re-trenchment of juniper and pinyon -- a result of drought. Removal of juniper and pinyon by mechanical methods.
4. Conversion of ponderosa pine timberlands to mountain brush -- a result of fire.
5. Conversion of spruce-fir to aspen -- a result of fire.

Research conducted almost entirely in the eastern United States mostly from plots or small watersheds has always shown higher surface runoff and erosion from row and field crops when compared with other vegetation (4). This is in line with logical deduction since dry-farming leaves the soil bare part of the year and in the case of row crops, partly bare in all seasons.

Regardless of how appealing type conversion may appear, its potential may be restricted when we consider management strictly from the water yield standpoint. For example, in north-central New Mexico, not more than 150,000 acres of sagebrush-woodland can be reseeded successfully to grass under the present status of knowledge. The cost of this operation has averaged about $8 per acre. Likewise, removal of juniper and subsequent maintenance is a costly operation and may not be economically justified from the standpoint of range improvement alone. The question might be raised as to possible changes in water or sediment yield from these range improvement operations. Some preliminary information derived from small infiltrometer plot (2.5 square feet) tests in north-central New Mexico indicates reseeding, as now practiced, has only a temporary effect on infiltration and erosion and that subsequent grazing use is the dominant factor determining surface runoff and sediment contributed from these areas.

An indication of the effect of removal of pinyon trees on water yield may be gleaned from results of the soil moisture study at Pine Flat, located in the upper elevation pinyon-juniper zone. The march of soil moisture in the upper 12" of soil under 3 cover conditions; pinyon trees, herbaceous cover (mostly blue grama) and bare soil, is shown in fig. 6. June, July and August were the rainy months, yet, summer rains were insufficient to restore soil moisture which was entirely depleted by fall. But the lower evapo-transpiration rate in late fall and early winter allowed precipitation to replenish soil moisture depletion. Based on this first year's measurements, soil moisture penetration was greater during the over-winter period of snowfall and low temperatures than during the growing season. Moisture failed to penetrate below 12 inches under pinyon or blue grama during the growing season nor below 21 inches during the dormant season. Soil moisture losses in the top 12 inches of soil during depletion periods amounted to 8 inches under herbaceous cover and 7 inches under pinyon trees. As over-winter (November 1 to April 1) precipitation was about 90 percent of the long-term average, based on the Tijeras Ranger Station record, it is unlikely that soil water would percolate to bedrock at 30 inches during years with similar or lower precipitation. Replacement of pinyon trees with herbaceous vegetation cannot be expected to appreciably increase water yields through percolation, except during years with above-average dormant season precipitation.

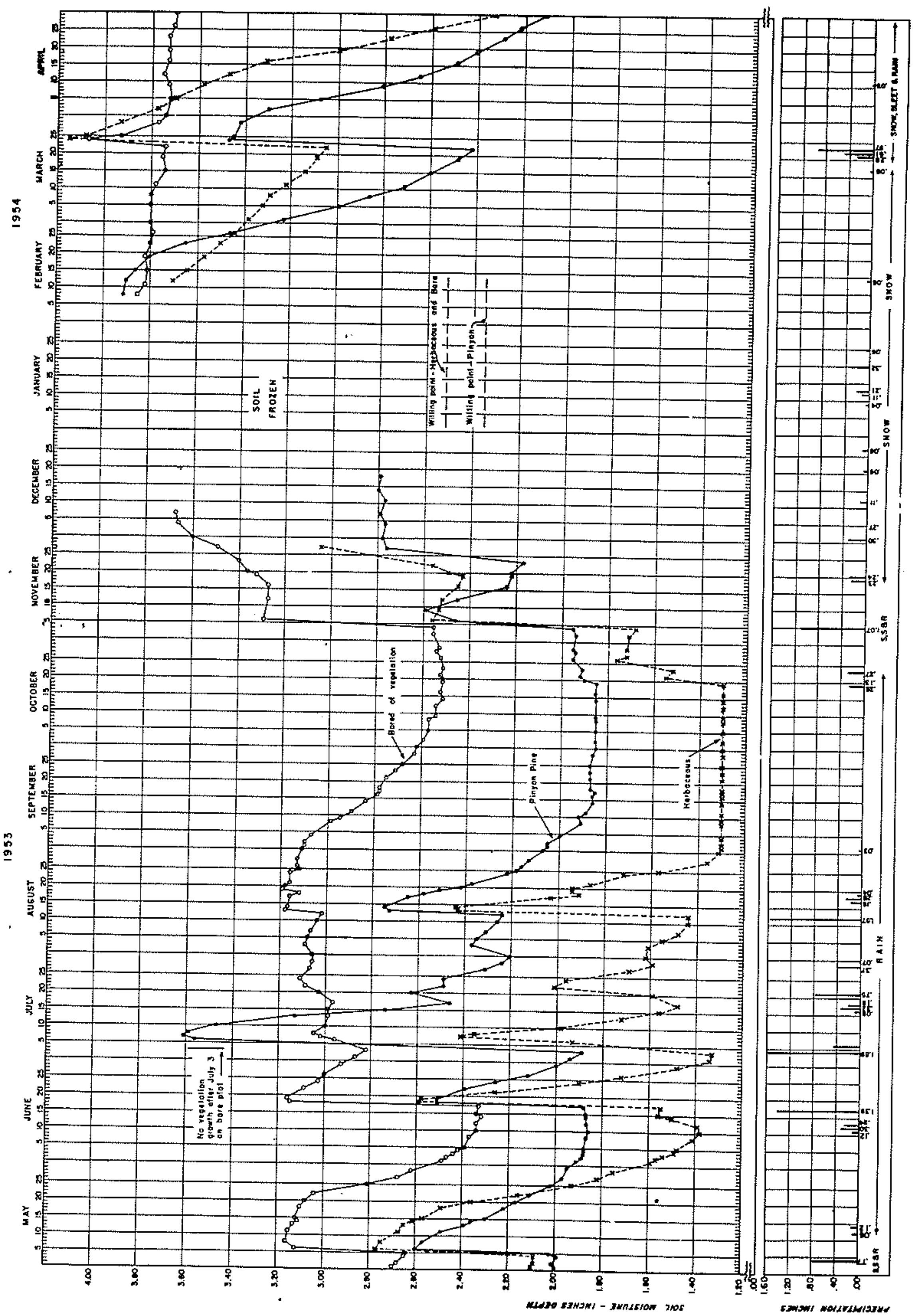

Figure 6.--Moisture content in first 12 inches of surface soil under pinyon pine, blue grama and bare soil. Pine Flat, New Mexico.

The main watershed problem in the pinyon-juniper zone of New Mexico is soil stabilization and this should be done by reducing surface runoff during the summer high intensity rainstorms. In accomplishing this, the amount of water yielded from the land may be actually reduced but by reducing surface runoff and erosion, both the regimen and quality of water will be improved and this kind of improvement seems more important than any reduction in water yield that may accompany it.

Above 8000 to 8500 feet, as mentioned previously, annual precipitation exceeds evapo-transpiration losses. Snow is the dominant form of precipitation and the snow cover persists to early summer with remnants still present in July in the alpine region of the Sangre de Cristo range. Management of forests through good sound practices appears to offer the most promising method of maintaining or possibly increasing water yields.

Fire as a Tool

Controlled burning is, at present, a subject of considerable controversy in the southwest. Much of it stems from the inadequacy of research information. Another is the difference in points of view of individuals which ties back to differences in wildland management objectives. Controlled burning has been advocated to thin pine reproduction and even for attempting type conversion. Burning as a means of changing vegetation can have temporary or lasting effects depending on the kind of vegetation burned, the degree to which it is burned, amount and type of vegetation killed by the fire and treatment given the land after the fire.

It is important to recognize that fires in grassland are considerably different than those in forests. Grassland fires usually consume everything above ground as flames are carried by dense dry fuel that forms a more or less continuous cover over the soil. Grass fires move quickly and the soil is heated for brief periods. Hence, seed on the ground and root crowns of perennial grasses are not killed. Rapid recovery of grassland from fire has been observed in the southeast, in the Prairie and in the semi-arid California foothills.

In contrast, forest fires are considerably more variable in the way they burn and in their effects on vegetation. When burning takes place during hot dry weather, all vegetation from the ground to treetops may be burned over large areas. Under less severe weather conditions fire may creep through the litter or consume low-growing vegetation. Between these extremes lie many conditions difficult of appraisal.

Studies in California, Utah, and elsewhere have shown (with one exception) that any type of burning on forest, brushland and woodland-grassland has increased surface runoff and erosion (4, 22, 34, 40). In July 1942, a lightning fire burned 100 acres of ponderosa pine and Douglas Fir within the Sierra Ancha Experimental Forest. Flash runoff and soil losses were measured from subsequent late July rainstorms on this watershed but the adjacent unburned watershed produced no flash flows nor erosion (18).

One need not travel far to see the effects of wildfires on former ponderosa pine timberlands in New Mexico. In many areas, mountain brush, mainly oak or Mexican locust, occupies the land. The Sacramento mountains, particularly the west side and burned over mountain-sides in north central New Mexico, provide good examples of this type of conversion. At higher elevations and on cool north slopes aspen is more apt to invade burned over coniferous forests (21).

CONCLUSION

In conclusion, the maintenance of an adequate supply of usable water for irrigation, domestic use, recreation, industry and power is the principal problem facing arid New Mexico today. How present water supplies can be maintained or improved in quality through management of vegetation and soil is now uppermost in many minds. It is, therefore, timely that problems associated with the use of watersheds be critically examined and that greater effort be made to put present day knowledge to practice. It is also timely that the need for certain types of information be brought to the attention of those concerned. For only through better knowledge of watershed behavior under variable climate, vegetation, soil and use can we expect to understand and solve the problems now confronting us. It is hoped that this presentation will contribute in a small way toward a better understanding of the water problems and the possibilities for improvement.

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Water Use and Water Control Planning on the Rio Grande

Harold B. Elmendorf[1/]

To better understand our present situation, suppose we look at what has taken place in the Upper Rio Grande Basin above Fort Quitman, Texas during the past 60 years. I use that period because in 1896 W. W. Follett made a complete canvass of irrigated lands in this basin, the first authoritative survey in modern times. He reported a total of about 450,000 acre irrigated, as shown in Table 1.

An interesting historical note is by C. R. Hedke, who estimated that about 125,000 acres were irrigated in the Middle Rio Grande Valley, Cochiti to San Marcial, in 1880. Due to seepage problems associated with sedimentation in the Rio Grande channel, this acreage dropped to about 45,000 acres in 1910. It has increased since formation of the Middle Rio Grande Conservancy District but is still considerably less than the reported 1880 acreage.

In 1936 the National Resources Committee, in what is known as the Rio Grande Joint Investigation, again surveyed the Upper Rio Grande Basin and found 646,000 acres irrigated, also shown in Table 1. This was probably the most detailed study ever made of irrigation in the Upper Rio Grande Basin. The Federal Departments of Agriculture, Army and Interior participated in this survey with the States of Colorado, New Mexico and Texas at a total cost around $400,000.

There were many other surveys of various parts of the Upper Rio Grande Basin in these 60 years by Herbert W. Yeo, John H. Bliss, E. B. Debler, R. J. Tipton, C. R. Hedke, E. P. Osgood, Russell Dallas, R. J. Hosea, J. L. Burkholder, and probably others. The Irrigation Census of 1949 gives the only available figures on irrigated acreages in recent years, a Basin total of 815,000 acres.

Table 1 shows one of the principal reasons for everyone being short of water. Even if the water supply had remained constant, an increase of some 80 percent in the irrigated acreage would have been felt. In addition, everyone knows that only in a few years of the past quarter-century has the Rio Grande produced what used to be called a "normal" yield of water, a little more than a million acre-feet delivered in Elephant Butte Reservoir.

Figures for New Mexico are divided at Elephant Butte Reservoir. As most of you know, compact commissioners from the three states, when negotiating the Rio Grande Compact, decided it was too difficult to divide

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1/ Head, Area Engineering & Planning Office, Soil Conservation Service

the water apportionment for the Rio Grande Project between New Mexico and Texas. For operation of the Compact, they stipulated that New Mexico would stop at Elephant Butte Reservoir. The entire Rio Grande Project would be considered to be in Texas. Figures in Table 1 can be added together to give the total acreage in geographical New Mexico, or the figures "south of Elephant Butte" can be added to Texas to give the compact acreage for Texas.

Table 1

Irrigated Acreages - Upper Rio Grande Basin 1/

Section of Upper Rio Grande Basin	Investigators		
	W. W. Follett 1896	Rio Grande Joint Investigation 1936	Irrigation Census 1949
Colorado (Excluding Closed Basin)	245,000	322,000	506,000
New Mexico			
North of Elephant Butte	150,000	153,000	133,000
South of Elephant Butte	37,000	90,000	89,000
Texas	18,000 2/	81,000	87,000
Totals	450,000	646,000	815,000

1/ National Resources Committee - Regional Planning, Upper Rio Grande - 1936

2/ Probable irrigated acreage in late 1860's. 1896 acreage not given.

Since the Rio Grande Compact has been mentioned, I would like to give my personal opinion of that compact, for what it may be worth. There has been much criticism of this agreement between Colorado, New Mexico and Texas, with approval of the United States Congress. Negotiations were begun in 1923 and a temporary compact was concluded in 1929. Permanent allocation of Rio Grande water was delayed until after the Rio Grande Joint Investigation and signing of the Rio Grande Compact in 1939.

In recent years the Rio Grande Compact has been criticized in all parts of the Basin. New Mexico was the first to feel the pinch. Texas, including that part of New Mexico below Elephant Butte Reservoir, followed in the list of aggrieved parties. We frequently hear statements in these sections of the Basin that they were gypped in the compact negotiations and that a new compact should be negotiated giving them more water than did the 1939 agreement. You may be surprised to learn that Colorado, which has been going in debt under the Compact for the past few years, feels the same way and makes identical statements. I honestly feel that if a new compact were negotiated today on the Rio Grande, Colorado would insist on the right to use more of the water originating in Colorado than it did during the 1936-1939 negotiations. Both New Mexico and Texas might wind up with less water than they are now entitled to.

We must remember that a compact on the use of interstate streams is essentially a horse trade. Almost always the total of original demands for water in each state is greater than the water supply in the river. Then the compact commissioners from each state have many long sessions at which each gives a little until the total demands are within the amount which the river normally supplies. Usually, after several years of negotiations and exhaustive engineering studies by each state, an unbiased view will find that each state came out with about as fair a deal as the others. I feel this was true for the Rio Grande Compact when it was signed in 1939. It was a pretty equitable compact, based upon what was known about the river up to 1929, the period of record used in the engineering studies.

Two natural phenomena about which little or nothing was known at that time have since become very important factors in the operation of this compact. They have caused most of the criticism. First, salt cedars, willows, cottonwoods, baccharis and other phreatophytes existed then but in smaller quantities and their effect on water was hardly known. They have spread throughout the Middle Rio Grande Valley since then and we now know they consume large quantities of water. Sediment blocked the river channel above Elephant Butte Reservoir and prevented low flows from reaching the reservoir. This deterioration in river bottom conditions consumed so much of New Mexico's apportionment of water that she went into debt on her compact deliveries of water to Texas for many years. Recent channelization of the river and partial eradication of phreatphytes has partially restored the ante-1929 conditions and New Mexico no longer incurs a water debt every year.

Second, the effect on the Rio Grande of pumping large quantities of groundwater for irrigation was unknown until a few years ago when most of the water from a very large snow pack disappeared in the river channel through the San Luis Valley in Colorado. Seemingly, most of this river flow went into recharge of the ground water aquifer which had been depleted by heavy pumping of irrigation wells. Now Colorado goes into debt each year under the Compact.

Granted that these two comparatively recent conditions have interfered with operation of the Rio Grande Compact as it was envisioned by the negotiators in 1939. But would a new compact now, knowing about these things, be any better for New Mexico and Texas than the compact we have? I doubt it.

Probably the chief defect in the Rio Grande Compact is the combining of the entire Rio Grande Project with Texas for operation of the Compact. This has created a psychological barrier between two parts of New Mexico which should think and act as one on all interstate water negotiations. It has caused the unique situation of the State Engineer and the Compact Commissioner for New Mexico having to represent the State in legal actions against a part of New Mexico which is joined to Texas.

We must grant that the boundary between New Mexico and Texas through this project is a meandering line. From Anthony to El Paso this boundary is the center line of the Rio Grande at the time of the Gadsden Purchase. It cuts through farms and makes it very difficult in this section to determine how much water is delivered to irrigated lands in each state. But much more difficult determinations have been made and I believe an engineering study could develop a sound basis for equitably apportioning water in that area to each state. Such a change in operation of the Compact would not directly provide any additional water in New Mexico but it would help to unify New Mexico's thinking and eventually lead to improvement in the water situation.

As everyone here probably knows, all waters of the Upper Rio Grande Basin, as in most other river basins of New Mexico, are fully appropriated. In common with many adjoining states, our last chance for additional water in the near future is by importation from the Colorado River. The Upper Colorado River Compact, signed in 1948, after allocating 50,000 acre-feet of water to Arizona, apportions to New Mexico 11.25 percent of the remaining water to which the Upper Colorado River Basin is entitled under the Colorado River Compact of 1922. Based on historical records of the Colorado River, this would average about 838,000 acre-feet annually, less some reservoir losses. Of course, with water yields declining everywhere in recent years, no one can be sure what our allocation in acre-feet will be in the future. Compared to the small amount of water originating in the San Juan Basin in New Mexico, this seems a very generous allotment. To implement this apportionment, Colorado has assented to storage and diversion into New Mexico of water originating in Colorado.

The diversion of water from headwaters of the San Juan River into the Rio Chama (Tributary to the Rio Grande) was studied on a reconnaissance basis during the Rio Grande Joint Investigation in 1936-1938 and was found to be feasible.

A few years ago when New Mexico explored ways to put out allotment of Colorado River water to beneficial use, the Interstate Streams Commission asked the Bureau of Reclamation to study the San Juan-Chama diversion more intensively. The first report was issued in March 1955. This plan includes three storage reservoirs and five diversion dams for collecting and storing water in the San Juan River in Colorado, and nearly 50 miles of main conduit. The imported water would be discharged into Willow Creek, a tributary of Rio Chama, and would be regulated in the proposed Heron Reservoir for use in the Upper Rio Grande Basin. This reservoir would be used only to adjust the imported water with the varying natural flow of Willow Creek, with no storage of water for more than a short time. Outlet works in El Vado Dam would be enlarged so releases from the Heron Reservoir would pass through El Vado and down to the Rio Grande unimpeded.

The plan published in March 1955 would provide supplemental water for 45,000 acres of presently irrigated lands in the smaller irrigated valleys in northern New Mexico. Considerable flood water from Rio Grande tributaries flows through these valleys and downstream to the Middle Rio Grande Valley and Elephant Butte Reservoir, where there are vested rights to its use. Four comparatively small storage reservoirs would have to be built in these headwater tributaries to hold the flood waters for use in the northern irrigated valleys. Imported water from the San Juan Basin would be delivered to the downstream irrigated areas to compensate for water they now use but which would in the future be used upstream.

Water from the San Juan would be supplied to help firm up water supplies of the Middle Rio Grande Conservancy District and the Elephant Butte Irrigation District. The El Paso County Water Improvement District No. 1 in Texas would not receive any San Juan water. The Upper Colorado River Compact prohibits water from that Basin being used outside of Upper Colorado Basin states. The 1955 plan does not include development of new land for irrigation.

Imported water would be provided for the City of Albuquerque. In addition, the 1955 plan would contribute enough water the Upper Rio Grande Basin, without allotment to any individual interest, to replace depletions which may have occurred in the past half-century because of more intensive use of watershed lands, improved forage and timber cover, small erosion control structures and other measures to control sediment. This is a subject about which few facts are known. Only estimates, on which few authorities agree, can be made of the additional water, if any, that has been consumed by these measures to halt deterioration of the Rio Grande watershed and reduce sedimentation in the river and in reservoirs.

The proposed allotment of water in this plan is as follows:

		Acre-Feet
Supplemental irrigation:		
Northern irrigated valleys	39,800	
Middle Rio Grande Irrigation District	25,000	
Elephant Butte Irrigation District	71,900	136,700
Municipal and industrial water supplies		55,800
Replacement of depletions caused by basin improvements		42,500
Total diversion from San Juan River Basin		235,000

Estimated project costs were allocated as follows:

	Total cost	Repayment
Irrigation	$87,531,000	$21,290,000
Municipal and industrial	27,503,000	27,503,000
General basin depletions	20,393,000	6,600,000
Recreation	360,000	1/
Stream measurements	110,000	1/
Colorado River Basin Fund 2/	----	80,034,000
Non-reimburseable items 1/	----	470,000
Totals	$135,987,000	$135,897,000

1/ Public Law 485, 84th Congress, provides that these costs shall be paid by the Federal Government.

2/ This act sets up a Basin fund by which excess revenues from sale of hydropower, after cost of power facilities is repaid with interest, will be used to pay the cost of participating irrigation projects which is beyond the repayment ability of the water users.

The San Juan-Chama Project is one of 24 so-called "participating" projects for which planning studies have been authorized by the Congress. The Inter-state Streams Commission of New Mexico and the Bureau of

Reclamation are exploring various suggestions for a feasible project which will enable New Mexico to use its apportionment of water under the Upper Colorado River Compact and which can be presented to Congress for approval and appropriation of funds. This and other irrigation projects in the Upper Colorado Basin are called "participating" because they will participate in revenues from the sale of hydro-power to be generated by the Colorado River Storage Project after construction costs for power facilities are repaid with interest. New Mexico was apportioned 17 percent of the Basin fund.

As the above tabulation shows, irrigation interests in general were expected to repay without interest only $21,290,000 of the estimated cost of $87,531,000 allocated to irrigation in the Bureau's 1955 plan. The rest would come from power revenues from large storage reservoirs in the Upper Colorado River Basin. This was an overall percentage for the Basin and varied between localities in proportion to their ability to repay. Repayment ability was determined on an irrigated-acreage basis. Examples are $1.79 per irrigated acre annually in the Elephant Butte Irrigation District and $0.61 in the Middle Rio Grande Conservancy District.

The Bureau's estimated repayment for the irrigation features is based on the promise that these costs will be paid entirely by the irrigated land. This has been the practice in most irrigation projects of the West but another concept has been applied in a few places. Under the "conservancy district" type of project, repayment of the irrigation costs is spread over urban property as well as irrigated lands. We all know that the business welfare and prosperity of most cities within an irrigation project is dependent to a large degree on the productivity of the irrigated lands. Why then, shouldn't business, industrial, and other city interests help pay for the irrigation features that produce much of the prosperity for the entire project area? An example of this type of project is the Middle Rio Grande Conservancy District, in which business, urban and industrial interests within the City of Albuquerque and Bernalillo County join with the irrigation farmers in paying for the irrigation project. True, there are good arguments for and against this type of project organization but it does relate repayments to the benefits derived from a project much better than does the usual method of assessing repayments. A district of this type can also represent all water-using interests in obtaining additional water which will be needed in the future and in making most efficient use of all available water supplies.

The 1955 Bureau plan was not accepted by all parties. It was rejected by the Elephant Butte Irrigation District, representing irrigation water users of this area. This rejection nullified the 1955 plan.

Since then the Interstate Streams Commission has been negotiating with other water-using interests willing to pay their share of the estimated project costs and for which an exonomically feasible project can be developed. Naturally, the State of New Mexico is interested in putting its allotment of Upper Colorado River water to beneficial use as soon as practicable. As you know, California and other states could use this water to advantage. While it is now legally allotted to New Mexico, we all realize that the national interest will not let our state hold it indefinitely under theis agreement; Water is getting too scarce for that. Sooner or later the Congress will take notice of outside demands for any water not being used beneficially and it might be allotted elsewhere.

Some elements which might be included in a revised plan for the San Juan-Cham Project are supplemental water for the City of Albuquerque, the AEC at Los Alamos, the Middle Rio Grande Conservancy District and Holloman Air Development Center near Alamogordo. These and other proposals are being considered by the Interstate Streams Commission and the Bureau of Reclamation. I understand the State has applications for water on behalf of the interests listed above, but it is too early to determine what form the revised project will take. It seems safe to assume that there are enough legitimate requests for the imported water, with favorable indications for economic feasibility, to assure that a San Juan-Chama Project will be submitted to the Congress in the next few years.

To be quite frank, the chief obstacle to importing more water into the Rio Grande, making more efficient use of present water supplies and otherwise improving the water situation in the Upper Rio Grande Basin, seems to be suspicion and distrust among the various groups of water users. This is only one man's opinion but most attempts to improve the general water situation in this Basin seem to have foundered because water interests in different parts of the Basin could not get together. To be sure, engineering, legal and financial difficulties have been and always will be great. But they have been overcome in rare instances where water-using groups have been able to agree on what should be done. Experience has shown that most obstacles can be overcome in an atmosphere of good will and genuine cooperation.

RIO GRANDE WATER FOR AGRICULTURAL USES

James Cole[1]

Some 1900 years ago a fellow by the name of Ptolemy advanced the idea that the earth was the center of the universe and the sun and stars revolved around it. 1400 years later a Prussian, Copernicus by name, decided that Ptolemy's view was limited and that the sun was the center of the universe and the earth only one of a number of bodies that revolved around it.

Except for one previous lapse we have been discussing New Mexico's water problems from a Copernician point of view. In discussing the problems of the Rio Grande from a Ptolemaic view, I don't know what to do and hardly know where to begin. Several previous speakers have alluded to the unprecendented water restrictions on the Rio Grande project. Without reviewing this in detail let me recall for you that in each of the last three years the irrigation allotment in the project has been six inches or less per acre foot.

Thus far in the conference we have managed to steer clear of controversy because we have been discussing the broader aspects of water resources. Statistics are nice. They enable us to cut a problem down to size so our finite minds can work on it. But they cannot tell us the whole story and they can be misleading like the logging camp where two women cooked for 100 lumberjacks. One of the lumberjacks married one of the cooks. 50% of the women married 1% of the men.

C. E. Busby says, "The more valuable water becomes, the more conflicts of interest arise over its use and management. These conflicts may lead to insecurity of investments and impeded economic growth if basic law is not provided to assure protection of rights and a fair apportionment of the supplies to satisfy the rights. Permits and licenses issued as in the case of appropriations of surface water, are specific, as to time, place, and quantity. The license constitutes real property and may be conveyed in the same manner that land is conveyed", unquote.

The first and foremost cause of our present plight is drouth. We are in the throes of the worst drouth on record. As far back as the Spanish conquistadors there is no recoreded evidence of such a severe and prolonged drouth.

The present drouth situation is aggravated by the failure of the Rio Grande compact to operate in an effective manner. This compact became effective in 1939 after ratification by Texas, New Mexico, and Colorado legislatures, the Congress and approval by the President. It was supposed to settle for all times controversies between the three states over the diversion of waters of the Rio Grande. In New Mexico we have been faced

1/ Farmer and Secretary of the Dona Ana County Farm Bureau.

with a situation where from the attitude and actions of upstream users it appears that no serious and sustained attempt has been made to comply with the compact and apparently little effort has been made to conserve water or reduce waste and make required deliveries downstream prior to the advent of the Bureau of Reclamation in the Middle Rio Grande Area.

This attitude, coupled with the failure of the state to see that its citizens and political subdivisions comply with the compact have made it necessary for Texas to file suit to compel compliance. We now find the state of New Mexico, as Mr. Reynolds pointed out, in the paradoxical position of being engaged in internecine conflict with its own political subdivisions, questioning interpretations of the compact previously accepted, refusing to officially accept the computations of engineering advisors to the compact commissioners, and doing everything possible to prevent the suit from coming to trial so that determination can be made of the issues.

The state of Colorado, while not a party to the suit, has refused to officially acknowledge data determined by compact engineering consultants which define the extent of their debit to the Rio Grande project.

So much for the controversial.

We in the project appreciate the effective work of the Bureau of Reclamation in the middle Rio Grande Valley which has resulted in considerable conservation of water and which will effect greater conservation in the future. The San Marcial channel has been extended further north and rehabilitation of drainage, irrigation and distribution systems is well underway. We commend the Bureau for its efforts to change the methods of operation of the conservancy district to make better use of available water.

Nor can we pass up the opportunity to express appreciation to the State Engineer, the Governor and the legislature for appropriating and making available funds for the purpose of keeping down the growth of water consuming vegetation north of Elephant Butte.

In view of the experience of the past few years, it seems that it would behoove the state and its organized irrigation districts up and down the river to attempt to make the best possible use of available waters by reducing wastes and losses and, consistent with finances available from users, strive for maximum efficiency. Our water users board of directors is now considering a rather ambitious plan for lining certain portions of the river below Elephant Butte. The proposition involves a very heavy financial burden on water users which cannot be entered into lightly. We realize that we in the project are not perfect in water use efficiency but significant progress has been made in the past ten years.

In spite of some differences it seems we should all unite in a sustained effort to achieve maximum conservation. It may well mean survival in the long run.

Like Lady Godiva, I'm approaching my close, the after thought on San Juan additions.

We in the project certainly do not object to the importation of additional water from any source provided quality is satisfactory but we are keenly interested for obvious reasons in the methods of operation to be employed and particularly in the accounting methods adopted and how and by whom will diversions be controlled. The question naturally arises - "Then why did you reject the opportunity to participate?" Stream flow records indicate close correlation between flows in the San Juan and the Rio Grande. No firm delivery offer was made but simply a supply fluctuating according to stream flow. When we, on the basis of past experience, might be in the greatest need of water there would be little available and when we might need it the least, a normal supply would be available.

To obtain this fluctuating supply it would have been necessary to assume a financial burden of $90 per acre, equal to the total original cost of the project including Elephant Butte, to assure a maximum delivery of one-half acre foot to the farm. Water users felt that it was simply not financially feasible.

We do, however, feel that as residents of the Rio Grande basin in New Mexico we are entitled to find out who will handle the water and how. How will the mingled waters be unscrambled? What allowances will be made for transportation losses. Will the diversions be accurately and fairly measured and properly controlled so that no more water will be taken out of mingled flows than the San Juan users on the Rio Grande may be entitled to use.

In closing let me pose this question to irrigations users. If you set up municipal uses of imported water and such uses expand to maximum amounts of imported water available for that purpose as they inevitably will; and we run into a series of years of subnormal stream flow, can the irrigation users be sure that municipal uses will be curtailed in proportion to the reduction in stream flow?

Thank you for your courteous attention.

The Water Supply of the
Upper Rio Grande River

by

Ernest Martinez[1]

In discussing the effects of the proposed programs on the water supply of the Rio Grande, two important questions are raised by water users in the area. First, what measures are included to conserve soil and water and also to reduce sedimentation and flood damage. Secondly, what will be the effect of these measures and of the overall program on the total water supply and how much water will be available for irrigation of agricultural crops.

It has been recognized by the authorities that in the semi-arid southwest an adequate supply of water is essential for a stable agriculture. This is indicated by some of the present programs which provide for federal aid on measures such as improved water application practices, land leveling, canal lining, rehabilitation of irrigation systems and the construction of small irrigation reservoirs. The inclusion of water salvage measures is also consistent with the broad policy of conservation at least insofar as it is directly assiciated with bringing about a favorable balance in the supply of irrigation water. The proposed efforts to retard surface run-off will decrease sedimentation and will improve water shed conditions and reduce flood damage. Such measures will minimize the adverse effects on the water supply and will be consistent with our concept of water rights and beneficial use. They conform to the premise that established water supplies and the use of that water should be improved wherever possible.

To confine the discussion more specifically to the Upper Rio Grande Valley the writer has obtained information from several of the local agencies of the state, county and municipal utilities. There is considerable information available but little is for public release at the present time.

The Carson National Forest, the U. S. Soil Conservation Service and the County governments together have accomplished a great deal in planning and developing this area. Proposals have been made for new dam sites particularly El Chiflo on the Rio Grande, as well as many smaller but similar projects. In addition new vegetation has been planted and ditches have been constructed for irrigation.

Several counties in Colorado, and Rio Arriba county in New Mexico have all benefited from the waters of the Rio Grande. Taos county, however, has received no water from this source since here the river runs through a gorge which varies from 400 to 1700 feet in depth. Although there are a number of other small rivers, creeks and streams in Taos county there

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1/ Manager, Taos Municipal Water and Sewer System, Taos, New Mexico is a general shortage of water for irrigation particularly in late summer. The water shortage begins in early August and becomes very acute by mid-September.

Today as one motors through some of the beautiful canyons in the Taos area one finds little or no water in the rivers and streams. In 1955 precipitation was considerably below normal. It was therefore not surprising that a river such as the Don Fernando de Taos, which flows just below the Taos city limits, looks like a dry arroyo from there to its head waters.

Despite the shortages of water the method of distributing irrigation water in Taos was much better in 1956 than in previous years. This resulted in a better growing season for the area.

The underground water source seems to be rather stable in Taos County. In the past few years the water table has dropped only 8 feet. The local water department last year supplied water to 40% more users than in 1949.

To discuss the factors that affect the total supply of water to the Rio Grande one must consider the physical and climatic conditions of the area.

The soil is predominately mountains with moderate to steep slopes. The soils are of medium to shallow depths and are frequently underlain by consolidated deposits.

The annual precipitation varies from 14 to 45 inches and averages about 18.5 inches. A large portion of it falls as snow and some of it runs off when the spring thaw occurs. The infiltration rate for the area averages about 1.2 inches per hour and on a large portion of the area may exceed 1.5 inches. The annual evaporation rate varies from less than 2 feet to about 4 feet. The average for a number of years has been 2.5 feet.

Therefore, most of the water yield to the rivers and streams in this area results from accumulated snow and occasional heavy rain. The losses from evaporation and channel seepage are much less here than on the Lower Rio Grande and the precipitation rate seldom exceeds the infiltration rate except when rapid thaws of snow occur. The surface run-off, which contributes to the Rio Grande water supply is estimated to be around 2 acre-feet per square mile per year. This is small when compared to the total yield of water which may be as high as 1600 acre-feet per square mile per year.

RIO GRANDE WATER FOR INDUSTRIAL AND MUNICIPAL USE

Carl Meriwether 1/

The subject assigned to me for presentation is "Rio Grande Water" city and industry representation. First, I would emphasize that I am not an engineer and certainly not an expert on the subject assigned.

I am not so much concerned about what has gone on in the past except, as the past may serve as a reasonable guide as to what can be expected in the future. There is no question in my mind as to the seriousness of our present situation as regards water supplies now available to city and industry, and certainly all of us can be alarmed when we attempt to look even five years forward. When we attempt to look ten, fifteen or twenty five years into the future, the problem becomes even more staggering. There is only one area in the state that now has a surplus of water for municipal, in industrial and agricultural use and that is the Tucumcari area. Even that plentiful supply of water appears to be in danger of being lost to our neighbors on the east.

Just what is an acre foot of water? Briefly, it is 325,850 gallons of water. How far does an acre foot of water go toward satisfying the demands of even a medium sized municipality in the state of New Mexico? For the last fiscal year of a community near here the average daily usage per person per day ran to 190 gallons, this adds up to the sizeable total of 69,350 gallons per year per person. Further projected this means that an acre foot of water will supply the needs of 4.7 persons for one year. This municipality in question, has an average water rate of 28¢ per thousand gallons of water delivered to the customer, whether to a household or to an industry. Further projected this means that an acre foot of water has a gross value of $91.24 for such use.

Now let us look at agricultural use of water and approximate gross value of an acre foot of water in growing crops. The primary money crop produced along the Rio Grande in New Mexico is cotton. Of course there are many other crops produced such as, vegetables, grains of many kinds and descriptions, alfalfa hay, fruits and others, but I believe that you will agree with me that cotton production should be the main yardstick to be used in this area. Based

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1/ Manager Western Cottonoil Company

on last years production and estimated average price for lint and seed we arrive at a gross income per acre of cotton of $275.04 per acre. When we consider that it takes an average of three acre feet of water to produce an acre of cotton we get a gross value of $91.68 per acre foot of water used. Other crops will not produce nearly so well if we exclude vegetables and nuts.

From the above comparisons we have these figures - an acre foot of water for municipal and industrial use is worth $91.24 while for cotton production it is worth very nearly the same or $91.68 per acre foot.

The time allotted to me will not permit a full development of the economics involved: so I had better get along with my real proposal. We all know that where a question of the welfare of our population is concerned that water for municipal and industrial use has and will come first regardless of the rights and legal questions raised by the confiscation of agricultural water for use by cities and industry.

If a city or municipality or industry confiscates water which rightly belongs to an individual, the only result will be one of real hardship on the individual; However, if that individual is reimbursed for the fair value of his land with water rights or his water rights are purchased outright, then this individual has suffered little economic loss.

Briefly what I propose is that municipalities and industry, which are mostly one and the same, since most municipalities furnish water to their industries, be encouraged to purchase sufficient water rights-or land with water rights to take care of the needs in the foreseeable future. Perhaps this is not possible under present laws and should this be the case, I would plead for the enabling legislation to be passed as quickly as possible. We must bear in mind that most cities and municipalities are not in a financial position to accomplish this in the near future, so some considerable thought and planning must be given to the problem of financing such purchases. Perhaps the financing is a job for the state or the federal government or a combination of the two. At any rate, the financing could be arranged so as to allow the city or municipality to pay for their water rights over a long period of time. This proposal could apply to any city or municipality in New Mexico, not necessarily just along the Rio Grande River.

On October 15, I presented this proposal to the New Mexico Economic Development Commission at a regular meeting held at Santa Fe, New Mexico, and recommended that the staff of the Economic Development Commission take this matter under study, and advisement. The Commission voted unanimously in favor of the study I proposed. I firmly admit that this plan is not perfect and that it needs much thought, study, and consideration before it can be placed in a workable form. I thank you for your attention.