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ECONOMIC FEASIBILITY OF INCREASING PECOS BASIN WATER SUPPLIES THROUGH REDUCTION OF EVAPORATION AND EVAPOTRANSPIRATION

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PUBLICATIONS

This report is one of a series in the project entitled "A Comprehensive Water Resources Analysis of a Typical Overdrawn Basin in an Irrigated Semiarid Area–Pecos River Basin, New Mexico."

Others published are:

Report 7– *An Economic Classification of the Irrigated Cropland in the Pecos River Basin, New Mexico*, by Robert R. Lansford, Edwin T. Garnett, and Bobby J. Creel.

Report 8– *Quantitative Water Resource Basin Planning: An Analysis of the Pecos River Basin, New Mexico*, by Ralph C. d'Arge.

Other reports covering the hydrology, geology, systems analysis, and a summary of this study are yet to be published.

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ABSTRACT

Each year a large portion of the southwestern water supply is lost through evaporation and plant transpiration. The growing threat of an insufficient water supply in the Southwest makes vegetation manipulation and evaporation suppression to reduce these losses increasingly attractive. These losses can be successfully reduced, but it has been difficult to estimate how much additional water could be produced by large-scale vegetation management and evaporation control, and whether such a program would be feasible.

A hydrologic model was developed for the Pecos River Basin in New Mexico to estimate the additional water that could be obtained by vegetation treatment in the forested headwater areas, by removing phreatophytes in the lower river valley, and by applying monolayer films on the major reservoirs in the Pecos Valley. The costs and benefits attributable to the increase in water supplies estimated by the hydrologic model were analyzed to determine the economic feasibility of such a program. Results of this analysis were as follows:

1. Removal of timber from the forested headwater region of the Pecos watershed would increase the water yield by about 15 percent, but was currently unfeasible because the recreational value of the forests far exceeded the value of the additional water.

2. The annual water gain of 70,000 acre-feet from the eradication of phreatophytes in the Pecos Valley justified the cost of their removal.

3. Suppression of evaporation during late summer and fall was feasible in the Pecos Valley and would yield approximately 4,000 acre-feet of water annually.

(Key words: evaporation reduction, transpiration reduction, economic models, cost-benefit analysis.)

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PREFACE

Water resource development has become almost a household phrase in the semiarid West. Even prior to John Wesley Powell's monumental *Report on the Lands of the Arid Region of the United States* in 1879, the idea of a special embedment for water in the mosaic of western natural resources arose in the minds of social planners, conservationists, and politicians. The evolution of specific areal water doctrines and Acts of Congress regarding water and land development in the West typify the early importance given to water problems. From the early twentieth century there has been an almost continuous public interest, perhaps highlighted by the Boulder Canyon Act of 1928 and extensive reclamation of lands by the Bureau of Reclamation.

More recently, several water development and transfer proposals have claimed the public eye, including the North American Water and Power Alliance (NAWAPA) proposal, and one called the Central North American Water Project (CeNAWP). Implementation of these proposals would not only significantly alter the physical distribution of North America's water resources, they would alter past trends in the nation's water resource development. These trends, with several important exceptions, have been in the direction of augmenting existing intrabasin water supplies from sources within a basin. NAWAPA and CeNAWP, alternatively, would not only require interstate cooperation, but would involve international cooperation as well.

One must question whether there are viable physical and economic alternatives to these massive and costly schemes of augmenting water supplies in the semiarid West. If the social goal, regardless of cost or alternatives, is to turn the region into a "green pasture," certainly massive importations of the scale proposed by NAWAPA (112 million acre-feet of water per year into the United States, and 29 million acre-feet to Mexico) are necessary. However, if the more limited objective is accepted of maintaining the growth rate in water costs equal to, or less than, the growth rates in costs of other natural resources, massive importations may not be required. In fact, there is practically no evidence indicating that water costs have substantially increased, or have increased faster than other natural resource costs, recently, in the semiarid West.

William Hughes's study is one step, but a significant one, in the direction of searching for alternatives to massive interbasin, inter-regional, and international water transfers, through intrabasin evaporation suppression, phreatophyte control, and forest vegetation manipulation. Though his analysis requires drawing a number of inferences from small-scale experiments to large-scale applications, particularly with regard to evaporation suppression and vegetation manipulation, the orders of magnitude of his results yield some interesting conclusions, especially regarding costs.

Preliminary cost estimates for irrigation water from the NAWAPA plan range from $10.00 to $25.00 per acre-foot, depending on interest rates and repayment schedules. The average cost per acre-foot for the Rio Grande-Gulf portion of the NAWAPA plan is somewhat less, between $5.00 and $10.00, though it is uncertain how construction costs will be prorated between geographical segments of the plan. The NAWAPA proposal may not be economically feasible in terms of the traditional benefit-cost criterion. If one assumes that total operating costs, including electric power generation and depreciation, exceed five percent of construction costs, the implied benefit-cost ratio is less than one. It is significant that water cost estimates contained herein for phreatophyte control, and in some cases for evaporation suppression, are comparable to irrigation water cost estimates for NAWAPA.

Through application of certain economic water-conserving practices, it appears likely that, for many basins in the semiarid West, enough additional water might be generated so that massive importations could be delayed or ameliorated. Delaying massive water importations would most certainly be less costly, at least in the very near future, and would allow more flexibility for adopting future technological changes in methods of water conveyance. From Hughes's estimates it appears reasonable to assume that, through the several water-conserving practices analyzed, water available for municipal, industrial, and agricultural use would be increased by 20 to 30 percent in the Pecos Basin area. While this amount is less than the percentage increase envisioned under the NAWAPA plan, it would provide enough water to meet projected requirements in the Pecos Basin for at least two decades.

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ECONOMIC FEASIBILITY OF INCREASING PECOS BASIN WATER SUPPLIES THROUGH REDUCTION OF EVAPORATION AND EVAPOTRANSPIRATION

William C. Hughes[1]

Chapter 1

INTRODUCTION

The State of New Mexico annually receives approximately 85 million acre-feet of water from precipitation. Of this amount, little more than 3 million acre-feet appears as runoff in the streams and rivers. Much of the remaining 82 million acre-feet returns to the atmosphere through evaporation and plant use. In a semiarid region such as New Mexico, where future development to a large degree depends upon the size of the water supply, the reduction of evaporation and plant transpiration is becoming increasingly attractive.

Although there has been considerable research with respect to methods for reducing evaporation and evapotranspiration losses, few studies have been made to determine the potential for augmenting the existing water supply through a large-scale application of these techniques.

The objective of the study described in this report was to examine the possibility for augmenting the existing water supply in the Pecos River Basin through the manipulation of vegetation in the forested headwater regions of the basin, the reduction of evaporation on the major reservoirs of the basin, and the partial removal of phreatophytes in the Pecos Valley.

Much of the material in this report was summarized from a dissertation written in partial fulfillment of requirements for a Doctor of Philosophy degree at the University of New Mexico. A major portion of the dissertation was devoted to the development of a hydrologic model that would estimate the effective increase in the Pecos Basin water supply resulting from the reduction of the water consumed by vegetation in the headwater regions of the basin and in the Pecos Valley, as well as the reduction of reservoir evaporation. These estimates are used in this report to explore the economic feasibility of such a program.

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Chapter 2

SUMMARY OF PRIOR EXPERIMENTS

This study was partly based on the experiments and the judgment of others. The following is a summary of these experiments and sources of information.

Plant Water Consumption Measurements

Meinzer acknowledges at least ten methods for measuring the water consumed by plants, but only two are significant to this study(11). (In the discussion that follows, the terms "water consumption" and "transpiration" will be used interchangeably, although there is some difference.)

Open-Tank Method. The plant under investigation is grown in a large tank where the water input required to keep the plant healthy is carefully controlled and measured. This system allows the measurement of the water consumed by individual plants, but has the disadvantage that the plant is in artificial surroundings. Further, because of space limitations, the open-tank method is generally limited to smaller plants such as farm crop plants, grasses, and brush.

Controlled-Watershed Method. Two adjacent and approximately identical watersheds are calibrated so that one can be used to predict the runoff from the other. Then the vegetal cover on one plot (the experimental plot) is removed or altered. The effects on the runoff are measured by comparing the runoff from the experimental plot with the runoff predicted by the control plot. Although the water consumed by individual plants cannot be measured, this system has the advantage of measuring the overall effect of the vegetation on runoff under natural conditions. The controlled-watershed method is most effective in areas where a shallow soil layer covers impervious rock so that both the surface runoff and groundwater can be accounted for. Therefore this method has been used extensively in mountainous areas.

Headwater Experiments

The headwater areas in the Southwest are located in mountainous terrain and are well adapted to the controlled-watershed method for measuring the effect of vegetation manipulation on water yield. Of the 39 studies of this type conducted between 1900 and 1968, three have been in the Southwest (5, p. 327).

The Wagon Wheel Gap study, the first controlled-watershed experiment, was undertaken by the United States Weather Bureau in 1911 on a tributary stream to the Rio Grande, located just north of the Colorado-New Mexico border. After eight years of calibration, the forested portion, which represented 84 percent of the experimental plot and consisted of aspen and conifers, was completely removed or clear-cut. The change in water yield was measured over the subsequent seven years and amounted to about 18 percent (5, p. 528).

Another study was conducted at the Workman Creek experimental watershed, which is located in east central Arizona and is operated jointly by the Salt River Water Users' Association and the United States Forest Service. The South Fork experimental plot was calibrated with the Middle Fork from 1938 to 1953, when the predominantly pine forest was reduced by 30 percent of its basal area, using the random selective logging process. The logging took place over a two-year period and resulted in an insignificant increase in water yield. Another 15 percent reduction in the basal area, due to a fire and thinning, also failed to produce any significant increase in water yield.

The North Fork of Workman Creek was calibrated with the Middle Fork from 1938 to 1958, when 32 percent of the timber, primarily fir and spruce, was removed from the moist area (several yards on either side of the stream for its entire length) which was then converted to grass. This treatment resulted in a 35 percent increase in runoff over a five-year study period (5, p. 528).

The third study was made at the Fool Creek experimental watershed located in the Rocky Mountains near Fraser, Colorado. After several years of calibration, 40 percent of the timber, which was lodgepole pine, spruce, and fir, was removed in clear-cut strips 66 feet wide and about 400 feet long. This treatment resulted in a 26 percent increase in runoff over a five-year period (8, pp. 111-115).

The results from the experiments are quite inconsistent, not only among watersheds but from year to year on the same watershed, but they are sufficiently adequate to show proof that water yield increases as vegetal cover is reduced.

There has been much speculation concerning the causes of the increased water yield experienced after vegetation is removed. The fact that most of the increased runoff came as snowmelt from the three experimental watersheds described above, and only a small increase was noted in the summer months, seems to indicate that decreased transpiration plays a minor role in increased water yield. This, with the results of an experiment performed in the Fraser experimental forest (which includes Fool Creek) where it was found that the water equivalent of the snowpack in cleared areas was two to three inches greater than in forested areas, led to the conclusion that increased runoff is largely attributable to a decrease in interception (8). It was thought that the intercepted snow was more exposed and therefore evaporated more quickly than in a snowpack. More recent studies at the Fraser experimental forest have shown that the overall snow volume was unchanged by the removal of vegetation but the snow was redistributed—that is, after the vegetation removal, part of the snow which formerly would have been held in the forested areas was being trapped and held in the cleared areas (6, p. 221).

Table 1. Water yield increase in headwater treatment experiments at southwestern sites.

Catchment	Area	Elevation	Date and Treatment	Water Yield Increase as Percent Normal Runoff
	(acres)	(feet)		
Wagon Wheel Gap (Colorado)	200	10,000	1910–100 percent clear-cut aspens and conifers	18
Fool Creek (Colorado)	713	10,000	1954–40 percent commercially clear-cut strips	26
Workman Creek North Fork (Arizona)	247	7,400	1958–32 percent clear-cut in moist site, grass seeded	35
Workman Creek South Fork (Arizona)	318	7,200	1953–30 percent basal area removed by selective logging	not significant

Source: A.R. Hibbert, "Forest Treatment Effects on Water Yield," *International Symposium on Forest Hydrology Proceedings*, Pergamon Press, New York, 1965, p. 528.

Hoover and Leaf (6, p. 222) believe that the redistribution satisfactorily explains the increase in runoff, as in the following example: Assume an area with a soil moisture deficit of 12 inches at the beginning of snowmelt and with 12 inches of water in the snowpack, which is evenly distributed. No runoff would be expected. On the other hand, if the snowpack were distributed so that one-half of the area was covered with eight inches and the other half with 16 inches, the runoff would be four inches from the area of deep snow, while the area with shallow snow would be left with a four-inch deficit. The average runoff per unit area would show a two-inch increase over the first case where the snow was evenly distributed.

Two major areas of agreement emerge from this speculation: 1) Transpiration reduction plays a minor role in the increase of water from forest areas of the southwestern United States. 2) The effectiveness of vegetation manipulation in forest areas is dependent on the proportion of the precipitation that falls in the winter.

An area of relevant research which is currently being explored deals with the distribution of a snowpack as it affects the amount of runoff. One method of studying this question is to artificially redistribute the snowpack to the high meadows and areas above the timber line by means of strategic placement of snow fences (1, pp. 355-373). This creates the possibility of increasing the water yield of an area, and also of decreasing the melt rate since, at the higher elevations, the snow melts relatively late in the season, thus spreading the runoff through the summer. Experiments relating increased snowpack depths in high mountain areas directly with increased runoff have not as yet been made. If the use of snow fences or other artificial barriers does prove successful in increasing water yields, this practice would seem to be superior to vegetation removal because it costs less, and because it would have less effect on the recreational aspects of forest areas.

Phreatophyte Experiments

The phreatophyte plant classification describes a distinct ecological group of desert plants that have adapted their root systems to survive in arid areas where the water table is between 5 and 30 feet below ground. The phreatophytes, including rushes, reeds, palm trees, cottonwood trees, willows, and others, are found in areas such as the lower flood plain of arid river basins, where it is difficult to account for the sources and interaction of surface and ground water flow. For this reason, attempts to measure the water consumed by phreatophytes in their natural surroundings have had limited success. By far the most successful and numerous of plant water use experiments have used the open-tank method. The results of a few such experiments are shown in table 2.

Table 2. Water consumption of plants in representative phreatophyte treatment experiments.

Common Name of Plant	Depth to Water	Water Quality as to Salinity	Water Consumed Annually at 100 Percent Density
	(feet)		(feet)
Water willow	2-15	poor	4.7
Wire grass	shallow	---	7.8
Cottonwood	4-30	good	6.0
Alkali sacaton	5-25	excellent to very poor	3.5-4
Greasewood	5-10	excellent to very poor	0.5
Salt cedar	4	---	9.17
Salt cedar	5	---	8.42
Salt cedar	6	---	7.75
Salt cedar	7	---	7.33
Salt cedar	8	---	7.00

Source: T.W. Robinson, *Phreatophytes*, U.S. Geological Survey Water Supply Paper No. 1423, United States Government Printing Office, Washington, 1958.

Phreatophytes in the Pecos Valley

The salt cedar (*Tamarix pentandra*), because of its prevalence, is the only significant phreatophyte in the Pecos Valley. It is believed to have been brought to the United States from the Mediterranean area in the nineteenth century as an ornamental shrub, and was first noticed in the lower Pecos Valley around the turn of the century. It spread rapidly and by 1939 had infested the Pecos Valley as far north as Roswell and had formed a dense jungle covering some 10,000 acres between Carlsbad and Artesia. The phenomenal spread of salt cedar has continued and in 1960 the Bureau of Reclamation estimated that between the state line and Santa Rosa there were some 40,000 acres of salt cedar, ranging in density from heavy near Carlsbad to light near Santa Rosa. Further, the Bureau estimates that, if the salt cedar is allowed to continue to spread, it could dry up the Pecos River by 2000 or 2010 (12, p. 91).

The spread of salt cedar has been of particular concern to the Pecos River Commission which, aided by the Bureau of Reclamation, in 1939, 1946, and 1950, made surveys of the areal extent and density of the salt cedar in the Pecos Valley (24, p. 3). These surveys are the basis for the projected acreages and densities used in this study.

Phreatophyte Eradication

Phreatophytes, salt cedar in particular, are difficult to eradicate since, even if the upper portion of the plant is killed, the roots, which may extend downward for 30 feet, continue to grow and propagate new plants.

The Bureau of Reclamation has established an experimental site on the Rio Grande near Belen, New Mexico, to study both the water consumption of salt cedar and methods for destroying it (17). Several sprays have been developed which can be applied either from air or ground spray units and which kill about 50 percent of the phreatophytes in the sprayed area. A second method of phreatophyte removal involves a mechanical clearing of the area, using tractors to pull the plants, followed by the mowing of new sprouts each year thereafter. This method is more effective, though more costly, than the spray. The Bureau of Reclamation recommends the mechanical removal of phreatophytes in their *Definite Plan Report* of the Pecos River Basin Water Salvage Project.

An area of current research which holds promise with regard to the reduction of transpiration in phreatophytes is the search for chemicals which partially close the plant stomata, retarding the transpiration without killing the plant. The water consumption of oak and pine seedlings has been reduced by spraying the seedlings with phenylmercuric acetate (25, p. 485). However, there is as yet no evidence that such sprays would significantly increase runoff, even if used on a large scale.

Evaporation Suppression

Two properties are necessary to make a chemical film effective for retarding evaporation: 1) the film must have the ability to spread rapidly over the water surface and 2) it must form a layer of closely packed molecules that impede the movement of water. In addition, if the film is to be used on rivers or reservoirs it must be nontoxic and allow the passage of oxygen and carbon dioxide molecules.

Since Rideal first noticed the evaporation-retarding qualities of monolayers in 1925, the range of possible monolayers has been narrowed to two—hexadecanol, $C_{16}H_{33}OH$ (cetyl alcohol), and a second compound, octadecanol, $C_{18}H_{37}OH$ (stearyl alcohol)—which seem best to fit the criteria for an evaporation suppressant (25, p. 483).

Table 3. Summary of evaporation suppression experiments in selected locations.

Location	Area	Evaporation Reduction
	(acres)	(claimed percent)
Australia	2	25-45
Australia	10.3	50-90
Australia	22	15-40
Lake Corella, Australia	unknown	40-100
Umberumberka Reservoir, Australia	300	21-52
Malya Reservoir, Africa	130	11-12
Nairobi, Africa, 4 reservoirs	15-200	15-24
India, several reservoirs	20-1,500	4-30
Beit Netofa Valley, Israel, 3 small ponds		15-20
Saguaro Lake, Arizona	1,260	9-27
Lake Cachuma, California	3,090	8-22
Lake Hefner, Oklahoma	2,587	7-14
Felt Lake, California	40	19-23
Illinois	2-3	22-43
Eagle Pass, Texas	80	35
Eagle Pass, Texas, 9 stock tanks		7-27
Russia, 3-m. evaporators		8-32
Japan, 20-cm. trays		10-95
England, 3-1. beakers		25-52
Nairobi, Africa, 4-ft. pans		50-70
Israel, Class A pan		40-70
New Delhi, India, Class A pan		32-80
Poona, India, 4-ft. pans		20-80
Arizona, outdoor tank		40-50
Denver, Colorado, Class A pan		9-64
Denver, Colorado, canal		13-16
San Antonio, Texas, 9-in. jars		20-50

Source: W. J. Roberts, "Evaporation Retardation by Monolayers," *Advances in Hydroscience*, Vol. 3, 1965, pp. 363-4.

In 1952 both the United States and Australia began field tests with hexadecanol and octadecanol to determine whether monolayers would be sufficiently effective outside the laboratory to make large-scale use feasible. Since that time some 27 experiments have been carried out in eight different countries. A summary of the tests is given in table 3.

From these experiments it was learned that the effectiveness of monolayer films in the field was severely affected by the wind. At wind speeds greater than 15 miles per hour, the monolayer completely lost its ability to retard evaporation (4, p. 68). Further, the effect of the wind seemed to be amplified as area of the water surface increased.

As a result of these experiments several methods were developed for applying monolayer films to the water surface. In the earliest experiments, solid blocks of fatty alcohols (combinations of hexadecanol and octadecanol) were simply allowed to "melt" in the water; however, the melt rate was too slow to maintain a film. Later, flakes and beads of fatty alcohols encased in wire cages were allowed to melt in the hope that the greater exposed surface area would increase the melt rate. But again, the melting was insufficiently rapid except over very small water surfaces.

In later experiments, pulverized fatty alcohol sprayed from a boat proved to be an effective but costly system for maintaining the monolayer. The Bureau of Reclamation has developed a device for spraying a water surface from an airplane but it has not been used in any major evaporation suppression studies.

The most effective method to date for applying the monolayer was developed in experiments conducted at Saguaro Lake, Arizona, in 1960 and perfected at Lake Cachuma, California, in 1961. The dispensers were 50-gallon tanks in which melted fatty alcohols were stored under pressure. The alcohols were released as a fine spray by wind-controlled valves, so that the rate of application was automatically increased as the wind speed increased. At the maximum wind speed of about 17 miles per hour, the spray shut off.

This system proved effective on Lake Cachuma which has a surface area of about 2,500 acres. Since the major reservoirs in the Pecos Valley are 5,000 acres or less in size, it was assumed that the molten-spray method of application would be the most effective, and that the fixed costs per acre incurred during Lake Cachuma experiments would be representative of the evaporation suppression costs that would probably be experienced throughout the Pecos Valley.

Chapter 3

MODEL DEVELOPMENT

A Hydrologic Model

A hydrologic model was developed for the Pecos River Basin to estimate the additional water which could be obtained from a program of vegetation management and evaporation control. The model was based on the hypothesis that the results from vegetation manipulation and evaporation experiments described in Chapter 2 could be applied to the Pecos watershed if the increase in water obtained in these experiments were expressed in terms of physical and climatological variables which were measurable at both the experimental site and in the Pecos watershed.

The hydrologic model was made up of three parts, or sub-models, representing: 1) vegetation manipulation in the forested headwater areas; 2) removal of salt cedar in the Pecos River Valley; and 3) suppression of evaporation by using a monolayer film on the major reservoirs in the Pecos Valley.

A Headwater Model

A headwater model was developed for each of the two major headwater regions of the Pecos River Basin. The first, designated as the Upper Pecos, is located in the Sangre de Cristo mountains north of Las Vegas, New Mexico, and the second, designated as the Lower Pecos, is situated in the Sacramento mountains west of Roswell, New Mexico.

As indicated by the basic hypothesis, the headwater model depends on the translatability of results from an experiment in which the degree of treatment and increase in water yield have been measured, therefore the headwater model was based on data from the Wagon Wheel Gap experiment because it is both geographically close to the Pecos watershed and similar in climate.

The development of the headwater model required that a precipitation-runoff relationship be established for both the Pecos and the Wagon Wheel Gap experimental watersheds–that is, a relationship which, given the monthly precipitation and monthly losses, would yield monthly runoff.

The losses occurring on the experimental watershed were related by regression techniques to parameters representing physical and climatological variables in order to establish a loss equation. In this case, mean monthly temperature and the departure of monthly precipitation from normal were the strongest climatological variables. In addition a vegetation parameter representing the type and density of vegetation in the basin was a mandatory term in the equation since it imparted to the model the effects of vegetation removal.

The loss equation was then combined with the experimental watershed precipitation-runoff relationship to form the experimental watershed headwater model. Constants in the headwater model were adjusted until it accurately reproduced the historic runoff from the watershed–and, through changes in the vegetation parameter, reproduced the increase in runoff measured on the experimental watershed.

The mean monthly temperature, precipitation departure, and a vegetation parameter representative of the Upper Pecos and Lower Pecos headwater areas were substituted into the loss equation, and a set of hypothetical losses was computed. This set of losses was then correlated with the actual Upper and Lower Pecos losses to derive constants that modified the loss equation to fit the Upper and Lower Pecos headwater areas. The modified loss equations were coupled with Upper and Lower Pecos precipitation-runoff relationships to form the Pecos headwater model. The Pecos headwater model was adjusted so that, given the average Upper and Lower Pecos precipitation, it would reproduce the average Upper and Lower Pecos runoff. The increase in runoff was obtained by varying the vegetation parameters to simulate the removal of timber.

The predicted additional water which would be received through the removal of varying amounts of timber in the Upper and Lower Pecos headwater regions is shown in table 4.

A Phreatophyte Model

The Bureau of Reclamation conducted experiments in the Rio Grande valley near Albuquerque in 1962 and 1963 in which they measured temperature, precipitation, evaporation, and the water consumed by salt cedar (19, p. 31, table 5). Water consumption by salt cedar was determined by growing the plants in large tanks and measuring the water required to maintain a given water table in the tank. After adjustments for precipitation and soil evaporation, the remaining water input was assumed to be consumed by the plant. These experiments were run for several salt cedar volume densities (19 to 55 percent), and with the water table set at depths ranging from three to eight feet.

The results from these experiments were used to derive an equation relating a parameter representing salt

Table 4. Average annual increase in runoff resulting from timber removal, Pecos Basin headwater model.

Timber Removed	Increased Runoff Upper Pecos		Increased Runoff Lower Pecos	
(percent)	(acre-feet)	percent)	(acre-feet)	(percent)
0	0	0	0	0
10	0	0	500	1
20	0	0	1,000	3
30	1,500	3	1,400	4
40	3,000	5	1,800	5
50	4,200	7	2,300	6
60	5,300	9	2,800	7
70	6,300	11	3,200	8
80	7,400	13	3,700	9
90	8,500	14	4,200	10
100	10,000	16	5,000	13

cedar water consumption per unit of volume density to evaporation and "potential evapotranspiration."[1] This equation was used to estimate the water consumed by salt cedar in four reaches of the Pecos Valley: 1) Carlsbad to Artesia, 2) Artesia to Acme, 3) Acme to Alamogordo Reservoir, and 4) Alamogordo Reservoir to Las Vegas. It was assumed that the average evaporation from Lake Avalon and the potential evapotranspiration computed from temperature data at Carlsbad were representative of the two southern reaches, and that the average evaporation from Alamogordo Reservoir and potential evapotranspiration computed from Santa Rosa temperature data were representative of the two northern reaches. The volume densities were assumed to be 100 percent for Carlsbad to Artesia, 67 percent for Artesia to Acme, 33 percent for Acme to Alamogordo Reservoir, and 25 percent above Alamogordo Reservoir.

The quantity of water that could be salvaged per acre of salt cedar removal was computed for two conditions: 1) where salt cedar was replaced by grass, and the net water gain was equal to the water consumption per acre by salt cedar minus the water consumed by an acre of grass; and 2) where the ground was left bare after the removal of the salt cedar, and the net water gain was equal to the water consumed by an acre of salt cedar minus the estimated increase in soil evaporation.

The total quantity of water that could be salvaged in each reach, shown in table 5, was computed by multiplying the net gain per acre by the number of acres of salt cedar in each reach, where the areal extent of the salt cedar was estimated from the rate of spread of salt cedar in the Pecos Valley, as established by the Pecos River Commission (24, pp. 4-5).

Assumptions Regarding Evaporation Suppression

There are four major reservoirs in the Pecos Valley north of the Texas border in New Mexico:

1. Alamogordo Reservoir, in the northern third of the valley, near Santa Rosa.

2. Two Rivers Reservoir, on the Rio Hondo, west of Roswell.

3. McMillan Reservoir, in the southern third of the valley, between Carlsbad and Artesia.

4. Avalon Reservoir, a small irrigation reservoir, north of Carlsbad.

Since Avalon Reservoir is closely linked, both geographically and in purpose, with the larger McMillan Reservoir, it was considered part of Lake McMillan for the purposes of this study. Further, since Two Rivers Reservoir is primarily a flood control reservoir, it was not included in the evaporation suppression study.

The efficiency of monolayer films and the rate at which fatty alcohol must be applied to maintain the film are strongly related to wind speed. Fitzgerald and Vines, in summing up three years' evaporation control work in Australia, presented the following guidelines (4, p. 55):

Wind speed 5 miles per hour—evaporation savings, 40 percent
Wind speed 10 miles per hour—evaporation savings, 10-15 percent
Wind speed 15 miles per hour—evaporation savings, 0 percent

Since, however, the degree of disturbance caused by the wind on a body of water is also related to the size or area of the body of water, these guidelines would hold only for reservoirs of about the same size used in the experiments by Fitzgerald and Vines, or about 300 acres. As Alamogordo Reservoir and the combined Avalon and McMillan Reservoirs are about 5,000 acres each, the Fitzgerald-Vines guidelines were adjusted as follows:

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[1] Potential evapotranspiration is a term based on temperature and latitude, developed by Thornwaite to compute the maximum evapotranspiration of a region.

Table 5. Estimated average annual water salvage from salt cedar removal, for 1968 and projected 2010 conditions, Pecos River Valley, New Mexico.

Valley Division (Reach)	Salt Cedar Volume Density	Salt Cedar Removed	Water Salvage Bare Soil	Water Salvage Replanted in Grass
	Given 1968 Conditions			
	(percent)	(acres)	(acre-feet)	(acre-feet)
Carlsbad to Artesia	100	14,000	35,400	29,300
Artesia to Acme	67	14,000	31,900	28,000
Acme to Alamogordo Reservoir	33	14,000	22,300	17,300
Alamogordo Reservoir to Las Vegas	25	4,000	4,900	3,000
Total		46,000	94,500	77,600
	Given Projected 2010 Conditions			
Carlsbad to Las Vegas	67	75,000	177,000	140,000

1. The measured evaporation reductions (both maximum and average) for the larger evaporation suppression experiments (see table 3) were plotted against reservoir area and the two resulting curves projected to a reservoir area of 6,000 acres.

2. The resulting maximum suppression in the 4,000- to 6,000-acre range was 20 percent and was assumed to correspond to the 40 percent found by Fitzgerald and Vines, or to a wind speed of five miles per hour; and, in the same way, the average suppression of 9 percent corresponded to wind of 10 miles per hour.

3. The adjusted guidelines for 4,000- to 6,000-acre reservoirs were:

Wind speed of 5 miles per hour—evaporation savings, 20 percent
Wind speed of 10 miles per hour—evaporation savings, 9 percent
Wind speed of 14 miles per hour—evaporation savings, 0 percent

The monthly United States Weather Bureau publication, *Climatological Data, New Mexico*, provided pan evaporation and wind speed data at Alamogordo Reservoir and Avalon Reservoir. However, the wind speed was recorded in miles per month and therefore was converted to average monthly wind speed in miles per hour, using a correlation between the Avalon wind speed in miles per month and the Roswell average monthly wind speed in miles per hour. Using the adjusted suppression-wind speed guidelines and the average monthly wind speed at each reservoir, the average percent reduction in evaporation was determined; from this, the average monthly water savings was computed. The predicted water gain for McMillan Reservoir and Alamogordo Reservoir from a program of evaporation suppression is shown in table 6.

Summary

The hydrologic model was based on the hypothesis that the effectiveness of vegetation manipulation and evaporation suppression found in experiments could be transferred from one basin to another if the effectiveness

Table 6. Additional water predicted by evaporation suppression model, Pecos River Basin, New Mexico.

	Alamogordo Reservoir		McMillan Reservoir	
	Percent Reduction	Additional Acre-Feet of Water	Percent Reduction	Additional Acre-Feet of Water
October	12.0	320	14.0	450
November	11.4	230	13.5	280
December	11.4	140	13.5	230
January	10.5	140	12.5	230
February	10.5	180	11.9	340
March	5.8	180	9.0	400
April	5.8	230	8.0	450
May	6.5	320	10.0	680
June	10.0	550	11.9	850
July	11.0	590	12.2	790
August	12.2	550	13.6	790
September	12.0	460	15.0	680
Annual	10.7	3,890 (total)	12.0	6,170 (total)

Table 7. Comparison of headwater model results with experimental watershed results, Pecos River Basin, New Mexico.

Watershed	Type of Clearing	Percentage of Precipitation Occurring in Winter	Percent Increase in Runoff
Wagon Wheel Gap	100 percent clear-cut	50	18
Fool Creek	40 percent clear-cut blocks	75	26
Workman Creek	30 percent selective	60	not significant
Workman Creek	32 percent clear-cut moist area	60	35
Upper Pecos Model	100 percent clear-cut	30	16
Lower Pecos Model	100 percent clear-cut	30	13

Table 8. Comparison of average annual water salvage of alternative phreatophyte removal models, Pecos River Basin, New Mexico.

Agency	Location	Plant	Water Saved per Acre (acre-feet)
Soil Conservation Service	Upper Rio Grande	Cottonwood, willow, Russian olive	2.0
Bureau of Reclamation	Lower Pecos	Salt cedar	2.19
Phreatophyte Model	Pecos Valley	Salt cedar	2.0 [1]

[1] No losses deducted.

Table 9. Effectiveness of evaporation suppression model, Pecos River Basin, New Mexico.

Reservoir	Season	Evaporation Suppression Maximum (percent)	Minimum (percent)	Average (percent)
Hefner	July-Sept.	----	----	9.0
Saguaro	Oct.-Nov.	22	14	18.0
Cachuma	Aug.-Sept.	22	8	15.0
Evaporation Model				
Alamogordo (4,600 acres)	July-Sept.	----	----	12.0
	Oct.-Nov.	----	----	11.7
McMillan (5,600 acres)	July-Sept.	----	----	14.0
	Oct.-Nov.	----	----	13.7

could be stated in terms of physical and climatological variables that were measurable on either basin. The objective was not to prove the hypothesis, but rather to accept it, and to develop from it a method for estimating the expected water gains attributable to various degrees of vegetation manipulation and evaporation suppression. Thus, the only test of validity for the hydrologic model is whether the computed increase in water for the test watershed is reasonable.

The amount of additional water that can be obtained from the headwater regions is related to the manner in which the timber is removed (selective, clear-cut blocks, and so on) and the proportion of the precipitation that occurs during the winter months. Thus, a comparison must be made of the percent increase in water received from vegetation manipulation in headwater areas within the framework of these variables. The increase in runoff predicted by the model is smaller than the measured increase at several experimental watersheds; however, when examined in light of the smaller proportion of winter precipitation, the predicted increases in runoff are within a reasonable range.

The phreatophyte model was based on the results of open-tank experiments in which the evapotranspiration of salt cedar was measured; however, the water consumption of salt cedar is not comparable with the amount of water that can be obtained by removal of phreatophytes along a river because it does not reflect the greater evaporation from water surface and soil that occurs when phreatophytes are removed. Therefore, the effectiveness of the phreatophyte model was measured by comparing the average annual water salvage predicted by the model for the Pecos Valley with estimates made by the Soil Conservation Service and the Bureau of Reclamation. As shown in table 8, the phreatophyte model predicted a value very close to the Bureau of Reclamation and Soil Conservation Service estimates.

The effectiveness of evaporation suppression is a function of wind speed, season, and lake size; however, since wind speed is rarely reported, the model was compared with experiments conducted in the late summer and fall on the assumption that wind was not a dominant factor during this relatively calm part of the year. Table 9 shows that computed and measured evaporation suppression are comparable.

The three divisions of the hydrologic model have been shown to yield reasonable results when compared with either measured results or estimates made by experts. Therefore it was concluded that the estimates of additional water from vegetation manipulation and evaporation suppression predicted by the model were reasonably accurate.

Chapter 4

ECONOMIC FEASIBILITY

This chapter presents an economic evaluation of three alternate methods of augmenting the existing water supply of the Pecos River Basin: 1) vegetation manipulation in the headwater region, 2) evaporation suppression on major reservoirs, and 3) salt cedar removal in the Pecos Valley. The first part of the chapter is concerned with estimating the cost of implementing each alternative; the second part determines the benefits attributable to the increase in water obtained by implementing each alternative; and the final division establishes an economically feasible and an optimal program of vegetation management and evaporation control, utilizing estimates of costs and benefits.

Cost Estimates

The vegetation manipulation and evaporation suppression projects discussed in this study would no doubt be undertaken as government-financed projects. Therefore an interest rate of six percent was used to discount future costs and benefits, since, according to Eckstein, this is approximately the return that taxpayers would receive on the project money if it were not collected in taxes (27, p. 99). Although these projects would be expected to have long economic lives, the planning horizon was assumed to be only 50 years because, at six percent interest, the discount factor becomes quite small beyond 50 years.

Treatment costs are measured in terms such as acres of timber removed or pounds of fatty alcohol applied, and must be converted to the cost of producing an additional acre-foot of water in order to be comparable with the benefits. Thus the relationships between degree of treatment and resulting increase in water which were estimated in the hydrologic models were combined with the costs of treatment, to yield the cost per acre-foot of additional water.

As in the development of the hydrologic models, costs were computed for the three major water-producing categories: headwater vegetation manipulation, phreatophyte removal, and evaporation suppression.

Headwater Costs

In addition to the costs of physically removing timber from headwater regions, there are certain benefits dependent upon the timber which must be sacrificed, such as the loss of potential lumber and the loss of recreational benefits. Offsetting these costs somewhat would be the additional grazing land made available through the removal of the timber. Each of these costs is defined and evaluated in the following sections.

Value of Recreation

The removal of timber will necessarily reduce the recreational potential of the headwater regions; therefore, the value of the recreation which is lost becomes a cost. The value of recreation, for the purposes of this study, was defined as the expenses incurred traveling to and from a recreation site plus any additional on-site expenses.[1] Recreation in the Pecos headwater regions is largely big-game hunting, stream fishing, and general recreation such as hiking, picnicking, and camping.

In addition, the northern 15 percent of the Upper Pecos headwater region has been designated a wilderness area, introducing a fourth recreational cost subdivision.

Small amounts of forest clearing, up to 10 percent on an area basis, would probably improve the recreational aspects of the headwater areas, making them somewhat more accessible by way of logging roads, for example. Even as much as 20 percent forest removal probably would not be detrimental to the recreational aspects of the headwater areas. Beyond 20 percent the value of hunting and general recreation was applied as a positive cost, increasing linearly with increase in forest removal. The positive wilderness costs were applied only to the last 15 percent of forest removal, on the assumption that this would be the last area treated. Since the value of fishing is a function of the amount of water available, and since timber removal increases the water yield of the headwater areas, the value of fishing was applied as a negative cost (benefit) which increased directly with the increase in water yield (see table 10).

Forest Clearing Costs

The clearing costs (table 11), which are partially offset by the sales value of the timber removed, include the timber removal cost, the cost of burning slash and replanting grass, and an annual maintenance cost (spraying and cutting seedlings, and the like) (7, pp. 51-62). Using an average tree two logs tall and 17 inches in diameter at breast height, an average timber yield of 127 board feet per square foot of basal area, and an average basal area for the Upper Pecos of 80 square feet per acre, the average timber volume yield was 10,000 board feet per acre (21, p. 20) (23, pp. xi-xii). At $10.80 per 1,000 board feet, the value of timber in the Upper Pecos headwater area was computed at $108.00 per acre (14, p. 80). In the Lower Pecos headwater area the estimated average yield was 7,500 board feet per acre, making the value of timber $81.00 per acre (22, p. 31).

Table 10. Estimated recreation costs, Pecos River Basin, New Mexico.

	Recreation Value per Visitor Day	Visitor Days (1962)[1]	Annual Cost[2]
	(dollars)	(dollars)	(dollars)
Lower Pecos Headwater Region			
Fishing	5.50[3]	120,000	660,000
Hunting	7.50	71,000	530,000
General recreation	5.00	705,000	3,525,000
Upper Pecos Headwater Region		(1967)	
Fishing	5.50	22,900	126,000
Hunting	7.50	18,000	135,000
General	5.00	79,500	395,000
Wilderness[4]	5.00	44,800	224,000

[1] Compiled by Pecos Ranger District and obtained from U.S. Forest Service, Albuquerque, New Mexico.

[2] Rounded to the nearest $10,000.

[3] Estimates may be high since opportunities for substitution of other recreational activities were not investigated.

[4] Wilderness value at least equal to the value of general recreation.

Source: James R. Gray and L. W. Anderson, *Recreation Economics in South-Central New Mexico*, New Mexico State University, 1964, table 3.

Table 11. Estimated forest-clearing cost, Pecos River Basin, New Mexico.

	Initial Cost per Acre				Annual Cost per Acre		
	Timber Removal	Slash Burning and Reseeding	Sales Value of Timber	Net	Treatment[1]	Maintenance	Total
	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)
Upper Pecos	92.50	16.00	-108.00	0.50	0.0	10.00	10.00
Lower Pecos	92.50	16.00	-81.00	27.50	1.75	10.00	11.75

[1] Annual cost at six percent over 50 years.

Grazing Benefits

Replacing timber with grass in the headwater areas increases the value of these areas for grazing. Therefore, the benefits attributable to increased grazing were included as negative costs. Using $92.00 per head as the grazing costs that a rancher would be willing to pay, or at least could pay, annually (see table A-7), and assuming 30 acres of grazing land required per head, the value of grazing land was $3.00 per acre (16, p. 10).

Phreatophyte Removal Costs

Phreatophyte costs include only clearing costs since salt cedar thickets were assumed to have no inherent value. The phreatophyte costs were computed under two

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[1] This estimate tends to overstate the actual opportunity cost of foregone recreation because no account is made for substituting alternative recreation activities (26, pp. 4-5).

Table 12. Estimated headwater treatment costs, Pecos River Basin, New Mexico.

Location and Percent Treated of Basin	Timber Removed	Added Water[1]	Costs						
			Wilderness	Fishing	Hunting	General Recreation	Clearing	Grazing	Total
	(acres)	(acre-feet)	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)
Upper Pecos Basin									
10	38,000	0	0	0	-8,000	- 25,000	380,000	-114,000	233,000
20	76,000	0	0	0	0	0	760,000	-228,000	532,000
30	114,000	1,300	0	-3,200	16,900	49,300	1,140,000	-342,000	860,000
40	152,000	2,750	0	-6,800	33,800	98,600	1,520,000	-456,000	1,189,000
50	190,000	3,700	0	-9,200	50,700	147,900	1,900,000	-570,000	1,519,400
60	228,000	4,650	0	-11,600	67,600	197,200	2,280,000	-685,000	1,848,200
70	266,000	5,600	0	-14,000	84,500	246,500	2,660,000	-800,000	2,177,000
80	304,000	6,550	0	-16,300	101,400	295,800	3,040,000	-913,000	2,507,900
90	342,000	7,500	74,700	-18,700	118,300	347,100	3,420,000	-1,020,000	2,921,400
100	384,000	8,500	149,000	-21,200	135,000	395,000	3,800,000	-1,140,000	3,318,200
Lower Pecos Basin									
10	53,780	400	0	-7,500	- 25,000	-200,000	632,000	-161,000	238,500
20	106,860	790	0	-15,000	0	0	1,270,000	-320,000	935,000
30	160,640	1,200	0	-21,500	66,000	440,000	1,900,000	-483,000	1,901,500
40	214,420	1,600	0	-30,000	132,000	880,000	2,530,000	-644,000	2,868,000
50	268,200	2,000	0	-37,700	198,000	1,320,000	3,170,000	-805,000	3,845,000
60	321,980	2,420	0	-45,500	264,000	1,760,000	3,800,000	-965,000	4,813,000
70	375,760	2,820	0	-53,000	330,000	2,200,000	4,420,000	-1,130,000	5,767,000
80	429,540	3,250	0	-60,500	396,000	2,640,000	5,060,000	-1,290,000	6,745,000
90	483,320	3,700	0	-69,000	463,000	3,080,000	5,700,000	-1,450,000	7,724,000
100	537,800	4,150	0	-77,000	530,000	3,525,000	6,320,000	-1,610,000	8,688,000

[1] Losses deducted.

Table 13. Headwater treatment costs per acre-foot of additional water, Pecos River Basin, New Mexico.

Percent of Timber Removed	Incremental Increase in Water Yield Acre-Feet	Marginal Cost[1]	Cost per Acre-Foot
	(acre-feet)	(dollars)	(dollars)
Upper Pecos			
10	0	233,000	---
20	0	299,000	---
30	1,300	328,000	250
40	1,450	329,000	235
50	950	330,000	350
60	950	329,000	350
70	950	329,000	350
80	950	330,000	350
90	950	413,000	425
100	1,000	397,000	400
Lower Pecos			
10	400	238,500	590
20	390	696,000	1,780
30	410	966,000	2,360
40	400	977,000	2,440
50	400	977,000	2,440
60	420	968,000	2,300
70	400	954,000	2,380
80	430	978,000	2,280
90	450	979,000	2,170
100	450	964,000	2,140

[1] Marginal Cost = increase in total cost attributable to a unit increase timber clearing: $MC_{20\%} = TC_{20\%} - TC_{10\%}$

conditions: 1) removal of 90 percent of the salt cedar and ground left bare, and 2) removal of 90 percent of the salt cedar and replacement by grass.

The per-acre clearing cost, which is the same under both conditions, was based on estimates developed by the Bureau of Reclamation for salt cedar eradication in the Lower Pecos Valley. The bureau's estimated cost for removing 40,000 acres of salt cedar (Acme to Carlsbad) was $2,500,000, or an average cost, including overhead, of $63.00 per acre (18). Further, the bureau estimated the clearing costs alone to be $50.00 per acre for a heavy density of salt cedar, $40.00 per acre for medium density, and $30.00 per acre for light density (20, p. 19). If the $63.00 per acre is for removal of salt cedar of primarily heavy density, the overhead costs equal $13.00 per acre. The bureau also estimated that it would cost $8.71 per acre, annually, to prevent the return of the salt cedar (20, p. 18). Computation and summary of clearing costs when ground is left bare are shown in tables 14 and 15.

With $92.00 per head as the annual cost that a rancher could pay for grazing land, and 20 acres of grass required per head, the estimated annual value for grazing land in the Pecos Valley would be $4.60 per acre. Further assuming only 70 percent of the cleared land is suitable for grazing, the value of grazing land becomes $3.00 per acre. The average cost for reseeding an area in grass is $1.75 per acre (1968 prices) (20, p. 29), or at six percent for 50 years, about $0.10 per acre annual cost (7, p. 61)[2]. Thus, the net value of grazing land was found to be $3.20 minus $0.10, or $3.10 per acre. The summary of salt cedar removal costs when replaced by grass is shown in tables 14 and 15.

Evaporation Suppression Costs

Evaporation suppression costs per acre-foot of additional water in the reservoir resulting from a reduction in evaporation vary with both the wind speed and the season. The seasonal cost variation occurs because, although the monthly costs are about the same for winter and summer, the summer evaporation, and consequently the water saved, is considerably larger in the summer months. For example, let the monthly cost of applying a monolayer film in December and in August

[2] Seeding intervals may be less than 50 years; however, this would not significantly change the annual per-acre cost.

Table 14. Computed annual costs of clearing salt cedar, Pecos River Basin, New Mexico.

Salt Cedar Density	Clearing Cost per Acre	Fixed Cost per Acre	Total Cost per Acre	Capital Recovery[1] Factor	Annual Cost per Acre	Total Annual[2] Cost per Acre 1968 Prices
	(dollars)	(dollars)	(dollars)		(dollars)	(dollars)
Heavy	50.00	13.00	63.00	.0634	4.00	13.90
Medium	40.00	13.00	53.00	.0634	3.36	13.25
Light	30.00	13.00	43.00	.0634	2.72	12.60
Very light						9.65[3]

[1] Assumed economic life at 6 percent interest and 1966 prices.
[2] Includes maintenance cost.
[3] Assumes clearing cost equal to annual maintenance cost.

Table 15. Summary of annual clearing costs of salt cedar, Pecos River Basin, New Mexico.

Region	Salt Cedar Density	Salt Cedar Removed	Clearing Cost per Acre	Grazing Cost per Acre	Net Cost per Acre	Total Cost	Additional[1] Water	Average Cost per Acre-Foot
		(acres)	(dollars)	(dollars)	(dollars)	(dollars)	(acre-feet)	(dollars)
Ground Left Bare								
Carlsbad–Artesia	heavy	12,600	13.90			175,000	31,200	5.60
Artesia–Acme	medium	12,600	13.25			167,000	28,000	6.00
Acme–Alamogordo Reservoir	light	12,600	12.60			159,000	19,600	8.10
Alamogordo Reservoir–Las Vegas	very light	3,600	9.65			34,700	4,300	8.10
Salt Cedar Replaced by Grass								
Carlsbad–Artesia	heavy	12,600	13.90	-3.10	10.80	136,000	25,800	5.30
Artesia–Acme	medium	12,600	13.25	-3.10	10.15	128,000	24,600	5.30
Acme–Alamogordo Reservoir	light	12,600	12.60	-3.10	9.50	120,000	15,200	7.90
Alamogordo Reservoir–Las Vegas	very light	3,600	9.65	-3.10	6.55	23,600	2,600	8.80

[1] Losses deducted.

equal $20.00. Further, let the evaporation suppression efficiency of the film be 10 percent in both months. Then, if the average evaporation in August is four feet of water, and in December is one foot of water, the effective gain in the reservoir due to evaporation reduction for August would be 0.4 of a foot of water, and in December 0.1 of a foot of water. Thus, the average cost per foot of additional water would be $50.00 in August, and $200.00 in December. Therefore the year was divided into three periods corresponding to relative wind speed and seasonal evaporation, and costs per acre-foot of water saved were computed for each division as follows:

1. Summer-fall season: June, July, August, September–high evaporation and low wind speeds.

2. Fall-winter season: October, November, December, January–low evaporation and low wind speeds.

3. Winter-spring season: February, March, April, May–moderate evaporation and high wind speed.

Table 16. Estimated costs of evaporation suppression, Pecos River Basin, New Mexico.

Season	Fixed Costs per Acre-Foot	Cost of Cetyl Alcohol per Acre-Foot	Total Cost per Acre-Foot
	(dollars)	(dollars)	(dollars)
Alamogordo Reservoir			
Summer-fall	3.60	13.60	16.60
Fall-winter	9.40	46.00	55.40
Winter-spring	8.60	72.00	80.60
McMillan Reservoir			
Summer-fall	3.00	10.90	13.90
Fall-winter	7.70	26.40	34.10
Winter-spring	4.90	29.80	34.70

The evaporation costs were based on the costs incurred for the Lake Cachuma experiment where molten spray applicators were used to dispense hexadecanol. The costs were as follows (4, p. 36) (15, p. 358):

1. Equipment costs of $490.00 per spray applicator, which effectively covered 200 acres of water surface.

2. Annual operation and maintenance costs of $1,380 per spray applicator.

3. Cost of hexadecanol of $0.27 per pound, where the number of pounds required to maintain a monolayer film was based on the experimentally developed relationship as follows (4, p. 54):

Wind speed, mi. per hr.	6	7	8	9	10	11	12	13
Cety alcohol per day per sq. mi. water surface, lb.	100	130	190	240	340	350	600	>800

Using the average monthly wind speed, the required number of pounds of hexadecanol was calculated for each seasonal division at both reservoirs and converted to a cost per acre-foot of additional water.

The total equipment costs at each reservoir were added to the present value of the annual operation and maintenance costs (based on 20-year economic life of the spray units) to form the fixed costs, which were converted to fixed costs per acre-foot of additional water.

Benefit Estimates

Water is an asset that is not normally bought and sold in the market place and thus its economic value must be computed indirectly, using the market value of goods for which it is a factor of production. Upper and lower bounds for the benefits attributable to additional water in the Pecos Valley were computed under two sets of conditions as follows:

1. The price that water-users (primarily farmers) would be willing to pay for water if it were sold in the market place, defined for the purposes of this study as the private value of water.

2. The potential increase in value of the total output of the Pecos Basin resulting from an additional acre-foot of water, under a pattern of water use which maximizes the output of the basin, defined in this study as the social value of water.

Both conditions assumed the current level of industrial and agricultural development in the New Mexico portion of the Pecos Basin.

The lower limit of the private value of water was assumed to equal current pumping costs in the portion of the basin irrigated primarily by ground water, since these costs indicate a price which the farmers are obviously willing to pay. This value was then averaged with representative costs for industrial and municipal water where the average was weighted according to the annual withdrawals made for each water use as shown in table 17.

The upper bound of the private value of water was found by computing net farm revenue (less pumping costs) obtained for various irrigated crops with water applied at particular quantities per acre (see table A-14).

Table 17. Computed lower limit of the private value of water in the Pecos Valley, New Mexico.

Water Use	Annual[1] Withdrawals	Value per[1] Acre-Foot	Weighted Value per Acre-Foot
	(percent)	(dollars)	(dollars)
Municipal	3.0	61.00	1.83
Manufacturing	1.0	61.00	0.61
Rural domestic	1.0	61.00	0.61
Electric power	0.5	61.00	0.30
Mining	3.0	7.00	0.21
Irrigation	91.5	6.70[2]	6.13
Weighted average			9.69

[1] Source: Ralph d'Arge, *Quantitative Water Resource Basin Planning--An Analysis of the Pecos River Basin, New Mexico*, Department of Economics, University of New Mexico, June 1968.

[2] Average pumping costs for Eddy, Chaves, and Torrance Counties, New Mexico.

Table 18. Computed upper limit of the private value of water in the Pecos Valley, New Mexico.

Water Use	Annual[1] Withdrawals	Value per[1] Acre-Foot	Weighted Value per Acre-Foot
	(percent)	(dollars)	(dollars)
Municipal	3.0	61.00	1.83
Manufacturing	1.0	61.00	0.61
Rural domestic	1.0	61.00	0.61
Electric power	0.5	61.00	0.30
Mining	3.0	7.00	0.21
Cotton	38.0	46.00	17.50
Alfalfa	43.2	49.80	21.50
Sorghum	3.1	3.80	0.11
Barley	5.4	14.80	0.78
Other	1.8	----	----
Weighted average			43.45

[1] Source: Ralph d'Arge, *Quantitative Water Resource Basin Planning--An Analysis of the Pecos River Basin, New Mexico*, Department of Economics, University of New Mexico, June 1968.

This value then represented the maximum price farmers could pay for water and remain in business. Again, an average which was weighted between industrial and agricultural use was computed; however, in this case the agricultural portion was a weighted average according to current water withdrawals for various crops grown in the Pecos Valley.

The upper and lower limits for the second condition came from a study recently completed in the economics department of the University of New Mexico where the pattern of water use which maximized the value of the output in the Pecos Valley was estimated(2). Since water is a relatively scarce resource in the Pecos Valley, it was assumed to be in the best interests of the Pecos area residents to maximize total output with respect to water. Therefore these estimates were utilized in this study to represent the social value of water.

The value of additional water varied, depending on whether it came from the river, a shallow ground water aquifer, or a deeper artesian aquifer. It was assumed that the additional water resulting from vegetation manipulation and evaporation suppression would not affect the artesian aquifer, but would appear either as surface water or in the shallow aquifer. Since it was unknown how the additional water would be divided between the shallow aquifer and surface flow, the value of additional water from the shallow aquifer was taken to be the upper limit of the social value of water, and the value of water taken from the river was used as the lower limit of the social value of water.

Table 19. Value of dilution water, Pecos Valley, New Mexico.

Salt Concentration	Dilution Water Required (Weighted Average)[1]	Total Revenue per Acre (Weighted Average)[2]	Value of Additional Acre-Foot of Water for Salt Dilution
(mmhos)	(acre-feet)	(dollars)	(dollars)
6.0	0.00	0.00	
4.0	2.62	55.34	21.00
2.25	8.98	115.89	9.45
0.75	37.43	152.29	1.30

[1] Assumes a linear relationship between required dilution water and salt concentration.

[2] Weighted according to annual water withdrawals for barley, cotton, alfalfa, and sorghum irrigation.

The estimated upper limit of the social value of water in the Pecos Valley was \$25.90 per acre-foot. The value of surface water varied with location, due to reusable return flows, so that the lower limit of the social value of water was \$14.58 per acre-foot in the portion of the basin north of Acme, and \$8.31 per acre-foot south of Acme.

Several benefits are derived from increasing the water supply which are independent of the conditions just discussed. One of these occurs because the additional water dilutes the salt concentrated in the river, thus making available a higher-quality water. The dollar value attributable to salt dilution was estimated by finding the additional net farm revenue derived from a higher-quality water and dividing it by the amount of additional water required to achieve the higher water quality. Since it is unlikely that the additional water is itself pure, computations were made for a dilution effectiveness of 25 percent, 50 percent, and 75 percent (see table 20) where a 25 percent dilution effectiveness level signifies that the additional water obtained from vegetation management and evaporation control is 25 percent as efficient as distilled water in reducing the salt concentration of the river by dilution (see table 20).

Secondly, a benefit inherent in the removal of salt cedar comes from halting the spread of salt cedar. The estimate of spread of salt cedar over the 50-year period from 1960 to 2010, made by the Bureau of Reclamation, was 35,000 acres or an average of 700 acres per year. At an average water salvage rate of 1.8 acre-feet per acre, this amounts to approximately 1,000 acre-feet of water, in addition to the first year's water increase for each succeeding year, at no additional cost. The benefits attributable to halting the spread of salt cedar depend on the value of water; therefore, if $B_\$$ equals the value of an additional acre-foot of water, and if B_s equals the annual benefit incurred through stopping the spread of salt cedar, then

$$1.\ B_s = B_\$ (.0634) \quad \frac{1{,}000}{(1.06)} + \frac{2{,}000}{(1.06)^2} + \frac{3{,}000}{(1.06)^3} + \ldots + \frac{50{,}000}{(1.06)^{50}}$$

$$\text{or } B_s = B_\$ (14{,}800)$$

where a halt in the spread of salt cedar yields 1,000 acre-feet of additional water the first year, 2,000 acre-feet the second year, and so on; and 0.064 equals the capital recovery factor for a uniform series at six percent for 50 years.

Table 20. Value of dilution water with respect to effectiveness, Pecos Valley, New Mexico.

Effectiveness Dilution	Value of Additional[1] Acre-Foot Water
(percent)	(dollars)
25	1.25
50	2.50
75	3.75
100	5.00

[1] Assumes original salt concentration of 2.25 mmhos, thus

$$\frac{\$9.45 - \$1.30}{3.13 - 1.50} = \frac{x}{2.25} \text{ or } x = \$5.00$$

Table 21. Summary of benefit estimates for additional water, in dollars per additional acre-foot, Pecos Valley, New Mexico.

Condition	Dilution Effectiveness[1] 25 Percent	50 Percent	75 Percent
	(dollars)	(dollars)	(dollars)
Lower limit	9.55	10.00	12.00
Upper limit, social value of water[2]	27.15	28.40	29.65
Upper limit, private value of water	44.70	45.95	47.20

[1] Dilution effectiveness is the relative efficiency of the additional water for reducing the salt concentration of the river when compared with distilled water.

[2] The upper limit of the social value of water is lower than the upper limit of the private value of water *primarily* because the social value was obtained from a model that included water requirements to meet state-imposed water quality standards, whereas the private value was computed exclusive of these requirements.

Assuming that the annual benefit is a linear function of the number of acres of salt cedar removed, or, therefore, of the additional water gained from the removal of salt cedar, the annual benefit from the removal of salt cedar becomes:

2. $B = B_{\$}Q_p + B_s$

$$\text{or } B = B_{\$} \quad Q_p + \frac{14{,}800}{Q_p} \; Q_p$$

where Q_p equals the additional water from salt cedar removal.

Further, since the terms used to derive equation 1 were average values, and the average amount of additional water obtained from the removal of salt cedar in 1968 was:

$$Q_p \cong 75{,}000 \text{ acre-feet, then}$$

3. $B = B_{\$}Q_p \quad 1 + \frac{14{,}800}{75{,}000}$

$$\text{or } B = B_{\$}Q_p \; [1.20]$$

Equation 3 is valid for salt cedar removal benefits only.

Since the lower limit of private value of water and the lower limit of social value of water were nearly the same, they were both assumed to equal $8.30 per acre-foot.

Cost-Benefit Comparisons

In this section the benefits and costs established earlier in the chapter are compared to determine the economic feasibility of supplementing the Pecos Valley water supply with water obtained from the three alternatives, 1) vegetation manipulation in the headwater regions, 2) evaporation suppression on the major reservoirs, and 3) removal of salt cedar from the Pecos valley. In addition, a treatment policy is determined regarding the degree to which each alternative should be implemented, and the ordering of the alternatives with respect to their relative economic significance, both statically and with time.

The optimum treatment policy is defined here as that amount of treatment, vegetation manipulation or evaporation suppression, which yields the maximum net benefit. The maximum net benefit occurs when the additional benefit received from a unit increase in treatment equals the additional cost of that unit increase in treatment, or when the marginal benefit equals the marginal cost (10, pp. 31-33).

Thus, the maximum net benefit occurs (figure 1) at the point where the slope of the benefit curve (marginal benefit) is equal to the slope of the cost curve (marginal cost). Figure 1 also reveals that, since the costs of treatment were linear, the maximum net benefit occurs at a "corner point" where the slope of the cost line changes. This corner point represents the completion of one project and the beginning of another—that is, completion of phreatophyte removal and beginning of an evaporation suppression program. Thus, as long as the cost curves are linear, the optimum policy will be to complete each project which has a cost per acre-foot of water that is less than the benefit per acre-foot of water.

Since the benefits of additional water were computed under several alternative sets of conditions, the optimum policy and maximum net benefits were computed for each condition, as shown in table 22. The table demonstrates several important facts:

1. The optimal policy with respect to evaporation suppression changes as the value of water increases from the lower bound to the upper bound.

2. The optimal policy regarding forest treatment for all benefit conditions calls for no vegetation removal.

3. A "bare ground" condition after removing salt cedar is economically superior to reseeding in grass, assuming that grass is valuable only for cattle grazing.

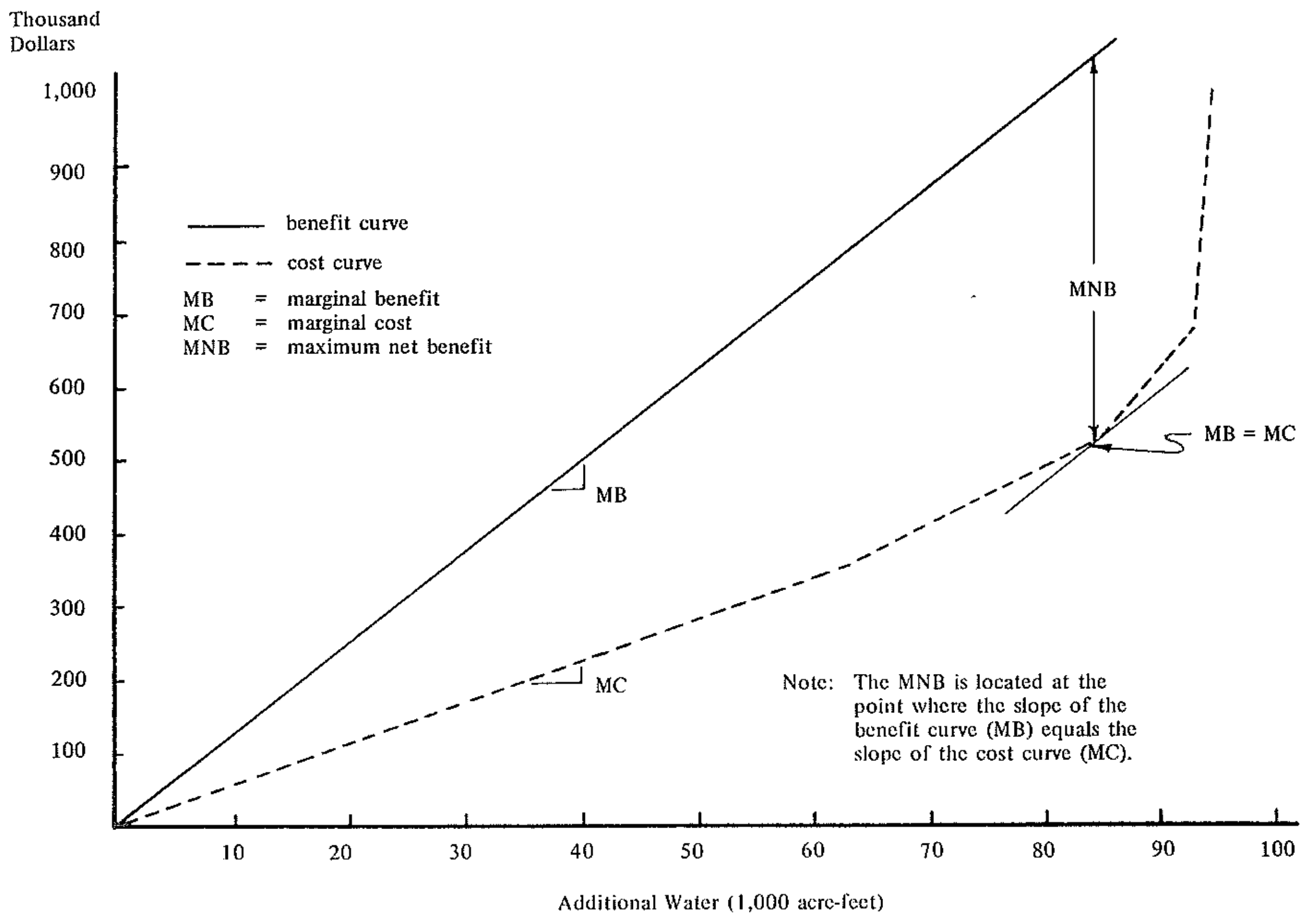

Figure 1. Cost-benefit curves for the lower limit of private benefit, 25 percent dilution effectiveness. (MNB = $559,000.)

Table 22. Treatment policy and net benefits with respect to benefit conditions.

Benefit Condition	Dilution Effectiveness	Treatment Policy[1]: Duration of Evaporation Suppression: Alamo. Res.	McMillan Res.	Phreatophyte Removal: Las Vegas-Alamo. Res.	Alamo. Res.-Acme	Acme-Artesia	Artesia-Carlsbad	Salt Cedar Replaced by Grass: Added Water per Year	Maximum Net Benefit per Year	Ground Left Bare After Removal: Added Water per Year	Maximum Net Benefit per Year
	(percent)	(months)	(months)	(acres)	(acres)	(acres)	(acres)	(acre-feet)	($1,000)	(acre-feet)	($1,000)
	25	0	0	3,600	12,600	12,600	12,600	68,000	372	83,000	410
Lower	50	0	0	3,600	12,600	12,600	12,600	68,000	472	83,000	540
Limit	75	0	0	3,600	12,600	12,600	12,600	68,000	572	83,000	660
Upper Limit	25	4	4	3,600	12,600	12,600	12,600	73,000	1,878	88,000	2,226
Social Value	50	4	4	3,600	12,600	12,600	12,600	73,000	1,987	88,000	2,365
of Water	75	4	4	3,600	12,600	12,600	12,600	73,000	2,090	88,000	2,488
Upper Limit	25	4	12	3,600	12,600	12,600	12,600	74,000	3,406	89,000	4,088
Private Value	50	4	12	3,600	12,600	12,600	12,600	74,000	3,484	89,000	4,196
of Water	75	4	12	3,600	12,600	12,600	12,600	74,000	3,624	89,000	4,346

[1] Forest treatment was not considered as the initial estimates of cost precluded its consideration as a viable economic alternative.

Table 23. Treatment policy and net benefit with respect to value of an additional acre-foot of water, Pecos River Basin, New Mexico.

Value of Additional Water per Acre-Foot	Treatment Policy						Added Water per Year	Maximum Net Benefit per Year
	Duration of Evaporation Suppression		Phreatophyte Removal[1]					
	Alamo. Res.	McMillan Res.	Las Vegas-Alamo. Res.	Alamo. Res.-Acme	Acme-Artesia	Artesia-Carlsbad		
(dollars)	(months)	(months)	(acres)	(acres)	(acres)	(acres)	(acre-feet)	($1,000)
6	0	0	0	0	12,600	12,600	59,000	83
8	0	0	0	12,600	12,600	12,600	79,000	259
10	0	0	3,600	12,600	12,600	12,600	83,000	459
12	0	0	3,600	12,600	12,600	12,600	83,000	664
14	0	4	3,600	12,600	12,600	12,600	86,000	868
16	0	4	3,600	12,600	12,600	12,600	86,000	1,064
18	4	4	3,600	12,600	12,600	12,600	88,000	1,275
20	4	4	3,600	12,600	12,600	12,600	88,000	1,485
22	4	4	3,600	12,600	12,600	12,600	88,000	1,795
24	4	4	3,600	12,600	12,600	12,600	88,000	1,805
26	4	4	3,600	12,600	12,600	12,600	88,000	2,115
28	4	4	3,600	12,600	12,600	12,600	88,000	2,325
30	4	4	3,600	12,600	12,600	12,600	88,000	2,535
32	4	4	3,600	12,600	12,600	12,600	88,000	2,745
34	4	4	3,600	12,600	12,600	12,600	88,000	2,945
36	4	12	3,600	12,600	12,600	12,600	89,000	3,208
38	4	12	3,600	12,600	12,600	12,600	89,000	3,320
40	4	12	3,600	12,600	12,600	12,600	89,000	3,532
42	4	12	3,600	12,600	12,600	12,600	89,000	3,744
44	4	12	3,600	12,600	12,600	12,600	89,000	3,956
46	4	12	3,600	12,600	12,600	12,600	89,000	4,148
48	4	12	3,600	12,600	12,600	12,600	89,000	4,360
50	4	12	3,600	12,600	12,600	12,600	89,000	4,562

[1] Ground left bare after salt cedar removal.

Since the treatment policy changes as the value of water increases, table 23 was prepared to show how the treatment policy responds to increases in the value of water over the full range from the lower to the upper limit. Again, it may be seen that, over the entire series, a change in treatment policy takes place with regard to evaporation suppression and that, within a large segment of the benefit range ($18.00 to $34.00 per acre-foot), evaporation suppression is indicated during the summer-fall season at both Pecos reservoirs.

The optimum treatment policies described in the preceding sections are based on a static investment model—that is, one that expresses the feasibility of a project in terms of the payoff it will yield at the present time only, where it is assumed that no change occurs in the value of water with time, and that unlimited funds for carrying out the treatment policies are available. Thus, the static model determines which treatment policies are feasible, but says nothing about when, or in what sequence, they should be undertaken.

In the following sections the static model assumptions are relaxed in order to develop optimum policies as to when the treatment projects should begin, and in what sequence they should be conducted.

The Timing Problem

If the industrial sector of the Pecos valley were to increase relative to the agricultural sector in the future, the value of water could increase significantly. Should this occur it might be advisable to begin a water resource project at some future date, after the value of water had increased, rather than at the present time. To determine the optimum time to begin a program of salt cedar removal and evaporation suppression, it was first necessary to estimate the future value of water in the Pecos valley, based on the projected levels of industrial and agricultural development. Projected water withdrawals in the years 1980 and 2000 for various uses are shown in table A-8. The estimated values of water per acre-foot in the Pecos valley in 1980 and 2000, computed by the same method used to compute the values of water in 1968, are shown in table 24 for the lower and upper limiting conditions.

The optimum time to begin the program was determined by computing the present value of the net benefits received from hypothetically executing the salt cedar and evaporation program at various future dates, where the largest present value indicated the optimum date to begin the project.

The salt cedar removal project presents a unique problem in determining the optimum time to begin the project, because the salt cedar is spreading. Part of the increase in the benefit attributable to removing the salt cedar occurs because a larger quantity of water can be salvaged in the future. However, at the same time, the spreading salt cedar is reducing the existing water supply. Therefore there is a cost equal to the value of the water lost attached to postponing the salt cedar project. For example, the cost attached to postponing the salt cedar project until 1970 would be equal to the value of the 2,000 acre-feet of water that was lost because the salt cedar spread to 1,200 more acres between 1968 and 1970.

As shown in tables 25 and 26, the optimum time to begin the salt cedar project is in 1968, under either the lower or upper limiting conditions on the value of water. The optimum time to begin the evaporation suppression project is in 1968 also, given the upper value limit. This result occurred primarily because the rate at which the benefits increase with time, from the relative increase in both the industrial and municipal sectors, is less than the discount rate. Had the reverse been true it might have been advisable to postpone the projects.

The Sequencing Problem

When there are several feasible projects under consideration and the annual budget is insufficient to allow all the projects to be started in the first year (or second, or third, and so on), it is important that the projects be carried out in a sequence that will produce the greatest net benefit.

As an example of a sequencing problem, assume there is under consideration a phreatophyte project and an evaporation suppression project. Project A is phreatophyte removal with a cost of $1,000 and a net benefit of $2,200, and Project B is evaporation suppression with a cost of $500 and a net benefit of $1,000. The annual budget for these projects is assumed to be $500, and the phreatophyte project can be done in two stages with each stage yielding one-half the net benefit.

Table 24. Estimated current and future benefits per acre-foot of water, 1968, 1980, and 2000, Pecos River Basin, New Mexico.

Condition	1968	1980	2000
	(dollars)	(dollars)	(dollars)
Lower limit at 25 percent dilution	10.95	11.80	14.70
Upper limit at 75 percent dilution	47.20	48.40	49.70

Table 25. Present value of salt cedar removal at a future date, using lower limit of value of water, Pecos Valley, New Mexico.

Year	Salt Cedar	Water Salvage	Value per Acre-Foot	Cost	Benefit	Net Benefit	Present Value of Net Benefit
	(acres)	(acre-feet)	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)
1968	46,000	83,000	10.80	540,000	1,090,000	550,000	550,000
1970	47,000	85,000	11.10	572,000	1,130,000	558,000	495,000
1975	51,000	92,000	11.40	700,000	1,260,000	560,000	372,000
1980	54,000	97,000	11.70	788,000	1,360,000	572,000	285,000
1985	58,000	104,000	12.30	910,000	1,540,000	630,000	240,000
1990	61,000	110,000	12.90	1,041,000	1,700,000	659,000	183,000
1995	65,000	117,000	13.50	1,175,000	1,890,000	715,000	148,000
2000	68,000	122,000	14.20	1,278,000	2,080,000	802,000	124,000
2005	72,000	130,000	14.80	1,446,000	2,300,000	854,000	98,000
2010	75,000	135,000	15.40	1,550,000	2,500,000	950,000	82,000

Table 26. Present value of salt cedar removal and evaporation suppression at a future date, using upper limit of private value of water, Pecos Valley, New Mexico.

Year	Water Added per Year from Salt Cedar Removal	Water Added per Year from Evaporation Suppression	Added Value per Acre-Foot	Cost	Benefit	Net Benefit	Present Value of Net Benefit
	(acre-feet)	(acre-feet)	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)
1968	83,000	7,000	47.20	703,000	5,105,000	4,346,000	4,346,000
1970	85,000	7,000	48.10	735,000	5,236,000	4,501,000	4,000,000
1975	92,000	7,000	48.50	863,000	5,690,000	4,827,000	3,210,000
1980	97,000	7,000	48.80	951,000	6,000,000	5,049,000	2,550,000
1985	104,000	7,000	49.00	1,073,000	6,460,000	5,387,000	2,000,000
1990	110,000	7,000	49.20	1,204,000	6,844,000	5,640,000	1,560,000
1995	117,000	7,000	49.50	1,338,000	7,296,000	5,958,000	1,240,000
2000	122,000	7,000	49.70	1,441,000	7,628,000	6,187,000	960,000
2005	130,000	7,000	49.90	1,609,000	8,119,000	6,510,000	755,000
2010	135,000	7,000	50.20	1,713,000	8,470,000	6,757,000	585,000

Table 27. Pay-off matrix, present value of net benefits.[1]

Policy	First Year	Second Year	Third Year	Total Net Benefit
Policy 1	1/2 A = \$1,100	1/2 A = \$1,030	B = \$890	\$3,020
Policy 2	1/2 A = 1,100	B = 943	1/2 A = 990	3,033
Policy 3	B = 1,000	1/2 A = 1,030	1/2 A = 990	3,020

[1] A discount rate of six percent was assumed.

Thus, there are three sequences or policies for completing all the projects.

It is evident (see table 27) that the optimum sequence of construction is Policy 2—that is, to complete half of Project A in the first year, Project B in the second year, and the remaining half of Project A in the third year. Since the pay-off matrix is made up of the present value of the net benefits attributable to each project, it is highly dependent on the discount rate. Thus the use of a discount rate other than six percent might have led to a different optimum policy. Obviously the complexity of sequencing problems increases rapidly as the number of projects and divisions of projects increases. Marglin has shown that the sequencing problem can be formulated as a linear programming problem, partially alleviating complexity of larger sequencing problems (9, pp. 37-57).

The treatment policy for the upper limit of the private value of water was chosen to demonstrate how the sequencing problem can be solved with linear programming, since it afforded the greatest number of projects. The procedure was as follows:

1. The salt cedar removal and evaporation suppression policies were divided into six separate projects:

A = salt cedar removal, Carlsbad–Artesia.
B = salt cedar removal, Artesia–Acme.
C = salt cedar removal, Acme–Alamogordo Reservoir.
D = salt cedar removal, Alamogordo Reservoir–Las Vegas.
E = evaporation suppression, McMillan Reservoir.
F = evaporation suppression, Alamogordo Reservoir.

2. A pay-off matrix was developed on the basis of present values of total net benefits (over 50 years at six percent) associated with each project (see table 28).

3. The objective function to be maximized was formed from the pay-off matrix by multiplying the present value of each net benefit by X_{it}, where X_{it} equals the portion of each project that is done in each year (*i* designates the project and *t* the year):

$$\text{Objective function} = X_{A1}(25{,}200) + X_{A2}(23{,}600) + X_{A3}(22{,}400) + X_{A4}(21{,}200) + X_{A5}(19{,}900) + X_{B1}(22{,}100) + X_{B2}(20{,}800) + \ldots X_{F5}(710).$$

Table 28. Pay-off matrix for projects.

Project	Year of Construction 1	2	3	4	5
			(thousands of dollars)		
A	25,200	23,600	22,400	21,200	19,900
B	22,100	20,800	19,600	18,600	17,400
C	15,000	14,100	13,300	12,600	11,900
D	3,280	3,080	2,920	2,750	2,690
E	1,440	1,350	1,280	1,210	1,140
F	900	845	800	755	710

Table 29. Optimum sequence for removing salt cedar and initiating evaporation control, Pecos Valley, New Mexico.[1]

Annual Budget	Years 1	2	3	4	5	Present Value Maximum Total Net Benefit
(dollars)						(dollars)
500,000	0.2-A[2]	0.2-A	0.2-A	0.2-A	0.2-A 0.1-B[2]	25,273,000
1,000,000	0.5-A	0.1-A 0.4-B	0.4-A	0.5-B	0.1-B 0.2-C[2] 1.0-D[2]	47,633,000
1,500,000	0.7-A	0.7-B	0.3-A 0.3-B 0.1-C	0.8-C	0.1-C 1.0-D 1.0-E[2] 0.5-F[2]	61,550,000
2,000,000	0 9-A	1.0-B	0.1-A 0.7-C 1.0-D	0.3-C 1.0-E 1.0-F		63,646,000

[1] Based on water value of \$48.00 per acre-foot.

[2] Project A = salt cedar removal, Carlsbad-Artesia; Project B = salt cedar removal, Artesia-Acme; Project C = salt cedar removal, Acme-Alamogordo Reservoir; Project D = salt cedar removal, Alamogordo Reservoir-Las Vegas; Project E = evaporation control, McMillan Reservoir; Project F = evaporation control, Alamogordo Reservoir.

4. Since X_{it} represents the portion of each project completed in each year, the summation of X_{it} over five years must be equal to or less than one:

$$0 \leqslant \sum_{t=1}^{5} X_{At} \leqslant 1$$

$$0 \leqslant \sum_{t=1}^{5} X_{Bt} \leqslant 1$$

$$\vdots$$

$$0 \leqslant \sum_{t=1}^{5} X_{Ft} \leqslant 1$$

Note that if the projects had to be completely built, partially built, or not built at all, this constraint set would be:

$$\sum_{t=1}^{5} X_{At} = 1,\ \alpha,\ \text{or } 0,$$

where α denotes the proportion of Project A that must be constructed.

5. The present value of the project costs were constrained to an annual budget which was set at values ranging from \$500,000 to \$2,000,000 per year. Thus,

$$X_{A1}(2{,}204) + X_{A2}(2{,}080) + X_{A3}(1{,}960) + X_{A4}(1{,}850) + X_{A5}(1{,}740) + X_{B1}(2{,}078) + X_{B2}(1{,}960) + \ldots + X_{F5}(395) \leqslant \text{present value of annual budget.}$$

The optimum developmental sequence for the projects with respect to annual budget is shown in table 29.

Chapter 5

CONCLUSIONS

As the economic model was simple and straightforward, little need be said about the model itself, but the results of the economic model yielded several conclusions regarding a program of vegetation manipulation and evaporation suppression in the Pecos Valley:

1. The removal of timber in forest (headwater) areas for the purpose of increasing water yield on the Pecos watershed is unfeasible at current benefit and cost levels. The increase in runoff that would result from vegetation manipulation (even if the prediction is doubled or tripled) is altogether too small in relation to the value of the forest for recreation to make such a program feasible.

There is some indication that the increase in water yield from forest areas might be greatest at something less than 100 percent timber removal, due to the redistribution of the snowpack in clear-cut blocks. For example, on the Upper Pecos where 100 percent removal produces a 16 percent increase in water yield, a 50 percent removal might create a 20 percent increase in water yield. If this were true, the removal costs would be reduced to about $70.00 per acre-foot of additional water, which begins to approach the realm of economic feasibility.

2. The possibility of using snow fences to increase the water yield from headwater areas was discussed in Chapter 2. Based on a cost of $3,358 per mile and a suggested spacing of 325 feet, the use of snow fences would have to produce an increase in water yield greater than one acre-foot per acre to be feasible at the upper limiting condition of the private value of water, which seems unlikely(13).

3. The eradication of salt cedar from the Pecos Valley for the purpose of augmenting the water supply is currently economically feasible. The removal of salt cedar from Acme to Carlsbad (the two southern divisions of the Pecos River) remains feasible at the lower limiting value of water, even when the increase in water predicted by the model is cut in half. The removal of salt cedar from Las Vegas to Carlsbad would probably yield between 60,000 and 70,000 acre-feet of additional water each year.

4. Evaporation suppression during the summer-fall season is feasible on both McMillan and Alamogordo Reservoirs if the value of additional water approaches the upper limit of the social value of water. This conclusion is valid even if the additional water predicted by the evaporation model were cut in half. Such a program of evaporation suppression would yield between 3,000 and 4,000 acre-feet of additional water annually.

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APPENDIX

Table A-1. Average travel and on-site recreation expenses, Ruidoso Area, New Mexico, 1962.

Item	General Recreation Expenses	Fishing and Hunting Expenses[1]
	(dollars)	(dollars)
Auto expenses	47.77	27.73
Lodging and motels	5.78	0.51
Additional food	21.38	21.31
Equipment rental	2.45	0.11
Horse rental	1.06	0.03
Total	78.44	49.99
Average per man-day	4.60	3.00

Source: New Mexico State University, *Recreation Economics in South-Central New Mexico*, table 3.

[1] The values for hunting and fishing reported in *New Mexico Business*, June 1966, p. 2, are $23.71 and $15.30, respectively; however, as these values include expenses other than travel and on-site expenses, the value of hunting was proportioned as follows:

$$\frac{23.71}{15.30} \times 3.00 \times \frac{4.60}{3.00} = \$7.15$$

Table A-2. Recreational visits in 1962, Ruidoso Ranger District, New Mexico.

Item	Man-Days	Percent of Total
General recreation and fishing	825,000	85.0
Hunting	71,000	7.3
Skiing	70,000	7.2
Cabins	4,905	0.5
Total	970,905	100.0

Source: New Mexico State University, *Recreation Economics in South-Central New Mexico*, table 3.

Table A-3. Recreational visits in 1967, Pecos Ranger District, New Mexico.[1]

Item	Man-Days	Percent of Total
Campgrounds	34,200	20.8
Picnic grounds	25,000	15.2
Lodges	17,000	10.2
Cabins	16,300	9.9
Wilderness	49,800	30.0
Streams and Lakes	22,900	13.9
Total	165,200	100.0

[1] From Jim Perry, Albuquerque District Office, United States Forest Service, personal interview.

Table A-4. Estimated timber removal costs.

Item	Reported Cost	Cost at 1968 Prices	Source
Value of timber	$10 per 1,000 board feet	$10.80 per 1,000 board feet[1]	New Mexico State Planning Office, *Summary Reports on New Mexico's Resources.*
Cost of timber removal	$74 per acre	$92.50 per acre[2]	Fred H. Kennedy, "National Forest Watershed Projects in Arizona." (For clearing pinon and juniper at Beaver Creek Experimental Watershed.)
Slash burning and reseeding cost	$13 per acre	$16.00 per acre[2]	
Annual maintenance cost	$8 per acre	$10.00 per acre[2]	

[1] Wholesale lumber index.

[2] Consolidated construction cost index.

Table A-5. Density and quantity of timber, Pecos watershed, New Mexico.

Location	Area	Average Yield per Acre
	(acres)	(board feet)
Upper Pecos	384,000	10,000[1]
Lower Pecos	537,000	7,500[2]

[1] Using "average tree" of 127 board feet per square foot basal area, from U.S. Forest Service, *Presale Report and Appraisal–Osha Unit.*

[2] From U.S. Forest Service, *Presale Report and Appraisal–Sacramento Mountain Timber Sale.*

Table A-6. Average basal area of trees in Pecos watershed , New Mexico.[1]

Location	Tree Density	Average Basal Area			
		Pine	Mixed Conifer	Spruce	Aspen
		(square feet per acre)			
Upper Pecos	Light	73	95	110	5.5
Upper Pecos	Marginal	21	---	---	---
Upper Pecos	Medium	---	57	110	25
Lower Pecos	Light	40	70	103	---
Lower Pecos	Medium	66	72	103	55
Lower Pecos	Heavy	82.5	106	---	---

[1] Upper Pecos data from U.S. Forest Service, *Timber Management Plan, Santa Fe National Forest*; Lower Pecos data from U.S. Forest Service, *Timber Management Plan, Lincoln National Forest.*

Table A-7. Estimated grazing costs and returns, Pecos River Basin, New Mexico.

Item	Returns per Head	Source
	(dollars)	
Gross revenue price is $22.40 per hundred-weight at 1,000 pounds per head	224.00	*New Mexico Business*, 21:11, April 1968.
Non-feed costs	-12.20	Ralph d'Arge, *Quantitative Water Resource Basin Planning*, Dept. of Economics, University of New Mexico, 1968, p. 136.
Labor costs for grazing cattle, 35 man-hours per head at $1.35 per hour[1]	-47.00	Mont H. Saunderson, *Western Stock Ranching*, University of Minnesota Press, 1950, p. 82.
5 percent profit, .05 X 224	11.20	
Net revenue less grazing land rent	153.00	
Annual net revenue less grazing land rent (assumes 20 months to grow one head of beef)	92.00	

[1] One man-year for each 200 to 300 head of cattle is the average for cattle ranches of southern plains.

Table A-8. Estimated future water withdrawals according to use, Pecos Valley, New Mexico.[1]

Water Use	1980		2000	
	Withdrawal (acre-feet)	Percent of Total	Withdrawal (acre-feet)	Percent of Total
Municipal	38,600	4.5	70,000	7.5
Industrial	12,000	1.5	30,000	3.0
Mining	12,000	1.5	12,000	3.0
Electric power	4,000	0.5	8,000	0.5
Irrigation	750,000	92.0	825,000	88.0
Total	816,600	100.00	935,000	100.0

[1] Table assumes:

a. Medium projections in all cases.
b. Irrigation will continue with trends similar to 1954-1965.
c. Three acre-feet per acre per year limitation on all crops.
d. Industrial projections from average value added relation.
e. Electric power based on 0.52 gallon of water per kilowatt hour.

Source: Ralph d'Arge, *Quantitative Water Resource Basin Planning*, University of New Mexico, 1968.

Table A-9. Lower limit value added per acre-foot of water, Pecos Valley, New Mexico.

Use	Value per Acre-Foot (dollars)	1980 (dollars)	2000 (dollars)
Municipal	61.00		
Industrial	61.00	.065 X 61.0 = 4.00	.11 X 61.0 = 6.70
Electric Power	61.00		
Mining	7.00	.015 X 7.0 = .10	.01 X 7.0 = .07
Irrigation	6.70	.92 X 6.7 = 6.15	88 X 6.7 = 5.90
Weighted average		10.30	12.70
Plus 25 percent dilution		11.80	14.20

Table A-10. Upper limit value added per acre-foot of water, Pecos Valley, New Mexico.

Use	Value per Acre-Foot (dollars)	1980 (dollars)	2000 (dollars)
Municipal	61.00		
Industrial	61.00	4.00	6.70
Electric power	61.00		
Mining	7.00	.10	.07
Irrigation	43.60	.92 X 43.60 = 40.00	.88 X 43.60 = 38.10
Weighted average		44.10	44.90
Plus 75 percent dilution		48.80	49.70

Table A-11. Agricultural water withdrawal estimates for 1959, Chaves and Eddy Counties, New Mexico.

Crop	Eddy County (acre-feet)	Chaves County (acre-feet)	Sum (acre-feet)	Percent of Total
Cotton	107,322	119,147	226,469	41.5
Alfalfa	112,042	145,623	257,665	47.2
Sorghum	5,940	12,098	18,038	3.4
Barley	9,195	22,602	31,797	5.9
Corn	891	1,626	2,517	.6
Other	1,340	5,925	7,265	1.4
Total	240,730	307,021	547,751	100.0

Source: Ralph d'Arge, *Quantitative Water Resource Basin Planning*, University of New Mexico, 1968.

Table A-12. Percentage of total water withdrawals by use in 1968, Pecos Valley, New Mexico.

Use	Chaves County	Eddy County	Average
Municipal	3	3	3.0
Rural domestic	1	1	1.0
Mining	0	6	3.0
Electric power generation	1	0	0.5
Manufacturing	1	1	1.0
Irrigation	94	89	91.5

Source: Ralph d'Arge, *Quantitative Water Resource Basin Planning*, University of New Mexico, 1968.

Table A-13. Net farm revenue per acre with respect to salt concentration of irrigation water, Pecos River Basin, New Mexico.

Salt Concentration (mmhos)	Revenue by Crop			
	Barley[1] (dollars)	Cotton[2] (dollars)	Alfalfa[3] (dollars)	Sorghum[4] (dollars)
6.00	12.21	113.96	0.00	0.00
4.00	28.10	242.78	0.00	12.03
2.25	32.44	285.72	85.84	54.60
0.75	32.44	285.72	160.61	68.79

[1] Water pumped = 27 inches.

[2] Water pumped = 45 inches.

[3] Water pumped = 88 inches.

[4] Water pumped = 39 inches.

Source: Ralph d'Arge, *Quantitative Water Resource Basin Planning*, University of New Mexico, 1968.

Table A-14. Estimated increase in farm net revenue per acre per additional acre-foot of water, Pecos River Basin, New Mexico.

Water Applied[1]	Net[2] Revenue per Acre	Water Cost per Acre	Net Revenue per Acre (Less Water Cost)	Increase in Acre-Feet of Water Applied	Increase in Revenue per Acre	Increase in Revenue per Acre-Foot
(acre-feet)	(dollars)	(dollars)	(dollars)	(percent)	(dollars)	(dollars)
			Barley			
2.25	32.44	6.70	39.14			
1.50	21.36	6.70	28.06	0.75	11.08	14.80
1.12	7.49	6.70	14.19	0.38	13.87	36.20
			Cotton			
3.75	285.75	6.70	292.42			
3.00	251.18	6.70	257.83	0.75	34.54	46.00
2.25	189.33	6.70	196.03	0.75	61.85	81.40
1.50	72.81	6.70	79.51	0.75	116.52	155.00
			Alfalfa			
7.30	85.84	6.70	92.54			
6.70	55.92	6.70	62.62	0.60	29.92	29.80
6.00	23.42	6.70	30.12	0.70	32.50	46.40
5.30	0.00	6.70	0.00	0.70	30.12	44.70
			Sorghum			
3.25	54.60	6.70	61.30			
3.00	53.64	6.70	60.34	0.25	0.96	3.80
2.25	16.72	6.70	23.42	0.75	36.92	49.20
c1.50	0.00	6.70	0.00	0.75	23.42	30.00

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[1] Assumes 2.25 mmhos salt concentration and Class I and II soils.

[2] Net revenue here equals total revenue less all costs excepting costs of irrigation.

Source: Ralph d'Arge, ***Quantitative Water Resource Basin Planning***, University of New Mexico, 1968.