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QUANTITATIVE WATER RESOURCE BASIN PLANNING: AN ANALYSIS OF THE PECOS RIVER BASIN, NEW MEXICO

WATER RESOURCES RESEARCH INSTITUTE
IN COOPERATION WITH
DEPARTMENT OF ECONOMICS
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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 9— *Economic Feasibility of Increasing Pecos Basin Water Supplies Through Reduction of Evaporation and Evapotranspiration*, by William C. Hughes.

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

QUANTITATIVE WATER RESOURCE BASIN PLANNING: AN ANALYSIS OF THE PECOS RIVER BASIN, NEW MEXICO

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ABSTRACT

QUANTITATIVE WATER RESOURCE BASIN PLANNING: AN ANALYSIS OF THE PECOS RIVER BASIN, NEW MEXICO

In this study the traditional water-requirements approach to water resource basin planning is explicitly integrated into an activity analysis type of planning model. The model is structured to include sequential interdependencies of surface water utilization, and conjunctive use of ground and surface waters. In addition, both water quality and quantity restrictions are introduced into the model simultaneously. Emphasis is given to the potential for intrabasin water transfer between competitive users, locations, and points in time.

Empirical data and requirements projections are generated for the Pecos River Basin, a typically overdrawn basin, characterized by substantial irrigated acreage in the semiarid Southwest. The model is tested, using the Pecos River Basin data, and policy implications of the results are explored.

KEYWORDS–activity analysis/ conjunctive water use/ ground water management/ water planning/ water projections models.

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Special thanks are due Allene Gibson for efficiently and expertly typing preliminary manuscripts. Needless to say, errors remaining, either in the logic or numerical content of this analysis, are attributable to the author.

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Chapter 1

INTRODUCTION

> For its size, the basin of the Pecos River probably presents a greater aggregation of problems associated with land and water use than any other irrigated basin in the western United States. These involve both quantity and quality of water supplies, the problem of salinity being particularly acute; erosion and silting of reservoirs and channels; damage from floods; and interstate controversy over the use of the waters. There is an abundance of good land so that the limit of development is the availability of water of satisfactory quality. The use of the water of the river has been fully appropriated.[2]

Man's activities with regard to producing goods and services are restricted to a large extent by attributes or characteristics of the natural environment in which he resides. In the Pecos River Basin of New Mexico the most restrictive natural characteristic is the quantity and quality of water.

The above quotation adequately summarizes current water problems within the Pecos River Basin except for their extreme intensification since 1942. Water resources in the basin have become increasingly scarce during the last three decades. Concomitant with increasing urban population and industrialization, no substantial water augmentation projects or importations were undertaken. The stock of ground water resources has been partially depleted through pumpage in excess of estimated natural recharge by as much as 30 percent in certain years. In consequence, the Pecos River Basin, particularly the Roswell-Artesia area, has undergone marked declines of ground water levels during the past three decades. These problems, along with those cited in the quotation, lead to the conclusion that, if the Pecos River Basin is to exhibit continuing economic development the limiting factor of water resources availability must be examined methodically, and a search must be initiated to identify means of ameliorating the economic impacts from increasing water scarcities.

A distinction should be made between physical and economic water shortages. Physical water shortages refer to the unavailability of water resources to meet all water requirements, whereas economic water shortages refer to shortages that a) seriously impede economic development and/or b) exhibit *relatively* higher costs or prices compared with water in other geographic areas. In the Pecos River Basin, water prices or costs in the recent past have not been substantially above costs in other river basins; yet, from the previous discussion, it is obvious that physical shortages have impeded economic development, particularly irrigated agriculture. In the future one may expect this physical shortage to continue and, concurrently, prices or costs of water to remain relatively constant. This constancy in prices or costs occurs because retarded economic development also limits to some degree the emergence of relatively high-value uses for water, which means that costs or prices cannot increase substantially.

The Pecos River Basin, with about 93 percent of its water resources devoted to irrigated agriculture and only 7 percent to relatively high-value uses such as manufacturing and municipal uses, exhibits a relatively low aggregate average value for water. In addition, the import value of water is quite low since water, potentially, could be transferred in small amounts from irrigated agriculture without seriously affecting this sector. This finding leads to the tentative conclusion that the value attached to imported water, while very low when measured as an increment to irrigated agriculture,

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[2] Federal Natural Resources Planning Board, *The Pecos River—Joint Investigation in the Pecos River Basin—Summary, Analyses, and Findings, Regional Planning,* Part X, June 1942.

might be quite high when one considers the long-run impact on overall economic development of the Pecos River Basin.

This study is an attempt to identify explicit policy choices for time-related reallocation of water resources within the Pecos River Basin. The economic feasibility of augmenting existing basin water resources from external basin sources is not analyzed, though economic values or shadow prices are estimated for water of particular quality to augment existing basin supplies. Thus, the Pecos River Basin is viewed, for this preliminary analysis, as a "closed water system" where a substantial amount of the basin's resources can be exhausted through runoff, evaporation, evapotranspiration, and ground water mining.

This report contains two major parts. The first includes a set of water requirements projections for major industrial, agricultural, and commercial water-using sectors in the Pecos Basin for the years 1980 and 2000. The second part contains an analysis of potential for intra-basin water transfers within the Pecos Basin drainage area in New Mexico. The two parts are not mutually exclusive in that the requirements projections in the first section are utilized as data inputs for the water transfer model developed in the second section.

Definition of Terms

To clarify the meaning of certain concepts and terms used in this study, precise definitions are given below.

Gross water use: The quantity of water utilized in a particular productive activity, including amounts of water recirculated or reused.

Consumptive use (depletion): The quantity of water used in a particular productive activity in such a manner that, in practice, it is unavailable for any other commercial or economic uses.

Withdrawals (diversion): The quantity of water taken from surface flows, shallow aquifers, or artesian aquifers for use in a particular productive activity, and measured at the point of source—that is, well pump or diversion canal.

Water requirements: The minimum amount of water necessary in a particular productive activity to sustain predetermined production levels, given existing technology and assumed constant costs per unit of water.

Water demand: The quantities of water demanded for particular activities, given a predetermined schedule of water costs or prices.

Value added (gross product): The value of total output of *new* goods and services produced by a firm, individual, sector, or basin, during a specified time interval.

Direct value added: The value of total output of new goods and services produced by a particular firm or sector.

Indirect value added: The value of total output of new goods and services generated in all other firms or sectors and induced by the total output of a particular firm or sector. In chapter 2, in terms of income, the reference is to "induced" income rather than "indirect" income, even though these concepts are identical.

Average value added: The value of total output of new goods and services in a particular sector or for a particular firm or industry, divided by water withdrawals required to produce that output by the firm, industry, or sector.

Marginal (incremental) value added: The potential change in value of total output of goods and services for a particular firm, industry, or sector, given a one-unit (acre-foot, 1,000 acre-foot) change in water withdrawals by that firm, industry, or sector.

Basin product: The sum of direct value added generated by all sectors or industries within the basin.

Social opportunity costs: The value of resources in alternative uses—that is, the value of machinery in its next best alternative use in contrast to its current use.

Social external costs: Social costs not included in market price computations, or not included in determination of efficient allocations of resources—for example, losses in wellbeing induced by labor migration.

Chapter 2

BASIC ECONOMIC DESCRIPTION OF THE PECOS BASIN

In the semiarid West, endemic water shortages characterize and determine to a large extent the location and structure of economic activity and therefore population. Continuing rapid economic development of many areas within this region, including the Pecos Basin of New Mexico, will increasingly require intrabasin water transfers unless water importations prove to be of reasonable cost. (This assumes that rates of technological change altering water requirements per unit of product or per capita do not markedly increase.)

The Pecos Basin is largely dominated by three types of commercial industrial activity: mining, particularly potash extraction; agriculture, with heavy emphasis on irrigated crop production; and light industrial and commercial enterprise. Irrigated agriculture accounts for an exceedingly high proportion of the total utilization of water resources in the Pecos Basin, amounting to more than 90 percent of total withdrawals in 1960. Alternatively, other sectors, such as mining and light industrial and commercial enterprise, account for both the largest amount of direct gross value added and for the greatest amount of employment within the basin. However, much of this commercial activity, with the possible exception of mining, is directly or indirectly dependent upon the agriculture sector as a major source of sales and income.

The Pecos Basin encompasses approximately 26,000 square miles, or one-sixth of the total land area within the State of New Mexico and a small portion of West Texas. For purposes of analysis in this study, only that portion of the Pecos Basin within the boundaries of New Mexico will be considered. This portion includes much of the total land area within the southeastern quadrant if the State of New Mexico is divided into four approximately equal rectangular quadrants.

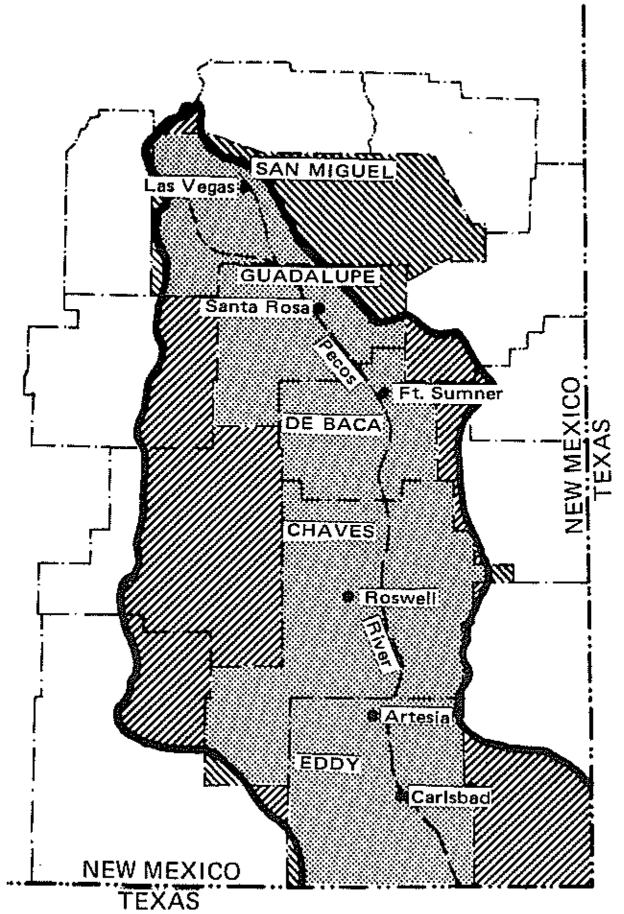
For the detailed economic description and analysis that follows, an even smaller area was delineated which included the five major counties within the Pecos Basin: San Miguel, Guadalupe, De Baca, Chaves, and Eddy. This reduction in areal dimensions was necessary in order to obtain meaningful economic data. Most data with economic dimensions are collected and published according to political boundaries—that is, for municipalities, counties, and states. Hydrological and geological data are usually published on the basis of drainage areas, river basins, or other predominantly physical characteristics. Only rarely do hydrological or physical subdivisions coincide with political subdivisions, and for the Pecos Basin in New Mexico there is only a small amount of coincidence. As costs of collecting economic data are usually prohibitively high at the basin and sub-basin levels of planning, it becomes necessary to select data in such a manner that the important components for analysis, both in terms of economic and physical or hydrological dimensions, are contained within the same geographic area.

For the Pecos Basin it was decided to include only five counties as representative of the 14 counties comprising the entire Pecos Basin Water Resource Region.

Figure 1 shows the land areas that are coincident between the Pecos Basin Water Resource Region (PBWRR) and what will be called the Pecos Basin Five-County Area (PBFCA). Land areas within the PBWRR not included within the PBFCA are identified, as are areas within the PBFCA that are not included within the PBWRR. Approximately one-third of the total land area in the PBWRR is omitted from the PBFCA but a large amount of this is semiarid desert with little or no population, commercial enterprise, or irrigated agriculture. About one-eighth of the total land area within the PBFCA is omitted from the PBWRR. This one-eighth, however, contains several irrigated crop production areas in San Miguel County which neither receive water from the Pecos Basin nor contribute to return flows. As these irrigated areas are a part of the Canadian River drainage basin, the estimated 1960, 1980, and 2000 withdrawals and depletions for irrigated agriculture will be slightly upward biased because of their inclusion.

The major objective in choosing the counties to be included was to select the combination that would yield a balance between the errors introduced from exclusion and the errors from inclusion. If all 14 counties were included, very large errors in overestimation of municipal, industrial, and agricultural water use and future requirements would emerge for the Pecos Basin drainage area. Conversely, including only two or three counties would exclude the consideration of potential intrabasin water transfers from or to those counties omitted. The five-county area selected appears to offer a balance between errors committed in estimating current and future economic activities and hydrological relationships within the Pecos Basin.

Hufschmidt has recommended that "the pattern of uses with strong links, physical, economic, and cultural . . . are included within the planning area, [and] links with the outside world should ideally be weak ones"(16). Excepting the already-mentioned irrigated crop-producing areas in northeastern San Miguel County, the five-county area (PBFCA) is almost completely contained within the Pecos Basin drainage area. Thus, the hydrological linkages appear to be reasonably strong. In terms of population, the PBFCA in 1960 contained more than 85 percent of the estimated population for the PBWRR, excluding the West Texas portion. In terms of numbers and size of municipalities, only seven communities had populations larger than 100 within the New Mexico portion of the PBWRR not included within the PBFCA. These findings suggest that the PBFCA encompasses most of the strong economic and hydrological linkages present within the PBWRR. The extent of certain weaker economic linkages between the PBFCA and contiguous areas, as well as national markets, is discussed in the appendices.



Legend:

░ –Coincident land area, Pecos Basin Water Resource Region and Pecos Basin Five-County Area.

▨ –Land area in Pecos Basin Water Resource Region but not in Pecos Basin Five-County Area.

▧ –Land area not in the Pecos Basin Water Resource Region but in the Pecos Basin Five-County Area.

Figure 1. Delineation of the Pecos Basin Water Resource Region and Pecos Basin Five-County Area, State of New Mexico.

Definition and Classification of Sectors

The partitioning of gross basin water use into particular sectors, activities, or demands is most important in the process of quantifying water allocation and transfer alternatives at the basin level of planning. The type of sectors selected depends on both the initial policy or planning questions posed and on considerations of economic interdependencies or linkages. Further, certain technological interrelationships, such as sequential water use and reuse, may help determine the type of sector.

The procedure in selecting sectors was to attempt aggregation into one sector of all economic activities having common linkages with the outside world and which could be considered competitive for existing basin water sources. Sequential water use linkages in selecting sectors for the Pecos Basin were not considered, as these linkages are explicitly included within the planning model developed in chapter 7. For the water requirements projections by sector and location, contained in chapters 3 and 4, adequate measures of physical interrelationships were unavailable and thus not considered.

The six major water-using sectors selected for analysis were: manufacturing, mining, municipal, rural domestic, steam electric power generation, and irrigation. For certain aspects of the projections analysis and in the planning models, the major sectors were further subdivided. Irrigation was divided into two or more subsectors, each defining irrigation water applied to a particular crop. Estimates of current and future municipal water use were developed by county and also by municipalities exceeding 100 population. Estimates of manufacturing water use were disaggregated into subsectors denoting specific SIC (Standard Industrial Classification) 2-digit manufacturing industries.

Two important water-using sectors omitted in this preliminary analysis were 1) water use for recreational purposes and 2) water use by the petroleum mining industry in eastern Eddy County and Lea County. Adequate secondary information was unavailable on the potential for fishing or other recreational activities in the Pecos Basin. Except for fishing and recreational activities on or near the several reservoirs along the Pecos River, it would seem that competition for water between other sectors and recreation would be minimal. A satisfactory method of estimating recreation benefits derived from water-related activities has apparently not yet been developed. Factors such as "latent" or "option" demand, describing demand by consumers not currently consuming but who may wish to, or what might be termed "adaptation demand," a demand generated over time by learning to participate in a given recreational activity, have only recently been studied(8) (26). The prospects for measuring these factors are only dimly apparent at this time. This is not to suggest that recreational activities be explicitly ignored in the development of water transfer or reallocation policies, but the following discussion recognizes the current relative unimportance of the recreational water-related sector.

The second omission of possible consequence was the exclusion of petroleum mining within the mining sector. Serious problems may arise from competitive uses, in terms of both water quantity and quality, in excluding the southern portion of Eddy County from the analysis. Again, lack of specific information on the petroleum mining sector and its relation to water resource activities on the Pecos River precludes an analysis at present. However, the model proposed in chapter 7 can easily be modified to include both a recreational and a petroleum mining water-use sector.

In chapter 3, estimates of water withdrawals and consumptive use for 1960 by each major sector are developed. The following sections of this chapter will be primarily concerned with other dimensions, specifically the economic dimensions of the six major sectors selected within the Pecos Basin Five-County Area (PBFCA). Manufacturing water uses were placed in a separate sector from trade, service, and finance because of the much larger quantities of water required per unit of product in manufacturing. The mining sector was also given a separate sector because of the relatively high water requirement per dollar of mined product. The municipal sector contains household water requirements and a potpourri of commercial firms with relatively low water requirements whose size, and by implication, water requirements, are expected to be related directly to population. Partitioning of the irrigated agricultural sector and steam electric power generation sector is obvious.

In table 1 the number of commercial enterprises and total employment in each category, excluding on-farm

Table 1. Number of firms and total employment, by nonagricultural industries, Pecos Basin Five-County Area, New Mexico, 1963.

	County									
	San Miguel		Guadalupe		De Baca		Chaves		Eddy	
Industry	No. of Firms	Total Employment	No. of Firms	Total Employment	No. of Firms	Total Employment	No. of Firms	Total Employment	No. of Firms	Total Employment
Agriculture[1]	N.A.	N.A.	0	0	N.A.	N.A.	11	N.A.	14	N.A.
Mining	5	37	—	—	—	—	45	653	119	4,297
Contract construction	15	45	10	105	5	28	211	1,354	132	748
Manufacturing	122	702	—	—	—	—	34	941	37	669
Transportation, utilities	37	653	—	—	—	—	51	606	40	625
Trade	28	506	95	393	41	154	467	3,440	451	2,556
Finance[2]	93	2,381	—	—	—	—	121	712	84	515
Service	297	1,478	27	117	12	27	317	1,267	273	1,107
Nonclassifiable	—[3]	—[3]	7	61	6	34	13	67	15	74
Total	597	5,802	139	676	64	243	1,270	9,040	1,165	10,591

[1] Agricultural service or processing firms.
[2] Includes insurance and real estate.
[3] Nonclassified included in service industry for San Miguel County.
Source: *New Mexico Employers, Industry, Size and Location*, Unemployment Insurance Division, Employment Security Commission of New Mexico, September 1963.

agriculture and agriculture-oriented service and processing firms, is shown by county for the year 1963. Mining was the largest single employer in Eddy County, and second to trade for the entire PBFCA. The six largest employers within the PBFCA were trade, mining, service, finance (including insurance and real estate), contract construction, and manufacturing, in that order.

With the exception of mining, average employment per firm rarely exceeded 250 and usually was less than 100. This is indicative that most firms are relatively small in the PBFCA, and a fairly high percentage (40 to 70 percent) of total employment, excluding agriculture, is sustained by nonindustrial types of enterprise.

In all categories listed in table 1 employment as a proportion of total urban population varied markedly between counties. The proportions for Eddy and Chaves Counties were approximately 28 and 25 percent, respectively. This differential is explained by the low employment in mining in Chaves County relative to Eddy County, and vice versa for the trade category. Chaves County has relatively more important interstate highways, making this finding quite reasonable.

Employment in the nonagricultural categories in proportion to total urban population in other counties varied markedly, from approximately 12 and 17 percent for De Baca and Guadalupe Counties, respectively, to about 40 percent for San Miguel County. High relative levels of employment in the finance and service categories in San Miguel County contributed to this disparity.

It would be expected that, as urban population (as a percentage of total population) expanded, employment would expand in the nonagricultural industry categories. However, in 1960 San Miguel County had the highest proportion of rural population of the five counties (see footnote 2, Appendix A). Because of this finding, the above statement regarding employment in specific categories and the proportion of urban to total population must be, at least partially, qualified for the PBFCA.

In the water requirements projections developed in chapters 3 and 4, the explicit hypothesis is made that as population increases, municipal water withdrawals per capita increase. The validity of this hypothesis is made slightly questionable from the above finding that a positive relationship between nonagricultural employment and urban population is not always present.

The categories of firms listed in table 1 were partitioned into three major water-using sectors: mining, manufacturing, and municipal. Other nonagricultural categories, including transportation, trade, finance, service and contract construction, except for mining and manufacturing, were included in the municipal sector.

Table 2. Estimated direct value added, by major sector and county, Pecos Basin Five-County Area, New Mexico, 1960.

Sector	San Miguel	Guadalupe	De Baca	Chaves	Eddy	Total
			(thousands of dollars)			
Municipal	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Manufacturing						
SIC 20, food products	480	—	—	6,320	2,640	9,440
SIC 28, chemicals	—	—	—	—	525	525
SIC 32, stone, clay and glass products	—	—	—	2,460	1,044	3,504
Mining[1]	—	—	—	—	121,480	121,480
Electric power generation	N.A.	N.A.	N.A.	2,719	2,411	5,130
Irrigation[2]	329	100	445	17,247	14,461	32,582
Other[3]	211	109	109	1,258	52	1,739
Total	1,020	209	554	30,004	142,613	174,400

[1] Source: Computed from M. M. Gilkey and R. B. Stotelmeyer, *Water Requirements and Uses in New Mexico Mineral Industries*, United States Department of Interior, Bureau of Mines, 1965, and *New Mexico Business*, October 1965.

[2] Source: Computed from *The Census of Agriculture*, 1959.

[3] Source: Computed from *New Mexico Business*, February 1968.

Table 3. Estimated total employment, by major sector and county, Pecos Basin Five-County Area, New Mexico, 1960.

Sector	San Miguel	Guadalupe	De Baca	Chaves	Eddy	Total
Municipal[1]	5,063	676	243	7,446	5,625	19,053
Manufacturing						
SIC 20, food products	48	—	—	632	264	944
SIC 28, chemicals	—	—	—	—	35	35
SIC 32, stone, clay, and glass products	—	—	—	205	87	292
Mining[1]	37	—	—	653	4,297	4,987
Electric power generation	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Irrigation[2]	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Other[2]	191	699	811	12,560	7,322	21,583
Total	5,339	1,375	1,054	21,496	17,730	46,894

[1] Estimates are for 1963.

[2] "Other" category contains employment in agriculture not in the irrigation sector. Note: because the municipal and mining sector estimates are for 1963, a slight downward bias might be expected in the "other" category.

Gross Output and Employment by Sectors

In tables 2 and 3, estimates of direct value added (yearly gross output of goods and services) and employment for each major sector by county are given. Direct value added estimates for the municipal sector are unavailable, but an estimate can be derived, assuming that direct value added in the municipal sector as a proportion of PBFCA total value added is equal to the proportion of PBFCA total employment in the municipal sector. Since municipal sector employment as a percentage of PBFCA total employment is approximately 40 percent, direct value added in this sector, by assumption, would be approximately $292 millions in 1960, or $2,085 per capita. This estimate is undoubtedly biased slightly upward because of omitting agricultural employment from the assumed PBFCA total employment estimate.

In table 4 the percentage distributions of value added by sector in 1960, for the United States, New Mexico, and the PBFCA are recorded. The PBFCA does not closely follow the percentage distribution pattern of either the United States or New Mexico. The PBFCA apparently generates a much larger proportion of its gross product from the mining and agriculture sectors. It is slightly above the New Mexico percentage for manufacturing, but much below the United States percentage in both the manufacturing and the municipal sectors.

Table 4. Percentage distribution of value added between sectors for United States, New Mexico, and Pecos Basin Five-County Area, New Mexico, 1960.

Sector	United States	New Mexico	Pecos Basin Five-County Area
Agriculture	4.3	5.0	11.5[1]
Mining	2.5	23.2	41.8
Manufacturing	28.6	4.8	4.9
Municipal	59.7[2]	62.7[2]	40.0[3]
Other	4.9	4.3	1.8
Total	100.0	100.0	100.0

[1] Includes only irrigated agriculture sector.

[2] Includes transportation, communications, public utilities, trade, finance, insurance, real estate, services, and government.

[3] Estimated by calculating the ratio of employment in this same sector to total basin employment and assuming the same ratio for value added.

Sources: A. D. Sandoval, "An Interindustry Study of the New Mexico Economy," *New Mexico Business*, Bureau of Business Research, University of New Mexico, May 1968, and tables 2 and 3 of this report.

Sector Interactions

In evaluating the potential for water transfer between major sectors, a question may be raised regarding the magnitudes of impact each sector has on the rest of the Pecos Basin economy. Estimates of interrelationships between sectors were unavailable for the PBFCA, but were available for the State of New Mexico. It was thought that estimates of total income impact multipliers for the state would tend to approximate what might occur in the PBFCA. In table 5, estimates of total income multipliers for the State of New Mexico are given, as derived from the state input-output table.

The total impact income multiplier includes direct and induced income effects for all sectors from a dollar change in final sales in one sector. If, for instance, final demand increases in the food products industry by one dollar, the total income multiplier indicates by how much incomes will increase in all other sectors as well. The "induced" income effect includes income changes in other sectors selling products to the food products sector, and, in one variant, the effect from positive changes in income in the household sector, induced by the initial dollar increase in food products sector's final sales.

Variability is great, not only in the direct income effects between sectors, but also in the total impact income multipliers. Income multipliers range from $1.45 to $2.42 per dollar in new final sales, excluding government purchases and sales, in the processing sector, and from $1.63 to $2.68 if government is included in the processing sector. This finding suggests that the secondary effects from water transference between sectors cannot easily be ignored or omitted from explicit consideration. For example, assuming that direct value added per acre-foot is 10 percent higher in sector A than in sector B, and assuming also that the indirect income multiplier is 50 percent higher for sector B compared to A, it is possible for the losses in total basin product due to the direct and indirect effects of reducing production in B to be larger than the gains in total basin product due to expanding production of A.

Table 5. Estimates of the multiplier effect per dollar change in final sales, by sectors, New Mexico, 1960.

Sector	Direct Income Effect[1]	Total Income Multiplier I[2]	Total Income Multiplier II[3]	Percent Imports[4]
	(cents)	(cents)	(cents)	(cents)
Agriculture				
Meat animals	27	215	248	55
Food grains and field crops	51	165	188	36
Mining				
Potash	28	161	204	44
Manufacturing				
Miscellaneous food products	19	232	268	56
Chemicals	20	205	250	14
Concrete and stone products	25	192	220	46
Municipal				
Trucking and other transportation	37	173	203	52
Wholesale	37	165	192	59
Gasoline service stations	54	159	181	34
Finance and insurance	42	160	183	54
Real estate	71	145	163	28
Personal services	34	174	203	52
Business services	46	161	183	51

[1] The change in income within the sector per dollar increase in final sales for that sector.

[2] The total income generated in all sectors per dollar increase in final sales for the specified sector. Includes households as a producing sector.

[3] The same as I, except state and local government also included as a producing sector.

[4] Purchases from out-of-state per dollar of gross output, as a percentage of total purchases per dollar of gross output.

Source: A. D. Sandoval, "An Interindustry Study of the New Mexico Economy," *New Mexico Business*, Bureau of Business Research, University of New Mexico, May 1968.

Another indicator of the secondary impact on the state's and the PBFCA's economy from growth or retardation in each major sector is the percentage of total purchases per dollar of output spent out-of-state. The larger the proportion of purchases within the state, the larger the expected secondary repercussions from particular water transfers might be. However, the correlation coefficient between total income multipliers and percentages of total purchases made out-of-state was positive, but very close to zero (<.01), for the sectors recorded in table 5.

In evaluating the impact of alternative water transfers on the PBFCA, both income multipliers and percentage out-of-state purchases must be analyzed, if it is desirable to include secondary effects in the weighting of policy alternatives. The apparent differences between sectoral total income multipliers and percentage out-of-state purchase by sectors suggests that, for policy-making purposes, an explicit analysis involving both of these secondary effects should be undertaken. This study makes such an analysis through sensitivity analyses of the value weights in the model for optimal water transfers discussed in chapters 7 and 8.

Value Added per Acre-Foot

In this section, estimates are presented for direct value added per acre-foot of diverted water for the six major sectors and several subsectors within the irrigation and manufacturing sectors. Average value added per acre-foot and, where available, incremental value added per additional acre-foot estimates are recorded in table 6.

It is apparent from these estimates that, on a criterion of allocation based on average value added per acre-foot estimates, irrigated agriculture would be excluded, except where residual water supplies might be made available. However, on the basis of incremental value added criteria, manufacturing and several irrigated crops may, in fact, be competitive. The estimate of incremental value added for chemicals (SIC 28) is below the estimate of incremental value added for cotton or alfalfa. Clearly, for small amounts of water transference between sectors, cotton and chemicals may be highly competitive.

Direct value added per acre-foot in potash mining, electric power generation, and municipal uses is much larger than for other major sectors except for food products (SIC 20) in the manufacturing sector. Incremental direct value added estimates were unavailable for these three sectors, thus a comparison in terms of incremental value added between all major sectors is impossible. However, it would seem reasonable to assume that incremental value added would be much higher for electric power generation, municipal uses, and mining than for manufacturing or irrigated agriculture, especially in light of the small anticipated change in output for mining (see Appendix F). In consequence, for the water transfer model developed in chapter 7, these three sectors were omitted from consideration as regards potential water transference between sectors.

Table 6. Estimates of average and incremental direct value added per acre-foot diverted water, Pecos Basin Five-County Area, New Mexico.

Sector	Average Value Added per Acre-Foot Diverted[1]	Incremental Value Added per Acre-Foot Diverted
	(dollars)	(dollars)
Irrigated agriculture[2]		
Alfalfa	49.00	49.00
Barley	29.00	15.00
Corn	33.00	33.00
Cotton	104.00	98.00
Grain sorghum	32.00	27.00
Mining		
Potash	7,552.00	N.A.
Manufacturing[3]		
Food products (SIC 20)	4,762.00	381.00
Chemicals (SIC 28)	980.00	88.00
Stone, clay and glass products (SIC 32)	3,333.00	167.00
Electric power generation	4,676.00	N.A.
Municipal	4,861.00	N.A.

[1] Here diversion means amount of water withdrawals by sector and not water depletion by sector.

[2] The average and marginal value added estimates for selected crops are calculated from appendix tables J-1 through J-5. It was assumed the water source measured .75 mmhos of salinity, and was applied on Class I and II soils at the maximum tabulated irrigation water pumped.

[3] United States average and incremental estimates were assumed to be applicable to the Pecos Basin. See appendix table E-1 for sources.

Urban and Rural Population Projections

Total population in the Pecos Basin Five-County Area (PBFCA) increased from about 118,000 in 1950 to more than 140,000 in 1960, or approximately 2,000 per year.

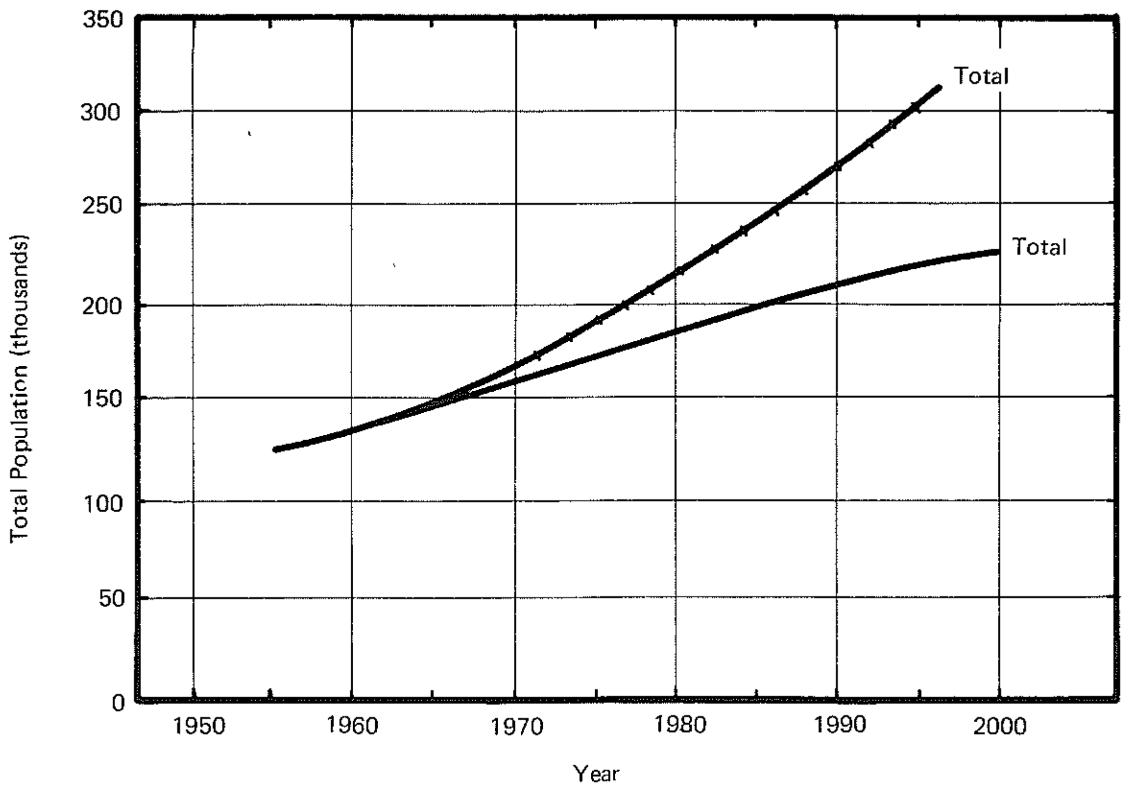


Figure 2. Medium projections of total population, Pecos Basin Five-County Area, New Mexico.

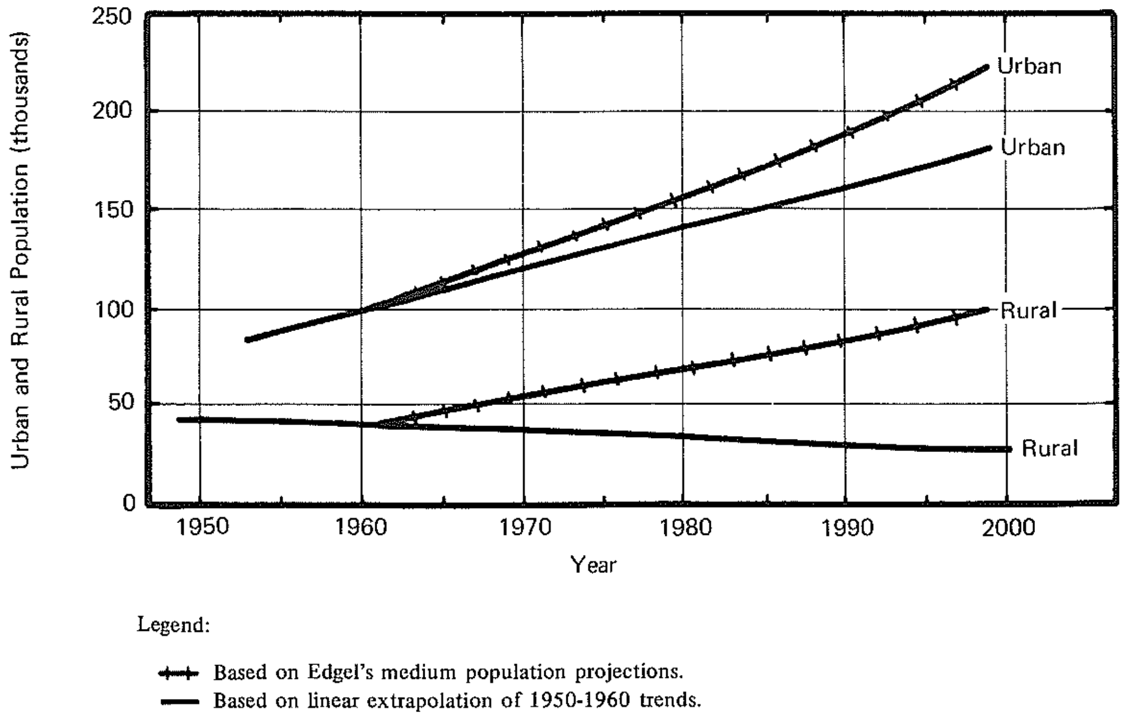


Figure 3. Medium projections of urban and rural population, Pecos Basin Five-County Area, New Mexico.

Population in urban locations (municipalities of 100 or more) increased by more than 30,000 while rural population actually declined during 1950-1960.

In figures 2 and 3, the change in population between 1950 and 1960 is presented along with alternative projections for growth through the year 2000. It appears reasonable to assume that the rural population in PBFCA will continue to decline; if this is the case, the rural population projections based on linear extrapolated projections of 1950 to 1960 might be the most appropriate estimate.

The PBFCA is becoming more urbanized in that the proportion of total population living in urban areas has increased markedly over the past two decades. If current trends persist, an urban population greater than 145,000 by 1980 and 180,000 by 2000 is not unlikely.

Summary

A complete economic description of the PBFCA would necessitate a voluminous amount of detail. To paint a brief portrait of the PBFCA's economic base, in this chapter estimates were presented of a few selected economic measures, including sectoral employment, value added (gross output), urban and rural population, and total impact income multipliers (for the state). Also, direct value added per acre-foot of water diverted to particular sectors was examined briefly to give insight as to the competitiveness of water between sectors.

Six major categories of water use were assumed, including irrigated agriculture, manufacturing, mining, municipal, rural domestic, and electric power generation. It was found that, in terms of direct value added or employment, the mining and municipal sectors were by far the largest contributors. This contrasts with the finding presented in the next chapter, that irrigated agriculture was the largest water-using sector in 1960, followed by the municipal and mining sectors.

The magnitude of the difference found between sectoral total income multipliers indicates that the secondary effects of the different sectors on output of other sectors may be quite varied. Also, the variability in out-of-state purchases as a proportion of total purchases by each sector (state estimates) indicates that reallocation of water resources based solely on direct value criteria (see chapter 8) may be in serious error regarding the potential impact on basin or state product from particular water transfers.

Chapter 3

SUMMARY–ESTIMATED 1960 WATER WITHDRAWALS AND CONSUMPTIVE USE, BY SECTOR AND LOCATION

The major purpose of this chapter is to set forth initial benchmark data on water use within the Pecos Basin Five-County Area (PBFCA) for 1960. The data assembled, or estimated, and tabulated here are required for specification of initial conditions for the transfer model, and also to provide a basis of comparison with projections for 1980 and 2000 as tabulated in chapter 4. Water withdrawal and consumptive use estimates were prepared for the six major sectors in each of the five counties. More detailed estimates of withdrawals and consumptive use within counties and for particular sectors by county are tabulated in Appendices B through G. Where subjective estimates were included, an attempt was made in each case to overestimate, rather than underestimate, water withdrawals.

Municipal Uses

Estimates of municipal withdrawals and consumptive use were derived from data collected by Dinwiddie in 1962 for communities exceeding approximately 100 total population(9) (10). No adjustments were made for changes of population between 1960 and 1962. Thus, benchmark data on municipal water withdrawals are slight overestimates, though the implied increase in urban population between 1960 and 1962 was less than 5 percent for the PBFCA. Urban population, according to census estimates, was approximately 96,000 in 1960 (appendix table A-1), and, according to Dinwiddie's estimates, about 102,000 in 1962 (appendix table B-1).

Consumptive water use for particular municipalities was estimated by assuming that 45 percent of municipal water withdrawals was consumptively used–that is, not available for reuse. The 45 percent figure was obtained from estimates made by Wollman and Bower for the entire Rio Grande-Pecos Water Resource Region (42) and should represent an upper limit to probable consumptive use as a proportion of municipal withdrawals within the Pecos Basin area.

Rural Domestic Uses

Estimates of rural domestic withdrawals for 1960 were constructed by applying a uniform estimate of 70 gallons per day per capita. No precise estimates of rural domestic withdrawals appear to be available, either for the Pecos Basin or for comparable areas in the southwestern United States. The 70-gallon-per-day (GPD) figure, however, corresponds closely to withdrawals in communities of less than 200 within the Pecos Basin area with little or no commercial activity. It was assumed, therefore, that this estimate of GPD per capita would bias upward, if at all, the estimate of rural domestic water withdrawals. Even if a large upward bias does exist, the impact of the error would be relatively small, as estimated rural domestic withdrawals in 1960 constituted less than one-half of 1 percent of total estimated basin withdrawals.

An estimate of consumptive use as a percentage of rural domestic withdrawals was unavailable. In lieu of an estimate, 45 percent consumptive use as a proportion of rural domestic withdrawals was arbitrarily utilized, which is identical to the municipal percentage discussed earlier.

Manufacturing Uses

Benchmark estimates of water withdrawals and consumptive use were developed for three SIC 2-digit industries within the Pecos Basin. These estimates were based on aggregate average United States (or Western Gulf Water Resource Region) relationships between value added and fresh water withdrawals, and also employment and fresh water withdrawals (see appendix table E-1). The estimates of coefficients were obtained for 1959 for the three selected industries, food and kindred products (SIC 20), chemicals and products (SIC 28), and stone, clay, and glass products (SIC 32), for the entire United States and for the Western Gulf Water Resources Region.

Estimates of manufacturing withdrawals were obtained by applying the United States or Western Gulf coefficients (relating fresh water withdrawals to total employment) to estimates of total employment by SIC 2-digit industry by county, prepared by the Employment Security Commission for 1959 (see appendix table E-4). A crosscheck on the accuracy of this estimate was obtained by applying *ancillary* estimates of direct value added per employee, and then computing an estimate of direct value added by each SIC 2-digit industry within the Pecos Basin area. The value added estimate was then multiplied by average United States fresh water withdrawals for each dollar of direct value added, by SIC 2-digit classification.

Relatively large differences were found between the two alternative estimates of fresh water withdrawals by manufacturing. Since the estimates based on total employment did not depend upon ancillary estimates of direct value added per employee, they were adopted as the benchmark estimate for 1960. Also, the estimates based on employment were higher in each case than those based on value added; thus possible bias, if present, may be expected to be in an upward direction. Consumptive use, as a proportion of fresh water withdrawals for SIC 2-digit industries 20, 28, and 32 in the PBFCA, was assumed to be equal to consumptive use as a proportion of total withdrawals for the United States. The consumptive use proportions in percentage terms were 7.9 percent, 5.5 percent, and 9.7 percent for SIC industries 20, 28, and 32, respectively(39). Since these percentages were computed on the basis of total rather than fresh water withdrawals, they probably understate actual consumptive use proportions in the Pecos Basin. Relatively greater scarcities of fresh water and practically no available brackish water would suggest greater applications of water-conserving or reuse technologies and thus, by implication, higher consumptive use percentages. The three SIC industries listed had wide variations in rates of reuse in 1959, depending on geographical location(39).

Mining Uses

Estimates of mining water withdrawals for 1960 were obtained directly from tabulations by the United States Bureau of Mines(17). The tabulations for Eddy and Chaves Counties were for 1962 and no adjustment was applied for changes in mining water withdrawals between 1960 and 1962. Given the relative stability in New Mexico potash production during this period, it appears that any bias would be slight, especially in light of the fact that basin mining water withdrawals accounted for less than 3 percent of total estimated Pecos Basin withdrawals in 1960.

Gilkey and Stotelmeyer's estimates of evaporation and other losses as a proportion of total water intake averaged 40 percent for the six potash-producing plants in Eddy County and other plants in contiguous areas(17). The variability of individual potash operation's rate of depletion (consumptive use) was relatively high, ranging from slightly less than 13 percent to more than 90 percent. An average percentage depletion, unweighted by the magnitude of individual company's withdrawals, yields a somewhat lower percentage or about 33 percent, indicating that larger water-using mining operations usually have larger rates of consumptive use. The 45 percent rate was adopted for the benchmark estimates tabulated here. Since potash mining currently is the only major type of mining operation within the PBFCA utilizing large quantities of water, both water withdrawal and consumptive use estimates for the mining sector included only water use by the potash industry.

Electric Power Generation Water Uses

Water withdrawal and depletion estimates for electric power generation within the Pecos Basin were derived from data provided by the Southwestern Public Service Company for their Roswell and Carlsbad steam plants. No data were available of water requirements for steam electric generation to supply electricity to the three northern counties. Estimates for the three northern counties were constructed by extrapolation of water requirements per capita for steam electric power generation in the two southern counties. Thus, the estimates of water withdrawals and consumptive use in the three northern counties only reflect water needed to generate the electrical power consumed in 1960 through the process of steam electric generation, and not *actual* water utilized to generate power requirements in those counties.

Irrigation

The estimates of water withdrawals and consumptive use for irrigated crop production in the Pecos Basin for 1960 are most crucial as regards initial benchmark estimates. Irrigated agriculture in 1960 accounted, at a minimum, for more than 90 percent of both water withdrawals and depletion within the PBFCA. Thus, even a small error in estimating initial benchmark data for the irrigated crop sector may have significant repercussions on future water requirements projections.

Three sets of data were compiled to estimate current 1960 water withdrawals and consumptive use: 1) irrigated crop acreages by county; 2) percentages of total acreage planted to particular irrigated crops by county; and 3) estimates of water withdrawals per acre, by irrigated crop and county (see appendix table D-7). With these three estimates, plus depletion coefficients by irrigated crop and county, it was possible to derive estimates of 1960 water use by the irrigated agricultural sector.

It is reasonable to assume that the data on irrigated acreages and percentages of irrigated acreage planted to particular crops are relatively accurate, though a slight upward bias might have been introduced by using planted rather than harvested acreages of particular crops. Of more importance is the probable variability in

Table 7. Water withdrawal estimates for 1960, by sector and county, Pecos Basin Five-County Area, New Mexico.

Sector	San Miguel	Guadalupe	De Baca	Chaves	Eddy	Total
			(acre-feet per year)			
Municipal	3,906	455	148	11,618	7,901	24,028
Rural domestic	810	158	99	1,516	1,113	3,696
Manufacturing	33	—	—	1,051	528	1,612
Mining	—	—	—	21	16,085	16,106
Electric power generation	170	41	22	727	370	1,330
Irrigation	25,410	7,340	19,012	323,375	242,470	617,607
Total	30,329	7,994	19,281	338,308	268,467	664,379

Table 8. Consumptive use estimates for 1960, by sector and county, Pecos Basin Five-County Area, New Mexico.

Sector	San Miguel	Guadalupe	De Baca	Chaves	Eddy	Total
			(acre-feet per year)			
Municipal	1,758	205	67	5,228	3,556	10,814
Rural domestic	365	71	45	682	501	1,664
Manufacturing	3	—	—	93	44	140
Mining	—	—	—	20	7,238	7,258
Electric power generation[1]	114	28	15	487	292	936
Irrigation	3,523	2,555	6,877	140,068	112,027	265,050
Total	5,763	2,859	7,004	146,578	123,658	285,862

[1] Based on consumptive use coefficients of .67 for Chaves and the three northern counties and .79 for Eddy County. See Appendix G for a more detailed description.

Table 9. Percentage distribution of estimated water withdrawals by major sectors, Pecos Basin Five-County Area, New Mexico, 1960.

Sector	San Miguel	Guadalupe	De Baca	Chaves	Eddy	Average
Municipal	13	6	1	3	3	4
Rural domestic	3	2	1	1	1	1
Manufacturing	*	—	—	1	1	*
Mining	—	—	—	*	6	2
Electric power generation	1	1	*	1	*	*
Irrigation	83	91	98	94	89	93
Total	100	100	100	100	100	100

* Less than 0.25 percent.

estimated water withdrawals per acre of irrigated crop. Two rules were followed in using these estimates in order to cause any bias that might arise to be in an upward direction. First, if more than one estimate of water withdrawals or depletion existed for a particular crop, the larger of the estimates was applied. Second, if estimates for a particular county were unavailable for an irrigated crop, the larger of the estimates for contiguous counties was assumed to apply.

Discussion of Estimates

The total estimated water withdrawal requirement in the Pecos Basin Five-County Area for 1960 was slightly less than 665,000 acre-feet. Estimated consumptive use as a percentage of total water withdrawals approached 43 percent. In terms of water use per unit of area, the Pecos Basin Five-County Area utilized approximately 33.6 acre-feet per square mile, which was much below estimates for other irrigated agricultural oriented water resource basins in semiarid areas.[1]

Potentially large errors may have been introduced into the estimates of irrigation requirements by using the questionably accurate water requirements per irrigated acre coefficients. For irrigation requirements estimates to be reasonably accurate, the coefficient estimate should be an estimate of the mean average. If the distribution of applications of irrigation water per acre is skewed to the right in each cotnty, and if our estimates are modal rather than estimates of the mean, the total irrigation requirement estimates contain a downward bias. However, because we have consistently followed the rule of selecting the largest coefficient estimate with respect to each crop, this probable bias may have been offset, either partially or totally.

It was decided, if possible, to overestimate rather than underestimate current (1960) sectoral withdrawals. The inherent nature of projections usually leads to overstatement of the short-run and understatement of the long-run. This is partially due to institutional rigidities impeding the potential for short-run changes, and institutional, technological, and structural changes broadening the potential for long-run change. In light of this hypothesis, overestimates rather than underestimates of current water withdrawals were thought to be desirable for developing long-run projections.

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[1] Water withdrawals in acre-feet per square mile in the California, Western Gulf, and Colorado Water Resource regions were approximately 486, 72, and 110, respectively, in 1954. (42)

Chapter 4

SUMMARY–PROJECTED PATTERNS OF WATER WITHDRAWALS AND CONSUMPTIVE USE, 1980-2000

Requirements projections of water withdrawals and consumptive use were developed for the six major competitive water-using sectors identified in chapter 1 within the Pecos Basin Five-County Area (PBFCA). A detailed description of projections methods and a discussion of the potential degree of variability for each major sector's requirements projections is included in Appendices A through G.

In developing a set of reallocation and/or redevelopment policies at the river basin level of planning, water requirements projections fulfill several crucial needs. An initial point of departure is developed, upon which alternative plans can be scrutinized and probable irrelevant policy alternatives discarded. These projections indicate what may be expected to prevail in the future, with no impact from increasing water shortages. Water requirements projections also may provide certain limits on the scope of plans for reallocation and redevelopment–that is, not only are irrelevant alternatives excluded, but given current and/or foreseeable water supplies, important areas of conflict within future use patterns are magnified. The magnifications are caused by omission of specific analyses regarding the cumulative effect of local and subregional water shortages and, by implication, sector water costs. Ancillary projections of water requirements not only aid in the initial formulation of policy alternatives, but also provide important constraints for the activity analysis model.

The timing of water resource transfers between sectors is important. The activity analysis model considered in chapter 7 contains explicit upper and lower limits to water resources transfer over time. Since transfer costs–that is, legal fees and/or changes in state water statutes–are not explicitly included within the model, water requirements projections can be utilized to determine the optimum time point or interval for transfer. For example, if recent trends in patterns of water utilization indicate a movement toward the optimal reallocation pattern, it very well could pay to forestall reallocation to take advantage of this trend. If foregone value added (gross output) from less than optimal current allocations is less than current transfer costs, postponement until existing water-use patterns more nearly conform to optimal use patterns is a better policy prescription.

Initial water requirements projections without explicit introduction of increasing water scarcities, and by implication higher costs, contribute in several ways to the formulation of policy choices. The contribution is both *ex ante* in clarifying and delineating potential conflicts in water-use patterns and irrelevant policy alternatives and *ex poste* as a basis of comparison with optimal allocations prescribed by the activity analysis model.

Requirements Projections Assumptions

The general procedure followed in developing low, medium, and high projections of water use was to review previous ancillary projections of rates of growth in urban and rural basin population, mining industries, irrigated acreage, and steam electric power generation, and to update, where possible, the previous projections with recent changes in trends or events. Where no previous forecasts had been constructed for major sectors (municipal water use, rural domestic water use, irrigation withdrawals, or manufacturing withdrawals), forecasts for 1980 and 2000 were developed. A complete description of the methods and assumptions used to adjust existing sectoral projections, develop new projections, and disaggregate projections into county and sectoral groupings is included in Appendices A through G.

In developing the projections, it was not assumed that increasing future water scarcities would be completely ameliorated during the forecasting period–that is, that water could again become a partially or completely free good–but only that water as a factor input or product would not become increasingly scarce relative to other factors of production or substitute products.

A second major assumption on which the forecasts in tables 10 through 14 are predicated is that underlying conditions of the economic system would remain as at the present (1960 through 1967), but with expanding or contracting output requirements. Where possible, expansion of basin output was related to probable national output expansion or output requirements, and basin output expansion was then related to water requirements for that scale of output.

In tables 10 through 14, high, medium, and low projections for 1980 and 2000 are recorded by sectors and by counties. The water withdrawal and depletion projections are for water assumed to contain less than 1,000 parts per million (ppm) dissolved solids. No other indicator of water quality was explicitly considered in developing the projections although water quality requirements vary markedly within and between sectors (compare tables in Appendix J).

If more than one set of high, medium, and low projections was constructed, a particular set was chosen to be included in the summary tables presented in this chapter. Reasons for a particular set of projections being selected are given in the respective appendices.

It should be noted that these projections reflect only magnitudes of yearly water requirements for 1980 and 2000, and do not show changing patterns of seasonal use or physical relationships between sequential water use

Table 10. Water withdrawals projections by sector and county for 1960, Pecos Basin, New Mexico.

Sector	Level of Projection	County					Total
		San Miguel	Guadalupe	De Baca	Chaves	Eddy	
		(acre-feet per year)					
Municipal							
	High	3,854	669	344	25,684	12,335	42,886
	Medium	3,283	603	306	23,611	10,824	38,627
	Low	2,829	544	283	20,675	9,570	33,901
Rural domestic[1]							
	High	1,387	266	201	3,171	1,900	6,925
	Medium	1,108	215	161	2,591	1,555	5,630
	Low	308	88	71	2,189	975	3,631
Manufacturing[2]							
	High	120	—	—	1,640	15,362	17,122
	Medium	86	—	—	1,195	10,356	11,637
	Low	81	—	—	1,134	7,654	8,869
Mining[3]							
	High	—	—	—	—	15,216	15,216
	Medium	—	—	—	—	15,216	15,216
	Low	—	—	—	—	12,328	12,328
Electric power generation[4]							
	High	N.A.	N.A.	N.A.	2,036	1,461	4,454
	Medium	N.A.	N.A.	N.A.	1,860	1,340	4,062
	Low	N.A.	N.A.	N.A.	1,727	1,243	3,755
Irrigation							
	High	40,441	32,189	27,029	620,256	487,147	1,207,062
	Medium	21,860	15,392	22,738	450,171	277,179	787,340
	Low	3,031	32	3,658	36,597	13,658	56,976

[1] Projections for high and medium levels are based on Edgel's population projections; those for low levels are based on linear 1950-1960 trends in rural population (see Appendix A).

[2] Projections are based on average water withdrawals per $1,000 direct value added.

[3] Medium estimates are based on Gilkey and Stotelmeyer's 1980 and 2000 projections, while low estimates take into account the loss of U.S. Borax Company output in Eddy County (see Appendix F).

[4] Projected totals presume all new electric power consumption in the Pecos Basin is generated from steam electric plants located within the basin. The projections are based on estimates made by the Southwestern Public Service Company (see Appendix G).

Table 11. Water withdrawal projections by sector and county for 2000, Pecos Basin, New Mexico.

		County					
Sector	Level of Projection	San Miguel	Guadalupe	De Baca	Chaves	Eddy	Total
				(acre-feet per year)			
Municipal	High	8,670	1,535	900	43,432	27,206	81,743
	Medium	6,950	1,332	712	38,717	22,452	70,163
	Low	5,997	1,179	680	34,951	18,926	61,733
Rural domestic[1]	High	2,324	544	448	5,357	3,076	11,749
	Medium	1,305	430	353	4,246	2,437	8,771
	Low	0	26	38	2,761	764	3,589
Manufacturing[2]	High	312	—	—	5,253	56,823	62,388
	Medium	168	—	—	3,357	27,114	30,639
	Low	130	—	—	2,851	15,122	18,103
Mining[3]	High	—	—	—	—	14,568	14,568
	Medium	—	—	—	—	14,568	14,568
	Low	—	—	—	—	12,328	12,328
Electric power generation[4]	High	N.A.	N.A.	N.A.	4,878	3,359	10,698
	Medium	N.A.	N.A.	N.A.	4,354	2,982	9,465
	Low	N.A.	N.A.	N.A.	3,951	2,706	8,589
Irrigation	High	42,472	35,526	29,685	716,106	544,298	1,368,087
	Medium	24,890	15,404	29,237	540,537	381,434	991,502
	Low	3,810	32	5,217	48,596	13,869	71,524

[1] Projections for high and medium levels are based on Edgel's population projections. Projections for low level are based on linear 1950-1960 trends in rural population (see Appendix A).

[2] Projections are based on average water withdrawals per $1,000 direct value added.

[3] Medium estimate based on Gilkey and Stotelmeyer's 1980 and 2000 projections, while low estimate takes into account the loss of U.S. Borax Company facilities in Eddy County (see Appendix F).

[4] Projected totals presume all new electric power consumption in the Pecos Basin is generated from steam electric plants located within the basin. The projections are based on estimates made by the Southwestern Public Service Company (see Appendix G).

Table 12. Consumptive use projections by sector and county for 1980, Pecos Basin, New Mexico.

		County					
Sector	Level of Projection	San Miguel	Guadalupe	De Baca	Chaves	Eddy	Total
				(acre-feet per year)			
Municipal[1]	High	2,048	336	176	12,699	6,383	21,642
	Medium	1,313	241	122	9,445	4,329	15,450
	Low	695	151	84	5,327	2,534	8,791
Rural domestic[2]	High	624	120	91	1,427	855	3,117
	Medium	443	86	64	1,036	622	2,251
	Low	307	60	46	734	440	1,587
Manufacturing[3]	High	10	—	—	131	871	1,012
	Medium	7	—	—	95	591	693
	Low	6	—	—	91	442	539
Mining	High	—	—	—	—	N.A.	N.A.
	Medium	—	—	—	—	N.A.	N.A.
	Low	—	—	—	—	N.A.	N.A.
Electric power generation	High	N.A.	N.A.	N.A.	1,615	1,102	3,510
	Medium	N.A.	N.A.	N.A.	1,473	1,008	3,201
	Low	N.A.	N.A.	N.A.	1,361	932	2,959
Irrigation	High	11,936	7,555	13,385	291,918	243,952	568,746
	Medium	6,461	6,749	11,260	211,868	138,805	375,143
	Low	1,353	29	1,717	13,785	4,542	21,526

[1] High, medium, and low withdrawal projections minus low, medium, and high return flow projections, respectively.

[2] Consumptive use coefficients of 35, 40, and 45 percent were assumed.

[3] Average United States consumptive use proportions of total intake for 1959 were applied here. These consumptive use proportions were 7.9, 5.5, and 9.7 percent for SIC industries 20, 28, and 32, respectively.

Table 13. Consumptive use projections by sector and county for 2000, Pecos Basin, New Mexico.

Sector	Level of Projection	San Miguel	Guadalupe	De Baca	Chaves	Eddy	Total
		(acre-feet per year)					
Municipal							
	High	6,360	802	508	22,138	14,857	44,665
	Medium	4,431	532	285	15,486	8,980	29,714
	Low	3,863	314	217	9,785	4,332	18,511
Rural domestic[1]							
	High	1,046	245	202	2,411	1,384	5,288
	Medium	722	172	141	1,698	975	3,708
	Low	0	9	12	846	234	1,101
Manufacturing							
	High	25	—	—	436	3,187	3,648
	Medium	13	—	—	286	1,534	1,833
	Low	10	—	—	245	869	1,124
Mining							
	High	—	—	—	—	N.A.	N.A.
	Medium	—	—	—	—	N.A.	N.A.
	Low	—	—	—	—	N.A.	N.A.
Electric power generation							
	High	N.A.	N.A.	N.A.	3,878	2,655	8,430
	Medium	N.A.	N.A.	N.A.	3,431	2,349	7,458
	Low	N.A.	N.A.	N.A.	3,113	2,132	6,768
Irrigation							
	High	12,911	15,590	14,946	343,484	273,798	660,729
	Medium	6,910	6,760	14,819	257,887	191,869	478,245
	Low	1,773	29	2,428	16,572	4,623	25,425

[1] Projections for high and medium levels based on Edgel's population projections. Projections of low levels are based on linear 1950-1960 trends in rural population (see Appendix A).

Summary Description of Requirements Projections

High, medium, and low projections of water withdrawals for 1980 are substantially above 1960 estimates for all sectors except mining and the low projections for irrigation and rural domestic use. The municipal, manufacturing, and high or medium irrigation projections for 1980 contain the largest absolute magnitudes of increase in water withdrawals. For the municipal sector an increase in requirements of approximately 10,000 to 16,000 acre-feet per year is forecast. For the manufacturing sector positive changes in requirements of about 7,000 to 16,000 acre-feet per year are anticipated. The combined impact of the increase in water requirements for the manufacturing and municipal sectors only raises the total of these two sectors' withdrawals from less than 5 percent to no more than 10 percent of total 1960 basin withdrawals. In fact, the sum of the 1980 high projections for all sectors except irrigation still accounts for less than 16 percent of total 1960 withdrawals and

Table 14. Water withdrawals and consumptive use projections by county for 1980 and 2000, Pecos Basin, New Mexico.

County	1980 Level of Projection High	1980 Level of Projection Medium	1980 Level of Projection Low	2000 Level of Projection High	2000 Level of Projection Medium	2000 Level of Projection Low
	(acre-feet per year)			(acre-feet per year)		
Withdrawals						
San Miguel	45,802	26,337	6,249	53,778	33,313	9,937
Guadalupe	33,124	16,210	664	37,605	17,166	1,237
De Baca	27,574	23,205	4,012	31,033	30,302	5,935
Chaves	652,787	479,428	62,322	775,026	591,211	93,110
Eddy	533,421	316,470	45,428	649,330	450,987	63,715
Total	1,292.708	861.650	118,675	1,546,772	1,122,979	173,934
Consumptive use						
San Miguel	14,618	8,224	2,361	20,342	12,076	5,646
Guadalupe	8,011	7,076	240	16,637	7,464	352
De Baca	13,652	11,446	1,847	15,656	15,245	2,657
Chaves	307,790	223,917	21,298	372,347	278,788	30,561
Eddy	253,163	145,355	8,890	295,881	205,707	12,190
Total	597.234	396.018	34,636	720.863	519.280	51,406

Table 15. Estimated percentages of total water withdrawals required by particular sectors, by county, based on medium projections[1] for 1960, 1980, and 2000, Pecos Basin, New Mexico.

	County and Year														
	San Miguel			Guadalupe			De Baca			Chaves			Eddy		
Sector	1960	1980	2000	1960	1980	2000	1960	1980	2000	1960	1980	2000	1960	1980	2000
	(percent)			(percent)			(percent)			(percent)			(percent)		
Municipal	13.0	13.0	21.0	6.0	4.0	8.0	1.0	1.0	1.0	3.0	5.0	7.0	3.0	4.0	5.0
Rural domestic	3.0	4.0	4.0	2.0	1.0	3.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Manufacturing	0	0	1.0	–	–	–	–	–	–	1.0	1.0	1.0	1.0	1.0	6.0
Mining	–	–	–	–	–	–	–	–	–	0	–	–	6.0	5.0	3.0
Electric power generation	1.0	N.A.[2]	N.A.	1.0	N.A.	N.A.	0	N.A.	N.A.	1.0	1.0	1.0	0	1.0	1.0
Irrigation	83.0	83.0	74.0	91.0	95.0	89.0	98.0	98.0	98.0	94.0	92.0	90.0	89.0	88.0	84.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Medium Projections, as recorded in tables, 8, 10, and 11.

[2] Since estimates were unavailable for 1980 and 2000, electric power generation withdrawals were not included in the estimate of total withdrawals. This leads to a slight upward bias in the other estimates of proportions.

for the year 2000 the sum is less than 28 percent of 1960 withdrawals.

The orders of magnitude of projected 1980 withdrawals in relation to 1960 withdrawals indicate that competition for existing supplies will not become a serious problem in the Pecos Basin for at least several decades. This conclusion, however, is based on the premises outlined previously and in Appendices A through G.

In table 14, projections of water withdrawals and consumptive use for the entire Pecos Basin Five-County Area are presented. The medium projections for water withdrawals indicate water requirements may increase by approximately 3.7 percent per year on the average to 1980, and also by about 3.7 percent per year between 1980 and 2000. Medium consumptive use projections indicate an average rate of growth slightly less, approximately 3.6 percent over the intervals 1960-1980, and 1980-2000.

Earlier it was conjectured that competition for water between major sectors would be unlikely to arise even over the next two decades or more. The conjecture was based on the finding that, given the medium sectoral water projections, no sector except irrigation would increase to the point of requiring more than 8 percent of total water requirements, with the exception of the municipal sector in San Miguel County (see table 15). And, in most counties, irrigation requirements will continue to account for more than 85 percent of total water requirements through the year 2000.

The requirements projections, taking little or no account of potential and existing scarcities and increasing relative costs of water, provide two preliminary premises regarding future water uses in the Pecos Basin Five-County Area. First, intersectoral competition for water will not be acute, provided the impact of increasing scarcity of ground water is not unduly rapid. Second, future water requirements for all sectors, including irrigation, can easily increase by more than 44 percent between 1968 and 1980, with irrigation accounting for the largest absolute increase in water requirements. However, the increase is predicated on the assumption of no change in costs or in technologies of application, or in significant upward or downward changes in the Pecos Basin's comparative advantage as an irrigated crop-producing area. The findings on intersectoral competition are predicated on the assumption of no radical change in the current proportional composition of output-generating activities between sectors and that no new important water-using sectors will emerge.

Section II

INTRABASIN WATER REALLOCATION

Chapter 5

INTRABASIN WATER TRANSFERS: AN INTRODUCTORY STATEMENT

Intrabasin water transfers involve the study of legal and institutional barriers to transfer, the physical and hydrological aspects of transfer, and consideration of economically feasible and efficient transfers. In this report the analysis is primarily focused on feasible and efficient transfers, although physical and hydrological aspects are not entirely omitted.

The study of feasible and efficient water transfers involves four important, interrelated components: 1) potential changes in time rates of use of stock water resources, where the emphasis is on transfer between points in time rather than between competitive users; 2) potential transfers from "low value" to "high value" uses within particular sectors—for example, transfers from one irrigated crop to another produced on the same acreage; 3) water transfers between sectors—that is, water shifted from agriculture to manufacturing sectors; and 4) transfers between geographical locations within the basin. In devising an optimal transfer policy, one must develop a model containing these four components. This is done in chapter 7, but a brief discussion of each component in isolation will be included here to offer a setting and flavor to the following analysis and to underscore the significance of studying these four components.

Water Transfers Through Time

The aggregate of water supplies in the Pecos Basin is currently derived from three interconnected sources: surface flows from the Pecos River and its tributaries, shallow aquifer pumpage, and deep or artesian aquifer pumpage. For surface water flows, transfer through time is not a relevant alternative unless expansion of existing or development of new water storage facilities is contemplated. Water transfers through time involve the time pattern of "stock resource water" use supplied from natural or artificial storage—a supply that, for all practical purposes, can be used up. To present the basic elements of "stock" water transfers through time, a model first proposed by M. M. Kelso(24) for Central Arizona will be applied to the Pecos Basin.

Kelso bases his analysis on the reasonable assumption that, once the net returns to farmers per acre-foot of water, excluding water costs, are less than the total pumping costs per acre, farmers will stop irrigating their crops. He also assumes that pumping costs are proportional to the depth of pumping. Given a relationship between amount of water pumped and the increase in pumping depth, Kelso is able to derive the number of years irrigation will continue, given current rates of withdrawals. He applies this formulation to an entire sub-basin by assuming that current effective pumping depth is uniform across the sub-basin, and also that the aquifer is deep enough so that economic depth limits appear before hydrological depth limits(24). The hydrological and economic limits to depth of pumpage in the shallow aquifer for the Pecos Basin may individually, or in combination, be binding to deeper pumpage, depending on location (see chapter 7, shallow aquifer depth constraints). However, for expositional purposes, it is assumed that no hydrological or physical constraint impedes shallow aquifer pumpage.

First, assume that net returns per acre-foot of water per acre in agriculture are approximately \$9.00 in the Pecos Basin. Secondly, assume that pumping costs, including amortized pump costs, per acre-foot of pumpage per foot of well depth are approximately \$0.02 to \$0.025[1]. Then the hypothetical break-even point of depth for farmers will be within the range of 360 to 450 feet, depending on whether the pumping cost estimate of \$0.025 or \$0.02 was assumed. Given the approximate average pumping depth of 217 feet, this leaves 143 to 233 feet of economic pumping depth remaining. Over the 22 years preceding 1969, wells increased in depth by about two feet per year in certain locations within Chaves and Eddy Counties. Thus, at current pumping rates, assuming linearity between withdrawals and pumping depth, the future economic life

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[1] Average well depth in Chaves and Eddy Counties was 217 feet, and average total cost of pumping 300 acre-feet was \$1,697. Thus, cost per acre-foot per foot of pumping depth was approximately \$0.02 (29).

span of irrigation pumpage from shallow aquifers ranges from 72 to 117 years.

The application of 25 percent less water per acre, from 3.9 to about 3.0 acre-feet per acre, may only reduce net returns by approximately $1.00 per acre-foot. Also, it has been estimated that depth of aquifer changes at a maximum of one-half foot per acre-foot of withdrawals. By reducing applications 25 percent the economic depth decreases to 400 feet, but the economic life span increases from 117 to 136 years. Reducing the rate of withdrawals extends the economic life span of irrigation from shallow aquifer sources. Given a social rate of discount so that extension of economic life span can be compared with higher current net returns, the decision whether to maintain the current rate of pumpage or reduce it by 25 percent can be rationally made. The comparison is between receiving $9.00 per year for 117 years or $8.00 per year for 136 years, each discounted to present value utilizing the social rate of interest. If the social rate of interest is above 0.5 percent, the policy of maintaining current withdrawals yields a greater present value of discounted net returns to farmers, given the hypothetical relationships assumed here.

Intrasector Water Transfers

In the preceding section, water transfers through time were briefly analyzed where the group of users was assumed to be homogeneous as regards the value of water and costs. This section will briefly explore feasible transfers of water within sectors. Table 6 in chapter 2 contains estimates of direct value added per acre-foot for field crops which range from $104.00 for cotton to $29.00 for barley. Thus, on the average, an acre-foot of water transferred from barley to cotton would yield more than $70.00 of additional basin gross product—that is, the sum of direct value added by sectors within the basin, by definition, equals gross basin product. However, it must be assumed that the transfer is not restricted by federal cotton allotment or feed grains programs, and also that the transfer does not affect prices or costs of either field crop.

This type of transfer may also lead to secondary effects on the Pecos Basin's economy. Cotton is apparently not processed beyond ginning in the basin, though barley and other feed grains, for the most part, are fed to feedlot animals within the basin. A transfer of one or more acre-feet from barley to cotton may influence costs and prices of feed grains to feedlots, and therefore indirectly influence the levels of gross basin product.

Appendix H contains a brief analysis of the indirect effects of irrigated acreage changes on the Pecos Basin feedlot industry. Two potential impacts were identified and estimated. Reductions in the production of certain field crops within the Pecos Basin could induce importation of feed produced externally and also reduce the numbers of cattle raised in feedlots within the Pecos Basin. Higher feed costs will induce a loss in comparative advantage for producing fed cattle in the Pecos area, and may cause a shift of production to other areas, resulting in a definite loss in gross basin product. Our estimates indicate value added in the feedlot industry will be reduced by approximately $2.00 to $4.00 per acre-foot reduction of irrigation water applied to feed grains production. If this estimate is even approximately accurate, transference of one acre-foot from barley to cotton production would still increase basin gross product by more than $65.00, utilizing average value added estimates.

An analysis based on incremental value added estimates provides a less clear justification of water transference between, for instance, corn and grain sorghum. The estimates of incremental value added per acre-foot for corn and grain sorghum are $33.00 and $27.00, respectively (see table 6). A gross increase (including indirect impacts) of $31.00 from grain sorghum production is approximately offset by a gross decrease of $37.00 for corn production.

Intersector Water Transfers

Currently, irrigated agriculture utilizes an extremely large proportion of Pecos Basin water supplies, but if the Pecos area undergoes a transformation directed toward industrialization, it may be expected that irrigated agriculture's domination of water use will slowly subside. One aspect of the water transfer problem is the identification of feasible and efficient transfers between sectors. For example, transferring an acre-foot of water from cotton production to the chemicals industry, and assuming this transfer allows expansion within the chemicals industry, on the basis of average direct value added per acre-foot estimates (table 6), can expand the gross product in the basin by approximately $876.00. Utilizing incremental direct value added estimates, basin gross product may potentially contract by more than $55.00 per acre-foot of transference.

Transferring water from alfalfa production to the food products industry apparently is a "better" transfer, both in terms of average and incremental direct value added per acre-foot measures of water value in alternative uses. Applying average direct value added measures indicates that a transfer of one acre-foot from alfalfa to food products (SIC 20) will increase basin product by more than $4,700.00, while incremental direct value added measures indicate, at minimum, a $70.00 increase in basin product per additional acre-foot transferred.

With the aid of the New Mexico Input-Output Table it is possible to partially estimate indirect effects on incomes of all sectors, from selected water transfers between sectors. Hartman and Seastone(20) included the total effects on income due to sectoral interdependencies in a recent analysis of interbasin water transfers. While Hartman and Seastone were concerned with interbasin rather than intrabasin transfers, the indirect effects on basin gross income due to interdependencies between sectors and induced by intrabasin water transfers cannot be omitted from explicit consideration, provided that one is searching for the most desirable transfers where "most desirable" connotes highest level of gross basin product (income).

For water transference between alfalfa and food products (SIC 20), a positive increase of more than $70.00 in direct value added was obtained. The total income multiplier effects of the transfer may be derived from estimates of total income multipliers given in table 5 in chapter 2. Of course, these income impact multipliers are estimated from average income rather than incremental income measures, so that such estimates are likely to be biased upward. For food products, a $1.00 increase in final sales will result in approximately $2.68 change in total basin income. For field crops, the estimate is $1.88. Applying these measures of indirect impact to our estimates of direct effects—that is, an increase of $120.00 in direct value added for food products per additional acre-foot of water, and a decrease of $49.00 for one acre-foot diverted from alfalfa production—a composite net effect on basin income might be nearly $230.00.

Water Transfers Between Geographical Locations

The Pecos Basin, for many practical considerations, can be divided into two parts: 1) an upper basin characterized by relatively low productivity and potential for agriculture, and a very small manufacturing sector; and 2) a lower basin characterized by high-productivity agriculture and a relatively large mining sector. Transfers of water that would allow expansion of particular sectors in the lower basin and contraction in the upper basin could quite conceivably increase gross basin product, although the magnitude of transfers is reduced by losses during transmission, such as evaporation and seepages, and by upper basin return flows that can be or are reused downstream.

To place these ideas within a pragmatic frame of reference, let us analyze briefly the potential transfers from alfalfa in the upper basin to alfalfa in the lower basin. In analyzing only one crop, it is hoped that indirect effects can be assumed to offset one another so that indirect income changes in the upper basin are just compensated by indirect income changes in the lower basin. For comparative purposes, incremental value added in the upper basin per acre-foot reduction for alfalfa will be assumed to equal $13.26[2], though in the basin model developed in chapter 7 a "potential" rather than "actual" incremental value measure was included for the upper basin.

An acre-foot of water applied to alfalfa, transferred from the upper Pecos to the lower Pecos Basin, would yield an approximate increase of $36.00 in basin gross product—that is, assuming upper basin return flows available for reuse in the lower basin were zero. If the proportion of upper basin diversions which can be reused on alfalfa in the lower basin is 20 percent, the approximate increase in basin gross product from such a transfer would be only $26.00[3]. In fact, if the reuse proportion is greater than 75 percent, basin gross product would decline if the proposed water transfer were undertaken.

Little or no evaporation or transmission losses would result if the transfer were completed by use of a pipeline, although costs of pipeline transference would need to be subtracted from the resulting increase in gross basin product. Typical pipeline total costs for transmitting 1,120 acre-feet per year for 100 miles would be approximately $490 per year, or $0.44 per acre-foot, according to Linaweaver and Clark (28). Though this estimate appears to be too low, it does lead to the conclusion that pipeline transmission very well may be a competitive alternative to the Pecos River for transmitting water within the basin when losses from evaporation and seepage are taken into account.

Utilizing the Pecos River or its tributaries as an intrabasin water transfer medium also offers a number of complications not considered in the above example. Downstream transfers create several problems when there are users located between the upstream and downstream points of transfer.

The point made in the paragraphs above may be further demonstrated in a graphic presentation that should serve as sufficient additional clarification.

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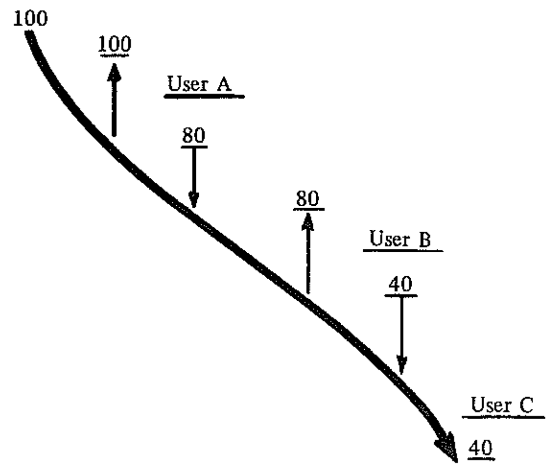
[2] This estimate was arrived at by assuming that the ratio of incremental value added to average value added was identical between the upper and lower basins. Given average and incremental value added for alfalfa of $32.00 and $33.00, respectively, for the lower basin (table 6) and average value added for the upper basin (appendix table J-6) of $12.86, then, for the upper basin, incremental value added is estimated to be $13.26.

[3] This computation assumes return flows from alfalfa in the upper basin are only utilized on alfalfa in the lower basin: $49.00 – $13.26 – .20($49.00) = $25.94. -

For example, then, let current use patterns be as set forth in the diagram below, where total stream flow equals 100 acre-feet per year at the top of the stream and the arrows denote direction of flow. If a transfer of



100 acre-feet is attempted from user A to user C, and user B just maintains current withdrawals at 80 acre-feet, only 20 additional acre-feet will become available to user C. Thus, a complete transfer is not accomplished. Referring to the alfalfa example previously given, one can determine that if user B maintains his pattern of withdrawals at 80 acre-feet, the transfer would lead to higher levels of gross basin product only if user A's return flow coefficient fulfilled the following condition: $.27 < \alpha_A \alpha_B$ where α_i is user i's return flow coefficient[4]. Should user B be allowed to change the amount of his withdrawals, the above allocation condition would also contain the value of water allocated to user B.

It has been shown that, if nonartificial means of water conveyance are utilized, additional problems arise in evaluating the efficacy of water transfers, the principal problem being that the impact of intermediate users (user B) must be taken into account. The complications in this problem are even greater if the prior appropriations doctrine or other water doctrines also influence potential transfers[5].

Water Transfers in a Dynamic Context

The four aspects of intrabasin water transfers that have been briefly described above, although independent of each other as presented, are not independent when one considers water transference within either a comparative static or dynamic general equilibrium framework. In recent contributions to the theory of economic growth, conflicts have been identified between efficient allocations based on the static resource allocation model, and efficient allocations based on most dynamic sectoral-interdependent growth models(3) (36).

The irrigated agriculture sector in the Pecos Basin accounts for more than 90 percent of current rates of depletion or diversion, while the municipal sector currently utilizes less than 3 percent. But, if the Pecos Basin's population and light industry expand, intrabasin transfers from low value agricultural uses to high value municipal uses will need to occur, unless adequate and inexpensive external sources of water are to be found.

The amount of water transferred between the two sectors over time will depend on the growth rate of the municipal sector in relation to the growth rate in irrigated agriculture—that is, assuming municipal values of water remain proportionately larger over time. In this case, emphasis will be on rates of growth in the municipal sector. If the rate of growth in municipal water requirements is constant over time, this would suggest that water transfers need to be made at a continuous rate. However, social costs of transfer may be lower by undertaking water transfers at discrete points in time. This policy may allow a certain portion of basin water sources to remain unutilized as soon as the transfer is culminated, or there might be short-run, planned shortages for the municipal sector. The benefits and costs of each alternative regarding time-related transfers between sectors needs to be computed in order that a suboptimal transfer policy may be derived. Theoretically, the social costs and benefits of potential transfers should be included in a general equilibrium model set forth to analyze water transfers. Yet many of the social costs are in the form of costs of removing institutional and legal barriers to transfer; and these cannot be evaluated at a reasonable cost unless one can identify, *a priori*, the likely pattern of optimal transfers.

Continuing rapid economic growth in many areas of the semiarid West, including the Pecos Basin, will increasingly require transfers of water from sectors or uses with relatively slow or negative rates of growth to sectors with relatively high, positive rates of growth. This assumes that rates of technological change altering water requirements per unit of product do not markedly increase. Conceptually, it is possible for technological change in water use for the rapid-growth industry to be high enough to offset expanding water requirements per unit of product. Also, it is possible for rates of water-related technological change in both sectors to be high enough so that potential rates of growth in each sector are not impeded by water shortages. Within the context of a fixed coefficients production model with technological change constantly reducing water input requirements per unit of product, the increase in the potential rate of growth as constrained by water availability in one sector is proportional to increases in technology in either sector—that is, assuming fixed total water supplies. The magnitude of proportionality depends uniquely on the initial percentages of total water supply used by each sector, and on the differential in rates of growth in the two sectors.

Summary

An attempt has been made in this chapter to offer a simplified description of five major aspects of the intrabasin water transfer problem. The pure timing problem of rates of utilization of stock resources was analyzed in the context of a model developed by Kelso(24). The possibility of water transfer within broad sector classifications, between sectors, and between geographical locations was also examined. Also, one dynamic complication, namely, the timing of transfers between sectors, was briefly discussed. It is evident that none of these aspects of water transfer is independent of the others within the context of water resource basin planning. Complications arise particularly from the simultaneous consideration of conjunctive use of ground water (a stock or non-renewable resource) and surface water (a recurring or renewable resource). Not only does the transfer problem involve consideration of the value of alternative uses for water, but also considerations of timing of the transfer, sequential use, and location. It must be recognized that the above estimates were not based on reliable or necessarily highly accurate data; and further, the examples given were developed for expository purposes and do not represent even *tentative* policy conclusions regarding intrabasin water transfers. However, the examples do offer some justification for considering alternative policies of water transference in the Pecos Basin.

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[4] Applying our estimate of incremental value added in the upper basin of \$13.26 and in the lower basin of \$49.00, and denoting W as initial stream flows and α_i as return flows as a proportion of initial withdrawals by user *i*, the criterion for transfer from user A to C to increase basin product is: $\$13.26W- < \$49.00(\alpha_A \alpha_B W)$ which by cancellation of terms yields $.27 < \alpha_A \alpha_B$. Note that this allocation criterion is independent of the magnitude of initial stream flows, though user B's withdrawals are presumed constant and the criterion is only operative over the range of transfers from A to C where B's withdrawals can remain constant. If user A can negotiate the transfer so that user B cannot withdraw water transferred to user C, the criterion becomes: $\gamma_B \alpha_A + \$49.00(\alpha_B \alpha_A) < \$35.74$, where γ_B denotes incremental value added per additional acre-foot diverted by user B. The allocation criterion becomes more complicated if additional intermediate users are included and where each changes withdrawals as the transfer is undertaken. This is the likely outcome where the prior appropriations doctrine is implemented.

[5] For a clear statement of the problem of markets for water rights and the prior appropriations doctrine within the context of the example given, see Ellis (15).

Chapter 6

PROBLEMS OF VALUATION CRITERIA

Introduction

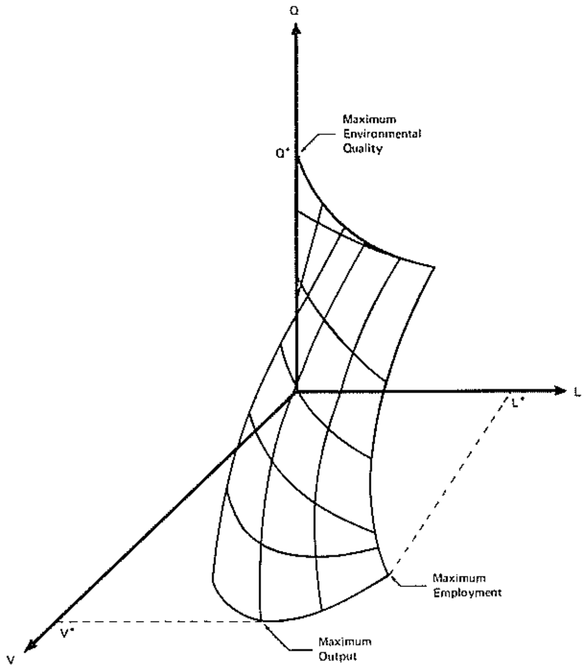
There are at least four identifiable goals associated with intrabasin water transfers in the situation where water, in relative terms, is the assumed scarce basin resource. These goals are to attain: 1) the highest level of gross output consistent with the degree of water shortage (V); 2) the highest rate of growth in output, either on a total $(\dot{V})$ or a per capita basis $\frac{(\dot{V})}{\ell}$; 3) the highest level of employment (ℓ); and 4) the highest level of environmental quality (Q). Needless to say, these goals are not complementary; rather, they tend to be competitive in that to achieve one usually means not achieving one or more of the others. A function relating the potential rates of substitution between goals, however, can theoretically be specified. To make the analysis even more general, let us add two goals: a specific distribution of income (H), and stability of income (K). Then our generalized transformation function for policy purposes becomes:

$$\Phi \; [\; V, \; \dot{V}, \; \frac{\dot{V}}{\ell}, \; \ell, \; Q, \; H, \; K_j; \; W \;] \; = \; 0$$

This function is assumed to be constrained only by scarcity of one resource, water (W). If labor, capital, rates of technological change, or institutional-legal barriers reduce the potential size of Φ in any dimension below that of water, they must also be included.

The problem facing water resource planners is to determine the magnitudes of the coefficients associated with Φ. The economist can only advocate that a feasible and efficient water transfer is one in which the outer frontier of the function, subject to the magnitude of water (W), is achieved. However, only the "body politic" in a democratic society can establish which point on the outer frontier is the "best."

A simplified three-dimensional diagram depicting the outer frontier between maximum employment, maximum gross output, and maximum environmental quality subject to a constraint on water resources is presented at right above. The frontier has been drawn quite arbitrarily to reflect global diminishing returns to labor, and to show zero output as being compatible with maximum environmental quality. This graphic presentation is not necessarily an adequate representation of what the three-dimensional surface would actually be if adequate measurement of this surface were possible, although it quite adequately portrays the difficulties of arriving at a single criterion for evaluation of water transfers.



In lieu of adequate knowledge on the potential for trade-off or transformation between the three alternative goals or the eight goals initially specified in the functional relationship for the model developed in chapter 2, the single goal of maximizing gross output will be chosen. In the opinion of the investigator, this single goal is not entirely acceptable but, for purposes of analyzing water transfers it at least insures that the optimal transference obtained will be on the frontier of the Φ transformation function. As improved methods are found for evaluating the Φ function, initial policy recommendations can be amended. It, therefore, is imperative that policy recommendations based on the single goal of maximizing gross output should be qualified by the extent of flexibility between this goal and other goals associated with optimal and nearly optimal policies of water transfer.

The limitations inherent in presuming the single goal of maximizing gross output are quite obvious, but the writer believes that establishing a clearly defined criterion, with its obvious inherent limitations, is preferable to only a reference to "willingness to pay"(13), or gross output (value added)(21) as the appropriate criterion.[1] Alternative criteria applicable to water transfers, but derived for investments in underdeveloped economies, are briefly examined in the section below. The assumptions necessary to justify the criterion adopted for this study are also analyzed.

Water Transfer Criteria

Admitting the possibility for potential water transfers which may lead to a more efficient utilization of Pecos Basin water resources indicates the conviction that the assumptions characterizing a perfectly competitive world are, in part or totally, violated. Technological external economies or diseconomies (26), institutional or legal barriers to water transfers, lack of an adequate market for water rights(15), lack of information, or other such factors can impede the achievement of a static optimal allocation of scarce water resources.

Within the context of a nonstatic basin—that is, a basin undergoing changes in economic conditions such as changes in sectoral independence as sector growth occurs (or structural and institutional changes)—water allocations based on the static competitive model, in most cases, would not even be efficient. Chenery (3, p. 128), in discussing the relationship between comparative advantage and growth models, writes: "The net effect of the discussion of dynamic interdependence and balanced vs. unbalanced growth is to destroy the presumption that perfect competition, even if it could be achieved, would lead to the optimal allocation of resources over time."

Sequential and time-related interdependencies between competitive water users is one of the most important economic facets of the water allocation problem. Very rarely can the utilization of water resources be studied without first analyzing the implications of the more general problem of "commonality" or interdependence of resource use. An upstream water user's return flows may in part be reused by competitive users downstream. The rate of depletion, and thus the time rate of use, of aquifer water storage when all are using it, depends exclusively on each user's rate of depletion. Thus, even within the context of an otherwise perfectly competitive market-oriented economy, water, from the historical patterns of use that have evolved for it, exhibits conditions that violate the assumptions necessary to yield optimal patterns of resource utilization in a static competitive framework.

Criteria for evaluating water transfers imply the development of rules for deciding which patterns of transfers, including zero transfers, are "better" than others. A particular set of valuation weights for alternative transfers must be chosen in order that a "better" transfer becomes identifiable.

Hartman and Seastone(18, p. 165) state, "the growth of a region requires transfers of water resources from lower value uses to higher value uses." They do not explicitly define "value" in the above context, but they do hint that, in efficiency terms it is analogous to the "value of the marginal product from the resource"(18, p. 167). Kahn has suggested a criterion based on the social marginal productivity of capital for investment programs with specific reference to underdeveloped countries where capital is assumed to be the scarce resource. Kahn's criterion is to maximize the social marginal productivity of capital (23). Accordingly, one should take a measure of gross output—that is, value added—resulting from each alternative investment or combination of investments, and subtract the "social opportunity cost" of labor to produce it (36, p. 15). Then, the combination of investments yielding the greatest difference between output generated by the investments and the "social opportunity cost of labor" should be chosen.

Given fixed coefficient production technologies, relative scarcity of water in relation to other resources, and therefore zero "social opportunity costs of labor," the Kahn criterion would simply be to maximize value added or gross output, subject only to the constraint on water—that is, equate marginal value added per additional acre-foot of water across all competitive sectors or uses. This criterion was applied in a more general form to allocating "newly discovered water resources" in a study conducted by Wollman for the Rio Grande Basin in New Mexico(43). The assumption of value added or gross output as the appropriate measure of value is utilized in the allocation model presented in chapter 7.

Eckstein has extended the Kahn social marginal product criterion to time-related or dynamic investment decisions(12). He suggests that the appropriate criterion for selecting between alternative investment projects is to choose those projects that maximize "the present

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[1] The "net benefit" criterion normally utilized in water resource planning, defined as total benefits less total costs, coincides with the value added (or gross output) criterion only if technologies are of the fixed coefficient type, if water is the scarce resource so that opportunity costs of other resources are zero, and if no intermediate products enter the production process, or if by chance the excess of benefits over costs just equals direct value added. Direct value added equals the value of gross output less the value of intermediate products, while "net benefit" equals the value of gross output less *all* costs, including the value of intermediate products.

value of the future consumption stream," subject to production technologies, and a capital or investment constraint(12, p. 68). This slightly more general criterion takes into account differences that may evolve between immediate levels of production and consumption for alternative projects, due to the assumption of differences in reinvestment as a proportion of national income generated by the project. Thus, while one project may have a higher ratio between output generated and the initial investment (or water transfer), the project may also have a lower reinvestment rate for income generated and may thus contribute less to future levels of production and consumption.

In this study it will be assumed that intrabasin reinvestment as a proportion of basin income generated by water transfers is identical for all sectors. This assumption allows one to utilize only marginal value added product per additional acre-foot as the appropriate valuation coefficient for water transference. Otherwise, what Eckstein refers to as the "marginal growth contribution" from alternative reinvestment rates in each sector must also be included (12, p. 68). It is also assumed that the discounted sum of future consumption coincides with the discounted sum of future production.

The Marginal Value Added Criterion and Intertemporal Reallocation

In chapter 7 a model is constructed where marginal value added for each additional acre-foot by sectors is applied as the value weight to achieve an optimal reallocation of basin water resources. Marginal (or incremental) value added is defined here as the change in value added in a particular sector or subsector, given a one-acre-foot change in water diverted to or from the sector. If sector A were to contribute an additional $70.00 to basin product by being allotted an additional diverted acre-foot of water, and if sector B's contribution to basin product were reduced by $50.00 per acre-foot through diversions to sector A, clearly basin product would be increased by a transfer from B to A. However, in analyzing potentially large inter-sector transfers, the question arises whether the marginal value added measure will change significantly. Of course, given constant marginal value added measures means that marginal and average value added measures coincide, and there is no purpose in attempting to apply marginal concepts.

Two considerations arise as regards the acceptability of average versus marginal value added measures as value weights. First, the type of distribution of water reductions or increases between the users within the sector influences the selection of "value weights." If, for example, water withdrawn from the irrigated agriculture sector is obtained by elimination of entire farm units, average as distinct from marginal value added would probably be the better measure of the reduction in basin product (value added). Alternatively, if water were withdrawn in small amounts from all farm units, marginal value added would undoubtedly be the more appropriate loss in value measure. Second, the rapidity of water transfers also influences the appropriateness of marginal versus average value added measures for reallocating water resources. For example, a very rapid and/or large intertemporal transfer of basin water resources would most certainly necessitate the application of average value added measures. Yet, changes in value added from slower rates and magnitudes of transfer may more closely approximate marginal value added measures.

In this study, marginal value added weights were selected because of the *a priori* belief that intertemporal transfers would be relatively slow and of small magnitude. Also, it was assumed that transfers to and from sectors would have the largest impact on basin product if the reductions or increases were distributed among all firms via the assumption of global diminishing productivities of diverted water. However, this assumption may not be valid if "new" firms or farms emerge, or if there are wide discrepancies of water productivity between firms or farms producing similar or identical products.

In our model the starting point for deriving optimal intertemporal reallocations was the current distribution of water resources between competing users and competing geographic areas. The procedure of starting with current actual allocations might be different from starting from optimal allocations because current use patterns are usually not optimal. Attempting to achieve a current optimal allocation and then searching for an intertemporal optimal reallocation is a special case within the context of the model which follows. One alternative reallocation policy in the model is to immediately reach an optimal basin allocation in the first time period specified by the model, but this policy may not be the best intertemporal policy in terms of maximizing value added[2]. Social external costs of rapid and/or large water transfers may be exceedingly high so that a slower rate or magnitude of transfer would increase basin value added.

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[2] In the actual model, rates and magnitudes of transfer are constrained both in an upward and a downward direction to take into account social external costs involved from unduly rapid water transfers between sectors. In addition, the model is run without these constraints to determine their cost and impact on reallocations.

Chapter 7

AN INTRABASIN WATER REALLOCATION MODEL

A model is developed in this chapter so as to prescribe certain policy recommendations regarding water transference within the Pecos Basin Five-County Area. The model is of the linear programming type, containing an explicit objective function and a set of constraints on water-related activities. The major competitive water-using sectors, briefly described in chapter 2, provide a base upon which the model is developed.

Model Characteristics

In this section the important properties and assumptions of the preliminary programming model are set forth. The model was designed so that hydrological data and relationships need not be entirely known. Complex hydrological systems, such as the Pecos Basin where surface flows interact both with shallow and deep aquifers, may in time be amenable to model simplification. But at this juncture the apparent large magnitudes of error associated with defining complex hydrological systems indicate that models constructed to study economic potentialities for water transfer should include only a minimal number of physical relationships. Ciriacy-Wantrup(5), alternatively, has suggested that models should be designed to emphasize hydrological relationships, in reference to the models constructed by Dorfman and Tolley(5). However, the hydrological or physical relationships to which Wantrup undoubtedly referred were of the measurable type—such as in Dorfman's model where reservoir inflows, plus storage minus evaporative losses, must be greater than outflows for each time period (11). The degree of error in measuring this type of physical relationship is quite small but this is not true, for example, for leakages between shallow and deep aquifers, or for estuarine flow patterns.

The implications of these informational constraining factors for intrabasin water resource planning, at least in its present state of development, are particularly conclusive. Planning models that are to contain the required economic data inputs need to be designed to encompass political subdivisions. And unless these subdivisions are in substantial accord with important hydrological and geological subdivisions, and unless the degree of error in identifying hydrological relationships is small, it would appear that the emphasis on economic relationships would be necessary for useful preliminary planning to emerge. This emphasis on economic relationships hinges on whether hydrological-geological divisions can, with some degree of realism, either be omitted entirely, or condensed within a general functional form, and whether the general functional form can be tested by way of sensitivity analyses over a wide enough range to include supposed limits on the hydrological-geological structure.

Mixing Requirements and Value Approaches in Water Resource Planning

Two approaches have emerged in projecting future water use: the requirements approach, and the productivity or demand approach(35). Water requirements are usually developed on the basis of assumed fixed relationships between water and one or several other variables, usually population, employment, or gross output (value added) (6) (41). The productivity or demand approach relates water use to water costs through the traditional economic models of firm or industry behavior(7) (35), or consumer demand(22) (33).

The activity analysis model for water transfers presented here makes use of characteristics of both approaches. Water transfer problems involve at least three major considerations: the type of water transfer, the location where the transfer is culminated, and the timing of transfers between sectors. One important use of the requirements approach is to establish probable upper and lower limits to future changes in water use by sectors. This approach allows the direction of broad policy objectives to be set forth and provides guidelines for feasible water transfers. For example, the food products industry (SIC 20) within the Pecos Basin Five-County Area accounted for less than 2 percent of total water withdrawals in 1960 (see table I). It is unlikely that within the next several decades the food products industry could utilize a very large percentage of PBFCA water resources. Yet, an allocation model with no constraints on water transference would probably allocate much of PBFCA water resources to the food products industry. Thus, exogenous projections of maximal future water requirements in this industry provide an upper limit to potential transfers to it.

Examples of other limitations on potential transfers between sectors or within sectors are: the federal cotton acreage allotment program which is restrictive on planted-cotton acreage; total irrigated acreage in each location; and maximum potential growth rates in urban and rural population and commercial enterprises located within municipalities. Each of these upper limits places constraints on the potential for water transfer to the sector with growth limitations. Transfers are not only constrained by upward limits but also by lower and possibly negative growth limits. Rapid rates of transfer may induce large social costs from immobility of labor and capital equipment. For example, a 50 percent reduction in alfalfa production may cause widespread unemployment within the irrigated agricultural sector if the percentage reduction is attempted over a one-year interval, though such unemployment may not arise if the time interval of reduction is extended to 10 years.

The following model includes both upward and downward constraints on rates of transfer to and from particular sectors. In some cases the constraints were related to particular exogenous forecasts of requirements, and in other purely intuitive transfer constraints were assumed. The subjectively established constraints were varied over a relatively wide range to check their impact on the solution of the model.

Underlying Assumptions

The Pecos River Basin, in terms of both hydrological and economic relationships, is much too complex to be easily expressed in model form. Consequently a rather large number of simplifying assumptions were made in order to make the model operational, and they are tabulated here.

1. It was assumed that, for planning purposes, the hydrological relationships between surface flows in the Pecos River, shallow aquifer depth of pumping, and deep or artesian aquifer depth of pumping could be satisfactorily omitted from explicit consideration. For planning units smaller than the basin level studied here, it would seem imperative to include such relationships. By this omission we are implicitly assuming, regardless of the amount of water transference either between locations or between sectors, that the historical relationships between shallow aquifers, deep aquifers, and surface flows will not markedly change.
2. The set of valuation weights to compare water transfers between competitive-complementary sectors is *incremental* direct value added per acre-foot of diverted water. The appendices contain estimates of incremental (marginal) direct value added for selected irrigated crops by county, soil class, and water salinity. Also, incremental value added estimates for selected SIC 2-digit industries are provided in the appendices. It was assumed that incremental value added was large enough in municipal uses, rural domestic uses, mining uses, and electric power generation, to preclude comparison with manufacturing or irrigated agriculture (see table 6).
3. It was assumed that recreational benefits would not markedly change from alternative water transfers within the PBFCA. Further, no explicit attention was given to operating policies of the several dams within the Pecos Basin as regards facilitating or impeding water transfer. Given the planning interval of one year applied here, this assumption may be less important than it first would appear to be.
4. There was no consideration of the impact that water transference may have on provisions of the Pecos River Compact between New Mexico and Texas.

Symbol Definitions

Variables and Parameters

F - Total irrigated crop acreage in acre units.

H - Pumping depth in shallow aquifer (in feet).

M_m - Consumptive use of surface water by certain high-value uses such as municipalities in reach *m* (in acre-feet).

R - Net returns to land and management per acre, excluding costs of pumping irrigation water.

V_m - River flows [mean of yearly average flows] at the beginning of reach *m*, including tributary flows not previously included (in acre-feet).

W_m - Water withdrawals in reach *m* (in acre-feet).

X_ℓ - Direct value added by any particular industry ℓ.

Coefficients

α_ℓ - Return flows to the Pecos River or tributaries as a proportion of initial withdrawals from surface sources.

β_ℓ - Quantity of surface flows in units of acre-feet required to dilute one acre-foot of return flows from sector or industry ℓ, so that minimal state water-quality standards are met.

γ_ℓ - Value added in industry ℓ per acre-foot of withdrawals by industry ℓ.

ϵ_m - Cost of pumping, including amortized installation costs and depreciation per acre, per foot of pumping depth.

η - Maximum annually compounded rate of growth in average pumping capacity for shallow aquifer wells, plus the maximal rate of growth in number of new shallow aquifer wells.

π - Reciprocal of maximum water requirement in acre-feet per acre for irrigated crops.

ρ_ℓ - Change in potential value added (incremental value added) in sector ℓ from a change of one acre-foot allocated to or from sector ℓ.

ψ - Discount factor appropriate for obtaining the present value of future production or value added.

Ω - Maximum annually compounded rate of growth in average pumping capacity for artesian wells, plus the maximal rate of growth in number of new artesian wells.

ω_ℓ - Maximum annually compounded growth rate in potential for transfers to or from sector ℓ.

Subscripts

j - Irrigated land quality, as specified by soil classes (see Appendix J).

k - Source of water; i.e., surface supply k=1, shallow aquifer supply k=2, and artesian aquifer supply k=3.

ℓ - Type of use for water; i.e., SIC 2-digit industry classification, or type of irrigated crop, such as cotton or alfalfa.

m - Location or reach where water is allocated between uses.

t - Allocation time unit, here assumed to be one year.

Superscripts

a - Refers to discrete points of linear segmented relationship between shallow aquifer withdrawals and pumping depth.

Objective Function

The initial planning objective outlined previously was to reallocate existing stock and flow water sources between competitive users so as to maximize value added (gross output) of the Pecos Basin. The objective function, given this assumption, can be expressed as follows:

$$\max.\ \phi = \sum_{t=1}^{\tau} \sum_{m=1}^{\theta} \sum_{\ell=1}^{\lambda} \sum_{k=1}^{\kappa} \sum_{j=1}^{\iota} \psi_t \, \rho_{k\ell mt} \, W_{k\ell mt}$$

where ρ is incremental direct value added per acre-foot of withdrawals; ψ, a discount factor equal to $1/(1+r)^t$ where r represents the social rate of discount; t, a time variable; and W is withdrawals in units of acre-feet. Note that, in this model, size of farms is omitted; rather, the question of crop proportions by geographic area is implicitly embedded into the objective function. Also, since the assumed time interval is one year, seasonal patterns of use and return flows are not explicitly considered, though some estimates of potential error introduced by their omission are obtained from the sensitivity analysis discussed later.

A finite time interval for planning the allocation of water resources is assumed in this model and is represented by the sum over τ years. To presume a finite planning interval implies the value of water is zero after the interval, so that as much as possible is allocated within the planning interval, or that some fixed amount of water is available at the culmination of the plan, which may be introduced in the form of a constraint.

Applying a positive discounting factor, however, almost precludes the allocation of existing stocks, but not flows, beyond a certain finite point in time. For example, a 5 percent rate of social interest will reduce the value added weights by more than 80 percent over an interval as short as 50 years. Thus, while a finite planning horizon is embedded into the structure of this model, it would appear reasonable to assume the potential error in allocating water stocks on this basis would be of little consequence.

The objective function, while being complete in terms of potential alternative reallocations between categories of water use, in dimensional terms is much too large for computational ease. If, for example, there are only three categories within each summation sign except for time, and the time horizon is assumed to be more than 50 years, then there will be at least 4,000 alternative withdrawal variables. In the discussion on preliminary applications of the model, certain simplifications will be applied to partially resolve the "size problem" encountered in the above objective function.

Constraints

Surface Water Constraints

In order to study the potential for intrabasin transfers of surface water, mainly along the Pecos River and its tributaries, a set of constraints between surface sources and potential uses must be established. It is assumed that return flow coefficients for each use are constant regardless of the magnitude of withdrawals, though this assumption can be dropped if the nonconstant relationship between withdrawals and return flows can be divided into linear segments. To further simplify, it is assumed that evaporation losses are unrelated to the magnitude of withdrawals by location. With these assumptions, a set of surface flow withdrawal constraints can be generated:

$$\sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} W_{j1\ell1t} \leqslant V_{1t} - M_{1t} \qquad t = 1, 2. \dots \tau$$

$$\sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} W_{j1\ell2t} \leqslant V_{2t} - \sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} (1 - \alpha_{\ell1t}) W_{j1\ell1t}$$

$$-M_{1t} - M_{2t} \qquad t = 1, 2 \dots \tau$$

$$\vdots$$

$$\sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} W_{j1\ell mt} \leqslant V_{mt} = \sum_{m=1}^{\theta - 1} \sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} (1 - \alpha_{jk\ell mt})$$

$$W_{j1jk\ell m\text{-}1t}$$

$$- \sum_{m=1}^{\theta} M_{mt} \qquad t = 1, 2 \dots \tau$$

Two additional problems arise in utilizing this particular constraint set. First, municipal uses as they change over time will have different return flows, yet no return flows or depletion from this source is included within the model. To take this into account, the magnitudes of the $M_{\ell t}$'s are adjusted, both over time and by location, to include estimates of depletion and return flows for municipal uses.

The second problem is determining the initial values of V_{mt} for programming purposes. Since this model is deterministic in construction, average river flow data provide the initial estimates of V_{mt}; but, due to the inclusion of return flows, the downstream figures for V_{mt} must be adjusted for return flows from upstream uses. However, the river flow data, unadjusted for upstream return flows, already contain tributary flows and evaporation losses, except for evaporation losses between gauging stations and sites of particular users.

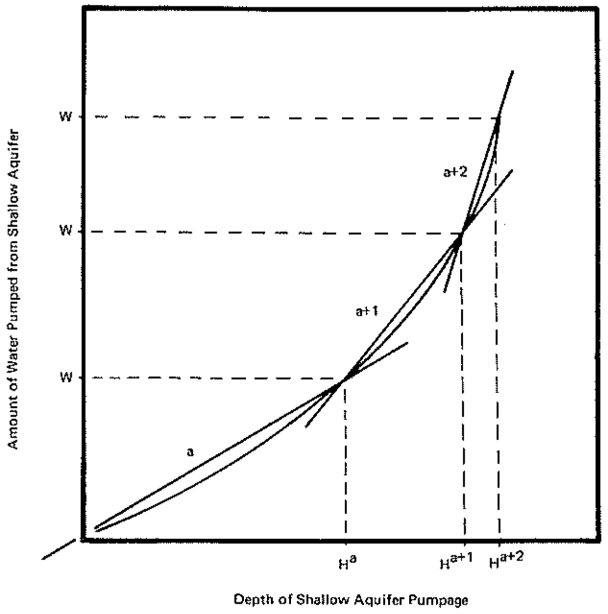
Shallow Aquifer Constraints

Let E_m^a denote the change in shallow aquifer depth in feet per acre-foot of shallow aquifer withdrawals over the range of depth *a*. A hypothetical example of how E_m^a normally changes with increasing depth of withdrawals is depicted in the diagram below. Also, the segments *a* are sketched in that approximate *E* over the range of *a* from zero to *a*, *a* to a+1, and a+1 to a+2.

Where *E* is a constant over the range from zero to a+2, water from the shallow aquifer has uniform depth by location, the physical constraint on pumping becomes:

$$E_m \sum_{t=1}^{\tau} \sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} W_{j2\ell mt} \leqslant H_m - Z \qquad m = 1, 2 \dots \theta$$

where H_m is the depth of the shallow aquifer in location *m*, and Z is the current pumping depth.



When E_m^a is allowed to vary over a range of three segments (see diagram), the above shallow aquifer constraints must be expanded by two, thus:

$$E_m^a \sum_{t=1}^{\tau} \sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} W^a_{j2\ell mt} \leqslant H_m^a - Z \qquad m = 1, 2 \dots \theta$$

$$E_m^{a+1} \sum_{t=1}^{\tau} \sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} W^{a+1}_{j2\ell mt} \leqslant H_m^{a+1} - H_m^a \qquad m = 1, 2. .\theta$$

$$E_m^{a+2} \sum_{t=1}^{\tau} \sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} W^{a+2}_{j2\ell mt} \leqslant H_m^{a+2} - H_m^{a+1} \qquad m = 1,2. .\theta$$

If return flows to shallow aquifers significantly augment existing shallow aquifer sources, the constraint set previously developed must be altered to include return flows. The empirical estimates of E_m^a, of course, already contain the balancing effects of previous aquifer return flows and aquifer augmentation from surface water return flow seepages. In addition, the empirical estimates of E_m^a contain the augmentation of shallow aquifer water through precipitation recharge.

In order to apply the estimates of E_m^a, one must know the hydrological relationships between shallow aquifer pumping depth, precipitation, and shallow aquifer return flow recharge, or assume the observed relationship in the past will continue into the future regardless of change in pumping depth or magnitudes of surface water recharge of the shallow aquifer.

A second set of constraints also affects the utilization of shallow aquifer water resources; namely, economic limits to the depth of pumping. Net returns per acre for certain crops are, in fact, so low that increasing costs of installation and pumping may exceed net returns when well depths go below a certain limit. Kelso(24) has suggested that, once installation and discounted operating expenses on wells exceed discounted net returns, irrigation from wells ceases on some low net return crops.

The introduction of this constraint tempers the model toward a "mixed" economy type containing both social and private goals, as the objective function stipulates a specific social goal—that is, reallocation to maximize gross basin output. The social objective is constrained in terms of fulfilling a private objective of net returns exceeding zero for all crops.

The constraint set for shallow aquifers in terms of economic pumping depths can be set forth as follows: Let ϵ_m denote total pumpage costs, including amortized pump construction costs plus pump operating expenditures per foot of pumping depth per acre-foot at location *m*. Note that this definition implies total pumping costs are constant per foot of pumping depth. Curvilinear relationships between pumping depth and cost can be accommodated in this model by splitting the relationship into linear segments as was illustrated for the physical depth constraints. The economic pumping depth constraints can be symbolically expressed as:

$$\epsilon_m E_m \sum_{t=1}^{\tau} \sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} W_{j2\ell mt} \leqslant R_m \qquad m = 1, 2. \dots \theta$$

where R_m is net returns per acre to management, excluding water costs in location *m*. Note that R_m in this constraint set must represent the lowest net returns for all uses competing for shallow aquifer sources. But once this constraint becomes binding for the lowest net returns crop, it precludes additional shallow aquifer pumpage for other competitive uses. This problem was partially resolved by iteration of the program, omitting the lowest return crop and changing the R_m whenever this constraint became binding. The final program then prespecifies when certain low value crops will stop being irrigated from shallow aquifer sources. A second problem, that of farmers who continued to irrigate low returns crops because returns covered variable costs, was not resolved. It was assumed here that pumping would cease when total costs, including fixed costs, exceeded net returns.

Shallow aquifer water withdrawals are also constrained by the number of wells, and the average capacity of wells, so that year to year changes in pumpage are limited by new well drillings (capital constraint) and average well capacity changes (a technological constraint). Let η_{2mt} equal the maximum compound rate of growth in shallow aquifer withdrawals. Then η_{2mt} equals the rate of growth in average pumping capacity plus rate of growth in number of new wells.[1]

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[1] Let P_t denote average pumping capacity per well and X_t the number of wells in time period t. Then $P_t X_t = W_t$, where W_t is the amount of withdrawals. Taking the first difference of W_t with respect to time, for small changes in P_t and X_t:

$$W_t - W_{t-1} = X_{t-1} [P_t - P_{t-1}] + P_{t-1} [X_t - X_{t-1}]$$

Dividing both sides by $W_{t-1} = P_{t-1} X_{t-1}$

$$\frac{W_t - W_{t-1}}{W_{t-1}} = \frac{P_t - P_{t-1}}{P_{t-1}} + \frac{X_t - X_{t-1}}{X_{t-1}}$$

the constraint on pumping capacity is expressible as:

$W_t \leqslant (1 + \eta) W_{t-1}$ or if the equality is fulfilled:

$$\frac{W_t - W_{t-1}}{W_{t-1}} = \eta$$

which by the definition given above:

$$\eta = \frac{P_t - P_{t-1}}{P_{t-1}} + \frac{X_t - X_{t-1}}{X_{t-1}}$$

In several counties the number of new wells drilled is restricted to replacement of currently operating wells, which would restrict the maximum potential rate of growth in pumpage to the potential rate of growth in average pumping capacity per well. The set of constraints appropriate for indicating well capacities by area then is:

$$\sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} W_{j\ell mt} \leqslant \sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} (1 + \eta_{\ell mt}) W_{j\ell mt-1}$$

$$m = 1, 2, \ldots \theta \qquad t = 1, 2, \ldots \tau$$

Artesian Aquifer Constraints

Within the Pecos Basin, as within most other river drainage areas, potential artesian aquifer development is neither economically feasible nor physically possible in many geographic areas. Thus, in this model, artesian pumpage is restricted by location. Secondly, certain low-value crops do not yield high enough dollar returns prior to subtraction of irrigation water costs to be economically irrigated with pumped artesian water. The amortized artesian pump installation and operating costs in this case exceed sales revenues less other operating and fixed expenditures. These irrigated crops will arbitrarily be omitted from consideration, as regards irrigation from artesian water sources. However, this constraint is only applicable for *potential* artesian well development and not on farms or within geographic areas where artesian wells are already installed. In this case, installation costs must be viewed as "sunk" or irretrievable costs, so that the relevant comparison becomes net returns and operating expenditures on artesian wells. The constraint set for artesian aquifers is:

$$\sum_{\ell=1}^{\lambda^*} \sum_{j=1}^{\iota^*} W_{jk\ell mt} = 0$$

k = 3
j* Selected low net
ℓ* return crops on particular soil classes.
$m = 1, 2 \ldots \theta$

$t = 1, 2 \ldots \tau$

For the low net return crops being irrigated by existent artesian aquifer sources, let C_{mt} denote water withdrawals from existing artesian wells in location *m* for period *t*. It is assumed that over time C_{mt} will decline as artesian pumping capacity declines. This constraint set becomes

$$\sum_{\ell=1}^{\lambda^*} \sum_{j=1}^{\iota^*} W_{jk\ell mt} \leqslant C_{mt}$$

k = 3
j* Selected low net
ℓ* return crops on particular soil classes.
$m = 1, 2 \ldots \theta$

$t = 1, 2 \ldots \tau$

Changes over time in artesian aquifer withdrawals are limited by changes in average pumping capacity and number of new wells drilled. Constraints on capital expenditures for artesian well development undoubtedly reduce the time rate of expansion in artesian well pumpage. For Chaves County the investment per artesian well ranges from about $8,400 to nearly $15,000, with an average of about $12,000 (29). If an arbitrary limit to new investment in artesian aquifers (k = 3) is established at location *m* for time period *t* equal to A_{3mt}, and a fixed amount of investment is required per new artesian well equal to a_{3mt}, then A_{3mt}/a_{3mt} equals the maximum number of *new* artesian wells in location for period *t*. Assuming that a_{3mt} remains relatively constant over time, *m*, the effective constraint on rates of growth in artesian aquifer withdrawals from new wells is the maximal rate of growth in capital expenditures—that is, $\frac{dA_{mt}}{dt} \cdot \frac{1}{A_{mt}}$ The maximum rate of growth for artesian aquifer withdrawals in location *m* then equals the maximum potential rate of growth in average pumping capacity for artesian wells plus the maximum potential rate of growth in the capital expenditure constraint. Letting Ω_{mt} denote the sum of these two maximum potential rates of growth, the positive constraint in year to year changes in artesian aquifer withdrawals becomes:

$$\sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} W_{j3\ell mt} \leqslant \sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} (1 + \Omega_{\ell mt}) W_{j3\ell mt-1}$$

$$m = 1, 2 \ldots \theta \qquad t = 1, 2 \ldots \tau$$

Other forms of constraints influence the magnitudes of water withdrawals within the Pecos Basin. There are constraints on total irrigable acreage within geographic sub-areas of the Pecos Basin, and maximal growth constraints on industrial production and therefore, by implication, on industrial water withdrawals.

Irrigated Acreage Constraints

To simplify the description of the irrigated acreage constraints, it will be assumed that maximal water requirements by crop, salinity, and soil class are constant through time. However, if measurements of potential future changes in water requirements by crop were available, the following constraint set could be modified to accommodate such changes by introducing time-related coefficients in much the same way as in the nonlinear shallow aquifer relationship previously discussed. Let $\pi_{jk\ell mt}$ denote the reciprocal of water requirements for crop ℓ on soil class *j*, and pumped from source *k* in location *m*, during time interval *t*. Further, let F_{jmt} denote total irrigable acreage of soil type *j* in location *m* during period *t*. Then the total irrigated acreage constraint by location becomes:

$$\sum_{\ell=1}^{\lambda} \sum_{k=1}^{\kappa} \pi_{jk\ell mt} W_{jk\ell mt} \leqslant F_{jmt}$$

$j = 1, 2 \ldots\ldots \iota$
$m = 1,2 \ldots\ldots \theta$
$t = 1, 2 \ldots\ldots \tau$

Industrial Output Constraints

Forecasts of value added by type of manufacturing industry within the Pecos Basin, by location, have been undertaken independently of the reallocations prescribed within the model. The upper limits of these ancillary forecasts of value added provide constraints to anticipated changes in industrial water withdrawals over time. Letting $\gamma_{k\ell mt}$ denote the reciprocal of water requirements per dollar of value added in industry ℓ in location *m* for period *t*, and $X_{\ell mt}$ value added in industry ℓ, at location *m*, for period *t*, the growth constraints for industrial water withdrawals are:

$$\sum_{k=1}^{\kappa} \gamma_{k\ell mt} W_{k\ell mt} \leqslant X_{\ell mt}$$

$\ell = 1, 2 \ldots\ldots \lambda$
$m = 1, 2 \ldots\ldots \theta$
$t = 1, 2 \ldots\ldots \tau$

Water Quality Constraints

Water quality standards for the Pecos River established by the State of New Mexico have been adopted in accordance with the federal Water Quality Act of 1965 (PL 89-234). In addition to a set of general standards on odor, pH range, turbidity, floating solids, color, bottom deposits, toxic substances, and radio nuclides, special standards were also established for temperature, dissolved oxygen, biochemical oxygen demand, coliform organisms, chlorides, sulfates, and total dissolved solids(32). For the most part, both general and specific standards are formulated in qualitative or descriptive terms not amenable to precise quantitative measurement. The specific standards on chlorides, sulfates, and total dissolved solids have been quantified in terms of maximal limits in parts per million (ppm) at varying Pecos River flow levels. Constraints for these three water-quality determinants are set forth below:

$$\sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} (1 + \beta_{j\ell 1t}) W_{j1\ell 1t} = V_{1t} - M_{1t}$$

$$t = 1, 2 \ldots \tau$$

$$\sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} (1 + \beta_{j\ell 2t}) W_{j1\ell 2t} = V_{2t}$$

$$- \sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} (1 - \alpha_{\ell 1t}) W_{j1\ell 1t} - M_{1t} - M_{2t}$$

$$t = 1, 2, \ldots \tau$$

$$\sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} (1 + \beta_{j\ell mt}) W_{j1\ell mt} = V_{mt}$$

$$- \sum_{m=1}^{\theta-1} \sum_{\ell=1}^{\lambda} \sum_{j=1}^{\iota} W_{j1\ell m-1t} - \sum_{m=1}^{\theta} M_{mt}$$

$$t = 1, 2 \ldots \tau$$

The set of water quality constraints developed here requires external analysis and choice of which pollutant will most extensively violate established standards for each source of return flows—that is, require the largest amount of dilution. Then the β associated with that pollutant is utilized for each source of return flows. Also, in deriving the constraint set for water quality above, state stream standards are presumed to be just met, but not exceeded—that is, water quality standards are neither violated nor exceeded at any time. The impact of these restrictions is evaluated by utilizing sensitivity analyses in chapter 8.

The final constraint sets are limitations on the amounts of water transferable between competitive sectors over time. These constraints imply a definite restriction on how rapidly water use may be reduced or increased in any given sector. Transfers to certain sectors have already been constrained through the application of exogenous projections on growth in those sectors. Here we are interested in how rapidly water may be transferred without severe social losses to the basin, including social costs of unemployment of labor and capital, and relocation or migration. Of course, these constraints are almost purely judgmental in character as there is no method of quantifying accurately the requisite coefficients. This constraint set can be written as:

$$\sum_{j=1}^{\iota} W_{j\ell mt} \leqslant (1 + \omega_{\ell mt}) \sum_{j=1}^{\iota} W_{j\ell mt-1} \qquad \begin{matrix} \ell = 1,2 \,.\,.\, \lambda \\ m = 1,2 \,.\,.\, \theta \\ t = 1,2 \,.\,.\, \tau \end{matrix}$$

$$\sum_{j=1}^{\iota} W_{j\ell mt} \geqslant (1 - \omega_{\ell mt}) \sum_{j=1}^{\iota} W_{j\ell mt-1} \qquad \begin{matrix} \ell = 1,2 \,.\,.\, \lambda \\ m = 1,2 \,.\,.\, \theta \\ t = 1,2 \,.\,.\, \tau \end{matrix}$$

Discussion of Complete Model

The water transfer model developed in this chapter is relatively simple in structure but exceedingly large in number of variables, coefficients, and parameters. The model was designed to provide a policy of reallocating water between competitive sectors on the basis of incremental direct value added measures used as valuation weights. Considerations regarding the sequence of optimal transfers as well as timing of these transfers were explicitly included in the model.

The model, as structured, emphasizes particularly the timing aspect of water transfers between competitive sectors. It also contains provisions for including private consideration of profit rates in that, for pumpage to be increased, the economic costs of pumping must be less than net returns for a particular irrigated crop within the irrigation sector. This provision is in addition to the more nearly orthodox social welfare criterion of reallocating water in order to maximize gross basin product (value added).

The model does not entirely deemphasize hydrological considerations regarding surface flows, or shallow aquifer depth. In the case of shallow aquifer pumpage constraints, both physical and economic limitations were included in separate constraints.

A combination of the productivity and requirements approaches to projecting future water-use patterns formed a major portion of the model's structure. Rather than establish an optimum, regardless of institutional or growth limitations, or establish future water requirements without consideration of the differentials in value of use between sectors, the model developed here blends components of both into a single planning model.

Chapter 8

PRELIMINARY TESTS OF THE INTRABASIN WATER TRANSFER MODEL

The intrabasin water transfer model developed and presented in symbolic form in chapter 7 is coupled in this chapter with empirical data for the Pecos Basin Five-County Area (PBFCA). The empirical results are given along with some preliminary conjectures on water policy derived from these results.

For purposes of simplification, the Pecos Basin is divided into two assumed competitive water-consuming geographical locations: an "upper basin" comprised of San Miguel, Guadalupe, and De Baca Counties; and a "lower basin" containing Chaves and Eddy Counties. In areal terms, the two sub-basins are approximately the same size, encompassing approximately six million acres each, although the lower basin contains almost 85 percent of the basin's irrigated acreage. Several other simplifications or aggregations are included, but discussion of these will be postponed until the empirical measures of the simplified parameters are introduced. Estimates of parameters, coefficients, and initial magnitudes of particular variables are constructed so as to reflect important differences between the two sub-basins.

Data Measures

Incremental Value Added

Estimates of incremental value added per additional acre-foot of water diverted by sector or crop are given in table 16. These estimates are the values imputed to the ρ's in the objective function. The estimates for crops were derived from crop yield response-irrigation water studies for the Pecos Basin by the Department of Agronomy at New Mexico State University. The particular incremental value added measure is taken at the *average* acre-foot diversion level in the basin at an assumed water-salinity level of 2.25 mmhos. Value added-water diversion estimates by crop and for varying salinity levels are recorded in Appendix J.

Incremental value added-water diversion coefficients for manufacturing industries are derived from modified Cobb-Douglas production functions estimated for 1959, using cross-section data (across states). A more detailed description of the estimation procedures is given in Appendix E. It is important to note that these industry estimates were not developed from detailed studies of Pecos Basin manufacturing industries. Moreover, the chemicals (SIC 28) and stone, clay, and glass products (SIC 32) industries in the Pecos Basin are relatively small in comparison to state aggregates. Thus, a degree of caution must be interjected in interpreting optimal water reallocations to these activities. Only with extensive case studies of each of these industries' water utilization in relation to production levels within the Pecos Basin can substantive policy recommendations be made. Estimates from other sources have indicated average value added per acre-foot of water diverted in manufacturing was ten

Table 16. Estimated incremental value added per additional acre-foot[1] for selected irrigated crops, industries, and water salinity[2], by location, Pecos Basin, New Mexico, 1965.

Crop or Industry	Location	
	Upper Basin[3]	Lower Basin
	(dollars)	(dollars)
Cotton	86.28	97.80
Alfalfa	48.84 (51.41)[5]	48.84 (52.89)[5]
Sorghum	27.36 (29.93)[5]	27.36 (31.41)[5]
Food products[4] (SIC 20)	381.00	381.00
Chemicals[4] (SIC 28)	–	88.00
Stone, clay, and glass products[4] (SIC 32)	–	167.00

[1] These estimates denote the values of ρ in the objective function.

[2] A particular water-salinity level was chosen of 2.25 mmhos for preliminary tests of the model.

[3] "Upper basin" estimates were derived by assuming equal proportionality between average and marginal value added coefficients for the upper and lower basins since marginal value added estimates were available only for the lower basin.

[4] Computed by taking estimates of average value added per acre-foot for each SIC industry in the Pecos Basin and applying these to estimated Cobb-Douglas production elasticities relating water withdrawals to value added.

[5] Includes adjustment for indirect value added generated by the fed-cattle industry. (See Appendix H.)

or more times as great as water diverted to agriculture (43). Incremental value added per unit of water allocated to industry is still substantially higher than incremental value added in irrigated agriculture, with the single exception in our estimates of cotton and chemicals (SIC 28).

Social Interest Rates

The choice of an appropriate social rate of discount or interest rate which reflects the collective rate of time preference (the social value of current production and income in relation to the social value of future production and income) involves considerations beyond the scope of this study. However, since the model explicitly introduces time into the reallocation process, a particular social interest rate must be selected. A higher rate would be applicable if the group of citizens within the Pecos Basin were concerned with deriving as much income as rapidly as possible. Alternatively, if the citizens of the Pecos Basin wished to sustain relatively large water-using activities or sectors as long as possible into the indefinite future, a low social interest rate is implied.

For the preliminary tests conducted here, a social rate of interest of 5 percent is utilized, with little justification beyond the finding of Krutilla and Eckstein that the opportunity cost in percentage terms of federal personal income taxes was slightly above 5 percent (27). To take into account the possibility that a 5 percent discount rate might be too high or too low, the complete intrabasin transfer model is also run with interest rates equalling 1, 2, and 10 percent.

The Planning Period

It was decided to apply a 20-year planning interval commencing in 1971 and extending through 1990. Planning beyond intervals of 20 years appears to be somewhat vacuous, particularly in light of the rapid increase in water-related technical developments, including evaporation suppression, desalination, and weather modification. In addition, there is the possibility of economic transfers of water to the Pecos Basin from sources outside the basin. It is also difficult to presume there will be no significant changes in the composition and types of agriculture within the United States and the Pecos Basin by 1990 which are unrelated to water problems or shortages. In developing *a priori* plans for the future, there are always the dual problems of selecting a planning interval that is too short so that nonidentified random forces negate expected outcomes, or one that is too long, so that technological and institutional changes negate the reasons underlying the initial plan. This is not to say that the selected interval of 20 years is justified or correct, only that such an interval subjectively offers more credence than extended or shortened planning intervals.[1]

Definition of Variables

A listing of the subscripts is given below to identify the variables included in the program. Irrigation water was assumed to be applied to three representative crops, on two broad groupings of soil classes:

Soil Class $j = 1$ Soil Classes I and II (Appendix J)
$= 2$ Soil Class III

Source $k = 1$ Surface water
$= 2$ Shallow aquifer
$= 3$ Artesian aquifer

Use $\ell = 1$ Cotton
$= 2$ Alfalfa
$= 3$ Sorghum
$= 4$ Food products (SIC 20)
$= 5$ Chemicals (SIC 28)
$= 6$ Stone, clay, glass products (SIC 32)

Location $M = 1$ Upper basin
$= 2$ Lower basin

Time $t = 0$ 1970
$= 1$ 1971
$= 2$ 1972
–
–
–
–
$20 = 1990$

Estimates of Parameters

In table 17, preliminary estimates of the coefficients, parameters, and initial estimates (t=0) of the variables are presented. Detailed description of their construction would require excessive space. An attempt was made, where possible, to develop alternative measures as a check on consistency. This was not always possible and, in consequence, several of the estimates must be viewed with caution, including the pumping cost coefficient, shallow and artesian growth coefficients, and transfer coefficients.

The linear relationship between withdrawals and depth of the shallow aquifer was provided by the Pecos Study Group at New Mexico Institute of Mining and

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[1] For a discussion of proper planning intervals, see Jaroslav Vanek, *Estimating Foreign Resource Needs for Economic Development*, McGraw-Hill, New York, 1967.

Table 17. Estimates of coefficients, parameters, and initial values of variables, Pecos River Basin, New Mexico, 1970.

Description	Estimate
Coefficients	
Shallow aquifer coefficient $(E_1 = E_2)$	$10.9 \times 10^{-6} - 18.1 \times 10^{-6}$
Pumping cost coefficient $(\epsilon_1 = \epsilon_2)$	0.02
Shallow aquifer growth coefficient $(\eta_{j2\ell m})$	0.015 $m = 1, 2$
Artesian aquifer growth coefficient $(\Omega_{j3\ell m})$	0.015 $m = 1, 2$
Industrial output coefficient	
(SIC 20–γ_{20})	\$4,762.00
(SIC 28–γ_{28})	\$ 980.00
(SIC 32–γ_{32})	\$3,333.00
Water quality coefficient[1] (β)	0.217
Alfalfa (β)	0.222
Irrigated acreage coefficients	
(cotton–π_1)	0.27
(alfalfa–π_2)	0.14
(sorghum–π_3)	0.31
Transfer growth coefficients $(\omega_1 = \omega_2)$	0.07
Return flow coefficients	
(cotton) α_{j111t}	0.44
(alfalfa) α_{j121t}	0.37
(grain sorghum) α_{j131t}	0.36
(SIC 20) α_{j141t}	0.30
Variables	
Initial shallow aquifer withdrawals (acre-feet per year)	
Upper Basin	43,086
Lower Basin	234,264
Initial artesian aquifer withdrawals (acre-feet per year)	
Lower Basin	311,192
Variables (continued)	
Initial water withdrawals by use (acre-feet)	
Upper Basin	
Cotton	1,328
Alfalfa	57,295
Grain sorghum	9,779
Food products (SIC 20)	225
Chemicals (SIC 28)	–
Stone, clay, glass products (SIC 32)	–
Lower Basin	
Cotton	173,900
Alfalfa	365,912
Grain sorghum	44,327
Food products (SIC 20)	4,209
Chemicals (SIC 28)	5,838
Stone, clay, glass products (SIC 32)	2,271
Parameters	
Pecos River flows–adjusted for consumptive use by high value uses (acre-feet per year) and tributary flows	
Upper Basin $(V_{1t} - m_{1t})$	143,033
Lower Basin $(V_{2t} - \sum_{m=1}^{2} m_{mt})$	295,056
Average depth of water table (in feet in 1971)	110
Shallow aquifer–unconstrained storage (acre-feet)	
$1.587 \times 10^6 \leqslant S_{1971} \leqslant 3.267 \times 10^6$	
Net returns per acre	
Upper Basin	\$12.67
Lower Basin	\$39.52
Cotton allotment acreage constraints (acres)	
Upper Basin	400
Lower Basin	47,000

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[1] This coefficient was constructed by assuming total dissolved solids was the binding pollution factor for dilution purposes, and that agricultural return flows averaged 1,600 ppm total dissolved solids. Also, it was estimated that, without agricultural or other surface water uses, dissolved solids would average 1,060 ppm in the Pecos River.

Technology, Socorro, New Mexico. This relationship is also provisional, and subject to revision[2]. The actual relationship is probably nonlinear, but the model developed in chapter 7 can include such a nonlinear relationship through linear segmentation of the equation when it becomes available.

The data tabulated in Appendix J indicate that the optimal intensity of irrigation water for all crops (which is implicitly assumed by the model) may be considerably greater than that currently being practiced. However, future pumping capacity was projected on the basis of current withdrawals, which, of course, are based on current practice. As a result, the pumping capacity for 1971 is insufficient to irrigate even 1959 acreages at optimal intensity. In order to allow for optimal intensities of irrigation water, acreages must be reduced.

For the purpose of establishing initial withdrawals (t=0) for our model, a reconciliation of this discrepancy was devised as follows: The intensities of irrigation water were set at optimal levels, and corresponding reductions in irrigated acreages, by crop, in the order of their value (to the farmer) were made. In this manner a reasonable, implicit path of adjustment was traced from current practice to the economically best practice assumed to prevail by 1971. It may be mentioned in passing that this procedure led to a reduction in sorghum and alfalfa acreages, but to an increase in profits received by farmers from these crops for all levels of salinity of irrigation water except 0.75 mmhos.

Projections of industrial production by SIC industry (see variable definitions previously given) and total irrigated acreage for the period 1970 through 1990 are presented in table 18. A complete description of the methods used to derive the exogenous projections in table 18 is given in Appendices D and E. These projections constitute upper, foreseeable limits to rates of expansion in the selected industrial and irrigated acreage sectors, and thus provide constraints to expansion as set forth in the intrabasin water transfer model.

Preliminary Results

In this section the empirical results obtained for the intrabasin water transfer model, utilizing the data inputs tabulated previously, are set forth. Six alternative variants are examined that differ, depending on specifications, with regard to: coefficients relating withdrawals to depth of water table for the shallow aquifers; variations in Pecos River and tributary flows; potential changes in industrial output; and deletion of certain structural constraints. The six variants are listed below, with short synopses indicating the specification of the variant.

A. Shallow aquifer coefficients are set at $E = 10.9 \times 10^{-6}$, the assumed lower boundary relating the volume of water in unconfined storage to depth of the water table.
B. Shallow aquifer coefficients are set at $E = 18.1 \times 10^{-6}$, the assumed upper boundary relating the volume of water in unconfined storage to depth of the water table.
C. The upper boundary shallow aquifer coefficient ($E = 18.1 \times 10^{-6}$) is assumed along with river flows V_{mt} being reduced by one-half their standard deviation of yearly flows for 1940-1960.
D. The upper boundary shallow aquifer coefficient is assumed and river flows are increased by one standard deviation of yearly flows for 1940-1960.
E. The upper boundary shallow aquifer coefficient is assumed and the constraints on industrial production of foods and kindred products (SIC 20), chemicals (SIC 28), and stone, clay, and glass products (SIC 32) are relaxed by approximately 20 percent.
F. The upper boundary shallow aquifer coefficient is assumed along with deletion of the constraints on rates of transfer from or to alfalfa and sorghum.

These six variants allow one to assess the effects of variation in river flows, in rate of exhaustion of the shallow aquifer, in industrial production (assumed to increase), in the technical coefficients for shallow aquifers, and in the appropriateness of constraints on rate of intra-sector transfers for one crop. While six variations do not delineate all the possibilities for specification in the model, these, coupled with results on the range of coefficients and activity levels reported later, offer a reasonably complete sensitivity analysis. From preliminary test runs it became obvious that the six variations described above would have a substantial effect on time-related allocations.

With sectoral transfer constraints for all users in the program, the computer was unable to complete the solution and abandoned it before the number of nonoptimal columns had been reduced by one-half. An examination of the progress of the solution indicated that the optimal solution was being approached almost asymptotically—and that, even if it were possible to force completion of the problem, it might require 6 to 12 hours of computer time. In response to this, the rate of transfer constraints was removed on all users except sorghum and alfalfa—the two users for which, on the basis of previous runs, the transfer constraints were judged to be relevant. Once again the computer abandoned procedure at a point only a little farther beyond that reached with all transfer constraints.

The following subjective procedure was then employed: The transfer constraints were removed on sorghum and it was assumed that sorghum acreages would be decreased at the maximum possible rate permitted by these constraints (7 percent per year). Other relevant variables in the model were exogenously adjusted for this assumption. This procedure was justified by the fact that, in all preliminary runs with the rate of transfer constraints omitted, no water was allocated to sorghum. With this change, the computer was able to complete the solution, although some evidence indicates that the problem was still near the limits of the computer's capacity.

In figures 4 and 5, optimal allocations by sector, location, and time, based on the incremental value added criterion, are depicted for the planning interval 1971-1990. In figure 4, allocations to food and kindred products (SIC 20) and alfalfa increased gradually in the upper basin while cotton was maintained at constraint levels specified by the allotment program. Sorghum-planted acreage, or course, continually declined in the upper basin.

In figure 5, lower basin allocations replicated allocations in the upper basin with the exception that alfalfa acreage declined in the early planning periods and increased thereafter. It is interesting to note that in the lower basin, with sorghum constrained to decline, alfalfa assumed the role of the "residual" crop. In consequence,

Table 18. Projections of industry output and irrigated acreage by location and time, Pecos Basin, New Mexico.

	Industry Output[1]				Irrigated Acreage[2]	
	Upper Basin	Lower Basin			Upper	Lower
Time	SIC 20	SIC 20	SIC 28	SIC 32	Basin[3]	Basin[3]
1960	0.5	9.0	0.5	3.5	18	160
–	–	–	–	–	–	–
–	–	–	–	–	–	–
1971	1.1	20.1	5.7	7.6	21	197
1972	1.1	21.1	6.2	7.9	22	200
1973	1.2	22.1	6.7	8.3	22	204
1974	1.2	23.1	7.1	8.7	22	207
1975	1.3	24.1	7.6	9.0	23	210
1976	1.3	25.1	8.1	9.4	23	213
1977	1.4	26.1	8.6	9.8	23	217
1978	1.5	27.1	9.0	10.2	23	220
1979	1.5	28.1	9.5	10.5	24	223
1980	1.6	29.1	10.0	10.9	24	227
1981	1.6	30.1	10.8	11.3	24	228
1982	1.7	31.0	11.6	11.6	24	229
1983	1.7	32.0	12.3	12.0	24	230
1984	1.8	32.9	13.1	12.4	24	231
1985	1.9	33.8	13.9	12.8	25	233
1986	1.9	34.8	14.7	13.1	25	234
1987	1.9	35.7	15.5	13.5	25	235
1988	2.0	36.7	16.3	13.9	25	236
1989	2.0	37.6	17.1	14.2	25	237
1990	2.1	38.6	17.9	14.6	25	239
–	–	–	–	–	–	–
00	–	–	–	–	–	–
2000	2.6	48.2	25.7	18.3	26	251

[1] Direct value added by SIC Industry in 1,000's of dollars.
[2] Total projections of irrigated acreage in 1,000's of acres.
[3] Assumed to be 85 percent of Soil Classes I and II, and 15 percent in Soil Class III.

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[2] The relationship is $D = 110 - ES$, where D is the average depth of the water table below ground and S is the volume of water in unconfined storage in acre-feet. In the judgment of the hydrologists at New Mexico Institute of Mining and Technology, there is a 90 percent chance that

$$10.9 \times 10^{-6} \leqslant E \leqslant 18.1 \times 10^{-6}.$$

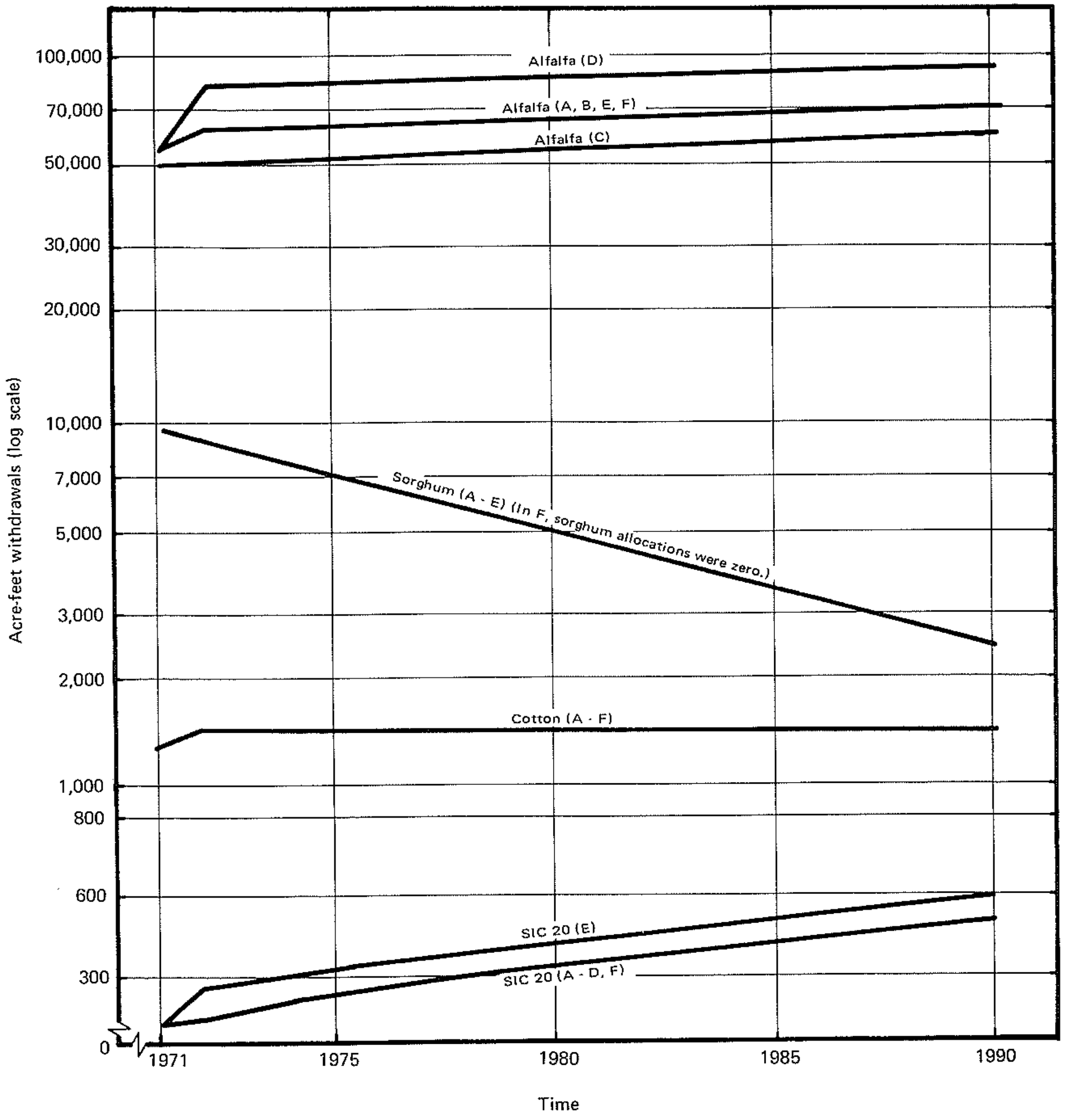

Figure 4. Summary of water allocations by activity, Upper Pecos Basin, New Mexico, 1971-1990.

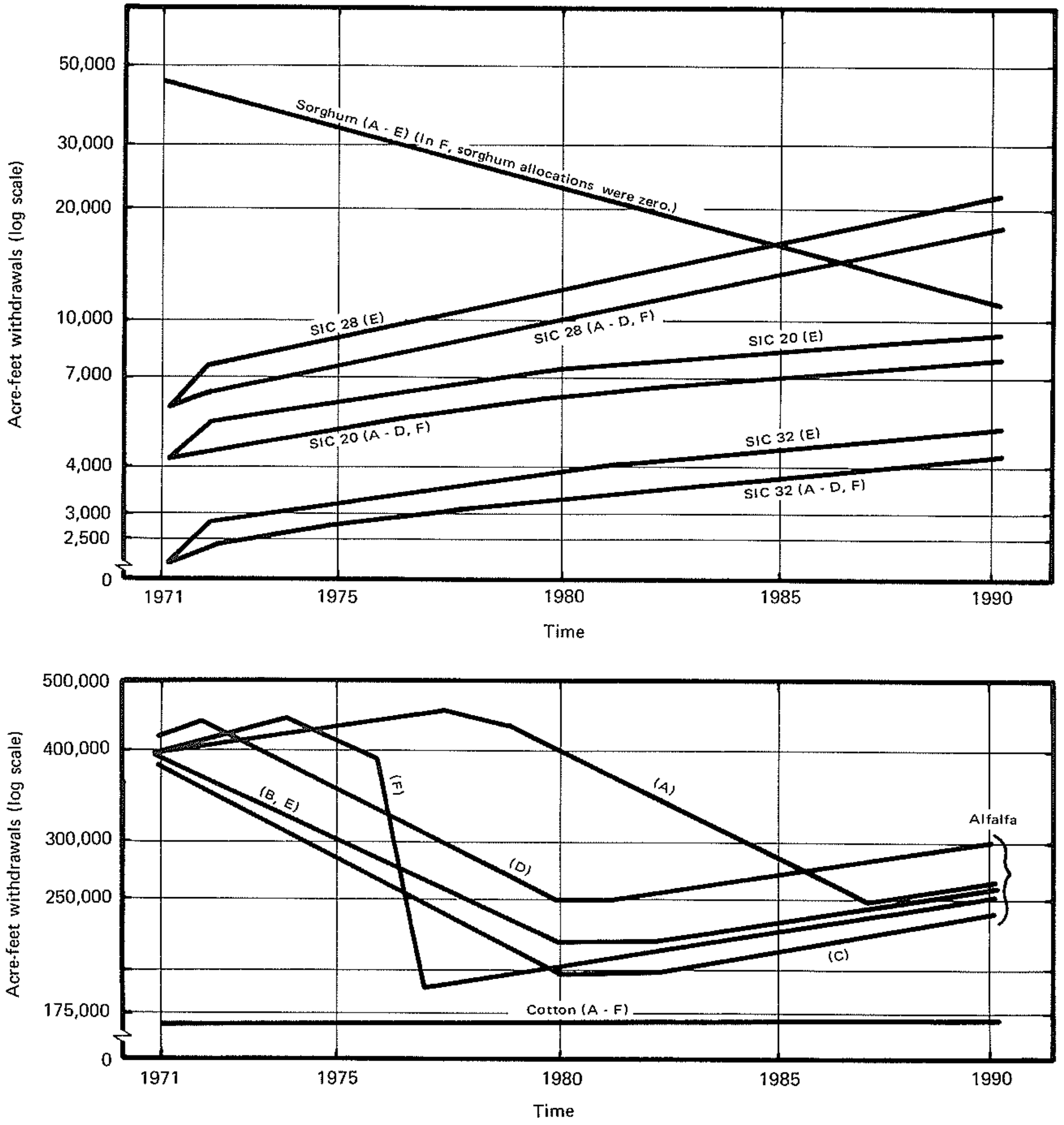

Figure 5. Summary of water allocations for selected activities, Lower Pecos Basin, New Mexico, 1971-1990.

the pattern of allocations to alfalfa became sensitive to changes in model specification. The results of water reallocations tabulated here are not surprising, given the incremental value added weights in table 16.

Shadow Prices

In tables 19 and 20, shadow prices are recorded for each type of constraint for the upper and lower basin, respectively. The only constraints for which shadow prices are sensitive (to variant specifications) are the initial water withdrawals by each sector. Second-year shadow prices were selected rather than first-year prices as the first-year prices exhibited significant variation due to the influence of initial allocations. After the second year, however, shadow prices, with the exception of transfer restrictions on alfalfa, exhibited practically no additional variation except for downward adjustment due to discounting value added in the future.

Shadow prices for the alfalfa transfer constraint are recorded in table 21. It is interesting to note that the shadow price increases during the first five years and then declines except for variant A, where the increase occurs between years 1979 and 1982. The shift in timing for A is clearly caused by a greater availability during the early years of shallow aquifer unconfined storage in the lower basin.

A Partial Sensitivity Analysis

The sensitivity analysis is divided into two parts. The first part tests the effect of forcing changes in the activity levels of the constraint rows on the characteristics of the optimal solution. Its primary output is a *range* of values for each constraint row, which the row could be forced to assume without changing the status[3] of any column vector (user) in the optimal solution or violating some other constraint. In addition, the test indicates what changes would take place in the optimal solution as the range values are exceeded. It is to be emphasized, however, that changes reported by the program and presented in table 22 are not necessarily unique: In certain instances more than one change would necessarily have been required by the structure of the model, even though only one of these was listed by the computer. The second part of the analysis performs identical tests on the objective function coefficients.

Another difficulty arose in the test of the objective function coefficients. The purpose of this test was to examine relationships between the users of water in the basin. However, owing to the structure of the program, single users were formally divided into several users, according to soil class and source of water. Thus, in a preliminary test, the range for each user was bounded by itself—that is, by what was in reality the same user, but, for the purposes of the program, was a distinct user.

This difficulty was surmounted with partial success by the inclusion of additional restrictions (consistent with the optimal solution) which permitted variations of only one type for each user. The problem was thereby eliminated for all users except cotton and alfalfa on Soil Class III in the upper basin, and alfalfa, Soil Class III, in the lower basin. The reason for the remaining variability appears to be embodied in the numerical characteristics of the computer algorithm over which we have no control. This vitiated the sensitivity test to the extent that it did not yield all the desired information; however, it does not constitute a computation error and does not bias any of the other results.

In table 22, a description of activity levels of all constraints is given, along with the range of the activity and limiting factors to the range. A discussion of the sensitivity of constraints (rows) is given below, particularly with reference to the limiting factors recorded in table 22.

Upper Basin River Water Quantity Constraint

The upper limiting factor seems a little puzzling until it is realized that alfalfa allocations in year 3 must be no less than 93 percent of those in year 2, due to the rate of transfer constraint on alfalfa. As available river flows are increased in year 2, the additional water is allocated to alfalfa, with the result that the minimum permissible alfalfa acreages in year 3 increase to the point where the available supply of water for alfalfa is not adequate to sustain the entire acreage. Presumably, after the third-year alfalfa transfer constraint becomes binding, additional quantities of river water could be allocated to sorghum, so that the upper limit reported here should not be interpreted as the maximum streamflow that can be economically utilized by the upper basin.

Lower Basin River Water Quantity Constraint

The shallow aquifer pumping capacity constraint, being at an intermediate level, is free to vary to offset the effects of the fluctuating river flows. The alfalfa transfer constraint is probably the major factor which causes the increase in pumpage in the third year, as a

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[3] The program assigns to each column (user) one of three statuses. For the purpose of the present study, these can be described as: 1) UL (Upper Limit), meaning in the optimal basis (i.e., receiving routine allocations), and that allocations to this user cannot be further increased without violating at least one constraint; 2) BS (in the Basis), meaning in the optimal basis, but not at an upper limit; and 3) LL (Lower Limit), meaning, in the present model but not in the basis (receiving zero allocations in the optimal solution). Thus, a "change in status" constitutes a somewhat more sensitive discrimination than a "change in basis," since it comprises both changes in basis (LL to BS) and changes from UL to BS.

Table 19. Second-year shadow prices,[1] intrabasin water transfer model, Upper Pecos Basin, New Mexico (in dollars).

Constraint	Unit	Variant					
		A	B	C	D	E	F
Surface	1 acre-foot	7.76	7.85	7.85	7.84	7.85	7.76
Shallow							
Capacity	1 acre-foot	0	0	0	0	0	0
Revenue	1 acre-foot	0	0	0	0	0	0
Growth	1 acre-foot pump capacity	664.35	664.35	664.35	664.35	664.35	664.35
Artesian Growth	1 acre-foot pump capacity	–	–	–	–	–	–
Irrigated Acreage							
Soil I and II	1 acre	0	0	0	0	0	0
Soil III	1 acre	0	0	0	0	0	0
Cotton Acreage	1 acre	117.15	117.15	117.15	117.15	117.15	117.15
Initial Withdrawals[1]							
Shallow	1 acre-foot	676.29	676.29	702.81	674.31	676.29	676.29
Artesian	1 acre-foot	–	–	–	–	–	–
Cotton	1 acre-foot	80.19	80.19	53.57	82.17	80.19	80.19
Alfalfa	1 acre-foot	46.98	46.98	20.46	48.96	46.98	46.98
Sorghum	1 acre-foot	26.58	26.58	0	28.50	26.58	26.58
SIC 20	1 acre-foot	361.26	361.26	334.36	362.86	361.26	361.26
SIC 28	1 acre-foot	–	–	–	–	–	–
SIC 32	1 acre-foot	–	–	–	–	–	–
Industrial Output							
SIC 20	1 acre-foot	285.72	285.72	285.72	285.72	285.72	285.72
SIC 28	1 acre-foot	–	–	–	–	–	–
SIC 32	1 acre-foot	–	–	–	–	–	–
Water Quality							
Cotton	1 acre-foot	6.38	6.47	6.47	6.46	6.47	6.38
Alfalfa	1 acre-foot	7.76	7.85	7.85	7.84	7.85	7.76
Sorghum	1 acre-foot	2.96	3.03	3.03	3.03	3.03	2.96
SIC 20	1 acre-foot	6.60	6.65	6.65	6.65	6.65	6.60
SIC 28	1 acre-foot	–	–	–	–	–	–
SIC 32	1 acre-foot	–	–	–	–	–	–

[1] First-year shadow prices indicated for initial withdrawal constraints.

Table 20. Second-year shadow prices,[1] intrabasin water transfer model, Lower Pecos Basin, New Mexico (in dollars).

Constraint	Unit	Variant A	Variant B	Variant C	Variant D	Variant E	Variant F
Surface	1 acre-foot	8.57	7.27	7.27	7.40	7.27	8.57
Shallow							
Capacity	1 acre-foot	29.46	40.72	40.72	41.45	40.72	41.44
Revenue	1 acre-foot	0	0	0	0	0	0
Growth	1 acre-foot pump capacity	88.26	0	0	0	0	12.98
Artesian Growth	1 acre-foot pump capacity	689.61	694.33	694.33	691.23	694.33	683.58
Irrigated Acreage							
Soil I and II	1 acre	0	0	0	0	0	0
Soil III	1 acre	0	0	0	0	0	0
Cotton Acreage	1 acre	150.85	177.72	177.72	175.00	177.72	150.85
Initial Withdrawals[1]							
Shallow	1 acre-foot	90.03	10.81	10.81	41.45	10.81	1.64
Artesian	1 acre-foot	729.87	734.65	734.65	701.60	734.65	723.74
Cotton	1 acre-foot	63.23	63.23	63.23	93.14	63.23	63.23
Alfalfa	1 acre-foot	20.46	20.46	20.46	50.37	20.46	20.46
Sorghum	1 acre-foot	0	0	0	29.91	0	0.0
SIC 20	1 acre-foot	332.95	332.95	332.95	362.86	332.95	332.95
SIC 28	1 acre-foot	53.90	53.90	53.90	83.81	53.90	53.90
SIC 32	1 acre-foot	129.14	129.14	129.14	159.05	129.14	129.14
Industrial Output							
SIC 20	1 acre-foot	285.72	285.72	285.72	285.72	285.72	285.72
SIC 28	1 acre-foot	29.40	39.20	39.20	39.20	39.20	29.40
SIC 32	1 acre-foot	99.99	99.99	99.99	99.99	99.99	99.99
Water Quality							
Cotton	1 acre-foot	7.16	6.08	6.08	6.19	6.08	7.16
Alfalfa	1 acre-foot	8.57	7.27	7.27	7.40	7.27	8.57
Sorghum	1 acre-foot	3.62	3.85	3.86	3.83	3.86	3.62
SIC 20	1 acre-foot	7.16	6.08	6.08	6.19	6.08	7.16
SIC 28	1 acre-foot	7.16	6.08	6.08	6.19	6.08	7.16
SIC 32	1 acre-foot	6.98	6.08	5.90	6.01	5.90	6.98

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[1] First-year shadow prices indicated for initial withdrawal constraints.

Table 21. Shadow prices of rate of transfer constraints on alfalfa, interbasin water transfer model, Pecos Basin, New Mexico, 1971-1990 (in dollars).

Year	Upper Basin A-E	Upper Basin F	Lower Basin A	Lower Basin B	Lower Basin C	Lower Basin D	Lower Basin E	Lower Basin F
t= 1971	0	Not Applicable	0	0	0	0	0	Not Applicable
1972	0		0	7.80	7.80	7.01	7.80	
1973	0		0	13.73	13.73	12.10	13.73	
1974	0		0	17.77	17.77	15.23	17.77	
1975	0		0	19.89	19.89	16.36	19.89	
1976	0		0	20.05	20.05	15.47	20.05	
1977	0		0	18.19	18.19	12.48	18.19	
1978	0		0	14.28	14.28	7.35	14.28	
1979	0		4.98	8.24	8.24	0	8.24	
1980	0		8.60	0	0	0	0	
1981	0		10.82	0	0	0	0	
1982	0		11.63	0	0	0	0	
1983	0		11.00	0	0	0	0	
1984	0		8.87	0	0	0	0	
1985	0		5.22	0	0	0	0	
1986	0		0	0	0	0	0	
1987	0		0	0	0	0	0	
1988	0		0	0	0	0	0	
1989	0		0	0	0	0	0	
1990	0		0	0	0	0	0	

Interpretation: This is the increase in the objective function, given an unconstrained one-acre-foot increase in withdrawals in year *t*, above the seven percent level.

response to increased allocations in the second. Similarly, in the second year, since alfalfa allocations are the only allocations with a constrained lower limit, it seems probable that the alfalfa transfer constraint is the constraining factor here also.

Upper Basin Shallow Aquifer Depth Constraint

This activity was strictly limited by the shallow aquifer pumping capacity constraint which remained at its upper limit throughout the 20-year planning period. Consequently, any change in the activity level requires a change in the status of the pumping capacity constraint, which explains the extremely narrow range reported by the program. Actually, any further variation in this activity would probably entail corresponding changes in alfalfa acreages.

Lower Basin Shallow Aquifer Depth Constraint

As in the case of the upper shallow aquifer depth constraint, this activity was strictly "connected" to the pumping capacity constraint, so that even small changes in it require changes in the status of at least one pumping capacity constraint. Thus, the reported downward variability is negligible. The upper limiting factor simply involves a structural change, with artesian aquifer allocations to food and kindred products (SIC 20) simply replaced by shallow aquifer allocations. As in the upper basin, further variation in this activity would almost certainly involve adjustments only in alfalfa acreages.

Upper Basin Shallow Aquifer Growth Constraint

The general form of this constraint for year *t* includes variables from years *t* and t-1. Thus, the third-year values are listed for this constraint in table 22, in preference to those of the second year, in order to avoid any reference to first-year variables, which are constrained by the initial conditions.

Lower Basin Shallow Aquifer Growth Constraint

The third year was chosen for analysis of this constraint for the same reason that it was chosen for the upper shallow aquifer growth constraint. The lower limiting factor, the entry of sorghum into the basis for the previous year, is explained by the alfalfa transfer constraint. The diminution of the available water supply in the third year implies reduced alfalfa acreages, which, owing to the alfalfa transfer constraint, can only be

Table 22. Description of activity levels and constraints on intra-basin water transfer model, Pecos Basin, New Mexico, 1971-1990.

Constraint	Type[1]	Limit	Activity	Range	Limiting Factors[2]
Upper river	L	143,033 (acre-feet)	143,033	41,810 to 172,682	Lower - alfalfa structural constraint, year 2, INT to BI Upper - alfalfa structural constraint, year 3, INT to BI
Lower river	L	295,056 (acre-feet)	295,056	176,139 to 485,298	Lower - shallow aquifer pumping capacity constraint, year 2, INT to BI Upper - shallow aquifer pumping capacity constraint, year 3, INT to BI
Upper shallow depth	L	116.1 (feet)	68.7	68.2 to 68.7	Lower - shallow aquifer pumping capacity constraint, year 20, BI to INT Upper - shallow aquifer pumping capacity constraint violated, year 2
Lower shallow depth	L	86.4 (feet)	86.4	83.6 to 89.5	Lower - shallow aquifer pumping capacity constraint, year 11, BI to INT Upper - artesian aquifer withdrawals, SIC 20, year 10, BS to LL
Upper shallow growth (third year)	L	1.5 (percent)	1.5	-9 to 64	Lower - alfalfa structural constraint, year 2, INT to BI Upper - shallow aquifer depth constraint, INT to BI
Lower shallow growth (third year)	L	1.5 (percent)	-15	-42 to 12	Lower - sorghum, year 2, LL to BS Upper - alfalfa structural constraint, year 3, BI to INT
Lower artesian growth (third year)	L	1.5 (percent)	1.5	-1 to 4	Lower - artesian aquifer water to SIC 20, BS to LL Upper - shallow aquifer pumping capacity constraint, year 10, INT to BI
Upper irrigated acreage, Soil Classes I and II	L	18,359 (acres)	9.117	9,117 to 12,190	Lower - sorghum, Soil Class III, river water, year 2, LL to BS Upper - sorghum, structural constraint, year 2, BI to INT
Upper irrigated acreage, Soil Class III	L	3,240 (acres)	0	0	Lower - none Upper - sorghum, Soil Class III, river water, year 2, LL to BS
Lower irrigated acreage, Soil Classes I and II	L	170,178 (acres)	101,059	101,059 to 107,208	Lower - sorghum, Soil Class III, river water, year 2, LL to BS Upper - sorghum structural constraint, year 2, BI to INT
Lower irrigated acreage, Soil Class III	L	30,031 (acres)	0	0	Lower - none Upper - sorghum, Soil Class III, river water, year 2, LL to BS
Upper SIC 20 max. output	L	1,126,-000 ($TVA)[3]	1,126,-000	0 to 87,-203,408	Lower - SIC 20, year 2, BS to LL Upper - alfalfa structural constraint, year 2, INT to BI
Lower SIC 20 max. output	L	21,056,-000 ($TVA)[3]	21,056,-000	0 to 122,-177,698	Lower - SIC 20, year 2, BS to LL Upper - shallow aquifer pumping capacity constraint, year 2, INT to BI
Lower SIC 28 max. output	L	6,195,-000 ($TVA)[3]	6,195,-000	0 to 27,-005,480	Lower - SIC 28, year 2, BS to LL Upper - shallow aquifer pumping capacity constraint, year 2, INT to BI
Lower SIC 32 max. output	L	7,940,-040 ($TVA)[3]	7,940,-000	0 to 78,-716,920	Lower - SIC 32, year 2, BS to LL Upper - shallow aquifer pumping capacity constraint, year 2, INT to BI
Upper max. cotton acreage	L	400 (acres)	400	0 to 1,729	Lower - cotton, Soil Classes I and II, year 2, BS to LL Upper - alfalfa structural constraint, year 2, INT to BI
Lower max. cotton acreage	L	47,000 (acres)	47,000	37,828 to 52,734	Lower - shallow aquifer pumping capacity constraint, year 3, INT to BI Upper - shallow aquifer pumping capacity constraint, year 2, INT to BI
Initial withdrawals,[4] shallow aquifer, upper	=	37,874 (acre-feet)	37,784	34,914 to 48,844	Lower - surface constraint, year 1, INT to BI Upper - alfalfa, Soil Classes I and II, year 1, river water, BS to LL
Initial withdrawals,[4] shallow aquifer, lower	=	221,292 (acre-feet)	221,292	205,671 to 233,942	Lower - shallow aquifer pumping capacity constraint, year 2, INT to BI Upper - initial withdrawals by sorghum constraint, INT to BI
Initial withdrawals,[4] artesian aquifer, lower	=	311,192 (acre-feet)	311,192	302,024 to 319,450	Lower - SIC 20, year 10, artesian aquifer, BS to LL Upper - shallow aquifer pumping capacity constraint, year 10, INT to BI
Alfalfa transfer, upper [year 6]	L[3]	7 (percent)	-1	-46 to 22	Lower - sorghum structural constraint, year 5, BI to INT Upper - sorghum structural constraint, year 6, BI to INT
Alfalfa transfer, lower [year 6]	L[5]	7 (percent)	7	5 to 10	Lower - shallow aquifer pumping capacity constraint, year 10, INT to BI Upper - SIC 20, artesian aquifer, year 10, BS to LL

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[1] L denotes a constraint of the form "less than or equal" (⩽).

[2] INT–intermediate status of a constraint row: the row contains non-zero variables, but the constraint is not completely filled or "binding."

[3] Total value added in dollars.

[4] Initial withdrawals constraints refer to year 1. All others refer to year 2, except as noted.

[5] Year 6 was chosen because the alfalfa transfer constraint was most restrictive in this year. Recall that the 7 percent is the maximum permissible *reduction* in alfalfa allocations per year. Thus, the negative rates in the range are interpreted as *increases* in alfalfa allocations. Unless noted, all other transfer constraints refer to the second year.

Notes: The sensitivity test on the water-quality constraints was vitiated by rounding. Certain users, expected to limit the range by entering the basis, were not reported as entering because they were already in the basis with minute, but non-zero, allocations. In consequence, the actual reported ranges were nonsensically large.

made feasible beyond a certain point by reducing alfalfa acreages in the previous year. Thus, this implies the replacement of alfalfa by sorghum. As was previously explained, however, sorghum acreages have been explicitly excluded under the assumption that they would be decreased as rapidly as the transfer constraint would permit; consequently no further increases in sorghum acreages are possible, and the actual lower limiting factor is the alfalfa transfer constraint.

Lower Basin Artesian Aquifer Growth Constraint

The third year was chosen for the reasons discussed above regarding the upper shallow aquifer growth constraint. The upper limiting factor suggests that a transfer of water use over time may be taking place. For this model the shallow aquifer was exhausted in the tenth year, and the final quantity of water pumped from it in this year was far below the limits of the available pumping capacity. However, the program reports that this pumping capacity would have been fully utilized, had there been a 4 percent increase in the artesian aquifer pumping capacity in the third year. This finding implies that the resultant increase in available artesian aquifer water would be accompanied by a reduction in the rate of use of shallow aquifer water. This, in itself, is at first surprising, since none of the variations of the model has shown any tendencies toward conservation. The reason this occurs, however, is straightforward enough. The total increase in available water in the third year cannot be allocated immediately to alfalfa because of its transfer constraint, nor to cotton or the industries, which are already at their upper limits. Some of the increase could then either be currently allocated to sorghum or to alfalfa at a later date. However, discounted incremental value added per acre-foot for alfalfa in any year before the fourteenth exceeds that of sorghum in the third year. Consequently, the program would substitute at least some of the additional artesian aquifer water for shallow aquifer water and save the latter for allocation to alfalfa in the tenth and eleventh years, rather than immediately allocating it to sorghum.

Upper Basin Irrigated Acreage Constraint (Soil Classes I and II)

If the quantity of Soil Classes I and II cultivated is reduced, sorghum is the first crop to be transferred to Soil Class III because the absolute difference in value of production between the two soil types is smallest for sorghum; hence the minimum loss in marginal basin product is incurred by transferring sorghum to Soil Class III before other crops. If the quantity of Soil Classes I and II under cultivation is increased, alfalfa ultimately reaches the maximum allocations that are allowed by its transfer constraint.

Upper Basin Irrigated Acreage Constraint (Soil Class III)

For the same reasons given immediately above, sorghum, rather than cotton or alfalfa, is transferred to acreage of Soil Class III as this acreage is forced into cultivation.

Lower Basin Irrigated Acreage Constraint (Soil Classes I, II, and III)

These results and their respective explanations are identical to the corresponding results for the upper basin, explained immediately above.

Upper Basin SIC 20 Maximum Output Constraint, Lower Basin SIC 20, 28, and 32 Maximum Output Constraints, and Upper Basin Maximum Cotton Acreage Constraint

The results for all of these constraints were essentially identical. These sectors each received the maximum possible allocations permitted by their respective maximum output or acreage constraints within the range allowed by the remainder of the constraint set. Competition from other sectors was not a limiting factor to allocations for these activities.

Lower Basin Maximum Cotton Acreage Constraint

The reason that cotton in the lower basin does not display as great a range as it does in the upper basin is that the shallow aquifer pumping capacity constraint is at an intermediate level of activity in the lower basin, and relatively moderate changes in cotton acreages are capable of forcing it to its upper limit. In the upper basin this constraint was at its upper limit throughout the planning period and consequently does not change status with changes in cotton acreages. We are confident that the lower basin cotton acreages would, except for the change in status of the shallow aquifer pumping capacity constraint, have shown a range of magnitude comparable to that of upper basin cotton.

Initial Withdrawals Constraints: Shallow Aquifer-Upper Basin, Shallow Aquifer-Lower Basin, and Artesian Aquifer-Lower Basin

The changes in program status which define the endpoints of these ranges are of little qualitative relevance. They either reflect attempts by the program to maintain initial withdrawals at as high a level as possible, or imply minor structural adjustments. The range within which these could vary without changing the basic pattern of allocations or rate of water use over time was for the most part not clarified. The upper limiting factor for initial artesian aquifer withdrawals does suggest, however, that an increase leads to some conservation of shallow aquifer water.

Upper Basin Alfalfa Transfer Constraint

If the rate of growth in alfalfa allocations yields a 46 percent increase between years 5 and 6, the quantity of alfalfa allocations in year 5 apparently is forced to decrease to expedite any higher rate of increase, and the water so released is allocated to sorghum. When the decrease in alfalfa acreages between years 5 and 6 reaches 22 percent, at least some of the additional water released is transferred to sorghum.

Lower Basin Alfalfa Transfer Constraint

The upper limit reported in table 22 represents simply a minor structural change of little apparent significance, so that a truly germane upper limit is likely to be encountered at transfer rates greater than 10 percent per year. The interpretation of the lower limiting factor is uncertain, though it seems to imply a transfer of water from years 6 through 9 to years 10 and 11. The *immediate* consequence of the 5 percent rate of reduction, however, is to increase water allocations to alfalfa in year 6.

Variation in Marginal Value Added Coefficients

Only water users on Soil Classes I and II were considered in the sensitivity test. The maximum available projected acreages for every year in each version of the model is far in excess of the capacity of the water supply to irrigate; and consequently, the poorer soil classes are invariably left partially or completely uncultivated. The only circumstance under which the use of these soils might become economically desirable would involve the purveyance of massive quantities of water (on the order of one-third to one-half million acre-feet per year) from outside the Pecos Basin.

Cotton

Because it is at its upper limit, the cotton allotment constraint allows no increase in the value of cotton, however large, to alter its status in the solution. The nearest competing user below cotton in value is alfalfa, and alfalfa allocations do not compete with cotton until the alfalfa objective function coefficient equals that of cotton exactly. Thus, it seems probable that the lower value limit for cotton, in the absence of variation in cotton on Soil Class III, would have been approximately $47.00 to $48.00 (see table 23, line 1).

Alfalfa

The upper limit to the range in alfalfa objective function coefficients in both sub-basins is incremental value added for cotton. As the incremental value added per additional acre-foot on alfalfa exceeds that of cotton, allocations to the latter begin to decrease. As in the case of cotton in the upper basin above, however, the lower bound was inadvertently limited by Soil Class III allocations. Arguing along similar lines, we can observe that sorghum does not compete with alfalfa until its objective function coefficient (incremental value added) equals that of alfalfa, and we thus conclude that the lower bound for alfalfa, in the absence of the undesired variability of alfalfa on Soil Class III, would most probably be around $28.00 to $29.00, at which point sorghum would be expected to replace alfalfa.

Sorghum

At the upper end of sorghum's range, in both regions, sorghum replaces alfalfa entirely. This change is not once-and-for-all, but is the end result of a gradual decrease in alfalfa acreages as incremental value added of sorghum increases, but the change is tempered by the transfer constraint for alfalfa. Since the optimal solution comprises a reduction of sorghum acreages as rapidly as sorghum transfer constraints allow, any further decrease in the incremental value added of sorghum has no effect on the solution.

Manufacturing Industries

Declines in industry allocations are accompanied by increases in alfalfa acreage irrigated, provided industry incremental value added measures decline to approximately $46.00 in the upper basin and $39.00 in the lower basin.

Variation in the Social Interest Rate

Interest rates of 1, 2, 5, and 10 percent were applied to the intrabasin water transfer model. We do not record the differences in allocations caused by specifying alternative social rates of interest as practically no perceptible differences were observed. Sectoral, locational, and time-related allocations did not differ by more than 1 percent from the tabulated allocations reviewed earlier, where a 5 percent social rate of interest was assumed. Thus, the model is not sensitive to interest rates ranging from 1 to 10 percent, which allows some degree of confidence in the preliminary results reported here.

Policy Implications

The sensitivity tests reported in the last section give a reasonably adequate portrayal of the internal construction of the intra-basin water transfer model. Moreover, the shadow prices obtained allow us to make several assertions regarding the value of water imported from outside the Pecos Basin. But, the crudeness of certain parameter and coefficient estimates obligates us to caution the reader against attempting to arrive at definitive policy conclusions from these preliminary

Table 23. Range of the incremental value added measure by sector and location, Pecos Basin, New Mexico.

User	Status in the Solution[1]	Objective Function Coefficient[2]	Range	Limiting Factors
Cotton I, upper basin	UL	78.26	68.87 to ∞	Lower - cotton Soil Class III enters the basis (LL to BS) Upper - none
Alfalfa I, upper basin	BS	46.63	39.99 to 78.26	Lower - alfalfa III enters the basis (LL to BS) Upper - cotton acreage decreases (UL to BS)
Sorghum I, upper basin	LL	27.14	- ∞ to 46.63	Lower - none Upper - alfalfa leaves production (BS to LL)
SIC 20, upper basin	UL	345.58	46.63 to ∞	Lower - SIC 20 allocations decrease (UL to BS) Upper - none
Cotton I, lower basin	UL	88.70	47.97 to ∞	Lower - cotton acreage decreases (UL to BS) Upper - none
Alfalfa I, lower basin	BS	47.97	41.33 to 88.70	Lower - alfalfa Soil Class III enters the basis (LL to BS) Upper - cotton acreage decreases (UL to BS)
Sorghum I, lower basin	LL	28.49	- ∞ to 47.97	Lower - none Upper - alfalfa leaves production (BS to LL)
SIC 20, lower basin	UL	345.58	39.48 to ∞	Lower - SIC 20 allocations decrease (UL to BS)
SIC 28, lower basin	UL	79.82	39.48 to ∞	Lower - SIC 28 allocations decrease (UL to BS) Upper - none
SIC 32, lower basin	UL	152.48	39.48 to ∞	Lower - SIC 32 allocations decrease (UL to BS) Upper - none

[1] LL–at the lower limit (zero allocations).
BS–in the basis, but not at the maximum possible level permitted by the constraint set.
UL–in the basis, and at the maximum possible level permitted by the constraint set.
[2] Second or third year, as noted in text.

results. While we have been able to construct and test a relatively large and inclusive model, it must be noted that the model is still a highly simplified characterization of the Pecos Basin economy and hydrology. With these reservations and disclaimers in mind, there appear to be some important policy implications for the Pecos Basin in New Mexico. The more significant of these implications may be summarized as follows:

1) The current value and values of water between 1971 and 1990, when measured as contributions to basin product, appear to be relatively low, less than $9.00 per additional acre-foot. This finding suggests that small amounts of additional water (10,000 to 30,000 acre-feet) could most efficiently be obtained from internal basin sources through water transfers. However, a problem arises with respect to large-scale water demands. Certain industries might be induced to locate in the basin if relatively large amounts of water were to become available, yet our model does not include this as one of the possibilities.

2) The transfer model results indicate that no major locational transfers of water within the basin need to be contemplated at this time. Instead of applying actual irrigated crop productivities in the upper basin, "adjusted" measures were used which, of course, do not differentiate actual differences in incremental value added per additional acre-foot between the two sub-basins. Because a portion of withdrawals in the upper basin can be reused in the lower basin, incremental value added would have to be 30 to 50 percent lower in the upper basin in order for the model to yield a sizable transfer. It is the writer's judgment, on the basis of the statistics recorded in Appendix J, that such a percentage difference does exist between actual measures of incremental value added for the two sub-basins, but there need not be a difference such as this if efficient farm management practices are instituted within the upper basin.

3) If transfers between sectors or between crops are necessary, from our computations it would be least costly to withdraw small amounts (one-tenth to three-quarters of an acre-foot) from each acre rather than withdrawing acreage. This statement, however, is based on average yields and average soil and water characteristics, and therefore may not apply in all situations. However, this finding indicates that the three-acre-feet limitation is a step in the right direction with regard to limiting water use for time or sectoral transfers.

4) The intrabasin water transfer model made practically no attempt to conserve water for future use over the 20-year planning period, even when a range of interest rates from 1 to 10 percent is utilized. This is suggestive that further studies need not concentrate on conservation problems or policies with respect to the entire Pecos Basin in New Mexico, though detailed water conservation studies are most certainly needed for sub-basin configurations such as the Roswell-Artesia area. In addition, the earlier statement with regard to conservation for the entire basin is qualified by several specific assumptions of the model; namely, that a terminal planning period is appropriate, and that forecasts of the growth path by sectors within the basin are reasonably accurate. The terminal planning period biases the model toward non-conservation, particularly when one introduces the idea that forecasts of future industrial development might be in error. After the twentieth year, implicitly the value of water equals zero. However, discounted values of water at the end of twenty years are much lower than their value today. Thus, even with relatively large values associated with industrial water use in the distant future, conservation may still not result.

5) Results of the model suggest that current state water-quality standards may be quite costly to the Pecos River Basin with regard to industrial development and locational shifts in irrigated agriculture. Practically no shift in location of current crop production areas within the basin can occur without violating state stream standards. While our results must be viewed as highly tentative with regard to water quality, they indicate that a large-scale study of water quality in relation to economic development may prove valuable in planning water utilization in the Pecos River Basin.
It is interesting to note that shadow prices for water quality, when transformed to quantity units, were of the same magnitudes as shadow prices for water quantity. Thus, water quality as a resource, given the state stream standards, is as scarce as water quantity in the Pecos River Basin.

6) A major criticism can be levied at the model; namely, the assumptions of deterministic (nonstochastic) stream flows and a planning unit of one year, thereby excluding seasonal flow variations. It is admitted that the model has these weaknesses, but it should also be noted that the model was developed for long-range planning purposes—and thus, seasonal variations are somewhat less important. In

addition, river flows in the upper and lower basins may vary over an extremely wide range before there is a change in the optimal reallocations and preliminary policy prescriptions enumerated here.

7) One of the most uncertain coefficient estimates in the model is the rate of transfer coefficient. This coefficient supposedly expresses the implicit social losses, such as unemployment of labor and capital from sectoral water transfers at too high a time rate. Initially, 7 percent was selected as the *highest* acceptable transfer rate, yet the evidence justifying this choice is slight. Our preliminary results indicate that the model is sensitive to the magnitude of transfer rates (see table 22). It is recommended that a comprehensive study be initiated on establishing socially acceptable sectoral transfer rates, as these rates would play an important role in judging the efficacy of any policy with regard to intrabasin water transfers.

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APPENDIX A

POPULATION PROJECTIONS, 1980-2000

Methodology

The two obvious determinants of population changes in a given region are net rates of migration and net birth rates. Population forecasts, to be reasonably accurate, require secondary forecasts of economic and social stimuli responsible for causing shifts in migration patterns and net birth rates. Net birth rates apparently do not depend on such regional economic characteristics as job availability, specialized industry development, or governmental military installation or agency location. Patterns of migration between states can largely be explained by changes in the level of employment and in the number of military personnel within states.[1]

This appendix briefly examines the existing projections of population for the Pecos Basin, the underlying assumptions on which the projections are based, and the degree of dispersion between them. The purpose is not to develop a complete projections model and apply it, rather to integrate existing projections and arrive at reasonable point estimates for the years 1980 and 2000, along with an index of potential variability in these point estimates.

Projections for rural and urban population, by county, within the Pecos Basin prepared by Edgel (14) serve as the basis for comparison of alternative projections. Edgel's estimates are compared with linear extrapolations of 1950-1960 population trends to 1980 and 2000, respectively.

Basic Population Projections

In table A-1, Edgel's low, medium, and high population projections are separated on the basis of urban and rural components. The two components were obtained from 1960 Bureau of Census estimates of urban and rural population in each of the counties within the Pecos Basin Five-County Area.[2] The urban-rural proportions were assumed as not changing between 1960 and 1980, or 1980 and 2000. This assumption undoubtedly introduces an upward bias in rural projections and, conversely, a downward bias for urban projections, though recent upward trends in location of urban housing toward rural areas may partially offset the recognized bias.

Population in each county, whether urban or rural, is assumed to increase between 1960 and 1980, and between 1980 and 2000, even though only Chaves and Eddy Counties had marked increases in population between 1950 and 1960. De Baca, Guadalupe, and San Miguel Counties underwent population reductions between 1950 and 1960, particularly in the rural areas. While the State of New Mexico as a whole registered a net outflow from rural areas of slightly over 4 percent between 1950 and 1960, San Miguel, De Baca, and Guadalupe Counties had net reductions of rural populations of 24, 14, and 17 percent, respectively. Thus Edgel's projections indicate complete reversal of recent trends of declining population, both rural and urban, between 1960-1980, as do other projections cited later. Edgel's projections apparently do not take into account recent changes in population by counties, but are based on probable outputs of various New Mexico industries in 1980 and 2000. Projections in table A-1 therefore depend almost exclusively on projected levels of employment by industry and not on other determinants of migration patterns.

If population trends over the interval 1960 to 1980 replicate the trends between 1950 and 1960 in the Pecos Basin, population will increase but only very slightly. The results of projecting linear trends by counties derived from the 1950 to 1960 period forward to 1980 and 2000 are presented in table A-2. The linear extrapolations of 1950 to 1960 population trends indicate a much lower Pecos Basin population for 2000 than Edgel's estimates. However, the 1980 population projection lies between Edgel's low and medium projections for 1980.

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[1] Blanco (2, pp. 69-76) found that more than 86 percent of the variation in civilian migration rates is explainable by changes in unemployment levels and military personnel within states.

[2] The 1960 and assumed future urban-rural proportions, in percent, for the five counties are as follows: Chaves, 69.0 urban, 31.0 rural; De Baca, 61.0 urban, 39.0 rural; Eddy, 74.0 urban, 26.0 rural; Guadalupe, 70.0 urban, 30.0 rural; and San Miguel, 59.0 urban, 41.0 rural. Source: 1960 Census of Population, *Volume I, Characteristics of the Population, Part 33*, Bureau of Census, United States Department of Commerce.

It would appear reasonable to assume that the 1950 to 1960 trends in population may not continue into the future, at least in terms of rural out-migration. Alternatively, Edgel's forecasts could not be fulfilled without a radical change in rural migration patterns. Thus Edgel's projections may be viewed as the probable upper limits, and our linear trend estimates as the probable lower limits, to the 1980 and 2000 population of the Pecos Basin.

In table A-3, alternative population projections are compared. Adjusted forecasts by the Bureau of the Census and the United States Senate Select Committee on Water Resources are tabulated for the Pecos Basin Five-County Area (PBFCA), along with Edgel's projections and the linear trends previously discussed. For 1980, the upper and lower limits of each of the five projections cover, at least partially, the range of each other projection, indicating a reasonable degree of similarity between the alternative forecasts. For 2000, Edgel's range of projections lies within the broad interval specified by the Senate Select Committee, but is more than 60,000 above the linear estimate based on the trend in population between 1950 and 1960.

Summary

Wide variation was found between alternative population projections, depending on whether recent migration trends were considered, or emphasis was placed on the future employment-generating capability of the Pecos Basin. The increasing relative scarcity of water in the Pecos Basin may greatly affect these projections. Thus, the alternative population projections should be viewed only as benchmarks in determining potential future demands for water resources, with constraints due to water scarcity remaining at 1960 to 1965 levels. Recent reductions in mining employment may also have a significant impact on Pecos Basin population levels, though it is too early to quantify this effect with reasonable accuracy.

Table A-1. Urban and rural population projections by county for 1980-2000, Pecos Basin Five-County Area, New Mexico.

County	1960	1980			2000		
		Low	Medium	High	Low	Medium	High
Chaves	57,649	85,400	92,400	100,500	136,700	151,400	169,800
Urban	(39,605)	(58,670)	(63,479)	(69,044)	(93,913)	(104,012)	(116,653)
Rural	(18,044)	(26,730)	(28,921)	(31,456)	(42,787)	(47,388)	(53,147)
De Baca	2,991	4,300	4,600	5,100	9,100	10,100	11,400
Urban	(1,825)	(2,623)	(2,806)	(3,111)	(5,551)	(6,161)	(6,954)
Rural	(1,166)	(1,677)	(1,794)	(1,989)	(3,549)	(3,939)	(4,446)
Eddy	50,783	61,400	66,500	72,200	94,100	104,200	116,900
Urban	(37,529)	(45,375)	(49,144)	(53,356)	(69,540)	(77,004)	(86,389)
Rural	(13,254)	(16,025)	(17,356)	(18,844)	(24,560)	(27,196)	(30,511)
Guadalupe	5,610	7,300	8,000	8,800	14,400	16,000	18,000
Urban	(3,927)	(5,110)	(5,600)	(6,160)	(10,080)	(11,200)	(12,000)
Rural	(1,683)	(2,190)	(2,400)	(2,640)	(4,320)	(4,800)	(5,400)
San Miguel	23,468	27,700	30,100	33,500	44,000	49,000	56,100
Urban	(13,823)	(16,021)	(17,729)	(19,732)	(26,269)	(28,861)	(33,043)
Rural	(9,645)	(11,179)	(12,371)	(13,768)	(18,331)	(20,139)	(23,057)
Total	140,501	185,600	201,600	220,100	298,900	330,700	372,200

Sources: Ralph L. Edgel, *Projections of the Population of New Mexico and Its Counties to the Year 2000*, Bureau of Business Research, University of New Mexico, July and August 1965.

1960 Census of the Population, Characteristics of the Population, Volume I, Part 33, Bureau of Census, United States Department of Commerce.

Table A-2. Population projections, linear extrapolation of 1950-1960 trends, by counties, Pecos Basin Five-County Area, New Mexico.

County	Population			
	1950	1960	1980	2000
Chaves	40,605	57,639	91,707	125,775
Urban	(25,738)	(39,583)	(67,273)	(94,963)
Rural	(14,867)	(18,056)	(24,434)	(30,812)
De Baca	3,464	2,991	2,045	1,099
Urban	(2,113)	(1,825)	(1,249)	(673)
Rural	(1,351)[1]	(1,166)	(796)	(426)
Eddy	40,640	50,783	71,069	91,355
Urban	(26,219)	(37,541)	(60,185)	(82,829)
Rural	(14,421)	(13,242)	(10,884)	(8,526)
Guadalupe	6,772	5,610	3,286	962
Urban	(4,740)	(3,927)	(2,301)	(675)
Rural	(2,132)[1]	(1,683)	(985)	(287)
San Miguel	26,512	23,468	17,380	11,292
Urban	(13,763)	(13,823)	(13,943)	(14,063)
Rural	(12,749)	(9,645)	(3,437)	(2,771)
Total	117,993	140,491	185,487	230,483

[1] Urban-rural proportions for 1950 were unavailable; 1960 proportions were used to distribute 1950 county totals.

Table A-3. Alternative population projections for 1980 and 2000, Pecos Basin, New Mexico.

Study	Year Projection Completed	Level of Projection	Year 1980	Year 2000
			(1000's)	
Edgel Estimates	1965	low	186	299
		medium	202	331
		high	220	372
1950-1960 Trend Extrapolation	1967	medium	193	231
Bureau of Census[1]	1966	low	175	—
		medium	190	—
		high	207	—
United States Senate Select Committee[2]	1960	low	156	191
		medium	169	235
		high	192	308
United States Senate Select Committee[3]	1960	low	162	197
		medium	175	243
		high	199	318

[1] The Bureau of the Census provides only a medium projection for the State of New Mexico. Low, medium, and high projections for the Pecos Basin were obtained by applying Edgel's relationship between low-medium and high-medium, and adjusting the state projections to include only the Pecos Basin population.

[2] Average annual migration of the period 1950-1958 was assumed to prevail through 1970; for the 1970-2000 period, average annual migration over 1940-1958 was assumed.

[3] Average annual migration over the 1958-2000 period is assumed to equal one-half the 1940-1958 average.

Source: Ralph L. Edgel, *Projections of the Population of New Mexico and Its Counties to the Year 2000*, Bureau of Business Research, University of New Mexico, July and August, 1965.

1960 Census of Population, Characteristics of the Population, Volume I, Part 33, Bureau of Census, United States Department of Commerce, *Water Resources Activities in the United States—Population Projections and Economic Assumptions*, Senate Select Committee on National Water Resources, Committee Print No. 5, March 1960.

APPENDIX B

MUNICIPAL WATER USES, 1980-2000

Methodology

Municipal water withdrawals per year equal municipal population multiplied by yearly average water withdrawals per capita. To forecast municipal water withdrawals, secondary forecasts of these two components must be developed. Forecasts of urban and rural population by counties were presented in Appendix A. To obtain forecasts of population by communities in the Pecos Basin, urban population projections by county for 1980 and 2000 were proportionately distributed on the basis of 1960 population to communities in each county listed in table B-1.

Projections of average per capita water withdrawals were obtained by utilizing a regression equation estimated for communities in the Pecos Basin between 1960 population and estimates of 1960 per capita water withdrawals. Projected population for 1980 and 2000 was inserted in the regression equation to obtain estimates of future per capita water withdrawals by community. Projections of municipal water withdrawals by community were then estimated by taking the product of the two ancillary forecasts. High, medium, and low forecasts were obtained by utilizing the high, medium, and low urban population forecasts presented in Appendix A.[1] An arbitrary ceiling of 350 gallons of water per capita per day (GPD) was imposed on projections that indicated a level of withdrawals higher than 350 GPD from the regression relationship. In light of current per capita withdrawals in larger urban areas, 350 GPD per capita may seem slightly larger than may be realistically expected.

For our purposes, an overestimate of per capita withdrawals is preferable to an underestimate. The degree of increased competitiveness between municipal uses and other uses over time will be more pronounced and identifiable where a slight recognized overestimate is embedded into the projection.

The regression equation, computed from population levels and estimated per capita withdrawals for a selected sample of Pecos Basin communities during 1960 and utilized to predict per capita withdrawals for 1980 and 2000, was:

$$W_n^* = 85.5707 + \underset{(.0026)}{.0045}\,N \qquad r^2 = .77$$

$W_n^* \leqslant 350$ GPD, where W_n^* denotes per capita withdrawals and *N* community population (the size of the sample was 13). While this estimated relationship provides a good fit for communities with populations ranging from several hundred to approximately 40,000, it would undoubtedly overestimate per capita withdrawals for medium- to large-sized cities. An upper limit of 350 GPD per capita was assumed for 1980 and 2000, and when one considers recent trends in both home and commercial water use, this figure appears not to be unreasonably high for periods commencing 13 years in the future.

Discussion

Dinwiddie (see sources, table B-1) found a range of 30 to 260 GPD for municipalities in southeastern New Mexico with the degree of variability apparently attributable to development of local water companies in addition to availability of water supplies. The degree of variability in the estimates found in table B-1 is even wider, suggesting the possibility of large errors in the estimated withdrawals per day.

In table B-2 population projections by community are presented which were used to forecast municipal water withdrawals. These estimates are based on Edgel's projections for the urban population component for each county.

If a substantial rural-urban population shift within the Pecos Basin occurs, it is likely that the projected water withdrawals for population centers such as Roswell, Artesia, Carlsbad, and Las Vegas will present lower limits to future municipal withdrawals. The community population projections should be viewed only as they might suggest a distribution of per capita withdrawals in a particular county, as the likelihood of any one community's replicating the individual forecast is very

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[1] Edgel's high, medium, and low estimates for urban population were used here.

small. The pattern of predicted withdrawals (table B-3) by community should be viewed in a similar manner.

The medium forecasts for municipal withdrawals presented in table B-3 for the entire Pecos River Basin are less than 10 percent smaller for 1980, and approximately 2 percent smaller for 2000, than earlier estimates prepared by DePass and presented in table B-4. The average basin estimate for per capita municipal withdrawals listed in table B-4 was 172 GPD and 199 GPD for 1980 and 2000 respectively. These estimates were constructed on the basis of national trends in per capita consumption rather than on intrabasin trends in per capita withdrawals, and also they apply to rural as well as urban withdrawals.

Compound rates of growth for the projection of municipal water withdrawals are approximately 1.75, 2, and 3 percent for low, medium, and high 1980 projections respectively, and 2.4, 2.7, and 3.2 percent for the low, medium, and high 2000 projections, respectively. The Senate Select Committee reports contain forecasts of compound growth rates for municipal water withdrawals of approximately 3.8 percent for the entire Rio Grande-Pecos (40) Water Resource Region. Our estimates are considerably below 3.8 percent, but the Senate Select Committee projection included the metropolitan areas of Albuquerque, Santa Fe, and El Paso.

To test the reliability of orders of magnitude in these projections, a comparison can be made on the basis of projected per capita income levels in New Mexico and per capita withdrawals as related to per capita income. Per capita money income in the State of New Mexico has risen at approximately the compound rate of 3.25 percent over the past decade. Assuming this rate to continue through 1980, and further assuming the relationship between money income and demand for municipal water in percentage terms to be between .31 and .44, projected percentage growth rate in municipal demand would be between 1.01 and 1.43 percent.[2] The range of these estimates is markedly lower than our projections based on a selected sample of New Mexico communities and a regression relationship between size of community and per capita withdrawals.

Consumptive Use

A certain proportion of municipal water withdrawals constitutes return flows which in part, depending on treatment, become available again for other uses. In New Mexico where return flows are not spilled into the ocean or estuarine coastal waters, a higher relative proportion of return flows is available for reuse. This is partly counterbalanced by higher levels of evaporation.

The degree of variability in municipal consumptive use between cities and water resource regions is quite large. For example, estimates of losses range from 6 percent for San Antonio, Texas, to 64 percent for El Paso, Texas, in a large sample of western United States cities.[3] The potential for error in these estimates is very large because withdrawals minus return flows to treatment plants are augmented by seepage and reduced by losses from pipes under pressure. Only if increases due to seepage from unpressurized sewer and drainage pipes equaled losses from pressurized pipes would an accurate measure of consumptive use be obtainable. A second problem is that of losses augmenting shallow aquifer supplies and thus increasing reusable return flows. Clearly, in this case, the estimates of consumptive use would be biased upward.

For lack of specific consumptive use coefficients for individual communities in the Pecos Basin, a range of coefficients is utilized based on estimates developed by Wollman and Bower for the Rio Grande-Pecos Water Resource Region. The three estimates applied here were 35 percent, 40 percent, and 45 percent for the percentage of municipal water withdrawals consumptively used or removed from potential reuse. The 40 percent estimate[3] was for eight western water resource regions and assumed that commercial and industrial water withdrawals constituted 35 percent of the municipal withdrawals.

In table B-5 projections of municipal return flows for 1980 and 2000 are presented, given the low, medium, and high consumptive use coefficients discussed previously, and medium projections of municipal withdrawals listed in table B-3. It is likely that these estimates represent upper limits to consumptive use. Increasing scarcity and water development costs in the future will provide additional incentives in reducing water system leakages, although this will be somewhat counterbalanced by the relatively greater amounts of water that are used for purely household tasks as population density and the tendency toward apartment living increase.

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[2] For the range of estimates applied here, see C. W. Howe and F. P. Linaweaver, "The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure," *Water Resources Research*, Vol. 3, 1967, p. 13.

[3] These estimates were obtained from a study of regional variations in municipal intake and losses by N. Wollman, Department of Economics, University of New Mexico.

Summary

While the projections in table B-3 infer a rapid increase in municipal water withdrawals for the Pecos Basin, even the forecasts for 2000 are relatively small compared with withdrawals of other uses. Given the upper limit projections of 42,885 and 81,743 acre-feet per year for 1980 and 2000 respectively, these magnitudes represent only about 8 and 16 percent, respectively, of Pecos Basin total withdrawals in 1960. Strictly from the viewpoint of adequate supply for municipalities, there are adequate sources through 2000; but if current supplies are not augmented from outside the Pecos Basin a substantial amount of intrabasin transfer of water may be indicated. An alternative is the application of secondary and tertiary treatment to increase the substitutability of once-used water for commercial and public supply augmentation. Of the 19 communities listed in table B-1, eight provided secondary treatment (all communities with population greater than 2,000). Most of the remaining communities used individual cesspools or septic tanks (9).

Table B-1. Population by communities and total and per capita water withdrawals, Pecos Basin Five-County Area, New Mexico, 1962.

County	Community	Population	Water Withdrawals[1] (gallons per day)	Per Capita Withdrawals[2] (gallons per day)
Chaves				
	Roswell	39,593	9,898,250	250
	Dexter	885	70,800	80
	Orchard Park	375	24,000*	60
	Greenfield	200	16,000*	80
	Hagerman	1,144	343,200*	300
	Lake Arthur	387	19,350	50
De Baca				
	Fort Sumner	1,809	132,057	70
Eddy				
	Artesia	12,000	2,400,000*	200
	Carlsbad	25,541	4,341,970	170
	Happy Valley	600	36,000*	60
	Hope	108	10,600	100
	Loving	1,646	164,600*	100
	White City	N.A.	100,000*	N.A.
Guadalupe				
	Anton Chico	300	22,500*	80
	La Loma	130	9,750*	80
	Puerto de Luna	150	10,000	67
	Santa Rosa	2,220	155,400	70
	Vaughn	1,170	128,700*	110
San Miguel				
	Las Vegas	13,818	1,105,500*	80

[1] Enumeration time of withdrawals varies, but is usually for late 1962. No adjustment was made for differences between 1960 and 1962.

[2] Rounded to the nearest 10 gallons.

*Estimated.

Sources: G. A. Dinwiddie, *Municipal Water Supplies and Uses, Northeastern New Mexico*, Technical Report 29B, New Mexico Engineer, 1964.

G. A. Dinwiddie, *Municipal Water Supplies and Uses, Southeastern New Mexico*, Technical Report 29A, New Mexico Engineer, 1963.

Table B-2. Population projections[1] by community for 1980-2000, Pecos Basin Five-County Area, New Mexico.

County	Community	1980			2000		
		Low	Medium	High	Low	Medium	High
Chaves							
	Roswell	54,600*	59,070	64,250	87,400	96,790	108,560
	Dexter	1,220	1,320	1,440	1,953	2,160	2,430
	Orchard Park	520	560	610	830	920	1,030
	Greenfield	280	300	320	440	490	550
	Hagerman	1,580	1,700	1,860	2,530	2,800	3,140
	Lake Arthur	530	580	630	860	950	1,060
De Baca							
	Fort Sumner	2,600	2,780	3,080	5,502	6,110	6,890
Eddy							
	Artesia	13,690	14,780	16,100	20,990	23,240	26,070
	Carlsbad	29,050	31,460	34,600	44,520	49,300	55,300
	Happy Valley	680	740	800	1,040	1,160	1,300
	Hope	120	130	140	190	210	230
	Loving	1,870	2,030	2,200	2,870	3,180	3,570
Guadalupe							
	Anton Chico	390	420	470	760	850	950
	La Loma	170	180	200	330	370	410
	Puerto de Luna	190	210	230	380	420	480
	Santa Rosa	2,860	3,130	3,450	5,640	6,260	7,050
	Vaughn	1,510	1,650	1,820	2,970	3,300	3,710
San Miguel							
	Las Vegas	16,020	17,730	19,730	26,270	28,860	33,040
Total		127,880	138,770	151,930	205,475	227,370	255,770

[1] Computed by distributing Edgel projections by county, utilizing weights equal to the ratio of 1960 population of community to 1960 county population, and assuming this ratio will remain relatively constant between 1960 and 2000.

*Population estimates rounded to the nearest ten.

Table B-3. Projections of urban water withdrawals by community for 1980-2000, Pecos Basin Five-County Area, New Mexico.[1]

County	Community	1980			2000		
		Low	Medium	High	Low	Medium	High
			(acre-feet per year)			(acre-feet per year)	
Chaves							
	Roswell	20,256	23,157	25,187	34,259	37,943	42,554
	Dexter	124	135	148	206	231	262
	Orchard Park	51	55	60	83	92	104
	Greenfield	27	29	32	43	48	54
	Hagerman	164	178	195	274	308	351
	Lake Arthur	53	57	62	86	95	107
De Baca							
	Fort Sumner	283	306	344	680	712	900
Eddy							
	Artesia	2,258	2,519	2,850	4,231	4,985	5,926
	Carlsbad	7,035	8,004	9,155	14,255	16,973	20,718
	Happy Valley	68	73	80	105	118	133
	Hope	12	12	13	18	20	23
	Loving	197	215	236	317	356	406
Guadalupe							
	Anton Chico	38	42	46	80	85	96
	La Loma	16	18	19	32	36	40
	Puerto de Luna	19	21	23	37	42	47
	Santa Rosa	315	350	390	701	798	926
	Vaughn	156	172	191	329	371	426
San Miguel							
	Las Vegas	2,829	3,283	3,854	5,997	6,950	8,670
Total		33,901	38,626	42,885	61,733	70,163	81,743

[1] See text for description of computational method.

Table B-4. Projected municipal water withdrawals for 1980-2000, Pecos River Basin, New Mexico.

		Population	Gallons per Day per Capita	Withdrawals	
				Gallons per Day	Acre-Feet per Year
1980					
	Low	185,600	172	31,923,200	35,758
	Medium	201,600	172	34,675,200	38,841
	High	220,100	172	37,857,200	42,406
2000					
	Low	298,900	199	59,481,100	66,627
	Medium	330,700	199	65,809,300	73,716
	High	372,200	199	74,067,800	82,967

Source: Unpublished estimates, N. Wollman and C.De Pass, University of New Mexico, Albuquerque.

Table B-5. Projections of municipal return flows by communities for 1980-2000, Pecos Basin Five-County Area, New Mexico.

County	Community	1980 55[1] percent	 60 percent	 65 percent	2000 55 percent	 60 percent	 65 percent
			(acre-feet per year)			(acre-feet per year)	
Chaves							
	Roswell	12,736	13,894	15,052	20,869	22,766	24,663
	Dexter	74	81	88	127	139	150
	Orchard Park	30	33	36	51	55	60
	Greenfield	16	17	19	26	29	31
	Hagerman	98	107	116	169	185	200
	Lake Arthur	31	34	37	52	57	62
De Baca							
	Fort Sumner	168	184	199	392	427	463
Eddy							
	Artesia	1,385	1,512	1,637	2,742	2,991	3,240
	Carlsbad	4,402	4,802	5,203	9,335	10,184	11,033
	Happy Valley	40	44	48	65	71	77
	Hope	7	8	8	11	12	13
	Loving	118	129	140	196	214	231
Guadalupe							
	Anton Chico	23	25	27	47	51	55
	La Loma	10	11	12	20	22	23
	Puerto de Luna	12	13	14	23	25	27
	Santa Rosa	193	210	228	439	479	519
	Vaughn	95	103	112	204	223	241
San Miguel							
	Las Vegas	1,806	1,970	2,134	2,310	2,519	2,729
	Total	21,244	23,177	25,110	37,078	40,449	43,817

[1] Return flows are assumed to be alternatively 55, 60, and 65 percent of water intake.

APPENDIX C

RURAL DOMESTIC WATER USE, 1980-2000

Methodology

If the rural population of the Pecos Basin increases in the future as rapidly as Edgel's forecasts suggest, a significant increase in rural domestic withdrawals will result. Unfortunately, adequate estimates of per capita rural withdrawals are apparently unavailable. In lieu of precise forecasts of per capita rural withdrawals, estimates were made on the basis of per capita withdrawals for very small communities in the Pecos Basin. For villages in southeastern New Mexico with less than 500 population and a few business establishments, per capita withdrawals center around 70 to 75 gallons per day (GPD). With this average in mind, low, medium, and high estimates of rural domestic withdrawals were set at 70, 80, and 90 GPD per capita, for both 1980 and 2000.

In table C-1, Edgel's rural population forecasts are presented by county for 1980 and 2000. Projected rural domestic water withdrawals are presented in table C-2, based on Edgel's population forecasts and on the estimates of GPD presented above. However, the upper limit rural domestic withdrawal estimates for 1980 and 2000 are less than 1 to 2 percent of estimated total 1960 basin water withdrawals. Note that Edgel's low estimates were coupled with the low per capita rural withdrawal estimates, and the same procedure was applied to obtain medium and high estimates.

A second set of rural domestic water withdrawal projections was constructed from the 1950-1960 linearly extrapolated population forecasts in table A-3. The same per capita estimates previously discussed, of 70, 80, and 90 GPD, were assumed, and the resulting projections are given in table C-3.

Discussion

Extreme differences exist in the two sets of projections presented in tables C-2 and C-3, both in terms of Pecos Basin totals, and in the relative amounts of population distributed between counties. The difference between 1980 projections of rural water withdrawals amounts to 35 to 40 percent, and for 2000 projections 55 to 65 percent. Of course, which set of projections is more likely to be true depends on whether a radical departure from recent trends is foreseen in rural population migration patterns. While the estimate of zero rural water withdrawals in San Miguel County seems totally unrealistic, the relative stabilization of rural withdrawals in other counties over the 1980-2000 period appears to be a reasonable hypothesis as projected from recent trends. The forecast based on Edgel's population projections indicates almost a two-fold increase in rural domestic water withdrawals, which appears unreasonably high unless water scarcity in the agriculture sector is alleviated, or a radical change in rural per capita withdrawals emerges.

Consumptive use by rural domestic users was computed by assuming a range of 35 to 45 percent for proportions of withdrawals consumptively used—the same range of proportions adopted for municipal withdrawals (see Appendix B). The estimates of rural domestic consumptive use are tabulated in table C-4.

Table C-1. Projected rural population by counties for 1980-2000, Pecos Basin Five-County Area, New Mexico.

County	1980 Low	 Medium	 High	2000 Low	 Medium	 High
Chaves	26,730	28,921	31,456	42,787	47,388	53,147
De Baca	1,677	1,794	1,989	3,549	3,939	4,446
Eddy	16,025	17,356	18,844	24,560	27,196	30,511
Guadalupe	2,190	2,400	2,640	4,320	4,800	5,400
San Miguel	11,179	12,371	13,768	18,331	20,139	23,057
Total	57,801	62,842	68,697	93,547	103,462	116,561

Source: R. E. Edgel, *Projections of the Population of New Mexico and Its Counties to the Year 2000*, Bureau of Business Research, University of New Mexico, July and August 1965.

Table C-2. Projected rural domestic water withdrawals[1] by county for 1980-2000, Pecos Basin Five-County Area, New Mexico.

County	1980 Low	1980 Medium	1980 High	2000 Low	2000 Medium	2000 High
	(acre-feet per year)			(acre-feet per year)		
Chaves	2,096	2,591	3,171	3,355	4,246	5,357
De Baca	132	161	201	278	353	448
Eddy	1,256	1,555	1,900	1,926	2,437	3,084
Guadalupe	172	215	266	339	430	544
San Miguel	876	1,108	1,387	1,437	1,805	2,324
Total	4,532	5,630	6,925	7,335	9,271	11,757

[1] Based on Edgel's population projections, Table C-1.

Table C-3. Alternative projections of rural domestic water withdrawals based on 1950-1960 population trends, Pecos Basin Five-County Area, New Mexico.

County	1980 Low	1980 Medium	1980 High	2000 Low	2000 Medium	2000 High
	(acre-feet per year)			(acre-feet per year)		
Chaves	1,916	2,189	2,463	2,416	2,761	3,106
De Baca	62	71	89	33	38	43
Eddy	853	975	1,097	668	764	859
Guadalupe	77	88	99	24	26	29
San Miguel	270	308	346	0[1]	0[1]	0[1]
Total	3,178	3,631	4,085	3,141	3,589	4,037

[1] Population forecast was negative.

Table C-4. Projections of rural domestic consumptive use of water for 1980-2000, Pecos Basin Five-County Area, New Mexico.

County	1980 Low[1]	1980 Medium[1]	1980 High[1]	2000 Low	2000 Medium	2000 High
	(acre-feet per year)			(acre-feet per year)		
Chaves	734	1,036	1,427	846	1,698	2,411
De Baca	46	64	91	12	141	202
Eddy	440	622	855	234	975	1,384
Guadalupe	60	86	120	9	172	245
San Miguel	307	443	624	—	722	1,046
Total	1,587	2,251	3,117	1,101	3,708	5,288

[1] Projections of high and medium levels based on Edgel's population projections. Projections of low levels are based on 1950-1960 linear trends in rural population of Pecos Basin Five-County Area.

APPENDIX D

PROJECTIONS OF IRRIGATED CROP ACREAGES AND IRRIGATION WITHDRAWALS, 1980-2000

Methodology

A set of alternative assumptions regarding irrigation water constraints and crop production trends was developed to indicate the magnitudes of probable changes in irrigated acreages and irrigation water withdrawals in the Pecos Basin over the next two to four decades. The set of assumptions reflects three major probable effects: potential irrigated acreage development, a three-acre-feet per acre irrigation water limitation, and trends in irrigated acreages by crop over the last 16 years.

The projections of irrigated acreages adjusted for these major effects and their possible combinations indicate only the direction of changes rather than probable absolute estimates. Important economic considerations such as alterations in federal government programs for feed grains or cotton, inter-basin transfers of water for irrigation, or continuing competition for existing flows from industrial and municipal users have not been considered. Also, limits in the economic depth of pumping from aquifers is not included. The underlying assumption for these projections is that, except for limitations imposed by a three-acre-feet maximum on irrigation water applied, no other constraints on irrigated acreage will become significant.

While the assumptions listed may not contribute importantly to changes in dimensions of irrigated agriculture over the next four decades, they provide reasonable projections of upper limits to the possible expansion of irrigated acreage in the Pecos Basin. The projections further indicate to some degree the probable upper limits in reduction of acreages caused by a three-acre-feet legal limitation. It was assumed that crops normally requiring more than three acre-feet per acre in the Pecos Area would not be planted, which provides the upper limit to potential acreage reductions. If trends in planted acreages of certain crops continue regardless of water scarcities, the projections tabulated here might be considered an adequate preliminary set of forecasts.

Assumptions

A. Crop acreages in the Pecos Basin in 1960 will continue to be irrigated, and maximum potential irrigated land in each county will be developed. To estimate withdrawals by crop, it was further assumed the crop planted on newly irrigated land will be in direct proportion to 1960 acreages by county. (Potential irrigated acreage development for the Pecos Basin is found in table D-6.)

Assumption A implicitly carries the idea that water resources will become available for potential acreage development, either through increasing the rate of reuse of existing Pecos Basin sources or by transference of fresh water to the Pecos from contiguous basins. The projections of irrigated acreage given Assumption A form what might be considered the future upper limit to potential irrigation withdrawals in the Pecos Basin.

B. All irrigated acreage is restricted to applications of less than three acre-feet per year for any crop.
   1. All crops requiring more than three acre-feet per year are not produced, and the residual acreage is assumed to be planted to crops that require less than three acre-feet, in direct proportion to percentages by crop of total irrigated acreages in 1960. In table D-7 assumed water requirements for this study are given in acre-feet by crop and county.
   2. The residual irrigated acreage caused by the three-acre-feet limitation's removal of certain crops from production is assumed to be planted and three acre-feet of water applied per year.
   3. The irrigated acreage previously planted to crops requiring more than three acre-feet per acre is no longer irrigated.

The three alternative assumptions under "B" reflect the extremes that might occur in changes of irrigated crop acreages. It is highly probable that none of these conditions will prevail; rather, some combination of them will occur with the assumed acre-foot limitation. The margin of error that may be introduced by mis-specification of water requirements for particular crops (table D-7) severely qualifies the estimates that follow.

C. Crop acreages by county in 1980 and 2000 will reflect trends in irrigated acreages planted between 1954-1965.

Assumption C indicates probable crop acreages in 1980 and 2000 if trends in certain crops in the Pecos Basin continue to persist into the future. Trend lines were calculated by crop and by county and are presented in tables D-9 and D-10. Only those trends for which the regression coefficient was significant at the 5 percent level in applying a single-tailed "t" test were used in predicting crop acreages under "C." Crops with insignificant trends were assumed to remain constant through 2000 by county within the Pecos Basin.

A total of 15 combinations of the three major assumptions plus the three variants under "B" are possible. The results are shown in tables D-1 and D-2 for the 15 combinations in terms of water withdrawals. In tables D-3 and D-4, consumptive use by county, given the 15 combinations, is recorded. In table D-5, the percentage of irrigated land planted to various crops is recorded by county for 1960. These percentages were used to distribute potential acreages between crops under "A" and residual acreages between crops under "B." It was assumed under "C" that if acreage for a certain crop was predicted to be less than zero, the actual acreage planted would be zero.

For projections under "A," the maximum potential acreage expansion was assumed, which is recorded in table D-6, line VI.

Discussion

The 15 combinations of assumptions regarding three-acre-feet limitations, potential acreage development, and recent trends in irrigated crops resulted in wide variations of projected acreages and water withdrawals. The three-acre-feet limitation with the additional assumption of no crops planted (B-3) created a substantial reduction in acreages in all five counties. Since the projections rested on the assumption that our estimates of water requirements per crop are correct and constant between 1960 and 2000, a substantial amount of error may have been introduced merely from these extremely rigid water requirements assumptions. It appears reasonable, then, to assume that projections containing B-3 would form the lower limit of potential crop acreages planted in 1980 and 2000. When B-3 is coupled with our third assumption (C) of trends in specific crops continuing through 2000, very small estimates of crop acreages by county are obtained. Both "C" and "B" assumptions contributed a downward component to the resulting projections, while "A" influenced the projections in an upward direction for the projection combination (A, B-3, C).

The upward limit on irrigated acreages and withdrawals was obtained from the combinations of assumptions A and C. Here, trends in irrigated crops favored crops with larger water requirements and consequently total withdrawals expanded through the influence of assumption C.

For medium projections, assumption C, or applying recent crop trends with no assumed acreage expansion (A), or three-acre-feet limitation (B) was utilized. The effect of assumption C in isolation was to reduce slightly irrigated acreage in the Pecos Basin between 1960 and 1980 (see table D-13). While projections containing "C" plus the three-acre-feet limitations (B-2) might appear more reasonable as medium estimates, the problem of sensitivity of the projections to small changes in water requirements by crop, limits the degree of confidence that might be placed in this projection. Also "B-1, C" or "B-2, C" indicate almost a 30 percent reduction in water withdrawals between 1960 and 1980, which appears unrealistic unless the three-acre-feet limitation in withdrawals is maintained and enforced.

Even with the degree of arbitrariness in water requirements per crop, it is apparent from our results that crop acreages in 1980 and 2000 are highly sensitive to changes in acre-foot limitations, potential acreage development, and recent crop production trends. Table D-13 makes a comparison of recent projections on irrigated crop acreages for the Pecos Basin in the form of a single index of projected change. The projections from three other studies indicate an upward change in irrigated acreage within the Pecos Basin Five-County Area, but they are within the high-medium range of projections contained in this study.

Table D-1. Alternative projections of irrigation withdrawals by county for 1980, Pecos Basin Five-County Area, New Mexico.

Assumptions[1]	County					Total
	Chaves	De Baca	Eddy	Guada-lupe	San Miguel	
			(acre-feet per year)			
A	542,358	26,047	402,150	27,235	37,449	1,035,239
B-1.	263,315	11,774	198,191	11,946	16,676	501,902
C	450,171	22,738	277,179	15,392	21,860	787,340
A, B	372,017	16,837	268,833	16,821	23,543	698,051
A, B-2.	389,329	19,271	284,059	19,125	27,463	739,247
A, B-3.	72,691	4,898	32,428	5,607	10,881	126,505
B-2.	275,574	13,475	201,473	13,582	19,454	523,558
B-3.	51,453	3,428	23,000	3,982	7,667	89,530
A, C	620,256	27,029	487,147	32,189	40,441	1,207,062
A, B-1., C	393,531	17,705	286,140	6,759	19,116	723,251
A, B-2., C	393,564	19,650	286,140	20,143	29,012	748,509
A, B-3., C	50,415	4,320	23,952	67	7,235	85,989
B-1., C	285,618	14,897	162,807	3,232	10,349	476,903
B-2., C	285,618	16,555	162,839	9,632	14,818	489,462
B-3., C	36,597	3,658	13,658	32	3,031	56,976

[1] Letter combinations denote assumptions listed in the text.

Table D-2. Alternative projections of irrigation withdrawals by county for 2000, Pecos Basin Five-County Area, New Mexico.

Assumptions[1]	County					Total
	Chaves	De Baca	Eddy	Guada-lupe	San Miguel	
			(acre-feet per year)			
A	615,122	28,307	445,116	30,146	41,453	1,160,144
B-1.	263,315	11,774	198,191	11,946	16,676	501,902
C	540,537	29,237	381,434	15,404	24,890	991,502
A, B	411,772	18,641	297,557	18,620	26,060	772,650
A, B-2.	430,938	21,336	314,409	21,168	30,399	818,250
A, B-3.	80,460	5,427	35,889	6,204	11,976	139,956
B-2.	275,574	13,475	201,473	13,582	19,454	523,558
B-3.	51,453	3,428	23,000	3,982	7,667	89,530
A, C	716,106	29,685	544,298	35,526	42,472	1,368,087
A, B-1., C	435,591	19,722	316,706	7,482	20,453	799,954
A, B-2., C	435,591	21,697	316,716	22,242	29,258	825,504
A, B-3., C	64,731	5,299	19,827	102	7,235	97,194
B-1., C	327,021	19,367	221,937	3,244	10,604	582,173
B-2., C	327,021	21,363	221,913	9,668	15,402	595,367
B-3., C	48,596	5,217	13,869	32	3,810	71,524

[1] Letter combinations denote assumptions listed in the text.

Table D-3. Alternative projections of consumptive use[1] from irrigation uses for 1980, by county, Pecos Basin Five-County Area, New Mexico.

Assumptions	County Chaves	De Baca	Eddy	Guada-lupe	San Miguel	Total
			(acre-feet per year)			
A	247,553	12,919	187,880	12,061	11,203	471,616
A-1.	105,728	5,922	80,028	5,536	6,151	203,365
C	211,868	11,260	138,865	6,749	6,461	375,143
A, B	149,360	8,469	109,129	7,795	8,684	283,437
A, B-2.	145,285	8,213	105,428	7,555	8,429	274,910
A, B-3.	29,184	2,464	13,163	2,598	3,991	51,400
B-2.	102,835	5,743	74,776	5,365	5,971	194,690
B-3.	20,657	1,724	9,336	1,845	2,829	36,391
A, C	291,918	13,385	243,952	14,114	11,936	575,305
A, B-1., C	134,700	8,302	95,380	6,083	8,535	253,000
A, B-2., C	143,065	8,158	104,119	7,422	8,306	271,070
A, B-3., C	17,254	2,026	7,983	60	2,499	29,822
B-1., C	97,763	6,985	54,269	2,909	4,621	166,547
B-2., C	105,093	6,876	59,242	3,549	4,496	179,256
B-3., C	13,785	1,717	4,542	29	1,353	21,426

[1] Consumptive use coefficients by crop and by county for 1960 were assumed to remain constant through 2000. The coefficients were obtained from estimates of the Department of Agronomy, New Mexico State University, Las Cruces.

Table D-4. Alternative projections of consumptive use[1] from irrigation uses for 2000, by county, Pecos Basin Five-County Area, New Mexico.

Assumptions	County Chaves	De Baca	Eddy	Guada-lupe	San Miguel	Total
			(acre-feet per year)			
A	274,009	14,301	207,955	13,350	12,401	522,016
B-1.	105,728	5,922	80,028	5,536	6,151	203,365
C	257,887	14,819	191,869	6,760	6,910	478,245
A, B	165,321	9,376	120,790	8,629	9,613	313,729
A, B-2.	160,811	9,093	116,693	8,362	9,330	304,289
A, B-3.	32,302	2,729	14,569	2,875	4,417	56,892
B-2.	102,835	5,743	74,776	5,365	5,971	194,690
B-3.	20,657	1,724	9,336	1,845	2,829	36,391
A, C	343,484	14,946	273,798	15,590	12,911	660,729
A, B-1., C	148,638	9,181	105,572	6,734	9,520	279,645
A, B-2., C	158,054	9,052	115,457	8,210	9,241	300,014
A, B-3., C	22,072	2,466	6,598	92	3,368	34,596
B-1., C	111,589	9,013	73,979	2,920	4,935	202,436
B-2., C	118,662	8,886	80,906	3,562	4,864	216,880
B-3., C	16,572	2,428	4,623	29	1,773	25,425

[1] Consumptive use coefficients by crop and by county for 1960 were assumed to remain constant through 2000. The coefficients were obtained from estimates by the Department of Agronomy, New Mexico State University, Las Cruces.

Table D-5. Percentage of irrigated acreage planted to specific crops, by counties, Pecos Basin Five-County Area, New Mexico, 1960.

Crop	County San Miguel	Guada-lupe	De Baca	Chaves	Eddy
Cotton	—	—	8.0	43.0	50.0
Alfalfa	54.0	67.0	63.0	36.0	36.0
Alfalfa seed	—	—	—	1.0	2.0
Barley	4.0	—	3.0	10.0	5.0
Oats	3.0	—	2.0	1.0	2.0
Sorghum	9.0[3]	13.0	19.0	7.0	4.0
Winter wheat	14.0[3]	5.0	2.0	—[2]	—[4]
Corn	15.0	15.0	2.0	1.0	1.0
Other[1]	1.0	—	1.0	1.0	—[4]
Total	100.0	100.0	100.00	100.0	100.0

[1] Includes rye, spring wheat, and grains produced and threshed in combination.
[2] Included under "other" crops.
[3] Irrigated acreages within San Miguel County not irrigated from waters draining into the Pecos Basin.
[4] Less than 0.25 percent.

Table D-6. Projected irrigated acreage with no constraints on water withdrawals, for 1980-2000, Pecos River Basin, New Mexico.

Description	Year 1980	2000
	(acres)	(acres)
I	181,045	184,795
II	209,688	245,109
III	218,805	246,455
IV	219,104	221,495
V	234,797	245,408
VI	250,340	277,093

I. Linear extrapolation of 1960-1966 trend.
II. Based on appraisal of production needs and accomplishments contained in United States Department of Agriculture, *Agriculture Land Resources*, Int. Bull., 40, June 1965.
III. Based on 1957 acreage plus United States Bureau of Reclamation proposed project acreages.
IV. Development of 25 percent of remaining federal potential, with 50 percent development of non-federal potential assumed.
V. Development of 50 percent of both federal and non-federal potential irrigated acreage assumed.
VI. Development of 100 percent of federal and non-federal irrigated land potential assumed.

Sources: N. Wollman, University of New Mexico, unpublished estimates. United States Department of Agriculture, *Land and Water Potentials and Future Requirements for Water*, Senate Select Committee, United States Senate, Committee Print No. 12, 1960.

Table D-7. Estimated water withdrawals per acre by crop and county, Pecos Basin Five-County Area, New Mexico, 1960-1961.

Crop	County San Miguel	 Guadalupe	 Eddy	 De Baca	 Chaves
			(acre-feet per year)		
Cotton	—	—	3.7	3.7[1]	3.7
Barley	3.0[1]	3.0[1]	3.0[1]	3.0[1]	3.0[1]
Corn	3.0	3.0	3.0[1]	3.0	3.0[1]
Oats	3.0[1]	3.0[1]	3.0[1]	3.0[1]	3.0[1]
Winter wheat	—	—	—	1.0[1]	1.0[1]
Sorghum	2.5[1]	2.5	2.5	2.5[1]	2.5
Alfalfa hay	4.8	4.8	5.3	4.5	5.3
Alfalfa seed	—	—	5.3[1]	—	5.3
Broomcorn	—	3.0[1]	—	—	—
Dry beans	4.0[1]	4.0[1]	4.0[1]	4.0[1]	4.0[1]
Vegetables	—	—	—	—	—
Chile	6.0	6.0	—	6.0	—
Apples	—	—	—	—	—
Irrigated pasture	3.5	3.5[1]	5.4	3.5	5.4

[1] Estimated. Estimates are subject to wide variability, which places definite restrictions on interpretation of projections based in part on assumption B.

Sources: Unpublished estimates, Department of Agricultural Economics, New Mexico State University, Las Cruces, and Colin Clark, *The Economics of Irrigation*, Pergamon Press, Oxford, 1967.

Table D-8. Estimated irrigated acreage by county, Pecos Basin Five-County Area, New Mexico, 1960-1966.

County	Irrigated Acreage 1960	 1966
	(acres)	(acres)
Chaves	92,850	96,441
De Baca	4,725	7,394
Eddy	67,650	64,245
Guadalupe	4,800	4,800
San Miguel	7,270	6,040
Total	177,295	178,920

Source: New Mexico Department of Agriculture, *New Mexico Agricultural Statistics*, Vol. 1, No. 5.

Table D-9. Estimated trends, selected irrigated crop acreages, by crop and county, Pecos Basin Five-County Area, New Mexico, 1954-1965.[1]

Crop and County	Constant Term (a)	Coefficient (b)	r^2	s^2
Alfalfa				
Chaves	17,156.00	1,328.09 (118.74)	.96	3,406.10
De Baca	1,970.80	56.30 (54.03)	.68	495.40
Eddy	12,396.90	993.95 (84.48)	.97	2,426.90
Cotton				
Chaves	46,177.00	-825.42 (411.70)	.45	11,832.00
Eddy	43,425.00	-1,262.23 (208.33)	.85	6,749.80
Guadalupe	38.35	-2.60 (0.71)	.73	20.27
Barley				
De Baca	247.50	-13.56 (4.62)	.63	132.76
Corn				
De Baca	163.94	-10.21 (3.09)	.69	88.86
Guadalupe	318.64	-16.89 (3.78)	.68	108.40
San Miguel	449.44	-12.49 (4.96)	.56	142.67

[1] The estimated equation was $V = a+bT$ where V and T are acres of irrigated crops and time, respectively.

[2] Standard error of the estimate.

Table D-10. Estimated trends, selected irrigated crop acreages, by crop and county, Pecos Basin Five-County Area, New Mexico, 1954-1965.[1]

Crop and County	Constant Term (a)	Coefficient (b)	r^2	s[2]
Oats				
De Baca	-37.53	8.89 (2.82)	.67	80.14
All Sorghums				
Chaves	8,738.87	-249.88 (84.21)	.64	2,388.20
Eddy	4,360.00	-204.89 (68.78)	.64	1,977.00
Guadalupe	154.35	-7.06 (3.87)	.40	111.58
San Miguel	44.80	13.32 (6.29)	.47	180.80
Winter Wheat				
Chaves	1,239.83	-84.24 (33.62)	.56	966.79
De Baca	279.70	-16.30 (5.56)	.63	159.37
Eddy	225.70	-16.14 (2.26)	.58	176.85
San Miguel	256.66	15.04 (6.19)	.54	177.90
Other				
Eddy	320.64	-26.21 (11.94)	.55	251.40

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[1] See footnote 1, table D-9 for explanation of estimated relationship.

[2] Standard error of the estimate.

Table D-11. Projections of irrigated acreage, alternative assumptions, for 1980, Pecos Basin Five-County Area, New Mexico.

	County					
Assumption	Chaves (acres)	De Baca (acres)	Eddy (acres)	Guadalupe (acres)	San Miguel (acres)	Total (acres)
A	131,178	6,759	95,380	6,759	10,264	250,340
A, B-1.	131,178	6,759	95,380	6,759	10,264	250,340
A, C	131,178	6,759	95,380	6,759	10,264	250,340
B-1.	92,850	4,725	67,650	4,800	7,270	177,295
B-2.	92,850	4,725	67,650	4,800	7,270	177,295
B-3.	18,143	1,376	8,159	1,600	3,341	32,619
C	95,206	5,686	54,269	3,232	5,556	163,949
A, B-2.	131,178	6,759	95,380	6,759	10,264	250,340
A, B-3.	25,632	1,968	11,503	2,253	4,716	46,072
A, B-1., C	131,178	6,759	95,380	6,759	10,264	250,340
A, B-2., C	131,178	6,759	95,380	6,759	10,264	250,340
A, B-3., C	16,085	1,649	7,984	67	3,005	28,789
B-1., C	95,206	5,686	54,269	3,232	5,556	163,949
B-2., C	95,206	5,686	54,269	3,232	5,556	163,949
B-3., C	12,199	1,387	4,542	32	1,627	19,787

Table D-12. Projections of irrigated acreage, alternative assumptions, for 2000, Pecos Basin Five-County Area, New Mexico.

	County					
Assumption	Chaves (acres)	De Baca (acres)	Eddy (acres)	Guadalupe (acres)	San Miguel (acres)	Total (acres)
A	145,197	7,482	105,572	7,482	11,361	277,094
A, B-1.	145,197	7,482	105,572	7,482	11,361	277,094
A, C	145,197	7,482	105,572	7,482	11,361	277,094
B-1.	92,850	4,725	67,650	4,800	7,270	177,295
B-2.	92,850	4,725	67,650	4,800	7,270	177,295
B-3.	18,143	1,376	8,159	1,600	3,341	32,619
C	109,007	7,369	73,979	3,244	6,080	199,679
A, B-2.	145,197	7,482	105,572	7,482	11,361	277,094
A, B-3.	28,371	2,179	12,732	2,494	5,220	50,996
A, B-1., C	145,197	7,482	105,572	7,482	11,361	277,094
A, B-2., C	145,197	7,482	105,572	7,482	11,361	277,094
A, B-3., C	21,577	2,016	6,609	102	4,020	34,324
B-1., C	109,007	7,369	73,979	3,244	6,080	199,679
B-2., C	109,007	7,369	73,979	3,244	6,080	199,679
B-3., C	16,198	1,987	4,623	32	2,116	24,956

Table D-13. Comparison of alternative projections, irrigated acreages, for 1980, Pecos Basin Five-County Area, New Mexico.

Projection Source	Level of Projection	Index of Change in 1980
U. S. Department of Agriculture[1]	Low	124
	Medium	125
	High	138
Bureau of Reclamation[2]		149
Ruttan study[3]	Demand model	173
	Equilibrium model	138
Projections from this study	Low	10
	Medium	98
	High	195

[1] United States Department of Agriculture, *Land and Water Potentials and Future Requirements for Water*, Select Committee on Water Resources, U.S. Senate, 86th Congress, 1st Session, Committee Print No. 12, 1960.

[2] United States Bureau of Reclamation, *Future Needs for Reclamation in the Western States*, Select Committee on Water Resources, U.S. Senate, 86th Congress, 1st Session, Committee Print No. 14, 1960.

[3] V. Ruttan, *The Economic Demand for Irrigated Acreage, Resources for the Future*, Johns Hopkins Press, Baltimore, 1965.

APPENDIX E

INDUSTRIAL WATER-USE PROJECTIONS, 1980-2000

Methodology

Precise estimates of value added and water withdrawals (either fresh or brackish), or consumptive use by the industrial sector within the Pecos Basin are unavailable. Thus, benchmark estimates must be estimated for 1960, in addition to the 1980 and 2000 projections. This procedure introduces a second condition on which the resulting forecasts must be viewed; namely, that the benchmark estimates are reasonably accurate. Data on employment by industry in the Pecos Basin are available for 1959, which should provide a partial crosscheck on the validity of water withdrawal estimates.

In table E-1, average water withdrawals per employee, average water withdrawals per thousand dollars value added, and marginal water withdrawals per additional thousand dollars of value added estimates are presented for selected geographic areas in 1959 by 2-digit SIC industry classifications. Marginal water withdrawals per additional thousand dollars value added are significantly greater than average water withdrawal estimates for the three SIC industries estimates as given in table E-1. The reason is that marginal value added in dollars per additional acre-foot of water is much lower than average value added when such considerations as capital and labor substitution for water are taken into account. If these industries, on the average, tend to operate under the goal of cost minimization for any given level of output, and if incremental costs of fresh water are very low, our relatively high estimates of the reciprocal of marginal value added for fresh water are realistic. The important point is whether to base forecasts of future industrial withdrawals on marginal or on average relationships. Continuing low average and marginal costs for fresh water might indicate marginal value added estimates would offer a more reasonable prediction. In the Pecos Basin, however, predictable future shortages, and thus implied higher water costs, seems to be a more realistic assumption. The procedure was to estimate fresh water withdrawals (less than 1,000 ppm dissolved solids) employing both marginal and average value added estimates. Also, fresh water intake per employee was forecast for 1980 and 2000 to offer a comparison for estimates based on value added.

Ancillary low, medium, and high forecasts of value added and employment were constructed, and the coefficients in table E-1 were used to predict fresh water withdrawals by the three key industrial users, by county, for 1980 and 2000 in the Pecos Basin. The resulting forecasts are recorded in table E-2. The ancillary forecasts of value added were obtained by calculating the ratio of value added in the Pecos Basin to that of the entire Rio Grande-Pecos Basin. It was assumed that this ratio would remain relatively constant between 1959 and 1980, and between 1959 and 2000. Projections prepared by N. Wollman, University of New Mexico, of value added by 2-digit industries for the Rio Grande-Pecos Basin were then multiplied by these ratios to obtain value added forecasts by 2-digit industry for the Pecos Basin.

Employment forecasts by 2-digit SIC industry within the Pecos Basin for the years 1980 and 2000 were constructed as follows: A ratio between 1959 employment within the SIC industry in the Pecos Basin to 1959 total state employment was calculated. This ratio was assumed to remain constant over the projection interval, 1960-2000. Secondly, the ratio of employment to total population within the state was determined. Assuming this ratio is also relatively constant between 1960 and 2000, and taking the product of these two ratios and state population projections (1) for 1980 and 2000, yields projections of 1980 and 2000 employment levels by SIC industry within the Pecos Basin. The projections approach of assuming two ratios that have exhibited wide variations in the past to be relatively constant in the future certainly is highly debatable. Yet, if no radical departures occur in the size or type of manufacturing industries within the Pecos Basin, a projection based on ancillary population projections such as are developed here may lead to reliable estimates.

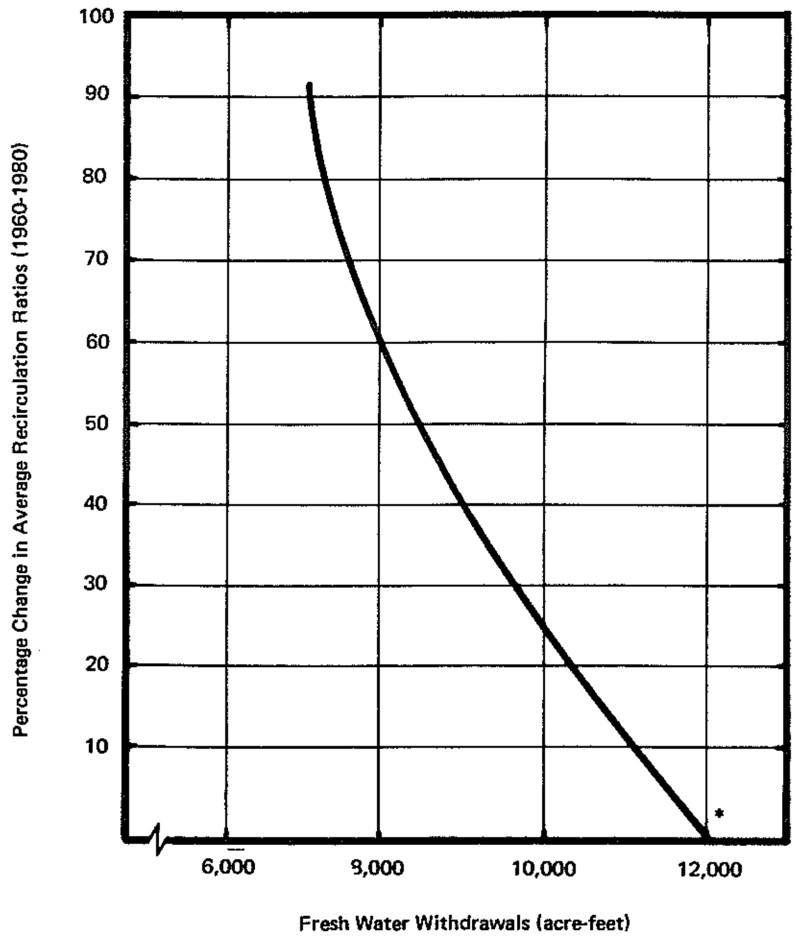
Discussion

The forecasts of fresh water withdrawals in table E-1 carry the implicit assumption that reuse technology as measured by the ratio of gross water use to water intake remains constant in each of the three industries over the next few decades within the Pecos Basin. In figure E-1, fresh water withdrawals in 1980 and 2000 are related to the recirculation rate, based on the average value added projections and constant water costs. It is evident that the adoption of water-saving technology by large water-using industries in the Pecos Basin will have a significant future impact on their respective water demands. In figure E-1, the relationships between withdrawals and recirculation ratios indicate water-saving technology may play a significant role in reducing industrial water use by 1980 for the Pecos Basin.

It is highly probable that, as fresh water becomes relatively more scarce in the Pecos Basin, large water-using industries will increase rates of recirculation or reuse through changes in the structure of production processes, and they will substitute more low-cost brackish water for higher quality, relatively high-cost, fresh water where particular processes permit.

These projections, which are not adjusted for water-saving technology, can be viewed with some confidence if water does not become relatively more scarce in the Pecos Basin; if it does, the potential for wide margins of error places restrictions on interpretation and application of the estimates. The average value added based projections, in this case, would probably have the smaller absolute error of prediction.

Only if water costs relative to other input costs—namely, inputs substitutable for water—remained constant for industrial users through 1980 and 2000, would the incremental withdrawal estimates remain valid, and then only if water-conserving technology were not increased. Due to the wide divergence between incremental and average water withdrawal value added estimates, it is reasonable, in light of the above, to assume that average water withdrawal based forecasts will more nearly conform to what might, in fact, occur.



*Based on medium projections for the three industries given in table E-3, with no change in water-conserving technology through 1980.

Figure E-1. Projected 1980 industrial fresh water withdrawals and recirculation ratios for a selected group of SIC industries (SIC 20, 28, 32), Pecos Basin, New Mexico.[1]

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[1] Average United States recirculation ratios were assumed to apply to the Pecos Basin for SIC 2-digit industries 20, 28, and 32 for 1959. These ratios were 2.13, 1.61, and 1.23 for SIC's 20, 28, and 32, respectively.

Table E-1. Estimated water intake-employee and water intake-value added coefficients for selected SIC 2-digit industries, 1959.

Area	Average Water Withdrawals per Employee (acre-feet per year)	Average Water Withdrawals per $1,000 Value Added (acre-feet per year)	Marginal Water Withdrawals per Additional $1,000 Value Added[4] (acre-feet per year)
United States			
20[1]	2.81	0.21	8.37
28[2]	23.37	1.02	23.55
32[3]	3.93	0.30	4.95
Western Gulf			
20	0.91	0.08	45.07
28	107.82	2.95	110.37
32	2.37	0.11	15.86[5]
*Pecos Basin**			
20	0.91	0.08	8.37
28	23.37	1.02	23.55
32	2.37	0.11	4.95

[1] SIC 20, food and kindred products.
[2] SIC 28, chemicals and products.
[3] SIC 32, stone, clay, and glass products.
[4] Estimated by averaging marginal value added per additional acre-foot of water coefficients across states. (See R. d'Arge, "Manufacturing Demand for Fresh Water," preliminary report, Cornell University Water Resources Center, September 1966.)
[5] Average of marginal value added water intake coefficients for Texas and Louisiana.

*Pecos Basin estimates are the largest of the Western Gulf or United States estimates. Thus, the projections that follow can be viewed as probable upper limits.

Table E-2. Projections of growth in value added for selected 2-digit industries for 1980-2000, Rio Grande-Pecos Basin, New Mexico.

Industry	1980			2000		
	Low	Medium	High	Low	Medium	High
	(percent increase from 1960 base of 100)					
Food and kindred products (SIC 20)	213	225	313	338	438	813
Chemicals and products (SIC 28)[1]	1,300	1,800	2,700	2,600	4,800	10,300
Stone, clay, and glass products (SIC 32)[2]	—	211	—	—	422	—

[1] The size of percentage increase is very large for chemicals because of the very low 1960 base estimate for the Rio Grande-Pecos Basin.
[2] Estimated by assuming that the ratio of value added to employment and employment to population remains constant between 1960-1980 and 1980-2000 for the State of New Mexico.

Sources: N. Wollman, unpublished estimates, University of New Mexico, Albuquerque.

P. Balestra and N. Rao, *Basic Economic Projections, United States Population, 1965-1980*, Stanford Research Institute, Menlo Park, California, 1965.

Table E-3. Projections of fresh water withdrawals by county and selected 2-digit industries for 1980, Pecos Basin, New Mexico.

County	I[1]			II[2]			III[3]
Industry	Low	Medium	High	Low	Medium	High	Medium
	(acre-feet per year)			(acre-feet per year)			(acre-feet per year)
Chaves							2,366
Food (SIC 20)	61,097	67,450	113,996	1,077	1,138	1,583	2,366
Stone, clay and glass (SIC 32)	—	1,038	—	—	57	—	1,701
Eddy							
Food (SIC 20)	25,522	28,175	47,619	450	475	661	989
Chemicals (SIC 28)	149,914	211,733	323,007	6,962	9,639	14,459	3,019
Stone, clay, and glass (SIC 32)	—	44	—	—	242	—	723
San Miguel							
Food (SIC 20)	15,544	6,030	9,562	81	86	120	180
Total		314,070			11,637		8,978

[1] Forecast based on fresh water withdrawal-marginal value added relationship.
[2] Forecast based on fresh water withdrawal-average value added relationship.
[3] Forecast based on fresh water withdrawal-employment relationship.

Table E-4. Projections of fresh water withdrawals by county and selected 2-digit industries for 2000, Pecos Basin, New Mexico.

County	I[1]			II[2]			III[3]
Industry	Low	Medium	High	Low	Medium	High	Medium
	(acre-feet per year)			(acre-feet per year)			(acre-feet per year)
Chaves							
Food (SIC 20)	127,220	180,157	378,496	1,709	2,215	4,111	3,156
Stone, clay and glass (SIC 32)	—	1,609	—	—	1,142	—	3,588
Eddy							
Food (SIC 20)	53,143	75,323	158,103	714	925	1,717	1,318
Chemicals (SIC 28)	310,643	582,645	1,250,288	13,923	25,704	54,621	2,372
Stone, clay and glass (SIC 32)	—	683	—	—	485	—	1,860
San Miguel							
Food (SIC 20)	10,567	14,584	29,650	130	168	312	239
Total		855,001			30,639		12,533

[1] Forecast based on fresh water withdrawal-marginal value added relationship.
[2] Forecast based on fresh water withdrawal-average value added relationship.
[3] Forecast based on fresh water withdrawal-employment relationship.

Table E-5. Estimates of total employment and value added by selected SIC industries, Pecos Basin, 1959.

County SIC Industry	Total Employment[1]	Estimated Value Added[2]
Chaves		
SIC 20	632	$6,320,000
SIC 32	205	2,460,000
Eddy		
SIC 20	264	2,640,000
SIC 28	35	525,000
SIC 32	87	1,044,000
San Miguel		
SIC 20	48	$ 480,000

[1] Obtained from ***Employment and Earnings***, Quarterly Report, 1959, Employment Security Commission of New Mexico.
[2] Estimated by assuming value added per employee was $10,000 for SIC 20; $15,000 for SIC 28; and $12,000 for SIC 32. Each of these value added employee coefficients was slightly below national averages by SIC industries in 1959, but slightly above coefficients for states with very small SIC 20, 28, or 32 industries.

APPENDIX F

MINING WATER-USE PROJECTIONS, 1980-2000

Methodology

Projections of water withdrawals by the mining sector were confined to the potash industry within Eddy County. Other peripheral mining activities, such as natural gas transmission compressor stations, will probably not add more than 5 percent to the total of mining sector water withdrawals in the Pecos Basin. The estimates that follow are based on the assumption that no large new mineral discoveries will occur in the Pecos Basin over the projection period.

Two alternative water withdrawal projections were developed, one based on projections by Gilkey and Stotelmeyer (17), and the other taking into account the announcement by the U. S. Borax Corporation in 1968 to close its Pecos Basin facilities. As this was being written, there was no indication of planned relocation by other major producers (33), and on this basis the second set of 1980-2000 projections was developed. The procedure employed was to estimate the percentage of New Mexico's output of raw ore produced in the Pecos Basin. Then this proportion was multiplied by Gilkey's and Stotelmeyer's projections of water withdrawals by the state potash industry for 1980-2000.

Since almost all potash produced within the Pecos Basin is produced in Eddy County, the predicted water requirements contained herein may be assumed to be entirely within Eddy County. In 1962, potash production in Eddy County accounted for more than 89 percent of total New Mexico potash production.

Gilkey and Stotelmeyer assumed output of raw ore processed would remain constant between 1980 and 2000, therefore projections of water withdrawals are identical for both future time periods. The projection of water withdrawals based on their projections of raw ore output is 15,216 acre-feet per year in 1980 and 2000, in contrast to 1962 estimated withdrawals of 14,568 acre-feet, a percentage increase of less than 4 percent.

With the withdrawal of U. S. Borax Corporation potash operations from Eddy County in 1967-1968, the proportion of state potash production produced in the Pecos Basin declined to 86 percent. In consequence, projected water requirements in 1980 and 2000 for New Mexico's potash industry will decline. The combined effect of this reduction is to decrease Pecos Basin potash industry projected water withdrawals to 12,328 acre-feet in 1980 and 2000, a decline of approximately 16 percent.

Discussion

It appears reasonable to adopt the projection of 12,328 acre-feet per year in 1980 and 2000 in light of the fact that U. S. Borax Corporation is relocating facilities outside the Pecos Basin. There is the possibility that some other producer will purchase and reactivate the U. S. Borax plant, though extensive changes in equipment and operation would probably be required. The comparative advantages in terms of costs and government subsidies between the newly discovered Canadian potash deposits and New Mexico's potash industry are not estimatable. It would appear realistic to assume that in the absence of major shifts in demand for potash or technological change in producing potash, our estimates would represent probably upper limits to future water requirements.

APPENDIX G

STEAM ELECTRIC POWER GENERATION: PROJECTIONS OF WATER USE, 1980-2000

Methodology

Estimates of electric power consumption are unavailable for residential or commercial users for the entire Pecos Basin Five-County Area. The Southwestern Public Service Company, which services Chaves and Eddy Counties, provided estimates of residential and total power consumption for these two counties in 1967, and also projections of power requirements over the interval 1967-2000. An estimate of total power consumption in the Pecos Basin for 1960 was obtained by weighting residential power consumption in the two counties by the ratio of 1960 total Pecos Basin population to 1960 population in the two counties. Nonresidential power consumption in Chaves and Eddy Counties was weighted by the ratio of 1960 total basin nonagricultural employment to nonagricultural employment within the two counties. The resulting estimate of total electric power consumption generated in the Pecos Basin for 1960 was 641.3 million kilowatt-hours (KWH), or approximately 4,564 KWH per capita per year. The Federal Power Commission reports the average per capita consumption of electric power in the United States at about 4,549 KWH per year, within 1 percent of the Pecos Basin per capita estimate.

Given the extremely close approximation of the Pecos Basin per capita electric power consumption to nationwide averages, it appears appropriate to utilize projections of future United States average per capita power consumption for the Pecos Basin. Projections of per capita power consumption for 1980 and 2000 prepared by the Federal Power Commission and alternatively the Edison Electric Institute were applied to Edgel's population forecasts (recorded in table A-1) in order to project total basin electric power consumption. A third set of electric power consumption projections was obtained by extrapolation of the Southwestern Public Service Company's 1980 and 2000 projections for Chaves and Eddy Counties. The alternative projections are recorded in table G-1.

Tables G-2 and G-3 record the projections of water withdrawals and consumptive use, respectively, for electric power generation in the Pecos Basin. These projections were developed by utilizing average water withdrawals per KWH at the Southwestern Public Service Company's plants in Roswell and Carlsbad. Consumptive use estimates were also obtained by applying consumptive use coefficients provided by Southwestern Public Service for Roswell and Carlsbad.

Discussion

While estimated per capita electricity consumption in the Pecos Basin was very close to the United States average per capita consumption, no consideration was made of electric power produced outside and delivered to the basin. Thus, our estimate of Pecos Basin 1960 average per capita power consumption could be significantly biased. Of even greater consequence is the utilization of existing average withdrawals per KWH to forecast future water withdrawals per KWH. Water withdrawals for steam electric generation depend on the type and construction of the physical plant, the amount of cooling required vis-a-vis plant capacity, and the degree of efficiency to which the water is used as a cooling agent (7). There is evidence that, even with current levels of power generation technology, substantial reductions in water requirements (both intake and consumptive use) per KWH are obtainable (7, ch. 6).

Electric power generated by direct-combustion turbines alternatively requires almost no water per KWH produced, and conversion to these types of turbines is not inconceivable in the distant future. With these possiblities in mind—increasing water use efficiency per KWH, inter-basin transfers of electric power, and changes in power generation technology—our estimates of water requirements for steam electric generation in 1980 and 2000 may be considered upper limits. In view of the increasing relative scarcity of water resources in the Pecos Basin and, therefore, implied rising costs of water, it appears likely that water-saving technology will be utilized as intra-basin power requirements increase.

Table G-1. Projections of total electric power consumption for 1980-2000, Pecos River Basin, New Mexico.

Per Capita Source[1]	Population Estimate	Year 1980	Year 2000
		(millions of KWH)	
Federal Power Commission	Low	1,968	4,196
	Medium	2,137	4,641
	High	2,334	5,226
Edison Electric Institute	Low	2,190	5,261—8,790
	Medium	2,378	5,820—9,723[2]
	High	2,597	6,553—10,948
Southern Public Service Company	Low	2,353	5,382
	Medium	2,555	5,954
	High	2,791	6,704

[1] Projections are based on Federal Power Commission and Edison Electric Institute estimates of United States per capita consumption in 1980 and 2000, and Edgel's low,. medium, and high population projections (Appendix A, table A-1). The Southwestern Public Service Company's estimates for 1980 and 2000 were adjusted by ratios of Pecos Basin population projections to population projections for Chaves and Eddy Counties.

[2] Edison Electric Institute estimates for the year 2000 were presented in terms of upper and lower limits.

Table G-2. Projections of water withdrawals for electric power generation for 1980-2000, Pecos River Basin, New Mexico.

Per Capita Source		1980 Low[1]	1980 Medium[1]	1980 High[1]	2000 Low	2000 Medium	2000 High
			(acre-feet per year)			(acre-feet per year)	
Federal Power Commission	I[2]	8,154	8,854	9,670	17,384	19,228	21,651
	II[3]	3,141	3,397	3,725	6,696	7,378	8,340
Edison Electric Institute	I	9,073	9,852	10,759	21,796-36,417	24,112-40,282	27,149-45,358
	II	3,495	3,780	4,001	8,396-14,027	9,252-15,456	10,457-17,471
Southwestern Public Service Company	I	9,749	10,585	11,563	22,298	24,667	27,775
	II	3,755	4,062	4,454	8,589	9,465	10,698

[1] Based on Edgel's high, medium, and low population forecasts.

[2] Based on Southwestern Public Service Company's average withdrawals of 1.35 gallons per KWH at their Roswell plant.

[3] Based on Southwestern Public Service Company's average withdrawals of 0.52 gallons per KWH at their Carlsbad plant.

Table G-3. Projections of consumptive use for electric power generation for 1980-2000, Pecos River Basin, New Mexico.

Per Capita Source		1980 Low[1]	1980 Medium[1]	1980 High[1]	2000 Low	2000 Medium	2000 High
			(acre-feet per year)			(acre-feet per year)	
Federal Power Commission	I[2]	5,439	5,906	6,450	11,595	12,825	14,441
	II[3]	2,475	2,677	2,935	5,276	5,814	6,572
Edison Electric Institute	I	6,052	6,571	7,176	14,538-24,290	16,083-26,868	18,108-30,254
	II	2,754	2,979	3,153	6,616-11,053	7,291-12,179	8,240-13,767
Southwestern Public Service Company	I	6,503	7,060	7,713	14,783	16,453	18,526
	II	2,959	3,201	3,510	6,768	7,458	8,430

[1] Based on Edgel's high, medium, and low population forecasts.

[2] Based on Southwestern Public Service Company's average consumptive use of 0.90 gallons per KWH at their Roswell plant.

[3] Based on Southwestern Public Service Company's average consumptive use of 0.41 gallons per KWH at their Carlsbad plant.

APPENDIX H

THE ECONOMIC IMPACT OF IRRIGATED ACREAGE CHANGES ON THE PECOS BASIN FEEDLOT INDUSTRY

Introduction

One important side effect of irrigated crop acreage reductions, if reductions are undertaken, will be to make feed sources less plentiful for feedlot operations within the Pecos Basin. Comparatively large reductions in the production of certain crops may potentially raise feed costs, induce importation of larger quantities of feed produced externally, and reduce the number of cattle in feedlots within the basin. Higher feed costs may cause a loss in comparative advantage of feedlot operations within the Pecos Basin. Importation of feed would normally cause feed costs to rise, due to transportation charges, and thereby reduce value added generated by feedlots within the Pecos Basin area, provided the total of transportation charges did not accrue to industries within the Pecos Basin. The losses in value added listed above, of course, are in addition to direct losses encountered from basin reductions in the production of feed for feedlots.

A conservative estimate of the direct value added generated by feedlot operations in the Pecos Basin would be upwards of $1.5 million per year. Thus, significant alterations in irrigated crop acreages may have pronounced effects on the Pecos Basin economy, not only through the direct impact of input purchases, but also indirectly through repercussions on the feedlot industry within the Pecos Basin. Reallocation of water resources utilizing only the criterion of direct value added generated from each potential use may be in serious error if reallocations are undertaken without first analyzing the high degree of interdependence between feedlot operations and irrigated agriculture.

Methodology

The procedure followed here to derive the losses in terms of value added within the fed cattle industry per acre-foot removed from irrigation of certain crops was quite simple.[1] Upper and lower limits for the estimate of losses were derived by assuming a) the number of fed cattle in the Pecos Basin remains constant and the reduction in value added is due entirely to higher feed costs (lower limit), and b) the number of fed cattle decreases in direct proportion to reductions in feed grains acreages (upper limit). The degree of averaging places serious limitations on interpretation of the estimates.

The average time interval that feeder cattle in New Mexico are maintained in the feedlot has been increasing over the past decade. The number of days assumed in the following calculations were 130 and 160 days, and it was further assumed the animal's average daily gain was 2.2 pounds. The composition of feed fed to New Mexico feeder cattle over the period 1961-1965 in terms of percentages of total weight was: hay, 25 percent; silage, 20 percent; barley, 4 percent; corn, 1 percent; milo, 45 percent; and protein supplement, 5 percent (30).

Given the above proportions plus crop yields and irrigation water requirements by crop and by county, recorded in Appendix D, the number of acres and acre-feet of water required to feed one "average" feedlot animal can be calculated.

A very high proportion of cattle feeding in the Pecos Basin is centered around the Roswell-Artesia area, which coincides with the areas of lowest acreage (and thus water) requirements per animal.

Costs per ton for the different components of the "average" New Mexico feed utilized in feedlots are: hay, $26.14; alfalfa,[2] $21.57; silage, $23.86; barley, $40.83; No. 3 yellow corn, $39.71; milo, $35.36; and protein supplement, $64.06 (38). The cost of feeding one "average" beef animal, based on the above prices is $45.79 for 130 days, and $58.40 for 160 days. Note that the above feed prices are based on average prices paid to New Mexico farmers during 1959-1965.

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[1] The procedure utilized to calculate these estimates was as follows: Let V_j equal value added per beef animal in county j, A_j water requirements for feed requirements per animal in county j, where A_j is computed by taking average feed requirements per animal over a specified time interval and deriving, by county, average water requirements per unit of feed and summing over total feed requirements. The reduction in value added in the fed-cattle industry per acre-foot of water diverted from feed grains production is then estimated by V_j/A_j.

[2] Alfalfa prices for the Pecos Basin were estimated by weighting average United States alfalfa prices by the ratio of total hay prices in New Mexico to total hay prices in the United States (prices paid to farmers).

Feeding costs when all feed is assumed to be shipped into the Pecos Basin from western Texas and southern Colorado increase substantially. Assuming all feed is imported from these two areas and that the same feed prices prevail in these areas as in New Mexico, and taking 200 miles and $0.14 per ton mile as representative distance and shipping costs, the costs of feeding imported feed for 130 and 160 days are $49.66 and $63.17 per animal, respectively. In the absence of reduced numbers of fed cattle from acreage and water use restrictions, the difference between the cost of Pecos Basin and imported feeds represents foregone value added accruing to the Pecos Basin cattle feeding industry. If shipping costs totally accrue to businesses within the Pecos Basin, the amount of value added lost to the basin as a whole from feed importation is reduced to zero, or nearly so.

In addition to feed costs, which on the average account for more than 65 percent of total feedlot production costs, other indirect costs (not contributing to value added generated by feedlot operations) must be estimated in order to derive value added per beef animal for a typical Pecos Basin feedlot operation. Indirect costs are tabulated in tables H-2 and H-3 along with water requirements to produce the physical input required for cattle feeding operations per average feedlot animal.

The total indirect cost (not contributing to value added in feedlot operations) per feedlot animal is the sum of feed costs plus other indirect costs. It is assumed in the calculations which follow that feedlot operations are separate entities of crop producing farms and that all feed is purchased by feedlot operators. While this assumption holds little validity in actual practice, it allows separation of value added contributing components between crop and livestock enterprises, and the inherent bias introduced by this assumption will cause estimates of value added to be smaller than actual values.

The estimated total indirect cost of feedlot operations per "average" beef animal for 130 days is $57.99 if feeds are produced locally, and $61.86 if all feed is imported. For 160 days, the total indirect costs equal $73.42 for locally produced feed and $78.19 when all feed is imported. To make these computations, it was assumed that grain prices were the same in Colorado and Texas as in the Pecos Basin.

Average slaughter cattle prices vary markedly between localities and between years. Average prices by grade are not reported for the Pecos Basin area by the U.S.D.A.; therefore, to calculate gross revenues per "average" beef animal, Denver and Ft. Worth average yearly prices weighted by the "average" grade composition of New Mexico fed cattle during 1952-1961 were utilized (30) (38). The "average" price per hundredweight developed from the above procedure was $23.26. Total revenue per "average" animal for 130 days then is estimated at $66.52; and for 160 days, $81.88, assuming the average weight gain per beef animal was 2.2 pounds per day.

An estimate of value added (total revenue less total indirect costs) per "average" beef animal for 130 days if all feed inputs are produced locally is $8.53; or if all feed grains are imported, $4.66. For 160-day feeding periods these estimates of value added change to $8.46, and $3.59, respectively. Note that this estimate of value added excludes value added generated directly by feed grains production in the Pecos Basin and is a measure of the net contribution of feedlot operations to value added for the basin.

Tables H-4 and H-5 present the estimated reduction in value added for livestock feeding operations per irrigated crop acre and per acre-foot reduction of irrigation water. The alternative upper and lower limits indicate two assumptions regarding supply response of feedlot operations to changes in feed costs: 1) that the reduction in feed grains supply within the Pecos Basin raises feed costs and hence reduces value added in the feedlot industry with no change in fed-cattle numbers; or, 2) the reduction in feed grains supply reduces fed-cattle numbers in direct proportion to average feed requirements per beef animal.

Estimates for the Pecos Basin as a whole were constructed by weighting the value added estimates in tables H-4 and H-5 by recent average fed cattle numbers in each county.[3]

Discussion

If the estimates made here are reasonable as to value added reductions in feedlot operations due to acreage restrictions or acre-foot reductions in irrigation water, reallocation of basin water based solely on direct value added generated from feed grains production may be significantly biased. For example, a $12.00 reduction in value added within the Pecos Basin due to the indirect effects on feedlot operations from rising feed costs may alter the optimal allocation of water resources between types of agricultural crops and between water uses within agricultural sectors. It might be expected that reductions in alfalfa and silage production would induce a similar response regarding livestock feeding operations, while, alternatively, cotton production may have a much smaller indirect impact on basin value added because

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[3] New Mexico Department of Agriculture and the U. S. Department of Agriculture Statistical Reporting Service, *New Mexico Agricultural Statistics*, Vol. VI, Las Cruces, 1967.

cotton is exported from the Pecos Basin prior to substantial degrees of processing.

Reductions in water requirements of industries providing inputs for livestock feeding operations other than feed production are so negligible that the effects of reduction in feed production and the consequent decrease in fed-cattle production would have practically no impact on other water requirements within the Pecos Basin (see tables H-2, H-3). Our estimates indicate an approximate 1/100 or less acre-foot reduction in indirect water requirements per dollar reduction in expenditures on inputs other than feed.

Table H-1. Acreage and water requirements per feedlot animal feeding periods of 130 and 160 days by county, Pecos Basin, New Mexico.

	130 Days		160 Days	
County	Acres	Acre-Feet[1]	Acres	Acre-Feet[1]
Chaves	0.54	1.70	0.66	2.09
De Baca	0.59	1.94	0.72	2.38
Eddy	0.52	1.70	0.64	2.10
Guadalupe	0.83	2.78	1.02	3.43
San Miguel	1.19	4.10	1.46	5.04

Sources: New Mexico Department of Agriculture and the U.S. Department of Agriculture Statistical Reporting Service, *New Mexico Agricultural Statistics*, Vol. VI, Las Cruces, 1967.

See tables D-7 and D-8 for estimate of water requirements per acre by crop.

[1] Acre-feet of irrigation water needed to produce the crops necessary for maintaining an average animal in the feedlot for 130 or 160 days.

Table H-2. Indirect costs and water requirements by industry per average feedlot beef animal (130-day feeding period) 1965.

Type of Industry	Indirect Input Cost[1]	Water Requirements
	(dollars)	(acre-feet)
Agricultural services	0.47	.00000150*
Grain mill and bakery	2.96	.000565
Miscellaneous food	0.11	.00000433
Lumber and wood	0.09	.0000598
Chemicals	0.06	.0000858
Petroleum refining	0.43	.000107
Concrete and stone	0.06	.00000535
Railroad	0.08	.000000256*
Trucking	0.23	.000000736*
Telephone and telegraph	0.17	.000000544*
Electric light and power	0.24	.000000768*
Wholesale	0.96	.00000307*
Gasoline service stations	0.41	.00000131*
Other retail trade	2.87	.00000918*
Finance and insurance	2.00	.00000640*
Real estate	0.70	.00000224*
Auto and other repair	0.36	.00000115*
Total	12.20	.0008544

*Estimated

[1] Sources: Bureau of Business Research, *Input-Output Study for New Mexico*, University of New Mexico, Albuquerque, 1964.
U.S. Bureau of the Census, *Census of Manufactures*, 1963, Vol. I, "Summary and Subject Statistics," U.S. Government Printing Office, Washington, D.C., 1966.
Eichberger, Willis G., *Industrial Water Use*, U.S. Department of Health, Education, and Welfare, Washington, D.C., 1961.

Table H-3. Indirect costs and water requirements by industry per average feedlot beef animal (160-day feeding period) 1965.

Type of Industry	Indirect Input Cost[1] (dollars)	Water Requirements (acre-feet)
Agricultural services	0.58	.00000186*
Grain mill and bakery	3.64	.000695
Miscellaneous food	0.14	.00000552
Lumber and wood	0.11	.0000730
Chemicals	0.07	.000100
Petroleum refining	0.53	.000131
Concrete and stone	0.07	.00000624
Railroad	0.10	.00000032*
Trucking	0.28	.000000896*
Telephone and telegraph	0.21	.000000672*
Electric light and power	0.30	.000000960*
Wholesale	1.18	.00000378*
Gasoline service stations	0.50	.00000160*
Other retail trade	3.53	.0000113*
Finance and insurance	2.46	.00000787*
Real estate	0.86	.00000275*
Auto and other repair	0.44	.00000141*
Total	15.00	.00104418

*Estimated.

[1] Sources: Bureau of Business Research, *Input-Output Study for New Mexico*, University of New Mexico, Albuquerque, 1964.
U.S. Bureau of the Census, *Census of Manufactures*, 1963, Vol. I, "Summary and Subject Statistics," U.S. Government Printing Office, Washington, D. C., 1966.
Eichberger, Willis G., *Industrial Water Use*, U.S. Department of Health, Education, and Welfare, Washington, D. C., 1961.

Table H-4. Estimated reduction in value added for feedlot operations per acre reduction in irrigated crop acreage by county, Pecos Basin Five-County Area, New Mexico, 1965.

County	130-Day Feeding Period		160-Day Feeding Period	
	Lower Limit (dollars)	Upper Limit (dollars)	Lower-Limit (dollars)	Upper Limit (dollars)
Chaves	-7.19	-15.84	-7.19	-12.76
De Baca	-6.61	-14.56	-6.61	-11.23
Eddy	-7.48	-16.48	-7.48	-13.28
Guadalupe	-4.67	-10.30	-4.67	- 8.30
San Miguel	-3.26	- 7.19	-3.26	- 5.79

Table H-5. Estimated reduction in value added for feedlot operations per acre-foot water reduction on irrigated crop acreage by county, Pecos Basin Five-County Area, New Mexico, 1965.

County	130-Day Feeding Period		160-Day Feeding Period	
	Lower Limit (dollars)	Upper Limit (dollars)	Lower Limit (dollars)	Upper Limit (dollars)
Chaves	-2.28	-5.03	-2.28	-4.05
De Baca	-2.00	-4.41	-2.00	-3.55
Eddy	-2.27	-5.01	-2.27	-4.04
Guadalupe	-1.39	-3.06	-1.39	-2.47
San Miguel	-0.94	-2.06	-0.94	-1.68

Table H-6. Estimated value added reduction per acre and per acre-foot water reduction on irrigated crop acreage, Pecos Basin, New Mexico, 1965.

Type of Reduction	130-Day Feeding Period		160-Day Feeding Period	
	Lower Limit (dollars)	Upper Limit (dollars)	Lower Limit (dollars)	Upper Limit (dollars)
Acre	-6.71	-14.79	-6.71	-11.91
Acre-foot (water)	-2.11	- 4.64	-2.11	- 3.74

APPENDIX J

ESTIMATES OF VALUE ADDED FOR SELECTED CROPS BY SOIL CLASS, SALINITY, AND IRRIGATION WATER PUMPED

Costs and net returns data by crop, soil class, water salinity, and amount of irrigation water pumped for the Pecos Basin were provided by the Departments of Agricultural Economics and Agronomy, New Mexico State University, Las Cruces. Direct value added per acre for each combination of the above characteristics was computed by summing overall direct costs plus net returns to management. Direct costs, as defined here, include wages and salaries, equipment and building prorated depreciation charges, taxes other than corporate or individual profits and income taxes, interest payments, and social insurance contributions. The direct value added measure also included estimates of net returns to management, defined here as the difference between gross sales revenues and total costs including all direct and indirect costs.

The value added estimates are presented in tables J-1 through J-5 for the Roswell-Artesia area, and table J-6 for De Baca County and the two upper Pecos Basin counties, San Miguel and Guadalupe. Value added estimates based on the varying parameters of soil class, salinity, and inches of irrigation water pumped were unavailable for the upper Pecos Basin counties and De Baca County.

These estimates, given the validity of relationships between crop yield, soil class, salinity, and inches of irrigation water pumped, should be within 10 percent of the actual direct value added generated by each crop per acre. Certain minor components of direct value added, such as the on-farm consumption of farm produce or the valuation of on-farm animal feed at less than market prices, were not considered.

Table J-1. Value added per acre for barley, by soil class, Roswell-Artesia area, Pecos Basin, New Mexico, 1966.

Salinity, mmhos	.75	1.5	2.25	3.0	4.0	5.0	6.0	7.0
Value added per acre	$	$	$	$	$	$	$	$
Soil Classes I and II								
Irrigation water pumped, acre-inches								
27.0	66.12	66.12	66.12	65.43	61.69	53.63	45.48	27.10
18.0	54.88	54.88	54.18	51.24	42.39	22.45	3.28	–
13.5	41.90	41.90	39.72	33.83	16.14	–	–	–
Soil Class III								
Irrigation water pumped, acre-inches								
27.0	48.65	48.65	48.65	48.08	45.27	39.06	32.85	18.77
18.0	40.94	40.94	40.38	38.12	31.36	16.12	1.43	–
13.5	31.46	31.46	29.76	25.25	11.71	–	–	–
Soil Class IV								
Irrigation water pumped, acre-inches								
27.0	31.38	31.38	31.38	30.99	29.03	24.74	20.60	10.67
18.0	27.14	27.14	26.75	25.19	20.50	9.95	.52	–
13.5	21.11	21.11	19.94	16.81	7.43	–	–	–

Table J-2. Value added per acre for cotton, by soil class, Roswell-Artesia area, Pecos Basin, New Mexico, 1966.

Salinity, mmhos	.75	1.5	2.25	3.0	4.0	5.0	6.0	7.0
Value added per acre	$	$	$	$	$	$	$	$
Soil Classes I and II								
Irrigation water pumped, acre-inches								
45	388.53	388.53	388.53	380.51	344.38	276.08	211.82	147.36
36	352.67	352.67	352.67	333.32	268.34	192.03	123.76	51.46
27	296.75	296.75	288.73	251.94	156.19	67.84	–	–
18	200.63	192.61	168.50	84.16	–	–	–	–
Soil Class III								
Irrigation water pumped, acre-inches								
45	341.94	341.94	341.94	314.92	303.26	243.48	187.21	131.37
36	307.85	307.85	307.85	291.27	234.00	167.18	107.39	42.77
27	259.42	259.42	252.40	220.74	136.76	58.98	–	–
18	175.84	168.81	147.71	73.85	–	–	–	–
Soil Class IV								
Irrigation water pumped, acre-inches								
45	291.87	291.87	291.87	285.85	258.70	207.41	159.14	110.88
36	262.85	262.85	262.85	247.76	199.50	142.18	90.90	36.60
27	228.74	228.74	215.95	188.81	116.41	50.04	–	–
18	150.95	144.86	126.82	64.47	–	–	–	–

Table J-3. Value added per acre for alfalfa, by soil class, Roswell-Artesia area, Pecos Basin, New Mexico, 1966.

Salinity, mmhos	.75	1.5	2.25	3.0	4.0	5.0	6.0	7.0
Value added per acre	$	$	$	$	$	$	$	$
Soil Classes I and II								
Irrigation water pumped, acre-inches								
88	230.64	195.27	151.73	108.18	45.59	–	–	–
80	208.99	168.18	119.19	48.77	10.34	–	–	–
72	184.56	135.64	83.94	35.85	–	–	–	–
64	157.62	103.10	86.28	–	–	–	–	–
56	130.44	47.86	–	–	–	–	–	–
Soil Class III								
Irrigation water pumped, acre-inches								
88	191.94	161.69	124.30	86.92	33.06	–	–	–
80	173.86	138.70	96.60	57.04	3.18	–	–	–
72	173.24	106.80	67.04	24.70	–	–	–	–
64	130.35	83.61	34.43	–	–	–	–	–
56	107.60	53.73	–	–	–	–	–	–
Soil Class IV								
Irrigation water pumped, acre-inches								
88	118.74	102.09	75.72	49.30	18.94	–	–	–
80	111.65	86.72	59.59	28.96	-9.06	–	–	–
72	97.97	68.11	36.76	7.63	–	–	–	–
64	82.79	49.48	14.68	–	–	–	–	–
56	67.15	29.14	–	–	–	–	–	–

Table J-4. Value added per acre for grain sorghum, by soil class, Roswell-Artesian area, Pecos Basin, New Mexico, 1966.

Salinity, mmhos	.75	1.5	2.25	3.0	4.0	5.0	6.0	7.0
Value added per acre	$	$	$	$	$	$	$	$
Soil Classes I and II								
Irrigation water pumped, acre-inches								
39	104.80	101.94	90.47	73.26	47.46	21.65	–	–
36	105.04	100.74	89.26	69.19	41.73	6.11	–	–
27	81.52	74.35	51.42	29.91	-4.50	–	–	–
18	12.14	-3.63	–	–	–	–	–	–
Soil Class III								
Irrigation water pumped, acre-inches								
39	82.66	80.24	70.55	56.03	34.23	12.44	–	–
36	83.10	79.47	69.79	52.83	29.82	-.45	–	–
27	63.83	57.78	38.40	20.29	-8.78	–	–	–
18	5.85	-7.39	–	–	–	–	–	–
Soil Class IV								
Irrigation water pumped, acre-inches								
39	62.66	60.64	52.57	40.44	19.18	4.12	–	–
36	63.31	60.27	52.19	38.07	18.89	-4.35	–	–
27	47.87	42.82	26.67	11.53	-12.71	–	–	–
18	0.12	-10.89	–	–	–	–	–	–

Table J-5. Value added per acre for corn, by soil class, Roswell-Artesia area, Pecos Basin, New Mexico, 1966.

Salinity, mmhos	.75	1.5	2.25	3.0	4.0	5.0	6.0	7.0
Value added per acre	$	$	$	$	$	$	$	$
Soil Classes I and II								
Irrigation water pumped, acre-inches								
42	90.01	79.51	46.01	-14.49	–	–	–	–
36	73.51	65.01	7.91	–	–	–	–	–
27	39.74	22.74	–	–	–	–	–	–
18	26.41	–	–	–	–	–	–	–
Soil Class III								
Irrigation water pumped, acre-inches								
42	70.51	65.51	35.51	-18.49	–	–	–	–
36	60.01	53.01	1.51	–	–	–	–	–
27	30.24	15.24	–	–	–	–	–	–
18	-3.82	–	–	–	–	–	–	–
Soil Class IV								
Irrigation water pumped, acre-inches								
42	59.51	44.01	27.51	-21.49	–	–	–	–
36	50.51	43.21	-2.99	–	–	–	–	–
27	23.74	9.74	–	–	–	–	–	–
18	7.32	–	–	–	–	–	–	–

Table J-6. Value added, irrigated land, by crop and location, Pecos Basin, New Mexico, 1966.

Crop	De Baca County	Upper Basin Potential[1]	Upper Basin Actual
	$	$	$
Corn			
per acre	95.76[2]	95.76	47.76
per acre-foot	38.30[2]	38.30	19.10
Alfalfa			
per acre	134.28[3]	133.13[3]	77.13[3]
per acre-foot	27.98[3]	22.19[3]	12.86[3]
Cotton			
per acre	141.56[3]	–	–
per acre-foot	53.23[3]	–	–
Grain Sorghum			
per acre	111.69[4]	111.69[4]	64.53[4]
per acre-foot	44.68[4]	44.68[4]	25.81[4]
Barley			
per acre	48.65[5]	–	–
per acre-foot	21.62[5]	–	–

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[1] Inefficient farming practices are common in San Miguel and Guadalupe Counties. The "potential" value added figure was derived by assuming that, with efficient management, productivities per acre in this region could be made to equal those of De Baca County.

[2] Costs of growing corn were available only for San Miguel and Guadalupe counties, hence costs in De Baca County were assumed to be the same.

[3] Value added in harvesting was unavailable for De Baca, San Miguel, and Guadalupe Counties. The Roswell-Artesia value added estimate for harvesting was utilized for this computation.

[4] Value added in harvesting grain sorghum was unavailable for De Baca County and the other two northern counties. The Upper Basin value added for harvesting corn was used as the best substitute. This also applies to sorghum production within the Roswell-Artesia sub-basin (table J-4).

[5] As data were unavailable for costs of growing barley in De Baca County, the Roswell-Artesia sub-basin estimate was used. Productivity per acre between the two areas is nearly the same.

Table J-7. Percentage of total irrigated acreage planted to crops included in tables J-1 through J-6, by county, Pecos Basin Five-County Area, New Mexico, 1959.

County	Percentage
Chaves	96
De Baca	95
Eddy	97
Guadalupe	95
San Miguel	78[1]

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[1] The percentage for San Miguel County is lower because of the relatively large planted acreage in winter wheat.

APPENDIX K

RELEVANT ALLOCATION VARIABLE: DEPLETION OR DIVERSION?

The question has been raised whether the objective of water resource planning is to obtain a value of water intake or a value of water depletion: Should models for river basins optimally allocate water according to highest value per acre-foot of diverted or depleted water? Olsen (34) suggests that the depletion concept is more relevant in the West because of continuous water shortages, whereas intake is the more appropriate concept in humid areas where average depletion rates are low (where manufacturing dominates in place of agriculture) and storage plus replenishment is relatively high.

It is suggested in this appendix that the selection of the allocation variable depends on types of interdependence between users and on the availability of benefit estimates, rather than on geographic differences as Olsen has suggested. But, the appropriate allocation variable is *always* consumptive use or depletion unless withdrawals equal consumptive use, even where average rates of consumptive use are very low. If no interdependence exists between competitive users, the fixed water supply, to maximize total net benefits, should be allocated so that: a) incremental net benefits are equalized for all users, and simultaneously the total water supply is exhausted; or b) allocated according to highest net benefits where net benefits per acre-foot are constant and not equal for all competitive users. If net benefits per acre-foot of some users are constant and those of others are declining, a combination of ranking and equalization of net benefits becomes the appropriate optimal allocation rule.

By no interdependence we mean user *i*'s return flows are not available to any other competitive user. Therefore, the appropriate allocation variable is either depletion or diversion, since they are identical. For expositional purposes assume *N* competitive water users, each with total benefits as a function of acre-feet of water diverted, $B_i(W_i)$ for i = 1, 2 . . . *N* and a fixed total stock of water, *W*. In order to simplify, we omit problems of timing in use of a stock resource and assume a one-period decision problem. The allocation problem then is simply to find those W_i's which maximize total net benefits subject to the total utilization of *W*, or:

$$\text{Max. } \phi = \sum_{i=1}^{N} B_i\,(W_i)$$

$$\text{Subject to} \qquad \sum_{i=1}^{N} W_i \leqslant W$$

$$\text{all } W_i \geqslant 0$$

A constrained maximum of this problem requires: $B_i' - \lambda = B_j' - \lambda$ for all *i* and *j* where λ is a Lagrangean multiplier attached to *W*, the total amount of water available.

If the problem is redefined so that the allocation variable remains withdrawals, but the potential for reuse is included (but only once), and consumptive use coefficients are α_i for each user *i*–that is, $\alpha_i W_i$ equals consumptive use–the above maximization requirements change to: $(B_i' - \alpha_i\lambda) = (B_j' - \alpha_j\lambda)$ for all *i* and *j*.

Clearly, optimal allocations will be different, depending on the magnitudes of α_i's, as depletion rates constitute the real foregone amount of water by all users. Only where $\alpha_i = \alpha_j$ for all *i* and *j* would maximization of benefits, excluding consideration of reuse potential, equal maximization of benefits including consideration of reuse potential.

The next step is to show the same result for instances where water users exhibit a complementary as well as substitute relationship to each other in their respective uses of water. There are three subdivisions: a) where each user exhibits a complementary relationship with all other users, b) where each user exhibits a complementary relationship with only some of the other users, and c) where some users are complementary with all other users and others only with a particular sub-group of the total group of water users. It is assumed that all users are to some extent competitive with all other users for the scarce resource, water. These three situations may be typified by farmers who are pumping water from a common aquifer where nonconsumptive use is returned to the aquifer; or for case b), farmers located along a river where upstream return flows are used downstream; and case c) where some farmers pump both river and aquifer water.

In case a), each user's return flows are presumed to be available to other users during the same period, but are reused only once, as in the previous example. Quality problems are not considered. Benefits for user *i* are the summation of user *i*'s benefits plus benefits from user *j* generated by return flows. Obviously benefits to each user are not independent of return flows, and thus the appropriate value weight for allocation purposes is net benefits per acre-foot depleted rather than diverted, and the correct allocation variable is either withdrawals adjusted for depletion or depletion by each user.

In case b), where complementarity exists in the form of a sequence of return flows within the set of constraints applied to sequential events, either consumptive use or withdrawals can be specified as the allocation variable so long as consumptive use variables are adjusted to reflect potential withdrawals. For example, a single river basin with two sequential users could have a constraint set of the form:

$$W_A \leqslant W$$

$$W_B + \alpha_A W_A \leqslant W$$

where α_A is the consumptive use coefficient for user A. If the W_i's are defined as withdrawals as above, the set of constraints in terms of consumptive use would be:

$$\frac{1}{\alpha_A} \quad C_A \leqslant W$$

$$C_A + C_B \leqslant W$$

where the consumptive use coefficient for *B* equals one. Thus, given the benefit functions adjusted for the change in allocation variables from withdrawals to consumptive use, optimal allocation will be identical for either depletion or diversion. The reason for either consumptive use or withdrawals being the correct allocation variable in this model involving sequences is obviously because both are embedded in the constraints and objective function regardless of the specified allocation variable.

For case c), the same results follow as for case b); namely, consumptive use and withdrawals are both contained in the constraint set and objective function, so the choice hinges solely on how one defines the constraints and objective function. Either depletion or diversion allocation variables will yield the same optimal solution. Where consumptive use coefficients are not constant, the standard linear program must be altered to take account of increasing or decreasing rates of consumptive use, but this can be handled by utilizing a linear segmented function, both in the constraint set and objective function, and by defining activity levels for each segment (4, pp. 289-290).

Problems involving case c), where farmers' return flows seep to an aquifer and are available for reuse by other farmers in the same period, along with sequential use of stream flows, conceptually do not involve any difficulties regarding the specification of the appropriate allocation variable. However, the constraint set becomes more complex as does the objective function. Assume farmer A withdraws water both from the stream and aquifer, and farmer B withdraws water only from the aquifer. Assume also that each farmer's entire return flows accrue to the aquifer and can be reused only once by the other farmer. Let *V* denote stream supply and *Z* denote aquifer supply for our one-period maximization problem, and W_{ij} denote withdrawals for use *i* from source *j*. Also let α_i denote consumptive use by user *i*. The constraint set in terms of withdrawals becomes:

$$W_{AZ} \leqslant \alpha_B W_{BZ} + (1\text{-}\alpha_A)\, W_{AV}$$

$$W_{BZ} \leqslant Z - \alpha_A W_{AZ} + (1\text{-}\alpha_A)\, W_{AV}$$

$$W_{AV} \leqslant V$$

$$W_{BV} = 0$$

$$W_{AZ}, W_{BZ}, W_{AV}, W_{BV} \geqslant 0$$

More complicated features such as interconnections between aquifers and surface sources, though increasing the complexity of constraints, do not alter the basic structure of the problem. And since both depletion and diversion relationships are embedded in the constraints and the objective function, either depletion or diversion can be applied as the allocation variable.

From this brief discussion it is apparent that depletion is the appropriate allocation variable if withdrawals do not equal consumptive use. However, the structure of constraints on sequential use allows either withdrawals or consumptive use to be specified as the allocation variable so long as the constraint set is properly defined.

Even under conditions of very low consumptive use, in a complex river basin system with many sequential users, maximization of benefits subject only to withdrawals with no consideration of return flows may lead to large errors. To cite one example, given N-1 users of return flows from user *N* and each user's return flows equal to 95 percent, the benefit withdrawal relationship for user *N* will be:

$$B_N = B_N\,[W_N] + B_{N\text{-}1}\,[(.95)W_N] +$$

$$\ldots\ldots B_1\,[(.95)^{N\text{-}1}\,W_N]$$

The larger the average return flows, *ceteris paribus*, the greater B_N will be. While W_i denotes diversion by user *i*, the actual variable to be maximized is benefits per unit of depletion, as W_i's are adjusted to reflect depletion at each sequential point of use. Only in the single case where depletion equals diversion (our .95 coefficient equals 0), would the relevant allocation variable be diversions only.

It has been argued that the relevant allocation variable is depletion rather than diversion since depletion is the true measure of economic loss. Yet, in many model simplifications of water resource systems, the diversion variable is easier to employ as the allocation variable and it yields the same results as depletion, provided the impact of return flows is explicitly included within the constraints and appropriate adjustments are made to the objective function weights.