AN ECONOMIC SUPPLY FUNCTION FOR THE DIVERSION OF IRRIGATION WATER TO TUCSON

by

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ABSTRACT

Water is a severely limited resource to the City of Tucson. Additional water imported from outside the city is one way to mitigate the shortage. One alternative source of such water is the diversion of irrigation water to the city from nearby farming areas. The direct cost of such water includes buying the land on which it is now used and installing the necessary works to develop and deliver it. Budgets of such costs were developed in units of 10 and 20 million gallons per day and the direct cost per acre-foot determined.

Irrigated agriculture is part of the economic base of the Tucson economy. Its elimination by diversion of the water upon which it depends will reduce the city's economy and is an indirect cost of such water. Estimates were made of the magnitude of such indirect economic costs and were added to the direct pumping and delivery costs. These two costs constitute the total economic cost of diverting irrigation water to municipal use. The increase in this cost as increasing quantities of water are acquired constitutes the supply schedule for increments of water diverted from irrigation to municipal and industrial use in Tucson.

CHAPTER 1

INTRODUCTION

Problem and Situation

The City of Tucson and the adjacent urban, industrial, and farming areas are completely dependent upon underground aquifers for their water supplies. Tucson's continual growth in population and the consequent increased pumping of water from the Tucson Basin which underlies the city, causes an increasing decline of the water table in the Basin. Intensive study is being directed to alternative sources of supplemental water sources for the city.

This increasing pumpage of groundwater in the Tucson urban area cannot continue indefinitely if the recent growth and prosperity of the city are to continue. Since a groundwater reservoir, like a mineral deposit, is a stock resource, continuous water withdrawal in excess of recharge will at some point in time totally exhaust the groundwater reservoir.

The declining groundwater table in the Basin poses a threat not only that the water it contains may be exhausted, but also the threat that at some depth the quality of the groundwater will become unsuitable for urban use. However, this problem of water quality will not be investigated in this study. Thus in the face of an increasing decline of the groundwater table in the Tucson Basin, there is need for research on alternative sources of water for the city from outside the Tucson

Basin in order to diminish if not arrest the rate of decline of the groundwater table underlying the city and to provide at minimum cost a sufficient supply of water to meet the increasing quantity demanded incident to urban growth.

There are several alternative sources of water available to Tucson (Prospectus, City of Tucson, 1962) including:

1. Reclamation of floodwater of the Santa Cruz River and Rillito Creek will require the construction of facilities for the diversion, storage, and treatment of floodwater and the development of recharge and extraction wells along both streams. The Rillito as a source of additional water is not included in this analysis in that this study concerns only the transfers of water from commercial agriculture of which there is little along the Rillito.
2. An estimated 15 million gallons per day can be developed and imported to Tucson from lands owned by the city on the San Pedro River. However, there are uncertainties with respect to water rights; and the delivering of water through the Rincon Mountains from this distant source will be quite costly.
3. Additional well fields can be developed in the Sahuarita Bombing Range south of the city, but obtaining more than five million gallons per day from that area is not considered feasible by the city until deep test wells are completed to determine water quality.

4. Development of the groundwater known to underlie the desert area southeast of Tucson is a further possibility. However, the drilling of test wells in this area to determine its feasibility as a possible source of additional water has not yet been accomplished.

5. The Santa Cruz River Basin can be further developed near Tucson and north of the Sahuarita Bombing Range. Increased development of water from this area will tend to increase the rate of decline of the water table in the Tucson Basin.

6. Importation of Colorado River water, either by the proposed Central Arizona Project or by direct aqueduct is another possible source. The former requires approval by Congress; both possibilities raise questions relative to their cost as sources of imported water.

7. The diversion of irrigation water now used in the Santa Cruz Valley south and north of Tucson and in the Avra Valley west of the city is the possible source examined in this study. It could provide Tucson with approximately 161,000 acre-feet of water per annum, which is the estimated quantity now being consumed annually on about 60,600 cropland acres including fallow lands in these areas.[1] Such diversion of irrigation water, in addition to the question of its costs, presents some institutional problems of water

1. Estimated acreage and its water use were determined from unpublished reports of the Department of Agricultural Engineering, The University of Arizona, Tucson.

law and will have indirect effects on the Tucson economy; both of these questions are considered herein in evaluating this alternative source of supply.

The Tucson urban area, as designated here, is located in the center of the broad central part of the Santa Cruz Valley. It extends from the Catalina Mountains on the north to Sahuarita Butte on the south, and from the Rincon Mountains on the east to the Tucson Mountains on the west. The population of the Tucson urban area in 1966 was about 284,000 (Population Study 1966, Tucson), and its estimated water use was about 82,300 acre-feet per year for all purposes.[2] Of this quantity, all but about 10,000 acre-feet per year imported from the Bombing Range just east of Sahuarita was pumped from aquifers underlying the city and its immediate environment, hereafter referred to as the Tucson Basin. Of the 82,300 acre-feet of water estimated as used in the Tucson urban area in 1966, municipal use accounted for about 53,700 acre-feet; irrigation use around 14,800 acre-feet; and miscellaneous uses such as industrial uses, irrigation of parks, recreation areas, etc., for the balance of 13,600 acre-feet. In the Tucson Basin the level of the groundwater table declined 10 to 25 feet between 1961 and 1965 or at an average rate of 2 to 6 feet per year (Matlock, Schwalen, Shaw, 1965).

The groundwater table is declining not only in the immediate Tucson urban area, but also in the urban, industrial, and agricultural areas surrounding Tucson. This entire area is designated herein as the

2. Based on 1966 population consuming an estimated 170 gallons per capita per day. Data from unpublished sources in the Department of Agricultural Engineering, The University of Arizona, Tucson.

Tucson Region and includes the subareas of Sahuarita-Continental, Tucson, Cortaro-Canada Del Oro, and Avra-Marana. This area is shown on the map in Figure 1.

As the groundwater table in the Tucson Region continues to decline and as water demands by urban and industrial users increase, it is likely that the long-run relative importance of agriculture in the Tucson Region will decline. Davis and Schwalen (1964) predict that municipal and domestic use in the Tucson Region will increase from the 1963 quantity of 56,300 acre-feet to 119,560 acre-feet by 1980 and to 294,000 acre-feet by the year 2000. They further predict that groundwater used for irrigation in the Region will decrease from the 1963 quantity of 165,565 acre-feet to 112,500 acre-feet by the year 2000. They expect that total groundwater pumpage will increase from the 257,045 acre-feet in 1963 to 277,260 acre-feet by the year 1980 and to 413,031 acre-feet by the year 2000.

The decline in the use of water for agricultural irrigation which will accompany a decline in the importance of agriculture in the Tucson Region will occur for two reasons.

First, the continued decline in the groundwater table will cause pumping costs to rise which in turn will decrease the net revenue of the industries using groundwater. This increasing cost of pumping will have its greatest effect on heavy water users of which agriculture is the only one of significance in the Region. Research at The University of Arizona has determined the quantities of water used by each of the several Arizona economic sectors per $1,000 of output produced in 1958 (Martin and Bower, 1966). These data show that agricultural irrigation

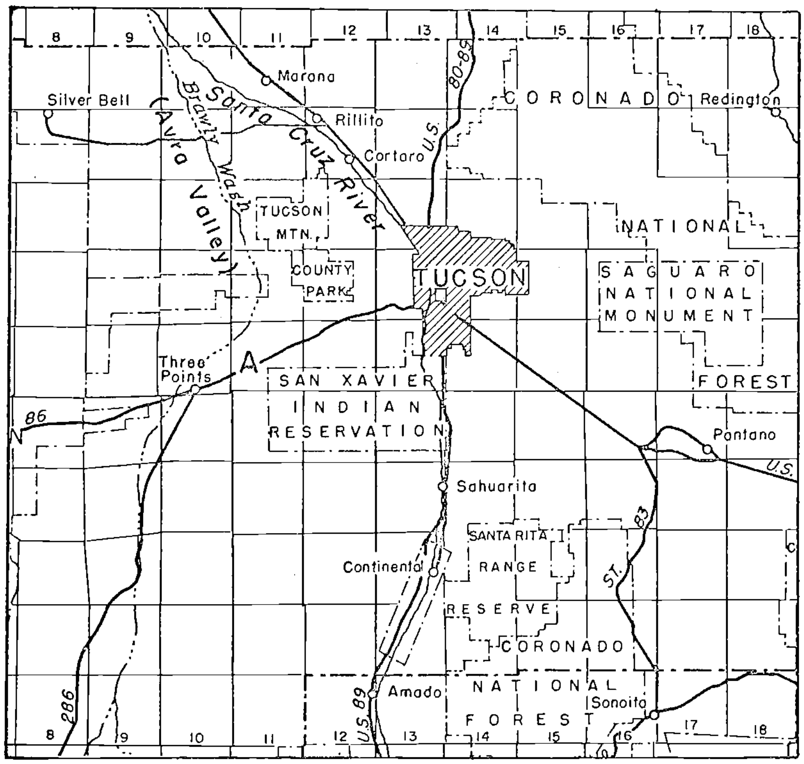

Figure 1. The Tucson Region

required from 5.13 acre-feet of water per $1,000 of output for vegetables to 50.434 acre-feet per $1,000 of output for food and feed grains, while in all other of the state's economic sectors water required was less than .5 acre-foot per $1,000 of output. These data reveal dramatically the relatively small quantity of water required per $1,000 of output in urban uses compared to that required in crop irrigation and the consequent ability of the former uses to pay increasing pumping costs compared to low-valued agricultural uses.

Another recent study at The University of Arizona reveals that the various agricultural sectors of the state's economy generated personal incomes of $14 to $80 per acre-foot of water consumed by them, while the various nonagricultural sectors generated incomes of $1,685 to $82,301 per acre-foot of water consumed (Young and Martin, 1967).

Thus, average productivity per unit of water in high water-using activities, such as agriculture, is low relative to other water uses in the area because of the large quantities of water required in the former per dollar unit of output. These high water-using activities thus tend to be the marginal users of water; as a result, they will be the first sectors to lose their positions in the economy as water costs increase insofar as anything resembling a true or simulated market for transfer of water use is permitted to operate.

The second reason why future agricultural use of water in the Region will decline is the expectation of continual expansion of urban and industrial areas in the Region accompanying economic growth and expansion. The expansion of industrial and urban areas will tend to force agriculture off some presently irrigated lands because of the higher site value the lands will have for nonagricultural uses. Land located in areas of municipal and industrial expansion will take on added value as a result of the willingness of urban users to pay more for it than its agricultural users can afford to pay, thus purchasing it away from agricultural uses.

Possible Legal Restraints on Diversion of Irrigation Water

The purchase of agricultural land by the city and diversion of irrigation water to urban use may be restrained by barriers in water law. Although it is clearly established that landowners have the right to use the underlying groundwater for beneficial use on their overlying lands, there is some question whether the groundwater can be exported by its owner to some other location for such beneficial use. Thus, there are possible legal complications confronting the city were it to undertake transportation of groundwater from presently irrigated lands lying above the underground water basin from which the supply may be pumped.

In Bristor v. Cheatham, 75 Arizona 227 (1953), the Arizona Supreme Court followed Howard v. Perrin and held that the common law rule created a vested property right in the owner of the land to the underlying groundwater. The Court further held that the owner's use of such water had to be reasonable, and explained the rule of reasonable use as follows:

> A majority of the states faced with this problem in recent years adhere to the principle that the owner of lands overlying groundwater may freely, without liability to an adjoining user, use the same groundwater without limitation and without liability to another landowner, provided his use is for the

> purpose of reasonably putting the land from which the water is pumped to beneficial use (Fourth Arizona Town Hall, 1964, p. 56).

The Court qualified the rule of reasonable use by limiting the use of groundwater only to those uses which permit beneficial use or enjoyment of the land from which the groundwater is pumped. Thus, if the diversion or sale of groundwater to others away from the land impairs the supply of groundwater underlying the property of an adjoining landholder, such action may be illegal and damages may be recoverable.

The legal restriction that groundwater must be used on the owner's overlying land may adversely affect municipalities, such as Tucson, which may find it necessary to transport some or all of their water from basins located outside their boundaries. If the transportation of such water away from the Basin adversely affects the water supply of other overlying landowners, the city may, at worst, be stopped entirely from so doing or, at best, be compelled to buy the water rights of some or all of the overlying landowners or pay them damages.

In this analysis it is assumed that the city must buy the agricultural land to obtain the right to the underlying groundwater. It is further assumed in the 10 million gallons per day case analyzed in this study that the city's diversion of groundwater from lands it may purchase will be limited to the quantity of water presently consumed by irrigators on that land. By so restraining its water withdrawals the city will not be increasing the consumption of groundwater in any area it acquires compared to present agricultural use of water in that area, and thus the city will not adversely affect the water supply of surrounding landowners any more than does present agricultural use.

These two assumptions are presumed, for purposes of this analysis, to eliminate or diminish any legal problems the city might face were it to divert 10 mgd of groundwater from each of the several diversion units it might develop in the surrounding agricultural areas. These assumptions do not, however, eliminate the legal problem which may face the 20 mgd model developed below which may, in fact, prove to be the principal restraint on that model.

Assuming the export of groundwater to Tucson from surrounding groundwater basins to be permissible, the city should obtain additional water supplies as needed from among irrigated cropland areas and/or from other alternative sources in order of their ascending cost.

Confronted by a continuously declining underground water table, Tucson must find additional sources of water to meet its long-run needs. With decreasing future agricultural use of water in the Region and with the willingness of urban and industrial users of water to pay more for it than can agricultural users, Tucson should consider the diversion of groundwater from irrigation to urban uses in the Region as one of the possible alternative sources of additional water open to it. This study explores this problem in a preliminary and unsophisticated manner.

Implications of the Problem for Economic Analysis

A declining groundwater table, with stable prices and technology, causes pumping costs to increase over time, thus being of some time-related consequence to any activity using groundwater. Rising pumping costs per unit of water withdrawn cause total variable costs per unit of such water to increase over time. Ceteris paribus, as illustrated in Figure 2, the total variable cost per unit of groundwater in time period T_3 will be greater than the per unit variable cost in time period T_2, which in turn will be greater than in time period T_1.

If the groundwater table were not declining, with prices and technology constant, the per unit variable cost of groundwater would remain constant over time as illustrated by the straight-line function in Figure 2. Were this the case, any user of pumped water, such as the City of Tucson, could continue to fill its continuing and even its increasing demands for water by continued or increased pumping from the underlying aquifer and would not need to consider alternative sources of water supply.

A declining groundwater table with its attendant increase in pumping costs, possibly accompanied by decreasing water quality as well, will cause per unit variable cost of water of suitable quality to increase over time. Such increasing costs of water will make it economically desirable at some point in time for a city like Tucson to obtain its further supplies of water, continuing and increasing alike, from some alternative source or sources assuming such alternative supplies exist.

There are several possible sources of additional water supply for Tucson, as described on pages 2-4 above. In determining, from a purely economic standpoint, which of the alternative sources of water to develop, the city should choose to develop additional water as needed from that alternative source having the lowest prospective per unit cost

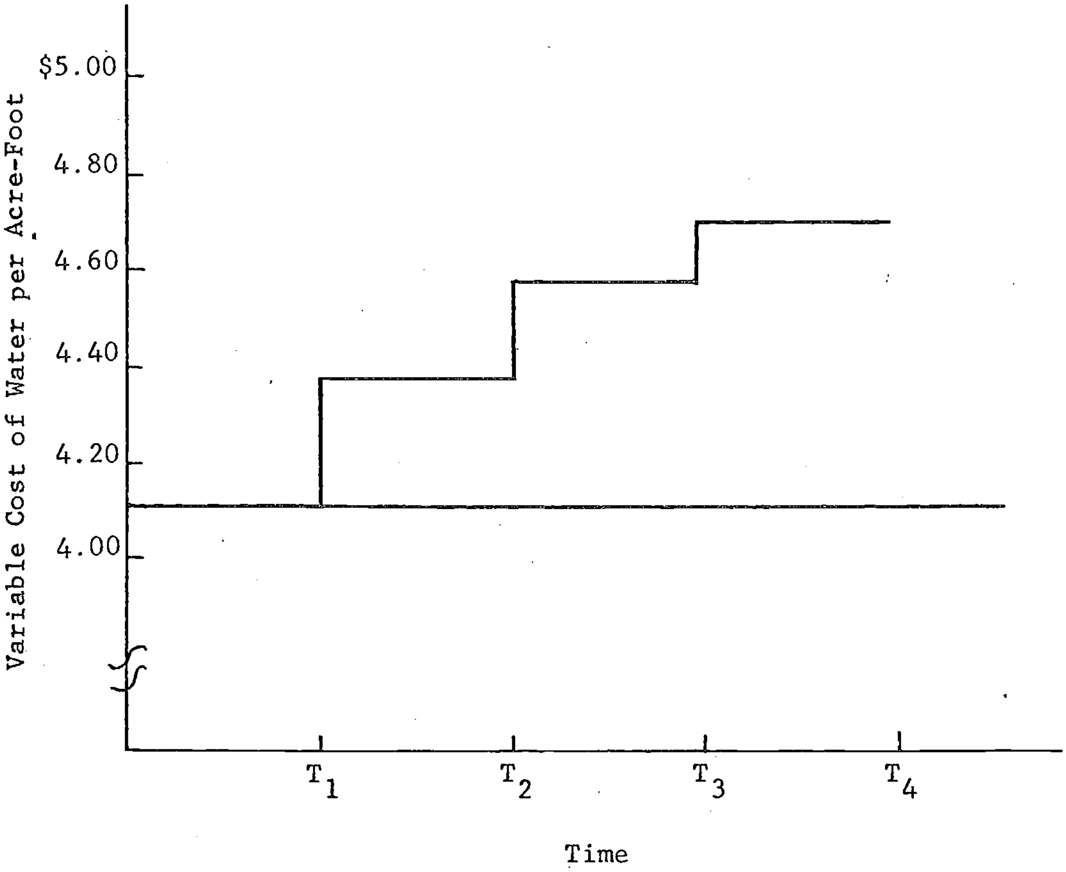

Figure 2. Per Unit Variable Cost of Pumped Water Over Time at Any Given Location (Hypothetical Data).

of water at each point in time when decision to expand must be made. If the new supplies are imported into the city from a distance, they can be used to meet stable year-round or seasonal base demands for water, thus making it possible to operate the relatively expensive importation facilities at capacity almost continuously and to draw on the declining aquifer underlying the city only to meet peaking demands. By so doing, the city may reduce overdraft on the Tucson Basin, possibly stabilizing it.

When the prospective pumping cost per unit of water pumped at a given location under conditions of overdraft is expected to rise over time at some determinable rate, such as illustrated in Figure 2, but decision must be made now as between two or more alternative areas of different initial pumping levels and different rates of future decline, it is necessary to convert the prospective rising cost of pumping for each alternative area into its average annual annuity equivalent value as viewed at the point in time (T_0) when decision between the areas must be made and which, once made, will be irrevocable for a lengthy period while sunk investments are depreciated. However, by so doing, the cost stream over time for any single location is transformed into a single-valued definitive figure thus making it possible directly to compare the present worth of the pumping cost stream of alternative A with that of alternatives B, C, . . . N.

Figure 3 illustrates the comparison of average per unit cost of water when secured from alternative sources that differ one from another in distance from the city, in depth to groundwater, and in rate of

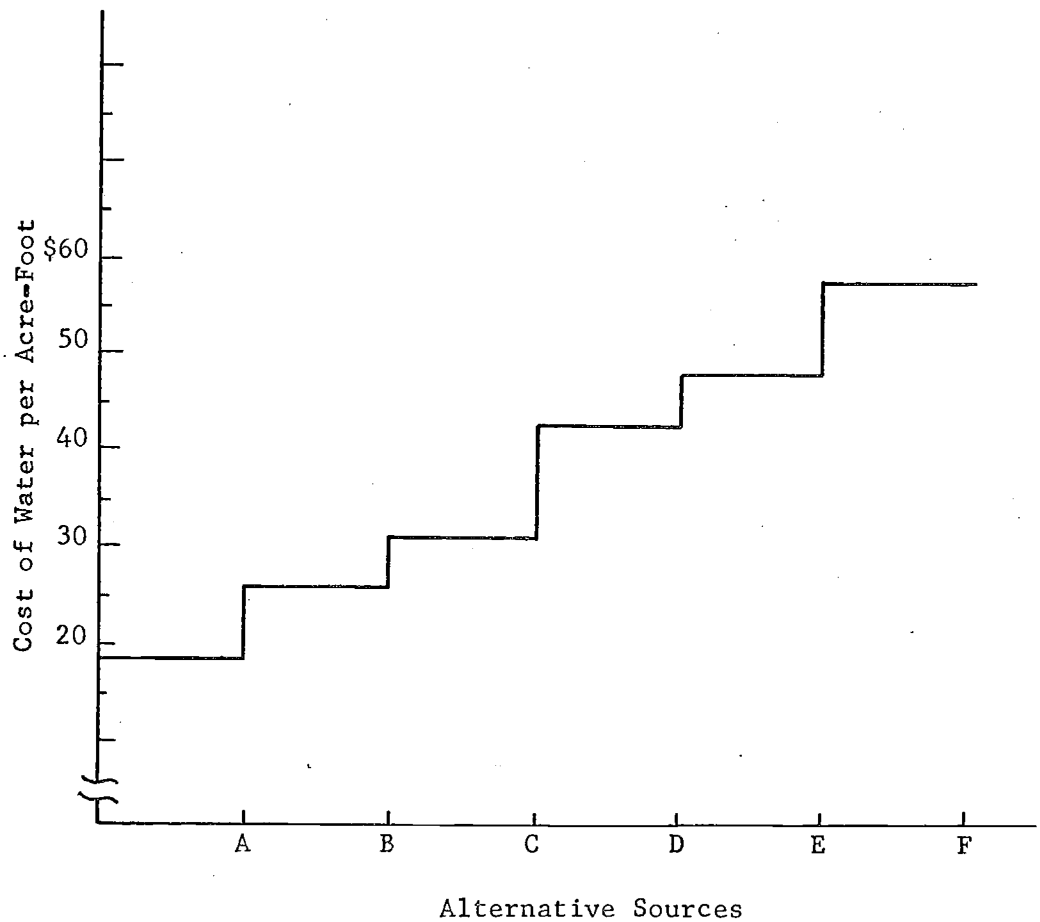

Figure 3. Water Cost per Acre-Foot from Alternative Sources (Hypothetical Data).

decline in the groundwater level. Though the water cost at each source includes an amount to cover future increases in cost due to expected declines in the water tables, the analysis is nevertheless static in that it offers no information other than as to which sources should be chosen for development if decision were made now. It does not forecast the order in time nor the dates when each source should be developed. All parameters bearing on water cost in this study are held constant as between sources except land prices, distance from Tucson, and the rate of decline of each aquifer. Future choices among water sources must repeat the analysis at each time of decision to make the then preferred choice under the conditions then prevailing. If Figure 3 were truly dynamic, all parameters would be variable including future prices, preferences, and technologies such that it would specify not only the best choices to make now among alternative water sources but the timing and order of development of all sources over the indefinite future. Such an analysis requires omniscience on a vast quantity of data and knowledge of the relations involved and thus is quite unworkable within the constraints of time and data available for this study.

When determining the per unit cost of water from each of the alternative sources, such as illustrated in Figure 3, there are several factors some or all of which will affect the per unit cost of water as between the several sources. These factors include declining groundwater table, engineering costs (installation and operation, for both extraction and delivery to the city's distribution center), quality of the water, institutional problems (legal and political), scale of operations, and the time horizon as to expected life of each unit system and as to when the additional water units will be needed. These factors will be mentioned in greater detail in the analysis to be reported herein, but are mentioned here because they will tend to differ as between the alternative sources considered, thus explaining increasing per unit cost of obtaining water from alternative sources, as illustrated in Figure 3.

Objective of this Analysis

As municipal and industrial demands for water in and about the City of Tucson increase over time and as the groundwater table beneath the city declines and pumping costs increase, an economic choice must be made by the city relative to expanding its water supplying sources in the face of such rising demands for and costs of water. A rational economic decision requires that the additional quantities of water required from time to time be obtained from those sources which at the point in time when the decision to expand must be made, add the least to per unit cost of water.

The objective of this analysis is restricted to determination of the supply (cost) function for additional municipal and industrial water for the City of Tucson obtained from one of the alternative sources available to it--the diversion of groundwater in the immediate vicinity of Tucson from commercial irrigation to urban use.[3] The supply

3. A companion or substitute choice might be to increase the water rates charged to water consumers in the city, thus tending to decrease the quantity of water taken by municipal consumers. The economic implications of this alternative for meeting the city's water problem are not analyzed in this study.

functions will be developed at two levels or scales--at the present volume of use by agriculture and at twice this volume. These supply functions are "partial functions" because they reveal only the additional quantities of water that the city might obtain at increasing costs by the diversion of increasing quantities of water from irrigation use. That is, these supply functions do not reveal the additional quantities of water that might be obtained from other sources at these increasing costs of water. They permit, nevertheless, comparing the cost of transferring water from irrigation to urban use with the cost of obtaining additional water from other sources, such as from the Colorado River through the Central Arizona Project.

Theoretical Framework of Analysis

The Direct Costs of Supplying Additional Water

A resource, such as water, may be regarded as an input or as an output; which it is depends on the focus of the analysis. For example, viewed by the consumer, water (resource) is an input, however, to a municipal water company, water (resource) is an output. Hence, the City of Tucson's Water and Sewerage Department may be regarded as a firm attempting to minimize the costs of producing water.

As municipal and industrial demands for water increase over time and as the groundwater table declines causing pumping costs to rise, the City of Tucson must make an economic choice. Such choice to be rational requires that the additional water expected to be needed over time be developed from that source or sources which at that point in time when the decision and irrevocable investments must be made will add the least to the prospective per unit cost of water.

A theoretical model pertinent to the economic analysis of this choice is developed below.

Let us consider first a static framework in the short run relative to costs of water development from a single source as is illustrated in Figure 4. In this short-run static single-source framework, the scale of water production; the location of the well field; the condition of the aquifer; time; size and location of the area; the market price of land; and all other exogenous variables are assumed to be constant.

The short-run cost curves in Figure 4 show the cost per unit of producing different quantities of water outputs with a given scale of plant from a single aquifer; they are expected to exhibit the usual U-shaped curvature. The output from this aquifer at which the average total cost per unit is the least quantity (Q_a) is the "optimum rate of output" for the given scale of plant. At this optimum volume of output, the value of resources sacrificed per unit output of water gained is a minimum in the short run.

Each point on the average total cost curve represents the lowest attainable per unit cost of producing from that source in the short run the output associated with that point and the given scale of plant; each output-cost point on the average total cost curve can be reached only if the firm combines variable resources with the given scale of plant in the proper proportions for each and every volume of output at which those points are located. Thus, if a firm's output is to be 10

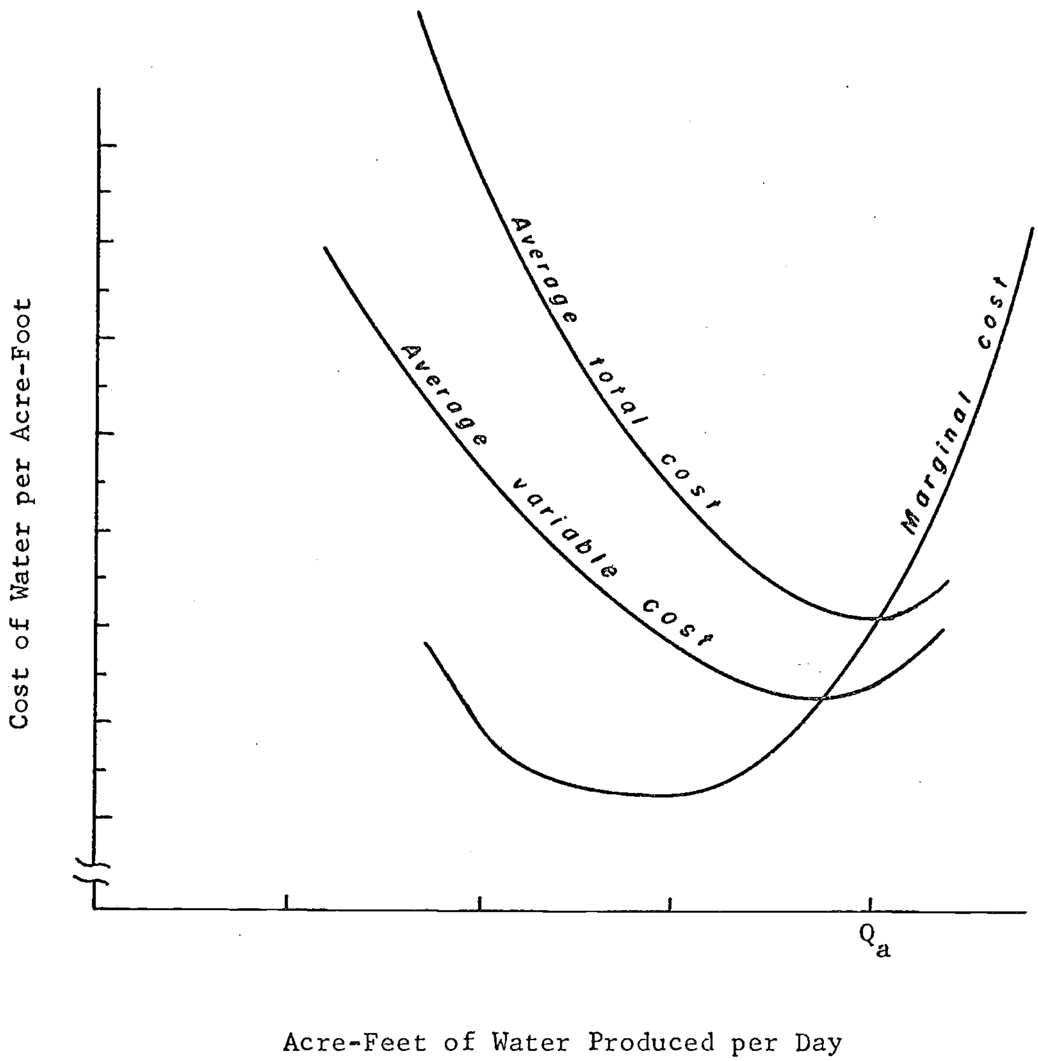

Figure 4. Short-Run Cost Curves for a Given Scale of Plant for Production of Water from a Given Aquifer (Hypothetical Data).

million gallons per day and if its average total cost is to be as low as possible for that output, the resources to produce it must be combined in such proportions that the marginal physical product of an additional dollar's worth of one resource is equal to the marginal physical product of an additional dollar's worth of each other resource. Failure to do so will result in higher costs. The least-cost point on the average total cost curve for a given scale of plant thus represents the cheapest possible way to produce with that scale of plant and shows the volume of output produced at this cheapest level of cost.

Now we shall turn to the long run, in which the firm is free to build any desired scale of plant again on a given source. Now, even the scale of the plant and its complements are variables though all other exogenous influences, as in the short run, are assumed to remain constant.

The long-run average cost, as illustrated in Figure 5, can be thought of as a series of alternative short-run situations, each with its short-run average cost curve and its particular scale of plant, into any one of which the firm is free to move. The long-run cost function shows the least possible cost per unit of producing various outputs from the given source so long as the firm is yet free to build any desired scale of plant.

Thus, the optimum scale choice from among the possible alternative scales at T_0 is plant (scale) A, assuming that the future cost flows are similar as between the alternative plants or, if not,

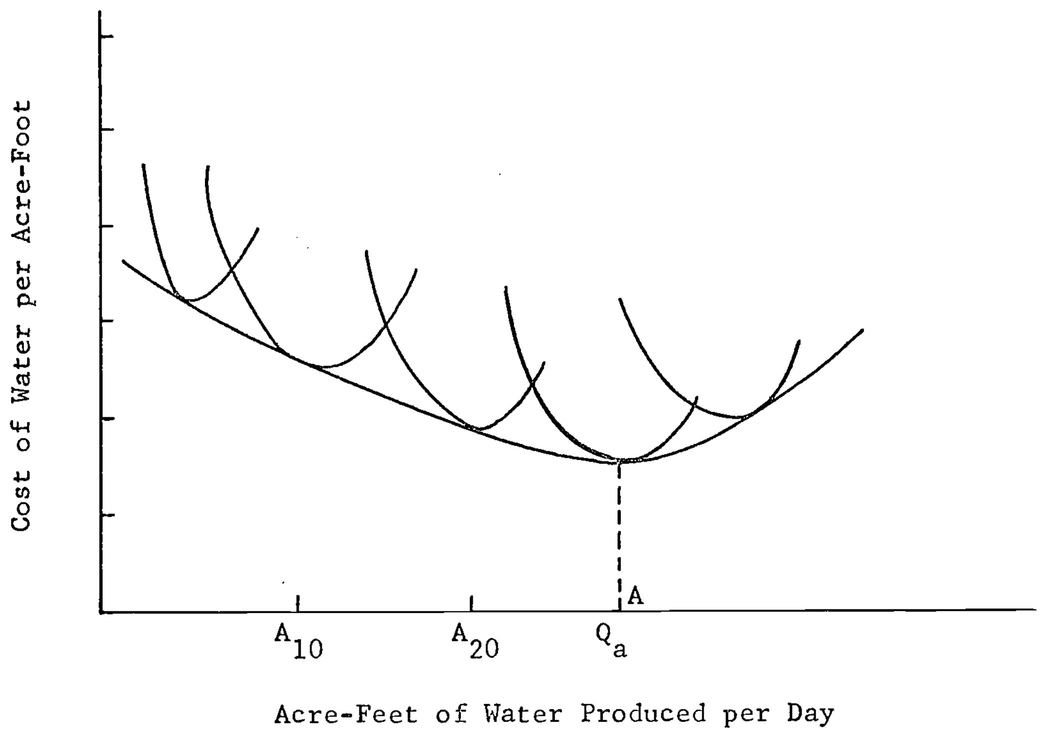

Figure 5. Long-Run Average Total Cost

assuming a zero discount rate. Under these conditions, the firm could expand production in incremental units of plant (scale) A each producing Q_a output of water, as is illustrated by the expansion path in Figure 6.

The City of Tucson chooses to expand water production in incremental units of plant (scale A_{10}) of 10 mgd average capacity (plant A_{10} in Figure 5) with maximum capacity of 15 mgd. Thus, the city's expansion is in lumpy units of 10 mgd each unit presumably designed to produce at the minimum cost for that scale. In this analysis, it is assumed that the city's judgments as to scale increments and design for each scale are valid and rational and represent the most efficient scales for long-run decision making. These judgments were not subjected to scrutiny in this study.

For purposes of this analysis increments of plant (scale) of 20 mgd (plant A_{20} in Figure 5), double the capacity of the above 10 mgd plants, with a maximum capacity of 30 mgd were also assumed. The hypothesis is that possible cost savings may exist if water production were expanded in larger increments. However, offsetting such savings may be the added cost of more unused capacity in the early years of life of the larger plants, a cost problem that is not explored in this analysis; as stated earlier, legal restraints may also arise to bedevil this alternative.

To this point the only variables have been scale of plant and its complements; all other parameters have been assumed constant. However, the level of the groundwater declines over time at these pumping

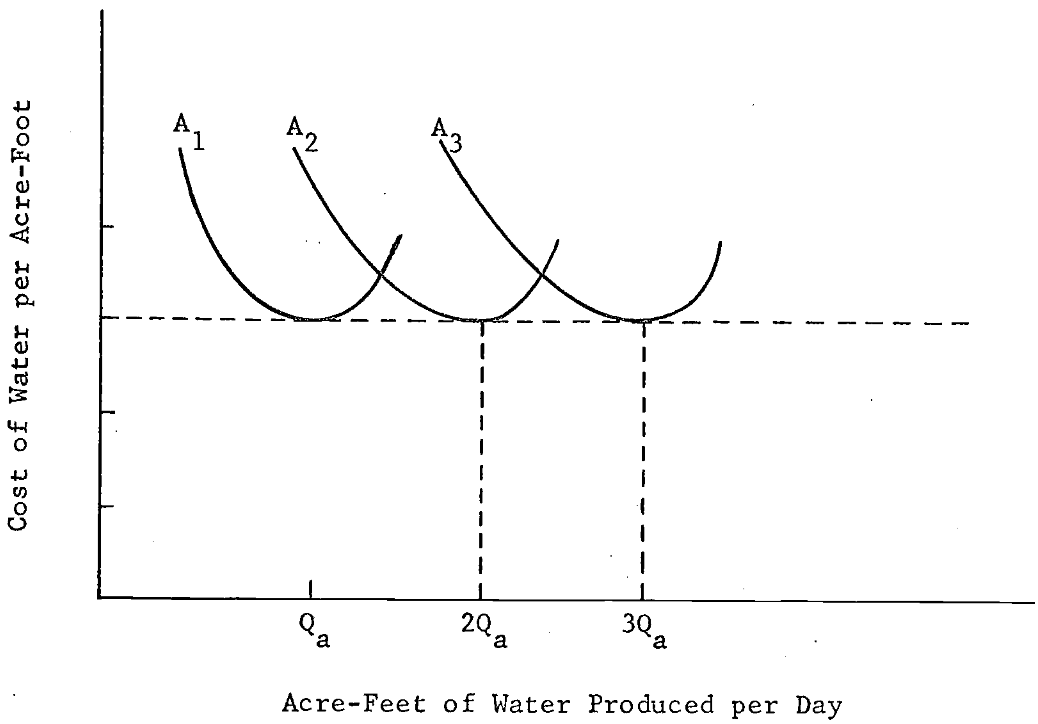

Figure 6. Expansion Path

volumes, thus introducing an implicit endogenous time-related variable into the analysis. The analysis is, however, dynamic only with respect to dated aquifer depths predicted directly and solely from pumping volumes; all other exogenous influences, including prices and technology and even specific yield and quality of the aquifers, are assumed to remain constant.

The presence of a declining groundwater table causes pumping costs per acre-foot to increase over time, in turn causing the average total cost per acre-foot for each plant size to increase over time. This is illustrated in Figure 7 which shows the minimum average total cost per acre-foot for a given plant size, such as plant A_{10}, in each time period with output held constant. Since the rate of decline in water level and thus the average pumping cost per acre-foot over time depends on the rate as well as the volume of groundwater withdrawal, choice by the firm at T_0 as between alternative plant sizes depends in part on the length of life of plant investment to which the city commits itself. The city assumes a 30-year life for all well, pump, and pipeline installations; this study adopts this planning horizon without critical appraisal. Figure 8 illustrates the differing levels of and increases in the average cost per acre-foot of water for plants of different sizes. The differing levels and increases in cost for plants of different sizes result from the differing rates of decline of the groundwater table due to differing pumping volumes and to differing levels of economic efficiency with which plants of different sizes extract water from the aquifer.

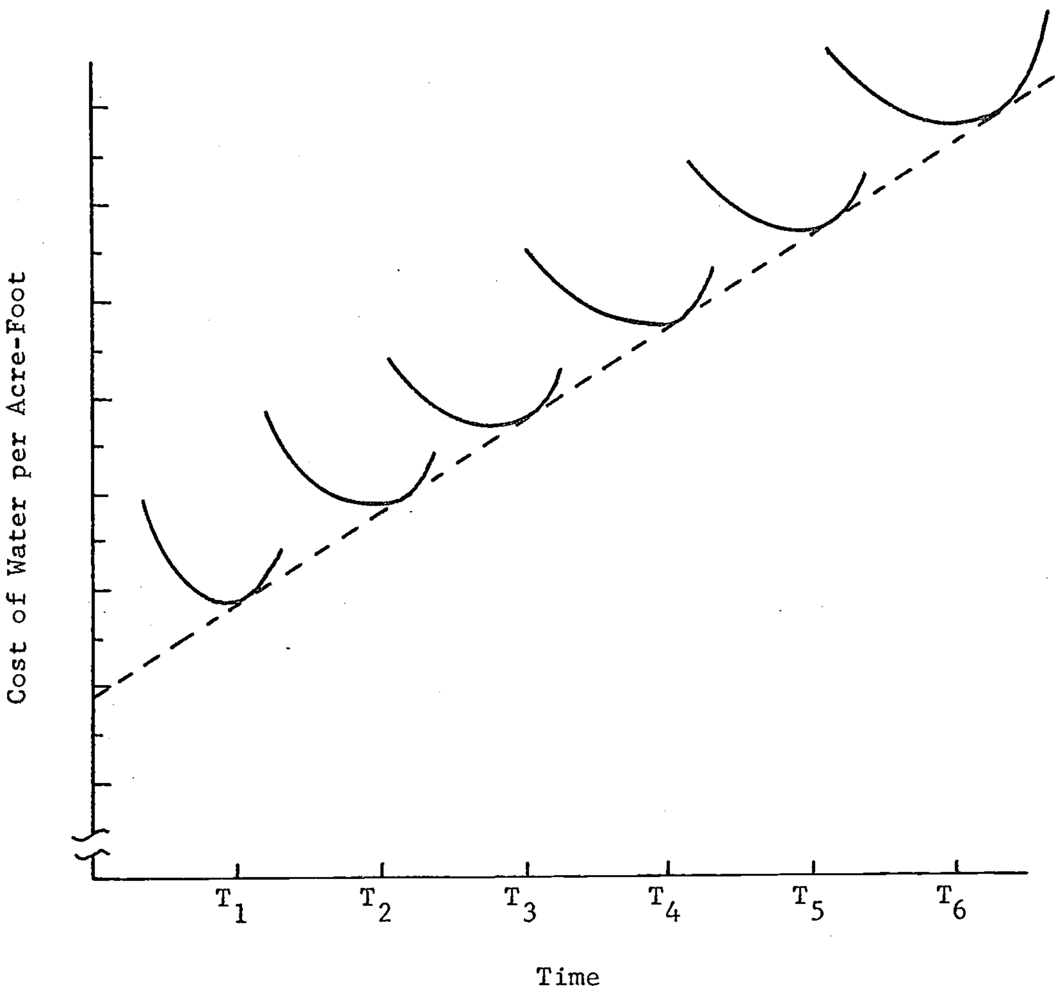

Figure 7. Average Total Cost per Acre-Foot Over Time, Scale of Plant Given, Groundwater Declining (Hypothetical Data).

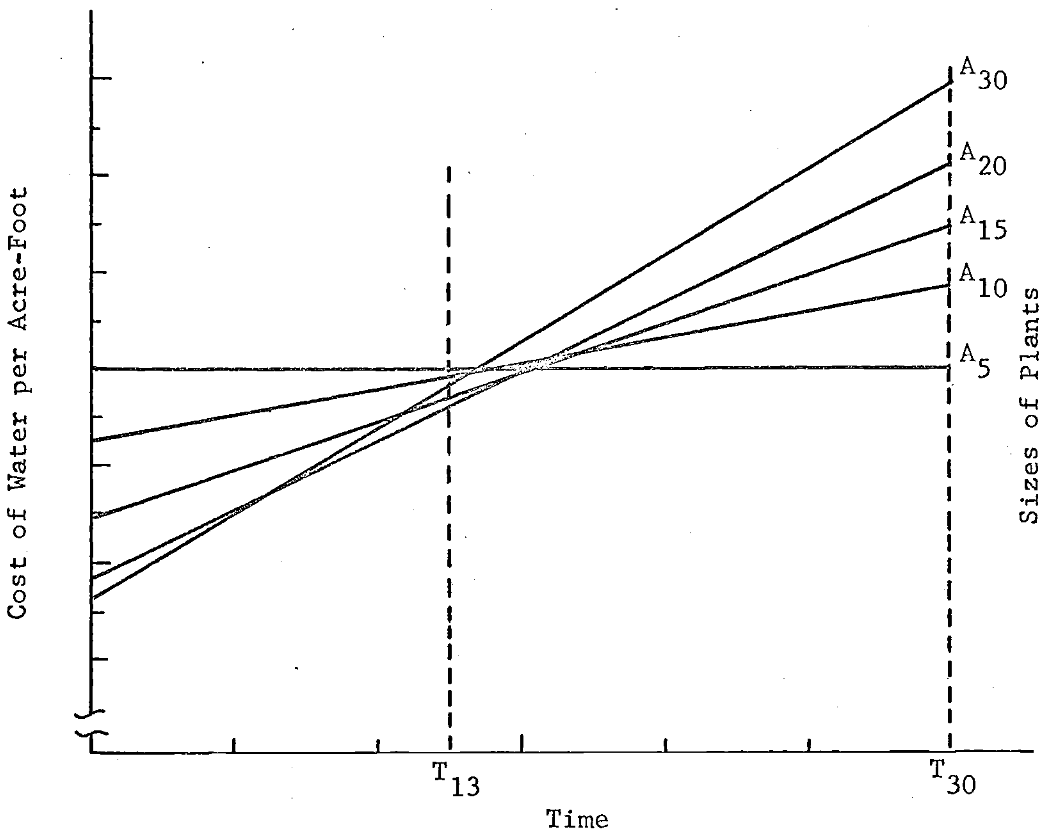

Figure 8. Level of and Increase Over Time in Average Total Cost per Unit of Water Relative to Plant Size (Rate of Withdrawal), Initial Pumping Lift Equal Among All Plant Sizes (Hypothetical Data).

In this analysis the projected annual rate of decline of the water level in any location is assumed to be a linear function of the annual volume of water withdrawn; since all pumping units are presumed to operate constantly (except for maintenance shutdowns), the annual volume of water withdrawn at each location is projected as constant from year to year; as a result the annual increase in pumping costs is constant and a straight-line function. A uniform average annual annuity value of this increasing pumping cost determined at T_0 and extending over the 30-year life of plant at three and one-half percent interest (the city's borrowing rate) is used in this study. Such an amortized average annual cost under the conditions of this problem turns out to be the same as the level of pumping cost reached in the 13th year of plant operation. (For derivation of this assertion, see pages 36-38.) Thus, the hypothetical data of Figure 8 show that plant A_{20} has the minimum amortized average annual cost (valued at T_0) over the 30-year period when discounted at three and one-half percent because it has the lowest level of pumping cost in T_{13}. Other plant sizes may have a lower cost (hypothetical) than A_{20} in T_0 (A_{30}, for example) or in T_{30} (A_5, A_{10}, A_{15}, for example), but none of them have a lower amortized average annual cost than A_{20} over the 30-year period when valued at T_0 at three and one-half percent interest.

The next element in the analysis will be to allow alternative subarea sources of water within the total irrigated area surrounding Tucson to vary with regard to distance from Tucson, number of areas of cropland that must be purchased in each subarea, and market price that must be paid for this cropland; but all other exogenous variables except plant size will be assumed to remain constant throughout. Plant size (scale) will be at two levels, 10 mgd and 20 mgd each in each water source subarea. That is, water extraction per subarea will be twice as rapid in the 20 mgd scale assumption as in the 10 mgd assumption.

Figure 9 illustrates the amortized average annual per acre-foot total cost, (extended over a 30-year period valued at T_0 at three and one-half percent), for obtaining additional increments of water in lump units of two scales from alternative subareas. The increase in the amortized average annual per acre-foot cost of water as between the alternative subareas is represented by the step supply function in Figure 9. The vertical heights of the steps are due to variation between subareas in the depth of the groundwater table at T_0 as between areas, the expected rate of decline of the groundwater table over the life of the investment in each area, the distance of the subareas from the city, and the purchase price of the irrigated land in each area.

The preferred choices at T_0 among the possible subarea alternatives available at T_0 are those that provide the additional water needed at T_0 and subsequently for 30 years which will add the least to the amortized average annual per acre-foot cost of water. This goal is achieved if those area sources are chosen for development at T_0 in the order of their ascending amortized average annual cost per acre-foot. That is, area A first, then area B, then area C, etc., until the required increment in volume of water to be supplied equates with the demand for additional increments.

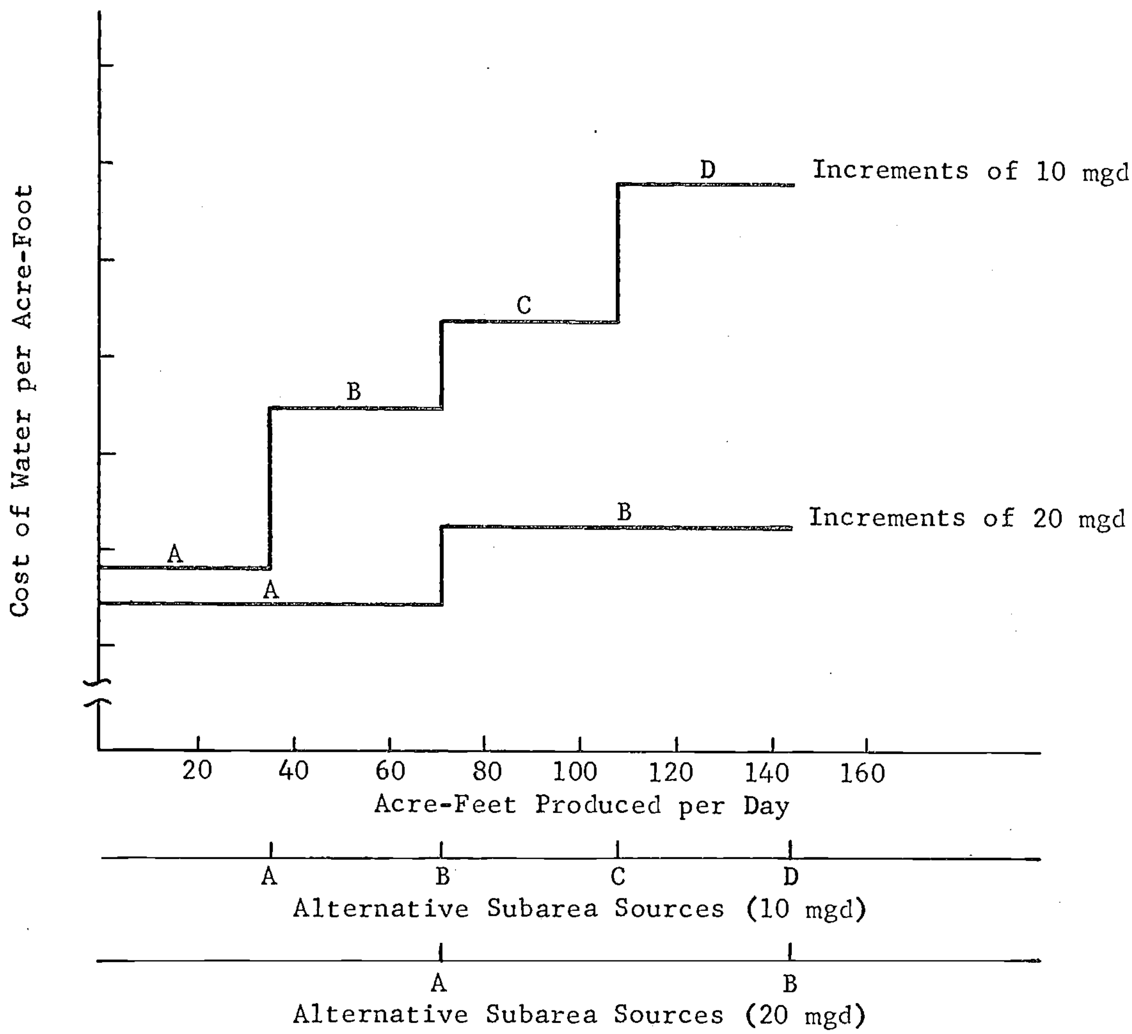

Figure 9. Supply Function for Water from Alternative Subareas for Two Given Plant Sizes (Hypothetical Data).

In a fully dynamic analysis of the economics of Tucson's water problem, both the city's demand for and supply of water would need to be considered with regard to time. The increments in quantity of water demanded would be dated as to when supplies to fill them would be needed. The inputs used in the production of these dated quantities of water would be valued at their anticipated opportunity costs for each date. These dated opportunity costs would be affected by anticipations as to changes in technology, institutions, water quality and other parameters, all of which must be allowed to vary in a fully dynamic model.

The _optimum optimorum_ choice at T_0 as to scale and timing of water development from all alternative sources and with reference to all future dates would be that program that maximizes the present value of the stream of net gains over time which it generates, with future values discounted to T_0 at the social rate of time preference.

This study does not attempt such a fully dynamic analysis, hence, does provide the basis for such an _optimum optimorum_ choice.

The static model used in this study in which all parameters are constant except volumes of withdrawal, depth of the aquifers, their rates of decline, distances of the sources from Tucson, and land prices permits one to make preferred (static) choice at T_0 as between alternative developments though not the _optimum optimorum_ choice in which all parameters are variable and dated as to time of their occurrence. After having made the T_0 (static) choice, to make the next preferred choice, say in T_1, this analysis would need to be repeated to determine the preferred choice under the conditions then prevailing. This is the process of <u>optimum incremental</u> choice moving us in the presently preferred direction at the presently preferred speed based on knowledge presently available.

The process conceptualized in the analysis described above permits development of (direct cost) supply functions for the diversion of irrigation water to urban use in the immediate Tucson Region. These supply functions reveal the per acre-foot direct costs of supplying water in discrete quantities valued at T_0 from the various agricultural subarea sources hereafter described.

The Indirect Cost of Supplying Additional Water

The direct costs of supplying additional increments of water to Tucson by diverting irrigation water to municipal use as described above include only the costs of land purchase, pumping, and delivering the water to the city. In addition, removal of agriculture in whole or in part from the Region removes some of the economic base from the Tucson economy. In order to derive a full economic cost of additional water from this source, it is necessary to estimate the indirect cost to the city's economy occasioned by this curtailment of commercial agriculture.

The conceptualization of the facet of water cost to the city is described in Chapter 5 and will not be repeated here.

The Total Economic Cost of Supplying Additional Water

The total economic cost of supplying additional water for municipal use by this diversion from commercial agriculture consists of the direct costs of so doing plus the indirect costs associated therewith. The total economic costs of this alternative as a source of additional water for Tucson are analyzed and described in Chapter 5.

CHAPTER 2

ANALYTICAL TECHNIQUE

Analytical Model

The analytical method used in this analysis to determine the diversion per acre-foot to divert irrigation water to municipal use will be the sum of (1) the amortization of depreciable capital in wells, pumps and pipelines over 30 years at three and one-half percent, (2) the annual operating costs of the pumps and pipelines, (3) the interest at three and one-half percent on land purchase costs, and (4) the amortized average annual cost of the increasing pumping costs due to decline of the groundwater level with interest at three and one-half percent over the 30-year period considered.

Budgeting is used to arrive at the direct cost per acre-foot of diverting irrigation water to urban use in the Tucson Region. Costs of water budgets are developed for each of the several water diversion units into which the Region is divided. (See Figure 12 on page 55 and the discussion on pages 53 and 54 where the water diversion units are illustrated and discussed.) Each diversion unit is arbitrarily bounded to include an area of reasonably contiguous cropland from which approximately 9,200 acre-feet of water per year (10 mgd for 300 days)[4]

4. The Tucson Water Department in its advance planning assumes well fields will operate at design capacity for 300 days per year.

presently consumed in irrigation annually within the unit can be diverted to Tucson for use as municipal and industrial water. The cropland included in these units lies north and west of Tucson along the Santa Cruz River from Jaynes Station to Marana and in Avra Valley from Marana to Three Points, together with that which lies along the Santa Cruz River south of Tucson to the Santa Cruz County line.

The acreage of cropland required to make up each diversion unit is derived from data as to the average volume of consumptive use of irrigation water on each section of the Region from 1960-65.[5] Each diversion unit is bounded so as to enclose an area that will supply approximately 9,200 acre-feet of irrigation water per year except for three isolated agricultural areas which were considered as separate diversion units, although each used less than the 9,200 acre-feet of water taken as the generally standard unit.

For each diversion unit costs are estimated for the production and delivery of water from that unit to the City of Tucson at the present rate of irrigation use in the unit (the 10 mgd assumption) and at twice the present rate of use (the 20 mgd assumption). These diversion units are so structured and will be brought into use in such order that the costs of diverting irrigation water to Tucson will be minimized subject to the selected constraints later described.

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5. Acreage and water-use data from 1960-65 were obtained from the Department of Agricultural Engineering, The University of Arizona, Tucson. Water use was based on a six-year average of the following crops: cotton, maize, grain, safflower, alfalfa, pasture and miscellaneous with a water use of 3.5, 2.5, 2.5, 3.5, 4.5, 4.0 and 3.0 acre-feet per acre per year, respectively, which is considered to be their consumptive use.

Assumptions

For purposes of this study, it is assumed that the price of factor inputs will be constant over time and that there will be no changes in technology. It is also assumed that the quality of the water remains constant as the water level falls. There is, however, evidence from present deep wells of 1,000 feet or more that the quality of water decreases at these depths. Whether this decrease in water quality at these depths occurs only in isolated areas or is generally true for all aquifers in the Tucson Region remains to be determined. In this analysis practically all wells are projected to be less than 600 feet deep even at the end of the 30-year period (1997) on which cost budgets are based, with the deepest well reaching about 760 feet. Thus, for purposes of this analysis, it is assumed that water quality will not deteriorate significantly within the relevant time horizon of current water supply planning for Tucson. It is further assumed that all legal and political barriers to groundwater diversion from use on overlying lands have been resolved. These assumptions have the effect of holding constant all exogenous parameters of the budgets for the diversion units throughout the period of analysis and of permitting the projected diversions legally to take place.

The analysis also assumes that the rate of decline of the groundwater table in each diversion unit will be equal to the rate experienced under present irrigation use when water is diverted at the present rate of irrigation use (9,200 acre-feet per year) and that the rate of decline will double in each diversion unit when water is diverted at twice the present rate of irrigation use (18,400 acre-feet per year). The effect of these assumptions is that the rate of decline in the water table is assumed to be a linear function, the slope of which is directly proportional to the rate of use or that the rate of decline is directly related to the quantity of water pumped. Although it may be argued that the groundwater reservoir is similar to a bowl with sloping sides and that, with a constant volume of extraction, the rate of decline will tend to increase, for purposes of this analysis the rate of decline is assumed to be linear and directly proportional to the rate of use. This assumption has the effect of holding the efficiency of the aquifer constant at the increased depths. The decline of the groundwater table in each of the diversion units is projected at the rate of decline experienced on the average over the period 1956-65.[6]

The presence of a declining groundwater table has the effect of increasing pumping costs over time. In this analysis, the increasing pumping costs are converted into an amortized average annual cost at three and one-half percent interest over the 30-year planning period.[7]

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6. Data to determine the present rate of decline in each area was obtained from unpublished well test data on file in the Department of Agricultural Engineering, The University of Arizona, Tucson.

7. The three and one-half percent interest rate and the 30-years planning horizon were obtained from the City of Tucson's Water and Sewerage Department plans for diverting water to Tucson.

This amortized average annual cost is determined by the following formula:[8]

$$A = \Delta P \sum_{n=1}^{n\ max} S_{\overline{n}|i} \quad \frac{1}{S_{\overline{n\ max}|i}} + K \text{ in which}$$

A = amortized average annual cost of regularly increasing pumping costs.

ΔP = average annual increase in pumping costs over the planning period.

n = years included within the planning period.

n max = last year of the planning period.

$S_{\overline{n}|i}$ = factor representing the end-of-period (after a term of n years) amount of an annuity of $1 per year received at the end of each year (n) at rate of interest (i) per year (the value of which can be found in any standard set of annuity tables).

K = pumping cost at beginning of year one (n = 0).

For purposes of this analysis, this formula becomes:

$$A = \Delta P \sum_{n=1}^{n=30} S_{\overline{n}|.035} \quad S \frac{1}{\overline{30}|.035} + K \text{ where}$$

the years (n) in the planning period extend from 1 to 30 and the interest rate (i) is three and one-half percent. Solving we get:

$$A = \Delta P\ (669.41274)\ (.01937) + K$$

$$= \Delta P\ (12.9665) + K$$

or, approximately

$$= \Delta P\ (13.0) + K$$

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8. Formula was developed by Professor M. M. Kelso, Department of Agricultural Economics, The University of Arizona, Tucson.

Since ΔP is the average annual increase in pumping cost, the multiplier (13.0) can be taken to be that year (the 13th) in which the pumping cost equals the amortized average annual cost of the stream of increasing pumping costs over the entire planning period or the "discounted time average" level of the water table in that well (over its 30-year life). Consequently, it becomes possible to determine the amortized average annual cost of pumping from any given well or wells by calculating simply the cost of pumping therefrom in the 13th year ($n = 13$). Knowing the average annual increase in pumping cost and the pumping cost at the beginning of the period (the initial pumping life at $n = 0$), the calculation is simply: average annual increase in pumping cost multiplied by 13 plus beginning pumping cost.

The analysis further assumes, with respect to the organization and operation of the diversion units, that:[9]

1. The well field in each diversion unit operates 300 days per year.
2. All new wells and pumping units are installed at $50,000 each, although, in practice, some existing irrigation wells might be used. This assumption is conservative in that it errs on the high side tending to make costs higher than might actually occur in establishing the well fields.
3. Well output is 1,500 gallons per minute. With an output of 1,500 gpm, 7 and 14 wells would be required to pump

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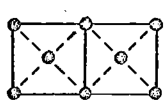
9. Personal conversation with Mr. J. F. Rauscher, Chief Engineer, City of Tucson Water and Sewerage Department and a study conducted by City of Tucson Water and Sewerage Department, unpublished.

a maximum of 15 and 30 mgd, respectively, which are the two design standards to which well and pipeline capacities are planned in this study. These wells plus one emergency well are a total of 8 or 15 wells planned for each diversion unit for the production and delivery of 10 mgd and 20 mgd, respectively.

4. The pumping cost per acre-foot per foot of lift is held constant at $.01663 throughout the analysis. The pumping units are powered with natural gas, pumping costs are based on a price of 52.2 cents per 1,000 cubic feet of gas plus an existing contract maintenance cost of 18 cents per 1,000 cubic feet of gas or a total of 70.2 cents per 1,000 cubic feet of gas, with an overall plant efficiency of 13.4 percent.

5. Wells are located in a single well field within each diversion unit and are spaced approximately three-fourths of a mile apart in an X pattern over the necessary sections thus tending to minimize costs of collection into the transmission pipeline from the several wells in a single well field. The eight wells composing a 10 mgd well field are assumed to be distributed thusly over a two square mile area:  . The fifteen wells composing a 20 mgd field are distributed similarly over somewhat more than twice the area.

6. The investment cost per foot of each pipeline size installed is held constant throughout the analysis.

7. Friction loss within each pipeline is held between three and four feet per mile by using the appropriate pipeline size for the volume of water to be transported, as suggested by the Tucson Water and Sewerage Department. The relevant factors can be obtained from Williams and Hazen (1945).

8. The delivery system is constructed to deliver a maximum of one and one-half times the average rate of delivery; that is, if the system is to deliver an average of 10 mgd, it is developed to deliver 10 mgd (1.5) or 15 mgd.

9. Capital costs are amortized at three and one-half percent over 30 years; the annual charge for capital invested thus amounts to initial capital cost times .05437.

10. Average pumping lifts for the purpose of determining the variable costs of pumping over the 30-year life of each well field are taken to be the pumping lift of the wells in each diversion unit in the 13th year of operation (see pages 36-38) plus the lift to deliver water from the well field in each unit to the Twenty-Second Street Reservoir in the City of Tucson.

11. The well fields are located in each diversion unit so as to minimize costs of pumping lift plus transportation which in this analysis turns out to be that point in each unit closest to Tucson.

12. Diversion units are based on acres of cropland which, at their present rate of consumptive use for irrigation, could supply 9,200 acre-feet of water per year, except for three isolated areas which are considered as separate diversion units although smaller than this standard.

13. It is assumed that the city will purchase all the agricultural real estate (land plus nonsalvageable improvements) in each diversion unit at the going market price in each area.[10] The value of cotton allotments is included in the market prices assumed.

Supply Function

The direct cost per acre-foot of diverting irrigation water to Tucson will vary as between diversion units because of differences in initial depth of the groundwater table and its rate of decline over time, price of land, elevation relative to the point of delivery in Tucson and the distance from the Tucson delivery point. The estimation of water production and delivery costs for each diversion unit, under the assumptions listed above, permits determination of the cost per acre-foot of diverting increasing quantities of irrigation water by acquiring and developing an increasing number of diversion units at one point in time (1967), producing the water therefrom at a constant

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10. The market price for irrigated cropland in each diversion unit was supplied in a personal conversation with Mr. Daniel W. Clarke, Vice President, Southern Arizona Bank and Trust Company; Mr. William O. Fraesdorf, Jr., Real Estate Broker, Canyon State Land Company; and Mr. Andrew W. Hodge, Assistant Vice President, Bank of Tucson.

rate over 30 years and transporting it to a single delivery point in Tucson.

From this analysis one can derive the (direct cost) supply function for the diversion to Tucson of irrigation water from within the Tucson Region by ordering horizontally the several diversion units and the cumulative quantities of water they could deliver annually in ascending order of their costs per acre-foot for supplying such water.

The (direct cost) supply function reveals the increased direct cost per acre-foot confronting the city were it to divert additional increments of irrigation water to meet its needs for municipal and industrial water; thus, it represents the marginal cost to the city for obtaining additional units of water by diversion from nearby irrigation. The quantity of irrigation water that could be actually diverted to Tucson, from a standpoint of direct economic costs only, would be that quantity for which marginal costs of delivery to Tucson are lower than the marginal cost of water from possible alternative sources.

The development of the analysis as presented in this section will provide the structural framework within which the answer to the major question posed in this study will be found. The answer is developed from data obtained from the Department of Agricultural Engineering, The University of Arizona, and from the City of Tucson Water and Sewerage Department. This answer, when found, will be in the form of a (direct cost) supply function for the diversion of irrigation water to municipal use from within the Tucson Region; it will be composed of discrete stepwise increments in number and location of diversion units with estimates of the direct cost per acre-foot to extract and deliver groundwater to Tucson from each.

Use of the Imported Water

A significant question has to do with extent to which additional water imported into the Tucson Basin will add to or substitute for water currently withdrawn by the city from its presently diminishing sources. Insofar as substituted for present water supplies, the imported water will prolong the life of the city's present sources but at the expense of aggregate volume available for short-run municipal growth; if added to present supplies, the reverse consequences will result.

During the period since 1960, annual deliveries by the city have grown from 13 billion 238 million gallons per year to 15 billion gallons. The average monthly distribution of these deliveries during this period has been as follows:

Month	Portion of Annual Delivery (percent)
January	4.6
February	4.9
March	6.4
April	8.6
May	11.5
June	13.0
July	12.4
August	10.3
September	9.3
October	8.0
November	5.8
December	4.9
	99.7

If we assume a current annual delivery by the city of 15 billion gallons per year, it may be assumed to be delivered by months on the average as follows:

Month	Deliveries per Month
	(millions of gallons)
January	690
February	735
March	960
April	1,290
May	1,725
June	1,950
July	1,860
August	1,545
September	1,395
October	1,200
November	870
December	735
	14,955

If it is assumed that the city will operate the sources of imported water in such manner as to keep them supplying a constant amount throughout the year, using its existing water sources to meet seasonal peaking demands, it can be expected to use the demands of the four lowest months (November, December, January and February) as the constant base demand to be supplied throughout the year. These four months demand an average of 758 million gallons or 2,318 acre-feet each. Over 12 months, this base demand therefore will be (2,318 acre-feet x 12) approximately 27,800 acre-feet. Total annual demand is 15 billion gallons or approximately 45,900 acre-feet. Hence, if base demand of 27,800 acre-feet is met from imported sources, the present sources of water drawn upon by the city will supply about 18,100 acre-feet, a net saving in withdrawal from the city's present sources of 27,800 acre-feet or 60 percent of present withdrawals.

From these estimates, it may be concluded that 60 percent of the water drawn by the city from outside its present sources can be assumed to be a replacement supply and 40 percent can be called additional supply. Another way of putting it is that each unit of water imported will be divided 60-40 between replacement of and addition to present supplies.

These calculations include nothing as to the possibilities of judicious mixing of waters of different qualities which might extend the efficiency with which present municipal supplies could be used. Neither do they include any reference to that rate of withdrawal from present municipal supplies that would stabilize present supplies nor to any other rate that might be considered to be a judicious quantity in reference to the rate of decline in present supplies that would follow therefrom. Incorporating into this demand analysis estimates on these two points might increase or decrease the proportion of imported water that would be available to increase total available supplies, hence be available to meet increasing future municipal demands. On the basis of these simplified estimates, one may conclude that immediate diversion of water from irrigated agriculture in the Tucson Region in the amount of 27,800 acre-feet per year (or from about three diversion units) will take most if not all of the excess pressure off the city's present supplies, and that as the city's future demands increase it can obtain additional supplies from this source of which about 40 percent will be available to meet expanded water demands.

CHAPTER 3

ANALYSIS OF THE DIRECT COST OF DIVERSION OF IRRIGATION WATER TO TUCSON IN TEN MILLION GALLONS PER DAY INCREMENTS

Cropland Acreage and Irrigation Use

The determination of cropland acreage surrounding Tucson and the quantity of irrigation water used by it was the starting point of this analysis. Data as to crop including fallow acreage by sections in the Tucson Region were obtained from annual surveys conducted by the Department of Agricultural Engineering, The University of Arizona, Tucson. Irrigation water use by sections was computed from these crop acreages and consumptive use in acre-feet per acre for the various crops as follows:[11]

Cotton 3.5	Maize 2.5	Grain 2.5
Safflower 3.5	Alfalfa 4.5	Miscellaneous 3.0

Inasmuch as these are consumptive use figures, they represent net withdrawal rather than gross pumpage of groundwater for irrigation purposes. Experiments in the Santa Cruz Basin (Halpenny, et al., 1952) have shown that 10 to 33 percent of the gross water applied for irrigation recharges the groundwater basin and that consumptive use approximates net disappearance of water applied for irrigation purposes. The acreage of each crop in each section was estimated for purposes of this

11. Consumptive use figures were supplied by the Department of Agricultural Engineering, The University of Arizona, Tucson.

study by taking the average of the acreage of each crop in each section for the period 1960-65, as shown in the crop acreage surveys referred to above. Multiplying this estimate of the acreage of each crop on each section by the consumptive use of irrigation water by each crop and summing by sections gave an estimate of the average annual net use of irrigation water on each section in the Tucson Region over the same period. The estimates of crop acres per section, consumptive use of irrigation water by each crop, and the resulting estimate of use of irrigation water on each section are assumed to remain constant over the time period of this analysis.

From these data it was estimated that 153,000 acre-feet of groundwater is the net withdrawal for irrigation in the Tucson Region and is used on about 61,000 acres of cropland. This is almost 65 percent of the estimated total annual pumping draft of about 248,000 acre-feet[12] in the same Region.

Present Groundwater Table Conditions

The continued population growth in the Tucson Region, the consequent increased pumping of groundwater and decline in groundwater levels underscore the importance of a detailed study of the groundwater system.

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12. Figures for estimating the total annual pumping draft were supplied by the Department of Agricultural Engineering, The University of Arizona, Tucson.

The United States Geological Survey has been collecting hydrologic and geologic data in the major irrigated basins of Arizona for many years as part of a continuous program of statewide groundwater surveys (White, Matlock and Schwalen, 1966). The Department of Agricultural Engineering, The University of Arizona, has also been collecting groundwater data in parts of the state with concentration on the immediate Tucson Region for nearly an equal period of time. The work of the Geological Survey is conducted mainly in cooperation with the Arizona State Land Department, while that of the Agricultural Engineering Department is mainly in cooperation with the City of Tucson and Pima County.

The volume of data collected has increased in recent years. With the growing demand for water, there is an increased need for a more comprehensive analysis of these data to provide the necessary quantitative solutions to the problems of water quality, water availability, and the effects of increasing withdrawals.

In the study reported herein the level of the groundwater table in 1965 and its average annual rate of decline during the period 1956-65 were determined for each township in the Tucson Region from well information on open file in the Department of Agricultural Engineering, The University of Arizona, Tucson. The Agricultural Engineering Department measures annually the depth below the surface in over 1,500 wells to determine changes in water level from the previous year (Matlock, Schwalen and Shaw, 1965). These well measurements are made on approximately the same date each year, winter or spring measurements being preferred since at that time of year the drawdown coning of the groundwater level is at a minimum because pumping is least active. Drawdown coning occurs when the pump is in operation and is equal to the gallons pumped per minute divided by the estimated specific capacity of the aquifer.[13] Such drawdown coning will be computed for each well field and added to the static pumping lift for purposes of computing dynamic pumping lift and, hence pumping costs. However, the initial and groundwater levels shown in this study are static levels taken directly from the measurements made during periods of reduced pumping activity.

The levels of the groundwater table in the spring of 1965, for the Tucson Region, are shown in Figures 10 and 11. These depths to water were determined also for the springs of 1956 and 1961.

The rate of decline of the water table for each township in the Tucson Region was determined by calculating the decline between the 1956 and 1965 water levels for each well measured in each township, and determining its average annual rate of decline during that period. The same procedure was used to determine the average annual rate of decline of each well for the 1956 to 1961 period and for the 1961 to 1965 period. Since, in almost all cases, the rate of decline did not change significantly during the 1961-1965 period, from what it was during the 1956-1961 period, the rate of decline in groundwater

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13. The estimated specific capacities were obtained from the Department of Agricultural Engineering, The University of Arizona, Tucson.

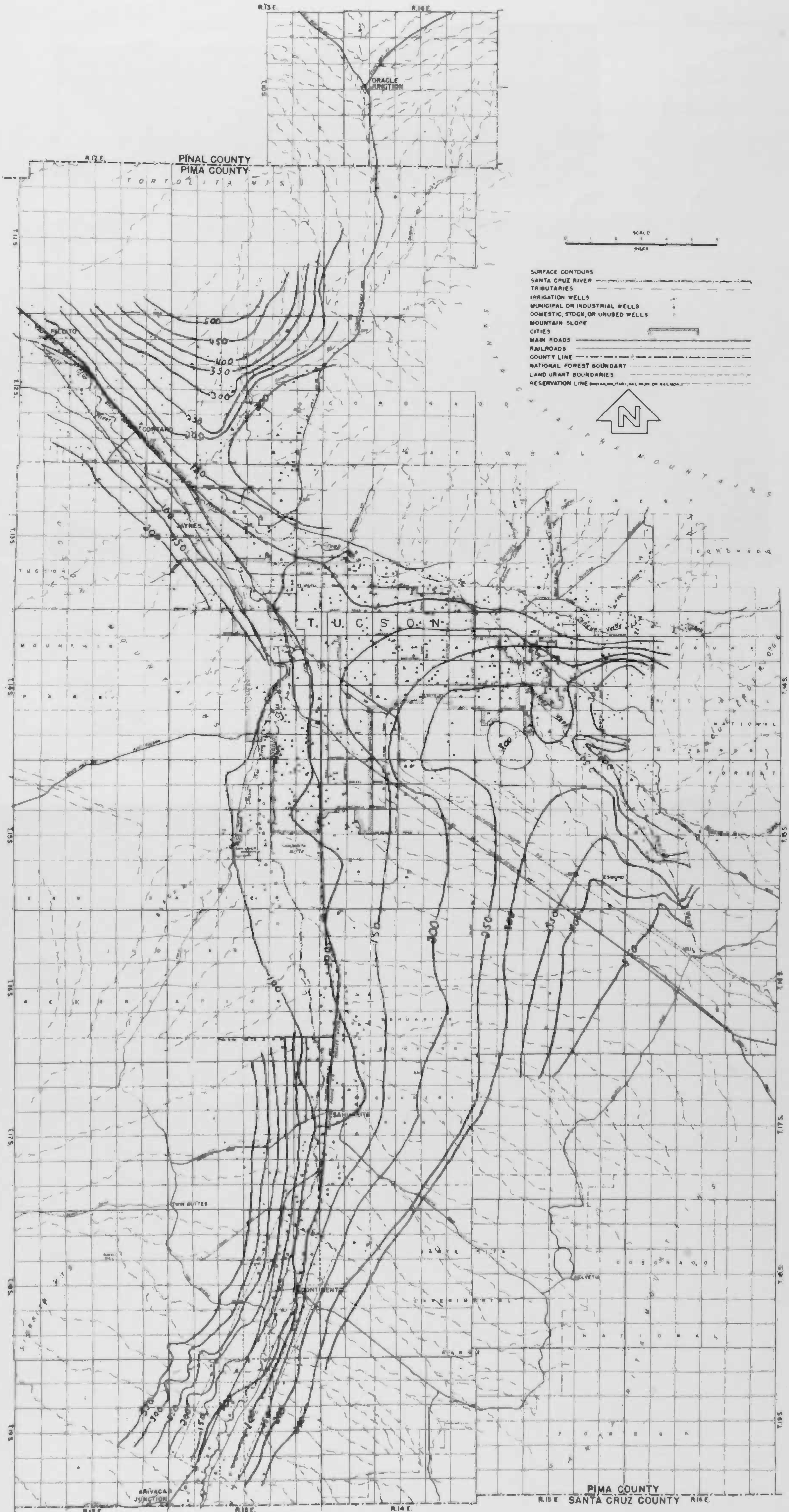

Figure 10. Water Level Contours, Spring 1965, in Santa Cruz Valley, Arizona, Depth Below the Surface.

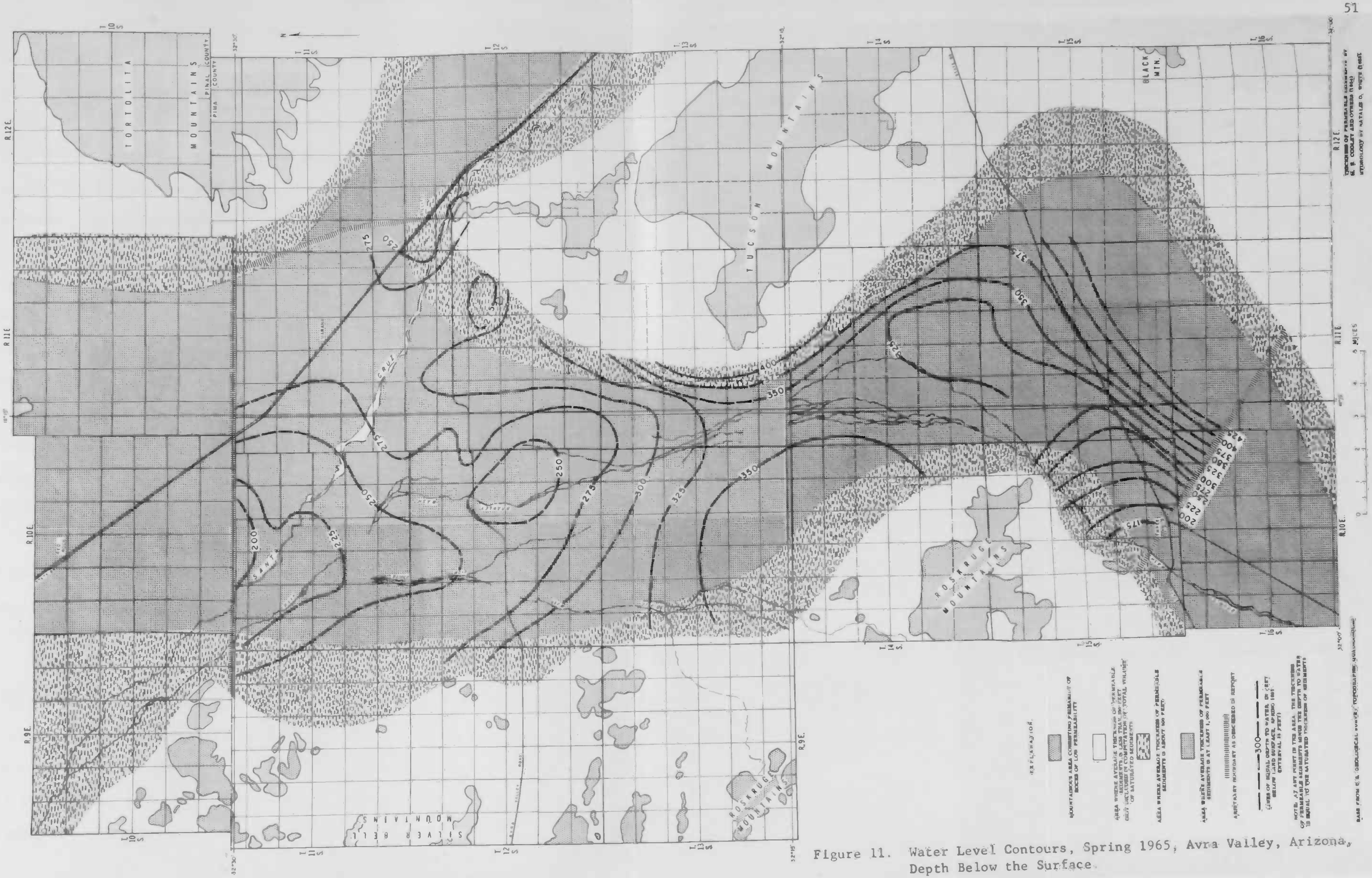

Figure 11. Water Level Contours, Spring 1965, Avra Valley, Arizona, Depth Below the Surface

level in all areas of the Region is estimated to be the average annual change in groundwater level between 1956 and 1965. This rate of decline is assumed to remain constant throughout the time period covered by this analysis. The computed level of the groundwater table in 1965 and the rate of decline used for each diversion unit are found in Tables 1-A through 18-A in the Appendix.

It is assumed that the groundwater table is at a uniform depth everywhere in the well field located in each diversion unit. Although the level of the groundwater table and its rate of decline vary continuously over the area of each diversion unit, for purposes of this analysis a single but separate groundwater level and rate of decline representative of each well field location is assumed for each diversion unit. Thus, the groundwater level and its decline rate for each well field will be taken to be the average level and decline rate of each particular well field location.

The importance to this analysis of the level of the groundwater table and its rate of decline will be discussed more thoroughly in connection with the analysis of pumping costs later in the chapter.

Irrigation Water Diversion Units

It is assumed that the City of Tucson in order to obtain irrigation water for its use must buy the agricultural land previously using the water to obtain the right to the underlying groundwater. It is also assumed that the city will not be permitted by choice or by regulation to withdraw water from any point at a rate greater than present irrigation use in each area. In unpublished studies of prospective water supply developments by the City of Tucson Water and Sewerage Department, delivery systems were planned that would deliver increments of an average of 10 million gallons per day, with maximum capacity of 15 mgd. Hence, in this study irrigation water diversion units and water delivery systems were developed that would produce and deliver an average of 10 mgd (15 mgd capacity) for 300 days per year, or approximately 9,200 acre-feet per year. Planning water production and delivery systems in units of 10 mgd (average) and 15 mgd (capacity) implicitly assumes that a unit of this size is the most economical size system, an assumption which will be discussed more thoroughly later in this chapter.

Since each diversion unit and its delivery system is to supply an average of 10 mgd and operate 300 days per year, it will produce about 3,000 million gallons of water per year or about 9,200 acre-feet. Knowing the number of cropland acres and their water use for each section in the Region, and since withdrawal by the city is assumed to be restricted to present net irrigation water use in each diversion unit, we can determine the acres of cropland the city would have to purchase to compare each diversion unit in order that it may supply 9,200 acre-feet of water per year. Thus, for this analysis the agricultural land surrounding Tucson was divided into diversion units, each of which could supply about 9,200 acre-feet per year without exceeding the present rate of irrigation water use in each. There were three exceptions to this standard. Because they were isolated from other areas of irrigation land, three small isolated areas (numbers XII, XIII, and XVIII in Figure 12) were considered as individual units which supply 6,700; 3,490; and 4,150 acre-feet of water per year, respectively. These small, separate units were developed at a delivery rate (mgd) which would exhaust, in the 300-day period, the average annual irrigation water used in each unit.

The agricultural diversion units thus determined for use in this study, based on the assumptions above, are shown in Figure 12.

Table 1 summarizes the crop acreage and water use for each agricultural diversion unit shown in Figure 12.

Direct Cost of the Diversion of Irrigation Water to Tucson in 10 mgd Increments

The location of the water diversion units, the groundwater level and its rate of decline in each, and the rate of delivery outlined in the first part of this chapter are used to determine the direct cost per acre-foot of diverting irrigation water to Tucson from each diversion unit.

The computation of costs for each of the component parts of a 10 mgd diversion system will be discussed individually below and can be found for each of the 18 diversion units in Tables 1-B through 18-B in the Appendix.

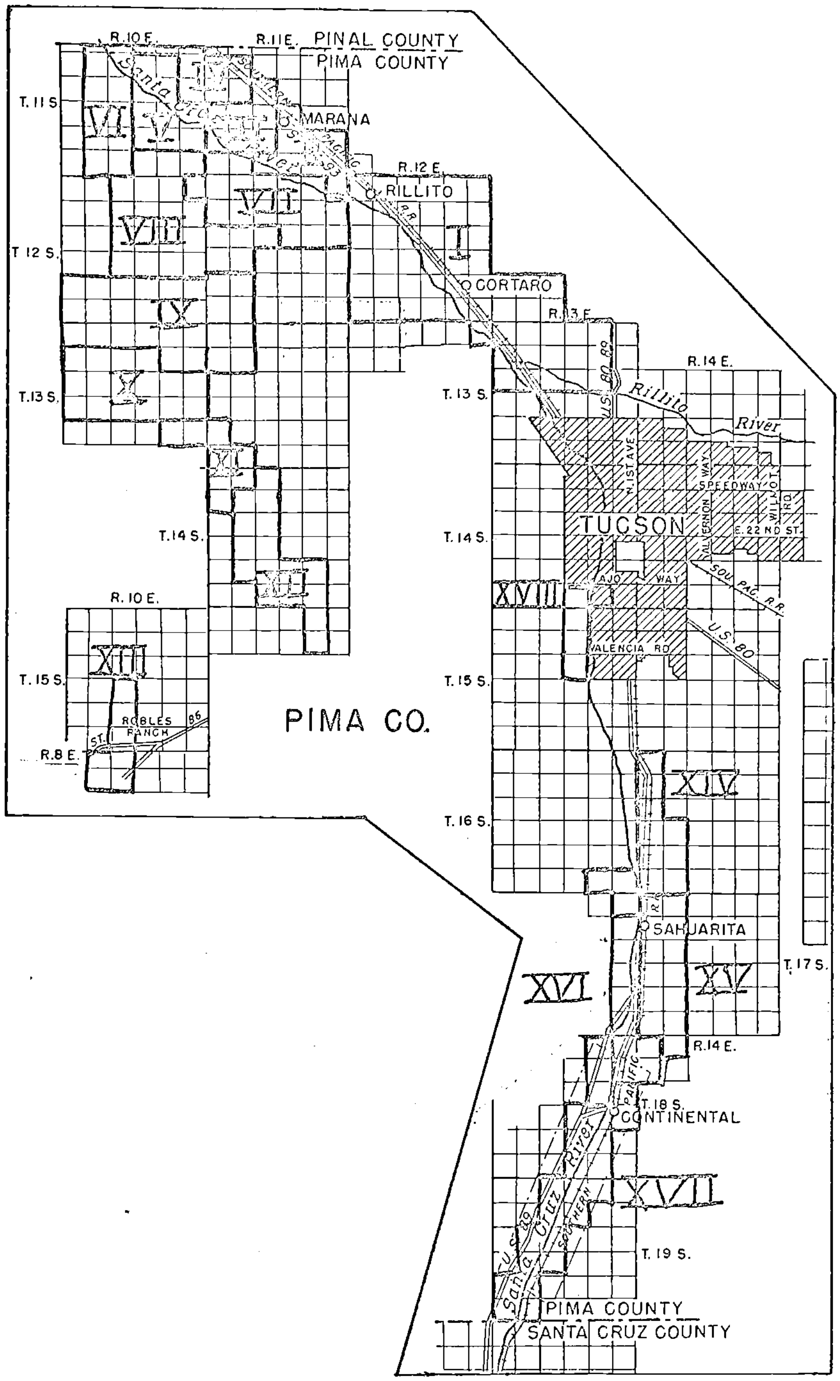

Figure 12. Irrigation Water Diversion Units in the Tucson Region.

Table 1. (Average Annual) Crop Acreage and Irrigation Water Use by Water Diversion Units (1960-65).[a]

Water Diversion Unit	Cropland	Irrigation Water Use per Year
	(acres)	(acre-feet)
I	3,636	9,190
II	3,283	9,170
III	3,367	9,270
IV	3,550	9,260
V	3,739	9,380
VI	4,042	9,220
VII	3,657	9,240
VIII	3,860	9,310
IX	4,161	9,320
X	4,019	9,290
XI	3,371	9,100
XII	3,042	6,700
XIII	1,219	3,490
XIV	3,634	9,270
XV	3,291	9,240
XVI	3,382	9,080
XVII	3,636	9,170
XVIII	1,748	4,150
Totals	60,627	153,050

a. For a legal description of each water diversion unit, see footnote a of Tables 1-A through 18-A in the Appendix.

Land Costs

We begin our discussion of costs with the computation of land costs. The acres of cropland in each diversion unit are determined as described above and are shown in Table 1. The current market value of cropland was estimated for each of these diversion units (see footnote 10, page 41). Thus, the total cost of land in each diversion unit were the city to buy it now is determined by the number of cropland acres and the estimated price per acre. For this study, it is assumed that land is an investment that is neither appreciable nor depreciable; hence, the annual land cost charged to the cost of water is only the interest cost of the funds borrowed or the opportunity cost of non-borrowed funds used by the city to purchase the land. The interest rate used was three and one-half percent, which is what the city considers to be its long-term borrowing rate.[14] After determining the acres of cropland and the market price of land in each unit and the interest rate, we can calculate the annual land cost in each diversion unit with the following formula: (See Tables 1-B through 18-B in the Appendix.)

$$\text{Acres} \quad \times \quad \text{Price per acre} \quad \times \quad .035$$

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14. The three and one-half percent interest rate used in this analysis is the expected long-term borrowing rate of the city. However, the opportunity cost to the taxpayer and the water rate payer is surely considerably higher than this. Thus, perhaps a higher interest rate may be appropriate. But, since the city's borrowing rate is more surely known than are these opportunity costs, the city's rate has been used here.

Construction Costs: Pumping and Delivery Systems

Given the locations and characteristics of the various diversion units (Tables 1-A through 18-A of the Appendix), one can determine the capital cost of constructing a water pumping and delivery system for each diversion unit capable of delivering an average of 10 mgd with a maximum capacity of 15 mgd, or at that rate (mgd) which will divert the present annual irrigation use in that unit to Tucson in a 300-day period.

Well Field Costs

The first part of the system to be discussed is the location of and installation of the wells and pumping units. Because pumping costs due to pumping lift and transportation costs due to distance from the city will vary with the location of the well field within a diversion unit, the well field should be located within each unit where the sum of pumping cost and transportation cost is a minimum within that unit. A comparison of pumping cost with transportation cost revealed that the cost per acre-foot of installing one mile of 36-inch pipeline (15 mgd capacity) is equal to a pumping lift of 51 feet.[15] Thus, it would be economical to locate the well an additional mile further from

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15. Pumping versus transportation cost: 36-inch pipeline @ $27 per foot costs $142,560 per mile which on an annual delivery capacity of 9,200 acre-feet equals $15.50 per acre-foot-year; this cost amortized at three and one-half percent over 30 years equals $.84, which is the annual cost per acre-foot. With a pumping cost of $.01663 per acre-foot per foot of lift, one additional mile of pipeline ($.84 per acre-foot) is equivalent in cost to 51 additional feet of pumping lift (51 x $.01663 = $.84).

Tucson only if the pumping lift were less by more than 51 feet in that mile. In this analysis, the most economical well field location in each diversion unit turned out to be that point closest to Tucson within each unit.

At this point particular reference must be made to the planned location of the well field for Area II. It is assumed that the well field for Area II will be located near Cortaro, which is in Area I, because 12,000 to 14,000 acre-feet of the water pumped near Cortaro presently are transported to the northwestern part of Area I and to the Marana area each year. Thus, the location of another well field in Area I will not raise withdrawals in that area above present levels and, because Cortaro is much closer to Tucson than is Area II, it is decidedly economical to locate Area II's well field in Area I.[16]

Each well and pumping unit in each well field is assumed to have an output of 1,500 gallons per minute and an estimated capital cost of $50,000.[17] Though this standard may be generally applicable, it may not hold for diversion units I, XIII and XVII which for hydrologic reasons may not permit the development of 1,500 gpm wells. Thus more wells may be needed in these areas which would make the estimate of well costs in these areas in this study somewhat on the low side.

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16. Omitted from this study is the minor circumstance that by so doing that part of the water formerly transported from near Cortaro to Area I to Marana that was not consumed thus percolating to the groundwater in those areas would be cut off by the city development assumed here.

17. Assumptions are based on planning standards used by the City of Tucson Water and Sewerage System.

From this we can determine the daily output of each well and from this the number of wells needed to produce a maximum of 15 mgd or whatever rate of delivery the diversion unit is assumed to have; to this number of wells one additional well is added for standby use. Thus, the total capital cost of the wells and pumping units can be computed for each diversion unit in the following manner:

$$\frac{\text{Rate of Delivery (mgd)}}{\text{Output of each well per day (mg)}} + 1 \times \$50{,}000.$$

The cost analysis of wells and pumping units just outlined implicitly assumes that the city will install all new wells and pumping units. It is quite likely that the city will be able to use some of the existing irrigation wells, which would tend to lower the capital cost of the well fields. But, in this analysis, the assumption is made that all new wells and pumping units will be installed, thus biasing the cost estimates on the high side.

Pipeline Costs

Having determined the location of the wells for each diversion unit, the capital cost of installing collection lines from each individual well to a collecting point within the diversion unit and the cost of constructing a transmission line to Tucson from each diversion unit can be calculated. The estimated transmission and collection line unit costs are shown on the following page.[18]

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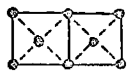
18. Personal conversation with Mr. John F. Rauscher, Chief Engineer, City of Tucson Water and Sewerage Department.

42-inch pipeline	-	\$30.00 per foot installed
36-inch pipeline	-	27.00 per foot installed
30-inch pipeline	-	22.00 per foot installed
24-inch pipeline	-	16.00 per foot installed
20-inch pipeline	-	12.00 per foot installed
18-inch pipeline	-	9.50 per foot installed
16-inch pipeline	-	8.50 per foot installed
14-inch pipeline	-	7.50 per foot installed
12-inch pipeline	-	7.00 per foot installed

The computation of the collection line costs for each diversion unit was based on the unit costs above and on the assumption that all wells would be approximately three-fourths of a mile apart and located in an  pattern over two sections of land. It was also assumed that pipeline sizes that would hold friction loss between three and four feet per mile (see footnote 9, page 38) would be used in all parts of each collection system.

Given the location and output of each well, we can determine the length of pipeline between each well and the mgd it must transmit. Given the mgd a pipeline must transmit and holding the assumed friction loss within the limit specified above, the appropriate pipeline size can be obtained from a set of hydraulic tables (Williams and Hazen 1945). Having determined the appropriate collection line sizes and lengths, one can calculate the capital cost of each pipeline size by taking cost per foot x 5,280 x miles and by summing overall pipeline sizes one can obtain the total capital cost of the unit collection system.

Since the volume of available water per year and the well field location in each diversion unit are both known, the distance to the city's collection point and the daily volume which will be delivered to Tucson from each diversion unit to exhaust in 300 days the irrigation water used annually within it can now be computed. Given the mgd, which in most cases is 10 with a maximum of 15 mgd, that the transmission line must carry, the distance to Tucson, and the above assumption on friction loss, one can calculate the appropriate pipeline size and the capital cost of the transmission line in the same manner as outlined for the collection lines.

In this analysis it is assumed that the city will construct an additional and independent 10 mgd delivery system for each diversion unit. It may in reality be economically desirable to build larger transmission lines to commingle water from two or more diversion units. Economy of this alternative depends on the sequence in which the several diversion units would come into development. This sequence would in turn depend on the cost savings made possible by larger pipelines and on a dynamic analysis of the city's (dated) demand for water increments. Since such an analysis required determining the transmission costs for all possible combinations of diversion units from which the likely savings seemed minimal at best, and since a dynamic demand analysis is required which is not possible in this study, it was decided to consider each diversion unit and its transmission line as an independent unit. But, by this assumption, this study again assumes conditions that make for conservatism (on the high side) in its cost estimates.

There is in addition another cost that must be incurred to tie into the city system any water imported from the areas northwest of Tucson, a cost which does not arise for water imported from areas west and south of Tucson because the tie-in facilities are already available in the southwestern part of Tucson but are not available to water imported from the north. These tie-in costs were estimated from the city's present unpublished plans for a reservoir and booster station north of the city and the various pipeline sizes and lengths needed to tie an additional (single) 10 mgd into the present system. A comparison of the tie-in cost (see Table 1-B in the Appendix) with the cost per mile of a 36-inch pipeline shows that the tie-in cost is equal to the cost of installing about nine miles of 36-inch pipeline. This makes it cheaper to import the water from Areas VI and IX from the west rather than from the north, which otherwise would have been the case.

The cost of securing easements for the pipeline rights-of-way across private property was estimated to be $387 per mile.[19] This cost was assumed to be the same for all areas.

The final component in the delivery system is the capital cost of constructing a reservoir and booster station at each well field location. The estimated cost of the reservoir and booster station was obtained from an unpublished study conducted by the City of Tucson Water

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19. Easement cost used is based on the following formula: $\frac{500}{43,560} \times 25 \times .25 \times 5,280$, where $500 is the estimated average land value per acre, 25 feet is the width of the easement, and .25 is 25 percent of the average land value. This formula was obtained from Mr. John F. Rauscher, Chief Engineer, City of Tucson Water and Sewerage Department.

and Sewerage Department and is assumed to be constant throughout the analysis.

The computation of costs for each component of each 10 mgd delivery system and the total of these capital costs is shown for each diversion unit in Tables 1-B through 18-B in the Appendix.

Annual Investment Costs

The sum of these capital costs is amortized at three and one-half percent interest over 30 years, which is the estimated life of the capital items, to determine the amortized average annual cost of these depreciable capital items. (See Tables 1-B through 18-B in the Appendix.)

Annual Operating Costs

Having determined the average annual fixed costs of diverting irrigation water to Tucson from each of the diversion units at 10 mgd or at the volume of present irrigation use in each area, the only direct costs remaining to be determined are operating costs. These operating costs are the pumping costs at the wellhead and the pumping costs for the delivery of water from the well to Tucson. The unit pumping cost used in this analysis is \$.01663 per acre-foot per foot of lift, which is based on information obtained from the City of Tucson Water and Sewerage Department (footnote 9, page 38).

This pumping cost, together with the pumping conditions in each diversion unit, permits the computation of the average annual pumping cost. For the pumping conditions that presently exist in each diversion unit see Tables 1-A through 18-A in the Appendix. The static water level in 1965, the annual decline (both of which were explained earlier in this chapter), and the drawdown[20] permit us to determine the pumping level for 1967.

In this part of the analysis it was assumed that the city's rate of withdrawal from each diversion unit would not exceed present irrigation use in that unit, although city pumping, compared to the agricultural pumping it would displace, would be in a more concentrated area in each unit. This will increase the rate of decline at the city's wells during the first few years of the operation of each well field. However, as the deepening cone at the wells increases, the rate of flow into the cone will increase thus causing the rate of decline to decrease, finally stabilizing at the earlier irrigation rate. Thus, the average rate of decline in each unit was assumed to be the same after city development of the diversion unit as before under irrigation withdrawal. Knowing the annual average rate of decline following city development and the assumption that the rate of decline is constant for a given rate of withdrawal permits determination of the 13th-year or "time weighted" average groundwater level over the life of the well and equipment (30 years). The 13th-year pumping cost represents the amortized average annual cost of pumping as described more fully on pages 36-38 in Chapter 2. Thus, the depth to water in each well in

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20. Drawdown is equal to $\frac{\text{gpm}}{\text{Specific Capacity}}$. The estimated specific capacity for each unit was obtained from the Department of Agricultural Engineering, The University of Arizona, Tucson.

the initial year (1967) and the additional depth reached in the 13th year gives the "time discounted" average annual water level or pumping lift at the wellhead for the 30-year period. This lift multiplied by acre-feet and, in turn, by \$.01663 will give presently valued amortized average annual cost of the annually increasing pumping cost at the wellhead over the 30-year period.

The next part of pumping cost to be considered is the lift and friction loss in delivering the water from each well field to Tucson. Tables 1-A through 18-A and 1-B through 18-B in the Appendix give us the elevation of each well field and the elevation of the Twenty-Second Street Reservoir, from which one can determine the lift in the delivery system. These tables also give us the rate of delivery (mgd) and the distance to Tucson which, together with the standard friction loss used in the analysis (see page 37) permit us to determine the appropriate pipeline size and the resulting friction loss from a set of hydraulic tables (Williams and Hazen, 1945).

The sum of the extraction lift in the 13th year, the delivery lift, and the feet of friction loss gives us the presently valued average annual overall pumping head for the 30-year period. Since the number of years (30) and the interest (.035) remain constant in this analysis, the overall pumping head depends on the initial water level, its rate of decline, the elevation of the well field relative to the Twenty-Second Street Reservoir, and the distance from Tucson.

Having computed the average annual overall pumping head, the acre-feet of water pumped each year, and knowing the pumping cost per acre-foot per foot of lift, the average annual pumping cost for each diversion unit can be computed by multiplying number of acre-feet pumped by feet of lift by \$.01663 per acre-foot per foot of lift. (See Tables 1-B through 18-B of the Appendix.)

Having calculated the present average annual cost of land, the present annual (amortized) cost of construction of an appropriate pumping and delivery system, and the amortized average annual cost of pumping for each diversion unit, their sum gives us the annual (amortized) total direct cost for diverting irrigation water to Tucson from each unit. This annual (amortized) direct cost of water from each diversion unit, when divided by the acre-feet delivered annually from that unit, gives the annual (amortized) total direct cost per acre-foot of water diverted from that unit. This annual (amortized) direct cost per acre-foot is the estimated direct cost that would be incurred now and in each year for 30 years in each diversion unit if the decision were made now to develop and divert all water from that unit. Table 2 is a summary of the annual (amortized) direct costs computed for each diversion unit.

Table 3 reveals the annual (amortized) direct cost per acre-foot for each diversion unit when they are ranked in order of the increasing cost of water, in other words, the supply schedule (direct cost) for this water. These costs do not include an estimate of costs resulting from possible water quality problems or the indirect economic effect that the disappearance of agriculture may have on the Tucson economy. These will be discussed later in the analysis.

Table 2. Summary of Annual (Amortized) Direct Costs for Diversion of Irrigation Water to Tucson by Diversion Units (10 mgd).[a]

Diversion Unit	Land	Capital	Pumping	Total	Water Quantity	Direct Cost per Acre-Foot
	(dollars)	(dollars)	(dollars)	(dollars)	(acre-feet)	(dollars)
I	222,705	151,519	85,585	459,809	9,190	50.00
II	89,939	225,353	78,231	393,523	9,170	42.90
III	91,821	303,074	170,809	565,704	9,270	61.00
IV	93,734	318,618	171,395	583,747	9,260	63.00
V	93,160	326,390	168,625	588,175	9,380	62.70
VI	84,847	318,161	163,278	566,286	9,220	61.40
VII	76,797	266,156	161,173	504,126	9,240	54.10
VIII	76,563	195,302	173,714	545,579	9,310	58.60
IX	72,818	294,845	162,431	530,094	9,320	56.90
X	70,332	255,953	153,720	480,005	9,290	51.70
XI	58,992	221,011	133,324	413,327	9,100	45.40
XII	53,235	142,917	82,674	278,826	6,700	41.60
XIII	21,332	139,037	23,680	184,049	3,490	52.70
XIV	127,190	85,000	37,153	249,343	9,270	26.90
XV	115,185	131,632	49,786	196,603	9,240	32.10
XVI	118,370	143,290	46,206	307,866	9,080	33.90
XVII	127,260	189,923	43,919	361,102	9,170	39.40
XVIII	152,950	54,377	27,054	234,381	4,150	56.50

a. For the computation of these costs see Tables 1-B through 18-B of the Appendix.

Table 3. The Supply Schedule: Annual (Amortized) Direct Costs per Acre-Foot for Diverting Irrigation Water to Tucson in 10 mgd Increments, Ranked in Order of Ascending Costs.

Area[a]	Water Quantity	Direct Cost per Acre-Foot
	(acre-feet)	
XIV	9,270	$26.90
XV	9,240	32.10
XVI	9,080	33.90
XVII	9,170	39.40
XII	6,700	41.60
II	9,170	42.90
XI	9,100	45.40
I	9,190	50.00
X	9,290	51.70
XIII	3,490	52.70
VII	9,240	54.10
XVIII	4,150	56.50
IX	9,320	56.90
VIII	9,310	58.60
III	9,270	61.00
VI	9,220	61.40
V	9,380	62.70
IV	9,260	63.00

a. See footnote a of Tables 1-A through 18-A in the Appendix.

The annual (amortized) direct costs per acre-foot for the diversion to Tucson of 10 mgd of irrigation water from the various diversion units are plotted in Figure 13. Figure 13 is an incremental (step) supply function. It tells us the additional (marginal) direct cost of obtaining additional water in 10 mgd increments in 1967 by diversion from irrigation in the Tucson Region.

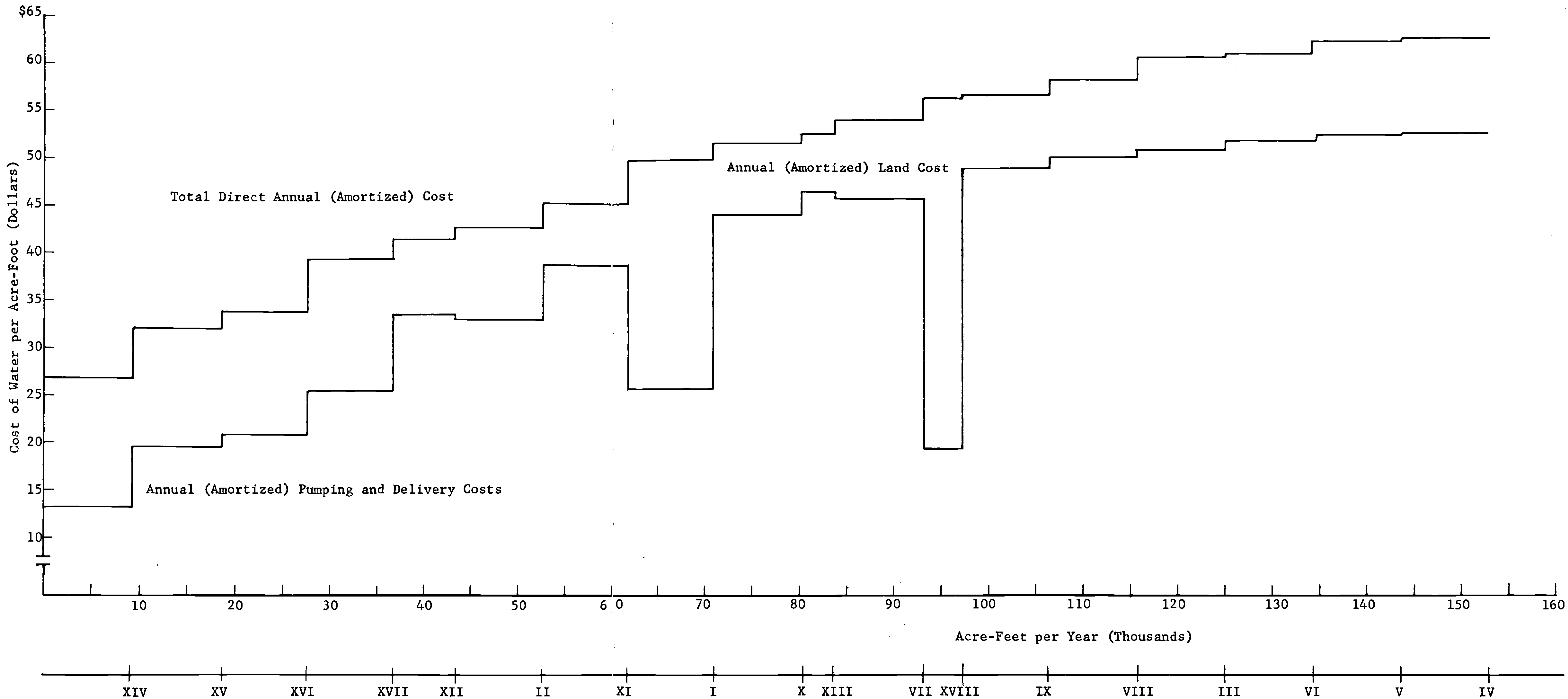

Figure 13. Supply Function (Direct Production and Delivery Costs) for the Diversion of Irrigation Water to Tucson in 10 mgd Increments.

CHAPTER 4

ANALYSIS OF THE DIRECT COST OF DIVERSION OF IRRIGATION WATER TO TUCSON IN TWENTY MILLION GALLONS PER DAY INCREMENTS

Cropland Acreage, Water Use and Diversion Units

The cropland acreage in the Tucson Region, its water use for irrigation, and the diversion units determined in Chapter 3 will remain the same for this part of the analysis. The well field location (though larger in area) in each diversion unit, the resulting distance to Tucson, and the size of individual wells and pumping units are also the same as those in Chapter 3.

Groundwater Table

The present level of the groundwater table and its current rate of decline by township under conditions of irrigation pumping were determined in the previous chapter (see pages 48-53) and will remain the same for the analysis in this chapter. These data for each diversion unit will be found in Tables 1-A through 18-A of the Appendix.

Irrigation Water Diversion Units

It will now be assumed that the city will withdraw water from each diversion unit at twice the present rate of irrigation use (or at 20 mgd) in each unit. Possible institutional constraints on withdrawal and exportation of groundwater at this rate relative to previous rates under irrigation will be ignored in this analysis. Pumping at this higher rate may so cheapen the cost of water as to make it possible for the city to pay damages to complaining irrigators and yet obtain water cheaper than at the 10 mgd rate of withdrawal.

In this part of the analysis, the well fields and delivery systems were developed to deliver to Tucson an average of 20 mgd per diversion unit with a maximum capacity of 30 mgd. These increased pumping and delivery rates were assumed in order to compare the cost per acre-foot of diverting irrigation water at two levels of scale--one level the city prefers and the other representing a probable maximum "lumpiness" of expansion.

Since each diversion unit and its delivery system will supply an average of 20 mgd and operates 300 days per year, it will supply 6,000 million gallons of water per year or about 18,400 acre-feet--twice the quantity assumed (9,200 acre-feet per year) in Chapter 3.

Cost Analysis of the Diversion of Irrigation Water to Tucson in 20 mgd Increments

Knowing the distance from Tucson of each diversion unit, the rate of delivery, and the groundwater level and rate of its decline outlined in the first part of the chapter, one can compute the cost per acre-foot to divert irrigation water to Tucson from each of the diversion units.

The calculation of costs for each of the component parts of a diversion system was discussed in the preceding chapter; the method used in the computation of these costs will remain the same in the cost analysis of a 20 mgd delivery system. The costs which were computed for the various parts of the 20 mgd diversion system are found in Tables 1-B through 18-B in the Appendix.

Since the area and location of each diversion unit for the 20 and the 10 mgd delivery system are the same, the annual land cost for each unit will also be the same. The computation of the annual land cost for each of the diversion units was explained in the preceding chapter (see page 58), and is shown for the 20 mgd systems in Tables 1-B through 18-B in the Appendix.

The next cost to be considered is the capital cost of constructing a system for each diversion unit that will deliver to Tucson an average of 20 mgd with a maximum capacity of 30 mgd. For three diversion units a 20 mgd delivery system is not needed. In these units the delivery system was planned to deliver at that rate which would divert twice the present annual irrigation water use in that unit to Tucson in the 300 day per year pumping period assumed.

We begin consideration of the investment cost of the pumping and delivery systems by taking up the location and installation of the wells and pumping units in each diversion unit. To determine the economically efficient location of the well field in each diversion unit, a comparison of pumping versus water transportation costs revealed that the annual cost per acre-foot of installing one mile of 42-inch pipeline, which is the size needed to hold the friction loss between the values assumed in Chapter 3, is equal to a pumping lift of 28 feet.[21] Thus, it will be economically desirable to locate the well another mile further from Tucson only if the pumping lift is decreased by 28 feet or more in that mile. The most economical location of the well field for each diversion unit turned out to be that point in the unit closest to Tucson (see Tables 1-A through 18-A in the Appendix). For an explanation of the location of the well field for Area II see page 60.

The number of wells and pumping units needed per diversion unit and their capital cost were computed in the same manner as in the preceding chapter (see pages 60 and 61). The individual wells and pumping units are the same size as analyzed in Chapter 3; however, 15 such wells were needed in each diversion unit except for the three isolated units previously mentioned.

Having determined the location of the well field for each diversion unit and the number of wells needed, the next capital cost to be computed is that of installing collection lines and a transmission line from each diversion unit to Tucson. The calculation of the capital costs of the collection lines and a 42-inch transmission line for each diversion unit is based on the costs shown on pages 61 and 62. The size and capital cost of the collection lines and a transmission line

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21. Pumping versus transportation cost: 42-inch pipeline @ \$30 per foot costs 158,400 per mile which on an annual delivery capacity of 18,400 acre-feet equals \$8.60 per acre-foot-year; this cost amortized at three and one-half percent over 30 years equals \$.47 which is the annual cost per acre-foot. With a pumping cost of \$.01663 per acre-foot per foot of lift one additional mile of pipeline (\$.47 per acre-foot) is equivalent in cost of 28 additional feet of pumping lift (28 x \$.01663 = \$.47).

were calculated in the same manner as was outlined in the preceding chapter, pages 61-63.

In addition to the collection and transmission line costs, an investment cost is also required to tie into the city system the water imported from areas northwest of Tucson. This cost is not required for water imported from the areas west and south of Tucson because tie-in facilities are already available for this water. These tie-in costs are based on unpublished plans by the city for a reservoir and booster station north of the city and the various pipeline sizes and lengths needed to tie an additional (single) 20 mgd increment into the city system. A comparison of these tie-in costs (see Table 1-B in the Appendix) with the cost per mile of installing a 42-inch pipeline shows that the tie-in cost is equal to about 10 miles of 42-inch pipeline. This tie-in cost makes it cheaper to bring in the water from Areas VI and IX from the west rather than from the north, which would otherwise be the case.

Easement, reservoir and booster station costs are assumed to remain the same for the 20 mgd systems as for the 10 mgd systems (see pages 64 and 65).

The computed costs for each of the component parts of the 20 mgd delivery systems (twice the present irrigation use), and the total capital costs are shown for each diversion unit in Tables 1-B through 18-B in the Appendix.

The total capital required for each diversion unit is amortized at three and one-half percent over 30 years to determine the annual amortized cost of these depreciable capital items.

Having computed the annual (amortized) fixed costs (land cost plus capital cost) of diverting irrigation water to Tucson from each of the diversion units in 20 mgd increments, the only costs remaining to be determined are the operating costs. These are composed of the pumping costs at the wellhead and the pumping costs to deliver the water to Tucson. The operating cost of pumping used in this analysis is $.01663 per acre-foot per foot of lift (see page 39).

This cost together with data related to pumping conditions for each diversion units permits the computation of the average annual pumping costs. The pumping conditions for the 20 mgd diversion systems are the same as for the 10 mgd diversion, except as to (1) the rate of decline in the groundwater level after city development resulting from the doubled volume of withdrawal and (2) the friction loss in the 42- compared to the 36-inch pipeline. (See Tables 1-A through 18-A in the Appendix.) Since the rate of groundwater withdrawal in the 20 mgd diversion systems is twice that in the 10 mgd systems, it is assumed that the rate of decline in the groundwater level after city development will be twice that when 10 million gallons per day are pumped. This assumes that the rate of decline in the groundwater level is a linear function directly proportional in magnitude to the rate of withdrawal.

The pumping conditions, which include friction loss in the 42-inch pipeline, for each of 20 mgd diversion systems and the two components of pumping costs were computed in the same manner as was outlined in the previous chapter.

Given the annual (amortized) investment costs and annual operating (pumping) costs, their sum will be the annual (amortized) total direct cost of diverting irrigation water to Tucson in units of 20 mgd. The annual (amortized) total direct cost for each diversion unit was divided by the acre-feet of water diverted from each unit to get the annual total direct cost per acre-foot for these diversions. These total direct costs per acre-foot constitute the annual (amortized) direct cost per acre-foot of diverting irrigation water to Tucson in 20 mgd increments over a 30-year period from each of the various diversion units. These annual direct costs are shown in Tables 4 and 5 and in Figure 14.

Figure 14 is a stepped incremental supply function of water available to Tucson for urban use when obtained by the diversion of irrigation water in 20 mgd increments from within the Tucson Region. It tells us the additional direct (marginal) cost of obtaining additional water from irrigation in 20 mgd increments in the Tucson Region if the decision were made now (1967). Thus it is a static supply function. It tells only which and how many diversion units to acquire and develop <u>today</u> to obtain whatever volume of water per day the city might wish to procure at this time and to do so at minimum direct cost. The supply function in Figure 14 tells nothing as to the order in time at which additional diversion units should be retained and developed.

The annual (amortized) total direct costs shown above (Tables 4 and 5 and Figure 14) do not include any estimate of the effect that the disappearance of agricultural production due to diversion of

Table 4. Summary of Annual (Amortized) Direct Costs for Diversion of Irrigation Water to Tucson in Increments of 20 mgd.[a]

Diversion Unit	Land	Capital	Pumping	Total	Water Quantity	Direct Cost per Acre-Foot
	(dollars)	(dollars)	(dollars)	(dollars)	(acre-feet)	(dollars)
I	222,705	211,594	181,867	616,166	18,380	33.00
II	89,939	293,609	170,492	554,040	18,340	30.20
III	91,821	379,942	380,159	851,922	18,540	46.00
IV	93,734	397,208	382,213	873,155	18,520	47.10
V	93,160	406,385	375,310	874,855	18,760	46.00
VI	84,847	391,356	361,549	837,752	18,440	45.40
VII	76,797	338,934	354,440	770,281	18,480	41.40
VIII	76,563	371,309	386,754	834,626	18,620	44.80
IX	72,818	365,456	355,861	794,135	18,640	42.60
X	70,332	332,259	342,974	735,565	18,580	39.60
XI	58,992	283,441	289,046	631,479	18,200	34.70
XII	53,235	211,735	166,240	431,210	13,400	32.20
XIII	21,332	231,628	45,270	298,230	6,980	42.70
XIV	127,190	132,359	86,946	346,495	18,540	18.70
XV	115,185	184,158	113,095	412,438	18,480	22.30
XVI	118,370	197,108	109,324	424,802	18,160	23.40
XVII	127,260	248,908	100,343	476,511	18,340	26.00
XVIII	152,950	77,228	61,285	291,463	8,300	35.10

a. For the computation of these costs see Tables 1-B through 18-B in the Appendix.

Table 5. The Supply Schedule: Annual (Amortized) Direct Costs per Acre-Foot for Diverting Irrigation Water to Tucson in 20 mgd Increments, Ranked in Order of Ascending Costs.

Area[a]	Water Quantity	Direct Cost per Acre-Foot
	(acre-feet)	
XIV	18,540	$18.70
XV	18,480	22.30
XVI	18,160	23.40
XVII	18,340	26.00
II	18,340	30.20
XII	13,400	32.20
I	18,380	33.00
XI	18,200	34.70
XVIII	8,300	35.10
X	18,580	39.60
VII	18,480	41.40
IX	18,640	42.60
XIII	6,980	42.70
VIII	18,620	44.80
VI	18,440	45.40
III	18,540	46.00
V	18,760	46.00
IV	18,520	47.10

a. See footnote a of Tables 1-A through 18-A in the Appendix.

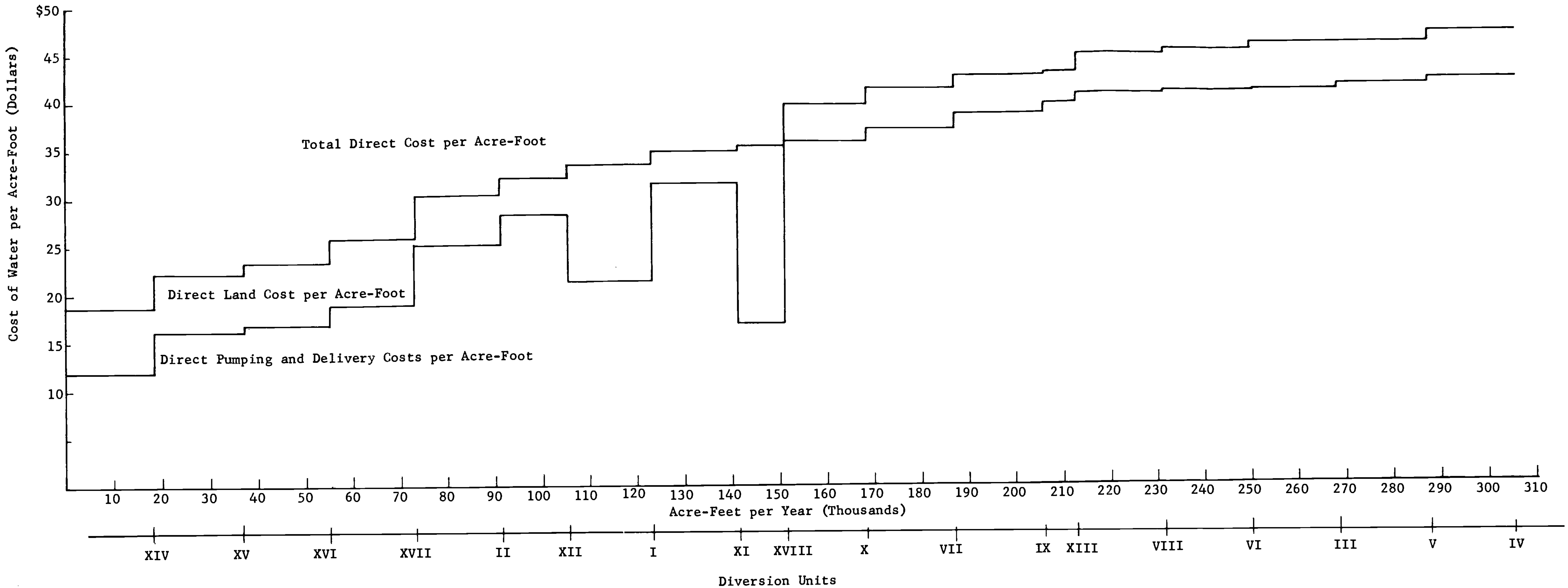

Figure 14. Supply Function for Diversion of Irrigation Water to Tucson in 20 mgd Increments.

irrigation water might have on the Tucson economy; neither does it include any economic costs of possible water quality problems. These two problems and their possible effects on the cost of diverting irrigation water to Tucson are discussed in Chapter 5.

10 and 20 mgd Diversion Units

The direct cost per acre-foot for diverting irrigation water to Tucson from the various diversion units in 10 and 20 mgd increments are shown in Table 6 in order of increasing costs.

The plots of these increasing costs per acre-foot (see Figures 13 and 14, respectively) represent the supply functions for diverting irrigation water to Tucson from within the Tucson Region at two different scales of plant development. These supply functions reveal the additional (marginal) cost of diverting successive 10 or 20 mgd increments of irrigation water now (1967) thus permitting comparison of total direct costs per acre-foot for diverting increasing amounts of irrigation water to urban use with the cost of obtaining such increments of supply from alternative available sources.

Table 6 indicates that the direct cost per acre-foot of diverting irrigation water to Tucson in increments of 20 mgd is from $8 to $16 less than diverting it in 10 mgd increments. This indicates a possible cost saving if the water were to be diverted in larger incremental units. However, offsetting such possible savings would be possible increase in cost resulting from unused capacity in the early years of life of the larger (20 mgd) diversion units, a cost which was

Table 6. The Supply Schedule: Direct Cost per Acre-Foot of Diversion of Irrigation Water to Tucson in 10 and 20 mgd Increments.

10 mgd			20 mgd		
Area[a]	Acre-Feet of Water	Direct Cost per Acre-Foot	Area[a]	Acre-Feet of Water	Direct Cost per Acre-Foot
XIV	9,270	$26.90	XIV	18,540	$18.70
XV	9,240	32.10	XV	18,480	22.30
XVI	9,080	33.90	XVI	18,160	23.40
XVII	9,170	39.40	XVII	18,340	26.00
XII	6,700	41.60	II	18,340	30.20
II	9,170	42.90	XII	13,400	32.20
XI	9,100	45.40	I	18,380	33.00
I	9,190	50.00	XI	18,200	34.70
X	9,290	51.70	XVIII	8,300	35.10
XIII	3,490	52.70	X	18,580	39.60
VII	9,240	54.10	VII	18,480	41.40
XVIII	4,150	56.50	IX	18,640	42.60
IX	9,320	56.90	XIII	6,980	42.70
VIII	9,310	58.60	VIII	18,620	44.80
III	9,270	61.00	VI	18,440	45.40
VI	9,220	61.40	III	18,540	46.00
V	9,380	62.70	V	18,760	46.00
IV	9,260	63.00	IV	18,520	47.10

a. See footnote a of Tables 1-A through 18-A in the Appendix.

unexplored here. Thus, a cost comparison of the 10 and 20 mgd diversion units would necessitate analysis of the cost of any unused capacity in the larger units in the early years after expansion, which in turn would depend on the rate of increase in the demand for water. Since population growth and resulting increase in demand for water were not analyzed in this study, a complete cost comparison of the 10 and 20 mgd diversion units was not possible. However, by assuming diversion by the city in 10 mgd increments, a probable upper limit of cost for increasing the supply of water to Tucson from this source was determined thus, again, emphasizing conservatism in the cost of this compared to other alternatives as a source of increased supply of water for the city.

CHAPTER 5

ECONOMIC EXTERNALITIES ASSOCIATED WITH DIVERTING IRRIGATION WATER TO URBAN USE IN THE TUCSON REGION[22]

Multiplier Effects

So far, this analysis has considered only the direct costs to the City of Tucson for obtaining, constructing, and operating the 10 and 20 mgd diversion units for municipal water in the Tucson Region. In addition to these direct costs to the city, there will be indirect or external costs which will affect the Tucson economy. These indirect or external costs are the reductions in or losses of income experienced by all those persons in the Tucson area whose incomes will be adversely affected by any decrease in agricultural production brought about by the diversion of irrigation water to municipal use. The magnitude of these costs is measured by the personal incomes that are lost directly in agriculture, indirectly in agribusinesses, and in consumer goods and service businesses in the Tucson Region by virtue of reduction or elimination of agricultural output. Thus, not only are personal incomes lost

22. Subsequent to completion of this thesis, a largely different and in many respects more satisfactory analysis of the economic cost of the externalities presented in this chapter was carried out. The conclusions drawn from this substitute analysis are not greatly different from those reached in this chapter in spite of the differing conceptualization of the problem. Readers of this thesis who may be interested in the analysis of such externality costs will find the substitute analysis of this problem in a paper by Kelso, M. M. and James J. Jacobs (1967).

directly by farmers, farm workers, and investors in farms and farming when agriculture is curtailed, but also there are personal incomes lost to associated nonfarm earners in the Tucson Region. This associated effect is called the <u>multiplier</u> effect.

The direct cost to the city of diverting irrigation water to supply its residents with municipal water consists of the costs incurred by the city to obtain, construct, and operate the water producing and transporting facilities. But, the full cost to the residents of the Tucson area must also include the indirect costs incurred by them in the form of incomes lost directly by those engaged in agriculture plus its multiplied effects in the form of incomes lost by nonfarm earners through reduction or elimination of agricultural output caused by diversion to the city of the water on which it depends. These income losses in the Tucson Region must be regarded as part of the economic cost of the water diversions, because additional municipal water imported into Tucson from sources that would not reduce irrigation in the area of the city would not cause a reduction in these incomes. Thus, these indirect costs are necessarily included in order to permit one to compare the cost of this means of increasing municipal water for Tucson, with the full cost of obtaining the water from possible alternative sources.

Measuring Direct and Indirect Income Effects

The economy, be it the Tucson Region's, the state's, or the nation's, is an interrelated structure. Each economic sector not only produces goods and services but also purchases goods and services for use in its production process.

This interdependence may be analyzed in two separate components. The first component is direct dependence, which is the direct purchases of one industry from another of things needed in the production of the first industry's product. The second component, the more difficult to measure, is the sum of the indirect effects generated by the direct purchases. These occur because any sector which supplies inputs to another sector must also acquire inputs, thus generating incomes in other economic sectors, ad infinitum.

The construction of analytical models and the collection of data necessary to measure the indirect income effects, caused by the diversion of irrigation water to urban use in the Tucson Region, are not possible within the time limits of this study. However, an indication of the probable order of magnitude of such indirect income effects of irrigated agriculture on the Tucson economy can be derived from studies which have attempted to measure these effects in other western irrigation communities. The indirect income multipliers derived in all such studies, though differing, are similar and of the same order of magnitude.

In this analysis, the multiplier determined for the Grand Valley trade area of Colorado is used as an indicator of the magnitude of indirect income losses we might expect were irrigation water diverted to urban use in the Tucson Region (Struthers, 1963).

In this analysis of the Tucson Region, the income effects flowing from reduced output from irrigated agriculture are measured in two components. The first component is the income lost directly in agriculture itself; the second component is the resulting indirect loss of incomes which occur in related nonfarm businesses.

We begin our analysis by determining the magnitude of direct income losses we might expect in irrigated agriculture itself. Since acreages of the various crops in the Tucson Region have already been determined (page 47), one can calculate the gross sales from irrigated agriculture that would be lost to the Region if all irrigation water were diverted by determining the gross income per acre for the various crops grown in the Region, multiplying by the acres of each crop in the Region and summing the results. The 1967 prices and yields per acre for the crops of the Tucson Region from which these gross incomes per acre can be determined are given in Table 7. However, only about 75 cents of each dollar of gross sales from irrigated agriculture appears as personal income to the persons engaged (Tenth Arizona Town Hall, 1967). Thus, 75 percent of the gross sales from irrigated agriculture in the Region measures the <u>direct</u> income effects within agriculture itself from reduction in agricultural output. These calculations are presented in columns 2, 3, 4 and 5 in Table 8.

Table 8, column 6, also shows the magnitude of <u>indirect</u> income effects (losses) we might expect in related nonfarm businesses in the Tucson Region resulting from reduction of incomes within irrigated agriculture. The multiplier determined for the Grand Valley trade area

Table 7. 1967 Prices and Yields of Irrigated Crops in the Tucson Region.[a]

Crop	Area	Yield	Price	Gross Income per Acre
Cotton	Avra-Marana	2 bales/acre	$.41/lb.[b]	$410
	Sahuarita	1.5 bales/acre	$.41/lb.	308
Barley	Tucson	1.58 tons/acre	$46/ton	73
Sorghum	Tucson	2.02 tons/acre	$42/ton	85
Forage	Tucson	4 tons/acre	$26/ton	104
Misc.	Tucson			90[c]

a. Prices and yields were obtained from Mr. N. Gene Wright, Research Associate, Department of Agricultural Economics, The University of Arizona, Tucson.

b. The $.41/lb. includes lint receipts, support payments, diverted acres payments on 35 percent diverted acres, and cottonseed receipts.

c. The gross return per acre for miscellaneous crops was estimated at $90.

Table 8. Direct, Indirect, and Total Personal Income Generated by Irrigated Agriculture in the Tucson Region (Based on Tables 1 and 7).

Crop	Acres[a]	Gross Income per Acre	Gross Sales per Crop	Direct Personal Income (75% of Column 4)	Indirect Personal Income Column 5 multiplied by[c] 2.0	Indirect Personal Income Column 5 multiplied by[c] 2.7	Total Personal Income (Column 5 plus Column 6) 2.0	Total Personal Income (Column 5 plus Column 6) 2.7
(1)	(2)	(3)	(4)	(5)	(6)		(7)	
Cotton - Avra-Marana	21,860	$410	$ 8,962,600	$6,721,950	$13,443,900	$18,149,265	$20,165,850	$24,871,215
Sahuarita	6,444	308	1,984,752	1,488,564	2,944,128	4,019,123	4,465,692	5,507,687
Food and Feed Grains[b]	16,313	80	1,305,040	978,780	1,957,560	2,642,706	2,936,340	3,621,486
Forage (largely alfalfa)	3,226	104	335,504	251,628	503,256	679,396	754,884	931,024
Miscellaneous	1,284	90	115,560	86,670	173,340	234,009	260,010	320,679
Total	49,127		$12,703,456	$9,527,592	$19,005,184	$25,724,498	$28,582,776	$35,252,090

a. Acres are averages of crop acres from 1960-66, based on annual crop surveys conducted by the Department of Agricultural Engineering, The University of Arizona, Tucson.

b. Food and feed grains consist of barley and sorghum grain.

c. These multipliers were obtained from a study of the Grand Valley trade area, Colorado.

and used herein lies between 2.0 and 2.7 (Struthers, 1963). In this analysis, both figures are used, thus determining the likely minimum and maximum magnitudes of indirect income effects. The multipliers 2.0 and 2.7 mean that for each dollar in personal income lost <u>within</u> irrigated agriculture there will be $2.00 to $2.70 of personal income lost in related nonfarm businesses in the Tucson Region.

Column 7 of Table 8 shows the sum of direct and indirect or the total of personal incomes generated in the Tucson Region by irrigated agriculture.

Table 8 gives reasonable estimates of the probable minimum and maximum orders of magnitude of total income losses (direct and indirect) one might expect if irrigation water in the Tucson Region were to be diverted to urban use. However, the incomes received directly as returns on investments in farm real estate in the Region have previously been accounted for in this analysis by the sums paid by the city to farmland owners in purchasing the agricultural lands. Thus, the sum of the direct and indirect income losses of $28,572,776 and $35,252,090 presented in Table 8 must be adjusted downward by the amount of farm real estate investment income generated within agriculture and already accounted for among the direct costs to the city of acquiring irrigation water for municipal use as shown in Table 2.

Table 9 gives an estimate of $2,382,931 as the farm real estate investment income generated within irrigated agriculture in the Tucson

Table 9. Farm Real Estate Investment Incomes (Rent) Generated in Irrigated Agriculture in the Tucson Region.

Crop	Rent per Unit of Output[a]	Output per Acre[b]	Rent per Acre	Acres	Total Rental Incomes
Cotton - Avra-Marana	$40 bale	2.0 bales	$80	21,860	$1,748,800
Sahuarita	$40 bale	1.5 bales	$60	6,444	386,640
Food and Feed Grains					
Barley	$9 ton	1.58 tons			
Sorghum	$6 ton	2.02 tons	$13[c]	16,313	212,069
Forage	$1.60 ton	4 tons	$ 7	3,226	22,582
Miscellaneous			$10[d]	1,284	12,840
Totals				49,127	$2,382,931

a. The rents generated per unit of output were estimated from Arizona Agriculture, 1966, Tables 14, 15, 16, 17 and 18, pages 26-30 by estimating returns to management at nine percent of gross income and assuming a pumping lift of 300 feet.

b. See Table 7, page 89.

c. $13 is the average rent per acre of barley and sorghum.

d. Rent per acre of miscellaneous crops is estimated at $10.

Region.[23] This real estate income of $2,382,931 is then subtracted from the estimate of total personal incomes of $28,252,776 and $35,252,090 (Table 8) which gives us an estimate of $25,869,845 to $32,869,159 as total personal income that would be lost in the Tucson Region and not compensated by the city if it were to acquire the Tucson Region's farmlands and divert their irrigation water to the city.

However, this personal income loss cannot legitimately be considered to be an annually recurring loss in perpetuity. All income recipients deprived of these incomes can, with differing degrees of difficulty and inflexibility, transfer their earning power (assets) to other locations or employments. In a full employment economy such as now exists in the United States, they can do so at earning levels fully comparable (on the average) to those lost by virtue of this agricultural curtailment and can do so with only temporary loss of earnings due to the frictions and inflexibilities in finding and transferring their earning assets to the new employments.

In this study, it is arbitrarily assumed that, on the average over all persons and assets affected, a half year's income will be lost due to these inflexibilities and frictions or between $12,934,222 and $16,434,580.

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23. $2,382,931 real estate income from 49,127 cropped acres is approximately $48.50 per acre. Capitalized at six to eight percent, such annual return per acre becomes $600 to $800 as the value per acre, an estimate of farmland values certainly within the ball park of crop production values for farmlands in this Region. Thus, this estimate of farm rental income appears reasonable.

But this loss of one-half year of income is incurred but once, hence, can be evaluated as if it were an investment cost attributable to change of employment and can be converted into an average annual cost as are the other costs of urban water supply summarized in Table 3 by assuming it, like these other costs, to be amortized over 30 years at three and one-half percent (the city's assumed borrowing terms) or at an annual cost of $.05437 per dollar of investment. The average annual costs of personal incomes lost directly and indirectly in the Tucson Region if irrigated agriculture were to be completely eliminated would at these rates be between $703,272 and $893,548.

Knowing the minimum-maximum average annual values of personal incomes lost in the Region by diverting irrigation water one can relate them to the total acre-feet of water used by agriculture and diverted to urban use (153,000 acre-feet--page 48) thus determining the average annual indirect economic cost to the Region's residents were irrigation water to be acquired by the city. This average annual indirect economic cost is, on this basis, found to be between $4.60 and $5.80 per acre-foot of irrigation water diverted. These amounts represent the minimum-maximum order of magnitude of the average annual indirect loss we might expect in the Tucson economy per acre-foot of irrigation water diverted to urban use.[24]

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24. This estimate of indirect economic cost to personal income receivers due to reduction of agricultural output is probably defensivle only in the event the city is assumed to use its credit and borrowing power to "pay off" all injured parties in the same way it is assumed to do respecting farmland owners thus holding all affected

Table 10 shows the range of probable total (direct and indirect) average annual costs we might expect per acre-foot of irrigation water diverted to urban use from the various diversion units in the Tucson Region. This range of costs is also presented in Figure 15. The data in Table 10 and Figure 15 may be defined as the static (1967) total cost supply schedule confronting the City of Tucson for additional increments of urban water supply obtainable by the diversion of irrigation water used within the Region.

It is illustrative of how these data may be used to compare the costs in Table 10 and Figure 15 with one of the alternative sources of municipal water--the Central Arizona Project at $50 per acre-foot for "raw" water (planned). Table 10 indicates that the water from diversion units XIV, XV, XVI, XVII, XII and II amounting to about 52,630 acre-feet per year could be diverted to Tucson municipal use currently at a total economic community cost less than $50 per acre-foot.

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income receivers free of harm. If, as is more conventional, the city were to hold only farm property holders free of harm by buying their assets and thus generate external economic effects on many other income receivers in the Region, the average annual equivalent cost of this loss would be significantly higher than shown above because many--maybe all--of those private income receivers adversely affected would not be able to amortize the loss nearly so favorably as could the city--the costs of consumer credit rather than municipal credit would be relevant to many of the injured income receivers. However, it is appropriate to observe, though magnitudes are impossible to establish, that to some degree even these "credit costs," whether municipal or private, are merely transactions within the regional economy thus becoming somebody's income as well as somebody's cost and hence are not fully chargeable as economic cost to the community, only the extra regional leakage being so chargeable. To the extent that this circumstance holds, the indirect income consequences of a program such as considered herein is distributional rather than efficient, that is, a question of "who gets it" rather than whether the "outlay"--cost--is "worth it."

Table 10. Total Community Economic Cost per Acre-Foot (Direct and Indirect) for Diverting Irrigation Water to Tucson from Various Diversion Units in Increments of 10 mgd (1967).

Diversion Units[a]	Water Quantity	Cumulative Water Quantity	Direct Cost[b] per Acre-Foot	Indirect Cost[c] per Acre-Foot		Total Economic Cost per Acre-Foot	
				Minimum[d]	Maximum[d]	Minimum[d]	Maximum[d]
	(acre-feet)	(acre-feet)					
XIV	9,270	9,270	$26.90	$4.60	$5.80	$31.50	$32.70
XV	9,240	18,500	32.10	4.60	5.80	36.70	37.90
XVI	9,080	27,590	33.90	4.60	5.80	38.50	39.70
XVII	9,170	36,760	39.40	4.60	5.80	44.00	45.20
XII	6,700	43,460	41.60	4.60	5.80	46.20	47.40
II	9,170	52,630	42.90	4.60	5.80	47.50	48.70
XI	9,100	61,730	45.40	4.60	5.80	50.00	51.20
I	9,190	70,920	50.00	4.60	5.80	54.60	55.80
X	9,290	80,210	51.70	4.60	5.80	56.30	57.50
XIII	3,490	83,700	52.70	4.60	5.80	57.30	58.50
VII	9,240	92,940	54.10	4.60	5.80	58.70	59.90
XVIII	4,150	97,090	56.50	4.60	5.80	61.10	62.30
IX	9,320	106,410	56.90	4.60	5.80	61.50	62.70
VIII	9,310	115,720	58.60	4.60	5.80	63.20	64.40
III	9,270	124,990	61.00	4.60	5.80	65.60	66.80
VI	9,220	134,210	61.40	4.60	5.80	66.00	67.20
V	9,380	143,590	62.70	4.60	5.80	67.30	68.50
IV	9,260	152,850	63.00	4.60	5.80	67.60	68.80

Table 10. (Continued).

a. See footnote a of the Appendix, Tables 1-A through 18-A.

b. Direct costs consist of land purchase, construction, and operation costs for wells, pumps, and pipelines.

c. Indirect costs consist of direct and indirect income losses experienced in the Tucson Region by other than the owners of farm real estate which is included in "direct costs."

d. Minimum indirect cost is obtained by using a multiplier of 2.

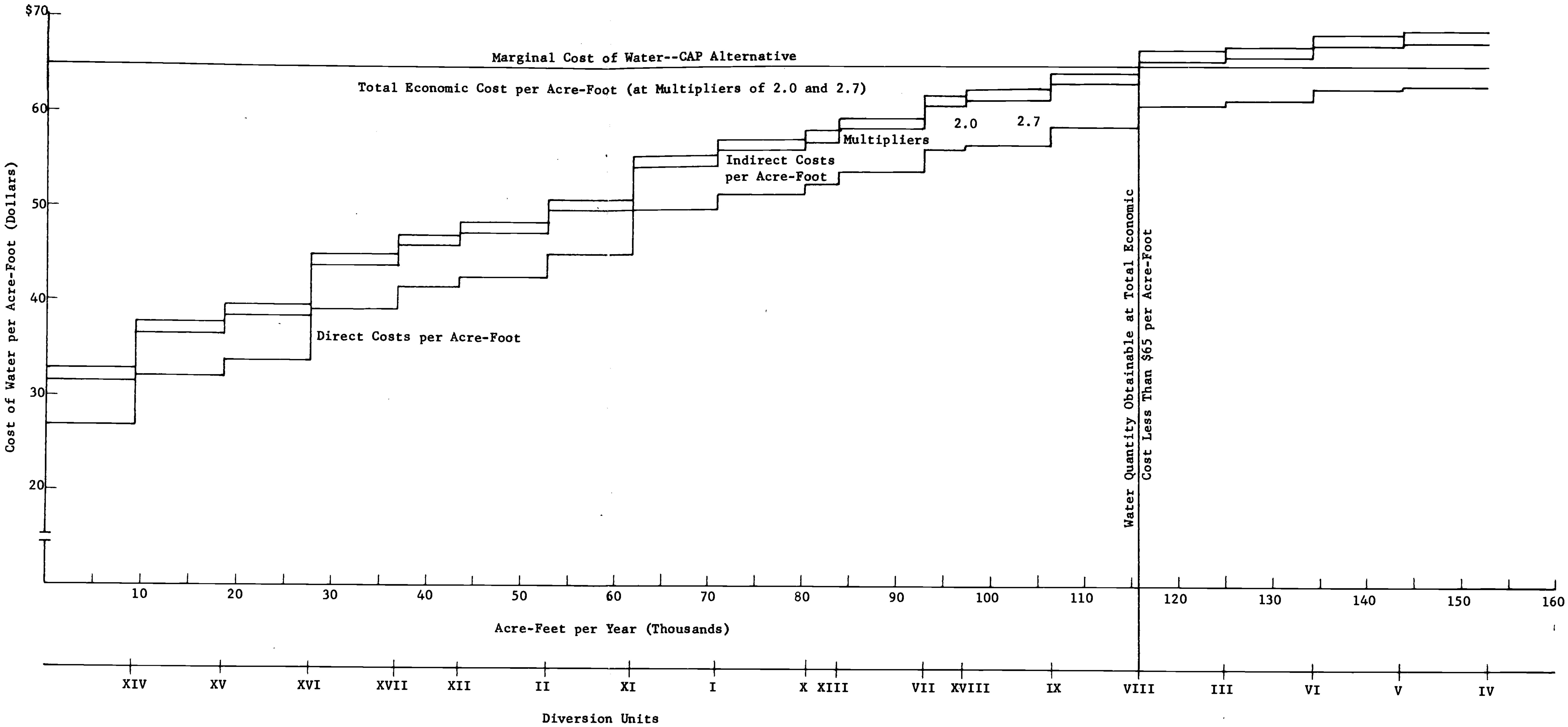

Figure 15. Expected Minimum and Maximum (Total Cost) Supply Function for the Diversion of Irrigation Water to Tucson in 10 mgd Increments.

Note that whether the value of the multiplier is 2.0 or 2.7 makes no difference to the decision.

If, however, an expected water treatment cost of $15 per acre-foot (Wheeler, Peterson and Coffeen, 1965) is added to the $50 charge per acre-foot for CAP water, the full cost of additional quantities of water from this alternative supply sould be $65 per acre-foot. This additional or marginal cost for increasing supplies of water from this alternative source is shown in Figure 15 in relation to the supply schedule derived from this study. Assuming the locally pumped and diverted irrigation water will need little or no treatment for many years at present groundwater levels and rates of decline particularly if judicious mixing of water of different qualities is practiced, the supply schedule of Table 10 and Figure 15 shows that, at an alternative cost of $65 per acre-foot for treated CAP water, the water from 14 of the 18 diversion units or about 115,720 acre-feet can be diverted to Tucson more cheaply. Note that in this connection also it is immaterial to the decision whether the size of the multiplier is 2.0 or 2.7.

A comparison of alternatives such as that described above reveals that if the city were to turn to the CAP alternative for additional water or for water to replace some of that currently pumped from existing sources, the Tucson economy would be penalized for any quantity obtained up to 115,720 acre-feet. The economic penalty for any quantity obtained by the city from the Central Arizona Project up to that quantity would be the difference between the CAP cost ($65 per acre-foot) the economic cost of each additional acre-foot diverted from agriculture (in order of the magnitude of such costs) multiplied by the number of acre-feet of water thus secured. For example, if 27,590 acre-feet of imported water were to be obtained by the city, the economic penalty on the city's economy by obtaining it from the CAP rather by diversion from local irrigation could be approximately three-quarters of a million dollars on $28.25 per acre-foot as shown in Table 11.

Table 11. Economic Penalty Imposed on the Tucson Economy by Obtaining the Indicated Quantities of Additional Water from the CAP in Place of Diversion from Local Irrigation.

Diversion Unit	Quantity of Water	Diversion Cost per Acre-Foot[a]	Total Diversion Cost	Total CAP Cost[b]	Economic Penalty per Acre-Foot	Economic Penalty Total
	(acre-feet per year)					
XIV	9,270	$32.70	$ 303,129	$ 602,550	$32.30	$299,421
XV	9,240	37.90	350,196	600,600	27.10	250,404
XVI	9,080	39.70	360,476	590,200	25.30	229,724
Total	27,590	36.75[c]	$1,013,801	$1,793,350	28.25[c]	$779,549

a. Assuming maximum indirect cost.

b. At $65 per acre-foot.

c. Average weighted by quantity obtained at each cost per acre-foot.

CHAPTER 6

SUMMARY AND APPRAISAL

Summary

The total economic cost of obtaining additional water for Tucson by diversion from irrigation in the Tucson Region is assumed to be the sum of the land cost, the construction cost, the diversion (operation) cost, and the value of the net income lost to Tucson's nonagricultural economic sectors from curtailment of agricultural output in the Tucson Region. Water in the Tucson Region is scarce because sacrifices of alternative enjoyments (costs) must be incurred to capture it for municipal use. It is growing progressively scarcer because withdrawals of groundwater from beneath the city are exceeding recharge and the water level is falling and because increasing demand for water by the city is expected to continue. The importation of any additional water into the city from any source will tend to diminish the amount of water pumped from the Tucson Basin now and in the future thus relieving the severity of the local overdraft. This additional water, assuming it to be obtained from sources with the lowest per unit costs, will permit the city to maintain its present rate of growth for a longer period of time with least economic sacrifice. As additional supplies of water are acquired from among the array of alternative sources, the least per unit cost of water to the city will increase because of variation in conditions prevailing in each source.

The level of the cost per acre-foot diverted from irrigated agriculture will vary among the water diversion units because of differences among them in (1) initial depth of the groundwater table, (2) rate of decline in that depth relative to rate of withdrawal, (3) the price of land, (4) the rate of water delivery, and (5) the distance from Tucson. The level of this cost will increase from year to year over time in each diversion unit as a result of the continual increase in the depth to groundwater resulting from continuous withdrawal in excess of annual recharge. This increasing level of cost for each diversion unit is in this analysis reduced to a constant cost for each diversion unit by amortizing it over the 30-year period of the life of wells and equipment at three and one-half percent interest.

Capital costs for wells and for pumping and pipeline equipment for each diversion unit are amortized at three and one-half percent over the 30-year life of equipment period to determine the annual cost against the capital account that would liquidate the investment by the end of the 30-year period. The land cost for each diversion unit, since land is considered to be nondepreciable, is the annual interest charge at three and one-half percent on the borrowed funds used in its acquisition.

The level of the total cost per acre-foot of water diverted from each unit is affected uniformly for all units by the amortized value of the net incomes lost by nonlandowners in agriculture and by all affected persons in the nonagricultural sectors of the Tucson

Region due to elimination of any part or all of agricultural production and incomes from the Region.

The sum of these operating costs of pumping and transporting the water, the amortized costs for each diversion unit and the amortized value of incomes lost due to elimination of some or all of irrigated agriculture is the amortized average annual total cost of diverting irrigation water to Tucson from each of the various diversion units. The amortized average annual total costs, divided by the acre-feet of water available in each diversion unit, is the amortized average annual total cost per acre-foot for irrigation water diverted to Tucson from each of the various diversion units.

The amortized average annual total costs of diverted irrigation water at delivery rates of 10 mgd and 20 mgd are found by this study to vary from $31.08 to $67.18 per acre-foot and from $22.88 to $51.28 per acre-foot, respectively. The costs per acre-foot for the 10 mgd delivery rate represent a reasonable upper limit of costs that the city would incur at the present time, were it to obtain its additional supply of water by the diversion of irrigation water in increments of 10 mgd or 9,200 acre-feet per year.

The increasing average annual costs per acre-foot for diverting additional irrigation water to Tucson in 10 or in 20 mgd amounts by increasing the number of diversion units brought into production are the marginal or incremental costs of expanded supplies. They represent the additional costs per acre-foot that must be paid annually to obtain additional supplies of urban water from irrigation in increments of 9,200 or 18,400 acre-feet per year.

Appraisal

The costs developed herein for the diversion of irrigation water to urban use are dependent upon the conditions and assumptions in the analysis. The elimination of or change in any one of these conditions or assumptions will result in different costs than those determined in this study. The validity and rationale of the conditions and assumptions in the analysis are developed and defended in all cases.

The cost of diverting water to urban use as developed herein relates only to the cost of diverting water from one possible source only; namely, the diversion of irrigation water to Tucson from the agricultural land immediately surrounding the city.

The use of simplifying assumptions where no exact information is available, necessarily places limitations upon the analysis. Some of the more pertinent of these are:

1. The budgets developed for the diversion of irrigation water to Tucson are constant over time because the prices and technology employed in the budgets are not permitted to vary. Over the period of time covered by the budgets in this analysis, prices and technology would ordinarily be expected to vary. However, due to the lack of relevant information and for purposes of simplifying the analysis, technology and price projections are held constant.

2. The analysis uses only two scales (sizes) of diversion units thus implicitly assuming that one of these two diversion scales is the most economical and would not change in the time period of this analysis. If, in fact, the costs resulting from economies or diseconomies of scale of diversion works do change over time, the size of the economically efficient diversion units may change.

3. The decline rate of the groundwater level is assumed to be directly proportional to the rate of withdrawal. This assumption holds the yield of the aquifer constant with increasing depth. In reality, however, there is some indication that water quality and aquifer yield tend to decrease at greater depths. If the efficiency of the aquifer does decrease at increased depths, it will cause the pumping costs to increase more rapidly and costs to be higher because of the increased rate of water level decline. Since the exact effects, if any, of the depth to groundwater on the efficiency of the aquifer are yet to be determined, it is assumed that the quality of water and the efficiency of the aquifer remain constant. In any case, over the ensuing 30 years (to 1997) the deepest well (at 10 mgd delivery) will reach no more than 576 feet of lift. It is doubtful that decline in aquifers or in water quality will have changed significantly at that depth.

4. The analysis assumes that the institutional difficulties of diverting groundwater from the land overlying the aquifer can be overcome. The Supreme Court has held that if the diversion of groundwater away from the land impairs the supply of groundwater on the property of another, it constitutes an illegal action for which damages are recoverable. In this analysis, it was assumed that the city would be required by law or public relations policy to buy the farmland from which it might wish to divert water; and, by restricting itself to withdrawals equal to present withdrawals from those lands, that it would be able to defend itself against claims that it is demaging other overlying owners. This, it is assumed, would diminish the legal problems and justly compensate landowners, thereby eliminating or minimizing the institutional constraints.
5. The supply functions developed in this analysis for the diversion of irrigation water to Tucson are of a tentative nature. A more comprehensive statistical analysis of the data used to develop the supply function may reveal inaccuracies. Although the general shape of the supply function is not likely to change, the level of costs determined for each of the various diversion units may be affected slightly.

6. The supply functions developed for the diversion of irrigation water to urban use relate only to Tucson and only to decisions that might be made now. At each succeeding point in time at which the city might consider further additions to its water supplies by diversion from irrigation as well as other alternatives, an analysis similar to this one will be required reflecting the conditions at that point in time for obtaining such additional supplies of water.

APPENDIX

BASIC DATA AND COST ANALYSIS FOR AREAS I-XVIII

Table 1-A. Location and Pumping Conditions of Area I.[a]

Location and Conditions	10 mgd	20 mgd
Well Field Location	T13S-R13E Sections 14 and 15	T13S-R13E Sections 9, 14, 15 and 16
Miles from City	3.5	3.5
	(feet)	(feet)
1. Average Well Field Elevation	2,250	2,250
2. Average Static Water Level (1965)	97	97
3. Annual Decline	1.3	1.3
4. Estimated Specific Capacity	25	25
5. Drawdown at 1,500 gpm	60	60
6. Pumping Water Level (1967)	160	160
7. Annual Decline Following Development	1.3	2.6
8. Thirteen-Year Decline	17	34
9. Pumping Water Level (1980)	177	194
10. Pumping Water Level (1997)	200	238
11. Average Pumping Level over 30 Years	177	194
12. Elevation of 22nd Street Reservoir	2,600	2,600
13. Booster Head--Well Field to 22nd Street Reservoir	350	350
14. Transmission Line Friction	8	14
Other Lines	25	37
15. Overall Pumping Head	560	595

a. Area I consists of cropland in T12S-R12E, T12S-R13E, T12S-R14E and Sections 6, 7, 8, 9, 14, 15, 16, and 17 of T13S-R13E.

Table 1-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 10 mgd and at 20 mgd from Area I,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	10 mgd	20 mgd	10 mgd	20 mgd
Land				
3,636 acres @ $1,750/acre @ .035 interest			$222,705.00	$222,705.00
Wells and Pumping Units				
8 @ $50,000	$ 400,000.00			
15 @ $50,000		$ 750,000.00		
Collection Line	341,580.00	799,260.00		
Easements	1,354.00	1,354.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
3.5 miles - 36" pipeline @ $27/ft.	498,960.00			
3.5 miles - 42" pipeline @ $30/ft.		554,400.00		
City Tie-in	1,294,920.00	1,536,720.00		
Total Capital Cost	$2,786,814.00	$3,891,734.00		
Amortized Capital Cost				
(Capital cost x $.05437)[b]			151,519.00	211,594.00
Pumping Cost				
(Acre-feet x lift x $.01663)[c]			85,585.00	181,867.00
Delivery Cost				
(Amortized capital cost and pumping cost)			237,104.00	393,461.00
Total Cost				
(Delivery cost and interest on land)			459,809.00	616,166.00
Delivery Cost/Acre-Foot[d]			25.80	21.40
Total Cost/Acre-Foot			50.00	33.00

a. See footnote a, Table 1-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 9,190 and 18,380 for the 10 and 20 mgd systems respectively.

Table 2-A. Location and Pumping Conditions of Area II.[a]

Location and Conditions	10 mgd	20 mgd
Well Field Location	T12S-R12E Sections 25 and 26	T12S-R12E Sections 25, 26, 27, and 35
Miles from City	13	13
	(feet)	(feet)
1. Average Well Field Elevation	2,250	2,250
2. Average Static Water Level (1965)	93	93
3. Average Annual Decline	1	1
4. Estimated Specific Capacity	120	120
5. Drawdown at 1,500 gpm	12	12
6. Pumping Water Level (1967)	95	95
7. Annual Decline Following Development	1	2
8. Thirteen-Year Decline	13	26
9. Pumping Water Level (1980)	108	121
10. Pumping Water Level (1997)	125	155
11. Average Pumping Head over 30 Years	108	121
12. Elevation of 22nd Street Reservoir	2,600	2,600
13. Booster Head--Well Field to 22nd Street Reservoir	350	350
14. Transmission Line Friction	30	51
Other Lines	25	37
15. Overall Pumping Head	513	559

a. Area II consists of cropland in Sections 22, 25, 26, 27, 33, 34, 35 and 36 of T11S-R11E and Section 1 of T12S-R11E.

Table 2-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 10 mgd and at 20 mgd from Area II,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	10 mgd	20 mgd	10 mgd	20 mgd
Land				
284 acres @ $600/acre @ .035 interest			$ 5,956.00	$ 5,956.00
2,999 acres @ $800/acre @ .035 interest			83,983.00	83,983.00
Wells and Pumping Units				
8 @ $50,000	$ 400,000.00			
15 @ $50,000		$ 750,000.00		
Collection Line	341,580.00	799,260.00		
Easements	5,031.00	5,031.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
13 miles - 36" pipeline @ $27/ft.	1,853,280.00			
13 miles - 42" pipeline @ $30/ft.		2,059,200.00		
City Tie-in	1,294,920.00	1,536,720.00		
Total Capital Cost	$4,144,811.00	$5,400,211.00		
Amortized Capital Cost				
(Capital cost x $.05437)[b]			225,353.00	293,609.00
Pumping Cost				
(Acre-feet x lift x $.01663)[c]			78,231.00	170,492.00
Delivery Cost				
(Amortized capital cost and pumping cost)			303,584.00	464,101.00
Total Cost				
(Delivery cost and interest on land)			393,523.00	554,040.00
Delivery Cost/Acre-Foot[d]			33.10	25.30
Total Cost/Acre-Foot			42.90	30.20

a. See footnote a, Table 2-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 9,170 and 18,340 for the 10 and 20 mgd systems respectively.

Table 3-A. Location and Pumping Conditions of Area III.[a]

Location and Conditions	10 mgd	20 mgd
Well Field Location	T11S-R11E Sections 28 and 29	T11S-R11E Sections 20, 21, 28 and 29
Miles from City	23	23
	(feet)	(feet)
1. Average Well Field Elevation	1,950	1,950
2. Average Static Water Level (1965)	281	281
3. Average Annual Decline	5.8	5.8
4. Estimated Specific Capacity	120	120
5. Drawdown at 1,500 gpm	12	12
6. Pumping Water Level (1967)	305	305
7. Annual Decline Following Development	5.8	11.6
8. Thirteen-Year Decline	75	151
9. Pumping Water Level (1980)	380	456
10. Pumping Water Level (1997)	479	653
11. Average Pumping Head over 30 Years	380	456
12. Elevation of 22nd Street Reservoir	2,600	2,600
13. Booster Head--Well Field to 22nd Street Reservoir	650	650
14. Transmission Line Friction	53	90
Other Lines	25	37
15. Overall Pumping Head	1,108	1,233

a. Area III consists of cropland in Sections 16, 19, 20, 21, 28, 29 and 30 of T11S-R11E.

Table 3-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 10 mgd and at 20 mgd from Area III,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	10 mgd	20 mgd	10 mgd	20 mgd
Land				
351 acres @ $600/acre @ .035 interest			$ 7,365.00	$ 7,365.00
2,016 acres @ $800/acre @ .035 interest			84,456.00	84,456.00
Wells and Pumping Units				
8 @ $50,000	$ 400,000.00			
15 @ $50,000		$ 750,000.00		
Collection Line	341,580.00	799,260.00		
Easements	8,901.00	8,901.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
23 miles - 36" pipeline @ $27/ft.	3,278,880.00			
23 miles - 42" pipeline @ $30/ft.		3,643,200.00		
City Tie-in	1,294,920.00	1,536,720.00		
Total Capital Cost	$5,574,281.00	$6,988,081.00		
Amortized Capital Cost				
(Capital cost x $.05437)[b]			303,074.00	379,942.00
Pumping Cost				
(Acre-feet x lift x $.01663)[c]			170,809.00	380,159.00
Delivery Cost				
(Amortized capital cost and pumping cost)			473,883.00	760,101.00
Total Cost				
(Delivery cost and interest on land)			565,704.00	851,922.00
Delivery Cost/Acre-Foot[d]			51.10	41.00
Total Cost/Acre-Foot			61.00	46.00

a. See footnote a, Table 3-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 9,270 and 18,540 for the 10 and 20 mgd systems respectively.

Table 4-A. Location and Pumping Conditions of Area IV.[a]

Location and Conditions	10 mgd	20 mgd
Well Field Location	T11S-R11E Sections 17 and 18	T11S-R11E Sections 7, 8, 17, and 18
Miles from City	25	25
	(feet)	(feet)
1. Average Well Field Elevation	1,950	1,950
2. Average Static Water Level (1965)	281	281
3. Average Annual Decline	5.8	5.8
4. Estimated Specific Capacity	120	120
5. Drawdown at 1,500 gpm	12	12
6. Pumping Water Level (1967)	305	305
7. Annual Decline Following Development	5.8	11.6
8. Thirteen-Year Decline	75	151
9. Pumping Water Level (1980)	380	456
10. Pumping Water Level (1997)	479	653
11. Average Pumping Head over 30 Years	380	456
12. Elevation of 22nd Street Reservoir	2,600	2,600
13. Booster Head--Well Field to 22nd Street Reservoir	650	650
14. Transmission Line Friction	58	98
Other Lines	25	37
15. Overall Pumping Head	1,113	1,241

a. Area IV consists of cropland in Sections 7, 17, and 18 of T11S-R11E and Sections 1, 2, 3, 12 and 13 of T11S-R10E.

Table 4-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 10 mgd and at 20 mgd from Area IV,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	10 mgd	20 mgd	10 mgd	20 mgd
Land				
809 acres @ $600/acre @ .035 interest			$ 16,997.00	$ 16,997.00
2,741 acres @ $800/acre @ .035 interest			76,737.00	76,737.00
Wells and Pumping Units				
8 @ $50,000	$ 400,000.00			
15 @ $50,000		$ 750,000.00		
Collection Line	341,580.00	799,260.00		
Easements	9,675.00	9,675.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
25 miles - 36" pipeline @ $27/ft.	3,564,000.00			
25 miles - 42" pipeline @ $30/ft.		3,960,000.00		
City Tie-in	1,294,920.00	1,536,720.00		
Total Capital Cost	$5,860,175.00	$7,305,655.00		
Amortized Capital Cost (Capital cost x $.05437)[b]			318,618.00	397,208.00
Pumping Cost (Acre-feet x lift x $.01663)[c]			171,395.00	382,213.00
Delivery Cost (Amortized capital cost and pumping cost)			490,013.00	779,421.00
Total Cost (Delivery cost and interest on land)			583,747.00	873,155.00
Delivery Cost/Acre-Foot[d]			52.90	42.10
Total Cost/Acre-Foot			63.00	47.10

a. See footnote a, Table 4-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 9,260 and 18,520 for the 10 and 20 mgd systems respectively.

Table 5-A. Location and Pumping Conditions of Area V.[a]

Location and Conditions	10 mgd	20 mgd
Well Field Location	T11S-R10E Sections 25 and 26	T11S-R10E Sections 23, 24, 25 and 26
Miles from City	26	26
	(feet)	(feet)
1. Average Well Field Elevation	1,950	1,950
2. Average Static Water Level (1965)	246	246
3. Average Annual Decline	5.3	5.3
4. Estimated Specific Capacity	75	75
5. Drawdown at 1,500 gpm	20	20
6. Pumping Water Level (1967)	277	277
7. Annual Decline Following Development	5.3	10.6
8. Thirteen-Year Decline	69	138
9. Pumping Water Level (1980)	346	415
10. Pumping Water Level (1997)	437	595
11. Average Pumping Head over 30 Years	346	415
12. Elevation of 22nd Street Reservoir	2,600	2,600
13. Booster Head--Well Field to 22nd Street Reservoir	650	650
14. Transmission Line Friction	60	101
Other Lines	25	37
15. Overall Pumping Head	1,081	1,203

a. Area V consists of cropland in Sections 10, 11, 14, 15, 22, 23, 24, 25, 26 and 27 of T11S-R10E.

Table 5-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 10 mgd and at 20 mgd from Area V,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	10 mgd	20 mgd	10 mgd	20 mgd
Land				
1,648 acres @ \$600/acre @ .035 interest			\$ 34,598.00	\$ 34,598.00
2,091 acres @ \$800/acre @ .035 interest			58,562.00	58,562.00
Wells and Pumping Units				
8 @ \$50,000	\$ 400,000.00			
15 @ \$50,000		\$ 750,000.00		
Collection Line	341,580.00	799,260.00		
Easements	10,062.00	10,062.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
26 miles - 36" pipeline @ \$27/ft.	3,706,560.00			
26 miles - 42" pipeline @ \$30/ft.		4,118,400.00		
City Tie-in	1,294,920.00	1,536,720.00		
Total Capital Cost	\$6,003,122.00	\$7,404,442.00		
Amortized Capital Cost				
(Capital cost x \$.05437)[b]			326,390.00	406,385.00
Pumping Cost				
(Acre-feet x lift x \$.01663)[c]			168,625.00	375,310.00
Delivery Cost				
(Amortized capital cost and pumping cost)			495,015.00	781,695.00
Total Cost				
(Delivery cost and interest on land)			588,175.00	874,855.00
Delivery Cost/Acre-Foot[d]			52.80	41.70
Total Cost/Acre-Foot			62.70	46.00

a. See footnote a, Table 5-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. \$.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 9,380 and 18,760 for the 10 and 20 mgd systems respectively.

Table 6-A. Location and Pumping Conditions of Area VI.[a]

Location and Conditions	10 mgd	20 mgd
Well Field Location	T12S-R10E Sections 20 and 21	T12S-R10E Sections 9, 16, 20 and 21
Miles from City	34	34
	(feet)	(feet)
1. Average Well Field Elevation	2,000	2,000
2. Average Static Water Level (1965)	260	260
3. Average Annual Decline	4.5	4.5
4. Estimated Specific Capacity	75	75
5. Drawdown at 1,500 gpm	20	20
6. Pumping Water Level (1967)	289	289
7. Annual Decline Following Development	4.5	9.0
8. Thirteen-Year Decline	58	117
9. Pumping Water Level (1980)	347	406
10. Pumping Water Level (1997)	425	659
11. Average Pumping Head over 30 Years	347	406
12. Elevation of 22nd Street Reservoir	2,600	2,600
13. Booster Head--Well Field to 22nd Street Reservoir	600	600
14. Transmission Line Friction	78	133
Other Lines	40	40
15. Overall Pumping Head	1,065	1,179

a. Area VI consists of cropland in Sections 4, 5, 8, 9, 17, 20, 21, 28, 29 and 33 of T11S-R10E and Sections 4, 9, 16, 20 and 21 of T12S-R10E.

Table 6-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 10 mgd and at 20 mgd from Area VI,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	10 mgd	20 mgd	10 mgd	20 mgd
Land				
4,042 acres @ $600/acre @ .035 interest			$ 84,847.00	$ 84,847.00
Wells and Pumping Units				
8 @ $50,000	$ 400,000.00			
15 @ $50,000		$ 750,000.00		
Collection Line	341,580.00	799,260.00		
Easements	13,158.00	13,158.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
34 miles - 36" pipeline @ $27/ft.	4,897,040.00			
34 miles - 42" pipeline @ $30/ft.		5,385,600.00		
Total Capital Cost	$5,851,778.00	$7,198,018.00		
Amortized Capital Cost				
(Capital cost x $.05437)[b]			318,161.00	391,356.00
Pumping Cost				
(Acre-feet x lift x $.01663)[c]			163,278.00	361,549.00
Delivery Cost				
(Amortized capital cost and pumping cost)			481,439.00	752,905.00
Total Cost				
(Delivery cost and interest on land)			566,286.00	837,752.00
Delivery Cost/Acre-Foot[d]			52.20	40.80
Total Cost/Acre-Foot			61.40	45.40

a. See footnote a, Table 6-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 9,220 and 18,440 for the 10 and 20 mgd systems respectively.

Table 7-A. Location and Pumping Conditions of Area VII.[a]

Location and Conditions	10 mgd	20 mgd
Well Field Location	T12S-R11E Sections 11 and 12	T12S-R11E Sections 2, 10, 11 and 12
Miles from City	18.25	18.25
	(feet)	(feet)
1. Average Well Field Elevation	2,050	2,050
2. Average Static Water Level (1965)	290	290
3. Average Annual Decline	4.9	4.9
4. Estimated Specific Capacity	25	25
5. Drawdown at 1,500 gpm	60	60
6. Pumping Water Level (1967)	360	360
7. Annual Decline Following Development	4.9	9.8
8. Thirteen-Year Decline	64	127
9. Pumping Water Level (1980)	424	487
10. Pumping Water Level (1997)	508	654
11. Average Pumping Head over 30 Years	424	487
12. Elevation of 22nd Street Reservoir	2,600	2,600
13. Booster Head--Well Field to 22nd Street Reservoir	550	550
14. Transmission Line Friction	42	71
Other Lines	25	37
15. Overall Pumping Head	1,041	1,145

a. Area VII consists of cropland in Sections 31 and 32 of T11S-R11E; Section 1 of T12S-R10E; and Sections 4, 6, 7, 8, 9, 10, 11, 12 and 15 of T12S-R11E.

Table 7-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 10 mgd and at 20 mgd from Area VII,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	10 mgd	20 mgd	10 mgd	20 mgd
Land				
3,657 acres @ $600/acre @ .035 interest			$ 76,797.00	$ 76,797.00
Wells and Pumping Units				
8 @ $50,000	$ 400,000.00			
15 @ $50,000		$ 750,000.00		
Collection Line	341,580.00	799,260.00		
Easements	7,063.00	7,063.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
18.25 miles - 36" pipeline @ $27/ft.	2,601,720.00			
18.25 miles - 42" pipeline @ $30/ft.		2,890,800.00		
City Tie-in	1,294,920.00	1,536,720.00		
Total Capital Cost	$4,895,283.00	$6,233,843.00		
Amortized Capital Cost				
(Capital cost x $.05437)[b]			266,156.00	338,934.00
Pumping Cost				
(Acre-feet x lift x $.01663)[c]			161,173.00	354,550.00
Delivery Cost				
(Amortized capital cost and pumping cost)			427,329.00	693,484.00
Total Cost				
(Delivery cost and interest on land)			504,126.00	770,281.00
Delivery Cost/Acre-Foot[d]			45.90	37.20
Total Cost/Acre-Foot			54.10	41.40

a. See footnote a, Table 7-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 9,240 and 18,480 for the 10 and 20 mgd systems respectively.

Table 8-A. Location and Pumping Conditions of Area VIII.[a]

Location and Conditions	10 mgd	20 mgd
Well Field Location	T12S-R11E Sections 16 and 17	T12S-R11E Sections 16, 17, 20 and 21
Miles from City	22	22
	(feet)	(feet)
1. Average Well Field Elevation	2,025	2,025
2. Average Static Water Level (1965)	320	320
3. Average Annual Decline	6.1	6.1
4. Estimated Specific Capacity	25	25
5. Drawdown at 1,500 gpm	60	60
6. Pumping Water Level (1967)	392	392
7. Annual Decline Following Development	6.1	12.2
8. Thirteen-Year Decline	79	159
9. Pumping Water Level (1980)	471	551
10. Pumping Water Level (1997)	576	758
11. Average Pumping Head over 30 Years	471	551
12. Elevation of 22nd Street Reservoir	2,600	2,600
13. Booster Head--Well Field to 22nd Street Reservoir	575	575
14. Transmission Line Friction	51	86
Other Lines	25	37
15. Overall Pumping Head	1,122	1,249

a. Area VIII consists of cropland in Sections 3, 11, 12, 14, 23 and 24 of T12S-R10E and Sections 16, 17, 18, 19 and 20 of T12S-R11E.

Table 8-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 10 mgd and at 20 mgd from Area VIII,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	10 mgd	20 mgd	10 mgd	20 mgd
Land				
1,285 acres @ $500/acre @ .035 interest			$ 22,484.00	$ 22,484.00
2,575 acres @ $500/acre @ .035 interest			54,079.00	54,079.00
Wells and Pumping Units				
8 @ $50,000	$ 400,000.00			
15 @ $50,000		$ 750,000.00		
Collection Line	341,580.00	799,260.00		
Easements	8,514.00	8,514.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
22 miles - 36" pipeline @ $27/ft.	3,136,320.00			
22 miles - 42" pipeline @ $30/ft.		3,484,800.00		
City Tie-in	1,294,920.00	1,536,720.00		
Total Capital Cost	$5,431,334.00	6,829,294.00		
Amortized Capital Cost (Capital cost x $.05437)[b]			295,302.00	371,309.00
Pumping Cost (Acre-feet x lift x $.01663)[c]			173,714.00	386,754.00
Delivery Cost (Amortized capital cost and pumping cost)			469,016.00	758,063.00
Total Cost (Delivery cost and interest on land)			545,579.00	834,626.00
Delivery Cost/Acre-Foot[d]			50.40	40.70
Total Cost/Acre-Foot			58.60	44.80

a. See footnote a, Table 8-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 9,310 and 18,620 for the 10 and 20 mgd systems respectively.

Table 9-A. Location and Pumping Conditions of Area IX.[a]

Location and Conditions	10 mgd	20 mgd
Well Field Location	T12S-R10E Sections 25 and 26	T12S-R11E Sections 29 and 30 T12S-R10E Sections 25 and 26
Miles from City	31	31
	(feet)	(feet)
1. Average Well Field Elevation	2,050	2,050
2. Average Static Water Level (1965)	270	270
3. Average Annual Decline	3.8	3.8
4. Estimated Specific Capacity	25	25
5. Drawdown at 1,500 gpm	60	60
6. Pumping Water Level (1967)	338	338
7. Annual Decline Following Development	3.8	7.6
8. Thirteen-Year Decline	49	99
9. Pumping Water Level (1980)	387	437
10. Pumping Water Level (1997)	452	566
11. Average Pumping Head over 30 Years	387	437
12. Elevation of 22nd Street Reservoir	2,600	2,600
13. Booster Head--Well Field to 22nd Street Reservoir	550	550
14. Transmission Line Friction	71	121
Other Lines	40	40
15. Overall Pumping Head	1,048	1,148

a. Area IX consists of cropland in Sections 25, 26, 27, 31, 32 and 33 of T12S-R10E; Sections 29 and 30 of T12S-R11E; Sections 4, 5, 6 and 11 of T13S-R10E; and Section 7 of T13S-R11E.

Table 9-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 10 mgd and at 20 mgd from Area IX,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	10 mgd	20 mgd	10 mgd	20 mgd
Land				
4,161 acres @ $500/acre @ .035 interest			$ 72,818.00	$ 72,818.00
Wells and Pumping Units				
8 @ $50,000	$ 400,000.00			
15 @ $50,000		$ 750,000.00		
Collection Line	341,580.00	799,260.00		
Easements	11,997.00	11,997.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
31 miles - 36" pipeline @ $27/ft.	4,419,360.00			
31 miles - 42" pipeline @ $30/ft.		4,910,400.00		
Total Capital Cost	$5,422,937.00	$6,721,657.00		
Amortized Capital Cost				
(Capital cost x $.05437)[b]			294,845.00	365,456.00
Pumping Cost				
(Acre-feet x lift x $.01663)[c]			162,431.00	355,861.00
Delivery Cost				
(Amortized capital cost and pumping cost)			457,276.00	721,317.00
Total Cost				
(Delivery cost and interest on land)			530,094.00	794,135.00
Delivery Cost/Acre-Foot[d]			49.10	38.70
Total Cost/Acre-Foot			56.90	42.60

a. See footnote a, Table 9-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 9,320 and 18,640 for the 10 and 20 mgd systems respectively.

Table 10-A. Location and Pumping Conditions of Area X.[a]

Location and Conditions	10 mgd	20 mgd
Well Field Location	T13S-R10E Sections 13 and 14	T13S-R10E Sections 12, 14, 23 and 24
Miles from City	26	26
	(feet)	(feet)
1. Average Well Field Elevation	2,150	2,150
2. Average Static Water Level (1965)	337	337
3. Average Annual Decline	5.7	5.7
4. Estimated Specific Capacity	65	65
5. Drawdown at 1,500 gpm	23	23
6. Pumping Water Level (1967)	371	371
7. Annual Decline Following Development	5.7	11.4
8. Thirteen-Year Decline	74	148
9. Pumping Water Level (1980)	445	519
10. Pumping Water Level (1997)	543	712
11. Average Pumping Head over 30 Years	445	519
12. Elevation of 22nd Street Reservoir	2,600	2,600
13. Booster Head--Well Field to 22nd Street Reservoir	450	450
14. Transmission Line Friction	60	101
Other Lines	40	40
15. Overall Pumping Head	995	1,110

a. Area X consists of cropland in Sections 8, 9, 10, 13, 14, 15, 16, 20, 22, 23 and 24 of T13S-R10E.

Table 10-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 10 mgd and at 20 mgd from Area X,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	10 mgd	20 mgd	10 mgd	20 mgd
Land				
4,019 acres @ $500/acre @ .035 interest			$ 70,332.00	$ 70,332.00
Wells and Pumping Units				
8 @ $50,000	$ 400,000.00			
15 @ $50,000		$ 750,000.00		
Collection Line	341,580.00	799,260.00		
Easements	9,482.00	9,482.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
24.5 miles - 36" pipeline @ $27/ft.	3,706,560.00			
24.5 miles - 42" pipeline @ $30/ft.		4,118,400.00		
Total Capital Cost	$4,707,622.00	$5,927,142.00		
Amortized Capital Cost				
(Capital cost x $.05437)[b]			255,953.00	322,259.00
Pumping Cost				
(Acre-feet x lift x $.01663)[c]			153,720.00	342,974.00
Delivery Cost				
(Amortized capital cost and pumping cost)			409,673.00	665,233.00
Total Cost				
(Delivery cost and interest on land)			480,005.00	735,565.00
Delivery Cost/Acre-Foot[d]			44.10	35.80
Total Cost/Acre-Foot			51.70	39.60

a. See footnote a, Table 10-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 9,290 and 18,580 for the 10 and 20 mgd systems respectively.

Table 11-A. Location and Pumping Conditions of Area XI.[a]

Location and Conditions	10 mgd	20 mgd
Well Field Location	T14S-R11E Sections 6 and 7	T14S-R11E Sections 5, 6 and 7
Miles from City	21.5	21.5
	(feet)	(feet)
1. Average Well Field Elevation	2,225	2,225
2. Average Static Water Level (1965)	334	334
3. Average Annual Decline	3	3
4. Estimated Specific Capacity	40	40
5. Drawdown at 1,500 gpm	38	38
6. Pumping Water Level (1967)	378	378
7. Annual Decline Following Development	3	6
8. Thirteen-Year Decline	39	78
9. Pumping Water Level (1980)	417	456
10. Pumping Water Level (1997)	468	558
11. Average Pumping Head over 30 Years	417	456
12. Martin Reservoir Elevation	2,560	2,560
13. Elevation of 22nd Street Reservoir	2,600	2,600
14. Booster Head--Well Field to 22nd Street Reservoir	375	375
15. Transmission Line Friction	49	84
Other Lines	40	40
16. Overall Pumping Head	881	955

a. Area XI consists of cropland in Sections 25 and 26 of T13S-R10E; Sections 30, 31 and 32 of T13S-R11E and Sections 5, 6 and 7 of T14S-R11E.

Table 11-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 10 mgd and 20 mgd from Area XI,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	10 mgd	20 mgd	10 mgd	20 mgd
Land				
3,371 acres @ $500/acre @ .035 interest			$ 58,992.00	$ 58,992.00
Wells and Pumping Units				
8 @ $50,000	$ 400,000.00			
15 @ $50,000		$ 750,000.00		
Collection Line	341,580.00	799,260.00		
Easements	8,320.00	8,320.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
21.5 miles - 36" pipeline @ $27/ft.	3,065,040.00			
21.5 miles - 42" pipeline @ $30/ft.		3,405,600.00		
Total Capital Cost	$4,064,940.00	$5,213,180.00		
Amortized Capital Cost				
(Capital cost x $.05437)[b]			221,011.00	283,441.00
Pumping Cost				
(Acre-feet x lift x $.01663)[c]			133,324.00	289,046.00
Delivery Cost				
(Amortized capital cost and pumping cost)			354,335.00	572,487.00
Total Cost				
(Delivery cost and interest on land)			413,327.00	631,479.00
Delivery Cost/Acre-Foot[d]			38.90	31.50
Total Cost/Acre-Foot			45.40	34.70

a. See footnote a, Table 11-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 9,100 and 18,200 for 10 and 20 mgd systems respectively.

Table 12-A. Location and Pumping Conditions of Area XII.[a]

Location and Conditions	7 mgd	14 mgd
Well Field Location	T14S-R11E Sections 27 and 34	T14S-R11E Sections 27, 33 and 34
Miles from City	16	16
	(feet)	(feet)
1. Average Well Field Elevation	2,325	2,325
2. Average Static Water Level (1965)	322	322
3. Average Annual Decline	1.4	1.4
4. Estimated Specific Capacity	40	40
5. Drawdown at 1,500 gpm	38	38
6. Pumping Water Level (1967)	363	363
7. Annual Decline Following Development	1.4	2.8
8. Thirteen-Year Decline	18	36
9. Pumping Water Level (1980)	381	399
10. Pumping Water Level (1997)	405	447
11. Average Pumping Head over 30 Years	381	399
12. Martin Reservoir Elevation	2,560	2,560
13. Elevation of 22nd Street Reservoir	2,600	2,600
14. Booster Head--Well Field to 22nd Street Reservoir	275	275
15. Transmission Line Friction	46	32
Other Lines	40	40
16. Overall Pumping Head	742	746

a. Area XII consists of cropland in Sections 4, 8, 9, 27, 29, 33 and 34 of T14S-R11E and Section 11 of T15S-R11E.

Table 12-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 7 mgd and at 14 mgd from Area XII,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	7 mgd	14 mgd	7 mgd	14 mgd
Land				
3,042 acres @ $500/acre @ .035 interest			$ 53,235.00	$ 53,235.00
Wells and Pumping Units				
6 @ $50,000	$ 300,000.00			
11 @ $50,000		$ 550,000.00		
Collection Line	213,840.00	553,740.00		
Easements	6,192.00	6,192.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
16 miles - 30" pipeline @ $22/ft.	1,858,560.00			
16 miles - 42" pipeline @ $30/ft.		2,534,400.00		
Total Capital Cost	$2,628,592.00	$3,894,332.00		
Amortized Capital Cost				
(Capital cost x $.05437)[b]			142,917.00	211,735.00
Pumping Cost				
(Acre-feet x lift x $.01663)[c]			82,674.00	166,240.00
Delivery Cost				
(Amortized capital cost and pumping cost)			225,591.00	377,975.00
Total Cost				
(Delivery cost and interest on land)			278,826.00	431,210.00
Delivery Cost/Acre-Foot[d]			33.70	28.20
Total Cost/Acre-Foot			41.60	32.20

a. See footnote a, Table 12-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 6,700 and 13,400 for the 7 and 14 mgd systems respectively.

Table 13-A. Location and Pumping Conditions of Area XIII.[a]

Location and Conditions	4 mgd	8 mgd
Well Field Location	T15S-R10E Section 33 T16S-R10E Section 4	T15S-R10E Section 33 T16S-R10E Sections 4 and 5
Miles from City	23.5	23.5
	(feet)	(feet)
1. Average Well Field Elevation	2,550	2,550
2. Average Static Water Level (1965)	175	175
3. Average Annual Decline	1.4	1.4
4. Estimated Specific Capacity	30	30
5. Drawdown at 1,500 gpm	50	50
6. Pumping Water Level (1967)	228	228
7. Annual Decline Following Development	1.4	2.8
8. Thirteen-Year Decline	18	36
9. Pumping Water Level (1980)	246	264
10. Pumping Water Level (1997)	270	312
11. Average Pumping Head over 30 Years	246	264
12. Martin Reservoir Elevation	2,560	2,560
13. Elevation of 22nd Street Reservoir	2,600	2,600
14. Booster Head--Well Field to 22nd Street Reservoir	50	50
15. Transmission Line Friction	72	36
Other Lines	40	40
16. Overall Pumping Head	408	390

a. Area XIII consists of cropland in Sections 21, 28 and 33 of T15S-R10E and Sections 4, 5 and 8 of T16S-R10E.

Table 13-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 4 mgd and at 8 mgd from Area XIII,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	4 mgd	8 mgd	4 mgd	8 mgd
Land				
1,219 acres @ $500/acre @ .035 interest			$ 21,332.00	$ 21,332.00
Wells and Pumping Units				
4 @ $50,000	$ 200,000.00			
7 @ $50,000		$ 350,000.00		
Collection Line	112,860.00	300,960.00		
Easements	9,094.00	9,094.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
23.5 miles - 24" pipeline @ $16/ft.	1,985,280.00			
23.5 miles - 36" pipeline @ $27/ft.		3,350,160.00		
Total Capital Cost	$2,557,234.00	$4,260,214.00		
Amortized Capital Cost				
(Capital cost x $.05437)[b]			139,037.00	231,638.00
Pumping Cost				
(Acre-feet x lift x $.01663)[c]			23,680.00	45,270.00
Delivery Cost				
(Amortized capital cost and pumping cost)			162,717.00	276,898.00
Total Cost				
(Delivery cost and interest on land)			184,049.00	298,230.00
Delivery Cost/Acre-Foot[d]			46.60	39.70
Total Cost/Acre-Foot			52.70	42.70

a. See footnote a, Table 13-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 3,490 and 6,980 for the 4 and 8 mgd systems respectively.

Table 14-A. Location and Pumping Conditions of Area XIV.[a]

Location and Conditions	10 mgd	20 mgd
Well Field Location	T16S-R14E Sections 6 and 7	T16S-R14E Sections 6, 7, 18 and 19
Miles from City	4	4
	(feet)	(feet)
1. Average Well Field Elevation	2,600	2,600
2. Average Static Water Level (1965)	83	83
3. Average Annual Decline	3.2	3.2
4. Estimated Specific Capacity	50	50
5. Drawdown at 1,500 gpm	30	30
6. Pumping Water Level (1967)	119	119
7. Annual Decline Following Development	3.2	6.4
8. Thirteen-Year Decline	42	83
9. Pumping Water Level (1980)	161	202
10. Pumping Water Level (1997)	215	311
11. Average Pumping Head over 30 Years	161	202
12. Martin Reservoir Elevation (Gravity)	2,560	2,560
13. Elevation of 22nd Street Reservoir	2,600	2,600
14. Booster Head--Well Field to 22nd Street Reservoir	40	40
15. Transmission Line Friction--30-inch (Gravity)	0	0
Other Lines	40	40
16. Overall Pumping Head	241	282

a. Area XIV consists of the cropland in Sections 35 and 36 of T16S-R13E; Sections 6, 7, 18, 19, 20, 29, 30, 31 and 32 of T16S-R14E; and Section 1 of T17S-R13E.

Table 14-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 10 mgd and at 20 mgd from Area XIV,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	10 mgd	20 mgd	10 mgd	20 mgd
Land				
3,634 acres @ $1,000/acre @ .035 interest			$127,190.00	$127,190.00
Wells and Pumping Units				
8 @ $50,000	$ 400,000.00			
15 @ $50,000		$ 750,000.00		
Collection Line	341,580.00	799,260.00		
Easements	1,548.00	1,548.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
4 miles - 36" pipeline @ $27/ft.	570,240.00			
4 miles - 42" pipeline @ $30/ft.		633,600.00		
Total Capital Cost	$1,563,368.00	$2,434,408.00		
Amortized Capital Cost				
(Capital cost x $.05437)[b]			85,000.00	132,359.00
Pumping Cost				
(Acre-feet x lift x $.01663)[c]			37,153.00	86,946.00
Delivery Cost				
(Amortized capital cost and pumping cost)			122,153.00	219,305.00
Total Cost				
(Delivery cost and interest on land)			249,343.00	346,495.00
Delivery Cost/Acre-Foot[d]			13.20	11.80
Total Cost/Acre-Foot			26.90	18.70

a. See footnote a, Table 14-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 9,270 and 18,540 for the 10 and 20 mgd systems respectively.

Table 15-A. Location and Pumping Conditions of Area XV.[a]

Location and Conditions	10 mgd	20 mgd
Well Field Location	T17S-R14E Sections 6 and 7	T17S-R14E Sections 5, 6, 7 and 8
Miles from City	10	10
	(feet)	(feet)
1. Average Well Field Elevation	2,700	2,700
2. Average Static Water Level (1965)	118	118
3. Average Annual Decline	3.4	3.4
4. Estimated Specific Capacity	20	20
5. Drawdown at 1,500 gpm	75	75
6. Pumping Water Level (1967)	200	200
7. Annual Decline Following Development	3.4	6.8
8. Thirteen-Year Decline	44	88
9. Pumping Water Level (1980)	244	288
10. Pumping Water Level (1997)	302	404
11. Average Pumping Head over 30 Years	244	288
12. Martin Reservoir Elevation (Gravity)	2,560	2,560
13. Elevation of 22nd Street Reservoir	2,600	2,600
14. Booster Head--Well Field to 22nd Street Reservoir	40	40
15. Transmission Line Friction (Gravity)	0	0
Other Lines	40	40
16. Overall Pumping Head	324	368

a. Area XV consists of cropland in Sections 5, 6, 7, 8, 17, 18, 19, 29, 30 and 31 of T17S-R14E and Section 5 of T18S-R14E.

Table 15-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 10 mgd and at 20 mgd from Area XV,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	10 mgd	20 mgd	10 mgd	20 mgd
Land				
3,291 acres @ $1,000/acre @ .035 interest			$115,185.00	$115,185.00
Wells and Pumping Units				
8 @ $50,000	$ 400,000.00			
15 @ $50,000		$ 750,000.00		
Collection Line	341,580.00	799,260.00		
Easements	3,870.00	3,870.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
10 miles - 36" pipeline @ $27/ft.	1,425,600.00			
10 miles - 42" pipeline @ $30/ft.		1,584,000.00		
Total Capital Cost	$2,421,050.00	$3,387,130.00		
Amortized Capital Cost				
(Capital cost x $.05437)[b]			131,632.00	184,158.00
Pumping Cost				
(Acre-feet x lift x $.01663)[c]			49,786.00	113,095.00
Delivery Cost				
(Amortized capital cost and pumping cost)			181,418.00	297,253.00
Total Cost				
(Delivery cost and interest on land)			296,603.00	412,438.00
Delivery Cost/Acre-Foot[d]			19.60	16.10
Total Cost/Acre-Foot			32.10	22.30

a. See footnote a, Table 15-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 9,240 and 18,480 for the 10 and 20 mgd systems respectively.

Table 16-A. Location and Pumping Conditions of Area XVI.[a]

Location and Conditions	10 mgd	20 mgd
Well Field Location	T17S-R13E Sections 12 and 13	T17S-R13E Sections 12, 13, 24 and 25
Miles from City	11.5	11.5
	(feet)	(feet)
1. Average Well Field Elevation	2,720	2,720
2. Average Static Water Level (1965)	123	123
3. Average Annual Decline	4.3	4.3
4. Estimated Specific Capacity	40	40
5. Drawdown at 1,500 gpm	38	38
6. Pumping Water Level (1967)	170	170
7. Annual Decline Following Development	4.3	8.6
8. Thirteen-Year Decline	56	112
9. Pumping Water Level (1980)	226	282
10. Pumping Water Level (1997)	298	428
11. Average Pumping Head over 30 Years	226	282
12. Martin Reservoir Elevation (Gravity)	2,560	2,560
13. Elevation of 22nd Street Reservoir	2,600	2,600
14. Booster Head--Well Field to 22nd Street Reservoir	40	40
15. Transmission Line Friction (Gravity)	0	0
Other Lines	40	40
16. Overall Pumping Head	306	362

a. Area XVI consists of cropland in Sections 12, 13, 24, 25, 35 and 36 of T17S-R13E; Sections 1, 2, 11, 12 and 14 of T18S-R13E; and Section 6 of T18S-R14E.

Table 16-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 10 mgd and at 20 mgd from Area XVI,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	10 mgd	20 mgd	10 mgd	20 mgd
Land				
3,382 acres @ $1,000/acre @ .035 interest			$118,370.00	$118,370.00
Wells and Pumping Units				
8 @ $50,000	$ 400,000.00			
15 @ $50,000		$ 750,000.00		
Collection Line	341,580.00	799,260.00		
Easements	4,450.00	4,450.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
11.5 miles - 36" pipeline @ $27/ft.	1,639,440.00			
11.5 miles - 42" pipeline @ $30/ft.		1,821,600.00		
Total Capital Cost	$2,635,470.00	$3,624,310.00		
Amortized Capital Cost				
(Capital cost x $.05437)[b]			143,290.00	197,108.00
Pumping Cost				
(Acre-feet x lift x $.01663)[c]			46,206.00	109,324.00
Delivery Cost				
(Amortized capital cost and pumping cost)			189,496.00	306,432.00
Total Cost				
(Delivery cost and interest on land)			307,866.00	424,802.00
Delivery Cost/Acre-Foot[d]			20.90	16.90
Total Cost/Acre-Foot			33.90	23.40

a. See footnote a, Table 16-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 9,080 and 18,160 for the 10 and 20 mgd systems respectively.

Table 17-A. Location and Pumping Conditions of Area XVII.[a]

Location and Conditions	10 mgd	20 mgd
Well Field Location	T18S-R13E Sections 13 and 24	T18S-R13E Sections 13, 23 and 24
Miles from City	17.5	17.5
	(feet)	(feet)
1. Average Well Field Elevation	2,880	2,880
2. Average Static Water Level (AGS)	119	119
3. Average Annual Decline	3.1	3.1
4. Estimated Specific Capacity	35	35
5. Drawdown at 1,500 gpm	43	43
6. Pumping Water Level (1967)	168	168
7. Annual Decline Following Development	3.1	6.2
8. Thirteen-Year Decline	40	81
9. Pumping Water Level (1980)	208	249
10. Pumping Water Level (1997)	260	354
11. Average Pumping Head over 30 Years	208	249
12. Martin Reservoir Elevation (Gravity)	2,560	2,560
13. Elevation of 22nd Street Reservoir	2,600	2,600
14. Booster Head--Well Field to 22nd Street Reservoir	40	40
15. Transmission Line Friction (Gravity)	0	0
Other Lines	40	40
16. Overall Pumping Head	288	329

a. Area XVII consists of cropland in Sections 13, 23, 24, 26, 27, 34 and 35 of T18S-R13E; Section 8 of T18S-R14E; and Sections 2, 3, 4, 9, 16, 20, 21, 29, 30, 31 and 32 of T19S-R13E.

Table 17-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 10 mgd and at 20 mgd from Area XVII,[a] 1967.

	Estimated Cost of Depreciable Capital		Average Annual Cost	
	10 mgd	20 mgd	10 mgd	20 mgd
Land				
3,636 acres @ $1,000/acre @ .035 interest			$127,260.00	$127,260.00
Wells and Pumping Units				
8 @ $50,000	$ 400,000.00			
15 @ $50,000		$ 750,000.00		
Collection Line	341,580.00	799,260.00		
Easements	6,772.00	6,772.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
17.5 miles - 36" pipeline @ $27/ft.	2,494,800.00			
17.5 miles - 42" pipeline @ $30/ft.		2,772,000.00		
Total Capital Cost	$3,493,152.00	$4,578,032.00		
Amortized Capital Cost (Capital cost x $.05437)[b]			189,923.00	248,908.00
Pumping Cost (Acre-feet x lift x $.01663)[c]			43,919.00	100,343.00
Delivery Cost (Amortized capital cost and pumping cost)			233,842.00	349,251.00
Total Cost (Delivery cost and interest on land)			361,102.00	476,511.00
Delivery Cost/Acre-Foot[d]			25.50	19.00
Total Cost/Acre-Foot			39.40	26.00

a. See footnote a, Table 17-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 9,170 and 18,340 for the 10 and 20 mgd systems respectively.

Table 18-A. Location and Pumping Conditions of Area XVIII.[a]

Location and Conditions	5 mgd	10 mgd
Well Field Location	T15S-R13E Sections 10 and 15	T15S-R13E Sections 10 and 15
Miles from City	3	3
	(feet)	(feet)
1. Average Well Field Elevation	2,450	2,450
2. Average Static Water Level (1965)	81	81
3. Average Annual Decline	3.8	3.8
4. Estimated Specific Capacity	25	25
5. Drawdown at 1,500 gpm	60	60
6. Pumping Water Level (1967)	149	149
7. Annual Decline Following Development	3.8	7.6
8. Thirteen-Year Decline	49	99
9. Pumping Water Level (1980)	198	248
10. Pumping Water Level (1997)	263	377
11. Average Pumping Head over 30 Years	198	248
12. Martin Reservoir Elevation	2,560	2,560
13. Elevation of 22nd Street Reservoir	2,600	2,600
14. Booster Head--Well Field to 22nd Street Reservoir	150	150
15. Transmission Line Friction	4	6
Other Lines	40	40
16. Overall Pumping Head	392	444

a. Area XVIII consists of cropland in Sections 34 and 35 of T14S-R13E and Sections 3, 10 and 15 of T15S-R13E.

Table 18-B. Estimated Costs for the Diversion of Irrigation Water to Tucson at 5 mgd and at 10 mgd from Area XVIII,[a] 1967.

	Estimated Costs of Depreciable Capital		Average Annual Cost	
	5 mgd	10 mgd	5 mgd	10 mgd
Land				
1,748 acres @ $2,500/acre @ .035 interest			$152,950.00	$152,950.00
Wells and Pumping Units				
5 @ $50,000	$ 250,000.00			
8 @ $50,000		$ 400,000.00		
Collection Line	150,480.00	341,580.00		
Easements	1,161.00	1,161.00		
Reservoir and Booster Station	250,000.00	250,000.00		
Transmission Line				
3 miles - 30" pipeline @ $22/ft.	348,480.00			
3 miles - 36" pipeline @ $27/ft.		427,680.00		
Total Capital Cost	$1,000,121.00	$1,420,421.00		
Amortized Capital Cost				
(Capital cost x $.05437)[b]			54,377.00	77,228.00
Pumping Cost				
(Acre-feet x lift x $.01663)[c]			27,054.00	61,285.00
Delivery Cost				
(Amortized capital cost and pumping cost)			81,431.00	138,513.00
Total Cost				
(Delivery cost and interest on land)			234,381.00	291,463.00
Delivery Cost/Acre-Foot[d]			19.60	16.70
Total Cost/Acre-Foot			56.50	35.10

a. See footnote a, Table 18-A.

b. Capital amortized at three and one-half percent interest over 30 years.

c. $.01663 is variable pumping cost per acre-foot per foot of lift.

d. The acre-feet of water delivered per year would be 4,150 and 8,300 for the 5 and 10 mgd systems respectively.

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