Estimating wastewater demand by agricultural producers

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ESTIMATING WASTEWATER DEMAND BY AGRICULTURAL PRODUCERS

by

Teddy J. Goldammer

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This thesis has been approved on the date shown below:

Paul N. Wilson
Dr. Paul Wilson
Professor of Agricultural Economics

11/24/86
Date

ACKNOWLEDGEMENTS

To my wife Wanda.

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ABSTRACT

The demand for wastewater effluent by Avra Valley and the Cortaro-Marana Irrigation District was evaluated. This was accomplished by the use of linear programming techniques. Evaluating the potential demand for wastewater effluent is important to the development of a water market in the Tucson Active Management Area. In Avra Valley there was no quantity of wastewater effluent demanded because of high conveyance costs. The Cortaro-Marana Irrigation District the annual quantity of wastewater effluent demanded was 11,385 acre-feet based on wastewater effluent supply of 18,600 acre-feet. The quantity of wastewater effluent demanded could have been greater had the quantity supplied been sufficient for all months. Relaxing the supply constriant for wastewater effluent the potential demand was 24,776 acre-feet. The nutient constriants had the greatest influence on the demand for wastewater effluent. Relaxing the supply and nutrient constraints in favor of the blending ratios the quantity of wastewater effluent demanded was 34,480 acre-feet per year.

CHAPTER 1

INTRODUCTION

The purpose of this study is to evaluate the demand for wastewater effluent as a source of irrigation water by the Cortaro-Marana Irrigation District and Avra Valley farmers. Presently the farmers of the Cortaro-Marana Irrigation District are irrigating primarily with percolating groundwater, "underflow" from the Santa Cruz River, and a small allotment of wastewater effluent. The farmers in Avra Valley irrigate soley with percolating ground water. Evaluating the potential demand for wastewater effluent is important to the development of a water market in the Tucson Active Management Area (AMA). The poorer quality water, such as wastewater effluent and Central Arizona Project (CAP) water, could be set aside for users with lower quality needs, while reserving the higher quality groundwater for users with higher quality requirements. One step to the creation of a water market is the exchanging of the City's wastewater effluent for groundwater from the Cortaro-Marana Irrigation District and Avra Valley.

CORTARO-MARANA IRRIGATION DISTRICT

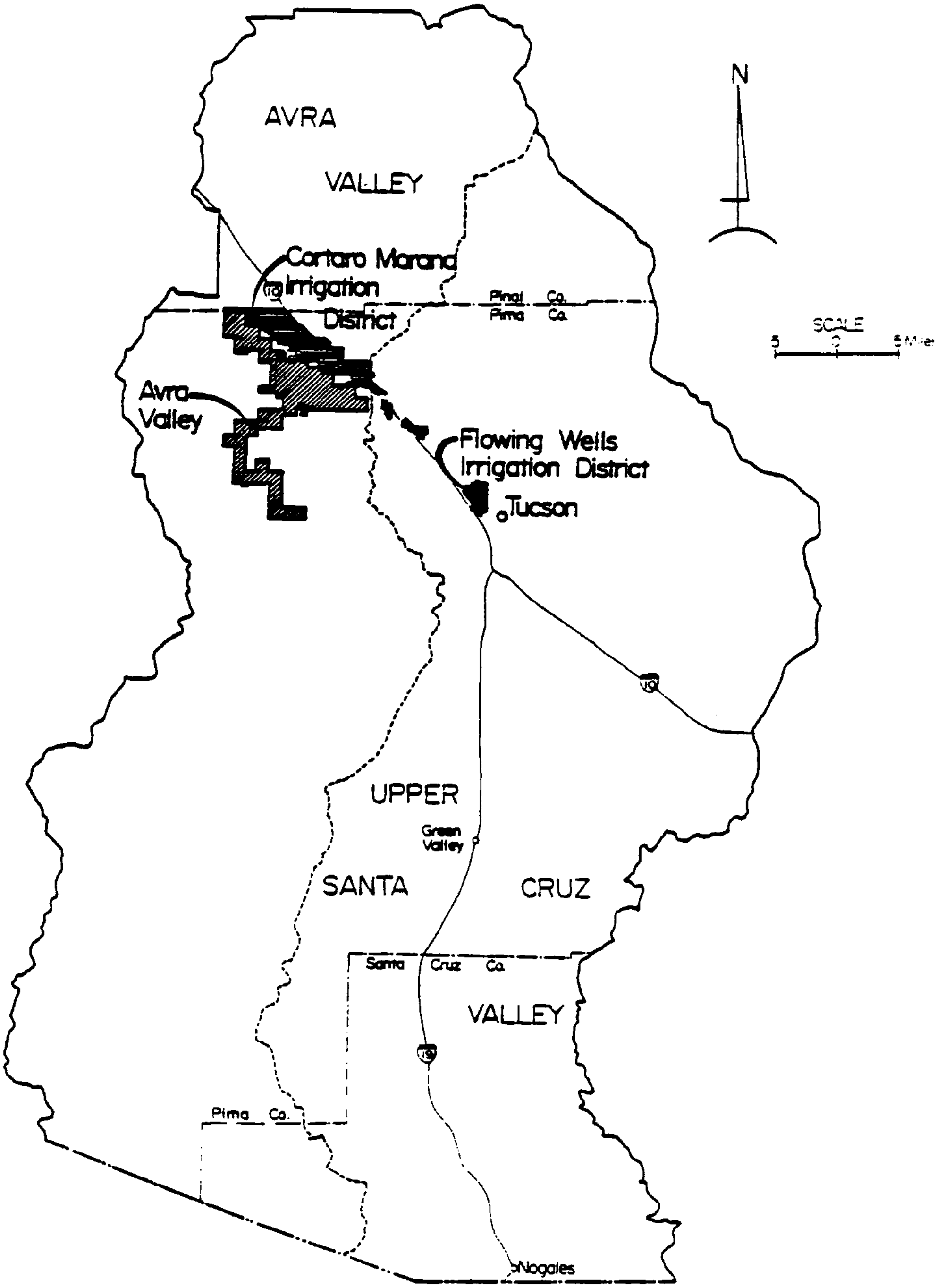
The Cortaro-Marana Irrigation District (CMID) is located 14 miles northwest of Tucson (Figure 1). The district located in the floodplains and major tributaries of the Santa Cruz consists of 14,700 acres of which approximately 12,000 acres are irrigated. The crops grown in the District include Upland and American-Pima cotton, spring and fall lettuce, alfalfa, milo, hay, wheat and pecans with the principle crop being Upland cotton.

The CMID's water supply is almost entirely from river subflow and percolating groundwater. The District, has appropriative water right to pump 29,100 acre-feet (AF) annually of Santa Cruz "underflow" in the Cortaro area. Approximately 45,000 AF of percolating groundwater and river subflow per year is pumped; 29,100 AF as mentioned from the Cortaro area and the remainder from percolating groundwater in the Marana area. As of 1982 the District has contracted with the Pima County government for 3,500 AF of wastewater effluent from the Ina Road treatment plant. This wastewater effluent is blended with the ground water and distributed to the extent possible for irrigation.

The pumping lift in the Cortaro area ranges from 75 to 125 feet. This is due in part to the natural recharge occuring in the Santa Cruz River bed during floodflows, and more significantly the recharge of sewage effluent occuring in the river down stream from the treatment plants. Consequently the quality of the groundwater in the Cortaro

Figure 1.

Cortaro-Marana Irrigation District and Avra Valley



area is strongly influenced by the treated wastewater effluent discharged into the Santa Cruz River. Unlike the Cortaro area, the qualtiy of groundwater in the Marana area is mostly influenced by irrigation water which leaches past the plant root zone and to a limited extent effluent and storm runoff. Approximately 40 percent of the CMID's water supply is provided by wells located in the Marana area (Bookman-Edmonston Engineering, 1978). Because of the greater pumping lift (approximately 350 feet), it is less economical to pump ground water from these wells than those of the Cortaro area. However, only 10 percent of the irrigated land is in the Cortaro area. The District cannot construct new wells in the Cortaro area since it overlies state designated critical ground water areas. The District can, however, reconstruct or replace existing wells. The CMID distribution system has open, concrete lined canals which deliver water with minimum losses.

Effluent from the Ina Road facility is now being delivered through a 24-inch pipeline capable of carrying 6000 gallons per minute (gpm) or about 9,680 AF per year (U.S. Army Corp of Engineers, 1979). However, the 24-inch pipeline is connected to a 18-inch District owned pipeline which when operated at full capacity is only capapble of carrying 3000 gpm or about 4,800 AF per year (Bookman-Edmonston Engineering, 1978). At this time, the 18-inch pipeline limits the District's ability to take wastewater effluent. The District has a regulating reservoir with a capacity of 35 AF at the lower end of the 18-inch pipeline through which effluent can be transported to the reservoir. The reservoir has the capacity of delivering 700 AF per month if the 18-inch pipeline were replaced with a 24-inch pipeline. However, because the effluent is delivered by gravity flow, and in part to the temporarily weak demand for irrigation water, the District is currently using about 3000 AF per year (Condit, 1985).

Estimates are that the CMID could use wastewater effluent up to 40 percent of the total water supply (Bookman-Edmonston Engineering, 1978). The crops considered in their study were cotton, milo, grain, lettuce, alfalfa, and pasture. The total annual amount of wastewater effluent could be intergrated directly into the irrigation system without constructing additional storage. Nitrogen needs of the principal crops would be met without causing excess nitrates to be leached into ground water.

AVRA VALLEY

Avra Valley is located west of the Tucson Mountains and south of the Cortaro-Marana Irrigation District (Figure 1). Unlike the farms in the CMID, farmers in Avra Valley Irrigation District (AVID) do not currently have an organized central irrigation district with a cooperatively owned water distribution system. Farms in the valley pump from their individual wells. Approximately 16,000 acres are irrigated, of which about 6,500 acres are on State land and 9,500 acres are privately owned. Crops grown in the valley are the same as those grown in the CMID.

Since 1968, the City of Tucson has been pumping ground water in Avra Valley for urban supply (Kelso and Jacobs, 1967). The City of Tucson began purchasing farmland, in order to claim the water rights, in 1971 from willing sellers due to a series of lawsuits initiated by Avra Valley farmers (Parker, 1986). The City of Tucson was restricted as to the amount of groundwater it could pump. The lawsuits were based on a law prohibiting the transfer of ground water from designated "critical areas". The City was permitted only to take the amount formerly consumed, pumpage minus return flow. Currently, the City is pumping only 18,000 AF of its 30,000 AF/year water right which has temporarily stabilized the valley's water table at 400 to 500 feet (Metzger, 1984). In 1985 Tucson one again began purchasing land to obtain the water rights. The City's pumping of ground water could conceivably increase in the near future.

There have been proposals for wastewater effluent delivery for agricultural reuse in Avra Valley, though these talks stalled upon adoption of "Gerneralized Effluent Reuse Policies" by the Mayor and Council (City of Tucson, 1982). Delivery to Avra Valley was given third priority behind the Tucson water service area and the upper Santa Cruz subbasin of the Tucson Active Management Area (TAMA). However, there still remains interest in Avra Valley reuse secondary effluent. Based on the 1982 Avra Valley proposal presented to the Water Resources Coordination Committe, Avra Valley could use 20,000 AF and possibly a good deal more (Avra Canal Company, 1982).

EFFLUENT REUSE IN THE TUCSON METROPOLITAN AREA

The City of Tucson began using untreated wastewater effluent for agricultural purposes in 1900. The City constructed a primary sewage plant in 1928 to improve the quality of the irrigation water for the City sewer farm. In 1952, the City discontinued its direct involvement and leased the farm to private farm managers. In the early 1960's, a pipeline was constructed to transport effluent, in excess of that required for the City sewer farm, to the Cortaro area. This practice was later discontinued by the purported pollution of ground water in the Cortaro Farms area. As this effluent received only primary treatment, its recharge after irrigation left a legacy of high nitrate concentrations in the ground water. The nitrate concentrations reached levels of about 100 milligrams per liter (mg/l) (Bookman-Edmonston Engineering, 1978). The Enviromental Protection Agency safe drinking water standard is 45 mg/l.

In 1975, the City of Tucson began treating sewage for irrigation at the Randolph golf courses. These golf courses irrigate with disinfected secondary effluent. In 1977, the Silverbell (city-owned) and Arthur Pack (county-owned) golf courses also began irrigating with disinfected secondary effluent. Since 1984 the La Paloma Golf Course (private) recieves tertiary treated effluent from the Roger Road Waste Treatment Plant. The Star Pass Golf Course will also receive tertiary treated effluent from the Roger Road Treatment Plant. State law requires the use of tertiary treated effluent because of the unrestricted access to these courses.

The major wastewater treatment facilities are the Roger Road Wastewater Treatment Plant and the Ina Road Water Pollution Control Faility. They have a design capacity of 30 million gallons per day (mgd) and 25 mgd average dry weather flow, respectively. The Roger Road Treatment Plant consists of screening, grit removal, primary sedimentation, biolfiltration, secondary clarification and chlorination, whereas the Ina Road Water Pollution Control Facility consists of screening, grit removal, primary and secondary clarification and chlorination. Over 95 percent of the municipally-treated wastewater in Eastern Pima County is handled by these two facilities.

In the "Annual Reports" for the fiscal year 1983-1984 for both Ina and Roger Road treatment facilities the total amount of wastewater effluent flow was 45,976 AF (Pima County Wastewater Management Department, 1984). The Roger Road facility wastewater effluent flow was 27,502 AF while the Ina facility wastewater effluent flow was 18,474 AF (Pima County Wastewater Mangagement Department, 1984). The Silverbell Golf course received 619 AF from the Roger Road facility with an additional 36 AF used by the Roger Road Treatment facility itself for grounds irrigation. The 26,847 AF of unused wastewater effluent was released into the Santa Cruz River. The Cortaro-Marana Irrigation District and Arthur Pack Golf Course received 4,102 and 424 AF respectively from the Ina Road facility of which 13,948 AF was released into the Santa Cruz River. La Paloma Golf Course which went into operation in the latter part of 1984 is expected to use about 700 AF annually of tertiary treated effluent form the Roger Road Facility.

Thus, only about 13 percent of the wastewater effluent is being directly reused. The remainder of the 40,795 AF per year of wastewater effluent is discharged into the Santa Cruz River. This poses no immediate threat of nitrate contamination of the ground water in the Cortaro area. The wastewater effluent which is discharged into the the Santa Cruz River undergoes denitrification by anaerobic activity and is covered and uncovered daily with wastewater effluent as the flow rate changes. This was not the case when primary effluent was used for irrigation.

Presently, the amount of wastewater effluent available within the City of Tucson is projected to increase from the present level of 53,000 AF to 144,000 AF by the year 2030 (CH_2M-Hill/Rubel and Hager, 1983). The Southern Arizona Water Rights Act mandates the City of Tucson to allocate 28,200 AF of effluent per year (plus evaporative losses which raise the total approximately 30,600 AF per year) to the Tohono O'Odham Indian Tribe beginning in 1992. Table 1 shows the projected increase in wastewater effluent along with the yearly Tohono O'Odham Indian Tribe allottement.

The City of Tucson Water has been noncommital about its plans for effluent reuse. In 1982, the Mayor and Council released "Generalized Effluent Reuse Policies" preferring Tucson Water service area users over outsiders (City of Tucson, 1982). In 1983, the City began planning a $44 million project to distribute up to 18,500 AF per year serving landscape irrigation projects in the Tucson

Table 1.

Projected Net Wastewater Effluent in Acre-Feet

Year	Projected Effluent	Tohono O'Odham Settlement	Cortaro-Marana Allotement	Potential Demand of Landscape Irrigation	Net Effluent
1985	53,000		3,500	1,700	47,800
1990	61,000		3,500	23,000	34,500
2000	79,000	30,600	3,500	28,000	16,900
2010	101,000	30,600	3,500	33,000	33,900
2015	111,000	30,600	3,500	35,500	41,400
2020	122,000	30,600	3,500	38,000	49,900
2025	133,000	30,600	3,500	40,500	58,400
2030	144,000	30,600	3,500	43,000	66,900

Metropolitan Area, particularly golf courses (Metzger, 1984). No date has been set for completion of the project. The total current estimated demand of 18,500 AF per year represents the estimated total amount of ground water presently being used on the identified sites, including approximately 1700 AF of effluent presently used on three golf courses--La Paloma, Silverbell, and Arthur Pack. Table 1 lists the potential demand for wastewater effluent based on total turf acreage projections (CH_2M-Hill/Rubel and Hager, 1983). However, it is now 1986 and only 1700 AF are presently used for landscape projects, which is far short of the potential use of 18,500 AF by 1985. This leaves open the possibility of a sizeable block of uncommited wastewater effluent.

Turf irrigation is emphasized for future effluent reuse because it reduces considerably potential groundwater contamination. The wide distribution of wastewater effluent spreads recharge and the large nitrogen uptake rates involved greatly reduces the nitrogen of percolating ground water. However, if contamination of the aquifer is a possibility then agricultural irrigation should be emphasized since it is located in a down gradient from areas of urban supply.

A more compelling reason for effluent reuse in agriculture is the enactment of the Ground Water Management

Act (the Ground water Code) in 1980. Under the Ground water Code, the Arizona Department of Water Resources must include a conservation program for municipal uses. The municipal conservation program must "require reasonable reductions in per capita use and such other conservation measures as may be appropriate for individual users" (Arizona Department of Water Resources, 1984). The municipal conservation program assigned providers of water per capita conservation requirements. However, when calculating the per capita rate in gallons per person per day (GPDC), ground water diverted or received and surface water diverted or received were considered, but not reused effluent. Therefore, the City of Tucson can reduce per capita consumption by substituting wastewater effluent for use on areas such as turf or landscape areas.

In 1985, all but 5,878 AF of wastewater effluent was being discharged into the Santa Cruz River. The portion of wastewater effluent not being discharged was used by the three golf courses, the Roger Road Plant, and the Cortaro-Marana Irrigation District. Although there are plans for increased use of effluent, a large proportion of wastewater effluent will continue to be released in ever increasing amounts into the the Santa Cruz River. There are plans for a recharge system of wastewater effluent but at the time of this study are still in the developmental phase. Table 1 shows the net balance of wastewater effluent.

Under the Papago Resettlement Act the Tohono O'Odham Indian Tribe are entitled to 30,600 AF per year of the effluent. The Tohono O'Odham Indian Tribe has shown no interest in the use of the effluent. Even if they were interested they have yet to develop plans to expand their agriculture to sustain the use of effluent. Consequently, it can be anticipated their allotment may be leased either to the farmers or the City of Tucson.

The quantities of municipal wastewater effluent produced by sewage treatment plants in Arizona are reported in Table 2. Approximately 240 million gallons per day (739 AF/day or 269,735 AF/year) of municipal wastewater effluent were produced in Arizona in 1985-86. Estimates are based on an informal telephone survey. The cities surveyed were reusing on the average 50 percent of their wastewater effluent for industry or agriculture. The City of Tucson is currently reusing only 13 percent.

OBJECTIVES

The overall objective of this study is to evaluate the demand for wastewater effluent as a source of irrigation water available to the farmers of the Cortaro-Marana Irrigation District and Avra Valley. A review of the literature is necessary to better understand the issues

Table 2.

Average Wastewater Effluent Discharge Rates from Municipal Water Treatment Facilities in Arizona in 1985-86.
(million gallons per day)

Locality	Average Wastewater Effluent Discharge	Percent Used	Comments
Avondale	0.75	0	
Benson	0.3	100	Farming
Bisbee	0.08	0	Phelps Dodge plans to use up to 100,000 gpd for copper tailings
Buckeye	0.085	100	Discharged into canal which is used by farmers
Casa Grande	2.0	85	Farming and golf course
Chandler			
Octillo Plant	2.2	100	Octillo Project
Lone Butte Ranch	3.3	100	Farming
Douglas	1.3	0	
Flagstaff	2.75	50	Golf course
Florence	0.9	50	Farming
Gila Bend	0.0095	100	Farming
Globe	1.0	90	Farming
Holbrook	1.0	75	Golf course
Kingman	0.7	0	Plans to irrigate golf course
Mesa	2.0	0	
Miami	0.11	0	Plans to irrigate golf course
Nogales	8.5	0	Plans to use for farming
Page	1.0	60	Golf course
Parker	0.5	15	Irrigate facility
Payson	0.75	70	Golf course
Phoenix			
23rd Ave.	15.0	0	See footnote 1
91st St.	135.0	85	See footnote 1 Eventually Palo Verde Power Station plans to use 90 mgpd

Table 2 continued.

Prescott	2.6	25	Golf course
Safford	0.005	100	Golf course
Sierra Vista	1.5	100	Farming
Snow Flake	0.175	100	Farming
Somerton	0.1	100	Discharge into canal
Superior	0.5	15	School grounds
Tucson			
Ina Road	16.5	25	Farming and golf course
Roger Road	24.6	5	Golf course
Tolleson	7.1	100	Palo Verde Power Station
Wickenburg	0.18	0	
Wilcox	0.4	?	Golf course
Williams	0.45	0	
Winslow	0.7	90	Golf course
Yuma	7.0	0	Plans to use for park
Total daily discharge	240.8		

---

[1] As of June, 1986 the City of Phoenix has contracted to supply the following amounts of wastewater effluent:

7,490 AF/year Arizona Game and Fish Department
1,230 AF/year Soil Conservation Service
30,870 AF/year Buckeye Irrigation District
140,000 AF/Year Palo Verde Nuclear Power Station

pertaining to the reuse of wastewater effluent. Issues of interest in the literature review are: (1) water treatment, (2) effluent quality, (3) irrigation water quality criteria, (4) fate of wastewater constituents in ground water and soil, (5) effect on crop production, (6) economic considerations, (7) institutional factors, and (8) human health effects. The basic concepts of production functions and economic optima, as related to the demand for ground water when given a substitute are dealt with. Detailed historical crop acreage are obtained from the local Agricultural Stabilization and Conservation Service (ASCS) office and from individual farmers. Department of Water Resources will supply grandfathered irrigation acreage. Crop production costs and returns are obtained from the University of Arizona and the Crop and Livestock Reporting Service. Next the supply function of the effluent delivery system is estimated to the farmers in the Marana-Cortaro Irrigation District and Avra Valley. The cost of of wasterwater effluent delivery systems are obtained from Bookman-Edmonston Engineering, Inc. and from the U.S. Army Corp of Engineers. Investment costs, as well as operation and maintenance costs, are estimated in the plan. A linear programming model is used to generate derived demand functions, all other conditions held constant, for wastewater effluent given the various production inputs.

Monthly and annual farm level demand functions for wastewater effluent are estimated by using different ground water and wastewater effluent cost and availability assumptions. The intersection of the supply function and farm level demand functions are discussed as far as the implications for Tucson water policies.

CHAPTER TWO

A REVIEW OF THE LITERATURE

Wastewater Treatment

Wastewater is water-carried wastes from residences, business buildings, institutions, and industrial establishments. The composition of which is influenced by the make-up of these inputs. The levels of treatment of wastewater are referred to as primary, or secondary and sometimes as tertiary treatment. Primary treatment consists of mechanical and physical removal of suspended solids. This step involves sedimentation with skimming, grit removal, and some form of sludge disposal. Primary treatment can be expected to remove approximately 60 percent of the total suspended solids and from 25 to 50 percent of the biochemical oxygen demand (BOD) (Sopper, 1979). The term "suspended solids" generally describes the quantity of organic and inorganic particles that are not dissolved. BOD is the biochemical oxygen demand of aerobic micro-organisms to meet their metabolic needs. Heavy metals such as chromium, copper, iron, and lead are reduced from 40 to 50 percent (Asano, Smith, Techobanoglous, 1984). Nitrogen and phosphorous are reduced by 5 to 10 percent.

Secondary treatment implies the presence of biological oxidation in addition to primary treatment. Biological oxidation is usually accomplished by trickling filters, oxidation ponds, in some form of activated sludge process or, a combination of these processes. Secondary treatment removes from 80 to 95 percent of the suspended solids and BOD (Sopper, 1979). Sewage effluent treated by secondary means is relatively colorless and usually clear. Tertiary treatment involves filtration, sorption, or demineralization.

Currently, both Roger Road and Ina Road treatment facilities are providing a secondary level of wastewater treatment plus disinfection. Treatment at the Roger Road plant consists of screening, grit removal, primary sedimentation, biofiltration, secondary clarification and chlorination. Whereas the Ina Road treatment process consists of screening, grit removal, primary clarification, pure oxygen activated sludge, secondary clarification and clorination.

EFFLUENT QUALITY

Knowledge of the characteristics of effluent is essential for the proper evaluation of wastewater reuse for agricultural purposes. The characteristics of wastewaters may be classified as physical, chemical, and biological.

Of the physical chacteristics suspended solids content is the most important. The solids include the quantity of organic and inorganic particles that are not dissolved. The suspended solids content is important because of their tendency to clog soil pores.

The chemical properties of wastewater can be divided into two categories: organic matter and inorganic matter. The organic matter is principally composed of proteins, carbohydrates, fats and oils. Other organic compounds present in small amounts are phenols, surfactants, and agricultural pesticides. More often these substances have no short-term effect on the soil of vegetation; though they could potentially effect ground water quality (Pound and Crites, 1973). Biochemical oxygen demand (BOD) is the most widely used paramenter in describing organic pollution.

The inorganic compounds provide nutrients, such as nitrogen, phosphorous, and potassium; however, these nutrients, among other elements, can be toxic to plants at certain concentrations. Examples of elements toxic to plants include boron, lead, nickel, and zinc. Total dissolved solids (TDS) is generally the most important standard for measuring chemical characteristics of effluent. Total dissolved solids consists primarily of sodium, potassium, calcium, and magnesium cations and

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The biological properties of wastewater consist of microorganisms such as bacteria, the predominant microorganism, and viruses parasites. The most significant of these are shown in Appendix A (Gerba, 1983). One of the most predominant of pathogens is Samonella which causes enteric fevers, septicemias, and acute gastroenteritis (Crook, 1984). The most important viruses are the enteroviruses (polio, echo, and coxsackie), abenoviruses, and hepatitis A (Crook, 1984). Viral contamination of the enviroment is of no minor concern since: 1) there is a scarcity of information concerning the occurence and significance of viruses, 2) studies show some viruses are not as efficiently removed by conventional treatment processes as otherwise thought, 3) a low infectious dose is capable of causing a disease and 4) the present system to verify the presence of microorganisms is not a valid measurement for indicating the presence of these viruses (Melnick et al., 1978). The most serious of parasites is protozoa Entamoeba histolytica, which is responsible for amoebic dysentary and amoebic hypetitis. A widely used standard to verify the presence of microorganisms in wastewater is to test for total or fecal coliform.

Primary treatment has only limited success in the removal of biological species present in the wastewater.

Secondary treatment reduces the quantities of biological organisms but does not eliminate them. Tertiary treatment is effective in removing biological organisms but does not eliminate them. From the standpoint of pathogen destruction disenfection is the most important treatment process. The disinfection process normally involves the injection of a chlorine solution. The effectiveness of disinfection is measured in terms of the concentration of indicator organisms, either total coliform or fecal coliform bacteria, remaining in the effluent after treatment. The number of organisms remaining are expressed in terms of the most probable number of organisms per 100 ml of water (MPN/100 ml) (Asano, Smith, and Tchobanoglous, 1984).

IRRIGATION WATER QUALITY CRITERIA

The quality of treated wastewater effluent depends on the nature of the wastes added by either the residential or commercial community. In order to evaluate both the short and long-term effects on soils and plants concerning impurities in wastewater effluent, consideration must be given to the quality of irrigation water.

One of the most important parameters in determing the suitability for irrigation water is salinity. Plant damage is tied closely to an increase in salinity. The problem arises from the total salt content and to the one or more types of salt found in irrigation water. The rate of accumulation of the quantity of salt applied in the irrigation water is in excess of the rate in which salts are removed by leaching; consequently salts accumulate. As the salinity concentration increases it becomes necessary to irrigate in excess of plant water requirements so that plants exposed maintain intracellular osmotic potentials lower than that of the media. Otherwise they would be subject to osmotic desication because water would move osmotically from the cells into the substrate. Total dissolved solids (TDS) and electrical conductivity (EC) are two measures of salinity. TDS can be approximated by evaporating a known weight of water sample to dryness and weighing the salt remaining. Electrical conductivity is commonly used to check the salt content of soils. Multiplying EC in mmhos/cm by 640 gives TDS in ppm.

Guidelines for evaluating irrigation water quality are given in Table 3 (Westcot and Ayers, 1984). These guidelines assume the leaching fraction is 0.15 and that the subsurface drainage is adequate. The leaching fraction is the minimum amount of water that must percolate below the root zone to permit salt concentration within an acceptable range. In addition the divisions of "Potential Restrictions in Use" are somewhat arbitrary. When the

Table 3.

Guidelines For Evaluating Irrigation Water Quality

Potential irrigation problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Salinity (affects crop water availability)				
EC_w[b]	dS/m or mmho/cm	<0.7	0.7 - 3.0	>3.0
TDS	mg/L	<450	450 - 2000	>2000
Permeability (affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)[c,d]				
SAR = 0 - 3		and EC_w = >0.7	0.7 - 0.2	<0.2
= 3 - 6		= >1.2	1.2 - 0.3	<0.3
= 6 - 12		= >1.9	1.9 - 0.5	<0.5
= 12 - 20		= >2.9	2.9 - 1.3	<1.3
= 20 - 40		= >5.0	5.0 - 2.9	<2.9
Specific ion toxicity (affects sensitive crops)				
Sodium (Na)[e,f]				
surface irrigation	SAR	<3	3 - 9	>9
sprinkler irrigation	mg/L	<70	>70	
Chloride (Cl)[e,f]				
surface irrigation	mg/L	<140	140 - 350	>350
sprinkler irrigation	mg/L	<100	>100	
Boron (B)	mg/L	<0.7	0.7 - 3.0	>3.0
Trace elements (see Table 3-5)				
Miscellaneous effects (affects susceptible crops)				
Nitrogen (Total-N)[g]	mg/L	<5	5 - 30	>30
Bicarbonate (HCO_3) (overhead sprinkling only)	mg/L	<90	90 - 500	>500
pH		Normal range 6.5 - 8.4		
Residual chlorine (overhead sprinkling only)	mg/L	<1.0	1.0 - 5.0	>5.0

Source: Westcot and Ayers, page 3-11.

guidelines indicate no restrictions in use, it is assumed that full production capability can be achieved. However, when the guidelines indicate "severe" restrictions, the possibility of experiencing soil and plant problems exist. Refer to Appendix B for TDS and EC levels of secondary treated effluent for both Ina and Roger Road treatment plants (Pima County Wastewater Management Department, 1984-1985).

A major benefit of wastewater effluent is its low concentration of soluble salts compared to ground water. For example irrigating wastewater effluent in Buckeye, Arizona has proven to be beneficial (Tucker, 1981). The ground water in Buckeye Irrigation District is marginally suited for irrigation, with TDS ratings of 3,000 to 3,500 ppm. Also, the area's alkali soil has aggravated the situation. Currently, 60 percent of the District's total water needs are satisfied with secondary treated effluent. The remaining 40 percent is ground water augmented with surface flow from the Salt River Project. There is less benefit for the farmers in Avra Valley and the Cortaro-Marana Irrigation District since the soluble salts in the ground water are low (approximetely 500 ppm).

Not only can salinity cause growth reductions but so too can individual ions. Ions of both major and trace elements occur in irrigation water. Trace elements normally occur in irrigation waters less than a few mg/l (Westcot and Ayers, 1984). Though they may be essential for plant growth at very low concentrations they do have the potential to become toxic as the concentration increases. The values in Appendix C give the suggested maximum concentrations of trace elements in irrigation waters that can be used for long-term irrigation (Westcot and Ayers, 1984). Note, none of these elements cause toxicities at the levels given, nor does it mean if the suggested limit is exceeded that phototoxicity will occur. What it does mean if there are repeated applications in excess of the level suggested the concentration of trace elements would eventually increase in the soil. This accumulation would take place regardless of the management used. Thus the long-term buildup in the soil could result in human and animal health hazards or cause phytotoxicity to plants. These suggested concentrations should be compared to the levels of major and trace elements contained in secondary treated effluent for both Ina and Roger Road treatment plants (Appendix B). This comparison reveals the the suitability of Tucson effluent for agricultural irrigation.

Individual ions can also cause growth reductions. Ions of both major and trace elements occur in irrigation water. Specific ion toxicity occurs when the ion is accumulated in the plant at levels that result in the damage or reduced yields. Of the specific ions boron tends to be the most prevalent (Westcot and Ayers, 1984). Household detergents or discharges from industrial plants are ususally the source of boron. Other specific ions are sodium and chloride whose levels increase, especially where water softners are used. If the ratio of sodium to other cations, such as calcium and magnesium, becomes too high, sodium tends to replace the calcium and magnesium ions on the exchage sites of the clay particles. Consequently, the predominace of sodium ions adversely effects soil permeability. The sodium absorption ratio (SAR) determines the sodium hazard. The permeability guidelines in Table 6 take into consideration the potential effect of both salinity and sodium on soil permeability. At a given SAR the infiltration rate increases as salinity increases or decreases as salinity decreases. A high concentration of bicarbonate and carbonate ions can result in precipitation of calcium carbonates, thereby freeing more exchange sites for sodium. The residual sodium carbonate ratio determines the carbonate and bicarbonate hazards. Table 3 gives the guidelines for specific ion toxicity.

The nutrients in treated municipal wastewaters provide fertilizer benefits to the irrigator. There are cases, however, where these nutrients can be in excess of plant needs and cause delayed and uneven maturity, reduced quality, or excessive vegetative growth. The nitrogen of treated wastewater is in the form of organic nitrogen, ammonium nitrogen, nitrate nitrogen, and nitrite nitrogen. The first three are readily available forms. The principal form of nitrogen is ammonium which commonly falls in the concentration range of 5 to 40 mg/l (Broadbent and Reisenauer, 1984). The organic fraction is readily convertible to ammonium through the action of microorganisms. The organic component usually represents less than half of the total nitrogen present. Nitrate concentrations may range from 0 to more than 30 mg/l. No concentration level was given for nitrite. Similarly, treated wastewater is high in phosphate; the main nutrient required by legume forage crops, such as alfalfa. The phosphate is mostly in organic form and because of this is more readily available. Since phosphate is in a more readily available form less is required than with an inorganic fertilizer (Tucker, 1986).

The relative quality of secondary treated municipal wasterwater produced by sewage treatment plants in Arizona is 30 ppm for nitrogen, 8.0 ppm for phosphate (P_2O_5), and 12.0 ppm for potassium oxide (K_2O) (Day and Weber, 1981). Note that 1 mg/l is equal to 1 ppm. For the levels of nitrogen, phosphate, and potassium oxide produced by the

Ina and Roger Road treatment plants refer to Appendix B.

Fate of Wastewater Constituents in Ground Water and Soil: Nitrogen, Trace Elements, Trace Organics and Pathogens

Nitrogen in wastewater used for crop irrigation is subject to leaching if not taken up by the plants, immobilized by microorganisms, or denitrified. Nitrate contamination of ground water is of primary concern particulary if the risk of methemoglobinemia exists. Methemoglobinemia or "blue baby disease" is the reduction of nitrate to nitrite in the digestive tract of infants. Nitrite reduces the capacity of homoglobin to carry oxygen. Methemoglobinemia is much more common with animals than in humans.

Normally, the concentration of trace elements in wastewater is not high enough to cause immediate concern, unless the level of industrial waste inputs is consistently high. Even with low concentrations, continued use of wastewater could substantially elevate the level of trace elements in the soil. Therefore, the build-up of trace elements could lead to (1) toxicity of plants, (2) absorption by plants of trace elements which are considered harmful to the health of humans and animals if consumed, and (3) contamination of the ground water.

The concentration of trace organics, even though reported at toxicologically low levels, has caused great concern because of the human health hazard. Trace organics can either occur naturally or as synthetic organic chemicals. Although most wastewater treatment plants are not designed for trace-organic removal, the plants are very effective, especially during biological treatment, in reducing the number and concentrations of trace organics. For this reason, the enviromental risk associated with using treated wastewater for irrigation is not expected to be very significant (Chang and Page, 1984).

Another concern in using wastewater effluent for agricultural irrigation is the potential health hazard resulting from exposure to pathogenic organisms such as bacteria and viruses. Generally, the survival rates of bacteria in the soil have been reported to vary from a few months to several years (Frankenberger, 1984). In most instances survival of bacterial pathogens in the soil is limitied to less than two to three months in temperate climates (Gerba, Wallis, and Melnick, 1975). But repeated applications could result in their accumulation. Cold temperatures favor the survival of bacteria while extreme acidic or alkaline conditions adversley affect their development. The presence of organic matter greatly enhances their development. Removal of bacteria occurs largely at the soil surface by straining as well as sedimentation and adsorption. Movement of bacteria in the soil can be the result of rodents, insects, birds, windblown soil, overland runoff, and leaching through the soil profile to ground water. However, evidence suggests that dissemination by bacteria by these means is of no major concern in crop production (Frankenberger, 1984). The migration of wastewater bacteria could be a potential problem in livestock grazing areas or feedlots.

Viruses, too, can survive in the soil for a year or more. Virus inactivation is affected by dispersion of viral aggregate clumps, pH, virucidal chemical, species, temperature, and the presence of suspended solids (Vilker, 1981). Low pH favors virus adsorption, while high pH favors virus inactivation. Virus inactivation increases with an increase in the presence of salts, though this effect can be partially suppressed by the presence of calcium and magnesium cations (Frankenberger, 1984). Virus inactivation increases with increasing temperature with most viruses surviving only a few days at temperature of 35 degrees centigrade or more (Lance, 1981). Suspended solids hinder viral inactivation in wastewater because soluble organic matter competes with viruses for adsorption sites on soil colloids. Adsorption interations are mainly responsible for the disappearence of infectious viruses from percolating wastewater. However, those viruses adsorbed are just as infectious. Evidence indicates adsorption of viruses by soil particles does not result in permanent immobilization and changes in water quality can result in deadsorption. Once a virus has been inactivated, there is no potential for infection. Low flow rates favor viral retention in the soil, thus soil texture is an important characteristic in limiting permeability. Clay and organic matter enhance viral adsorption because of their greater number of active sites for adsorption. Intermittent wetting and drying of the soil promotes the growth of aerobic bacteria thereby enhancing viral inactivation. Viral survival is only prolonged if viruses penetrate deep into the soil where anerobic conditions are prevalent. Contamination of groundwater in Arizona by viruses is remote since all agricultural soils are effective in removing the viruses from the treated wastewater (Lance, 1981).

Effect on Crop Production

The general consensus of agronomists is that treated wastewater can provide a source of irrigation water and plant nutrients for commerical crop production. Experiments have been conducted in Cortaro, Arizona to compare the yield and quality of grain and barley, oats, and wheat irrigated with secondary effluent (Day, Tucker, and Vavich, 1962). Replications with no additional fertilizer, different amounts of commercial fertilizer and ground water were tested. Those crops irrigated with sewage effluent produced more grain than those that received ground water and equivalent amounts of nitrogen, phosphorous, and potassium. In general, as the amount of nitrogen was increased in the ground water, the average yield also increased.

However, the authors found that crops irrigated with sewage effluent produced very tall, fast growing plants that tended to lodge at maturity. Barley was more sensitive to the detrimental effects of sewage effluent than either wheat of oats. Since then new variaties of grain have been introduced. The Buckeye Irrigation District irrigates with straight secondarily treated effluent in the winter months and experiences no problems with lodging (Jones, 1986). The average percentage of digestible laboratory nutrients (D.N.L.) for barley, oats, and wheat grown with sewage effluent was similar to the D.L.N. values obtained when crops were grown with ground water. Additional studies determined grain protein contents were similar to those crops grown on treated wastewater as those obtained when produced with ground water with N, P, and K (Day and Kirkpatrick, 1973). Ground water, with applications of N, P, and K, produced significantly higher dry matter yields than obtained from treated wastewater.

Later experiments were conducted to study the effect of irrigating wheat (Triticum aestivum L.) in southern Arizona with a mixture of ground water and treated wastewater and with ground water alone (Day, McFayden, Tucker, and Cluff, 1979). Evidence clearly indicated wheat grown with a mixture of ground water plus treated wastewater produced more vegetative growth than did wheat produced with only ground water. The increased vegetative growth was believed to be responsible for increased lodging. Although higher grain yields were obtained when grown with a mixture of ground water and treated wastewater, the lower grain volume-weight of wheat produced indicated that wastewater may lower the quality of wheat grain below the quality of wheat grain produced with ground water alone. Consequently, the grower may expect to obtain higher yields of pasture forage, green chopped feed, and hay for livestock feed when treated wastewater is blended with ground water.

The influence of treated wastewater on the growth and yield of alfalfa (Medicago sativa L.) was studied in Buckeye, Arizona (Day, Swingle, Tucker, and Cluff, 1982). Alfalfa was irrigated with ground water and a 50:50 mixture of treated municipal wastewater from Phoenix and ground water from the Buckeye Irrigation District. Plants irrigated solely with ground water were supplemented with the recommended fertilizer rate for Arizona. Plants grown with the mixture of treated wastewater and ground water were taller and produced more dry matter. The data indicated higher yields of similar quality can be expected when treated wastewater is used as a portion of the irrigation water. This was due to the lower concentration of soluble salts and higher concentration of N and P in the treated wastewater. In Sierra Vista, Arizona the sewage treatment plant irrigates alfalfa with 100 percent secondarily treated effluent. The alfalfa is sold to farmers at market value. The alfalfa yield is about the same as alfalfa grown solely with ground water (White, 1986). Nothing was mentioned about the quality.

A similar experiment was conducted in Buckeye, Arizona with cotton (Day and McFayden, 1984). Cotton grown with a mixture of ground water and treated wastewater produced more seed cotton than plants irrigated with only ground water. The seed weight was also higher with the effluent mix. The lower salt content of the mixture may have been a contributing factor. The lint weight was the same for cotton produced using the two irrigation water sources. Cotton grown on a mixture of ground water and wastewater was taller. The taller plants have more vegetative growth which is not advantageous for cotton production because lodging makes defoliation more difficult. Also, lodging increases the level of plant material in the cotton lint during harvesting, thereby lowering the fiber quality.

Economic Considerations

The utilization of wastewater effluent is a promising source of irrigation water as the demand for ground water increases and as the cost of developing new water supplies increases. But before wastewater reuse can be widely accepted as a partial replacement for ground water in agriculture, it must be shown to be economically profitable to the end user, the grower.

The costs of treating wastewater in acordance with the minimum federal standards can be considered as a sunk cost--costs that must be incurred regardless of whether or not the water is reused. Any additional costs incurred in treating wastewater for a higher level of reuse can be viewed as the marginal costs of wastewater treament. For example, the cost of treating wastewater for park irrigation is approximately $0.55 per 1,000 gallons while the cost of disinfected secondary treated effluent, which meets the minimum federal standards, is currently about $0.32 per 1,000 gallons (Bruvold, Olson, and Rigby, 1981). Therefore, the marginal cost of wastewater treated to the level appropriate for park irrigation is $0.23 per 1,000 gallons. However, for orchard irrigation, for which disinfected secondary effluent is sufficient, the marginal cost of treatment would be zero.

Although a great deal of research has been done concerning the uilization of treated wastewater, very little has been done pertaining to its economic value as a commodity. Victurine, Lacewell, and Goodwin (1984) evaluated the benefits derived by farmers in using wastewater effluent on the Southern High Plains of Texas. The crops included in the linear programming (L.P.) model were: (1) rainfed and irrigated cotton, (2) irrigated soybeans, (3) irrigated corn, (4) rainfed and irrigated sunflowers, (5) rainfed and irrigated grain sorghum and (6) irrigated wheat. Only 320 and 640 acre farms were considered. Scenarios were established for the evaluation of the net benefits accruing to farmers. The scenarios were based on the amount of effluent available, availability of supplemental irrigation, the two farm sizes, and pond storage capacity. Two L.P. models were employed, one using water provided by effluent only, the other using a combination of effluent and ground water.

This Texas study found that for the 320 acre farm the dryland scenario had the lowest returns above variable costs. The highest net return for a 320 acre farm was the scenario where effluent was used without supplemental irrigation. For the 640 acre farm net returns were lowest for the dryland farm and highest when wastewater effluent and ground water were combined. The benfits not taken into account were the savings in fertilizer and pumping costs. In addition, the authors assumed that the effluent was delivered to the growers at no charge.

A study by Cabbiness and Badger (1980) estimated the economic value of nutrients in municipal sewage effluent used for irrigation. They estimated the equivalent fertilizer values per acre-inch of effluent for the years 1976 through 1980. These values are given in Table 4 (Cabbiness and Badger, 1980). Values for nitrogen are presented in two forms, as anhydrous ammonia and as ammonium nitrate. The total value of N-P-K fertilizer depends on the form of nitrogen fertilizer preferred.

Crops, acreages, effluent applications, and the value of resulting equivalent fertilizer applications are presented in Table 5 for the Cabbiness and Badger study. The equivalent fertilizer values of the effluent depend on the amount of irrigation water received by each crop and the form of nitrogen. The estimates given are the potential value and not necessarily the actual value of the nutrients. The study did not take into consideration another form of nitrogen--organic nitrogen. Thus, the

Table 4.

Value of Nutrients Per Acre-Inch of Effluent[1]

Crop Year beginning Oct. 1	N as NH_3	N as NH_4NO_3	P as 46% P_2O_5	K as 60% K_2O	Total N-P-K (N as NH_3)	Total N-P-K (N as NH_4NO_3)
1975-76	$0.23	$0.34	$0.43	$0.34	$1.00	$1.11
1976-77	0.20	0.36	0.43	0.34	0.97	1.13
1977-78	0.20	0.36	0.43	0.34	0.97	1.13
1978-79	0.22	0.36	0.57	0.42	1.21	1.35
1979-80	0.27	0.43	0.73	0.46	1.46	1.62

1-Based on average prices paid by Oklahoma farmers for each fertilizer, 1976-1980 (Source: Agricultural Prices 1976-1980, U.S.D.A.).

Source: Cabbiness and Badger, page 25, 1984.

Table 5.

Crops, Effluent Applications, and Value of Nutrients Per Acre

Crop Year beginning Oct. 1	Crop	Acres	Effluent Applied Million Gallons	Effluent Applied Acre-Inches per Acre	Total N-P-K Applied per Acre N as NH_3	Total N-P-K Applied per Acre N as NH_4NO_3
1975-76	Alfalfa, Field 1	65	12.4	7.0	$7.00	$7.80
	Alflafa, Field 2	60	1.8	1.1	1.10	1.20
	Bermuda	120	7.2	2.2	2.20	2.40
	Rye, Field 1	60	11.0	6.7	6.70	7.40
	Rye, Field 2	40	1.2	1.1	1.10	1.20
	Total	345	33.6			
1976-77	Alfalfa	70	15.8	8.3	8.00	9.40
	Bermuda	130	28.5	8.1	7.90	9.20
	Total	200	44.3			
1977-78	Alfalfa	70	27.0	14.0	14.00	16.00
	Bermuda	120	19.0	5.8	5.60	6.60
	Rye	110	19.5	6.5	6.30	7.30
	Total	300	65.5			
1978-79	Alfalfa, Field 1	75	31.0	15.0	18.00	20.00
	Alfalfa, Field 2	60	6.7	4.1	5.00	5.50
	Bermuda, Field 1	30	7.7	9.4	11.00	13.00
	Bermuda, Field 2	90	17.1	7.0	8.50	9.40
	Sudan	40	1.5	1.4	1.70	1.90
	Total	295	64.0			

Table 5 continued.

1979-80	Alfalfa	65	32.0	18.0	26.00	29.00
	Bermuda, Field 1	30	22.0	27.0	39.00	44.00
	Bermuda, Field 2	25	2.1	3.1	4.5	5.00
	Bermuda, Field 3	25	4.2	6.2	9.0	10.00
	Sudan	50	4.2	3.1	4.50	5.00
	Total	195	64.5			

Source: Cabbiness and Badger, page 28, 1980.

potentional value is actually lower than it ought to be. Soil analysis indicated nitrogen was needed but the levels of phosphorous and potassium were adequate. Therefore, P and K would have no real value in this situation. No value was placed on the micronutirents in the effluent nor was there a value placed on the water itself.

Recently, Moore, Olson, and Marino (1984) conducted a study focusing on the farmer's view concerning the financial and economic feasibility of using reclaimed wastewater for irrigation. The study site was Davis, California, a city of approximately 35,000 people with no major water-using industry. Seasonal variation in wastewater flows varied from about 2.45 million gallons per day (MGD) in August to 3.05 MGD in June. As in other studies, Moore, Olson, and Marino used a linear programming model in the analysis. The LP model maximizes net income by choosing the optimal cropping pattern given specified resource constraints. The price, yield, and cost information for this study is included in Table 6. The options of either irrigating with ground water or reclaimed wastewater are included. If the crop's nitrogen need is not met from wastewater, nitrogen can be purchased. Several cases are evaluated for the different conditions that may occur. The cases are defined below:

Table 6.

Prices, yields, costs, and other parameters used in the LP model.

	Wheat	Barley	Corn	Alfalfa	Irrigated pasture	Sugar beets	Tomatoes
Price, $	7	6	7	80	100	25	56.5
Yield per acre	55	50	90	7	1	28	25
Units	cwt	cwt	cwt	ton	acre	ton	ton
Variable cost excluding water and nitrogen costs	91.48	76.57	227.55	176.82	8.6	579.49	670.16
Return over Adj. Var. Costs	293.52	223.43	402.45	383.18	91.4	120.51	742.34
Water Requirements: (1000 gallons/acre)							
January	0	0	0	0	0	0	0
February	13	13	0	1	0	0	0
March	105	105	0	72	72	0	0
April	203	203	0	158	162	74	28
May	277	277	47	231	235	256	98
June	189	189	197	293	297	352	293
July	0	0	389	322	330	389	384
August	0	0	330	275	284	344	263
September	0	0	173	211	215	240	0
October	0	0	0	130	130	143	0
November	0	0	0	35	30	0	0
December	0	0	0	0	0	0	0
Nitrogen required: (lbs, @ $.20/lb)	80	80	200	0	200	125	100

Source: Moore, Olson, and Marino, page 9-20, 1984.

> Case I. Maximum size is 350 acres. Primary effluent is used, and blending with fresh water (at $16.00 per acre ft. or $0.49/1,000 gal) is allowed. This includes the more likely situation where the total supply of effluent does not need to be used on the farm. No off-line storage is allowed.
>
> Case II. Acreage is unlimited. Only primary effluent is available; blending with fresh water is not allowed. The total supply of effluent does not need to be used on the farm. No off-line storage is allowed.
>
> Case III. Maximum size is 350 acres. Secondary effluent is used, and blending with fresh water is allowed. The total supply of effluent does not need to be used on the farm.

The results of this study are presented in Table 7. For Case I the cropping pattern changes only once as the effluent price changes. The use of primary effluent decreases by 19.6 percent when the price reaches $0.025 per 1,000 gallons with the use of ground water increasing by 20 percent. As the price of primary effluent increased from $0.01 to $0.025 per 1,000 gallons, gross farm receipts minus variable expenses decreased. For Case II there was no change in the cropping pattern by varying the effluent price. In comparing Case II's cropping pattern with Case I's there is a shift away from alfalfa hay to wheat. This shift results in a lower net return per acre. Acreage expansion to utilize all or nearly all of the effluent without benefit of storage actually reduces net farm income. For Case III the cropping pattern changes only slightly as the price increases. The quantity of effluent

Table 7.

Summary of crop acreages, water use and surplus, and nitrogen oversupply in all cases.

Item	Case I		Case II		Case III	
Effluent price range ($ per 1,000 gal)	.01-.02	.025-.045	.01-.03	.01-.02	.025-.035	.04-.045
Crop acreages						
Wheat	0	0	173	0	0	0
Corn	138	245	111	204	216	238
Alfalfa	107	0	0	41	29	7
Tomatoes	105	105	122	105	105	105
Totals	350	350	406	350	350	350
Reclaimed wastewater (1,000 gal)[a]						
Used	390,219	313,609	393,086	342,878	334,299	318,584
Oversupply	626,291	702,901	623,424	673,632	682,211	697,926
Fresh-water use (1,000 gal)	63,497	76,512	0	71,539	72,996	75,667
Nitrogen oversupply (lb/acre)						
Wheat	0	0	205	0	0	0
Corn	137	138	137	24	24	24
Alfalfa	455	0	0	216	216	216
Tomatoes	89	89	248	39	39	39

a. To convert to acre-ft, divide values (in 1,000 gal) by 325.85

decreases by 7 percent when the price increases from $0.025 per 1,000 gallons to $0.40 per 1,000 gallons. Consequently, as the price of reclaimed wastewater increases, there is a shift away from reclaimed wastewater to ground water.

Knapp and Dinar (1984) evaluated the reuse of agricultural drainage waters on crops. Although they didn't deal with effluent, they handled the quality problem, as others have done with effluent in a similar manner. They were interested in estimating the profit maximizing quantities of drainage water to be used for several combinations of crops, irrigation water prices, costs of reusing drainage water, and the resulting gains to farmers. Two areas in California were considered, the Imperial/Coachella Valley, and Kern County which is located in the San Joaquin Valley. In this study they used water prices of $8/AF and $30/AF for the Imperial and Coachella Valleys and $10/AF and $100/AF for Kern County. The primary costs of obtaining drainage water is assumed to be the fixed costs in installing reuse systems, the energy needed to generate sufficient head for irrigation, and risk.

The results are summarized in Table 8 for fruit and vegetable crops and Table 9 for field crops. For each crop grown in a specific region there were six possible cases,

Table 8.

Reusing Drainage Water on Fruit and Vegetable Crops in Kern County and the Imperial and Coachella Valleys.

Crop	Lettuce		Grapes		Navel Oranges			
Region	Imperial		Kern		Coachella		Kern	
Price of Good Water (\$/a-f)	8	30	10	100	8	30	10	100
				NO REUSE				
W^*	1.85	1.85	2.44	2.44	3.35	3.34	2.82	2.82
D^*	0	0	0	0	0	0	0	0
R^*	0	0	0	0	0	0	0	0
π^*	2275	2234	2401	2181	1885	1811	1647	1393
				REUSE (COST OF DRAINWATER = \$1/a-f)				
W^*	1.85	1.85	2.44	2.44	9.22	10.00	2.82	2.82
D^*	0	0	0	0	79	100	0	0
R^*	0	0	0	0	0	2.6	0	0
π^*	2275	2234	2401	2181	1889	1852	1647	1393
				REUSE (COST OF DRAINWATER = \$5/a-f)				
W^*	1.85	1.85	2.44	2.44	3.35	5.96	2.82	2.82
D^*	0	0	0	0	0	58	0	0
R^*	0	0	0	0	0	0	0	0
π^*	2275	2234	2401	2181	1885	1819	1647	1393

REMARKS:

W^* – Optimal quantity of irrigation water (a-f/acre).

D^* – Percent of Drainwater in irrigation water.

R^* – Rate of yield reduction (percent).

π^* – Returns net of water costs (\$/acre).

Source: Knapp and Dinar, 1984.

Table 9.

Reusing Drainage Water on Field Crops in Imperial Valley and Kern County.

Crop	Alfalfa				Wheat				Cotton			
Region	Imperial		Kern		Imperial		Kern		Imperial		Kern	
Price of Good Water (\$/a-f)	8	30	10	100	8	30	10	100	8	30	10	100
					NO REUSE							
W^*	7.86	7.85	3.40	3.40	2.09	2.09	2.03	2.03	3.42	3.42	2.53	2.53
D^*	0	0	0	0	0	0	0	0	0	0	0	0
R^*	0	0	0	0	0	0	0	0	0	0	0	0
π^*	638	465	635	329	353	308	278	95	1056	981	715	487
					REUSE (COST OF DRAINWATER = \$1/a-f)							
W^*	9.93	10.00	3.40	10.00	2.39	2.39	3.12	3.12	3.71	3.71	3.25	3.25
D^*	26	100	0	100	100	100	100	100	100	100	100	100
R^*	0	12	0	15	0	0	0	0	0	0	0	0
π^*	639	608	635	560	367	367	295	295	1080	1080	737	737
					REUSE (COST OF DRAINWATER = \$5/a-f)							
W^*	7.86	10.00	3.40	10.00	2.39	2.39	3.12	3.12	3.71	3.71	3.25	3.25
D^*	0	100	0	100	100	100	100	100	100	100	100	100
R^*	0	12	0	15	0	0	0	0	0	0	0	0
π^*	638	568	635	520	358	358	283	283	1065	1065	724	724

REMARKS:
W^* – Optimal quantity of irrigation water (a-f/acre).
D^* – Percent of Drainwater in irrigation water.
R^* – Rate of yield reduction (percent).
π^* – Returns net of water costs (\$/acre).

Source: Knapp and Dinar, 1984.

depending on water prices and whether or not drainage water was allowed. The results indicate the salt sensitive crops (lettuce and grapes) used no drainage water. Navel oranges and alfalfa, which are more salt tolerant, used drainage water for some water price combinations. They found drainage water reuse to be profitable for some water prices on navel oranges in the Coachella Valley and alfalfa in the Imperial Valley. Wheat and cotton used drainage water for all water price combinations considered, and was profitable at all prices for wheat and cotton in Kern County and the Imperial Valley. However, in several cases the returns net of water costs from reusing drainage water was not sufficient enough to cover the primary costs. When those cases were dropped, they found that reuse of drainage water was likely to be profitable for field crops in Kern County and the Imperial Valley at the highest prices for good water considered ($30/AF and $100/AF in the Imperial Valley and Kern County, respectively). They also found it paid to reuse drainage water completely (100 per cent mix) and found small or no yield reductions at the optimal point.

The pricing of effluent by municipalities is more likely done by a modified "market value" approach rather than by the marginal cost pricing approach. The City of Tucson charges the Cortaro-Marana Irrigation District (CMID) a fee of $5.00 per acre-foot for wastewater effluent. Since the conveyance system cost was incurred by CMID it can be assumed that a modified "market value" approach was used in pricing the wastewater effluent. The same can be said for Buckeye Irrigation District which pays 70 percent of the cost of Salt River Project Water at a price of $8.50 per acre-foot. The first 150 acre-feet of wastewater effluent delivered to Buckeye in each calendar month is without chagre. They receive their effluent from a natural channel of the Salt River.

INSTITUTIONAL FACTORS

The legislative action that stimulated wastewater reclamation and reuse was the Federal Water Pollution Control Act of 1972. This law required secondary treatment for most municipal wastewater (Walter and Cox, 1978). Adherence to the new federal enviromental requirements thus created new supplies of usable water. The Federal Clean Water Act 1977 provided even greater incentives for wastewater reclamation and beneficial use. These federal legislative actions produced incentives for wastewater reclamation and encouraged the use of reclaimed wastewater for irrigation of agricultural crops.

Under the Southern Arizona Water Resources Settlement Act of 1982 (SAWRSA), the Tohono O'Odham were awarded a combination of ground water, treated effluent, and CAP water in satisfaction of tribal claims. The Tohono O'Odham are entitled to 28,000 acre-feet of secondarily treated effluent per year plus evaporative losses. Evaporative losses raises the total amount to approximately 30,600 acre-feet. SAWRSA includes a provision that allows the Tribe to transfer their water, whether it be ground water, effluent or CAP water, to any use including sale or lease off the reservation. The right to transfer their rights has given the Indian community more flexibility and a better chance of actually benefiting from their water allocation (Laney, 1984). Not having the option to transfer, the Tribe's only alternative would have been to develop extensive farming operations which would be dependent upon obtaining adequate capital and managerial expertise.

LOCAL GOVERNMENT POLICIES

In June of 1979 the City of Tucson and Pima County adopted an intergovernmental agreement establishing ownership of the area's wastewater effluent. As part of the agreement, the City transferred its sewer system to Pima County while Pima County relinquished almost all of its control over the wastewater effluent. The County is still entitled to 10 percent of the effluent available after distribution is made to the Tohono O'Odham Tribe.

The City further agreed it will use effluent in such a manner as to preserve the underground water supply and to minimize costs to water rate payers in the City and the County (CH_2M-Hill/Rubel and Hager, 1983).

In 1982 the City of Tucson adopted "The Generalized Effluent Reuse Policies" to reduce ground water pumping and conserve potable ground water supplies. Among the provisions set forth were the geographical priorities for effluent reuse which are the (1) Tucson Water Service Area, (2) Upper Santa Cruz Subbasin of the Tucson Active Management Area (TAMA), (3) Avra Valley Subbasin of the TAMA, and (4) outside the TAMA. Refer to Appendix D for specific provisions.

The reason for the geographical priorities has to do with the Groundwater Code requiring municipal water providers, such as the Tucson Water Service Area, to achieve a per capita use rate of 140 gallons per day (GPD), by the year 2025. This level of use is considered a safe yield for the underlying aquifers. However, when calculating the per capita rate in gallons per person per day (GPCD), ground water diverted or received and surface water diverted or received were considered, but not reused effluent. Therefore, the Tucson Water Service Area can reduce per capita consumption more easily by substituting effluent for potable water in turf or landscape irrigation.

The effluent discharged into the Santa Cruz River from Pima County's sewage treatment plants is subject to use by others. The discharge of effluent is considered defacto abandonment and the effluent is not appropriable unless it is commingled with the subflow of the river. Effluent users, absent a contract, cannot require the county to continue this abandonment policy, nor can they rely upon it.

The Cortaro-Marana Irrigation District has secured from the State Land Department of Arizona an appropriative water right for 29,100 acre-feet per year from the underflow of the Santa Cruz River. This amount of water is vested to the CMID. Pima County and the District have also entered into annual contractual agreements, whereby the District pays for a small amount of treated wastewater.

EFFLUENT DISCHARGE STANDARDS: ARIZONA VERSUS CALIFORNIA

Standards in which to evaluate wastewater discharge were first established by the Federal Water Quality Control Act of 1965. This act, along with later amendments, is administered by the Enviromental Protection Agency (EPA). The Arizona Department of Health Services (ADHS) is responsible for enforcement of both state and federal water quality requirements. Standards for the quality of discharge into navigable streams from publicly owned treatment works were published in the Federal Register on August 17, 1973. These standards effectively define decondary treatment as given in Table 10 (Brown and Caldwell, 1977).

The Arizona Department of Health Services has established effluent discharge requirements for the Santa Cruz River under a cooperation agreement with the EPA's National Pollutant Discharge Elimination System (NPDES). The most recent guidelines for effluent quality parameters established by the Department of Health Services for direct discharge to the Santa Cruz River are listed in Table 11 (Arizona State Department of Health, 1972). Along with these standards are those required by the NPDES.

In California primary effluent has been used for surface irrigation of orchards and fodder, fiber, and seed crops with no apparent health effects (Crook, 1978). To reduce the number of viable pathogens the fields are allowed to dry before grazing or harvest of fodder crops. Surface irrigation is acceptable with orchards and vineyards because of the distance between the edible fruit and the ground. Care has to be taken when harvesting the fruit so that is does not come in contact with the ground or irrigation water. Regulations prohibit harvesting of fruit that has come in contact with the irrigation water or the orchard.

Table 10.

Standards for Quality of Secondary Effluent for Discharge into Navigable Streams

1. Biochemical oxygen demand (five-day)
    a. The arithmetic mean of the values for effluent samples collected in a period of 30 consecutive days shall not exceed 30 milligrams per liter.

    b. The arithmetic mean of the values for effluent samples collected in a period of seven consecutive days shall not exceed 45 milligrams per liter.

    c. The arithmetic mean of the values for effluent samples collected in a period of 30 consecutive days shall not exceed 15 percent of the arithmetic mean of the values for effluent samples collected at approximately the same times during the same period (85 percent removal).

2. Suspended solids
    a. The arithmetic mean of the values for effluent samples collected in a period of 30 consecutive days shall not exceed 30 milligrams per liter.

    b. The arithmetic mean of the values for effluent samples collected in a period of seven consecutive days shall not exceed 45 milligrams per liter.

    c. The arithmetic mean of the values for effluent samples collected in a period of 30 consecutive days shall not exceed 15 percent of the arithmetic mean of the values for effluent samples collected at approximately the same times during the same period (85 percent).

3. Fecal coliform bacteria
    a. The geometic mean of the value for effluent samples collected in a period of 30 consecutive days shall not exceed 200 per 100 milliliters.

Table 10 continued.

b. The geometric mean of the values for effluent samples collected in a period of seven consecutive days shall not exceed 400 per 100 milliliters.

4. pH. The effluent values for pH shall remain within the limits of 6.0 to 9.0.

Note: These standards may be modified when industrial wastesare particulary difficult to treat; specifically, those effluent values for BOD_5 and suspended solids. However, 85 percent removal of these parameters is required in any case.

Source: Brown and Caldwell, pages 92-93, 1977.

Table 11.

Effluent Discharge Requirements

Parameters	State Department of Health Services	NPDES Permit No. AZ002093a
Biochemical oxygen demand (5 day)	35 mg/l	30 mg/l
Suspended solids	35 mg/l	30 mg/l
Total Dissolved solids	Domestic supply plus 300 mg/l	-------
Settleable Solids	-------	0.1 mg/l
Fecal Coliform	-------	200/100 ml
Chlorine Residual		
15 minute contact	2.0 mg/l	-------
30 minute contact	0.5 mg/l	-------
Toxic Subtances	USPHS drinking water standards	Water Quality standards for Arizona
pH	-------	6.5 to 8.6

Source: Arizona Department of Health Services, 1972.

As with food crops, which are surface irrigated, a disinfected, secondary effluent is acceptable providing there is no contact between the edible portion of the crop and the reclaimed water. Sprinkler irrigation of food crops, because of direct contact, requires more stringent requirements than surface irrigation. Tertiary treated effluent which is pathogen free is recommended for the sprinkler irrigation of all crops that are eaten or sold raw. Thwe quality requirements can be relaxed if the food crops undergo commercial processing to destroy pathogens before they are sold for human consumption. The treatment and the quality requirements for irrigation in California are summarized by the "Wastewater Reclamation Criteria" in Table 12 (California Dept. of Health Services, 1978).

The Arizona Department of Health Services has also developed criteria for treatment requirements for reuse of wastewater. Secondary treatment is the minimum treatment required for all cases. The most recent guidelines for effluent quality established by the Department of Health Services for various wastewater reuses are set forth in Title 9, Chapter 20, Article 4 of "Regulations For The Reuse of Wastewater" (Arizona Department of Health Services, 1985). Numerical parameter limits pertaining to specific reuse categories are

Table 12.

Wastewater Treatment and Quality Criteria for Irrigation

Treatment level	Coliform limits	Type of Use
Primary		Surface irrigation of orchards and vineyards
Oxidation and disinfection (Secondary)	$\leq$ 23/100 ml	Pasture for milking animals
		Landscape impoundments
		Landscape irrigation (cememtaries, golf courses, etc.)
	$\leq$ 2.2/100 ml	Surface irigation of food crops (no contact between water and edible portions of crop)
Oxidation,	$\leq$ 2.2.100 ml	Spray irrigation of crops
coagulation, clarification, filtration, and disinfection (Tertiary)	max. = 23/100 ml	Landscape irrigation (palygrounds, parks, etc.)

Source: California Department of Health Services, 1978.

contained in Table 13. The current levels of fecal coliform and pH of secondary treated effluent for both Roger and Ina Road treatment plants are found in Appendix B.

The treated wastewater received by Cortaro-Marana Irrigation District is secondarily treated and disinfected. The effluent upon blending does not necessarily meet tertiary treatment standards. This is because the parameters mentioned in Table 11 can vary for one reason or another. If a vegetable crop were to be grown and consumed raw the blending ratio would have to be constantly adjusted in order to meet tertiary treatment standards. This is nearly impossible since there is always some delay in testing these parmeters. Consequently, there is the risk of irrigating the vegetables with a blend which does not meet tertiary treatment standards. This could result in impoundment of the contaminated vegetables (Brown, 1986).

Concentrations of trace elements, organic chemicals, toxic substances, and radiochemicals in waters for reuse must meet the allowable limits contained in the State surface water quality standards, A.C.R.R. Title 9, Chapter 21, Article 2 (Arizona Department of Health Services, 1984). The allowable limits for protected uses are contained in Table 14.

Table 13.

Allowable Limits For Specific Reuses

PARAMETER	A ORCHARDS	B FIBER, SEED & FORAGE	C PASTURES	D LIVESTOCK WATERING	E PROCESSED FOOD	F LANDSCAPED AREAS RESTRICTED ACCESS	G LANDSCAPED AREAS OPEN ACCESS	H FOOD CONSUMED RAW	I INCIDENTAL HUMAN CONTACT	J FULL BODY CONTACT
pH	4.5-9	4.5-9	4.5-9	6.5-9	4.5-9	4.5-9	4.5-9	4.5-9	6.5-9	6.5-9
FECAL COLIFORM										
(CFU/100 ml)[a]										
geometric mean (5 sample minimum)	1000	1000	1000	1000	1000	200	25	2.2	1000	200
single sample not to exceed	4000	4000	4000	4000	2500	1000	75	25	4000	000
TURBIDITY (NTU)[b]	-	-	-	-	-	-	5	1	5	1
ENTERIC VIRUS[c]	-	-	-	-	-	-	125 per 40 liters	1 per 40 liters	125 per 40 liters	1 per 40 liters

Notes:
a. CFU = colony forming units
b. NTU = nephlometric turbidity units
c. expressed as PFU, plaque forming units; MPN, most probable numbers

Source: Arizona Department of Health Services, "Regulations for the Reuse of Wastewater", 1985.

Table 14.

Allowable Limits For Protected Uses

PARAMETER	PROTECTED AREAS				
	Domestic Water Source	Recreation		Agricultural	
		Full Body	Partial Body	Irrigation	Livestock
Trace Substances (maximum allowable limits), (mg/l)					
Arsenic (As As)	0.050 D	0.050	a,c	2.000 T	0.200 T
Barium (As Ba)	1.000 D	1.000 D	a,c	NS	NS
Boron (As B)	NS	NS	a,c	1.000 T	NS
Cadium (As Cd)	0.010 T	0.010 T	a,c	0.050 T	0.050 T
Chromium (As Cr, Hexavalent, Trivalent)	0.050 D	0.050 D	a,c	1.000 T	1.000 T
Copper (As Cu)	1.000 D	NS	a,c	0.500 T	0.500 T
Lead (As Pb)	0.050 D	0.050 D	a,c	10.000 T	0.100 T
Manganese (As Mn)	NS	NS	a,c	10.000 T	NS
Mercury (As Hg)	0.002 T	0.002 T	a,c	a	0.010 T
Selenium (As Se)	0.010 D	0.010 T	a,c	0.020 T	0.050 T
Silver (As Ag)	0.050 D	0.050 D	a,c	NS	NS
Zinc (As Zn)	5.000 D	NS	a,c	10.000 T	25.000 T
Ammonia (As un-ionized NH_3)	NS	NS	NS	NS	NS
Cyanides (As cyanide ion and complexes)	0.200	0.200	a,c	NS	0.200
Phenolics	0.005	0.005	a,c	NS	0.005
Sulfides (Total)	NS	NS	NS	NS	NS

Table 14 continued.

Notes:
- a. Too little is known about adverse health effects for this use to adequately select a number.
- b. Abbreviations used in this table: NS = NO STANDARD, T = TOTAL TRACE SUBSTANCE, D = DISSOLVED FRACTION
- c. When "Partial Body Contact" is the only designated protedted use for a surface segment, the allowable limits listed for "Full Body Contact" shall apply until posible adverse health effects are better understood for "Partial Body Contact" use.

Source: Arizona Department of Health Services, "Water Quality Standards for Surface Waters"

OCCUPATIONAL SAFETY AND HEALTH ACT

The Occupational Safety and Health Act (OSHA) was passed to insure the safety of employees during employment. Arizona has passed similar legislation. While there are no specific standards in dealing with the use of effluent, ARS 23-403, the "General Duty" clause, requires the employer to provide for the employees an enviroment "free from recognized hazards that are causing or likely to cause death or serious physical harm to his employees" (Bookman-Edmonston Engineering, 1978). This may require proper instructions or training where necessary. An adequate warning (bi-lingual) of the dangers of drinking or swimming in irrigation water should be given.

Farmers cannot insist on water being delivered from a specific source when growers are members of water users' associations. The source of supply is immaterial as long as the irrigation water is suitable and fit for irrigation. Thus, a water users' association may legally substitute effluent which meets health requirements specified for groundwater.

Compliance with the law may not be a complete defense, even though by blending the effluent with groundwater the mixture surpasses the minimum requirements of the Arizona Department of Health Services. To minimize the risk of incurring a liability a warning of the dangers of effluent is necessary. There should be a conspicuous posting which warns those of the nature of the substance, its proper use, and possible hazards of improper use. There are instances under "strict liability" where liability will be imposed upon a party without any finding of any actual negligence. Again if adequate warning is given to the dangers involved, conditions may outweigh any application of the strict liability standard.

THE GROUNDWATER MANAGEMENT ACT

The Groundwater Management Act (the Groundwater Code) was enacted in 1980 due to the overdraft of Arizona's ground water. The Code established four active management areas (AMAs). These are geographical areas in which management of groundwater is needed. One active management area is the Tuscon Active Management Area. Within the TAMA, the Groundwater Code limits the withdrawls of groundwater to those with groundwater rights.

A grandfathered right (GFR) to withdrawal water are for those persons who pumped or received groundwater from non-emempt wells prior to June 12, 1980. There are three types of GFRs: an Irrigation GFR, a Type 1 Non-Irrigation GFR and a Type 2 Non-Irrigation GFR. An Irrigation GFR applies to two or more acres used for the purpose of growing plants for sale or human consumption or to use as feed for livestock or poultry. For an Irrigation GRF the management plan specifies the amount of groundwater that may be used to irrigate acreage. Generally, Irrigation GFRs may not be transferred to other locations.

The Type 1 Non-Irrigation GFR applies to farmland that has been retired from irrigation between January 1, 1965 and the date of enactment (June 12, 1980) in anticipation of non-irrigation use. To qualify for the right, the land must have been held under the same ownership and, prior to retirement of the land, a development plan must have existed. Irrigated land retired subsequent to June 12, 1980 must be located outside of an existing service area to qualify for a non-irrigation use. Type 1 rights may not be tranferred to another location.

Type 2 Non-Irrigation GRFs applies to non-irrigation withdrawls of groundwater in existence as of June 12, 1980. The right to withdrawal groundwater equals the maximum amount of water withdrawn and used for nonirrigation purposes in any one of the five years before the enactment date of the Groundwater Management Act. Unlike the Irrigation GFR and Type 1 Non-Irrigation GRF the Type 2 rights may be transferred.

To withdrawl and transport groundwater cities, towns, private water companies, and irrigation districts have "service area rights." The code defines a service area as an area of land which is served by the entity and any additional areas that contain an operating distribution system.

The Groundwater Code permits the transportation of groundwater without liability or injunction within the subbasin from which it is withdrawn. Under certain circumstances, groundwater may be transported between subbasins or away from an AMA without payment or damages providing the groundwater withdrawn is in accordance with an "irrigation grandfathered right" or from farmland which is retired from irrigation. However, no more than three acre-feet per year may be transported.

An Irrigation Grandfathered Right is conveyed to the land to which the right pertains. If the land is within the service area, an Irrigation Grandfathered Right may only be conveyed for an irrigation use. An exception would be for land included within a service area subsequant to the designation of the AMA, which in most cases is 1980. The owner of the land included subsequent to the designation must demonstrate to the Director's satisfaction that adequate water service is unavailable for the proposed use. This concession was made to prevent water rights from loosing value for industrial or other commercial development if the farms were eventually encircled and included in a city. The Irrigation

Grandfathered Right then becomes a Type 1 Non-Irrigation Grandfathered Right. Irrigation Grandfathered Rights located outside a service area can be transfered for either an irrigation or non-irrigation use. The full amount of the grandfathered right is conveyed with the land if used for irrigation. If used for non-irrigation, the amount transfered per irrigation acre is the lessor of the amount based on the water duty computation, or three times the number of water duty acres divided by the number of irrigation acres.

A Type 1 Non-Irrigation Grandfathered Right may be used for any purpose except irrigation. Once the right has been converted to non-irrigation use, it may not be converted back to irrigation. If located within the service area the full amount of the right is conveyed providing the retirement of the land was prior to the date of enactment. The amount of the Type 1 Right will usually be three-acre feet per year per acre of retired land. This groundwater can only be used on that land to which the right pertains unless a use on other land occured prior to the designation of the AMA or the original owner acted in accordance to a development plan filed with the Director prior to the land being included within the service area. If the land is located outside a service area, the owner of a Type 1 Right can use the water for any non-irrigation use either on or off the land, subject to the transportation restrictions. If irrigated land is within a service area at the time it is retired, no Type 1 Right may be created. An exception would be if the needed water service is not available at fair rates within the service area or it is used for electrical generation.

Type 2 Rights may also be conveyed for other non-irrigation uses, but mines and power utilities may convey Type 2 Rights only for mining and power generating, respectively. Other owners of Type 2 Rights may sell their Type 2 Rights to any person for any purpose except irrigation. Type 2 Rights, which are not associated with the land, may be sold apart from the sale of the land. Type 2 Rights cannot be conveyed in part; the full amount of the right must be conveyed. More importantly, concerning the exchange of groundwater, a Type 2 Right currently being used by an industry can be conveyed for another industrial use regardless of whether it is within a service area. Examples of general industrial uses include shopping centers, livestock watering, agricultural product processing, parks, golf courses, commercial property landscaping, fish and wildlife, recreation, and industry other than mining and power generation.

The law allows the transportation of groundwater away from a parcel of land without any threat of injunction or payment of damages providing it is not across a subbasin boundary. However, service areas cannot transport groundwater outside their boundaries even though it would be within the same subbasin. An exception would be the transportation of groundwater by city or town, but not a private water company, to supply another city, town, or private water company in accordance to a delivery contract approved by the Director and consistent with the management plan. The Groundwater Code also permits the transportation across basin and subbasin lines of three acre feet per year from retired irrigated land under a Type 1 Right or from land holding and Irrigtion Grandfathered Right. They are not subject to payment of damages providing the three acre-feet allotment is not exceeded. Also, a party can transport groundwater out of a subbasin subject to damage claims.

The transportation of groundwater between Avra Valley and the City of Tucson has been going on since 1968. Tucson has been purchasing farmland from willing sellers and putting it out of production inorder to claim the appurtenant water rights for municipal use. If the exchange of effluent were to occur between the two service areas in lieu of groundwater from Avra Valley the City of Tucson could conceivably reduce its costs in aquiring additional water supplies.

The Cortaro-Marana Irrigation District they may be in the position of transporting surface water, not groundwater, to the Tucson Water Service Area without having to adhere to the Groundwater Code. This is because the Santa Cruz River flows through their District which affords them the opportunity of having surface water rights. These rights pertain to surface and subsurface waters flowing in defined natural channels. Thus, the District may be in the position of selling "surface water" to the City of Tucson.

SOCIAL FACTORS

Public opinion on the appropriatness of various uses of reclaimed wastewater cannot be ignored because of its importance in developing wastewater reuse projects.

The public should be involved, and its opinion given proper weight to prevent ill will and mistrust between the public and government institutions. Thus, for success in taking on such projects it is imperative that public attitudes be considered if the project is to have wide popular support.

Public opinion regarding reuse of treated wastewater has been carefully surveyed (Bruvold, 1972) and then resurveyed in a later study (Olson et al., 1979). Regarding agricultural irrigation, only 8 percent in both studies opposed use of treated wastewater for hay or alfalfa irrigation; and about 15 percent from both opposed its use for vegetable crops. People were not in favor of direct reuse of reclaimed wastewater, even high degrees of treatment, when used for drinking, food preparation, and bathing. Another survey (Bruvold, 1980) found respondents wanted wastewater treatment and reuse that would conserve scarce water resources, protect the public health, and enhance their enviroment. Economic concerns were not of much importance to the respondents. People who are older, and less educated, and less affluent are the most negative in their attitudes in reuse of treated wastewater (Bruvold, 1975). The younger, more educated, more affluent people were more positive in their attitudes. Brouvold believes information campaigns should then be aimed at the older, the less affluent, and less educated segments of a population to better persuade public opinion. The information campaign should focus on the need for new water supply sources, availability of modern technology for treating wastewater, the fact that public health officials do approve of reuse of treated wastewater, and that by using treated wastewater taxpayers could benefit.

HUMAN HEALTH EFFECTS

The main goal of wastewater treatment is to reduce the health risks. Usually health concerns are related to the degree of human contact, effluent quality, and the reliability of the treatment system. Typically, contaminants in wastewater have been divided into two major categories--biological and chemical. Historically, the biological agents have received the closest attention (Crook, 1978). A common characteristic of the diseases are their epidemic potential of having relatively short incubation periods which creates the possibility of rapid infection. To a great extent disease outbreaks of epidemic proportions have been controlled by sanitary engineering and preventive medical practices. Thus, control is accomplished by severence of the the transmission chain, not by eliminating the pathogenic organism.

Inorganic chemical agents can not be overlooked such as nitrates, sodium, heavy metals, and fluorides. For it is these elements that can have an impact on public health. Depending on the chemical characteristics, heavy metals may or may not be immobilized in the soil (Bouwer, 1978). The immobilization of heavy metals leads to the possibility of translocation through the food chain to man (Epstein and Chaney, 1978). Also, organic chemicals are causing increasing health concerns since the methods for identification and control are not fully developed. Furthermore, there lies the possibility that some of these unknown organic chemicals could be carcinogenic.

Irrigation of crops with treated wastewater presents a complicated problem for risk assessment, depending on the crop and how it is irrigated. Irrigation of fiber and fodder crops poses no significant risks to people from pathogenic organisms, except those who come directly in contact with the irrigation water. Though constituents in treated wastewater could affect fodder-consuming animals and ultimately the people who consume the animals or their products, as is the case with cadmium (Roberts et al., 1979). There is epidemiological evidence indicating the the reuse of treated wastewater has resulted in the transmission of diseases. However, in all these cases, either raw sewage or undisinfected effluent was the source of irrigation water. There has been no confirmed disease outbreaks resulting from use of disinfected treated effluent (Crook, 1984).

CHAPTER 3

ANALYTICAL FRAMEWORK

CONCEPTUAL MODEL

Cortaro-Marana Irrigation District and Avra Valley produce such crops as cotton, spring and fall lettuce, alfalfa, milo, hay, wheat and pecans, with the principal crop being cotton. All of these crops are irrigated. The demand for wastewater effluent as an alternative water source will depend largely on the price of wastewater effluent, the price of ground water, the value and type of crops grown, and the nutrient requirements of the crop.

If the price of wastewater effluent is lower than that of existing sources it can be expected growers will irrigate with wastewater effluent. Demand for wastewater effluent will be inelastic so long as its price does not exceed the price of ground water. Any demand for wastewater effluent where the price of wastewater effluent exceeds the price of ground water will be due to the marginal value of the nutrients contained in wastewater effluent. Thus, demand for wastewater effluent will be elastic when its price exceeds the price of ground water.

The value and type of crops grown will have an influence on the demand for wastewater effluent. It can be assumed crops having a high value are grown more. If these high value crops have high nutrient requirements than there will be a greater demand for wastewater effluent. Irrigating vegetables that are to be consumed raw, with a blend of secondarily treated effluent and ground water, is a health risk and thus not recomended. Consequently it can be assumed no wastewater effluent will be demanded if vegetables are to be grown and consumed raw.

Another factor affecting demand is the concentration of nutrients in wastewater effluent. Although nutrients are necessary for plant growth, the concentration of nutrients in wastewater effluent when blended with groundwater (too high of ratio) may be in excess of the nutrient requirements of the crop. This could have the affect of reducing yields. Hence, the nutrient requirements of the crop will indirectly affect the demand for wastewater effluent. However any wastewater effluent used by the growers will result in a proportionate decrease in the use of commercial fertilizer.

For a simple, static economic analysis, the relationship between the quantity of inputs and outputs can be expressed in the form of a production function. The individual firm employs factors of production to produce a product. The assumption is made that firm buys inputs and sell products in purely competitive markets. It is further assumed that firms attempt to maximize profits in order to assure their long-run existence. Prices and input-output relationships are assumed to be known with certainty. For economic analysis a production function expresses the technical relationship between the variable factors of production and output.

Factor-Product Relationships

A production function is a schedule (or mathematical equation) showing the maximum amount of output that can be produced from any specified set of inputs, given the existing technology. Symbolically, a production function can be expressed as

$$Y = f(X_1 \P X_2) \qquad (3.1)$$

where Y denotes output, X_1 is the variable factor of production (input) and X_2 is a fixed factor, and f is a function. The production function can be represented by a Total Physical Product (TPP) curve. Total Physical Product portrays the relationship between the quantity of output and any single input, all other inputs held constant. Problems associated with allocation of one variable input are often referred to as the factor-product relationship.

The objective of the factor-product relationship is to find the amount of X where the slope of the TPP curve is equal to the price ratio, Pw/Py, when the goal is profit maximization. To maximize the function with respect to the variable input, the first derivative would be set to zero as follows:

$$\frac{dProfit}{dW} = Py\frac{dy}{dW} - Pw = 0 \qquad (3.2)$$

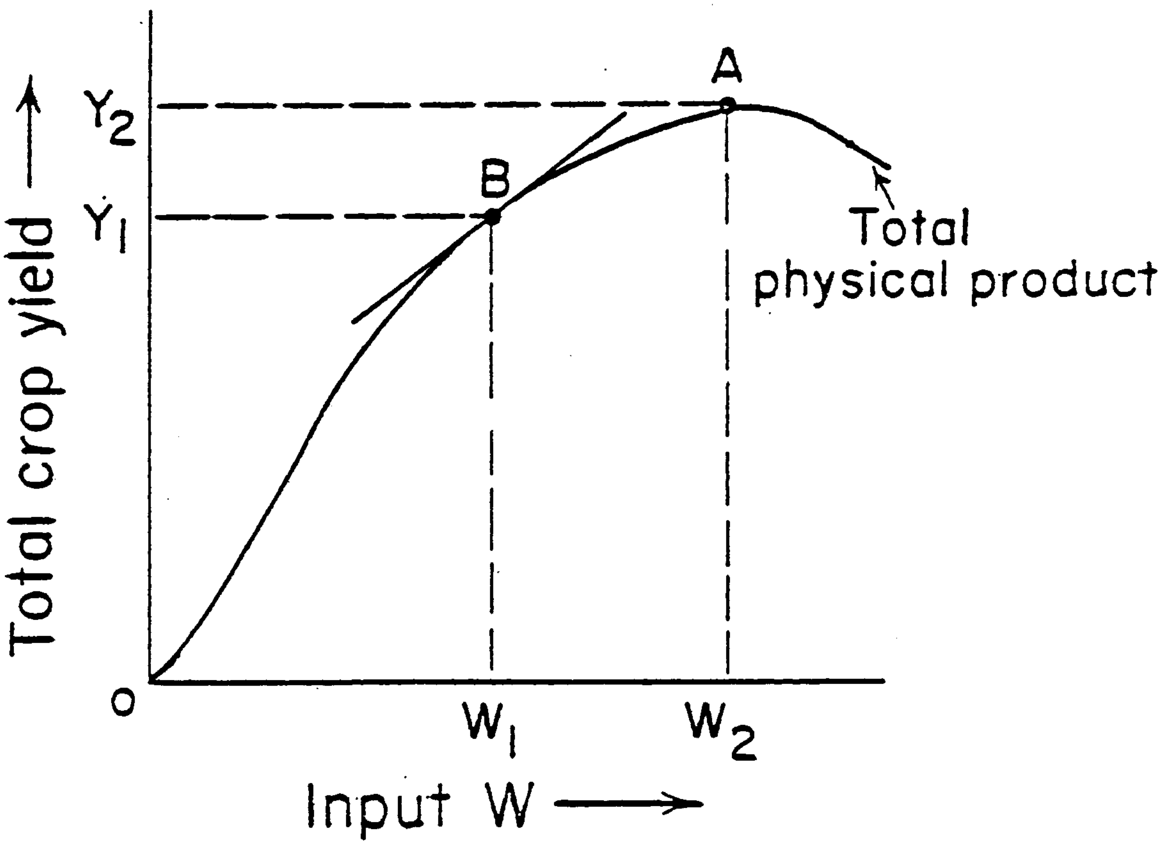
$$= PyMPP - Pw = 0$$

$$MPP = Pw/Py \qquad (3.3)$$

MPP is the marginal physical product which is the change in output resulting from a unit change in the variable input. It measures the amount that total output increases or decreases as input changes. Geometrically, as shown by point B of Figure 2, MPP represents the slope of the total physical product curve. Equation (3.2) represents the main principle of the factor-product relationship; that is, the marginal product of the variable input (measured in physical units of output) must equal the inverse ratio of the number of units of input that can be purchased from sale of one unit of output (as represented by the input-output price ratio). Therefore, when short-run profits are maximized, the firm will continue to increase the amount of the variable input used in the production as long as the addition to revenue exceeds the addition to cost. When the

Figure 2.

Solution to the Factor-Product Decision Using a Total Physical Product Curve



marginal value product equals marginal cost, the optimum is obtained. Point A of Figure 2 represents the maximum level of output per acre obtainable, given all other inputs are held constant. However, maximum profits from a firm do not occur where physical output is a maximum The reason is that the efficiency of production decreases, because the added inputs cost more than they are able to earn.

Equation (3.2) can be rewritten as:

$$Py \cdot MPP = Pw \qquad (3.4)$$

The term $Py \cdot MPP$ is called the value of the marginal product (VMP). The term Pw is the slope of the total cost function--the increment to total cost caused by using an additional unit of input. In perfect competition, Pw will always be a constant. The value of the marginal product curve is considered to be the producer's input demand curve. By equating VMP to the input price the firm determines the amount of input to be purchased. As the input price changes, the firm's purchases move along the value of the marginal product curve. Changes in output price will cause the "demand" curve to shift.

The value of the marginal product curve is considered to be the producer's input demand curve for water. As the price for water varies the firm's purchases of water move along the input demand curve. Demand for water and its price are inversely related. Changes in crop prices will cause the "demand" curve to shift. For example, and increase in crop prices will increase production thus the total demand for water will increase.

Factor-Factor Relationships

In the factor-product relationship a given level of output can be produced in only one way. When two or more inputs are variable, a given amount of output may be produced in more than one way. Substitution possibilities among inputs or factors of production create what is often called the factor-factor relationship. The factor-factor relationship adds an extra dimension to decision making. As before, the assumption is made that the firm uses the most profitable combination of inputs.

The production function for two variable inputs does not differ conceptually from that for one variable input. Each combination of inputs produces a unique amount of output. In the factor-product relationship the input was water. For the factor-factor relationship the two inputs will be the ratio of groundwater used to wastewater effluent and fertilizer. Because of effluent's high nutrient content and the varying seasonal demand of plants for these nutrients a ratio of groundwater and effluent is necessary. Thus, the production for these two variable inputs is as follows:

$$Y = f(W,F) \qquad (3.5)$$

where Y is the amount of product, W the ratio of groundwater used to wastewater effluent, and F the fertilizer used to produce the crop, f_{WW} and $f_{FF} < 0$ and $f_{WF} > 0$.

In production economics the goal of the firm is often referred to as the objective function. The objective function (3.6) assumes economic efficiency (maximization of profit) subject to the allocation of scarce resources among competing alternatives.

$$\max f(W,F) \quad \text{s.t. } TVC = PwW + PfF \qquad (3.6)$$

Where TVC is total varialbe cost, Pw is the cost per unit of W and Pf is the cost per unit of F.

Factor-factor relationships and the resulting substitution possibilities among variable inputs permit a given level of output to be produced with different combinations of inputs. The curve representing all combinations of W and F that produce a given level of output is called an isoquant. Since the technical interrelationship is complementary between F and W--the marginal productivity of W and F is enhanced as F and W are increased respectively. Inputs that increase output only when combined in fixed proportions are called technical complements. Figure 3 shows such an isoquant. When the isoquant appears as a right angle, the input combination at the vertex is used; other combinations of the isoquant would cost more but produce no more.

The slope of the isoquant represents the marginal rate of input substitution in the factor-factor relationship. The marginal rate of substitution of W for F is defined as the amount by which F must be decreased to maintain output at a constant amount when W is increased by one unit. The marginal rate of substitution of W for F, abbreviated MRS of W for F, is:

$$\text{MRS of W for F} = -\text{change in F}/\text{change in W} \quad (3.7)$$

The MRS is negative because the isoquant has a negative slope. The MRS represents the ratio of the marginal physical products. Recall the MPP is the change in output resulting from a unit change in the variable input which represents the slope of the total physical product curve. Thus using the MPP equations derived from the production function (3.5) the exact MRS will be

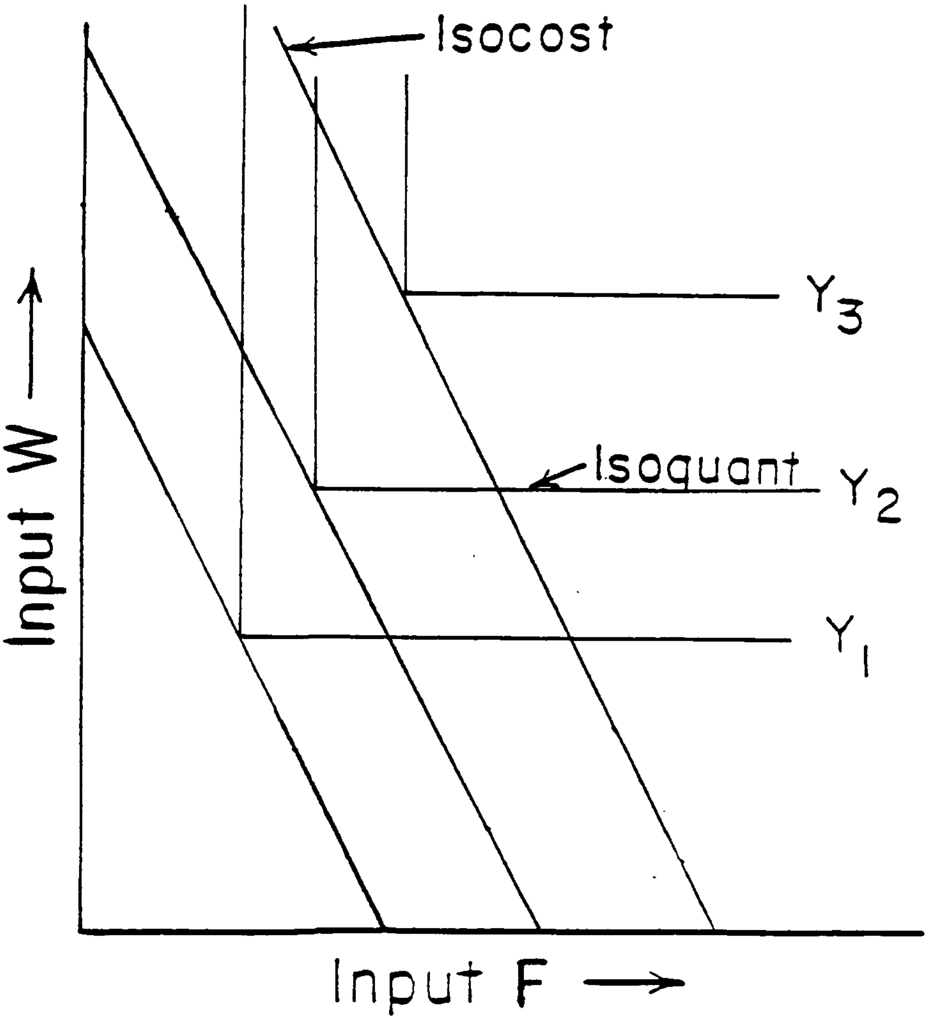
$$\text{MRS of W for F} = -\text{MPPw}/\text{MPPf} = -f_w/f_f \quad (3.8)$$

Since isoquants are derived from production functions they show the relationship between input and output.

Each combination of inputs has a cost associated

Figure 3.

Solution to the Factor-Factor Decision Using Isoquants and Isocosts (Hypothetical)



with it. The cost is variable because the inputs considered are variable. The input prices are assumed known, and as a result TVC can be computed for each combination of inputs. Total variable cost surfaces can be described using isocost lines. Isocost lines determine all combinations of the two inputs that cost the same amount. Each point on the isocost line represents a combination of inputs that can be purchased with the same outlay of funds. As an isoquant, the isocost line can be placed on a two-dimensional graph as shown in Figure 3. The slope of the isocost line is -Pw/Pf. Changes in the input price change the slope of the isocost line. A decrease in the input price means that more of that input can be purchased with the same total variable cost; and increase means that less is purchased.

The isoquant in Figure 3 has an infinite number of points--only one will represent the cost minimizing combination. At this point the following criterion, called the least cost criterion, will hold:

$$\text{MRS of W for F} = -Pw/Pf \qquad (3.9)$$

Because of the definition of MRS, the criterion can be written

$$MPPf/MPPw = -Pw/Pf \qquad (3.10)$$

The left side of the equation represents the slope of an isoquant; the right side the slope of the isocost line. Thus, the least cost combination of inputs occurs at the point where the isocost line is tangent to the isoquant.

The expansion path is found at the points of tangencies (Eq. 3.10). The expansion path passes through points of equal marginal rates of substituion. Expansion paths have important economic implications. If the expansion path is curved the least cost combination of inputs will vary among yield levels. When the expansion path is a straight line, then the inputs will be used in the same proportion at all output levels.

The inputs W and F will be used in the same proportion at all output levels since the technical interrelationship between F and W is complementary. The nutrient requirement of the crops are supplied by both W, the ratio of ground water used to wastewater effluent, and F, the fertilizer used to produce the crop. What one input doesn't supply the other one will. For example, if W decreases which means a greater proportion of wastewater effluent is being used then F decreases. The lower ratio of ground water to wastewater effluent will have a higher nutrient content therefore less fertilizer is required.

In the case of profit maximization comparative statics is important because it involves determination of qualitative information (i.e., signs) of the partial derivatives of the model. That is how the optimal factor levels and output change in response to changes in product and factor prices. One method is to maximize profits directly by maximizing the objective function. For one output and two variable inputs the profit function is

$$\pi = Pyf(W,F) - PwW - Pf(F-g(W)) \qquad (3.11)$$

where = profit
Py = price of output
f = production function for output where $Y_i > 0$, $Y_{ii} < 0$ and $Y_{ij} > 0$ where $i \neq j$
W = the ratio of groundwater used to effluent (ground water/effluent)
F = fertilizer used to produce the crop
Pw = the ratio of the price of groundwater to the price of effluent
Pf = the price of fertilizer
g = the fertilizer content effluent varies where $h_i < 0$ and $h_{ii} > 0$

The first derivative (f_i) measures the instantaneous rate of change of the function f(F,W) as the dependent variable changes (f) for every small change in W and F, the independent variables. To maximize π for output f(W,F) the first (f_i) and second (f_{ii}) order derivatives must be greater than and less than zero, respectively. The cross partial derivative (f_{ij}) is concerned with the technical interrelationship between factors of production. Since $f_{ij} = f_{ji} > 0$ the technical interrelationship is complementary between F and W. W is the ratio of ground water used to wastewater effluent. Wastewater effluent because of its high nutrient content must be diluted with ground water. If not diluted, plant growth could be adversely affected. The ratio must be low enough so that the crop grown with the least nitrogen demand is not affected. F is the fertilizer used to produce the crop. The nutrients not supplied by wastewater effluent are supplied by applying fertilizer. The first derivative (g_1) measures the instantaneous rate of change of the function g(W) as the dependent variable changes (g) for every small change in the ratio of ground water to wastewater effluent (W), the independent variable. To maximize the function g(W) the first (g_1) and second (g_{11}) order derivatives must be greater than greater than and less than zero, respectively. Maximizing the function g(W) inturn minimzes the cost of one factor of production, namely fertilizer.

Maximizing the profit function (3.11) with respect to the variable inputs gives two equations in two unknowns

$$\text{Profit}_W = Py \cdot f_W - Pw + Pfg_W = 0 \qquad (3.12)$$

$$\text{Profit}_f = Py \cdot f_f - Pf = 0 \qquad (3.13)$$

where f_W and f_f are the partial derivatives of the dependent variable (f) with respect to the independent variables W and F, respectively. In equation (3.12) the first derivative (g_W) represents the fertilizer content in the ratio of groundwater used to effluent times the cost of fertilizer (Pf). The unknowns are W and F--the solution of (3.13) will determine the profit-maximizing amounts of the two inputs. Equations (3.12 and 3.13) can be written as follows:

$$VMPw = Pw - Pfg_W \qquad (3.14)$$
$$VMPf = Pf$$

Thus, the profit-maximizing criterion requires that the marginal earnings of each input must be equal to its cost; this must be true for both inputs simultaneously. In equation (3.14) the price of the input (Pw) is offset by the value of the fertilizer in the ratio of groundwater used to effluent. The optimum criterion for two variable inputs is often expressed as

$$VMPw/Pw = VMPf/Pf = 1 \qquad (3.15)$$

Because the ratios are all equal to one at the optimum, they are also equal to each other. The ratios in the expression would never be equated to a number less than one because to do so would require input use above the optimum; added cost would exceed added returns. The exception would be constraints on supply. When capital available to buy inputs is limited or some other condition is imposed such as a fixed ratio of groundwater used to effluent, the ratios may be equal to some value greater than one.

$$VMPw/Pw = VMPf/Pf \geq 1 \quad (3.16)$$

In the profit-maximization model we are also interested in how optimal factor levels and output change in response to changes in product and factor prices. Comparative static analysis measures the nature of these changes, the direction of change, of all partial derivatives. The partial derivatives measures the instantaneous rate of change of the dependent variable with respect to one of the independent variables, when the other independent variable or variables are assumed to be held constant. Thus, to determine how factor levels change in response to price changes, we take the total differential of the first-order conditions treating W, F, Py,Pf, and Pw as variables. That is,

(3.17)

$$Pyf_{ww}dW + Pyf_{wf}dF + f_{w}dPy - dPw + g_{w}dPf + Pfg_{ww}dW = 0$$

(3.18)

$$Pyf_{wf}dW + Pyf_{ff}dF + f_{f}dPy - dPf = 0$$

Simplified

(3.19)

$$dW(Pyf_{ww} + Pfg_{ww}) + Pyf_{wf}dF = dPw - g_{w}dPf - f_{w}dPy$$

(3.20)

$$Pyf_{fw}dW + Pyf_{ff}dF = dPf - f_{f}dPy$$

In equations (3.17 and 3.18) dW and dF are treated as endogenous variables whose values are determined, whereas dPw, dPf, and dPy are treated as parameters (exogeneous variables). To determine either dW or dF for factor changes, dPw or dPf, equations (3.19 and 3.20) must be solved simultaneously. Equations (3.19 and 3.20) are stated in matrix form as

(3.21)

$$\begin{vmatrix} Pyf_{ww} + Pfg_{ww} & Pyf_{wf} \\ Pyf_{fw} & Pyf_{ff} \end{vmatrix} \begin{vmatrix} dW \\ dF \end{vmatrix} = \begin{vmatrix} dPw - f_{w}dPy - g_{w}dPf \\ dPf - f_{f}dPy \end{vmatrix}$$

Consequently, we can use linear algebra techniques to solve (3.19 and 3.20) for dW and dF. By Cramer's rule,

(3.22)

$$dW = \frac{\begin{matrix} dPw - f_{w}dPy - g_{w}dPf & Pyf_{wf} \\ dPf - f_{f}dPy & Pyf_{ff} \end{matrix}}{\begin{matrix} Pyf_{ww} + Pfg_{ww} & Pyf_{wf} \\ Pyf_{fw} & Pyf_{ff} \end{matrix}}$$

(3.23)

$$dW = \frac{Pyf_{ff}(dPw-f_{w}dPy-g_{w}dPf)-Pyf_{wf}(dPf-f_{f}dPy)}{Pyf_{ff}(Pyf_{ww}+Pfg_{ww})-Pyf_{fw}(Pyf_{wf})}$$

(3.24)

$$dW = \frac{Pyf_{ff}dPw - Pyf_{ff}f_{w}dPy - Pyf_{ff}g_{w}dPf - Pyf_{wf}f_{f}dPy}{Py^{2}f_{ff}f_{ww} + Pyf_{ff}Pfg_{ww} - Py^{2}f_{fw}f_{wf}}$$

(3.25)

$$dF = \frac{\begin{matrix} Pyf_{ww} + Pfg_{ww} & dPw - f_{w}dPy - g_{w}dPf \\ Pyf_{fw} & dPf - f_{f}dPy \end{matrix}}{\begin{matrix} Pyf_{ww} + Pfg_{ww} & Pyf_{wf} \\ Pyf_{fw} & Pyf_{ff} \end{matrix}}$$

(3.26)

$$dF = \frac{dPf - f_{f}dPy(Pyf_{ww} + Pfg_{ww}) - Pyf_{fw}(dPw - f_{w}dPy - g_{w}dPf)}{Pyf_{ff}(Pyf_{ww} + Pfg_{ww}) - Pyf_{fw}(Pyf_{wf})}$$

(3.27)

$$dF = \frac{Pyf_{ww}dPf + Pfg_{ww}dPf - Pfg_{ww}f_{f}dPy - Pyf_{fw}dPw + Pyf_{fw}f_{w}dPy + Pyf_{fw}g_{w}dPf}{Py^{2}f_{ff}f_{ww} + Pyf_{ff}Pfg_{ww} - Py^{2}f_{fw}f_{wf}}$$

Assuming $dPy = dPf = 0$, equation 3.24 reduces to

(3.28)

$$dW = \frac{Pyf_{ff}dPw}{Py^{2}f_{ff}f_{ww} + Pyf_{ff}Pfg_{ww} - Py^{2}f_{wf}f_{fw}}$$

(3.29)

$$\frac{dW}{dPw} = \frac{f_{ff}}{Py(f_{ff}f_{ww} + f_{ff}Pfg_{ww} - Py^{2}f_{fw})}$$

(3.30)

$$dW/dPw < 0$$

The second-order condition for profit maximization requires that the production function for the two-factor case be strictly concave--$f_{ff} < 0$ and $Py(f_{ff}f_{ww}+f_{ff}Pfg_{ww}-Py^2f_{fw}) > 0$. Therefore, the factor demand function is downward sloping, a negative relationship, as Pw increases the quantity of W decreases.

Assuming $dPy = dPf = 0$, equation 3.27 reduces to

(3.31)

$$dF = \frac{-Pyf_{fw}dPw}{Py^2f_{ff}f_{ww}+Pyf_{ff}Pfg_{ww}-Py^2f_{fw}f_{wf}}$$

(3.32)

$$\frac{dF}{dPw} = \frac{-f_{fw}}{Py(f_{ff}f_{ww}+f_{ff}Pfg_{ww}-Py^2f_{fw})}$$

(3.33)

$$dF/dPw < 0$$

A negative relationship (3.33) which states as the price of the ratio of groundwater to effluent used increases the use of fertilizer will decrease.

Assuming $dPy = dPw = 0$, equation 3.24 reduces to

(3.34)

$$dW = \frac{-Pyf_{ff}g_wdPf}{Py^2f_{ff}f_{ww}+Pyf_{ff}Pfg_{ww}-Py^2f_{fw}f_{wf}}$$

(3.35)

$$\frac{dW}{dPf} = \frac{-f_{ff}g_w}{Py(f_{ff}f_{ww}+f_{ff}Pfg_{ww}-Py^2f_{fw})}$$

(3.36)

$$dW/dPf < 0$$

A negative relationship (3.36) which states as Pf increases, the ratio of groundwater used to effluent decreases because of the increased use of effluent for its fertilizer content. However, since there is a limit as to the amount of effluent that can be used, this relationship only holds up to the maximum allowable level of effluent to groundwater. Beyond the maximum allowable level of effluent to groundwater the sign is zero, thus as an increase in Pf will have no effect on the ratio of groundwater used to effluent.

Assuming dPy = dPw = 0, equation 3.27 reduces to

(3.37)

$$dF = \frac{Pyf_{ww}dPf+Pfg_{ww}dPf+Pyf_{fw}g_{w}dPf}{Py^{2}f_{ff}f_{ww}+Pyf_{ff}Pfg_{ww}-Py^{2}f_{fw}f_{wf}}$$

(3.38)

$$\frac{dF}{dPf} = \frac{f_{ww}+f_{fw}g_{w}+Pfg_{ww}}{Py(f_{ff}f_{ww}+f_{ff}Pfg_{ww}-Py^{2}f_{fw})}$$

(3.39)

$$dF/dPf < 0$$

The second-order condition for profit maxmization requires that the production function for the two-factor case be strictly concave--$f_{ww}+f_{fw}g_{w}+Pfg_{ww} < 0$ and $Py(f_{ff}f_{ww}+f_{ff}Pfg_{ww}-Py^{2}f_{fw}) > 0$. Therefore, the factor demand function is downward sloping, a negative relationship, as Pf increases the quantity of F decreases. Assuming dPw = dPf = 0, equation 3.24 reduces to

(3.40)

$$dW = \frac{-Pyf_{ff}f_{w}dPy-Pyf_{wf}f_{f}dPy}{Py^{2}f_{ff}f_{ww}+Pyf_{ff}Pfg_{ww}-Py^{2}f_{fw}f_{wf}}$$

(3.41)

$$\frac{dF}{dPy} = \frac{-f_{ff}f_{w}+f_{wf}f_{f}}{Py(f_{ff}f_{ww}+f_{f}Pfg_{ww}-Y^{2}f_{fw})}$$

(3.42)

$dW/dPy > 0$

A positive relationship (3.42) stating as the price of the output increases so to does the ratio of groundwater used to effluent. However, with an increase in the price of the output there is no agronomic reason why the ratio of groundwater used to effluent needs to increase. In fact with an increase in the price of the output the price of fertilizer could increase with increased demand in the short run. The increased value of the fertilizer will increase the demand for effluent, thus the ratio of groundwater used to effluent will decrease, assuming the grower is not using the maximum allowable level of effluent to groundwater. Consequently, the sign of the relationship is not all that clear.

Assuming dPw = dPf = 0, equation 3.27 reduces to

(3.43)

$$dF = \frac{-Pfg_{ww}f_{f}dPy+Pyf_{fw}f_{w}dPy}{Py^{2}f_{ff}f_{ww}+Pyf_{ff}Pfg_{ww}-Py^{2}f_{fw}f_{wf}}$$

(3.44)

$$\frac{dF}{dPy} = \frac{-(g_{ww}f_{f}-Pyf_{fw}f_{w})}{Py(f_{ff}f_{ww}+f_{ff}Pfg_{ww}-Py^{2}f_{fw})}$$

(3.45)

$$dF/dPy > 0$$

A positive relationship (3.45) which states as the price of output increases more growers will be induced to grow more, thus more fertilizer will be demanded. If more fertilizer is demanded than the demand will increase for wastewater effluent because of its nutirents.

Product-Product Relationships

The economic analysis of the production process as presented has emphasized the allocation of inputs. Rather than emphasizing the allocation of variable inputs for a given commodity, the allocation of variable inputs between competing products is of concern. This is called the product-product relationship.

Given two competing products, a production possibility curve is a convenient device for depicting the maximum attainable output of two products given a fixed resource base. The concept of marginal rate of product substitution is similar to that defined in the factor-factor relationship. The marginal rate of product substituion, MRPS, refers to the amount by which one product changes in quantity when the other product is increased by one unit along the prodction possibility curve. The marginal rate of product substitution is defined as the slope of the production possibility curve. Thus,

$$\text{MRPS of } Y_1 \text{ for } Y_2 = \text{change in } Y_2/\text{change in } Y_1 \quad (3.46)$$

Given the price of each commodity, Py_1 and Py_2, the maximum revenue combination of output on a production possibility curve can be determined using the criterion

$$\text{MRPS of } Y_1 \text{ for } Y_2 = -Py_1/Py_2 \quad (3.47)$$

The left side of the criterion represents the slope of the production possibility curve, and the right side the slope of the isorevenue line. The maximum revenue point is that point where the isorevenue line is tangent to the production possibility curve.

Enterprise Equilibrium

The profit maximizing position of a firm is found by the simultaneous solution to the factor-product, factor-factor, and product-product decisions, given the production functions of each product. The factor-product relationship involves how much yield per acre of each crop to produce, given the variable inputs of the ratio of ground water to wastewater effluent used and fertilizer. The factor-factor relationship involves the optimal mix of the ratio of ground water to wastewater effluent and fertilizer. The product-product relationship determines the optimal crop mix. However, the functional relationships are not known. Instead, since one can assume that the functional relationships between points are linear, linear-programming techniques are employed to solve for the optimal solution.

ANALYTICAL MODEL

Linear programming (LP) is a mathematical procedure for determining optimal allocation of scarce resources. The linear programming problem is made up of three components: (1) the objective function that is to be optimized, (2) a set of activities, or decision variables, to achieve the desired objective, and (3) constraints on the values of the decision variables.

The objective of this linear program model is profit maximization. This is accomplished by maximizing net returns above variable production costs. Fixed costs are not considered since they are constant in the short run and occur regardless of the level of farming activity.

Farms are restricted in the quantity of resources available for use in production. Resource restrictions could limit the farm in the amount and extent of obtaining its objective of maximum profits. Such restrictions on resources include: monthly crop water demands and fertilizer requirements, maximum quantity of wastewater effluent available during the year and during each month, and a limit on how much wastewater effluent that can be blended with ground water at any one time.

Farm sizes are varied in Cortaro-Marana Irrigation District and Avra Valley. The linear-programming model will represent a farm of 1000 acres with the typical crop mix. However, for policy analysis the model can be thought of as on a sub-regional basis (Cortaro-Marana Irrigation District or Avra Valley). This will aid policy makers in determing the total demand for wastewater effluent and the prices growers are willing to pay for a given quantity of wastewater effluent for a particular sub-region.

Crops typically grown in Cortaro-Marana Irrigation District and Avra Valley include American-Pima Cotton, Upland cotton, barley, milo, alfalfa, and durum wheat. There are other crops grown but because of their minor importance or the fact that they are vegetables excludes them from the study. Since cotton is the most profitable crop grown, its acreage must be restricted to prevent all cotton solutions. Acreage restrictions for cotton are based, as well for the other crops in the study, on an average of the acres planted for each crop for the years 1980 through 1984. Thus crop restrictions are based on their proportional make up. The growing season is one year.

Even though acreage restrictions have been imposed the model does allow for rotation of crops. Most of the acreage will be devoted to growing Upland cotton, a summer crop, since it the most profitable use of resources. Grain crops, such as barley and durum wheat, are grown in the winter months to use resources that otherwise would have been left idle. The variable costs and some if not all of the fixed costs will be covered by growing these winter crops. Seldom are all the fixed costs covered with these grain crops.

Cultural practices also play a role in the rotation of crops. Grain crops add mulch to the soil which maintains the soil structure. Grain crops are often planted in rotation with cotton because of its adverse affect soil structure. However, there may be a time conflict in the harvesting of cotton and the planting of the grain crop, in which case the land is left fallow until the following spring. If left fallow the grower has the option of either planting cotton or milo. Milo and barley are often double cropped. Alfalfa is usually followed up by cotton because, like grain crops, it too maintains soil structure. Even though cultural practices are important growers are more likely to respond to market conditions when deciding how to rotate their crops.

The following is a mathematical statement of the generalized representative-farm linear programming model. Specific models will vary slightly from the generalized model as noted in the later discussion.

The objective of this model is to:

$$\text{Max } \pi = \sum_{k=1}^{K} P_k \cdot Q_k - \sum_{k=1}^{K} NWFC \cdot Land_k - \sum_{k=1}^{K}\sum_{t=1}^{T}\sum_{n=1}^{N} NFC_{ktn} * NBUY_{kn} - \sum_{k=1}^{K}\sum_{t=1}^{T}\sum_{p=1}^{P} PFC_{ktp} * PBUY_{kp}$$

Subject to:

Constraint 1 (Land):

$$\sum_{k=1}^{K} Land_k \leq Land$$

Constraint 2 (Crop Acreage):

$$Land_k \leq PCA_k \quad k \neq 6,7$$

$$Land_6 + Land_7 \leq PCA_7$$

Constraint 3 (Commodity Balance):

$$Q_k - \sum_{k=1}^{K} Y_k \cdot Land_k \leq 0$$

Constraint 4 (Nitrogen Plant Balance):

$$\sum_{k=1}^{K}\sum_{t=1}^{T} (ND_{kt} * Land_k - NAMT * WD_{kt} -$$

$$\sum_{n=1}^{N} NBUY_{ktn}) \leq 0$$

Constraint 5 (Phosphorous Plant Balance):

$$\sum_{k=1}^{K}\sum_{t=1}^{T} (PD_{kt} * Land_k - PAMT * WD_{kt} -$$

$$\sum_{p=1}^{P} PBUY_{ktp}) \leq 0$$

Constraint 6 (Water Balance):

$$\sum_{k=1}^{K}\sum_{t=1}^{T} TWD_{kt} * Land_k - GWSUP_t - EFSUP_t \leq 0$$

Constraint 7 (Ground Water Supply):

$$\sum_{k=1}^{K}\sum_{t=1}^{T} GWSUP_{kt} \leq GWSUP_t$$

Constraint 8 (Ground Water Purchase Balance):

$$\sum_{k=1}^{K}\sum_{t=1}^{T} GWSUP_{kt} - GWQTY \leq 0$$

Constraint 9 (Wastewater Effluent Supply):

$$\mathop{}\limits_{k=1}^{K}\mathop{}\limits_{t=1}^{T} EFSUP_{kt} \qquad \leq EFSUP_{t}$$

Constraint 10 (Wastewater Effluent Purchase Balance):

$$\mathop{}\limits_{k=1}^{K}\mathop{}\limits_{t=1}^{T} EFSUP_{kt} - EFQTY \qquad \leq 0$$

Constraint 11 (Ground Water-Wastewater Effluent Balance):

$$\mathop{}\limits_{k=1}^{K}\mathop{}\limits_{t=1}^{T} GWRAT_{kt} * GWSUP_{kt} -$$

$$\mathop{}\limits_{k=1}^{K}\mathop{}\limits_{t=1}^{T} EFRAT_{kt} * EFSUP_{kt} \qquad \leq 0$$

Where the variables listed in alphabetical order, are:

$EFRAT_{kt}$ = Percentage of wastewater effluent to be blended with ground water for crop k in month t.

EFQTY = Acre-inches of wastewater effluent used.

$EFSUP_{kt}$ = Wastewater effluent supply for k^{th} crop in month t.

$EFSUP_{t}$ = Wastewater effluent supply available in month t.

$GWRAT_{kt}$ = Percentage of ground water to be blended with wastewater effluent for crop k in month t.

GWQTY = Acre-inches of ground water used.

$GWSUP_{kt}$ = Ground water supply for k^{th} crop in month t.

$GWSUP_{t}$ = Ground water supply available in month t.

k = Type of crop.

1 = Upland Cotton

2 = American-Pima Cotton

3 = Durum Wheat

4 = Milo

5 = Barley-Milo Double Crop

6 = Alfalfa Establishment

7 = Alfalfa Production

Land = Total irrigated land available.

$Land_k$ = Number of acres of land devoted to crop k.

n = Source of nitrogen fertilizer

1 = Ammonium phosphate-sulphate

2 = Diammonium phosphate

3 = Uran 32

4 = Anhydrous ammonia

NAMT = Nitrogen contained for the k^{th} crop, from wastewater effluent.

$NBUY_{kt}$ = Pounds of n source of nitrogen purchased and applied for k^{th} crop in month t.

ND_{kt} = Nitrogen demand for the k^{th} crop in month t.

NFC_{ktn} = Net cost per pound of purchasing and applying n source of nitrogen fertilizer to the k^{th} crop in month t.

$NWFC_k$ = Nonwater fertilizer costs for k^{th} crop.

P_k = Cost of commodity k.

p = Source of phosphorous fertilizer.

1 = Ammonium phosphate-sulphate

2 = Diammonium phosphate

PAMT = Phosphorous contained for k^{th} crop, from wastewater effluent.

$PBUY_{kt}$ = Pounds of p source of phosphorous purchased and applied for crop k^{th} in month t.

PCA_k = Maximum acreage for crop k.

PD_{kt} = Phosphorous demand for the k^{th} crop in month t.

PFC_{ktp} = Net cost per pound of purchasing and applying p soucre of phosphorous fertilizer to the k^{th} crop in month t.

Q_k = Unit weight of commodity k.

s = Source of water.

1 = Ground water

2 = Wastewater Effluent

t = Month of the year, 1, 2, ... 12.
t.

TWD_{kt} = Total water demand by k^{th} crop in month t.

$WD_k t$ = Amount of wastewater effluent demanded by crop k in month t.

Y_k = Yield of crop k.

CHAPTER FOUR

THE DATA

This chapter dicusses the data requirements of the linear programming model used in the analysis. The cost and availability of local water sources are discussed in the first section. The nutrient content of wastewater effluent and the required ratio of ground water to wastewater effluent are provided in the second section. The third section gives the yield-water use relationships for the crops. The crop fertilizer requirements and, associated costs are in the fourth section. Net returns data necessary for each production activity are given in the fifth section. The final section discusses crop acreage restrictions.

Cost and Availability of Local Water Sources

Cost of Ground Water

The variable cost for an acre-foot of ground water to a farm in Avra Valley, based on a 375 foot lift, is $37.66 or $42.01 for electric and natural gas power respectively (Hathorn, 1986). These costs which relate directly to the operation of the well are variable costs and include energy costs, repair and maintenance. The cost of an acre-foot of ground water to a farm in the Cortaro-Marana Irrigation District is $20.00 (Hathorn, 1986). This fee is assessed by the Cortaro Water Users Association.

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The Engineering-News Record (ENR) Construction Index is used to convert the cost of the project to 1986 dollars. The following equation is used to convert the cost of the project to a different time period:

$$\text{Cost in 1986} = \frac{\text{Cost at 1978(ENR Index for 1986)}}{\text{ENR Index for 1978}}$$

$$= \frac{\$850{,}000(392.7)}{258.4}$$

$$= \$1{,}291{,}776.00$$

The useful life of the project is considered to be 20 years. The cost of the project is financed by the City of Tucson by issuing revenue bonds, which are repaid from revenues generated by the project. The cost of capital or the interest rate on the local bond is 10 percent. The annual cost of the project is $151,731, which is determined by ammortizing the cost of the construction project over a 20 year period at 10 percent. The conveyance cost per acre-foot of wastewater effluent is then calculated at $8.16. The conveyance cost is computed by dividing the annual cost of the project by 18,600 acre-feet. The total cost per acre-foot is then $13.16 based on a conveyance cost of $8.16 in additon the $5.00 assesement fee charged by the City of Tucson.

As for Avra Valley a conveyance system will have to built. The cost of conveying wastewater effluent to Avra

Valley was estimated by RGA Consulting Engineers in 1979. The system was designed which would receive wastewater effluent from both Roger and Ina Road treatment facilities. The system was designed to convey 41,120 acre-feet in a concrete-lined canal. The size of the canal was based on the monthly wastewater effluent demand for Avra Valley. A lift station and approximately two miles of force main will also be required. A pipeline was considered, but the costs were calculated at twice that of an open canal.

The cost of the project in Avra Valley 1979 was estimated at $24,529,670 plus $436,985 per year for energy costs. No cost was given for repair, maintenance, or attendance. The cost of the project for 1986 is $34,464,406. The energy cost of $436,985 per year is based on a power cost of $0.05 per kilowatt-hour. Since the growers in Avra Valley are currently paying $0.047 per kilowatt-hour the annual power cost can be assumed to be $410,938. (Hathorn, 1986).

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Cost of Central Arizona Project Water

The cost of Central Arizona Project (CAP) Water at canal side rates is $56.00 per acre-foot. Cortaro-Marana Irrigation District and Avra Valley would be responsible for the conveyance costs. Since conveyance costs have not been determined the farm-gate price for CAP water will be probably be anywhere from $80 to $200 an acre-foot.

Availability of Ground Water and Wastewater Effluent

For the time being neither Avra Valley nor Cortaro-Marana Irrigation District are restricted in the use of ground water. This is due largely to farmers participating in government programs which requires them to set aside acreage. For 1985 the available supply of wastewater effluent for Cortaro-Marana Irrigation District and Avra Valley was about 47,800 acre-feet per year. Total wastewater effluent discharge then was 53,000 acre-feet, but 1,700 acre-feet was used by golf courses and 3,500 by the Cortaro-Marana Irrigation District. Refer to Table 1 in Chapter 1 for net wastewater effluent projections. Currently the available supply of wastewater effluent to Cortaro-Marana Irrigation District is 4,800 acre-feet. However, assuming a new conveyance system is built the available supply of wastewater effluent would increase to 18,600 acre-feet per year. A supply of 18,600 acre-feet per year for 12,000 acres for 12 months of the year means there is 1.55 acre-inches per month per acre available for use. Avra Valley has no supply of wastewater effluent. If a new conveyance system is built then the available supply would be 41,120 acre-feet under the proposed design. A supply of 41,120 acre-feet per year for 16,000 acres for 12 months of the year means there is 2.57 acre-inches per month per acre available for use.

Nutrient Content of Wastewater Effluent and the Required Ratio of Ground Water to Wastewater Effluent

The principal nutrients in wastewater effluent are nitrogen, phosphorous, and potassium. Only nitrogen and phosphorous are considered since there is no demand for potassium by the crops involved in this study. These nutrients do have a potential economic value.

The total available nitrogen concentration in wastewater effluent averages 9.58 milligrams per liter (mg/l). Nitrogen is in the form of organic nitrogen, ammonium nitrogen, and nitrate nitrogen. This is equivalent to 2.2 pounds of N per acre-inch. The phosphorous concentration is 2.46 mg/l which is equivalent to 0.56 pounds per acre-inch. These values are based on a 12 month average for 1984 as shown in Table 15 (Pima County Wastewater Management Dept, 1984). The monthly figures are an average of the Ina and Roger Road Treatment Plants.

The ratio of ground water to wastewater effluent is important because over fertilization could lower the quality of the crop and reduce yields. A suitable blend of about 40 to 45 percent wastewater effluent of total water use has been recommended (Bookman-Edmonston Engineering, 1978). This was based on a nitrogen concentration of 76 pounds per acre-foot for wastewater effluent. Another study by RGA Consulting Engineers suggested the blend should be 100 percent for the months January through April, 84 percent May through July, no effluent August through October, and 65 percent for November and December. Buckeye Irrigation District irrigates with about 60 percent wastewater effluent in the summer and about 90 percent in the winter months (Jones, 1986). There have been no complaints from the growers in the Buckeye Irrigation District. In this study 90 percent wastewater effluent will be used December through April, 84

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Nitrogen and Phosphorus Concentrations for Wastewater Effluent for Ina and Roger Road Treatment Plants for 1984
(mg/l)

Month	NO_3-N	NH_4-N	Org. N	PO_4-P
Jan.	2.21	11.67	2.96	8.34
Feb.	1.35	4.88	3.74	8.28
March	5.47	6.26	3.67	8.70
April	6.15	6.97	4.64	8.46
May	NA	NA	NA	NA
June	4.25	2.21	3.68	9.00
July	3.88	5.50	3.00	6.31
Aug.	4.97	0.48	3.17	8.44
Sept.	6.64	1.11	3.56	9.64
Oct .	8.50	3.85	3.51	4.05
Nov.	16.76	11.92	4.13	8.17
Dec.	1.55	11.47	3.77	5.46
Avg.	5.61	6.03	3.62	7.70
Avg. Elemental Form	1.27	4.69	3.62	2.46

Source: Pima County Wastewater Management Department, 1984.

percent May through July, 40 percent August through November.

Yield-Water Use Relationships

Yield

The yields for the crops used in this study, as shown in Table 16, are based on an average of the years 1980 through 1984 for Pima County (Arizona Crop and Livestock Reporting Service, 1984).

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Crop water requirements are based on field crop budgets for Pima County (Hathorn, 1986). The consumptive use requirement for each crop is not used but rather the actual amount of ground water applied. Effective annual rainfall is not considered in the model. Table 17 gives monthly water usage by crops.

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Fertilizer Requirements

The fertilizer requirements, nitrogen and phosphorous, are on a monthly basis. Potassium is of no concern because none of the crops require it. However, no place in the literature are monthly fertilizer requirements given for the crops in the study, except for cotton, and that is only for nitrogen. Fertilizer requirements are only given for the growing season of the crop. Table 18

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Milo	44.50 cwt.
Barley	42.00 cwt.
Alfalfa	6.14 tons

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CHAPTER FOUR

THE DATA

This chapter dicusses the data requirements of the linear programming model used in the analysis. The cost and availability of local water sources are discussed in the first section. The nutrient content of wastewater effluent and the required ratio of ground water to wastewater effluent are provided in the second section. The third section gives the yield-water use relationships for the crops. The crop fertilizer requirements and, associated costs are in the fourth section. Net returns data necessary for each production activity are given in the fifth section. The final section discusses crop acreage restrictions.

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Source: Pima County Wastewater Management Department, 1984.

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Yield

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The fertilizer requirements, nitrogen and phosphorous, are on a monthly basis. Potassium is of no concern because none of the crops require it. However, no place in the literature are monthly fertilizer requirements given for the crops in the study, except for cotton, and that is only for nitrogen. Fertilizer requirements are only given for the growing season of the crop. Table 18

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Milo	44.50 cwt.
Barley	42.00 cwt.
Alfalfa	6.14 tons

Source: Arizona Crop and Livestock Reporting Service, 1984.

Table 17.

Monthly Water Usage by Crops for Pima County

(acre-inches per month)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Alfalfa Stand Estb.	0	0	0	0	0	0	0	0	0	16.0	4.0	0	20.0
Alfalfa Hay	0	0	6.0	6.0	12.0	12.0	12.0	12.0	6.0	6.0	0	0	72.0
Upland Cotton	1.2	6.0	4.8	0	0	6.0	12.0	12.0	0	0	0	0	42.0
Pima Cotton	3.6	8.4	0	0	0	6.0	12.0	12.0	6.0	0	0	0	48.0
Barley Double Crop	0	0	6.0	12.0	6.0	0	0	0	0	0	0	12.0	36.0
Durum Wheat	0	0	6.0	12.0	10.0	0	0	0	0	0	0	12.0	40.0
Milo Double Crop	0	0	0	0	0	8.0	12.0	12.0	6.0	0	0	0	38.0

Source: Hathorn, 1986.

lists the type and the amount of fertilizer applied for the growing season (Hathorn, 1986).

The nitrogen requirements were determined for Upland cotton and American-Pima cotton by Mezainis for Maricopa County (Mezainis,1985). Mezainis derived a nitrogen uptake curve. Extrapolating from the nitrogen uptake curve, using Water Level II, the percentage nitrogen per month required can be determined (Figure 4). To determine the percent nitrogen required per month the nitrogen uptake curve is broken down into months of the growing season with the planting date begining the 1st of April. Any increase in grams of nitrogen per meter over last month can be considered the percentage nitrogen required for that month. For example, from 5/1 to 6/1 there was an increase of 1.5 grams of nitrogen per meter over last month. With the total grams of nitrogen per meter being 21.0 grams for 9/30 the percentage required for the month of May is 7.1%.

Thus, knowing the monthly percentage of nitrogen required and the amount of elemental nitrogen applied during the growing season the amount of nitrogen per acre per month can be determined. Table 19 gives the percent nitrogen required per month along with the pounds of nitrogen per acre per month required by both Upland cotton and American-Pima cotton.

Table 18.

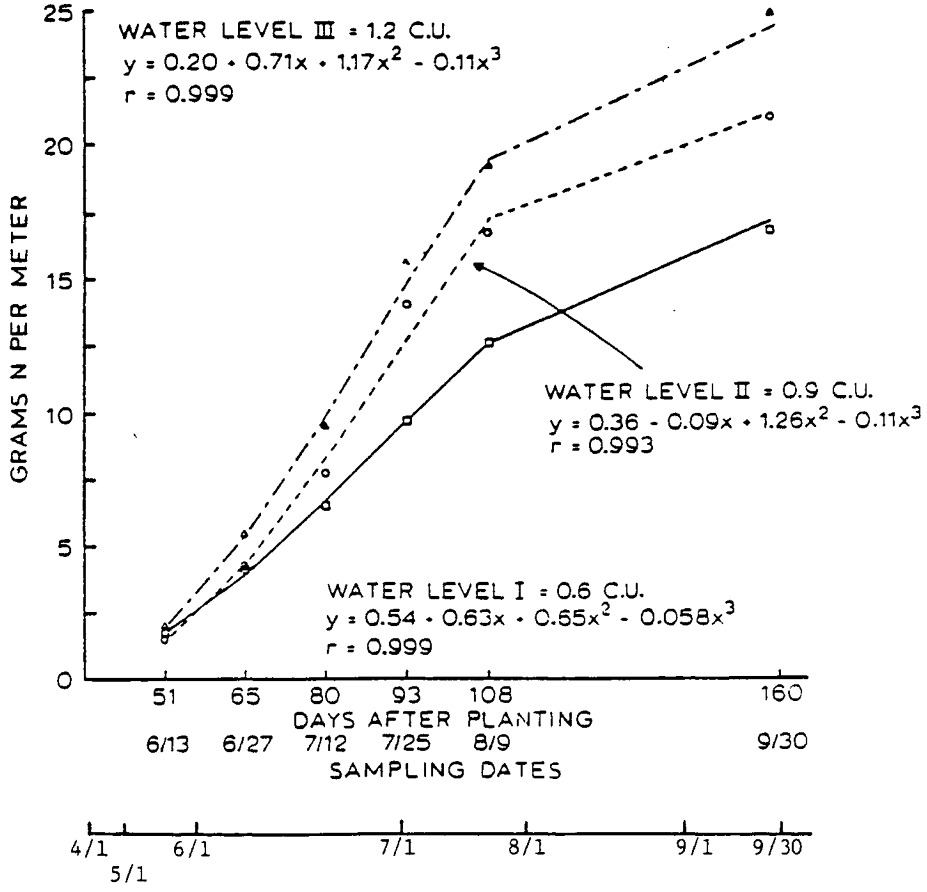
Fertilizer Application by Crops by Growing Season

Crop	Fertilizer	Quantity
Alfalfa Stand Estb.	Diammonium phosphate (11-48-0)	200.0 lbs.
Alfalfa Hay	-------	------
Upland Cotton	Ammonium Phosphate-sulfate (16-20-0)	250.0 lbs.
	Uran 32 (32-0-0)	220.0 lbs.
American-Pima Cotton	Ammonium Phosphate-sulfate (16-20-0)	250.0 lbs
Barley Double Crop	Ammonium phosphate-sulfate (16-20-0)	200.0 lbs
	Anhydrous ammonia (82-0-0)	122.0 lbs.
Durum Wheat	Ammonium phosphate-sulfate (16-20-0)	200.0 lbs.
	Anhydrous ammonia (82-0-0)	150.0 lbs.
Milo Double Crop	Ammonium phosphate-sulfate (16-20-0)	250.0 lbs.
	Anhydrous ammonia (82-0-0)	61.0 lbs.

Source: Hathorn, 1986.

Figure 4.

Cubic Polynomial Regression Model for Total N Uptake Over Time for Three Water Levels for Upland Cotton, Maricopa, 1984



Source: Mezainis, 1985.

Table 19.
Percent N and the Pounds of N Required per Month per Acre for Upland Cotton and American-Pima Cotton

Crop	Month	% N/Month	lbs. of N/Month
Upland Cotton	April	4.5 %	5.0 lbs.
	May	7.0	7.7
	June	48.0	53.0
	July	24.0	26.5
	Aug.	12.0	13.2
	Sept.	4.5	5.0
American-Pima Cotton	April	4.5	1.8
	May	7.0	2.8
	June	48.0	19.2
	July	24.0	9.6
	Aug.	12.0	4.8
	Sept.	4.5	1.8

Source: Estimates derived from Hathorn, 1986.

The monthly nitrogen needs are estimated for alfalfa stand establishment, alfalfa hay, durum wheat, barley double crop and milo double crop. These will be based on the amount of nitrogen applied and when the crop is most likely in need of nitrogen. Since cotton is the principal crop requiring nitrogen in the linear programming model, total nitrogen demand will be reasonably accurate. Table 20 gives the estimated percent nitrogen required per month along with the pounds of nitrogen required per month per acre required by alfalfa stand establishment, alfalfa hay, durum wheat, barley double crop, and milo double crop.

The monthly phosphorous needs are estimated for all the crops in the study. These will be based on the amount of phosphorous applied and when the crop is most likely in need of phosphorous. Phosphorous demand can be considered the same for each month, even though phosphorous demand is greater during flowering (Tucker, 1986). Table 21 gives the estimated percent phosphorous required per month along with the pounds of phosphorous required per month per acre by all the crops.

Cost of Fertilizer

The cost of fertilizer is on an elemental basis. In addition to the elemental cost of nitrogen and phosphorous there is an application cost, unless anhydrous ammonia or Uran 32 are applied. Application costs are for machinery

Table 20.

Estimated Percent N and the Pounds of N Required per Month per Acre for Alfalfa Stand Established, Alfalfa Hay, Durum Wheat, Barley Double Crop, Milo Double Crop

Crop	Month	% N/Month	Lbs. of N/Month
Alfalfa	Oct.	33.3 %	7.3 lbs.
Stand	Nov.	33.3	7.3
Estb.	Dec.	33.3	7.3
Alfalfa Hay	---	----	---
Durum	Jan.	5.0	8.0
Wheat	Feb.	5.0	8.0
	March	5.0	8.0
	April	40.0	61.5
	May	40.0	61.5
	Dec.	5.0	8.0
Barley	Jan.	8.0	10.6
Double	Feb.	8.0	10.6
Crop	March	38.0	50.0
	April	38.0	50.0
	Dec.	8.0	10.6
Milo	June	11.0	9.9
Double	July	33.0	29.7
Crop	Aug.	39.0	35.1
	Sept.	17.0	15.3

Source: Estimates derived from Hathorn, 1986.

Table 21.

Estimated Percent P and the Pounds of P Required per Month per Acre by Upland Cotton, American-Pima Cotton, Alfalfa Stand Established, Alfalfa Hay, Durum Wheat, Barley Double Crop, and Milo Double Crop

Crop	Month	% P/Month	lbs. of P/Month
Alfalfa Stand Estb.	Jan.	8.34 %	3.5 lbs.
	Feb.	8.34	3.5
	March	8.34	3.5
	April	8.34	3.5
	May	8.34	3.5
	June	8.34	3.5
	July	8.34	3.5
	Aug.	8.34	3.5
	Sept.	8.34	3.5
	Oct.	8.34	3.5
	Nov.	8.34	3.5
	Dec.	8.34	3.5
Alfalfa Hay	---	----	---
Upland Cotton	May	20.0	4.3
	June	20.0	4.3
	July	20.0	4.3
	Aug.	20.0	4.3
	Sept.	20.0	4.3
American-Pima Cotton	May	20.0	4.3
	June	20.0	4.3
	July	20.0	4.3
	Aug.	20.0	4.3
	Sept.	20.0	4.3
Barley Double Crop	Jan.	16.7	2.9
	Feb.	16.7	2.9
	March	16.7	2.9
	April	16.7	2.9
	May	16.7	2.9
	Dec.	16.7	2.9

Table 21 continued.

Durum	Jan.	16.7	2.9
Wheat	Feb.	16.7	2.9
	March	16.7	2.9
	April	16.7	2.9
	May	16.7	2.9
	Dec.	16.7	2.9
Milo	June	20.0	4.3
Double	July	20.0	4.3
Crop	Aug.	20.0	4.3
	Sept.	20.0	4.3
	Oct.	20.0	4.3

Source: Estimates derived from Hathorn, 1986.

and labor. Fertilizer application costs run any where from \$0.0036/lb. to \$.0046/lb. In this study an average of the two (\$0.0041) is used. Total cost per pound is determined from the elemental cost of nitrogen and phosphorous for each fertilizer, plus the application cost per pound. Table 22 gives the cost of each fertilizer along with the total cost of nitrogen and phosphorous per pound. An example in deriving the total cost per pound for each element is determined as follows:

Step 1. Determine the cost per pound for ammonium phosphate-sulphate.

\$225.00/2000 lbs. = \$0.1125/lb.

Step 2. Determine the percentage of nitrogen and phosphorous in the fertilizer.

Ratio (16-20-0)

20% P_2O_5

8.6% P

16% N

Step 3. Determine the cost per pound of each element.

16% + 8.6% = 24.6%

16%/24.6% = 65% of the cost is N

\$0.1125 x 0.65 = \$0.073/lb. for N

8.6%/24.6% = 35% of the cost is P

\$0.1125 x 0.35 = \$0.039/lb. for P

Step 4. Determine total cost per pound for N and P.

Table 22.

Fertilizer Cost Plus Total Cost of N and P per Pound

Fertilizer	Fertilizer Cost	Total Cost of N/lb.	Total Cost of P/lb.
Ammonium Phosphate-Sulphate	$225/ton	$0.077/lb.	$0.043/lb.
Diammonium Phosphate	280	0.10	0.053
Uran 32	185	0.093	-----
Anhydrous Ammonia	300	0.15	-----

Source: Hathorn, 1986.

$0.073/lb. for N x $0.0041 = $0.077/lb. for N

$0.0.039/lb. for P x $0.0041 = $0.043/lb. for P

Variable Costs and Returns

Linear programming models require data on variable costs for each production activity. A production activity in the model is one acre of crop. Variable costs per acre are determined by subtracting the cost of irrigation water, the cost of fertilizer and its application cost from total operating costs (Hathorn, 1986). Refer to Table 23 for variable costs per acre for each crop. The cost of irrigation water and fertilizer are two decision variables or activities in the linear progamming models and thus must be subtracted. Net returns per acre is the difference between gross income and variable costs. Gross income is the product of yield and product price. Product prices will be held constant (Table 24).

Crop Acreage Restrictions

Cotton is the most profitable crop grown in Cortaro-Marana Irrigation District and Avra Valley. Therefore acreage must be restricted somewhat to prevent all cotton solution by the model. No acreage restrictions would impart an unrealistic view of grower's perception concerning risk and rotational requirements. Acreage restrictions are based, as well for the other crops, on an

Table 23.

Variable Costs per Acre Minus the Cost of Irrigation Water, the Cost of Fertilizer and its Application Costs

Crop	Variable Cost per Acre
Alfalfa Stand Estb.	$79.04
Alfalfa Hay	121.83
Upland Cotton	306.38
American-Pima Cotton	393.34
Barley Double Crop	111.41
Durum Wheat	116.44
Milo Double Crop	110.46

Source: Hathorn, 1986.

Table 24.

Product Prices

Crop	Price/unit
Upland Cotton	
Lint	$0.65/lb.
Seed	0.055/lb.
American-Pima Cotton	
Lint	1.02/lb.
Seed	0.05/lb.
Durum Wheat	6.75/cwt.
Milo	6.00/cwt.
Barley	6.25/cwt.
Alfalfa	85.00/ton

average of acres planted for each crop in Pima County for the years 1980 through 1984 in relation to the total average acres planted for all the crops (Arizona Crop and Livestock Reporting Service, 1984). Thus crop restrictions are based on their proportional make up as shown in Table 25. The exception is barley and milo. Barley and milo are double cropped. Since 1200 acres are planted to barley it can be assumed 1200 acres are planted to milo. A total of 2400 acres which is 9 percent of the total acreage, or 27,218 acres. This leaves 584 acres to be planted in milo which is 2 percent of the total acreage. By imposing these acreage restrictions a more realistic value will be obtained as far the quantity of wastewater effluent demanded.

Table 25.

Average Planted Acreage for Upland Cotton, American-Pima Cotton, Durum Wheat, Barley Double Crop, Milo Double Crop, and Alfalfa for Pima County

Crop	1980	1981	1982	1983	1984	Avg.	Percent
Upland Cotton	17900	19800	15700	10100	15500	15800	58.0%
American-Pima Cotton	2350	2150	2800	1540	1230	2014	7.4
Durum Wheat	3500	5000	4700	4000	5000	4440	16.3
Milo	2000	2500	2000	1300	1120	1784	6.6
Barley	2000	1000	900	900	1200	1200	4.4
Alfalfa	2000	1800	2000	2000	2100	1980	7.3

Source: Arizona Crop and Livestock Reporting Service, 1984.

CHAPTER FIVE

RESULTS OF THE ANALYSIS

The major objective of this study, as stated in Chapter 1, is to determine the demand for wastewater effluent for agricultural irrigation. Parametric analysis provides a way of approximating the demand curve for it traces out how the solution changes, the quantity demanded, as the price for wastewater effluent changes. This method has its merit because buyers will usually understate the true price they are willing to pay for a given quantity when queried informally. It is necessary to know the true economic value in order to measure the benefits of wastewater effluent as opposed to using only ground water.

In estimating the demand curve for wastewater effluent changes in the price of ground water must be considered. Sensitivity analysis permits the determination of how sensitive the demand for wastewater effluent is to a change in the price of ground water. In order to perform sensitivity analysis, a range of ground water prices will be considered in estimating their effect on the demand for wastewater effluent.

The objective of the linear programming model is to determine the optimal allocation of scarce resources among competing activities. This requires optimizing the function subject to several constraints. An algorithum is a set of rules or a systematic procedure for finding the solution to the problem. The process of solving the linear programming model in this study requires a large number of calculations and is therefore best performed by a computer program. The computer program used in this study is called LINDO (Schrage, 1984).

In estimating the demand curve for wastewater effluent four different scenarios are to be evaluated. Scenario 1 estimates the quantity of wastewater effluent demanded under current ground water prices given a supply of wastewater effluent of 18,600 AF. Plant nutrient requirements are the most constraining. Scenario 2 estimates the quantity of wastewater effluent demanded under current ground water prices with an unlimited supply of wastewater effluent. Plant nutrient requirements are the most constraining. Scenario 3 estimates the quantity of wastewater effluent demanded under current ground water prices with an unlimited supply of wastewater effluent. However, in scenario 3 the plant nutient requirements are relaxed in favor of the blending ratio. Scenario 4 estimates the quantity of wastewater effluent demanded at various prices for alternative sources of water given a supply of wastewater effluent of 18,600 AF. Plant nutrient requirements are the most constraining.

Scenario 1: Demand for Wastewater Effluent Under Current Ground Water Prices with a Supply of Wastewater Effluent of 18,600 AF

In Avra Valley there was no quantity of wastewater effluent demanded because of high conveyance costs. No economic incentive exists to use wastewater effluent since the total cost of wastewater effluent is too high compared to the cost of ground water. The cost per acre-foot for wastewater effluent is $113.44 which is based on a conveyance cost of $108.44 and an assesment fee of $5.00 per acre-foot. The variable cost for ground water, pumped by electric power, is $37.66 per acre-foot. For Avra Valley, the conveyance cost is the most limiting constraint.

As for the Cortaro-Marana Irrigation District the annual quantity of wastewater effluent demanded is 11,385 acre-feet given a potential supply of 18,600 acre-feet. This is based on a price of $13.16 and $20.00 per acre-foot for wastewater effluent and ground water, respectively. Total quantity demanded could have been higher had the quantity of wastewater effluent supplied been sufficient for every month. Table 26 shows a list of the prices and quantities demanded per period of time at each price in the list. This list of prices and quantities is called a

Table 26.

Demand Schedule for Wastewater Effluent for Cortaro-Marana Irrigation Disrict Given Monthly Supply Constraints

Quantity Demanded (acre-feet)	Price per Acre-Foot (dollars)
3,412	24.25
4,197	24.00
4,197	23.00
8,408	22.50
10,088	22.00
10,088	21.00
10,975	20.25
11,385	20.00
11,385	13.16

market demand schedule. Given the price-quantity data of the demand schedule the demand curve can be derived.

Scenario 2:
Demand for Wastewater Effluent Under Current Ground Water Prices with an Unlimited Supply of Wastewater Effluent

As mentioned the quantity of wastewater effluent demanded for the Cortaro-Marana Irrigation District could have been greater had the quantity supplied been sufficient for all months. The potential demand for wastewater effluent relaxing the supply constraint for wastewater effluent is 24,776 acre-feet per year. The market demand schedule, Appendix E, shows a list of the prices and quantities demanded per period of time at each price in the list. Given the price-quantity data of the demand schedule the demand curve can be derived.

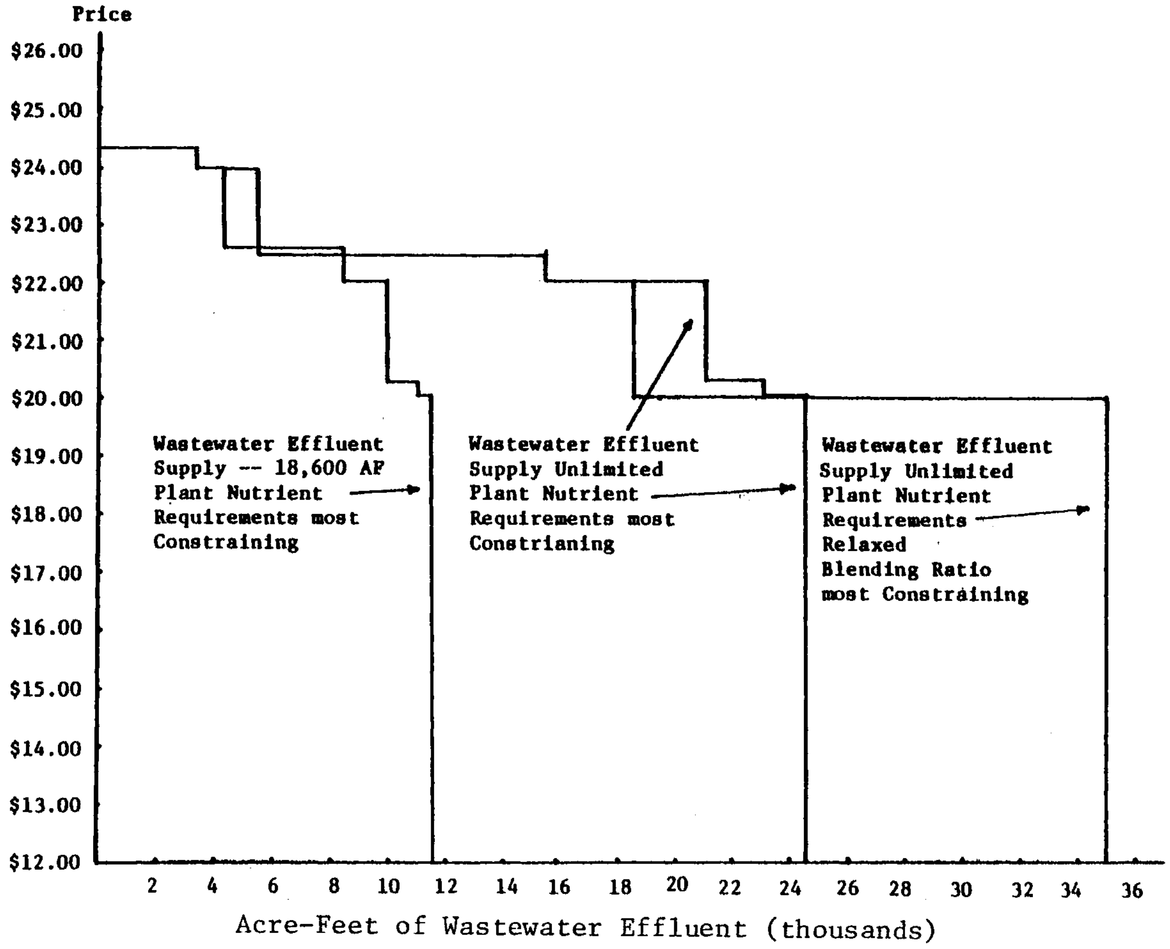
Scenario 3:
Demand for Wastewater Effluent Under Current Ground Water Prices Relaxing Plant Nutrient Constraints in Favor of the Blending Ratio

The nutrient constraints had the greatest influence on the demand for wastewater effluent. In any given month the blending ratio, varied due the nutrient requirement of the crops. Having different blending ratios within the same month is physically impossible since ground water and wastewater effluent cannot be mixed separately for each individual crop. The blending ratios must remain the same for all crops for that particular month. However, by forcing the blending ratios to remain the same, there will be months when nutrients are applied in excess of what is actually required. As mentioned in Chapter 4, Buckeye Irrigation District irrigates with about 90 percent wastewater effluent in the winter months and about 60 percent in the summer months, well in excess of the crop's nutrient requirements. The District experiences no loss in crop production. Their ratios are slightly higher than those in the linear programming model. When the nutrient requirements ere disregarded in favor of the blending ratio the quantity wastewater effluent demanded for Cortaro-Marana Irrigation District is 34,480 acre-feet per year. The market demand schedule, Appendix F, shows a list of prices and quantities demanded per period of time at different water prices. Given the price-quantity data of the demand schedule the demand curve can be derived. Consequently, the blending ratio is the most significant constraint influencing the quantity demanded for wastewater effluent.

The derived demand curves for wastewater effluent for scenario 1 are shown in Figure 5. The demand for wastewater effluent is inelastic to price changes until the price reaches $20.00 per acre-foot for all three demand

Figure 5.

Demand Curves for Wastewater Effluent



curves. This can be expected since its substitute, ground water, is priced at $20.00 per acre-foot. Demand becomes more elastic when the price for wastewater effluent price is greater than $20.00 per acre-foot. The reason why wastewater effluent is still in demand at prices greater than $20.00 per acre-foot relates to the marginal value of nutrients in wastewater effluent. The elasticity of the demand curves is the same when the quantity demanded is constrained by the nutrient requirements of the crops, whether or not the availability of wastewater effluent is restricted or not. However, when the quantity demanded is based on the blending ratio the demand curve is more elastic for wastewater effluent. This is because the nutrients in wastewater effluent have a lower marginal value. The lower marginal value is the result of the blending ratio which applies nutrients in excess of what is actually required, thus the value of those nutrients applied in excess is zero.

The contribution of each crop to total net benefit for the Cortaro-Marana Irrigation District in irrigating with wastewater effluent as opposed to irrigating with ground water is shown in Table 27. The total net benefit is based on scenario 1 where the quantity demanded of wastewater effluent is constrianed by the nutrient requirements of the crops. The quantity available of

Table 27.

Total Net Benefit in Irrigating with Wastewater Effluent Based on the Crop's Nutrient Requirements Limiting the Supply of Wastewater Effluent to 18,600 Acre-Feet

	Net Returns per Acre			
Crop Crop	Ground Water	Ground Water/ Wastewater Effluent	Net Benefit	Total Net Benefit
Upland Cotton	$294.28	$299.97	$5.69	$39,602
American-Pima Cotton	176.33	177.89	1.56	1,385
Durum Wheat	116.94	136.95	20.01	39,139
Milo	81.50	88.20	6.70	1,608
Barley-Milo Double Crop	154.32	179.77	25.45	27,486
Alfalfa	221.44	223.89	2.45	2,146
Total Net Benefit to Cortaro-Marana Irrigation District				$111,366

wastewater effluent was 18,600 acre-feet. The winter crops benefited the most because they used a higher proportion of wastewater effluent. Their irrigation schedule also coincided with the crop's nutrient requirements. The total net benefit based on the blending ratio rather then the plant's nutrient requirements is shown in Table 28. Again the winter crops benefited the most because of the higher proportion of wastewater effluent used.

Scenario 4:

Demand for Wastewater Effluent at Various Prices for Alternative Sources of Water Given a Supply of Wastewater Effluent of 18,600 AF

Estimating the change in the quantity demanded at various prices for alternative water sources is essential in determing how sensitive the demand for wastewater effluent is to a change in its price. The market demand schedule, Appendix G, shows a list of prices and quantities demanded per period of time at different prices for alternative sources of water as the price of wastewater effluent changes. The prices for the alternative sources of ground water are $25.00, $50.00, and $75.00 per acre-foot. The available supply of wastewater effluent is held at 18,600 acre-feet per year. The nutrient requirements of the crops are the most constraining.

When alternative sources of water is priced at $25.00 per acre-foot the quantity of wastewater effluent

Table 28.

Total Net Benefit in Irrigating with Wastewater Effluent Based on the Blending Ratio

	Net Returns per Acre			
Crop Crop	Ground Water	Ground Water/ Wastewater Effluent	Net Benefit	Total Net Benefit
Upland Cotton	$294.28	$316.30	$22.02	$153,259
American-Pima Cotton	176.33	200.29	23.96	19,243
Durum Wheat	116.94	163.01	28.53	90,113
Milo	81.50	100.60	22.47	4,584
Barley-Milo Double Crop	154.32	198.31	46.53	47,509
Alfalfa	221.44	244.97	16.74	20,612
Total Net Benefit to Cortaro-Marana Irrigation District				$335,320

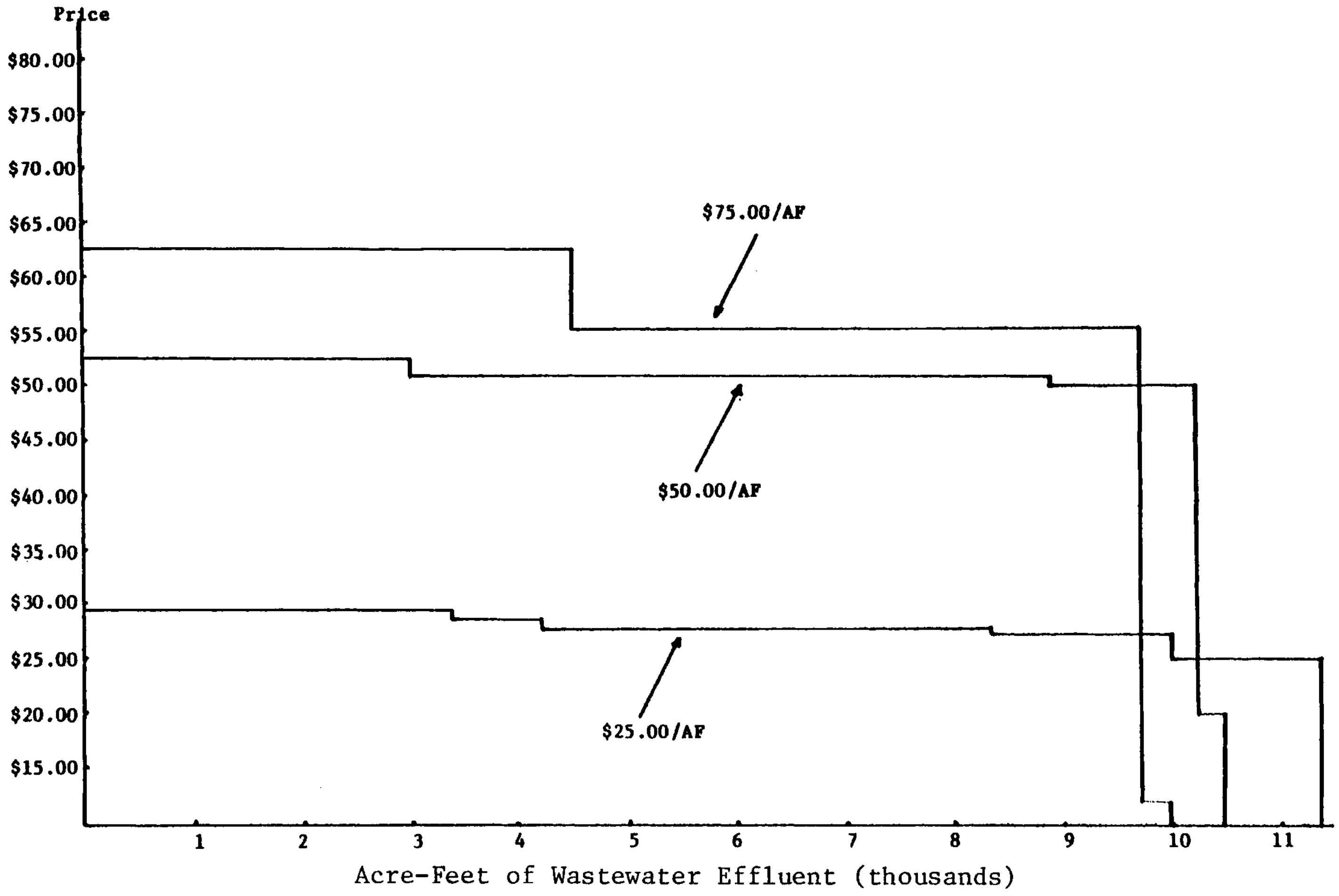
demanded when priced at $13.16 an acre-foot is 11,385 acre-feet per year. Demand for wastewater effluent remains inelastic as long as the price for wastewater effluent does not exceed the the price of $25.00 per acre-foot for alternative sources of water. When the price of wastewater effluent exceeds the price of alternative sources of water then demand becomes more elastic to price changes. Given the price-quantity data of the demand schedule the respective demand curve can be derived (Figure 6).

When alternative sources of water is priced at $50.00 per acre-foot the quantity of wastewater effluent demanded at $13.16 per acre-foot is 10,915 acre-feet per year. The decrease in the quantity demanded for wastewater effluent is because at $50.00 an acre-foot for alternative sources of water it is no longer profitable to grow milo. The variable costs are not being covered by crop sales. Even though wastewater effluent is priced at $13.16 an acre-foot, which is a cheaper substitute, the nutrient constraints limited its use. Had the nutrient constraints been relaxed milo might of have been grown. Milo is still grown when double cropped with barley because the profits from barley offset the losses from growing milo. The reason milo is still grown is due to cultural practices.

Demand for wastewater effluent is some what elastic to price changes up to a price of $50.00 per acre-foot. At

Figure 6.

Demand Curves for Wastewater Effluent for Increasing Prices for Ground or Surface Water



$50.00 an acre-foot for wastewater effluent demand is 10,454 acre-feet. At this price it is no longer profitable to grow barley and milo as a double crop. It can be assumed the profits from growing barley could no longer offset the losses of growing milo. Once the price of wastewater effluent exceeds the price of alternative sources of water the demand for wastewater effluent becomes more elastic to price changes in wastewater effluent. Given the price-quantity data of the demand schedule in Appendix E the respective demand curve can be derived (Figure 6).

When alternative sources of water is priced at $75.00 per acre-foot the quantity of wastewater effluent demanded when priced at $13.16 per acre-foot is 10,454 acre-feet per year. The decrease in the quantity demanded for wastewater effluent is because at $75.00 an acre-foot for alternative sources of water it is again no longer profitable to grow milo. As the price for wastewater effluent nears $55.00 an acre-foot it is no longer profitable to grow American-Pima cotton and alfalfa. The variable costs are not being covered by crop sales. Milo is still grown when double cropped with barley because the profits from barley offset the losses from growing milo. At $60.00 an acre-foot for wastewater effluent the quantity of wastewater effluent demanded is 4,650 acre-feet per year. At this price it is only profitable to grow Upland cotton. At $78.00 per acre-foot for wastewater effluent it is no longer profitable to grow Upland cotton. Given the price-quantity data of the demand schedule in Appendix E the respective demand curve can be derived (Figure 6).

CHAPTER SIX

SUMMARY AND CONCLUSION

The purpose of this study was to evaluate the demand for wastewater effluent as a source of irrigation water by the Cortaro-Marana Irrigation District and Avra Valley farmers. Evaluating the potential demand for wastewater effluent is important to the development of a water market in the Tucson Active Management Area (AMA). Generally, poor quality water, such as wastewater effluent, should be set aside for users with lower quality needs (e.g., agriculture, golf courses). One step to the creation of a water market is the exchanging of the City's wastewater effluent for ground water from the Cortaro-Marana Irrigation District and Avra Valley.

Wastewater effluent for the purposes of this study is sewage water that has been secondarily treated and disinfected. The total amount of wastewater effluent flow from Tucson's wastewater treatment facilites was approximately 46,000 AF for fiscal year 1983-1984. Only 13 percent of the wastewater effluent is being directly reused. The remainder of which is discharged into the Santa Cruz River. Presently, the amount of wastewater effluent available within the City of Tucson is projected to increase from the present level of 53,000 AF to 144,000 AF by the year 2030.

Although there are plans for increased use of wastewater effluent, a large proportion of wastewater effluent will continue to be released in ever increasing amounts into the Santa Cruz River. Under the Papago Resettlement Act the Tohono O'Odham Indian Tribe are entitled to 30,600 AF beginning in 1992. The Tohono O'Odham Indian Tribe has shown no interest in the reuse of the effluent. Even if they were interested they have yet to develop plans to expand their agriculture to sustain the use of effluent. There were plans by the City of Tucson to begin distributing up to 18,500 AF of wastewater effluent by 1985 serving landscape irrigation projects in the Tucson Metropolitan area. However, it is now 1986 and only 1700 AF are presently reused for landscape projects, which is far short of their projections. Therefore it is unlikely the potential demand for wastewater effluent based on total turf acreage projections will be met in the following years. Consequently, this leaves a sizeable block of uncommited wastewater effluent. There are also plans for a recharge system of wastewater effluent but at the time of this study are still in the developmental phase.

The general consensus of agronomists is that wastewater effluent can provide a source of irrigation water and plant nutrients for commercial crop production. However, due the high concentration of nutrients in wastewater effluent it must be blended with ground water. The ratio of ground water to wastewater effluent depends on the nutrient requirements of the crops.

Crops typically grown in the Cortaro-Marana Irrigation District and Avra Valley include American-Pima Cotton, Upland cotton, barley, milo, alfalfa, and durum wheat. There are other crops grown but because of their minor importance or the fact that they are vegetables excludes them from the study. Since cotton is the most profitable crop grown, its acreage must be restricted to prevent all cotton solutions. Acreage restrictions for cotton are based, as well for other crops in the study, on an average of the acres planted for each crop for the years 1980 through 1984. Thus crop restrictions are based on their proportional make up. The growing season is one year.

The reuse of wastewater effluent poses no health risks so long as the laws and recommendations governing its use are adhered to. Orchard and field crops and even vegetables can be irrigated with wastewater effluent. However, the water quality standards for vegetables are more stringent. Since vegetables are often consumed raw there is the risk of disease outbreaks. Therefore the grower will need to assess the level of risk if vegetables are to be irrigated.

Although a great deal of research has been done concerning the utilization of treated wastewater, very little has been done pertaining to its economic value as a commodity. As previously mentioned, the purpose of this study is to determine the demand for wastewater effluent and its net benefit. This is accomplished by the use of linear programming techniques.

Parametric analysis provides a way of approximating the demand curve for it traces out how the solution changes, the quantity demanded, as the price for wastewater effluent changes. This method has its merit because buyers will usually understate the true price they are willing to pay for a given quantity when queried informally. Sensitivity analysis permits the determination of how sensitive the demand for wastewater effluent is to a change in the price of ground water. In order to perform sensitivity analysis, a range of ground water prices were considered in estimating their effect on the demand for wastewater effluent.

The objective of the linear programming model is profit maximization. This is accomplished by maximizing net returns above variable production costs. Fixed costs are not considered since they are constant in the short run and occur regardless of the level of farming activity.

In estimating the demand curve for wastewater effluent four different scenarios were evaluated. Scenario 1 estimated the quantity of wastewater effluent demanded under current ground water prices given a supply of wastewater effluent of 18,600 AF. Plant nutrient requirements were the most constraining. Scenario 2 estimated the quantity of wastewater effluent demanded under current ground water prices with an unlimited supply of wastewater effluent. Plant nutrient requirements were the most constraining. Scenario 3 estimated the quantity of wastewater effluent demanded under current ground water prices with an unlimited supply of wastewater effluent. However, in scenario 3 the plant nutrient requirements were relaxed in favor of the blending ratio. Scenario 4 estimated the quantity of wastewater demanded at various prices for alternative sources of water given a supply of wastewater effluent of 18,600 AF. Plant nutrient requirements were the most constraining.

In scenario 1 for Avra Valley there was no quantity of wastewater effluent demanded because of high conveyance costs. No economic incentive exists to use wastewater effluent since the total cost of wastewater effluent was too high compared to the cost of ground water. The cost per acre-foot for wastewater effluent was $113.44 as opposed to a variable cost for ground water of $37.66 per acre-foot. Particularly it was the conveyance costs which prevented the resue of wastewater effluent. The reason was the distance from the wastewater treatment plants and the fact that pumping stations were required. Cortaro-Marana Irrigation District was closer and required no pumping stations. Thus, proximity of agricultural areas to wastewater treatment plants and the lift are important when considering its reuse.

For the Cortaro-Marana Irrigation District the quantity of wastewater effluent demanded was inelastic to price changes until the price reaches $20.00 per acre-foot. This can be expected since its substitute, ground water, was priced at $20.00 per acre-foot. Demand becomes more elastic for wastewater effluent when the price of wastewater effluent exceeded the price of ground water. The reason why wastewater effluent was still in demand at prices greater than $20.00 per acre-foot has to do with the marginal value of nutrients in wastewater effluent.

The nutrient constraints had the greatest influence on the demand for wastewater effluent. The quantity of wastewater effluent demanded was 11,385 acre-feet. The quantity of wastewater effluent demanded could have been greater had the quantity supplied been sufficient for all months. For scenario 2 the potential demand for wastewater effluent relaxing the supply constraint for wastewater effluent was 24,776 AF per year.

Because the nutrient constraints had the greatest influence on the demand for wastewater effluent in any given month the blending ratio varied due to the nutrient requirement of the crops. Having different blending ratios within the same month was physically impossible since ground water and wastewater effluent cannot be mixed separately for each individual crop. The blending ratios must remain the same for all crops for that particular month. However, by forcing the blending ratios to remain the same, there are months when nutrients are applied in excess of what is actually required. In scenario 3 the nutrient requirements were disregarded in favor of the blending ratios the quantity of wastewater effluent demanded for Cortaro-Marana Irrigation District would have been 34,480 AF per year.

The total net benefit for the Cortaro-Marana Irrigation District in irrigating with wastewater effluent as opposed to irrigating with ground water was $111,366. The total net benefit was based on a demand of 11,385 AF for wastewater effluent. The winter crops benefited the most because their irrigation schedule coincided with the crop's nutrient requirements. The winter crops also used a higher porportion of wastewater effluent. The total net benefit based on the blending ratio rather than the plant's nutrient requirements was $335,320. The total net benefit was based on a demand of 34,480 AF. Again the winter crops benefited the most because of the higher porportion of wastewater effluent used.

For scenario 4 the quantity of wastewater effluent demanded at various prices for alternative sources of water was estimated. This is essential in determining how sensitive the demand for wastewater effluent is to a change in its price. When alternative sources of water were priced at $25.00 per acre-foot the quantity of wastewater effluent demanded when priced at $13.16 an AF was 11,385 AF per year. When alternative sources of water were priced at $50.00 per AF the quantity of wastewater effluent demanded at $13.16 per AF was 10,915 AF per year. The decrease in the quantity demanded for wastewater effluent was because at $50.00 an AF for alternative sources of water it was no longer profitable to grow milo. When alternative sources of water were priced at $75.00 per AF the quantity of wastewater effluent demanded when priced at $13.16 an AF was 9,999 AF per year. When the price for wastewater effluent was approximately $55.00 an AF it was no longer profitable to grow American-Pima cotton and alfalfa. At $60.00 an AF for wastewater effluent the quantity of wastewater effluent demanded was 4,650 AF per year. At this price it was only profitable to grow Upland cotton. At $78.00 per AF for wastewater effluent it was no longer profitable to grow Upland cotton.

Reusing wastewater effluent would not only benefit the District but also the City of Tucson. The District would benefit from the savings in using a cheaper source of irrigation water. The District would also benefit from the savings in fertilizer because of the nutrients contained in wastewater effluent. The City of Tucson would benefit from the revenue generated from the sale of wastewater effluent. More importantly the City of Tucson would benefit if an exchange of wastewater effluent for ground water were to occur. Acquiring ground water from the Cortaro-Marana Irrigation District might not be as costly for the City of Tucson as opposed to obtaining water from other sources. The City of Tucson has been pumping ground water from Avra Valley since 1968. Due to a series of lawsuits the City had to purchase the land in order to claim the water rights. A conveyance system was also needed which greatly added to the cost in acquiring the ground water. There is also the added expense of mowing down the tumble weeds on the land which costs the City appoximately $100,000 annually.

As so often is done, the City of Tucson has placed more emphasis on the engineering and institutional aspects of a water project rather than its economic efficiency. The case can be made with the planned wastewater effluent distribution system for landscape irrigation projects in the Tucson Metropolitan area. Since wastewater effluent will be used on golf courses, school playgrounds, and parks where public access is not controlled it will have to be tertiary treated. This will require the building of a treatment facility. The cost of the treatment facility in addition to the cost of the distribution system will be paid for by its users. However, most of the wastewater effluent will be used by the City of Tucson which means the City will bear most of the cost of the project. The cost of which will be much higher on a per acre-foot basis compared to alternative sources of water (e.g., ground water, Central Arizona Project Water).

The City of Tucson is compelled to use wastewater effluent because of the enactment of the Groundwater Management Act. Under the Groundwater Code, the Arizona Department of Water Resources must include a conservation program for municipal uses. The municipal conservation program assigned providers of water per capita conservation requirements. However, when calculating the per capita rate in gallons per person per day (GPDC), wastewater effluent was not considered. Therefore, the City of Tucson can reduce per capita consumption by substituting wastewater effluent for use on areas such as turf or landscape areas. However, using tertiary treated effluent rather than cheaper sources of water adds to the cost of a project and thus economic efficiency is sacrificed.

In conclusion, the development of a water market would improve economic efficiency--to put water of varying quality levels to its highest value uses at the least cost to society. Water sources considered should include not only ground water and surface water, but also municipal effluent and CAP water. Water uses considered should include irrigated agriculture, turf and landscape areas, industrial, and recharge.

APPENDIX A

Bacteria, Viruses, and Parasites in Sewage and Sludge.

Group	Pathogen	Disease Caused
Bacteria	*Salmonella*	Typhoid, paratyphoid, salmonellosis
	Shigella	Bacillary dysentary
	Enteropathogenic *Escherichia coli*	Gastroenteritis
	Yersinia enterocolitica	Gastroenteritis
	Campylobacter jejuni	Gastroenteritis
	Vibrio chlorea	Chlorea
	Leptospira	Well's Disease
Viruses	Enteroviruses	
	Poliovirus	Meningitis, paralysis, fever
	Echovirus	Meningitis, diarrhea, rash, fever, respiratory disease
	Coxsackievirus	Meningitis, hepangina, fever, respiratory disease
	Coxsackievirus	Myocarditis, congential heart anomlies, pleurodynia, respiratory disease fever, rash, memingitis
	New enteroviruses	Meningitis, encaphalitis, acute hemorrhagic conjunctivitis, fever, respiratory disease
	Hepatitis Typs A	Infectious hepatitis
	Norwalk virus	Diarrhea, vomiting, fever
	Calicivirus	Gastroenteritis
	Astrovirus	Gastroenteritis
	Reovirus	Not clearly established

Appendix A continued.

	Rotavirus	Diarrhea, vomiting
	Adenovirus	Respiratory disease, eye infection
Protozoa (parasites)	*Entamoeba histolytica*	Amebic dysentary, liver abcess, colonoid ulceration
	Giardia lamblia	Diarrhea, malabsorption
	Balantidium coli	Mild diarrhea, colonic ulceration
Helminths	*Ascaris lumbricoides* (round worm)	Ascariasis
	Ancyclostoma duodenale (hook worm)	Anemia
	Necator americanus (hook worm)	Anemia
	Taenia saoinata (tape worm)	Taeniasis

Source: Gerba, 1983.

APPENDIX B

Characteristics of Secondary Treated Effluent in Pima County
mg/l (except as noted)

Constituent	Roger Road	Ina Road
Physical		
Total Suspended Solids	16.0	20.0
Chemical		
Electrical Conductivity mhos/cm	NA	NA
Total Dissolved Solids	543	445
pH, units	7.1	6.4
Biological Oxygen Demand	10.0	12.0
Residual Chlorine	5.1	3.5
Nitrate-Nitrogen	7.8	4.0
Ammonium-Nitrogen	6.1	6.0
Organic-Nitrogen	3.3	5.2
Phosphorous-PO_4	6.3	7.8
Potassium	NA	NA
Sodium	NA	NA
Sulfate-SO_4	84.0	58.0
Carbonate-CO_3	NA	NA
Bicarbonate-HCO_3	NA	NA
Calcium	NA	NA
Magnesium	NA	NA
Arsenic	0.007	0.007
Barium	0.067	0.068
Boron	0.251	0.207
Cadium	0.005	0.003
Chromium	0.023	0.012
Copper	0.055	0.063
Cyanide	0.008	0.009
Iron	0.169	0.167
Lead	0.022	0.020
Manganese	0.021	0.023
Mercury	0.0006	0.0003
Nickel	0.027	0.017
Selenium	0.005	0.004
Silver	0.004	0.003

Appendix B continued.

Zinc	0.01	0.117
Biological Coliforms MPN/100	22.0	76.0

Note: Concentration levels based on a monthly average from 1 July 1984 to 1 July 1985.

Source: Pima County Wastewater Management Department, 1985.

APPENDIX C

Recommended Maximum Concentrations of Trace Elements in Irrigation Waters

Element	Recommended maximum concentration* (mg/l)	Remarks
Al (aluminum)	5.0	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 5.5 will precipitate the ion and eliminate any toxicity.
As (arsenic)	0.10	Toxicity to plants varies widely, ranging from 12 mg/l from Sudan grass to less than 0.05 mg/l for rice.
Be (beryllium)	0.10	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Cd (cadium)	0.01	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommeded because of its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Co (cobalt)	0.05	Toxic to tomato plants at 0.1 mg/l in nutriebnt solution. Tends to be inactivated by neutral and alkaline soils.
Cr (chromium)	0.1	Not generally recognized as an essential growth element. Conservative limits recommended because of lack of knowledge on toxicity to plants.

Appendix C continued.

Cu (copper)	0.2	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
F (flouride)	1.0	Inactivated by neutral and alkaline soils.
Fe (iron)	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of reduced availability of essential phosphorous and molybdenum.
Li (lithum)	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low levels (>0.075 mg/l). Acts similar to boron.
Mn (manganese)	0.2	Toxic to a number of crops at a few tenths mg to a few mg/l, but usually only in acid soils.
Mo (molybdenum)	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high levels of available molybdenum.
Ni (nickel)	0.2	Toxic to a number of plants at 0.5 to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Pb (lead)	5.0	Can inhibit plant cell growth at very high concentrations.
Se (selenium)	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element for animals but in very low concentrations.

Appendix C continued.

Sn (tin)	---	Effectively excluded by plants; specific tolerance unknown.
Ti (titanium)	---	(See remark for tin.)

Appendix C continued.

W (tungsten)	---	(See remark for tin.)
V (vanadium)	0.1	Toxic to many plants at relatively low concentrations.
Zn (zinc)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.

Source: Westcot and Ayers, pages 3-14 and 3-15, 1984.

APPENDIX D

Generalized Effluent Reuse Policies for the City of Tucson

1. Wastewater effluent should be fully utilized to reduce groundwater pumping, evaporation and evapotranspiration.

2. In considering contract proposals, geographical priorties of effluent use shall be as follows:

    a. Tucson Water Service Area
    b. Upper Santa Cruz subbasin of the TAMA
    c. Avra Valley subbasin of the TAMA
    d. Outside the TAMA

3. Sale of effluent to reduce groundwater pumping shall be favored over recharge. After all practical sales, exchanges, and reuses have been made, effluent shall be recharged into the Upper Santa Cruz subbasin.

4. All effluent sales contracts shall specify a minimum and a maximum annual effluent use.

5. Contracts for effluent uses outside the Upper Santa Cruz subbasin shall provide that, in the event of effluent shortages, effluent deliveries shall be subject and subordinate, on a pro-rata basis among users outside the Upper Santa Cruz subbasin, to effluent uses within the Upper Santa Cruz subbasin pursuant to existing or future effluent sales contracts.

6. All future effluent sales contracts shall be subordinate to any negotiated settlement with the Papago Indians and/or the United States. Said contracts shall provide for a pro-rata reduction in quantity where the Indians take delivery from the City leaving insufficient effluent to satisfy the than existing effluent sales contracts.

Appendix D continued.

7. The price of wastewater effluent shall be based on market value. Market value is initially defined as current cost of an alternative source for each user. Effluent sales prices shall be adjusted periodically to reflect changes in effluent market value.

8. The price of effluent sold may be adjusted to account for capital costs for construcing transmission and treatment facilities. Sales of effluent from the system shall be controlled by the City.

9. While contract terms can vary, unit prices for effluent shall be adjusted annually proportional to a negotiated and appropriate index.

10. As a condition of effluent contracting, pending or threatend lawsuits relating to effluent ownership or appropriation shall be dismissed.

11. The length of term for effluent sales agreements shall take into account the negotiated financial arrangements and facility requirements.

12. Wastewater reclamation applications shall protect and preserve the existing quality of groundwater insofar as possible.

13. The City shall monitor effluent sales and deliveries by the Pima County Wastewater Management Department to assure compliance with the sewer system tranfer intergovernment agreement and, where necessary, shall take steps to correct any failure to so conform.

14. Irrigation of existing golf courses should be accomplished through the use of wastewater effluent wherever economically feasible to preserve potable water resources.

15. New golf course developement shall only be permitted using wastewater effluent. Potable water may be used on an interim basis provided that the developer agrees to use effluent when available and assist the City in facilitating the construction of a regional effluent delivery system. Incentives to encourage prompt action by developers in switching to effluent use shall be part of water service agreements and other appropriate contracts.

Appendix D continued.

16. Changes in the Groundwater Management Act of 1980 shall be sought to allow credits to the City for recharged effluent and to allow exchanges of effluent for groundwater.

17. Use of effluent for irrigation as a substitute for groundwater may result in added value of a user's property. Contracts should recognize this possibility and shall require waiver by the owner of any such acquired value in the event of purchase of the property by the City through negotiation or condemnation.

Source: City of Tucson, 1982.

APPENDIX E

Demand Schedule for Wastewater Effluent for Cortaro-Marana Irrigation District Relaxing the Supply Constraints for Wastewater Effluent

Quantity Demanded (acre-feet)	Price per Acre-Foot (dollars)
3,412	24.25
5,397	24.00
5,397	23.00
15,630	22.50
21,163	22.00
21,163	21.00
23,006	20.25
24,776	20.00
24,776	13.16

APPENDIX F

Demand Schedule for Wastewater Effluent for Cortaro-Marana Irrigation District Based on Blending Ratio

Quantity Demanded (acre-feet)	Price per Acre-Foot (dollars)
3,412	24.25
5,397	24.00
5,397	23.00
15,540	22.50
18,504	22.00
18,504	21.00
18,549	20.25
34,480	20.00
34,480	13.16

APPENDIX G

Demand Schedule for Wastewater Effluent at Various Ground or Surface Water Prices as the Price of Wastewater Effluent Changes

Quantity Demanded (acre-feet)	Price per Acre-Foot (dollars) Price of Ground or Surface Water per Acre-Foot		
	$25.00	$50.00	$75.00
2,919	-----	53.00	-----
3,412	29.00	-----	-----
4,197	28.00	-----	-----
4,650	-----	-----	77.00
4,650	-----	-----	60.00
8,408	27.50	-----	-----
8,904	-----	51.00	-----
9,730	-----	-----	55.00
9,999	-----	-----	13.16
10,086	27.00	-----	-----
10,454	-----	50.00	-----
10,454	-----	40.00	-----
10,454	-----	30.00	-----
10,915	-----	20.00	-----
10,915	-----	13.16	-----
11,385	25.00	-----	-----
11,385	13.16	-----	-----

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