CHANGES IN RIPARIAN VEGETATION FOLLOWING RELEASE OF RECLAIMED EFFLUENT WATER INTO THE SANTA CRUZ RIVER: AS A COROLLARY, THE EFFECTS OF CHANNELIZATION ON VEGETATION IN THE SANTA CRUZ RIVER

by

JOSHUA FIORA GORMALLY

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APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Margaret M. Livingston, Ph.D. — 8·16·02 Date
Professor of Landscape Architecture

H. Randall Gimblett, D.P.L.A. — 8-16-02 Date
Professor of Landscape Architecture

Lauri Macmillan Johnson, M.L.A. — 8 . 16 . 02 Date
Professor of Landscape Architecture

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ABSTRACT

Recharge has been conducted very efficiently for twenty-five years near Roger and Ina roads along the Santa Cruz River using reclaimed water. This project seeks to determine the composition of river vegetation due to the release of the reclaimed water, and as a corollary, to examine the effects of channelization on the vegetation of the Santa Cruz River.

Using belt and line transects the vegetation along the Santa Cruz River was surveyed. Treatment with effluent was found to increase plant density, diversity, richness, cover, and incidence of exotic plants. Channelization was found to increase only plant richness and incidence of exotic plants. Furthermore, effluent encouraged the growth of tree plant types while channelization discouraged such growth.

Recommendations were made regarding future release of effluent into the Santa Cruz River and future attempts to restore the once prolific, willow-cottonwood forests and mesquite forests.

INTRODUCTION

In the dry Southwest the need for water has inspired such engineering feats as Hoover Dam and the Colorado Acquisition Project (CAP). These projects and those like them have brought enormous amounts of water to burgeoning cities and agricultural areas allowing fast paced growth and prosperity. Although these advances have been integral to western growth, the use of the Southwest's water sources have greatly altered the composition of its riparian areas. The majority, upwards of 90%, of all riparian areas in the Southwest have been significantly changed due to the invasion of exotic plant species, the disruption of natural flooding and drought patterns, the extinction and decline of native riparian plant and animal species, the conversion of annual rivers to dry washes, and the lowering of the water table (Briggs, 1996). One or more of these effects are evident in most riparian areas across the Southwest. Locally, the effects can be seen in all of Tucson's major riparian areas; the Santa Cruz River and its tributaries, the Canyon Del Oro, Rillito, Pantano and Tanque Verde Washes.

The Santa Cruz River was once perennial along most of its length supporting a small community of Hohokam villages; but since the late 1920's water harvesting of the local groundwater has caused the springs which fed the river to dry up and hence the river to stop flowing. The invasion of exotic plants and animal species has further changed this delicate ecosystem.

Relatively recent attempts to recharge the grossly depleted water tables around Tucson have created a 28-mile perennial stretch of the Santa Cruz River. This study seeks to understand the effect of this renewed water source on the ecosystem of the river. The study focus is on the impact of the newly released water on the vegetation of the river.

PRESENT STUDY

Problem Statement

Use of Tucson's water resources and other factors related to human development have led to severe degradation of the Santa Cruz River. To what degree, if any, has the recent release of reclaimed water from the Roger Road and Ina Road Sewage Treatment Plants into the Santa Cruz River changed its vegetative composition?

Hypothesis

Release of reclaimed water into the Santa Cruz River has led to an increase in plant cover and diversity and has had a negative effect on the ratio of native to non-native plant composition.

Goals

The goal of this research is to determine the effect of the introduction of reclaimed water along the Santa Cruz on the vegetative community. The research questions that guide this study are as follows: 1. Has vegetative density, diversity and cover increased since release of the effluent water in the early 1980's? 2. What is the vegetative species composition in these areas? 3. What is the percentage of native to exotic species in areas treated with effluent water compared to those areas not treated with effluent water? 4. What recommendations can be made based on the information gathered in this study to assist future effluent and CAP groundwater recharge projects? 5. What recommendations can be made to assist future restoration efforts of the willow-cottonwood forests and mesquite forests of the Santa Cruz River.

REVIEW OF LITERATURE

Brief History of the Santa Cruz River

Approximately 3500 years ago, there was enough water in the Santa Cruz River to support Hohokam villages with over 3,000 irrigation fields (Doelle, 2002). The Santa Cruz River was still perennial along much of its length as little as 100 years ago. During rare periods when the river was dry, the once high water table fed springs at the base of Sentinel Peak, now known as A Mountain, and at Black Mountain near the San Xavier Mission (Wood, et al., 1999). The Santa Cruz and its tributaries supported abundant Cottonwood and Willow forests and giant Mesquite forests.

Headwaters, Course, and Outflow

The Santa Cruz River begins as a small stream in the Canelo Hills of Southern Arizona. It flows south for about 15 miles and then crosses the U.S./Mexico Border. It then makes a 30-mile loop in and out of Mexico, crossing the border again just East of Nogales, Arizona. From there the river flows northerly, merging with Sonoita Creek tributary and passing Tubac, Green Valley and the San Xavier Mission, before flowing through Tucson. In Northern Tucson, the river merges with Rillito Creek and Canada Del Oro Wash tributaries and veers to the Northwest towards Phoenix. Along the way it picks up the Brawley Wash, Santa Rosa Wash and Vekol Wash tributaries. Approximately 15 miles from Phoenix, the Santa Cruz River combines with the Gila River before joining with the westward-flowing Salt River (Wood, et. al., 1999).

Wildlife and Ecological Importance

One hundred years ago the wildlife of the Santa Cruz riparian area included such extant species as muskrats, beaver, black tailed prairie dogs, edible fish and wild turkey (Jensen and Glinski, 2002). Today, exotic species of wildlife which have replaced many of the natives include, bullfrogs, crayfish, Green Sunfish, Starling, Brown Garden Snails and Mosquito Fish (Tucson Regional Water Council and Glinski, 2002).

The Santa Cruz River is one of four major migratory corridors which run along the North/South axis through the Sonoran bioregion (Nabhan, et. al., 1999). In addition, the Santa Cruz River is a species "stronghold" for the Grey Hawk, Rose-Throated Becard and Velvet Mesquite and serves as valuable nesting area for Arizona's raptor species. Of 36 species of raptors that nest in Arizona, 31 do so in the Santa Cruz watershed (Glinski, 2002).

Vegetation of the Santa Cruz River

As stated earlier, the Santa Cruz River and its tributaries once supported abundant cottonwood and willow forests and vast mesquite forests. Without perennial water flow however, these riparian woodlands began to deteriorate when the groundwater depths fell below 10 ft. (Arizona Department of Water Resources, 1994), and the once prolific riparian woodland forests of the Santa Cruz River became a thing of the past. Removal of groundwater during the 1940's, led to the final demise of native riparian woodland in the Santa Cruz River (Betancourt, 1991)

However, release of effluent water into the Santa Cruz River has begun to restore some of these woodlands. Marc A. Baker, Ph.D., conducted a vegetative survey of this area in 1999 and 2000. Baker found that the 28-mile stretch of the Santa Cruz River downstream of the Roger Road and Ina Road effluent release sites contained 35% (3,499 acres) of the hydromesic vegetation (plant life dependent on above regionally-normal soil moisture content) in the Tucson Basin (Table 1). This vegetation is mostly dependent on the effluent release into the river (Fonseca, et. al., 1998). Baker stated that there is significantly more cover of riparian woodland within the Santa Cruz River than there was 20 years ago. Baker also stated "at present, the extent of riparian woodland along the lower Santa Cruz River is greater than any other time during its recent history". He stipulated that this was entirely due to the continuous release of effluent water since 1977. However, due to channelization of the river and the nature of its substrate, scouring caused by floods tends to wipe out most existing vegetation and it is unlikely that cottonwood-willow riparian forests will re-establish permanently in the river bottom (DeShields, et. al., 1997).

Table 1. Findings of Baker's vegetation study of the 28-mile area of the Santa Cruz River exposed to effluent.

HYDROMESIC WOODLAND MOSAICS	
Goodding Willow	120.6 acres
Goodding Willow/Saltcedar	175.5 acres
Saltcedar	333.5 acres
Velvet Mesquite	1497.0 acres
HYDROMESIC NON-WOODY MOSAICS	
Burrobush	556.6 acres
Desert Broom	700.0 acres
Willow-Weed	11.9 acres
Grasses/Forbes	103.9 acres

Besides the mesoriparian species, the Santa Cruz River supports an abundant number of hydroriparian and xeroriparian plant species. Thornber, Kendall and Glinski have conducted previous studies on the vegetation of the Santa Cruz River. See Appendix A for a compilation of the plants they observed.

Water Usage and The State of the Water Table in and Around the Tucson Metro Area

Two hundred years ago the ground water table was less than 50 ft. below the surface (WRRC, 2002). By 1923, groundwater usage rates had surpassed recharge rates (Nabhan, 1999). Today the ground water level is 200 - 250 ft. below the surface (AWC Map and Fonseca, 1970, 1998), and the river runs only during severe flooding or in places recharged with effluent. The river is dry and in some places it is defined with concrete re-enforced banks. Currently, the Tucson area withdraws water from the groundwater aquifers at a rate 5 times greater than the rate at which it is recharged (TRWC, 2002).

Current Legislation and Future Plans for Aquifer Recharge

Several State laws bode well for the possibility of rehabilitation and restoration of parts of the Santa Cruz River. Recent Arizona State Legislation requires cities and water harvesting facilities to balance the amount of water pumped from the ground with the amount of recharge by the year 2025 (Jensen, 2002). In addition the more recent Water Consumer Protection Act of 1995 directs the city of Tucson to use its CAP water allotment for recharge or to trade with area farms and mines instead of direct delivery to homes (WRRC, 2002). This encourages and almost guarantees the future use of CAP water for recharge of ground water. One way this may be accomplished is through the release of the CAP water into the Santa Cruz River and its tributaries. Proposals for implementation have already been made to city leaders and although none have yet been approved it seems to be an imminent and very real possibility (WRRC, 2002).

Effluent Recharge, Past, Present and Future

It will not be the first time the City of Tucson has recharged groundwater by releasing water into its watersheds. Since 1977, the Roger Road and Ina Road Sewage Treatment Plants have been releasing reclaimed water at two points into the Santa Cruz River (Jensen and DeShields, et. al., 2002, 1997) near Sweetwater Drive and Ina Road. This portion of the Santa Cruz River receives approximately 50,000 acre-ft. of secondary effluent flow per year (Fonseca, et. al., 1998). Depending on humidity and evaporation rates, this water flows anywhere from 4 to 25 miles down the river (Lacher, 1996).

Of the average 62 million gallons of wastewater processed at the Roger and Ina Road Treatment Facilities every day, 20-25% is used for agricultural irrigation, golf course irrigation, and other related reclaimed water uses, while 75-80% of the treated effluent is released into the Santa Cruz River (Linwood, 2000).

In a recent study conducted by the U.S. Geological Survey in cooperation with the City of Tucson, Ken Galyean concluded that during the period from October 1990 to September 1993 an average of 89.8% of the released reclaimed water percolated down through the ground to reach and recharge the groundwater tables (Galyean, 1996). This evidence suggests that recharge through riverbed water release is an efficient method of ground water table replenishment.

By 2015 the amount of effluent generated at the Roger Road and Ina Road Treatment Plants is expected to double to 100,000 acre-ft./year. Long-term estimates project that effluent will continue to be released into the Santa Cruz River well into the year 2015. The Bureau of Reclamation is developing a long-term plan for effluent use within the Tucson area. Potential effluent use activities could include turf irrigation, aquifer recharge basins, tertiary treatment facilities, and development of wetlands. (Stromberg, 2001).

Upstream in Nogales, Arizona the Nogales International Wastewater Treatment Plant also releases reclaimed water into the Santa Cruz River. The nutrient rich water supports a rich riparian ecosystem, which in turn supports large and diverse migratory and resident bird populations and other wildlife (Lawson, 1995).

Given the fact that current Arizona legislation encourages future groundwater recharge through CAP water release into watersheds and that in addition to being an efficient method of recharge, this water release has an apparent environmental benefit, the proposed research seeks to measure the vegetative benefit of effluent on a portion of the lower Santa Cruz River vegetation.

In the 17 contiguous states that contain arid and semi-arid areas, there are over 78 wastewater discharge sites. The majority of these sites are located in Eastern California, Arizona, New Mexico, and West Texas. In Arizona, the cities and towns of Winslow, Flagstaff, Jerome, Payson, Globe, Mesa, Phoenix, Tolleson, Prescott, Avondale, Goodyear, Nogales, and Tucson all implement wastewater discharge projects (Linwood, 2000).

METHODS

Project Model

The project follows a quasi-experimental model. The test is similar to a control group study. The causal variable is the release of reclaimed water into the treated areas. This model will compare areas exposed to the reclaimed water to adjacent areas not receiving reclaimed waters.

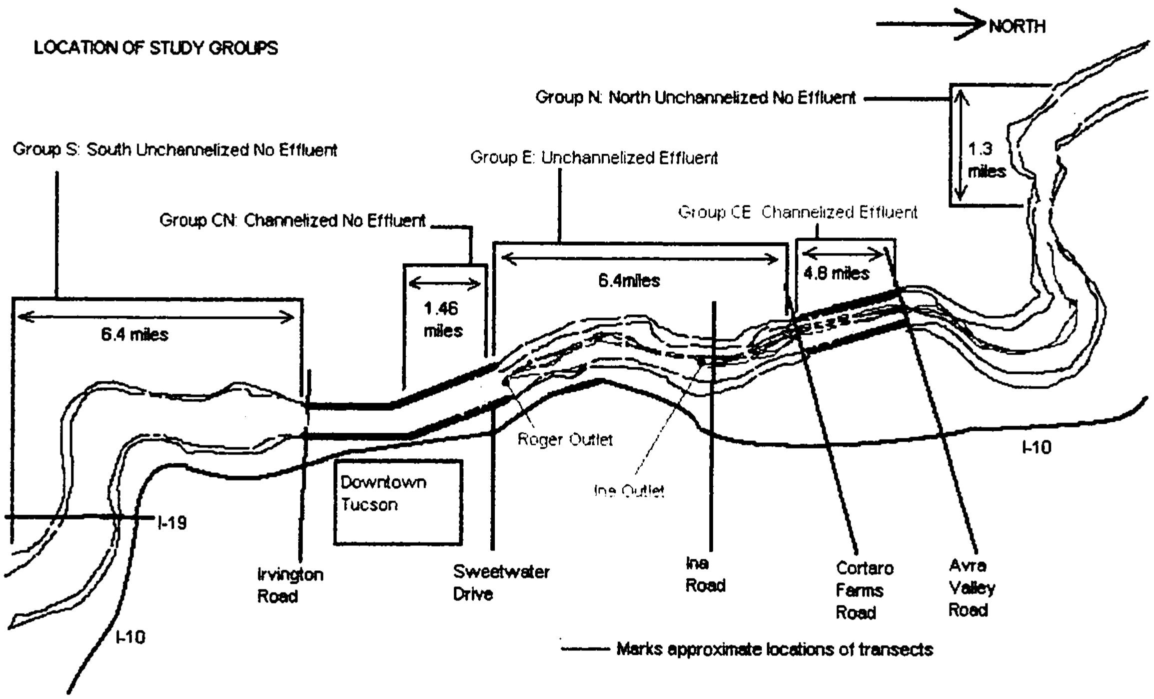
Treated areas are designated as stretches of the river containing annual above-ground effluent flow and represent the treated study sites. Non-treated areas are areas within the vicinity, both upstream and downstream of the effluent release outlets not exposed to effluent waters.

As a corollary to the study, the effect of channelization on vegetation will also be examined.

Study Sites

For the purpose of this project, five study sites were designated along the Santa Cruz River (Figure 1). Two represent the effluent treatment sites and one of these treatment sites is designated as unchannelized. For the purpose of this study, this indicates it contains only one or no concrete re-enforced embankments. The other effluent treatment site is designated channelized and has cement re-enforced embankments on both sides of the river. The remaining three sites contain no above-ground effluent flow and serve as the study control sites. Two of the study control sites are designated as unchannelized and one contains above ground effluent flow. These two unchannelized control sites were selected on either end of the study area in an attempt to compensate for geological changes which may occur along the course of the river and affect vegetation types, a problem Baker notes in his vegetative study. Baker wrote, "Regardless of data however, a comparison between the vegetation of the Lower and Upper reaches of the Santa Cruz River may not be warranted. The Upper Santa Cruz River, for instance, has much more varied topography and higher groundwater level than the lower section. Both of these attributes can greatly affect the extent of riparian vegetation." To compensate for these differences noted by Baker, control sites both upstream and downstream were selected. The third, and final, control site area is a channelized portion of the river without effluent. It contains concrete re-enforced embankments on both sides of the river and represents the channelized control site (Figure 1).

Figure 1. Location of Study Sites



Effluent (Treatment) Sites

Unchannelized With Effluent (E): This site, (site E), is the first of two treatment sites. It is defined as the area of the river traveling northward and downstream from the Roger Road Treatment Plant Effluent Outlet located 0.35 miles downstream from the Sweetwater Drive and Santa Cruz River intersection. From this point it extends 6.4 miles in a northward direction and downstream to the Cortaro Farms Road, Santa Cruz River Bridge. It contains steady, above ground effluent flow and has one or no cement re-enforced embankments.

Channelized With Effluent (CE): This site, (site CE), is the second of two treatment sites. Site CE consists of channelized portions of river treated with effluent. It is defined as the area of river, which has concrete re-enforced embankments on both sides and extends downstream and northward from the Cortaro Farms Road, Santa Cruz River Bridge, 4.8 miles to the Avra Valley Road Bridge.

No Effluent (Control) Sites

Southern Unchannelized No Effluent (S): This site, (site S), is defined as the area of river traveling southward and upstream from the Irvington Road, Santa Cruz River Bridge. It consists of the first unchannelized continuous stretch of river upstream from the Roger Road Treatment Plant Effluent Outlet. It begins approximately 10 miles upstream from the outlet and continues upstream 6.4 miles in a southeasterly direction. The length of this site was fixed at 6.4 miles in order to be an equivalent area to Site E.

Northern Unchannelized No Effluent (N): This site, (site N), is the area of river traveling northwestward and downstream from a point 28 miles downstream from the Ina Road Treatment Plant Effluent Outlet. The river is reported to have above-ground effluent flow anywhere from 4 to 28 miles downstream of the effluent release sites (Lacher); this site begins at that boundary. This arbitrary point, approximately 28 miles downstream of the Ina Road Treatment Plant Outlet was selected to represent the upstream border of Site N. Site N then was determined to extend 6.4 miles downstream and northwestward in order to be equivalent to Sites E and S. During field work however, it was found that Site N, could be extended only 1.3 miles downstream and northward to the Baumgartner Road, Santa Cruz River Crossing, because of severe agricultural effects on the river and its vegetation further downstream. Therefore, the effective length of Site N is 1.3 miles. The beginning of this site area can be found on a map or by driving to the point where Baumgartner Road turns North for 0.4 miles. This turn is located approximately 1.3 miles eastward on Baumgartner Road from the Baumgartner Road Santa Cruz River Crossing.

Channelized No Effluent (CN): This site, (site CN), represents the channelized portion of the river directly upstream from the first effluent outlet, the Roger Road Treatment Plant Effluent Outlet. Initially, it was planned to stretch southward and upstream from the first outlet 4.8 miles to be equivalent to Site CE, but during fieldwork it was found that this section was completely degraded due to construction 1.46 miles upstream. Therefore, this site was determined to extend to the construction boundary and its total length is 1.46 miles from the Roger Road Treatment Plant Outlet to said boundary.

Data Collection *

Belt and LineTransects

Vegetation data was collected in a total of 23 belt transects. The upstream and downstream boundary lines of each belt transect were used to gather line transect data on cover. Cover data was collected in a total of 46 line transects. Diversity data was collected using belt transects. Six belt transects were taken in study sites E and S. Four belt transects were taken in study sites CN and CE. Three belt transects were taken in study site N. Transect locations were selected randomly within each site (Figure 1). See Appendix B for exact transect locations and effluent outlet locations. See Appendix E for photographs at the transect locations.

Randomized Selection of Transects

Each site was subdivided into individual miles along the path of the river downstream within that site's area. The number of miles within the site area were placed into a hat. A number was drawn and the corresponding mile was recorded. Then, each mile was divided into tenths of a mile. The tenths were placed into a hat and a number was drawn. The corresponding tenth of a mile was recorded. Each tenth of a mile was then divided into 25-ft. increments. A number was placed in the hat for each corresponding 25-ft. increment. A number was drawn and the corresponding 25-ft. increment was recorded. This location was then used as the upstream boundary line for the belt transect. These locations were found on maps and then found in the field using a Global Positioning System (GPS) unit.

* Data was collected during April and May 2002. The following measurements were recorded or determined using the gathered data:

Density: Number of plant individuals divided by sq. ft. of transect area. Units: No. of plants/1000 sq. ft.

Richness: Number of different species located within each transect.
Units: No. of different plant species/10,000 sq. ft.

Diversity: Shannon-Weiner Diversity Index: $H = -\Sigma$ (pi lnpi), where pi = proportion of individuals in one species / number of total individuals.

Percent Native Plants: Number of individual native plants divided by the total number of plants.

Cover: Total length of all plant canopies per length of the line transect.

Proportion Plant Type or Plant Origin Type Cover: Length of plant type or plant origin type divided by the length of total plant cover.

RESULTS AND DISCUSSION

Data Analysis

Determining the effect of effluent on vegetation was the main objective of this study and these results are presented in the following tables. However, channelization effects were also studied based on its extensive use in the watercourse. Results are organized as follows: plant density, species richness, diversity, plant type composition, species nativity, and plant cover.

For statistical analysis, a p-value of 0.05 or less was designated for significance. All t-test p-values are based on the Mann-Whitney/Wilcoxon Two Sample Test also known as the Kruskal-Wallis test for two groups, which takes into account abnormally distributed data. Chi-square tests were used where individual plant recordings were treated as individual observations in order to boost sample size and, therefore, statistical power. Chi-square tests were utilized where noted.

Density

A constant source of water, in this case the release of effluent into the Santa Cruz River, appears to have had a significant effect on plant density in the river course. Among sites with and without effluent there was a significant increase in vegetation density in effluent areas. When channelization was factored into the analysis, there was also a significant increase in vegetation among unchannelized sites with effluent. However, this increase was not significant among channelized sites. This is probably due to the smaller sample size among the channelized sites as the p-value fell just short of significance at 0.0833 (Table 2). Presence of channelization seemed to have no significant effect on plant density among all sites when effluent was factored into the analysis.

Table 2. Mean plant density (number of plants per 1000 sq. ft.) in sites with and without effluent, by channelization.

	EFFLUENT				
	Absent		Present		
CHANNELIZATION	n	mean	n	mean	p-value
Present	4	35.2	4	78.1	0.0833
Absent	9	21.2	6	69.7	0.0015 *
Total	13	25.5	10	73.1	0.0002 *

* denotes statistical significance @ $p \subseteq 0.05$

Richness

There was a total of 71 different plant species found across all sites. See Appendix C for an alphabetical list of all plant species and Appendix D for a list of plants found among effluent transects, non-effluent transects and both transects.

In effluent areas, Goodding Willow, Giant Reed, Bermuda Grass, Lady's Thumb, and Curly-Leaf Dock were the predominant species. In areas without effluent, Desert Broom, Burrobush, Bermuda Grass, and Grama Grass were the predominant species.

As might be expected, the release of effluent water into the Santa Cruz has had a significant effect on plant richness in the river course. Between sites with and without effluent, there was a significant increase in vegetative richness in effluent areas. When channelization was factored into the analysis, there was also a significant increase in vegetative richness among unchannelized sites with effluent. However, this increase was not significant among channelized sites. Curiously, unlike plant density, the effect is probably not due to the smaller sample size among the channelized sites as the p-value fell at absolutely no significance at 1.0000. Perhaps the disturbance of channelization or the enhanced effect of flooding disturbances due to a narrower channelized water course, encourages the growth of more plant species. This is supported by the fact that among channelized and unchannelized sites without effluent there was a significant increase in mean plant richness of 6.3 more plant species per 10,000 sq. ft. among the channelized sites than among the unchannelized sites ($p = 0.0206$).

Table 3. Mean plant richness (number of plant species per 10,000 sq. ft.) in sites with and without effluent, by channelization.

	EFFLUENT				
	Absent		Present		
CHANNELIZATION	n	mean	n	mean	p-value
Present	4	10.8	4	12.0	1.0000
Absent	9	4.5	6	20.0	0.0015 *
Total	13	6.5	10	16.8	0.0016 *

* denotes statistical significance @ $p \leq 0.05$

Diversity

As hypothesized, the release of effluent into the Santa Cruz River has had a significant effect on plant diversity. Among sites with and without effluent there was a significant increase in vegetation diversity in effluent areas. When channelization was factored into the analysis, there was also a significant increase in vegetative diversity among unchannelized sites with effluent. However, this increase was not significant among channelized sites. As with plant density, this is probably due to the smaller sample size among the channelized sites. Channelization had no significant effect on plant diversity among all sites.

Table 4. Mean Shannon-Weiner Diversity Index (measurement of plant diversity) in sites with and without effluent, by channelization.

	EFFLUENT				
	Absent		Present		
CHANNELIZATION	n	mean	n	mean	P-value
Present	4	1.3	4	1.6	0.1489
Absent	9	1.0	6	2.0	0.0032 *
Total	13	1.1	10	1.8	0.0010 *

* denotes statistical significance @ p⊆ 0.05

Nativity

The proportion of exotics was significantly higher in all disturbed sites. A significant difference between native and exotic plant species percent existed between areas with and without effluent (Table 5). In addition, a significant difference was found to exist between channelized and unchannelized areas. As might be expected, both disturbances, effluent release and channelization, had a significant impact on the number of exotic species in the ecosystem. Channelized sites had an average of 37.4 % exotic species compared to 25.8% among unchannelized sites (Chi square = 224, p < 0.0000001).

Table 5. Percent native and exotic plants in effluent and non-effluent sites.

Effluent	Number of Plants	Percent Native	Percent Exotic	TOTALS
Present	n = 10284	62.8 %	37.2 %	100 %
Absent	n = 4292	85.3 %	14.7 %	100 %
TOTAL	n = 14576			

Chi Sq. = 722, p<0.0000001 *

* denotes statistical significance @ p⊆ 0.05

Plant Type Composition

Among sites with and without effluent a significant difference was indicated in plant composition: effluent seems to promote tree and herb growth, while channelization seems to inhibit tree growth (Table 6). Possibly, this is due to the effects of flooding on young tree saplings (Table 7).

Table 6. Plant type composition in effluent and non-effluent sites.

Effluent	Number of Plants	Percent TREES	Percent SHRUBS	Percent HERBACEOUS	TOTALS
YES	n = 10284	3.3 %	17.9 %	78.8 %	100 %
NO	n = 4292	0.9 %	31.5 %	67.6 %	100 %
TOTAL	n = 14576				

Chi Sq. (2df) = 378, $p<0.0000001$ *

* denotes statistical significance @ $p \subseteq 0.05$

Table 7. Plant type composition among all groups.

Effluent	Channelized	Percent TREES	Percent SHRUBS	Percent HERBS	TOTALS
YES	YES	1.6 %	13.4 %	85.0 %	100 %
YES	NO	5.0 %	22.4 %	72.6 %	100 %
NO	YES	0.1 %	41.0 %	58.9 %	100 %
NO	NO	1.0 %	28.7 %	70.3 %	100 %
Chi Square, p-value		8.4, 0.00718 *	16.8, 0.00004 *	962, <0.00001 *	

* denotes statistical significance @ $p \subseteq 0.05$

Cover

A significant difference in total plant cover was found to exist between sites with and without effluent (Table 8). In all sites, effluent release corresponded with a higher percent of plant cover. This is to be expected because effluent release also correlated with a higher plant density in most sites. Channelization was found to have no significant effect on vegetation cover.

Table 8. Mean plant cover (%) in sites with and without effluent by channelization.

	EFFLUENT				
	No		Yes		
CHANNELIZATION	n	mean	n	mean	P-value
Yes	8	8.5	8	21.3	0.0008 *
No	18	8.9	12	26.2	0.0044 *
Total	26	8.8	20	24.2	<0.0001 *

* denotes statistical significance @ $p \leq 0.05$

Cover Based on Percent Nativity

A significant increase in exotic plant cover was found to exist among all disturbed sites, whether the disturbance was effluent release or channelization. Those sites with effluent, whether channelized or not, had a higher percentage of cover by exotic plants (Table 9). Sites which were channelized, had a mean 5.0% exotic cover compared to 2.7% in unchannelized sites (p = 0.0245).

Table 9. Mean exotic plant cover (%) in sites with and without effluent by channelization.

	EFFLUENT				
	Absent		Present		
CHANNELIZATION	n	mean	n	mean	p-value
		--%--		--%--	
Present	8	1.1	8	9.0	0.0008 *
Absent	18	0.5	12	5.9	<0.0001 *
Total	26	0.7	20	7.1	<0.0001 *

* denotes statistical significance @ $p \leq 0.05$

Plant Type Cover

Those sites with effluent had a significantly higher percentage of tree cover and herbaceous plant cover compared to sites without effluent (Tables 10 and 12). Moreover, no significant difference was observed among these sites in shrub cover (Table 11).

Table 10. Mean tree cover (%) in sites with and without effluent.

	EFFLUENT				
	Absent		Present		
CHANNELIZATION	n	mean	n	mean	p-value
		--%--		--%--	
Present	8	0.0	8	0.3	0.0012 *
Absent	18	2.7	12	17.1	0.0006 *
Total	26	1.9	20	12.3	<0.0001 *

* denotes statistical significance @ p⊆ 0.05

Table 11. Mean shrub cover (%) in sites with and without effluent.

	EFFLUENT				
	Absent		Present		
CHANNELIZATION	n	mean	n	mean	p-value
		--%--		--%--	
Present	8	8.5	8	7.9	0.9163
Absent	18	5.4	12	6.1	0.8989
Total	26	6.4	20	6.8	0.6416

* denotes statistical significance @ p⊆ 0.05

Table 12. Mean herb cover (%) in sites with and without effluent.

	EFFLUENT				
	Absent		Present		
CHANNELIZATION	n	mean	n	mean	p-value
		--%--		--%--	
Present	8	1.2	8	8.0	0.0008 *
Absent	18	0.9	12	5.4	<0.0001 *
Total	26	1.0	20	6.5	<0.0001 *

* denotes statistical significance @ $p \leq 0.05$

CONCLUSIONS

Effects of Effluent

The findings of this study support the hypothesis that the release of reclaimed effluent water into the Santa Cruz River has significant effects on plant cover, diversity and native and exotic plant composition. As a corollary, the effects of channelization on vegetation have also been investigated, and were significant for some variables.

Effluent was found to significantly increase plant density, richness, cover, diversity, and exotic species. Plant density, richness, and cover were increased by effluent flow by an approximate factor of 3 in areas treated with effluent. Diversity was increased from a mean 1.11 on the Shannon-Weiner Index without effluent compared to a 1.82 on the Shannon-Weiner Index with effluent. The percent of exotic species more than doubled among effluent sites. Effluent had a significant effect on plant type composition as well. It encouraged growth of trees and herbaceous plants and discouraged growth of shrub plant types. It appears the most desirable plant type composition, the larger mesoriparian trees, was strongly supported among sites with effluent and without channelization. These sites had a mean of 4-5 times more trees than any other sites.

Effects of Channelization

Channelization had no significant effect on plant density, diversity, and cover. Channelization did, however, more than double plant richness among sites without effluent. This is probably to do the greater impact of flood disturbances in the channelized areas. Channelization also had a significant effect on exotic species composition. Exotic composition went from a mean 25.8% without channelization to a mean 37.4% with channelization.

Channelization also had a significant effect on plant type composition. It appeared to encourage growth of shrub plant types and discouraged growth of tree and herbaceous plant types.

Assumptions About Wildlife Presence

If any assumptions can be made about wildlife presence and habitat in effluent and non-effluent areas they would suggest that effluent increases the diversity of wildlife habitats and therefore wildlife populations. In general, any water source in the dry Arizona desert will attract wildlife. Coupled with increased plant cover, plant diversity, plant density, and plant richness, one can assume the effects of effluent on the Santa Cruz River has increased wildlife habitat and diversity of populations in the area. Whether or not this holds true in reality is unknown, but the assumption is that it has had an overall positive effect. This does not mean however, that such extant species as muskrats, beaver, black tailed prairie dogs, edible fish and wild turkey have or will return to the area.

Because channelization increased only plant richness and exotic species with little value to native wildlife species, it can be assumed that channelization has little or no positive effect on wildlife habitat or presence.

Suggestions and Recommendations for Decision Makers Designing Policy For Future Effluent Recharge Projects

The results of this study suggest that effluent release into the Santa Cruz River has had an over-all positive effect on the river course. Due to a physically substantial and statistically significant increase in plant cover, plant density, plant richness, and plant diversity in areas with effluent it is assumed that wildlife habitat and presence has also been increased in these areas. Furthermore, the release of effluent into these areas has encouraged and increased growth of trees. However, when effluent release is coupled with channelization, the percentage of cover by trees drops greatly. This is most likely due to the constricted flow of violent flood water flows which scour the river course in channelized areas. In addition, a negative effect of the effluent treatment is the encouragement of exotic species to these areas.

Release of effluent into watercourses is not only an efficient method of groundwater recharge but has a beneficial effect on the vegetation and wildlife of the area where it is released. In order to foster healthy and protected riparian vegetation through the release of effluent into watercourses, perhaps effluent should not be released into channelized portions of the river. These portions of the river are extremely sensitive to flooding as they are often narrow and contain the most concentrated flood flows. In addition, in areas where long-term riparian vegetation is wanted, special attention should be placed on flood protection in unchannelized areas. One way this could be done is through the construction of wetlands off to the sides of the main watercourse.

Suggestions and Recommendations for Restoration Efforts of the once prolific Willow-Cottonwood Forests and Mesquite Forests of the Santa Cruz River

Of the plants surveyed in this study, there were very few Cottonwood or Mesquite trees. There were however many Willow trees. The lack of Cottonwood trees may be due to seedling dispersal patterns of the Cottonwood trees (Stromberg). Cottonwood seeds need to be significantly scoured in order to germinate and it is possible that this does not occur. In any event, future restoration projects directed at the Willow-Cottonwood Forests and Mesquite Forests would have to pay special attention to the encouragement of Cottonwood and Mesquite trees.

Based on the findings of this study, no such attempts should be made in areas which are channelized, whether or not they contain effluent. These areas had the lowest tree cover. This is most likely due to the enhanced effects of flood waters in these areas.

Furthermore, restoration efforts should pay close attention to potential flooding effects in unchannelized areas. Severe flooding such as the September 1996 flood, can wipe out the majority of vegetation along the river course. Therefore special planning should be made to protect future Willow-Cottonwood Forests and Mesquite Forests from flood damage.

The release of effluent into the Santa Cruz River presents an opportunity for city planners and designers to create wildlife wetland park recreation projects. The water creates a riparian system similar to that which existed prior to European settlement. If fostered majestic and ecologically significant wildlife wetland parks can be created. The encouragement of cottonwood, willow and mesquite forests in these areas through seed dispersal, sapling planting and flood protection will create an oasis in the desert with habitat for many migratory bird species. In addition, these areas can become beautiful shaded wetland park recreational areas with trails and perhaps fishing for the citizens and visitors of Tucson.

Appendix A: List of plants found in the Santa Cruz River.

The following compilation of native and exotic trees, shrubs, half-shrubs, and perennial herbs of the Santa Cruz River was taken from, J.J. Thornber, A.M., William T. Kendall and Richard Glinski.

NATIVE TREES

Acacia greggii var. arizonica	Catclaw Acacia
Celtis reticulata	Canyon Hackberry
Fraxinus pennsylvanica var. velutina	Arizona Ash
Juglans major	Arizona Black Walnut
Populus femontii var. fremontii	Fremont Cottonwood
Prosopis pubescens	Screwbean Mesquite
Prosopis velutina	Velvet Mesquite
Salix exigua	Coyote Willow
Salix gooddingii	Goodding Willow
Sambucus mexicana	Desert Elderberry
Sapindus drummondii	Western Soapberry

EXOTIC TREES

Tamarix ramosissima	Salt Cedar

NATIVE SHRUBS

Atriplex canescens	Four-winged Saltbush
Atriplex polycarpa	Desert Saltbush
Baccharis salicifolia	Seepwillow
Cephalanthus occidentalis var. californicus	Common Button Bush

Condalia warNockii var. kearneyana	Kearney Condalia
Koeberlinia spiNosa var. spinosa	Allthorn
Lycium andersonii var. wrightii	Wright Desert Thorn
Lycium fremontii	Fremont Desert Thorn
Lycium torreyi	Torrey Desert Thorn
Tessaria sericea	Arrow Weed
<u>EXOTIC SHRUBS</u>	
Arundo donax	Giant Reed
Caesalpinia gilliesii	Bird of Paradise Flower
Nicotiana glauca	Tree Tobacco
<u>NATIVE HALF-SHRUBS</u>	
Acacia angustissimai var. hirta	Fern Acacia
Suaeda suffrutescens	Seepweed
Suaeda torreyana	Desert Seepweed
<u>EXOTIC HALF-SHRUBS</u>	
Marrubium vulgare	Horehound
<u>NATIVE PERENNIAL HERBS</u>	
Asclepias subverticillata	Poison Milkweed
Aster commutatus var. crassulus	Prairie Daisy
Aster spiNosus	Spiny Aster
Boerhaavia coccinea	Red Spiderling
Cyperus esclentus	Yellow Nut Sedge
Chamaesaracha coroNopus	Small Ground Cherry
CheNopodium berlandieri	Goose Ft.

Datura metaloides	Sacred Datura
Distichlis spicata var. stricta	Desert Saltgrass
Elymus triticoides	Beardless Wild Rye
Guitierrezia microcephala	Three Leaf Snakeweed
Helenium thurberi	Sneeze Weed
Hoffmanseggia glauca,	Hog Potato
HymeNothrix wislizenii	Wislizenus Beeflower
Malvella lepidota	Scurfy Sida
Maurandya antirrhiniflora	Blue Snapdragon Vine
Panicum obtusum	Vine Mesquite Grass
Pappophorum vaginatum	Pappus Grass
Physalis virginiana var. sonorae	Long Leaf Groundcherry
Ruellia nudiflora	Ruellia
Rumex hymenosephalus	Canaigre
Sarcostemma cynanchoides	Climbing Milkweed
Setaria macrostachya	Plains Bristlegrass
Solanum douglasii	Douglas Nightshade
Solanum elaeagnifolium	Silverleaf Nightshade
Solidago altissima	Tall Goldenrod
Sphaeralcea angustifolia var. cuspidate	Narrow-leaved Globe Mallow
Sporobolus wrightii	Sacaton Grass
Teucrium canadense var. angustatum	American Germander
Teucrium cubense ssp. Depressum	Small Coast Germander
Trichloris crinita	Feather Fingergrass
Verbena neomexicana	Hillside Vervain

EXOTIC PERENNIAL HERBS

Convolulus arvensis	Field Bindweed

CyNodon dactylon	Bermudagrass
Malva parviflora	Cheeseweed
Plantago major	Common Plantain
Rumex crispus	Curly-leaf Dock
Sorghum halepense	Johnson Grass
	Lehman's Lovegrass

Appendix B: Locations

Locations of effluent release outlets.

- Roger Road Treatment Plant effluent outlet is located 0.35 miles Northward and downstream of Sweetwater Drive.
- Ina Road Treatment Plant effluent outlet is located 330 ft. (0.063 miles) southward and upstream from the Ina Road Bridge.

Locations of Unchannelized With Effluent (E) Transects

Unchannelized With Effluent (E): Stretches of river which have one or less embankments and nearly continuous above ground effluent flow.

Transect E1: 0.63 miles downstream from Canyon Del Oro Wash Inlet.
Location: N 32° 19.736' W 111° 04.256'
Marked: Red Flags

Transect E2: 0.9 miles downstream from Sweetwater Drive.
Location: N 32° 17.394' W 111° 02.092'
Marked: Red Flags

Transect E3: 0.20 miles upstream from Ina Road Bridge.
Location: N 32° 20.199' W 111° 04.800'
Marked: Red Flags

Transect E4: 0.55 miles downstream from Ina Road Bridge.
Location: N 32° 20.648' W 111° 05.087'
Marked: Orange Flags

Transect E5: 0.35 miles downstream from Northeast corner of Rillito Inlet.
Location: N 32°19.017' W 111° 03.447'
Marked: Orange Flags

Transect E6: 0.25 miles upstream from Northeast corner of Rillito Inlet.
Location: N 32° 18.621' W 111° 03.119'

Marked: Orange Flags

Note: All above locations refer to the Southeast corner of the lowland transect unless otherwise Noted. Flags were left in place.

Locations of Southern Unchannelized No Effluent (S) Transects

Southern Unchannelized No Effluent (S): Stretch of river beginning at Irvington Rd. and continuing upstream (South) for 4 miles, which has one, or less embankments and No effluent flow.

Transect S1: 0.2 miles upstream from Valencia Road Bridge.
Location: N 32° 07.860' W 110° 59.566' (marks the Southwest corner of the lowland transect)
Marked: Red Flags

Transect S2: 250 ft. upstream Irvington Road Bridge.
Location: N 32° 09.765' W 110° 59.540'
Marked: Neon Pink Flags

Transect S3: 0.13 miles upstream Irvington Road Bridge.
Location: N 32° 09.686' W 110° 59.538'
Marked: Neon Pink Flags

Transect S4: 0.70 miles upstream Irvington Road Bridge.
Location: N 32° 09.303' W 110° 59.491'
Marked: Neon Pink Flags

Transect S5: 0.31 miles upstream from Valencia Road Bridge.
Location: N 32° 07.810' W 110° 59.491'
Marked: Neon Pink Flags

Transect S6: 0.32 miles upstream from Northbound I-19 Bridge.
Location: N 32° 06.237' W 110° 59.285'
Marked: Neon Pink and Green Flags

Note: All above locations refer to the Southeast corner of the lowland transect unless otherwise Noted. Flags were left in place.

Locations of Northern Unchannelized No Effluent (N) Transects

Northern Unchannelized No Effluent (N): Stretch of river beginning 28 miles downstream (North) from the Roger Road outlet and running for four miles which has one or less embankments and contains No above ground effluent flow.

Transect N1: 0.18 M upstream from second, Northward, dirt, agricultural access road, off of Baumgartner Road after it turns from paved to dirt.
Location: N 32° 35.066' W 111° 27.518'
Marked: Yellow Flags

Transect N2: Directly South of first, Northward, dirt, agricultural access road, off of Baumgartner Road after it turns from paved to dirt.
Location: N 32° 35.146' W 111° 27.664'
Marked: Yellow Flags

Transect N3: 240' upstream from Baumgartner Road Bridge.
Location: N 32° 35.331' W 111° 28.068'
Marked: Yellow Flags

Note: All above locations refer to the Southeast corner of the lowland transect unless otherwise Noted. Flags were left in place.

Locations of Channelized With Effluent (CE) Transects

Channelized With Effluent (CE): Stretch of river downstream (North) of the Cortaro Farms Road Bridge extending to the Avra Valley Road Bridge, which has embankments on both sides and contains nearly continuous above ground effluent flow.

Transect CE1: 0.39 miles downstream Cortaro Farms Road Bridge.
Location: N 32° 21.389' W 111° 06.069'
Marked: Green Flags

Transect CE2: 0.50 miles downstream Cortaro Farms Road Bridge.
Location: N 32° 21.444' W 111° 06.146'
Marked: Green Flags

Transect CE3: 1.25 miles downstream Cortaro Farms Road Bridge.
Location: N 32° 21.979' W 111° 06.576'
Marked: Green Flags

Transect CE4: 2.31 miles downstream Cortaro Farms Road Bridge.
Location: N 32° 22.636' W 111° 06.850'
Marked: Green Flags

Note: All above locations refer to the Southeast corner of the lowland transect unless otherwise Noted. Flags were left in place.

Locations of Channelized No Effluent (CN) Transects

Channelized No Effluent (CN): Stretch of river directly upstream (South) from the Roger Road outlet, which has embankments on either side and contains No effluent flow.

Transect CN1: 0.39 miles upstream from Sweetwater Drive.
Location: N 32° 16.578' W 111° 01.427'
Marked: Red Flags

Transect CN2: 0.47 miles upstream from Sweetwater Drive.
Location: N 32° 16.553' W 111° 01.312'
Marked: Red and Orange Flags

Transect CN3: 1.17 miles upstream from Sweetwater Drive.
Location: N 32° 16.162' W 111° 00.864'
Marked: Red and Orange Flags

Transect CN4: 0.61 miles upstream from Sweetwater Drive.
Location: N 32° 16.518' W 111° 01.171'
Marked: Neon Pink Flags

Note: All above locations refer to the Southeast corner of the lowland transect unless otherwise Noted. Flags were left in place.

Appendix C: Plants found in the transects, Alphabetical by plant type and origin

Native Trees

Acacia constricta	Whitethorn Acacia
Acacia greggii	Catclaw Acacia
Cercidium microphyllum	Ft.hills Palo Verde
Populus fremontii	Fremont Cottonwood
Prosopis velutina	Velvet Mesquite
Salix gooddingii	Goodding Willow

Exotic Trees

Cercidium parkinsonia aculeata	Mexican Palo Verde
Prosopis south american hybrid	South American Mesquite
Tamarix ramosissima	Salt Cedar

Native Woody Shrubs

Ambrosia aptera	Ragweed
Atriplex canescens	4-Wing Saltbush
Atriplex cf. lentiformis	Saltbush
Atriplex polycarpa	Desert Salt Bush, Cattle Spinach, Sage
Baccharis salicifolia	Seepwillow
Baccharis sarathroides	Desert Broom
Encelia fariNosa	Brittlebush
HymeNoclea momogyra	Burrobush, Romerillo, Jecota
Isocuma tenuisecta	Burroweed
Koeberlina spiNosa var. spiNosa	All-Thorn
Larrea tridentata	Creosote

Opuntia engelmannii	Prickly Pear
Exotic Woody Shrubs	
Arundo donax	Giant Reed
Nicotiana glauca	Tobacco Tree
Sinapsis arvensis (Brassica arvensis)	
Native Herbaceous	
Astoraceae species unidentifiable	
Bidens cernua	Spanish Needles
Bothricchioa bardiNodis	
Bouteloua artistidoides	Grama
Calibrachoa parviflora	
Clematis drummondii	
Conyza canadensis	
Cryptantha angustifolia	
Cupressus species unidentifiable	Cyperus
Datura meteloides	Datura
Eriogonum deflexum	Skeleton Weed
Gaura parviflora	
Gnaphalium wrightii	Cud Weed, Everlasting
Heterotheca subaxillaris	Camphor Weed
HymeNothrix wislizenii	
Hydrocotyle ranunculoides	Water Pennywort
Melilotus species unidentifiable	Sweet Clover
Mentzelia albicaulis	
Mentzelia species unidentifiable	Stick Leaf
Mimulus guttatus	Monkey Flower
Nicotiana obtusifolia	Tobacco
Polanisia doderandra	Clammy Weed

Polygonum pensylvanicum	Lady's Thumb, KNotweed, Smartweed
Polygonum species unidentifiable	KNotweed, Smartweed
Rumex crispus or hymeNosepalus	Curly-Leaf Dock
Rumex dentatus L.	Curly Dock, Sorrel
Sarcostemma cyanchoides (Funastrum cynanchoides)	Milk Weed
Solanum nigrum or americanum	Nightshade
Suaeda moguinnii	Seep Weed, Quelite Salado
Teucrium cubense	Germander
Verbesina encelioides	Crown Beard
Veronica anagallis-aquatica	Speedwell
Xanthium stranarium	Cocklebur

Non-Native Herbaceous

Brassica species unidentifiable	
CheNopodium murale	Nettle Leaf Goose Ft.
Conium maculatum	Poison Hemlock
CyNodon dactylon	Bermuda Grass
EchiNochloa colonum	Jungle Rice, Cock Spur
Malva neglecta	Mallow, Cheeseweed
Melilotus indicus	Sour Clover
Phalaris miNor	Canary Grass
Rorippa nasturtium-aquaticum	Watercress
Salsola kalivar	Russian Thistle, White Man's Plant
Sisymbrium orientale or irio	
Sonchus oleraceus	Sow Thistle
Sorghum halepense	Johnson's Grass
Veronica species unidentifiable	

Appendix D: Plants by Effluent and Non-Effluent and Origin.

Plants Found Only In Effluent Transects

Scientific Name	Common Name	Origin
Ambrosia aptera	Ragweed	Native
Arundo donax	Giant Reed	Exotic
Atriplex canescens	4-Wing Saltbush	Native
Atriplex cf. lentiformis	Saltbush	Native
Baccharis salicifolia	Seepwillow	Native
Bidens cernua	Spanish Needles	Native
Brassica species unidentifiable		Exotic
Calibrachoa parviflora		Native
Cercidium microphyllum	Ft.hills Palo Verde	Native
CheNopodium murale	Nettle Leaf Goose Ft.	Exotic
Conium maculatum	Poison Hemlock	Exotic
Conyza Canadensis		Native
Cryptantha angustifolia		Native
Cupressus species unidentifiable	Cyperus	Native
Datura meteloides	Datura	Native
EchiNochloa colonum	Jungle Rice, Cock Spur	Exotic
Encelia fariNosa	Brittlebush	Native
Gaura parviflora		Native
Gnaphalium wrightii	Cud Weed, Everlasting	Native
Heterotheca subaxillaris	Camphor Weed	Native
Hydrocotyle ranunculoides	Water Pennywort	Native
Malva neglecta	Mallow, Cheese Weed	Exotic
Melilotus indicus	Sour Clover	Exotic
Melilotus species unidentifiable	Sweet Clover	Native

Mimulus guttatus	Monkey Flower	Native
Nicotiana glauca	Tobacco Tree	Exotic
Nicotiana obtusifolia	Tobacco	Native
Phalaris miNor	Canary Grass	Exotic
Polanisia doderandra	Clammy Weed	Native
Polygonum pensylvanicum	Lady's Thumb, KNot Weed	Native
Polygonum species unidentifiable	KNot Weed, Smart Weed	Native
Prosopis south american hybrid	South American Mesquite	Exotic
Rorippa nasturtium-aquaticum	Watercress	Exotic
Rumex crispus or hymeNosepalus	Curly-Leaf Dock	Native
Rumex dentatus L.	Curly Dock, Sorrel	Native
Salix gooddingii	Goodding Willow	Native
Sinapsis arvensis (Brassica Kaber)		Exotic
Sisymbrium orientale or irio		Exotic
Solanum nigrum or americanum	Nightshade	Native
Sonchus oleraceus	Sow Thistle	Exotic
Sorghum halepense	Johnson's Grass	Exotic
Suaeda moguinnii	Seep Weed, Quelite Salado	Native
Teucrium cubense	Germander	Native
Veronica anagallis-aquatica	Speedwell	Native
Veronica species unidentifiable		Exotic
Xanthium stranarium	Cocklebur	Native

Plants Found Only In Non-Effluent Transects

Scientific Name	Common Name	Origin
Acacia greggii	Catclaw Acacia	Native
Atriplex polycarpa	Desert Saltbush, Sage	Native
Clematis drummondii		Native

Eriogonum deflexum	Skeleton Weed	Native
HymeNothrix wislizenii		Native
Koeberlina spiNosa var. spiNosa	All-Thorn	Native
Mentzelia albicaulis	Stick Leaf	Native
Mentzelia species un-identifiable	Stick Leaf	Native
Opuntia engelmannii	Prickly Pear	Native
Sarcostemma cyanchoides	Climbing Milk Weed	Native
Verbesina encelioides	Crown Beard	Native

Plants Found In Effluent and Non-Effluent Transects

Scientific Name	Common Name	Origin
Acacia constricta	Whitethorn Acacia	Native
Astoraceae species unidentifiable		Native
Baccharis sarathroides	Desert Broom	Native
Bothricchioa bardiNodis		Native
Bouteloua artistidoides	Grama	Native
Cercidium parkinsonia aculeata	Mexican Palo Verde	Exotic
CyNodon dactylon	Bermuda Grass	Exotic
HymeNoclea momogyra	Burrobush, Romerillo, Jecota	Native
Isocuma tenuisecta	Burroweed	Native
Larrea tridentata	Creosote	Native
Populus fremontii	Fremont Cottonwood	Native
Prosopis velutina	Velvet Mesquite	Native
Salsola kalivar	Russian Thistle	Exotic
Tamarix ramosissima	Salt Cedar	Exotic

Appendix E: Transect Photos

Group: Effluent Unchannelized

Trabsect E1: by the effluent water flow

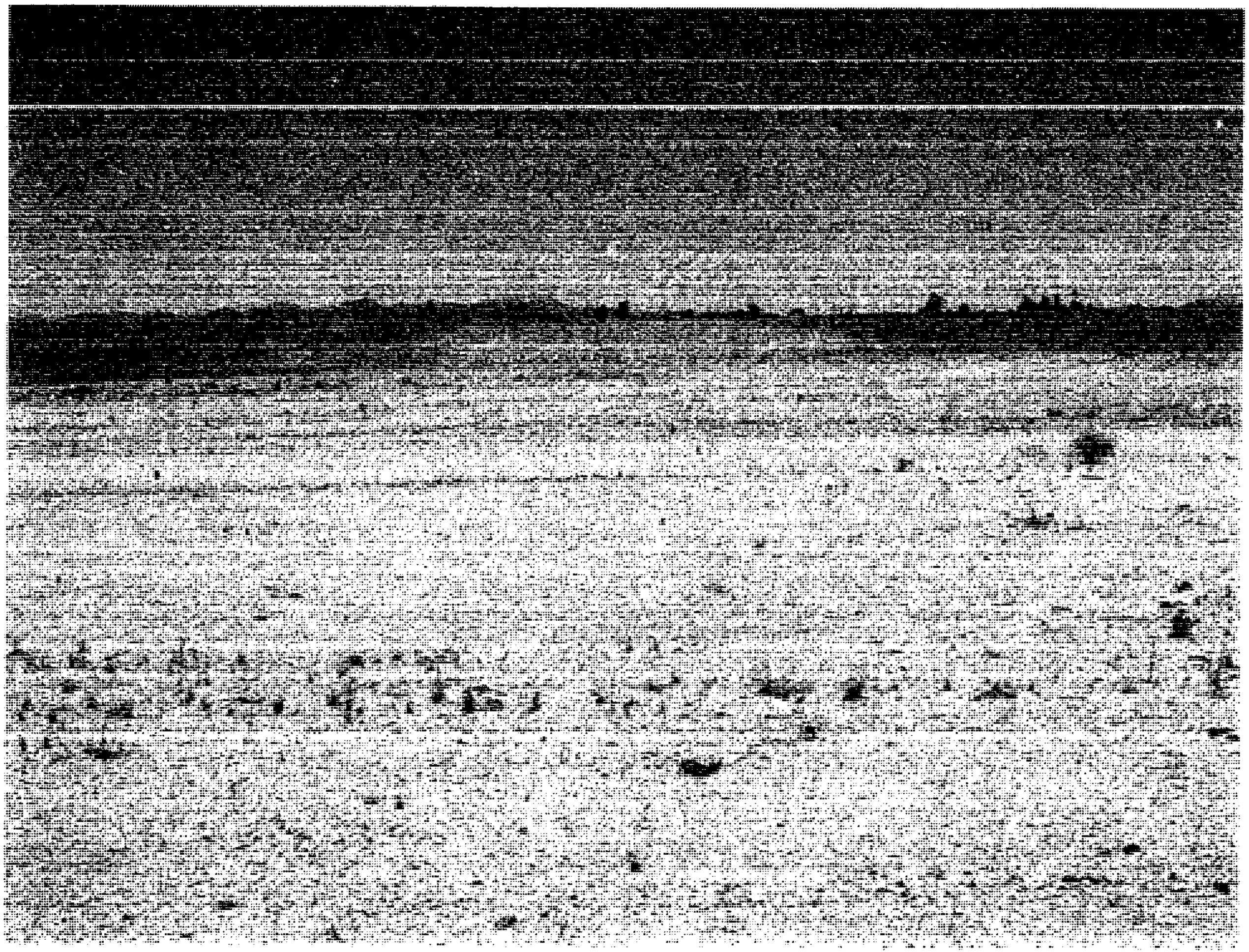
Transect E1: from western edge of transect

Group: Effluent Unchannelized, cont.

Transect E2: from eastern edge of transect

Transect E3: from water looking eastward

Group: Effluent Unchannelized, cont.



Transect E4: looking westward from the water's edge

Transect E4: looking eastward from the water's edge

Group: Effluent Unchannelized, cont.

Transect E5: looking westward from the eastern edge of transect

Transect E5: looking downstream from transect E5

Group: Effluent Unchannelized, cont.

Transect E6: looking downstream from transect E6

Transect E6: looking upstream from transect E6

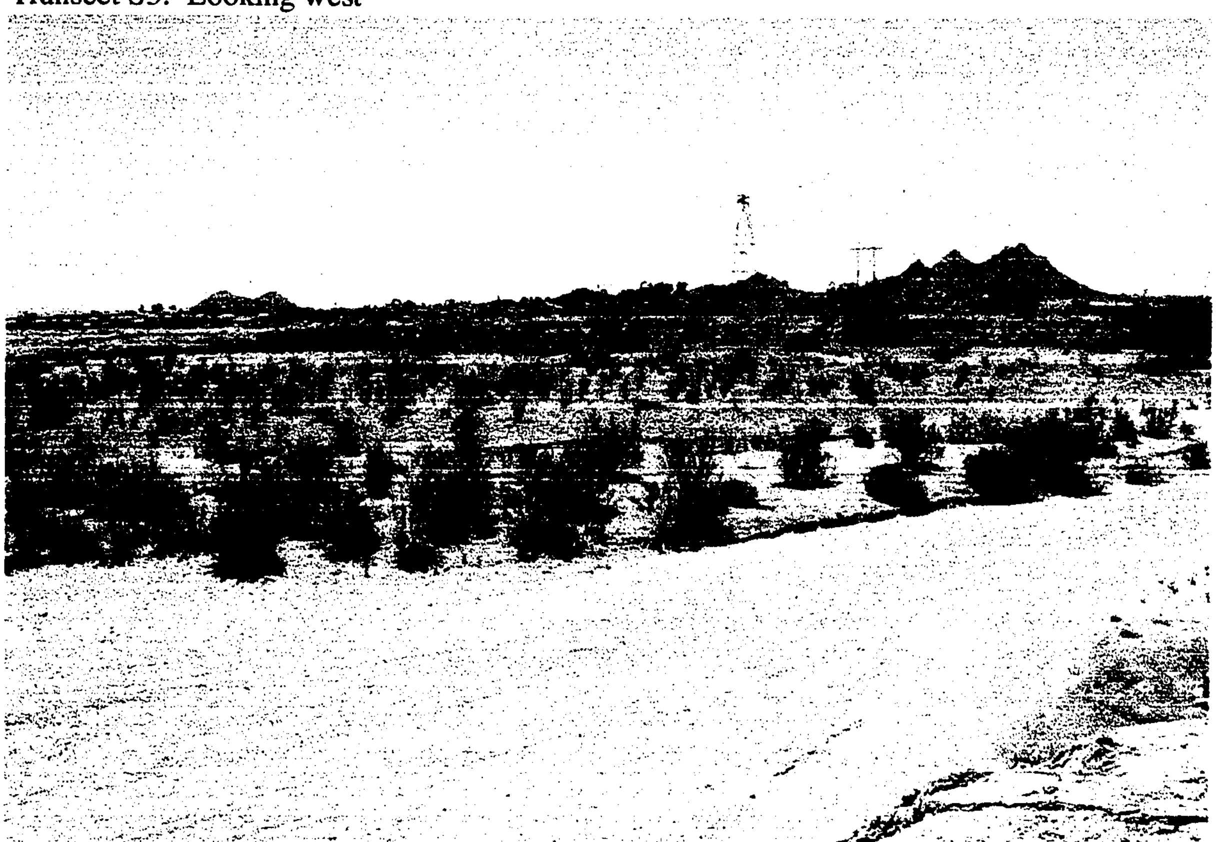
Group: Southern, No Effluent, Unchannelized

Transect S1: Looking west

Transect S2: Looking east

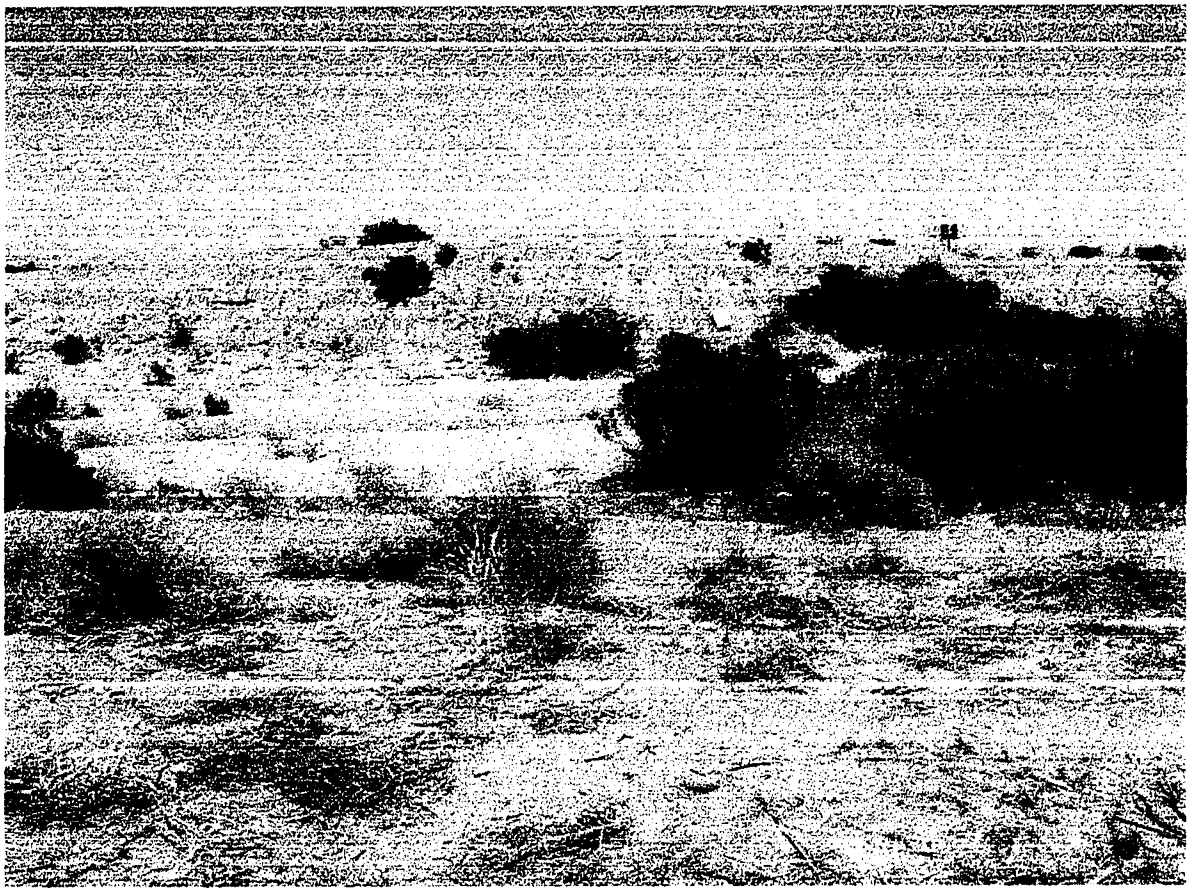
Group: Southern, No Effluent, Unchannelized, cont.

Transect S3: Looking west

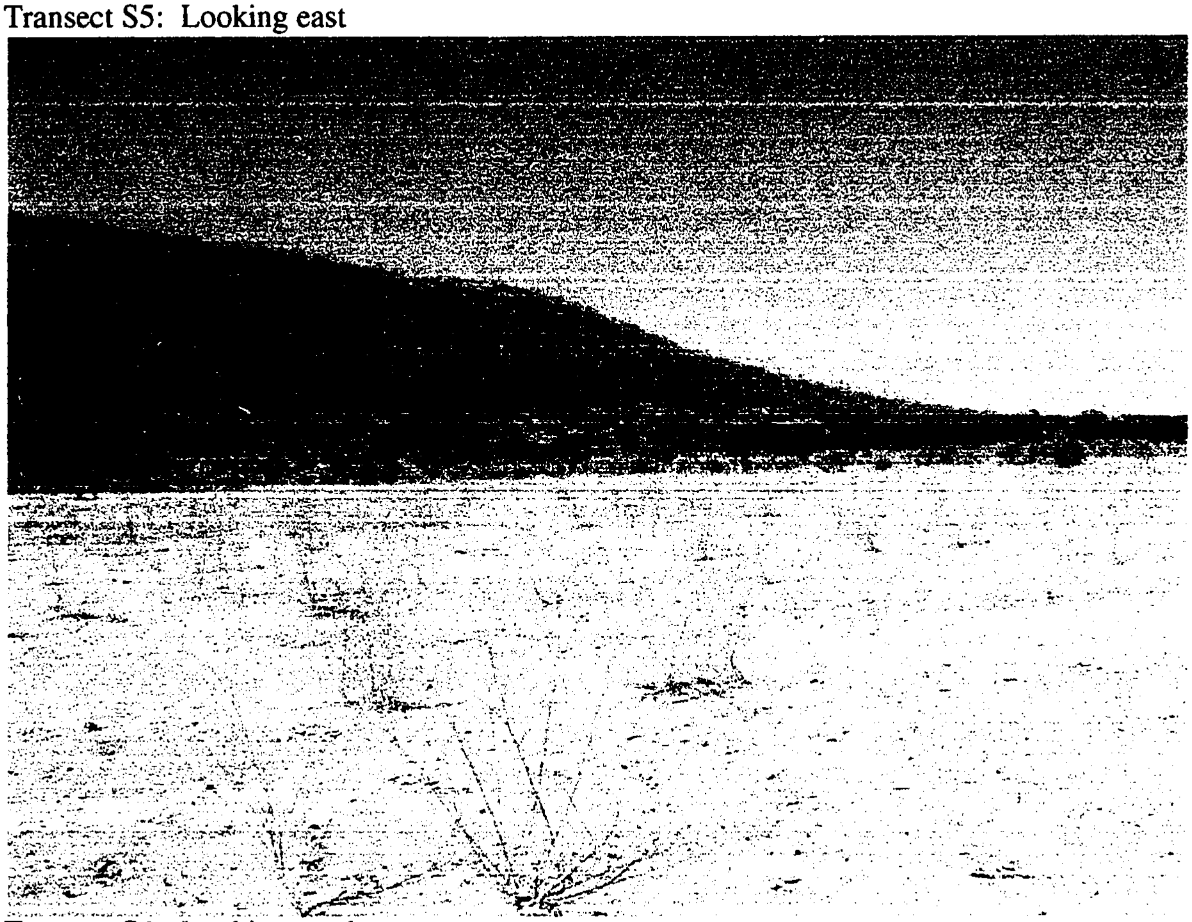


Transect S4: Looking west from above

Group: Southern, No Effluent, Unchannelized, cont.



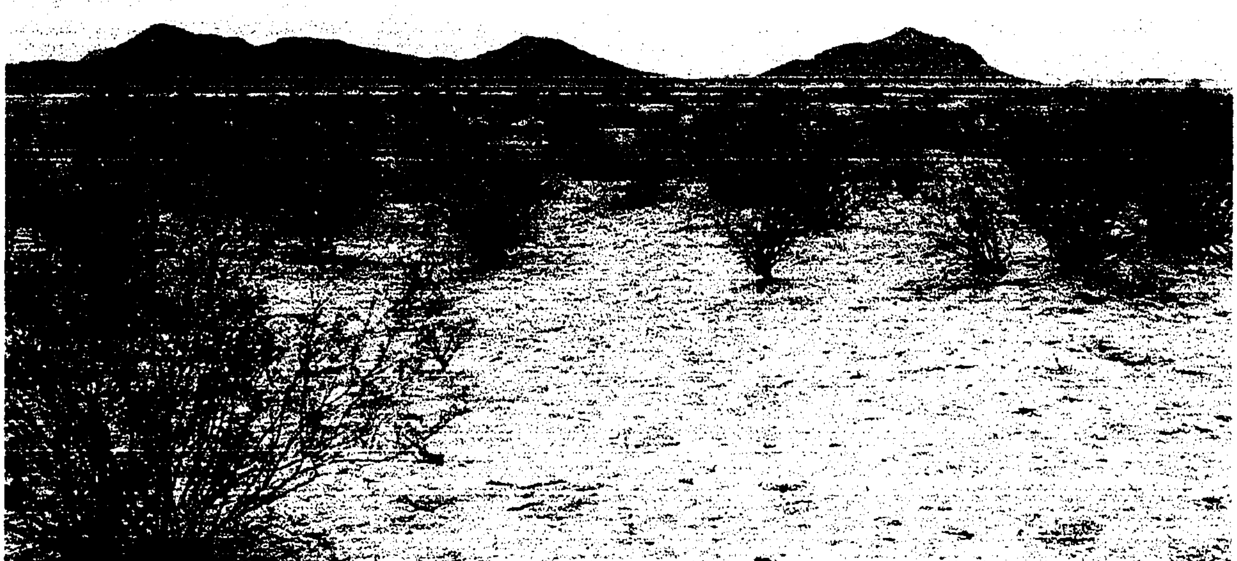
Transect S5: Looking east



Transect S6: Looking north

Group: Northern, No Effluent, Unchannelized

Transect N1: Looking south



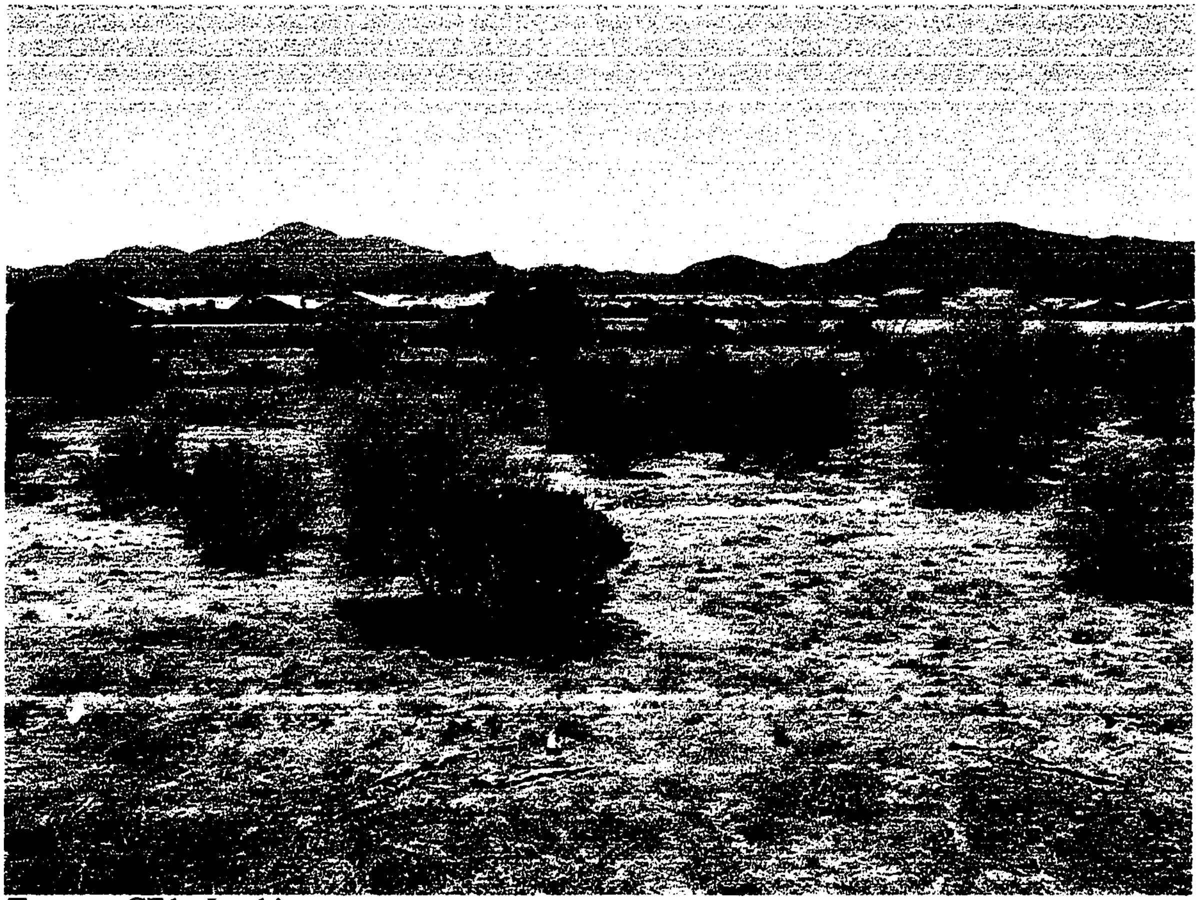
Transect N2: Looking south

Group: Northern, No Effluent, Unchannelized, cont.

Transect N3: Looking east

Transect N3: Looking upstream

Group: Channelized Effluent



Transect CE1: Looking west

Transect CE2: Looking upstream

Group: Channelized Effluent, cont.

Transect CE3: Looking east from effluent flow

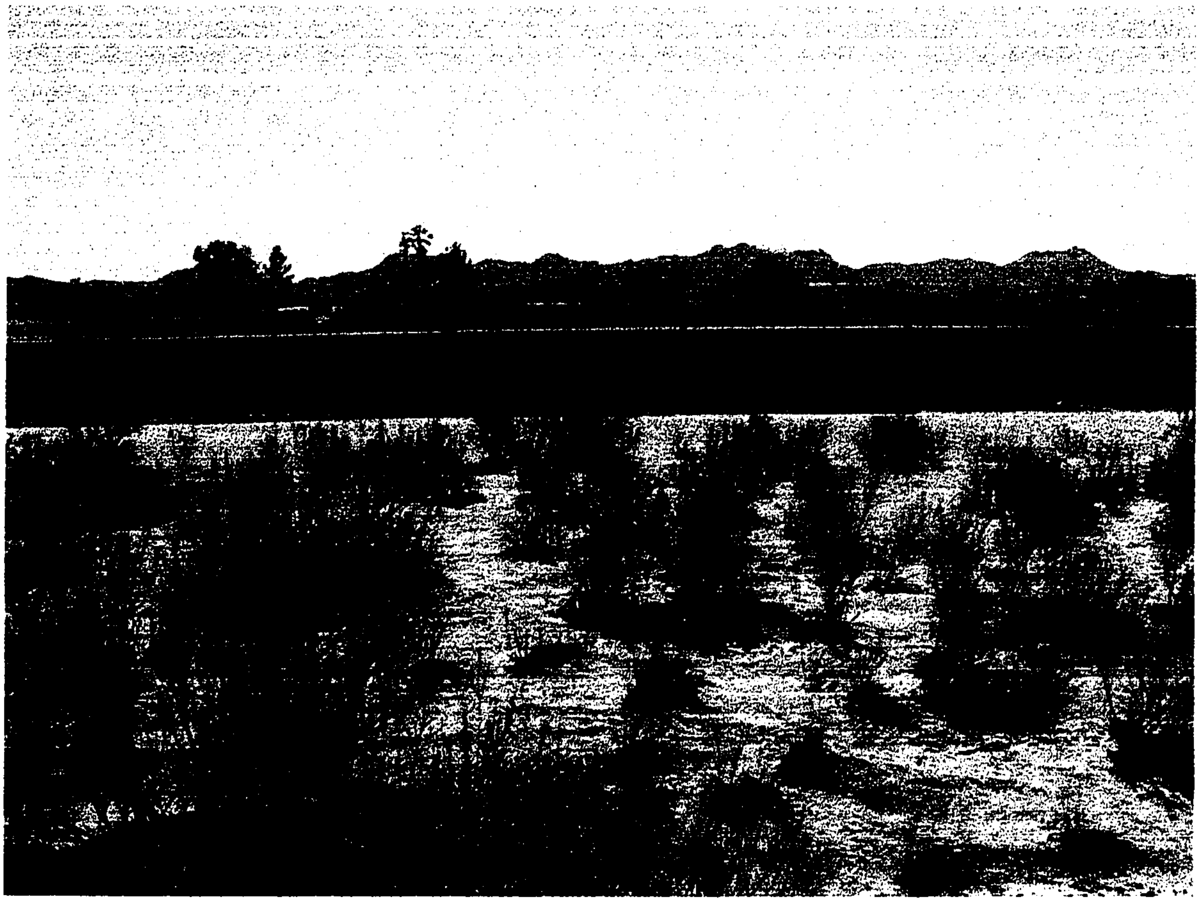
Transect CE4: Looking west from effluent flow

Group: Channelized, No Effluent


Transect CN1: Looking east


Transect CN2: Looking west

Group: Channelized, No Effluent, cont.



Transect CN3: Looking west

Transect CN4: Looking west

FACULTY COMMITTEE

1. Margaret Livingston, Ph.D., Landscape Architecture
2. Randy Gimblett, Ph.D., Landscape Architecture
3. Lauri Johnson, MLA, Landscape Architecture

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