US Army Corps
of Engineers
Los Angeles District

Paseo de las Iglesias Environmental Restoration Study
Tucson, Arizona
Draft
Groundwater and Water Budget Analysis
(Future With Project Conditions)

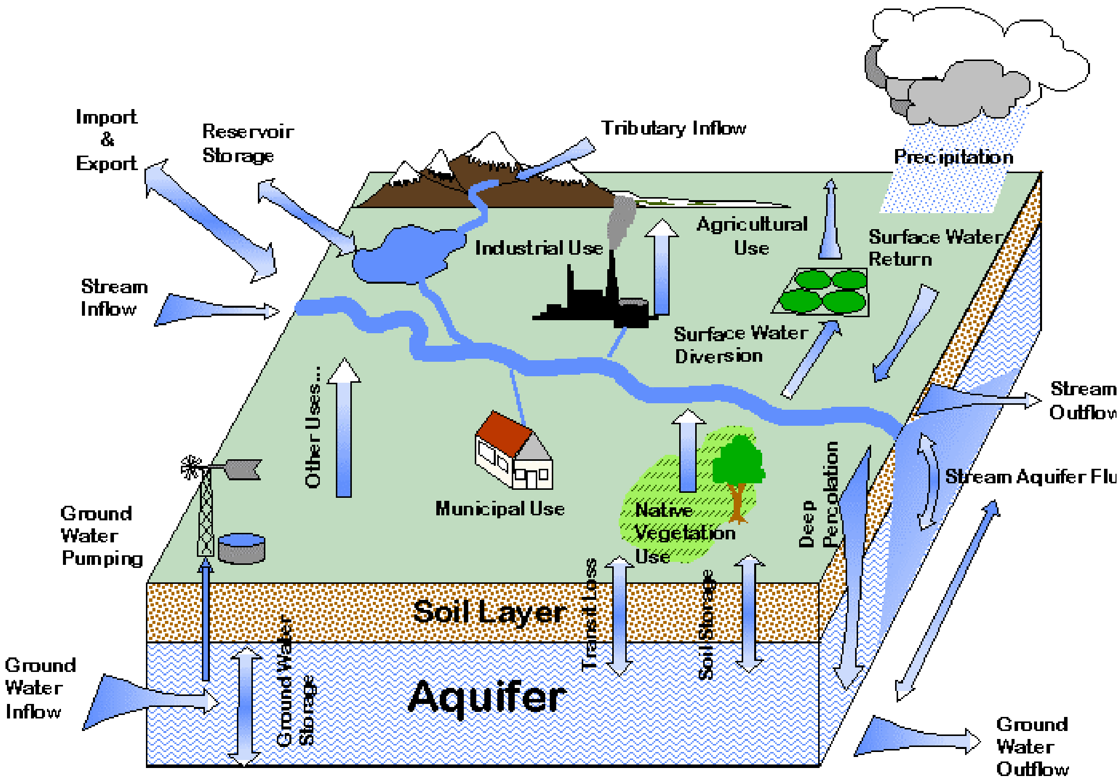

Illustration courtesy of: Colorado Division of Water Resources, Office of the State Engineer

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LOS ANGELES DISTRICT, CORPS OF ENGINEERS
HYDROLOGY AND HYDRAULICS SECTION

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1.0 INTRODUCTION

1.1 Purpose and Scope

The Feasibility Study and Environmental Impact Statement for Paseo de las Iglesias, Tucson, Arizona is being conducted by the U.S. Army Corps of Engineers, Los Angeles District (Corps) and the Pima County Flood Control District. The purposes of this report are to present water resources with project conditions and to analyze a water budget in support of feasibility study for Santa Cruz River Environmental Restoration Project in the City of Tucson and Pima County, Arizona.

Specific objectives of this report are:

1. Collection and analyses of existing groundwater data including groundwater elevations, aquifer characteristics, and review of previous studies for Santa Cruz River basin.

2. Collection of water quality data under existing conditions.

3. Water budget analysis under future with project conditions, including mass balance calculations based on inflow (infiltration and reclaimed water/effluent), outflow (pumping at well exempt and non-exempt well locations), and plant consumptions (evapotranspiration).

4. Water budget for the proposed alternative plans.

Brief discussions on the hydrogeologic setting, geology, and aquifer characteristics based on previous studies for Santa Cruz River basin were also included in the report.

1.2 Project Area

The Paseo de las Iglesias study area consists of a 7-mile reach of the Santa Cruz River and its tributary washes beginning where Congress Street crosses the river in downtown Tucson and extending upstream to the south along the river to the boundary of the San Xavier District of the Tohono O'Odham Nation (**Figure 1-1**).

The study area was defined in coordination with the Pima County Flood Control District and the City of Tucson. The area comprises approximately 5,005 acres of urban and suburban Tucson. The main channel of the Santa Cruz River flows in a relatively straight northerly direction from the southern to the northern borders of the study area. The West Branch of the Santa Cruz River currently extends from the southern border of the study area north approximately 3.5 miles to where it flows into the mainstem Santa Cruz River just north of Irvington Road. The portion of this channel just north of Irvington Road has been re-routed. The former channel (before it was re-routed) extends from just north of Irvington to just south of 22nd Street where it joins the main branch of the Santa Cruz River. The climate in the Santa Cruz River Basin is desert in character with short, dry winters and long, hot summers. High diurnal temperature variations are characteristic of the region due to the low humidity and general lack of cloud cover. Precipitation occurs in two distinct seasons of the year: summer and winter, and primarily occurs in the form of rainfall. Summer runs from June into October. Winter runs from December through February. The primary precipitation falls during the summer months as a result of thunderstorms caused by moist air flowing from the Gulf of Mexico.

The alluvial deposits in the study area consist mainly of recent stream channels and floodplain deposits. These alluvial basin sediments are generally gravel and gravelly sand. Locally, the sediments in the study area are sand to sandy silt of fluvial origin. Lithified sediments do not crop out along the Santa Cruz River and generally they should not be present within excavation depths of the channel for structure installation, though such formations do approach the riverbed elevation in the vicinity of 22nd Street.

1.3 Expected Future Without-Project Conditions

The assessment of existing conditions within the study area is described in detail in this report. The future without-project conditions include the base year, 2012, the earliest year that the project could be in operation; and year 2062, 50 years after the project operation begins. Assuming that the present regional trend in decline of groundwater table elevations will continue, availability of groundwater for riparian use is likely to decrease in the future as depths to the water table increase and water is allocated to municipal or other uses within the study area and vicinity. Availability of reclaimed water and secondary effluent are also likely to decrease in the future as water is allocated for other uses. Such changes in availability of groundwater, secondary effluent, or reclaimed water will be minimal at the base year (2012) but are likely to be significant by 2062. Availability of surface water in future (2012 or 2062) from the Santa Cruz River and tributaries, however, is likely to remain the same as in current conditions.

1.4 Summary

The potential water sources including groundwater, Santa Cruz River and its tributaries water, and wastewater treatment plant effluents (both secondary effluent and reclaimed water) were evaluated based on the quality, quantity, and seasonality of flow. The analysis of water sources shows that the wastewater treatment plant effluent is a reliable water source to the project. The Santa Cruz River and its tributaries water, and groundwater can serve as supplemental water sources.

Also, preliminary water demand estimates were calculated for each of the alternatives based on a hydrologic balance equation with the monthly and annual precipitation, evapotranspiration, evaporation, and infiltration data. A summary of water budget for each restoration alternatives is described below (Table 1-1).

Table 1-1 Summary of Water Budget

Water Supply Sources	Water Sources (acre-feet/yr)	Water Sources (mgd)
Reclaimed Water[1]	~64,000	~57.1
Surface Water[1]	~17,681	~15.78
Secondary Effluent[1]	~1,343 – 3,577 [2]	~1.2 – 3.2 [2]
Water Demands for Alternatives	**Water Demand (acre-feet/yr)**	**Water Demand (mgd)**
NMX	562.52	0.50
NMM	1889.12	1.69
XXX	252.73	0.23
MXN	55.11	0.05
MXX	261.73	0.23
MMN	474.71	0.42
MMX	681.33	0.61
MMM	1924.53	1.72
HNN	7394.19	6.60
HXN	7280.55	6.50
HXX	7296.35	6.51
HHN	7842.77	7.00
HHX	7963.37	7.11
HHM	8977.77	8.01

1- These water supply sources and volumes are provided for information purposes only. This should not be construed as meaning these respective water volumes are available for restoration purposes. See Table 9-1 for additional information.

2- Effluent projections from Avra Valley WWFT: Source: Avra Valley Basin Study, Pima County Wastewater Management Department (July 2002)

Figure 1-1 Location Map

2.0 HYDROGEOLOGIC CHARACTERISTICS

The complex geological history of Arizona has resulted in the formation of three geologic physiographical provinces. The three provinces consist of the Colorado Plateau (in the northern area of the state), the Basin and Range Province (encompassing southern and western Arizona), and the Central Highlands or Transitional Zone (encompassing the central part of the state). The Santa Cruz River Watershed lies within the Sonoran Desert of the Basin and Range Physiographic Province. The north to northwest trending alluvial basin is characterized by a semi-arid to arid broad valley.

The Santa Cruz River Basin is paralleled by steep mountain ranges composed of igneous, metamorphic, and sedimentary rocks of Precambrian (over 600 million years old) to Tertiary (63 to 2 million years ago) age (Anderson 1987). The mountains lie upon a Precambrian igneous and metamorphic basement complex that is composed predominantly of granite and diorite, schist and gneiss, and volcanic.

The alluvial sediments deposited within the basin have been divided into four geologic units that are, in descending order of depth: surficial or recent alluvial deposits, the Fort Lowell Formation, the Tinaja Beds, and the Pantano Formation (ADWR 1996). The extent of these layers in the study area is shown in **Table 2-1**. The surficial deposits occupy the streambed channels and are generally less than 100 feet thick. The coarse surficial deposits allow the infiltration of surface water to recharge the underlying units. The Fort Lowell Formation underlies the recent alluvial deposits and consists of unconsolidated to moderately consolidated sands and silts 300 to 400 feet thick throughout most of the basin (AMA 1998). The Tinaja Beds lie under the Fort Lowell Formation and are composed of sandstones and conglomerates with a total thickness of up to 5,000 feet at the center of the basin (AMA 1998). The Pantano Formation, which underlies the Tinaja Beds, is up to 6,400 feet thick near Davidson Canyon, which is about 20 miles southeast of Tucson along I-10. This formation consists of consolidated sandstones, conglomerates and mudstones. In addition to these sediments, as a result of intermittent periods of volcanism, there are areas of extrusive igneous rocks interbedded within the valley alluvium layers. Below the alluvial units and beds of volcanic rock, there is an impermeable basement complex, which extends to the surrounding mountainsides.

The main groundwater in the Tucson basin occurs in the sedimentary rocks and alluvium that form a single aquifer. The aquifer consists of the Pantano Formation, the Tinaja Beds, and the Fort Lowell Formation. The Pantano Formation yields small to moderate amounts of water to wells while the Tinaja beds yield small to large amounts of water to wells, frequently in excess of 1,000 gal/min. The water table for this main aquifer is within 350 ft. of the ground surface throughout most of the basin. Due to localized and/or perched water tables, the depth to groundwater ranges from less than 20 feet to about 170 feet below the ground surface along the Santa Cruz and Rillito Rivers.

Table 2-1 Stratigraphic Sediment Layers

Stratigraphic Sediment Layers (from Well Logs)	
At Marana	
Fort Lowell Formation and Recent Alluvium	73 m-thick (240 ft) layer
Upper Tinaja Beds	73 m-thick (240 ft) layer
Volcanic Bedrock	Top at -146m (-480 ft)
Near Grant Road Crossing	
Fort Lowell Formation and Recent Alluvium	24 m-thick (80 ft) layer
Upper Tinaja Beds	73 m-thick (240 ft) layer
Middle Tinaja Beds	49 m-thick (160 ft) layer
Volcanic Bedrock	Top at -146m (-480 ft)
1/2 Mile South of I-19/I-10 Interchange	
Fort Lowell Formation and Recent Alluvium	46 m-thick (150 ft) layer
Upper Tinaja Beds	46 m-thick (150 ft) layer
Volcanic Bedrock	Top at -91m (-300 ft)
1.5 Miles South of San Xavier Mission	
Fort Lowell Formation and Recent Alluvium	49 m-thick (160 ft) layer
Upper Tinaja Beds	37 m-thick (120 ft) layer
Lower Tinaja Beds	24 m, minimum (80 ft)
1.5 Miles North of Sahuarita/I-19 Interchange	
Fort Lowell Formation and Recent Alluvium	52 m-thick (170 ft) layer
Upper Tinaja Beds	43 m-thick (140 ft) layer
Lower Tinaja Beds	195 m, minimum (640 ft)
1 Mile North of Green Valley	
Fort Lowell Formation and Recent Alluvium	73 m-thick (240 ft) layer
Upper Tinaja Beds	37 m-thick (120 ft) layer
Lower Tinaja Beds	180 m, minimum (600 ft)
* logs adapted from Anderson 1987	

3.0 GROUNDWATER DATA INVENTORY

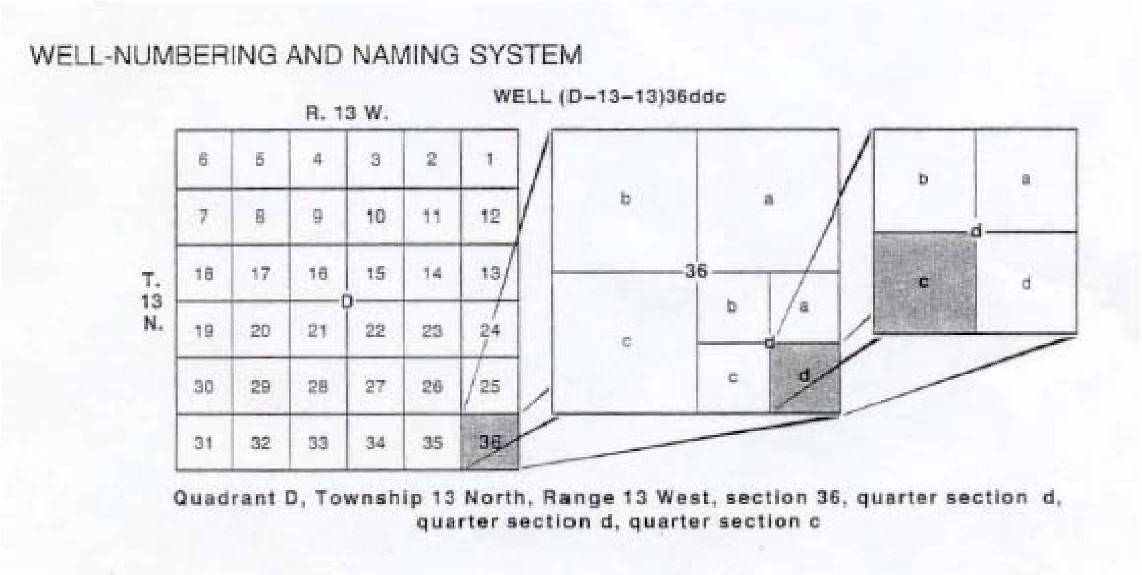
3.1 Well Inventory and Pumpage

Groundwater (perched) was encountered at depths ranging from about 5 to 35 feet at Congress St., Irvington Rd., and Valencia Road. No groundwater was encountered in the test borings for the 22nd St. Bridge where the borings were advanced to depths of 45 to 60 feet. Due to the perched and/or localized nature of the groundwater along the Santa Cruz channel, these groundwater conditions are expected to vary in relation to flows in the River, well pumping, subsurface stratification, and other factors.

Long-term groundwater withdrawal has resulted in a general decline in water levels in the Tucson area since the 1900's. This groundwater decline can be noted in the ADWR data for the depth to groundwater for the wells in this vicinity. Explanation of well numbering system used in Arizona is provided in **Figure 3-1**.

Large-scale pumping of groundwater in the Tucson basin began about 1900 and increased dramatically in the 1940's. Most of the groundwater pumped in 1940 was used for irrigation. Later, groundwater pumpage was approximately equally divided among irrigation, municipal, and industrial uses (Anderson et al. 1982). The centers of greatest water-level decline are along the Santa Cruz River near Sahuarita and in the City of Tucson. Declines exceeding 100 ft have occurred in Tucson and portions of the study area, while to the south along the river, the maximum decline has been about 150 ft (Schumann and Genualdi 1986). This difference has resulted in the formation of two distinct cones of depression in the groundwater table.

According to Arizona Department of Water Resources (ADWR), some exempt wells are associated with groundwater rights. Historic situations sometimes allow these small wells to be attached to groundwater rights, however, according to ADWR this is not currently allowed. If new wells are needed to pump groundwater, the Community could allow the wells to be drilled on their land. The wells should be located to produce minimal interference to existing wells. The well sitting would involve a hydrogeologic investigation, but state permits are not required. However, drilling new wells to pumped groundwater is not being considered as a viable water source for irrigation purposes, as this conflicts with ADWR policy.



The well numbers used by the U.S. Geological Survey in Arizona are in accordance with the Bureau of and Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the state into four quadrants and are designated by capital letters A, B, C, and D in a counterclockwise direction, beginning in the northeast quarter. The first digit of a well number indicates the township, second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicates the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northwest quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (D-13-13) 36ddc designates the well as being in the SE1/4, SE1/4, SW1/4, section 36, Township 13 North, and Range 13 West. Where more than one well is within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

Figure 3-1 Well-numbering and Naming System

3.2 Depth to Groundwater

Due to excessive groundwater withdrawals, Santa Cruz River in the project area flows in response to storm events. The Santa Cruz at one time flowed perennially and supported a variety of native species. However, because of extensive groundwater withdrawals along the river corridor for municipal, agricultural, and industrial uses, this is no longer the case. Groundwater levels continue to drop as water withdrawals exceed recharge.

Information was obtained from the Arizona Department of Water Resources (ADWR) regarding depth of groundwater in wells in this study area. This information is delineated on the graph for each well in **Appendix A**. These well locations are noted as ADWR Well Locations A through K on the aerial photo of the study region included with **Appendix A**.

The current well information indicates that depths to groundwater in the wells generally ranged from about 100 to 200 feet below ground surface in areas close to the Santa Cruz channel in Township 14 South, Range 13 East and Township 15 South, Range 13 East (**Figure 3-2**). Groundwater data was also obtained from soil borings made for bridges along the Santa Cruz River.

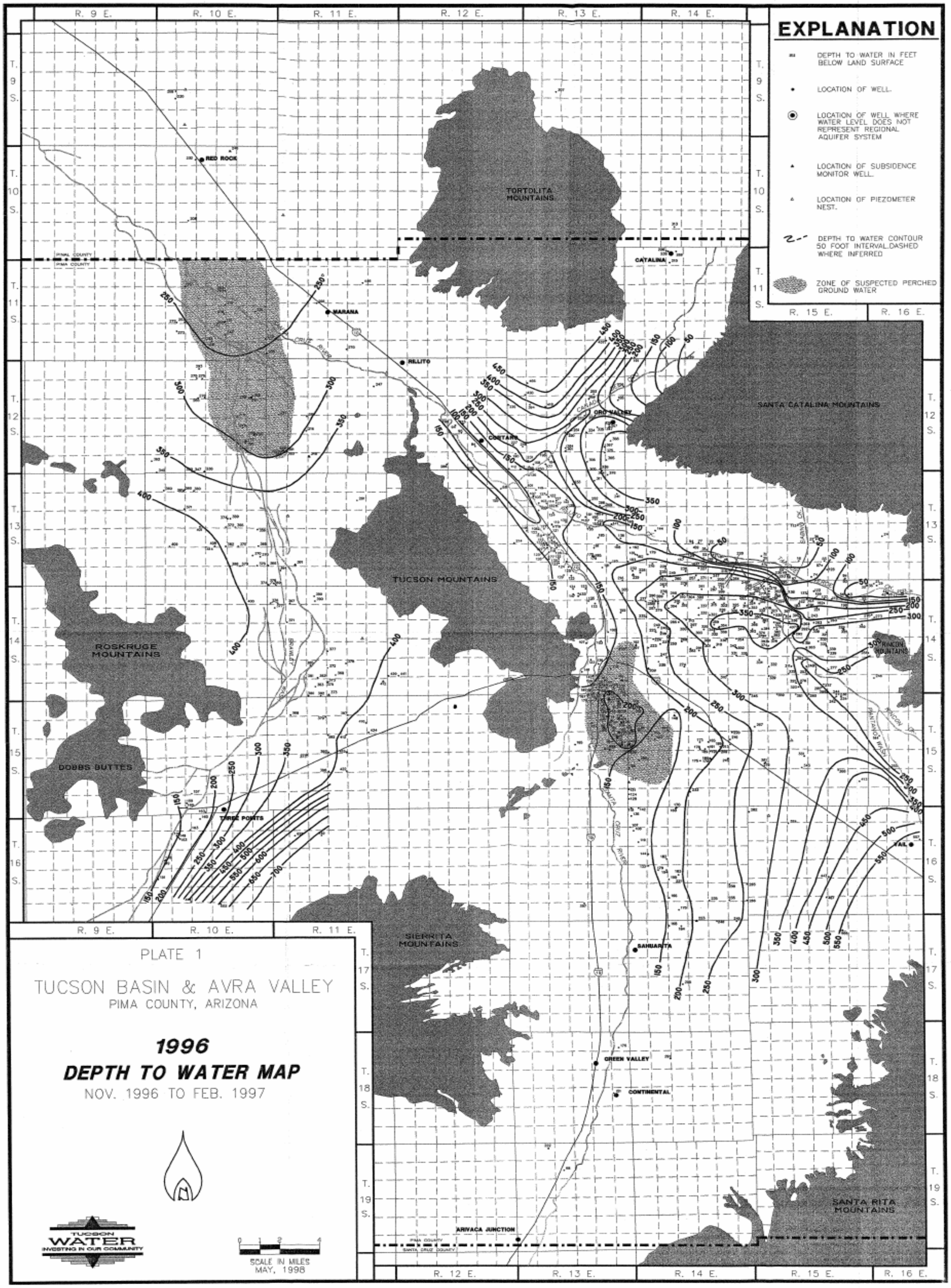


Figure 3-2 Depth to Water Map

3.3 Groundwater Quality

The groundwater delivered by Tucson Water meets all drinking water standards without treatment, with the exception of the water supplied from the Tucson Airport Area Remediation Project (TARP) wells. The TARP program was developed in order to clean and make beneficial use of water contaminated with the industrial solvent, primarily trichloroethylene (TCE). Tucson Water operates TARP under an agreement with the U.S. Environmental Protection Agency (EPA) and other industrial and governmental agencies, which pay for operation of the TARP program.

All drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. Tucson's groundwater contains dissolved minerals and organic compounds, which have been leached from the rock, sediments, and plant materials through which the water traveled. One would expect to find beneficial minerals such as calcium and magnesium, harmless minerals such as chloride, bicarbonate, and sulfate, and metals such as iron, copper, arsenic, and lead, which may be either beneficial or harmless at low concentrations, but harmful at high concentrations. In addition to these naturally occurring contaminants, our groundwater may contain contaminants resulting from human, industrial, or domestic activities. For this reason, water utilities must currently monitor for approximately 90 regulated and 12 unregulated contaminants.

Three inorganic contaminants of special interest are arsenic, fluoride, and nitrate. Fluoride and arsenic are naturally occurring and tend to increase as water is drawn from greater depths. Nitrate, on the other hand, is typically found in higher concentrations near the surface of the groundwater table because it is frequently associated with fertilizer use, septic tanks and other human activities.

Groundwater quality data was obtained from seven Tucson Water Wells. Noteworthy constituent concentrations are given in **Appendix B**. Concentration of pH is larger in sample from well (D-14-13 26ACC) than in sample from any other wells. Concentrations of Total Dissolved Solids (TDS), Chloride, Nitrate as N, Sulfate, Calcium, and Magnesium are relatively larger values in sample from wells (D-14-13 35CAC and D-14-13 35CAD) than in sample from any other wells. Concentration of Sodium is larger value from well (D-14-13 14ABC) than other wells. Consequently both of wells (D-14-13 35CAC and D-14-13 35CAD) have the larger values of contaminant among the seven wells. Tucson well data ranges between year 2000 and 2002.

Table 3-1 provides National Primary and Secondary Drinking Water Standards established by the EPA. Primary standards are legally enforceable standards that apply to public water systems. Secondary standards are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (skin or tooth discoloration) or aesthetic effects (taste, odor, or color).

Table 3-1 Drinking Water Standards (Primary and Secondary)

Constituent	Primary Standards		Secondary Standards
	Maximum Contaminant Level (MCL)	Maximum Contaminant Level Goal (MCLG)	
Nitrate (mg/l as N)	10	10	-
Sulphate (mg/l)	-	-	250
Chloride (mg/l)	-	-	250
Fluoride (mg/l)	4.0	4.0	-
Total Dissolved Solids (mg/l)	-	-	500
Arsenic (mg/l)	0.05	0	-
Barium (mg/l)	2.0	2.0	-
Copper (mg/l)	-	-	1.0
PH	-	-	6.5-8.5
Total Coliforms	5%*	0	-
Nitrite (mg/l as N)	1.0	1.0	-
Antimony (mg/l)	0.006	0.006	-
Beryllium (mg/l)	0.004	0.004	-
Cadmium (mg/l)	0.005	0.005	-
Chromium (total mg/l)	0.10	0.10	-
Cyanide (mg/l)	0.2	0.2	-
Mercury (inorganic) (mg/l)	0.002	0.002	-
Tetrachloroethyene (mg/l)	0.005	0.0	-
Trichloroethylene (mg/l)	0.005	0.0	-
Aluminum (mg/l)	-	-	0.05-0.2
Iron (mg/l)	-	-	0.3
Manganese (mg/l)	-	-	0.05
Lead (mg/l)	0.015(action level)	0	-

*-More than 5% samples total coliform-positive in a month.

Note: Sodium, Calcium, Magnesium, Potassium, Silica, Hardness and Alkalinity have no drinking water standards set by EPA.

4.0 SANTA CRUZ RIVER WATER

4.1 General

The Santa Cruz River has its headwaters in the San Rafael Valley in southeastern Arizona. From there, the river flows south into Mexico. After a 35-mile loop through Mexico, it reenters Arizona about six miles east of Nogales. The river continues northward to Tucson then northwest to its confluence with the Gila River 12 miles southwest of Phoenix. The river runs approximately 43 miles north of the US-Mexico border before entering the study area. The Paseo de las Iglesias study area consists of a 7-mile reach of the Santa Cruz River and its tributary washes beginning where Congress Street crosses the river in downtown Tucson and extending upstream to the south along the river to the boundary of the San Xavier District of the Tohono O'Odham Nation.

In the Santa Cruz River basin, flood events are linked to at least three differing storm types, categorized as *cyclonic*, *monsoon*, and *frontal*. There is some interrelationship between the meteorological circumstances leading to these differing types of storms, but generally speaking they result from differing factors, occur at different times of the year, and have different precipitation and runoff characteristics, including magnitude (both intensity and depth) and duration.

Mean annual precipitation ranges from 11 inches in the valleys to over 37 inches at elevations greater than 8000 feet National Geodetic Vertical Datum (NGVD). Studies conducted in the Tucson vicinity show an extremely low percentage (about 1%) of the rainfall appears as runoff, generally evaporating, or returning to groundwater. Precipitation occurs in two distinct seasons of the year; summer - late June, July, August, September, and into October; and winter - December, January, February, and March.

In general, the 100-year peak discharges developed by the COE in **Table 4-1** to support the Pima County's regulatory discharges, which have been adopted by FEMA.

Table 4-1 Comparison Table: Floods of Record, COE/PIMA County 100-Year Discharges

LOCATION	D.A. (mi^2)	WATER Year, POR PEAK[(a)]	DISCHARGE (Ft^3/s)			
			POR PEAK[(a)]	OCT 83 PEAK[(b)]	COE 100-Year[(c)]	PIMA 100-Year
Santa Cruz River at Continental	1662	1993	32,400	45,000	45,000	45,000
Santa Cruz River at Tucson	2222	1993	37,400	52,700	55,000	60,000

(a) Period-of-Record peak discharges excluding event of 10-2-83.
(b) Water Year 1984, annual maximum peak on 10-2-83 or 10-3-83 in Santa Cruz River.
(c) Mixed population analysis results - 1999 to 2000 COE study.

The results presented herein are based upon a *regional* **mixed population** approach in order to provide *consistent* discharge-frequency values, which are in agreement with observed streamflow data, and based upon reasonable application of statistical analysis

Floods can occur from heavy thunderstorms, but are typically of short duration (lasting up to three hours). The frequently occurring 2-year, 6-hour event in Tucson is about 1.5 inches of rainfall. The extreme 100-year, 6-hour event is about 3.6 inches in Tucson. Occasionally, longer-term summer storms occur, associated with tropical storms from the Gulf of Mexico or the Pacific Ocean. These storms may provide heavy precipitation for up to 24 hours, causing longer lasting flood events (24 hours or more). The 2-year, 24-hour event is about 1.8 inches in Tucson. The more extreme 100-year, 24-hour event is about 4.6 inches in Tucson. The mountainous areas may receive up to 5.5 inches during a 100-year event. Winter storms provide lesser amounts of precipitation and are associated with frontal storm systems from the Pacific Ocean.

The City of Tucson Report "Existing Conditions Hydrologic Modeling for the Tucson Stormwater Management Study (TSMS), Phase II, Stormwater Master Plan, Task 7, Subtask 7A3" provided most of the hydrologic data for existing (baseline) storm water quantity conditions for tributaries along the Santa Cruz River within the City limits.
The results of that analysis are presented in **Table 4-2**.

Table 4-2 Santa Cruz River Tributary Washes: Discharge Frequency Data at the Confluence with the Santa Cruz River (cubic feet per second)

Tributary Names South to North	WS Acres	100-yr	50-yr	25-yr	10-yr	5-yr	2-yr
Hughes Wash	5338	2376	1875	1258	738	334	93
Santa Clara Wash	250	389	314	221	143	86	47
El Vado Wash	1466	1558	1327	1003	716	474	287
Valencia Wash	1050	1510	1292	1026	721	441	230
Airport Wash	14547	5164	3981	2691	1549	7740	346
Wyoming Wash	448	877	719	519	335	184	82
Irvington Wash	160	427	343	237	145	75	40
Rodeo Wash	5370	3453	2839	2448	1340	744	321
Julian Wash	27859	5962	4767	3202	1901	945	389
Mission View Wash	1037	1802	1538	1201	885	599	355
18th Street Wash	2342	3085	2503	1921	1363	886	523
Cushing Street Wash	320	1165	993	770	562	375	221
Ajo Wash	1222	3465	2817	2007	1286	689	242
Enchanted Hills Wash	1990	3968	3270	2386	1540	801	256
San Juan wash	730	1757	1470	1104	757	423	152
Cholla Wash	832	2273	1882	1379	920	529	224
Old West Branch at Confluence with SCR	6541	6621	5417	3818	2447	1352	397
New West Branch at Confluence with SCR	21248	9908	7925	5250	3665	2020	595
Los Reales Road	12198	7638	6000	4000	2780	1530	450

Notes: 7900 indicates peak discharge estimated by LAD; 7900 indicates peak discharge provided by Pima County for this study.

4.2 Monthly Statistics and Low Flow Analysis for SCR

The stream flow primarily occurs in the two distinct rainfall seasons: summer and winter. The monthly statistics analyses were calculated for two gaging stations, Santa Cruz River at Tucson (09482500) and at Continental (09482000) in **Table 4-3** and **Table 4-4**.

At Tucson station located in Congress Street bridge, average daily stream flow rates are 17 cfs to 90 cfs in summer (July-October) and 11 cfs to 42 cfs in winter (December-February) and the annual average daily stream flow rate is 24.4 cfs. Maximum monthly stream flow rates are 312 cfs to 682 cfs in summer (July-October) and 202 cfs to 895 cfs in winter (December-February) and the annual maximum stream flow is 112 cfs. For the Continental station located in the upstream from this study area, the statistical analysis is summarized in **Table 4-4.**

Most precipitation falls during the summer months as a result of thunderstorms caused by moist air "monsoon" flow from the Gulf of Mexico. Winter storms provide lesser amounts of precipitation and are associated with frontal storm systems from the Pacific Ocean.

The Monthly Statistics view displays a suite of summary statistics on a month-by-month basis. This suite summarizes data over the entire period of record, reporting three types of statistics: daily statistics, period statistics (monthly), and exceedences. Daily statistics are calculated against the daily observations. Period statistics are calculated against the population of valid monthly totals or means for each period (month). Exceedences are calculated against all non-missing daily observations. **Appendix D** indicated the meanings of all text of table to help understanding.

4.3 Average Annual/Monthly Stream Flow for SCR Tributaries

There are nineteen notable tributaries joining the SCR in the study reach. Twelve tributaries – Hughes Wash, Santa Clara Wash, El Vado Wash, Valencia Wash, Airport Wash, Wyoming Wash, Irvington Wash, Rodeo Wash, Julian Wash, Mission View Wash, 18th Street Wash, Cushing Street– join the East bank, while seven tributaries – Ajo Wash, Enchanted Hills Wash, San Juan Wash, Cholla Wash, Old West Branch at Confluence with SCR, New West Branch at Confluence with SCR, Los Reales Road – join the West bank of the Santa Cruz River. Streamflow data are generally not available for the tributaries mentioned above.

Appendix C presents results of tributary analysis performed in support of this study. Average annual/monthly streamflow data of tributaries will be used to analyze the future available water resources. As shown in **Table 4-5**, eleven of the tributaries are urban tributaries and eight tributaries are rural or natural tributaries. Most of east bank tributaries are relatively urban while west bank tributaries are relatively rural or natural. Average annual tributary runoff is 9,020 AF, 3,535 AF from urban watersheds, and 5,485 AF from natural watersheds, as indicated in **Table 4-5**.

To estimate average monthly runoff volume (**Table 4-6**), the percentage of annual runoff volumes from the available records of the gaged watersheds was used as indicated in **Appendix C**.

Based on the results, the runoff from urban watersheds is more available in July, August, and September, while the runoff from rural or natural watersheds is more available in December, January, February, and March.

Table 4-3 Monthly Statistics of Santa Cruz River at Tucson, AZ

Parameter:	Stream Flow CFS	ID:	09482500
Year:	1905-2001	Statistic:	Mean
State:	AZ	Latitude:	32:13:16
County:	PIMA	Longitude:	110:58:52
		Elevation:	2317.82
		Drainage Area:	2222.00

	Jan (cfs)	Feb (cfs)	Mar (cfs)	Apr (cfs)	May (cfs)	Jun (cfs)	Jul (cfs)	Aug (cfs)	Sep (cfs)	Oct (cfs)	Nov (cfs)	Dec (cfs)	Year (cfs)	Year (ac-ft/yr)
# Days	2,335	2,119	2,325	2,250	2,325	2,250	2,329	2,328	2,250	2,388	2,310	2,387	27,596	
Avg Day	41.7	10.7	4.7	0.6	0.1	1.5	51.8	90.3	31.3	17.1	7	32.8	24.4	17,681
Max Day	24,700	1,580	1,240	142	70	403	3,120	4,570	6,400	11,200	3,200	9,840	24,700	17,898,551
Min Day	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# Months	75	75	75	75	75	75	75	75	75	77	77	77	75	
SDev Month	78.4	35.8	16.9	3.8	0.3	4.6	68.9	111.3	57.9	84.9	28.4	138.4	22.4	16,232
Skew Month	5.2	4.2	4.7	8.4	5.3	3.9	3.2	2.8	3.5	6.6	6	4.9	2.1	
Min Month	0	0	0	0	0	0	0	0	0	0	0	0	1.3	942
Max Month	517.6	202.4	102.5	32.9	2.3	24.7	429.6	681.8	311.9	656.3	214.5	895	111.8	81,014
Exceedences														
1%	759.8	308.1	107.3	9.4	0.1	35.5	1,060.0	1,568.8	505.0	184.9	164.9	703.3	525.2	380,580
5%	20	17	5	0	0	0	266.2	483.8	123	2	4.3	15	49	35,507
10%	9.5	2.1	0.1	0	0	0	110.1	216.4	21	0	0	5	5.3	3,841
20%	0	0	0	0	0	0	18	56	0	0	0	0	0	0
50%	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80%	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90%	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95%	0	0	0	0	0	0	0	0	0	0	0	0	0	0
99%	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Note- Refer to the appendix D for description of table.

Table 4-4 Monthly Statistics of Santa Cruz River at Continental, AZ

Parameter: Stream Flow CFS — ID:09482000
Year: 1940-2001 — Statistic:Mean
State: AZ — Latitude:31:51:12
County: PIMA — Longitude:110:58:40
Elevation:2832.28
Drainage Area:1682.00

	Jan (cfs)	Feb (cfs)	Mar (cfs)	Apr (cfs)	May (cfs)	Jun (cfs)	Jul (cfs)	Aug (cfs)	Sep (cfs)	Oct (cfs)	Nov (cfs)	Dec (cfs)	Year (cfs)	Year (ac-ft/yr)
# Days	1,581	1,441	1,581	1,530	1,612	1,560	1,601	1,581	1,530	1,612	1,560	1,612	18,801	
Avg Day	49.6	15.9	10.5	0.7	0	0.5	29.3	80.4	18.7	51.9	5.3	40.8	25.5	18,478
Max Day	14,800	2,290	2,450	291	31	180	1,720	4,290	6,110	17,800	3,000	9,800	17,800	12,898,551
Min Day	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# Months	51	51	51	51	52	52	51	51	51	52	52	52	50	
SDev Month	210.5	45.8	35.2	4.4	0.2	1.4	43.3	152	42.7	235.5	25.4	136	39.8	28,841
Skew Month	5.6	3.4	3.9	7	6.2	3.1	2.8	3.2	5.2	5.5	4.9	3.5	2.7	
Min Month	0	0	0	0	0	0	0	0	0	0	0	0	0.3	217
Max Month	1,386.5	207	181	31.5	1.3	6.2	227	753	285	1,524.5	133	658	205.9	149,203
Exceedences														
1%	1,267.6	383	249	2	0.7	8.6	667	1656	388	645.1	101	802	536	388,406
5%	92.9	69.9	8	0	0	0	157	420	63	9.4	0	20	44	31,884
10%	8.2	1.3	0	0	0	0	54.8	145	8.5	0.3	0	0	2.5	1,812
20%	0	0	0	0	0	0	8.4	32	0	0	0	0	0	0
50%	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80%	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90%	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95%	0	0	0	0	0	0	0	0	0	0	0	0	0	0
99%	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4-5 Average Annual Runoff for Tributaries

Tributary Names	Drainage Area (mi^2)	Drainage Area (Acres)	Impervious Area (Acres)[1]	Impervious Area (%)	Basin Rainfall (inch)	Urban[2]	Natural or Rural[3]	Ave. Annual Runoff (AAR_u) for Urban (Acre-ft)	Ave. Annual Runoff (AAR_n) for Natural (Acre-ft)
Hughes Wash	8.3	5,337.5	320.3	6.0%	11.55		X		486.3
Santa Clara Wash	0.4	249.6	74.1	29.7%		X		77.6	
El Vado Wash	2.3	1,465.6	524.7	35.8%		X		150.7	
Valencia Wash	1.6	1,049.6	436.6	41.6%		X		135.1	
Airport Wash	22.7	14,547.0	1,265.6	8.7%	11.55		X		1,228.2
Wyoming Wash	0.7	448.0	109.3	24.4%		X		82.7	
Irvington Wash	0.3	160.0	38.9	24.3%		X		72.7	
Rodeo Wash	8.4	5,369.5	1,127.6	21.0%		X		275.2	
Julian Wash	43.5	27,858.9	5,627.5	20.2%		X		2,174.8	
Mission View Wash	1.6	1,036.8	500.8	48.3%		X		146.4	
18th Street Wash	3.7	2,342.4	958.0	40.9%		X		237.1	
Cushing Street Wash	0.5	320.0	183.4	57.3%		X		93.8	
Ajo Wash	1.9	1,222.4	55.0	4.5%	11.55		X		124.6
Enchanted Hills Wash	3.1	1,990.4	13.9	0.7%	11.55		X		195.5
San Juan wash	1.1	729.6	16.1	2.2%	11.55		X		77.3
Cholla Wash	1.3	832.0	151.4	18.2%		X		89.0	
Old West Branch at Confluence with SCR	10.2	6,540.7	529.8	8.1%	11.55		X		586.8
New West Branch at Confluence with SCR	33.2	21,247.8	2,124.8*	10.0%	11.55		X		1,743.0
Los Reales Road	19.1	12,198.3	731.9*	6.0%	11.55		X		1,043.8
Total	164.0	104,946.1	11,933.0					3,535.0	5,485.6

*-Assume based on Aerial Photo.

Impervious Area (Acres)[1]- Source is HEC-1 Brief Summary provided by PIMA County.

Urban[2]-Assume the urban if impervious area (%) is greater than 10%.

Natural or Rural[3]-Assume the natural or rural if impervious area (%) is equal or less than 10%.

Table 4-6 Average Monthly Runoff (Acre-ft) for Tributaries

Watershed	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
East Bank													
Hughes Wash	42.3	34.5	26.3	2.4	4.9	6.3	95.8	97.7	99.7	34.5	15.6	27.2	486.3
Santa Clara Wash	6.8	5.5	4.2	0.4	0.8	1.0	15.3	15.6	15.9	5.5	2.5	4.3	77.6
El Vado Wash	13.1	10.7	8.1	0.8	1.5	2.0	29.7	30.3	30.9	10.7	4.8	8.4	150.7
Valencia Wash	11.8	9.6	7.3	0.7	1.4	1.8	26.6	27.2	27.7	9.6	4.3	7.6	135.1
Airport Wash	106.9	87.2	66.3	6.1	12.3	16.0	242.0	246.9	251.8	87.2	39.3	68.8	1228.2
Wyoming Wash	7.2	5.9	4.5	0.4	0.8	1.1	16.3	16.6	17.0	5.9	2.6	4.6	82.7
Irvington Wash	6.3	5.2	3.9	0.4	0.7	0.9	14.3	14.6	14.9	5.2	2.3	4.1	72.7
Rodeo Wash	23.9	19.5	14.9	1.4	2.8	3.6	54.2	55.3	56.4	19.5	8.8	15.4	275.2
Julian Wash	189.2	154.4	117.4	10.9	21.7	28.3	428.4	437.1	445.8	154.4	69.6	121.8	2174.8
Mission View Wash	12.7	10.4	7.9	0.7	1.5	1.9	28.8	29.4	30.0	10.4	4.7	8.2	146.4
18th Street Wash	20.6	16.8	12.8	1.2	2.4	3.1	46.7	47.7	48.6	16.8	7.6	13.3	237.1
Cushing Street Wash	8.2	6.7	5.1	0.5	0.9	1.2	18.5	18.9	19.2	6.7	3.0	5.3	93.8
West Bank													
Ajo Wash	28.4	23.4	22.1	5.6	0.6	0.1	3.1	8.3	6.4	3.6	2.1	20.7	124.6
Enchanted Hills Wash	44.6	36.8	34.6	8.8	1.0	0.2	4.9	13.1	10.0	5.7	3.3	32.5	195.5
San Juan wash	17.6	14.5	13.7	3.5	0.4	0.1	1.9	5.2	3.9	2.2	1.3	12.8	77.3
Cholla Wash	20.3	16.7	15.8	4.0	0.4	0.1	2.2	6.0	4.5	2.6	1.5	14.8	89
Old West Branch at Confluence with SCR	133.8	110.3	103.9	26.4	2.9	0.6	14.7	39.3	29.9	17.0	10.0	97.4	586.8
New West Branch at Confluence with SCR	397.4	327.7	308.5	78.4	8.7	1.7	43.6	116.8	88.9	50.5	29.6	289.3	1743
Los Reales Road	238.0	196.2	184.8	47.0	5.2	1.0	26.1	69.9	53.2	30.3	17.7	173.3	1043.8

5.0 TREATED WASTEWATER

5.1 Reclaimed Water

Secondary effluents generated by the Pima County Wastewater Management Department (PCWMD) sewage system receive additional treatment. Subsequent filtration and disinfection of secondary effluent produces reclaimed water, which is suitable for irrigation, industrial uses, and groundwater recharge. The Pima County Flood Control District (PCFCD) provides the monthly operating statistical data (**Table 5-1** and **Table 5-2**) of the Avra Valley Wastewater Treatment Facility (WWTF), which is a of potential water resource for irrigation needs. A capacity of existing WWTF is 1.2 MGD (1,343 acre-ft/year) but it is going to be extended with additional capacity, 3.2 MGD (3,577 acre-ft/year) until 2007. There are currently three possible use/disposal methods: 1) The majority of the effluent is disposed in the on-site percolation beds; 2) up to 2,000 gallons per day is authorized to leases for on-site landscaping needs, which is far less than that is actually used (this use is expected to be unlimited under future permitting because of the addition of an NO_3 removal system since that authorization was granted); and, 3) the facility is currently authorized to release effluent to Waters of the US, but only does so as needed during testing, repairs, or upgrades. The release is done in the spray field adjacent to the percolation beds and water flows downstream into the Black Wash.

Tertiary treated reclaimed water can be considered as another potential water resource for this project. Tucson Water Department owns 90% of this reclaimed water and delivers it through the Tucson Water reclaimed water distribution system to the City of Tucson Department of Parks & Recreation and to private users for non-potable uses, primarily turf irrigation. The reclaimed water is also made available to recharge facilities. Tucson Water has one of the largest community reclaimed water systems in the United States. Tucson Water delivers reclaimed water to nearly 400 sites, including: 13 golf courses; 32 parks; 35 schools (the University of Arizona and Pima Community College included); and more than 300 single family homes. Our reclaimed water production facilities at Roger Road near I-10 have been filtering and disinfecting treated wastewater for 18 years. Using reclaimed water for irrigation saves groundwater for drinking. In 2001, reclaimed customers saved 3.4 billion gallons of drinking water: enough for 31,000 families for a year. Existing and proposed Tucson Water Reclaimed Water System under the fiscal year 2003-2007 Capital Improvement Program (CIP) is shown in **Figure 5-1**. The total volume of effluent water generated at the Ina Road and Roger Road treatment plants is estimated at 74,000 acre-ft /year, of which approximately a total amount of 10,000 acre-ft /year is currently used for various purposes and the remaining amount discharged into the Santa Cruz River. Tucson Water estimates projected use of reclaimed water in the year 2007 at 12,000 acre-ft/year. Three environmental restoration studies (Tres Rios Del Norte, El Rio Antiguo, and Paseo de las Iglesias) around the City of Tucson are considering the reclaimed water as a potential water resource. Currently there are no effluents from the existing Tucson Reclaimed Water System to this study area, but it will be considered a viable water resource for the future plans.

Table 5-1 Monthly Operating Statistical Data of Avra Valley WWTF, (Fiscal Year 2001-2002)

FISCAL YEAR 2001-2002	LIMITS	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
INFLUENT TOTAL FLOW MG	N/A	24.352	23.881	23.806	26.6	27.23	28.175	30.23	27.4	29.73	28.53	28.23	26.07
INFLUENT AVG MGD	APP 2.2	0.786	0.77	0.794	0.858	0.908	0.909	0.975	0.978	0.959	0.951	0.91	0.869
RAW INFLUENT (PREOXIDATION DITCH)													
BOD AVG (mg/l)	N/A	184	157	207	170	165	222	205	191	238	210	243	194
pH	N/A	7.48	7.41	7.39	7.54	7.58	7.5	7.53	7.49	7.47	7.43	7.45	7.39
TSS AVG (mg/l)	N/A	244	228	280	265	221	230	270	258	332	273	268	286
SLUDGE DISPOSAL													
AVG (%sol)	N/A	0.9	1.04	0.95	0.89	0.88	0.93	1.27	0.8	0.89	1.09	0.96	1
GALLONS (Hauled)	N/A	363,880	373,700	380,840	443,520	372,140	428,560	442,640	401,280	398,256	334,530	440,880	338,960
GALLONS (Drying Bed)	N/A	0	0	0	0	0	0	76,560	147,400	0	100,760	228,000	111,760
EFFLUENT													
BOD AVG (mg/l)	30	2	4	2	2	2	2	4	3	3	3	4	<2
pH	6.0/9.0	7.59	7.61	7.54	7.55	7.53	7.34	7.42	7.38	7.4	7.38	7.48	7.5
TN AVG (mg/l)	30	<5	<5	<5	<5	5	<5	5	<5	<5	<5	<5	<5
TSS AVG (mg/l)	<10	1.9	1.7	1.6	1.7	1.3	1.9	1.8	2	2.1	1.3	1.4	1.6
NO3 AVG (mg/l)	<10	0.7	1	0.6	0.6	0.7	0.6	0.6	0.5	<0.5	<0.2	<0.8	<0.7
EFFLUENT REUSE													
REUSE TOTAL MG	N/A	0.355	0.562	0.85	0.147	0.152	0.058	0.155	0.13	0.236	0.529	0.54	0.85
AVG T. CL2	N/A	3.74	3.72	2.06	2.44	2.75	3.94	3.56	2.62	2.82	2.24	0.94	0.8
AVG F. COLIFORM	200	<2	<2	2	2	<2	<2	<2	<2	2	<2	4	2
Ph (Avg)	4.5/9.0	8.83	8.37	8.47	8.04	8.72	8	8.23	8.25	8.56	8.5	8.1	8.47
GROUNDWATER DOWNGRADIENT: AV-3*													
TN	<10	4.7	4.7	4.7	4.9	5	5.2	5.9	5.4	4.9	5.3	6.1	7.4
NO3	<10	4.7	4.7	4.7	4.9	5	5.2	5.9	5.4	4.9	5.3	6.1	7.4
GROUNDWATER DOWNGRADIENT: AV-1													
TN	N/A	15	13.2	14	15.8	19.3	N/A	12.6	14.6	14.2	13.8	12.7	12.6
NO3	N/A	15	13.2	14	15.8	19.3	N/A	12.6	14.6	14.2	13.8	12.7	12.6
GROUNDWATER UPGRADIENT: AV-4													
TN	N/A	N/A	1.6	N/A	1.1	N/A	N/A	2.7	N/A	N/A	N/A	1.6	N/A
NO3	N/A	N/A	1.6	N/A	1.1	N/A	N/A	1.8	N/A	N/A	N/A	1.6	N/A
SODIUM HYPOCHLORITE APPLIED GAL		3300	2560	1875	2335	2740	2000	1545	790	1040	1395	1670	1158
ELECTRICITY KWH		841	846	876	1061	1090	1123	1144	1045	1222	1176	1209	1745

Table 5-2 Monthly Operating Statistical Data of Avra Valley WWTF, (Fiscal Year 2002-2003)

FISCAL YEAR 2002-2003	**LIMITS**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**
INFLUENT TOTAL FLOW MG	N/A	28.88	29.5	27.91	27.49	28	28	30.08	27	29	28.7	27.56	
INFLUENT AVG MGD	APP 2.2	0.931	0.95	0.93	0.886	0.926	0.92	0.97	0.966	0.975	0.956	0.918	
RAW INFLUENT (PREOXIDATION DITCH)													
BOD AVG (mg/l)	N/A	217	155	186	204	200	212	228	177	215	203	222	
pH	N/A	7.4	7.44	7.45	7.53	7.56	7.46	7.56	7.48	7.46	7.5	7.45	
TSS AVG (mg/l)	N/A	265	270	253	203	302	299	339	259	295	331	270	
SLUDGE DISPOSAL													
AVG (%sol)	N/A	0.72	0.81	1.37	1.67	1.14	1.03	1.19	1.06	0.73	1.19	1	
GALLONS (Hauled)	N/A	490,160	446,600	347,600	376,120	348,040	394,680	497,017	486,040	445,800	438,130	505,120	
GALLONS (Drying Bed)	N/A	0	0	0	0	0	0	44,440	105,160	0	0	50,600	
EFFLUENT													
BOD AVG (mg/l)	30	2	<2	2	3	3	3	3	3	4	4	4	
pH	6.0/9.0	7.51	7.54	7.53	7.5	7.48	8.4	7.37	8.4	7.4	7.45	7.53	
TN AVG (mg/l)	30	<5	<5	<5	6	6	5	6	11	12	6	5	
TSS AVG (mg/l)	<10	1.6	1.6	1.5	2	2.4	0.9	2	2.3	2.2	2.1	106	
NO3 AVG (mg/l)	<10	<0.6	0.5	0.6	0.6	1	0.9	0.5	0.5	0.5	0.5	0.5	
EFFLUENT REUSE													
REUSE TOTAL MG	N/A	0.314	0.636	0.204	0.55	0.742	0	0	0	0	0	0	
AVG T. CL2	N/A	2.55	1.86	2.18	3.7	1.32	N/A	N/A	N/A	N/A	N/A	N/A	
AVG F. COLIFORM	200	<2	18	3	2	<2	N/A	N/A	N/A	N/A	N/A	N/A	
Ph (Avg)	4.5/9.0	8.16	8.14	8.29	8.8	8.4	N/A	N/A	N/A	N/A	N/A	N/A	
GROUNDWATER DOWNGRADIENT: AV-3*													
TN	<10	9.4	11.3	1.36	11	8.6	9.9	8.8	6.6	6.4	5.6	5.2	
NO3	<10	9.4	11.3	13.6	11	8.6	9.9	8.8	6.6	6.4	5.6	5.2	
GROUNDWATER DOWNGRADIENT: AV-1													
TN	N/A	10.9	7.8	5.7	4.8	4.8	6.3	6	6.6	5.6	5.7	7	
NO3	N/A	10.9	7.8	5.7	4.8	4.8	6.3	6	6.6	5.6	5.7	7	
GROUNDWATER UPGRADIENT: AV-4													
TN	N/A	N/A	1.8	N/A	N/A	1.8	N/A	1.8	1.9	N/A	1.9	N/A	
NO3	N/A	N/A	1.8	N/A	N/A	1.8	N/A	1.8	1.9	N/A	1.9	N/A	
SODIUM HYPOCHLORITE APPLIED GAL		2125	1475	2415	1310	2090	1070	1010	1200	1150	1900	1975	
ELECTRICITY KWH		1175	1157	1335	1150	1242	1337	1395	1364	1445	1425	1506	

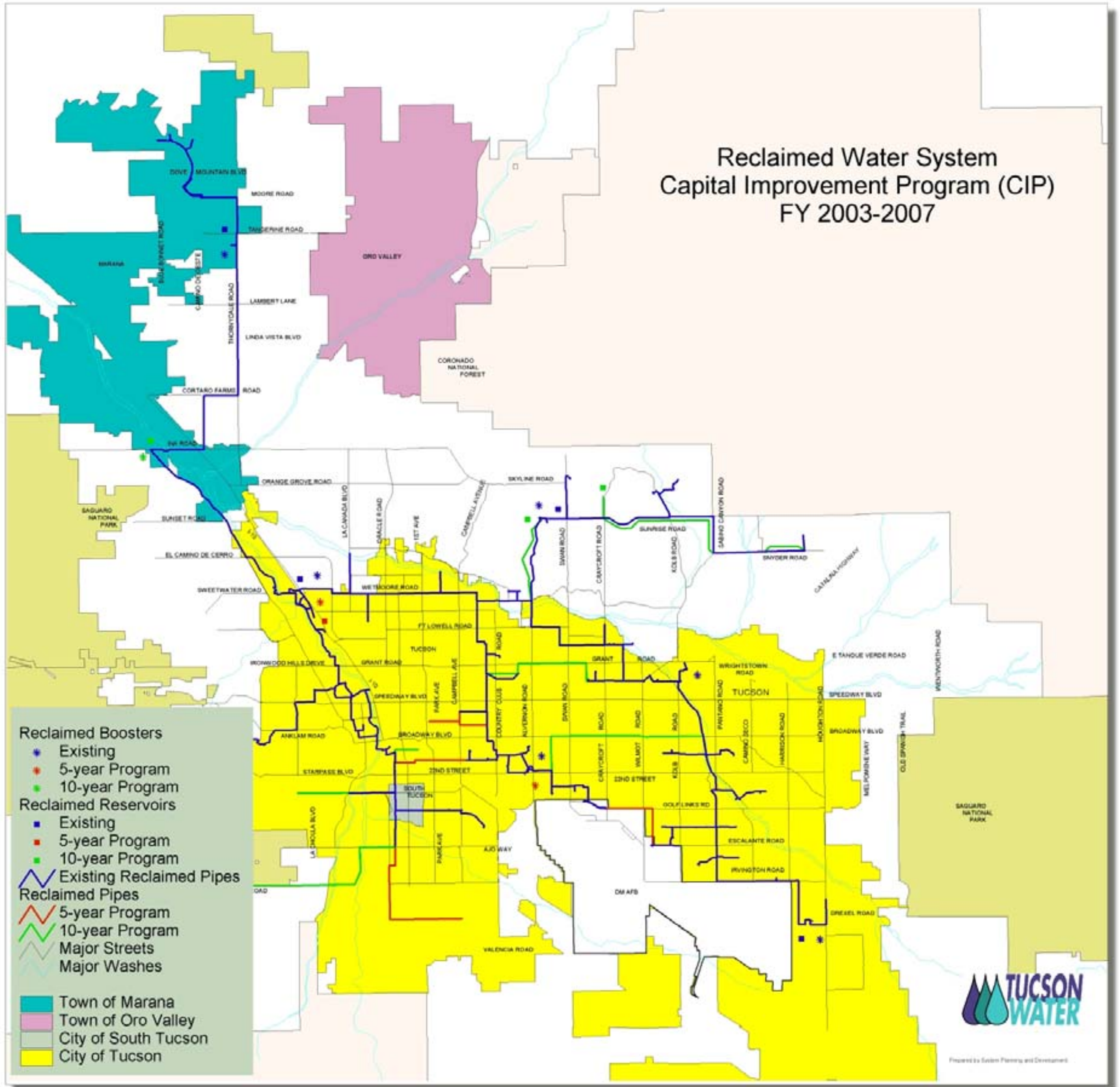


Figure 5-1 Reclaimed Water System Capital Improvement Program (CIP) FY 2003-2007

5.2 Reclaimed Water Quality

Reclaimed water ideally suited for turf irrigation and other commercial and industrial uses (Tucson Water, 2001; Pima Association of Governments (PAG), 1994a). Under a state wastewater reuse permit the reclaimed water is monitored for flow, turbidity, fecal coliform, pH, enteric virus, and *Ascaris lumbricoides* (Dotson, 2001). Water is sampled at a point that is representative of the quality of water received by the reclaimed water customers. The reclaimed water has a higher TDS concentration then secondary effluent. This is due in part to mixing with groundwater at the facility, where background TDS levels are higher than most Tucson Water wellfields (PAG, 1994a). **Tables 5-3** and **5-4** present data provided by Tucson Water for this sample point. All data is within permitted limits.

Table 5-3 Average Values, Water Quality Data, Tucson Water Reclaimed System, January-July 2001, Data from Tucson Water

Constituent	Average	No. of Samples
Total Dissolved Solids	657 mg/l	6
Total Kjeldahl Nitrogen	10.09 mg/l	6
Total Organic Carbon	7.35 mg/l	6
Total Suspended solids	1.6 mg/l *	7
Turbidity	3.28 NTU	6
Ammonia as N	6.29 mg/l	6
Nitrate as N	3.87 mg/l	7
Chloride	107.43 mg/l	7
pH	7.7 su	6
Conductivity	1012.66 umhos/cm	6
Fluoride	0.9	7
Potassium	8.2 mg/l	2
Phosphate as P	1.52 mg/l	6
Sulfate	120.8	7
Calcium	59.5	2
Total Alkalinity	247	3
Sodium	130 mg/l	2

*-This value calculated using a value of zero for one sample with a result of <1.

Samples collected on January 4, 2001, and April 12, 2001, were also analyzed for volatile organic compounds (VOCs) and metals. In general these constituents were only detected at levels less than the lowest standard or qualification limit of the method. Aluminum, Arsenic, Barium, Boron, Copper, Iron, Magnesium, Nickel, and Zinc were all present at detectable levels, but below permit limits. The results of the two samples are listed on **Table 5-4**.

Table 5-4 Analytical Results for Reclaimed Water, Sample Dates January 4, 2001 and April 12, 2001, Data provided by Tucson Water

Constituents (mg/l)	Sample Date 1/4/2001	Sample Data 4/12/2001
Aluminum, Total	<0.1	0.12
Arsenic, Total	0.0038	0.0055
Barium, Total	0.033	0.031
Boron, Total	0.3	0.29
Copper, Total	0.015	<0.01
Iron, Total	0.11	0.084
Magnesium, Total	10	9.9
Nickel, Total	0.013	<0.01
Zinc, Total	0.026	0.039

mg/l=milligrams per liter.

6.0 INFILTRATION

The infiltration of storm runoff in the stream channels during the rainy seasons is the major source of recharge to the groundwater basin (Davidson 1973). The seepage of runoff along the mountain fronts constitutes the second largest source of recharge. This natural system recharges about 100,000 ac-ft/yr; however, there is currently a demand for 300,000 to 400,000 ac-ft annually. The resulting deficit is causing the water table to decline at an approximate average annual rate of 2.7 ft (PCDOT 1986). For additional information regarding groundwater see the Geotechnical Appendix.

Several studies have been performed to evaluate the rate of recharge for both the Santa Cruz and Rillito Rivers (Wilson 1979; Katz 1987; Wilson and Newman 1987; Cluff et al. 1987; Galyean 1996). These studies attempted to evaluate the recharge rate using primarily empirical methods. The study by Katz indicated for the short-term loss that the infiltration rates, volumes of recharge per day, and volumes of recharge per day normalized to stream length were computed. For the Santa Cruz, these figures were roughly 1.37 ft/day, 551 ac-ft/day, and 18 ac-ft/day/mi, respectively. For the Rillito River, the same figures were roughly 1.67 ft/day, 479 ac-ft/day, and 41 ac-ft/day/mi, respectively. The study by Galyean indicated the infiltration of wastewater effluent in Santa Cruz River Channel, to simulate the effluent recharge volume with long-term rates. The average (1991-1993) volume of infiltration, 43733 acre-ft/yr, was divided by the average acreage of open-channel area, 136.83 acres, to get the infiltration rate, 320 ft/yr, or 0.88 ft/day. The studies by Cluff, et al., and Wilson and Newman, evaluate the effects of channel stabilization on infiltration and ground water recharge. These reports are available at the Pima County Flood Control in-house library.

Limited data is available on infiltration/recharge into the aquifer in the study area. Majority of the tests were performed locally, giving infiltration rate in ft/day at various location along the Santa Cruz River reach. These studies attempted to evaluate the recharge rate using primarily empirical methods. The Paseo de las Iglesias study area consists of a 7-mile reach of the Santa Cruz River. USGS streamflow data supports the ephemeral behavior of the Santa Cruz River. Data for water years 1995-2001 suggests that on the average, Santa Cruz River flows (above 30 cfs) 21 days per year. Based on this information, the infiltration rate was estimated as the 2,646 ac-ft/year [7 miles x (18 ac-ft/day/mi) x (21 day/year) = 2646 ac-ft/yr].

7.0 WATER DEMAND

Two different sources are available for the water demand from Environmental Restoration in Pima County (1999), and El Rio Antiguo feasibility study (2003). The water demand of an acre of habitat is different depending on whether the vegetation type is hydroriparian (such as cottonwood), mesoriparian (such as mature, dense mesquite), xeroriparian (such as less dense mesquite), or desert upland (such as native grass or cresotebush). Meso- and hydroriparian vegetation are groundwater dependent (i.e., they use water stored underground for their life cycles). **Table 7-1** quantifies the water needed (per unit area) to support various types of native vegetation, which could occur or might occur in or along our watercourses.

Table 7-1 Water Needs for Vegetation in Tucson Area

Type of Vegetation	Water Needs (acre-ft/acre/yr)
Desert Upland	
Saltbush	0.5 - 1.0
Cresotebush	0.8
Xeroriparian	
Less Dense Mesquite	1.6
Mesoriparian	
Mature, Dense Mesquite	3.0
Hydroriparian	
Mature Cottonwoods	5.0 – 5.8
Young Cottonwoods/Willows	8.3
Wetlands	
Cattails	6.9
Other Features	
Open Water	5.4
Park with turf and trees	2.9 - 4.0
Pecan Grove with Ground Cover	5.7
Golf Course with Water Features	4.7

Source: Pima County Administrator's Office

The following three groups of plant communities will be utilized: (1) Mesquite Communities include Mesquite, Desert Willow, Blue Palo Verde, Wolfberry, Graythorn, and Hackberry: (2) CW Forest Communities include Fremont Cottonwood, Gooding's Willow, Sycamore, Ash, Arizona Walnut, and Hackberry; and (3) Scrub/Shrub Communities include Wolfberry, Graythorn, Hackberry (upper edge), Seep Willow, Bursage, and Saltbrush. Secondly, water use requirements for the three groups (Mesquite, CW Forest and Scrub/Shrub Communities) are given in **Table 7-2**.

Table 7-2 Water Demand for Riparian Habitat Units

Type of Vegetation	Water Demands (ft/yr)*
Scrub Shrub	3.0
Mesquite	4.0
Cottonwood/Willow	8.5

Source: El Rio Antiguo AFB Feasibility Study Report
*- Includes infiltration loss

Sustaining xeroriparian scrub shrub and smaller less-dense mesquite in this manner without irrigation is consistent with the water demand research obtained Pima County, as well as ongoing restoration projects managed by the Audubon Society in the Tucson area. That research indicates xeroriparien mesquite requires 1.6 feet/year and the majority of the xeroriparian scrub shrub require 1.0 feet/year or less. The water demand values utilized in El Rio Antiguo were consistent with the highest or hydroriparian levels of evapotranspiration founded in the existing research. As such, the values of El Rio Antiguo are proposed for the hydroriparian. The new values are selected to provide estimates of the water demand that will be needed to sustain the vegetation communities for the alternatives based on the Pima County data and the El Rio Antiguo data in the **Table 7.3**. When the project alternatives are finalized, multiplying the per-acre demands by the number of acres for each land use category can project the total demands.

Table 7-3 Water Demand for Paseo de las Iglesias Project

Type of Vegetation	Xeroriparian Water Demands (ft/yr)	Mesoriparian Water Demands (ft/yr)	Hydroriparian Water Demands (ft/yr)
Scrub Shrub	1	2	3
Mesquite	<1.6	3	4
Cottonwood-Willow		7.5	8.5
Emergent Marsh	5	6	7

8.0 RESTORATION ALTERNATIVES

The specific objectives identified for this study are to:

- Restore wetland and riparian vegetative communities within the river corridor to a more natural state
- Increase the acreage of functional wetland habitat within the resource
- Minimize disturbance-type impacts to restored wetlands
- Minimize potential for sediment and organic matter accumulation in restored wetlands (low maintenance design)
- Increase habitat diversity by providing a mix of habitats within the river corridor including the riparian fringe
- Reduce flood damages in specified areas

Prior to developing restoration alternatives constraints were also identified that would affect the plan formulation process. Those constraints were:

- Availability of Water
- Maintenance of Floodway Capacity
- Proximity of Recreation to Restoration
- Endangered Species
- Landfills and HTRW Sites

The principal limiting constraint for ecosystem restoration in an arid environment is the availability of water; however this formulation process initially assumed that unlimited volumes of water could be made available. The kinds of restoration techniques and measures to be implemented were also used to define alternatives. Land was presumed to be available within the study area, particularly near the larger stream channels within the study area. Alternatives were developed by varying the volumes of water that could be supplied, the area of land utilized and the restoration measures that might be constructed within a carefully selected area of land adjacent to the Santa Cruz River and its major tributaries. This approach allows decision makers to weigh the relative cost of the biologic outputs resulting from commitment of large volumes of water when evaluating plans for implementation of ecosystem restoration measures within a fixed area of land.

The plan formulation process began with three broad concepts for restoration that were characterized by high, medium and low water demand. These became the starting point for development of an initial array of alternatives.

The initial restoration concept included introducing periodic releases of water into washes in the western portion of the study area that are tributaries of both the old and new West Branches of the Santa Cruz River. The land at the southern end of the study area would have been acquired to maintain and expand the existing artificial wetland areas and altering those areas to permit periodic releases from the pools into the Santa Cruz River. The concept also included modifications to the Santa Cruz River to create ponding of low flows; widening of the Santa Cruz River channel between Valencia Road and Irvington Road and between Los Reales Road and Valencia Road in order to expand riparian areas; and modification of tributary confluences to facilitate habitat restoration throughout the study area.

Another concept relied entirely on storm water harvesting to provide water to support habitat restoration. Water to support restored habitat would have come from eight storm water harvesting sites located at confluences of tributary washes with the Santa Cruz River, the Old West Branch and the New West Branch. Confluences would be modified to capture and distribute storm water. Establishment of banks and terraces vegetated with a mix of riparian species was included on both banks of the river between Valencia Road and Irvington Road and on both banks from Ajo Way north through the Cottonwood Lane area. A third concept considered restoration activities similar to those developed for the second concept but differed in that it would have included irrigation of restored areas. As measures were refined and areas for alternative implementation were identified these concepts evolved into the initial array of alternatives.

In the process of developing the initial array of alternatives the low water concept was replaced by a “Xeroriparian” concept. The team felt that development of a grouped restoration features conceived to be supported entirely by concentration of rainfall and harvesting of runoff ensured a viable minimum project as well as providing a basis for assess the gains produced by differing levels of irrigation. As alternative design proceeded the team recognized that the Xeroriparian features would need irrigation for a short period during the initial establishment of habitat and could need supplemental water during periods of extended drought. However, these alternatives have no requirement for regular irrigation. In addition to the Xeroriparian concept (number 2 above), features were also placed into “Mesoriparian” and “Hydroriparian” groups. The project area was divided into three regions or geomorphic settings: 1) the active channel, 2) the adjoining terraces, and 3) the historic floodplain. The active channel refers to the area where water flows most frequently and where perennial flow would be found if it still existed. The terraces are the adjacent land features that are elevated only slightly above the active channel. Lower terraces might be flooded by a 2-5 year event and the upper terraces would be flooded by a 5-10 year event. The historic floodplain is the area adjacent to the entrenched channel of the Santa Cruz River. Although the historic floodplain has been cut off from the river due to down cutting resulting from human activities, in the past this area would have been flooded by infrequent events in the range of a 25-year and greater event.

Using the concepts of riparian communities and geomorphic setting a matrix of grouped features was created. This matrix is included as **Table 8-1**. The matrix allowed initial consideration of every potential combination of feature groups, including no action, to create forty-seven potential alternatives. Preliminary screening of these alternatives was accomplished applying three factors that embodied the planning objectives and constraints identified in the early stages of the study. Based on the planning objectives, alternatives were screened out that:

- Failed to provide sufficient area of diverse habitat
- Were inconsistent with the natural progression of riparian communities
- Were likely to produce unacceptable impacts on flood conveyance

The first criterion is relatively straightforward. In applying the first criteria both the number of cover types restored and the total acreage restored were taken into consideration. Alternatives restoring two or fewer riparian cover types were discarded unless they occupied all or most of the project area. Alternatives that restored only the active channel were considered too small unless they utilized the majority of that area.

The second criterion, "consistency with natural progression" merits some explanation. It is based on the fact that hydroriparian communities occur where water flows on or near the surface at all, or nearly all times of the year; mesoriparian communities experience occasional prolonged surface water flow and occur where subsurface water is usually within the reach of the roots of larger bushes and trees, and xeroriparian communities experience infrequent surface flows of shorter duration. In geomorphic terms, hydroriparian plants are most often found adjacent to the active channel or in the adjoining lower terraces. Mesoriparian plants would be found in the lower or upper terraces and xeroriparian would be found in the upper terraces or the historic floodplain. While diminished flows might lead to drier communities occurring nearing the active channel, one would never expect to find hydroriparian plants in the historic floodplain or to find a drier community near the channel with a wetter one up gradient at a greater distance from the channel.

As used in this analysis, the active channel includes primary low flow and any channel braids or back waters that would be inundated when the low flow channel is filled. With a few exceptions described later, alternatives that violated this "natural logic" were eliminated. The terraces refer to those areas elevated above the active channel but below the tops of the soil cement banks and their natural counter parts while the historic floodplain takes in the areas adjacent to the incised river that were historically part of the Santa Cruz River's riparian ecosystem.

Finally, while the Santa Cruz River channel has substantial capacity to convey flood flows, restoration measures that encourage the growth of thick stands of vegetation throughout the channel would reduce that capacity and run a high risk of inducing flood damages as a result. Therefore, alternatives that would create extensive new woody vegetation and obstructions in both the terraces and the active channel were eliminated.

Application of these screening criteria resulted in elimination of thirty-three (33) of the forty-seven (47) possible alternatives. The results of this screening are presented in **Table 8-2**. Those alternatives eliminated from further consideration are gray shaded.

Table 8-1 Alternative Features Matrix

	Active Channel Features	Floodplain Terrace Features	Historic Floodplain Features
No Action* (Without Project) *Listed items are anticipated consequences rather than measures to be implemented as in the other rows.	1. Continued instability of channel due to erosion. 2. Continued refuse dumping. 3. Continued degraded habitat.	1. Continued erosion loss of lower terraces creating cliff-like banks. 2. Eventual application of soil cement on unprotected banks armoring entire reach.	1. With expanded soil cement bank protection, continued historic floodplain encroachment by development.
Xero-Riparian (Establishment & Emergency Irrigation)	1. Construct aquitards upstream of existing and new grade control structures. 2. Divert low flow from New West Branch into remnant headwaters of Old West Branch. 3. Plantings of riparian grasses/shrubs	1. Water harvesting from local runoff. 2. Create tributary aquitard deltas with two-tiered aquitards. 3. Plantings on terraces and aquitards.	1. Amend soil with nutrients, moisture trapping, contouring. 2. Water harvesting from local runoff. 3. Replace steep banks with stabilized planted terraces
Meso-Riparian (Irrigation)	1. Construct and provide supplemental irrigation to aquitards upstream of existing and new grade control structures. 2. Introduce periodic flow into the Old West Branch just upstream of its confluence with the Enchanted Hills Wash and on other tributaries downstream of that point. 3. Plantings of riparian grasses	1. Create tributary single-tiered aquitard deltas. 2. Irrigate and plant terraces with mesquite along upper terrace. 3. Stabilize active channel banks by establishing thickly rooted mesquite at the edge of the lower terraces.	1. Amend soil with nutrients, moisture trapping, contouring. 2. Plant and irrigate historic floodplain. 3. Replace steep banks with stabilized planted terraces
Hydro-Riparian (Perennial Flow With Irrigation)	1. Restore perennial flow with multiple points of distribution into the main Santa Cruz and tributary channels. 2. Plant cottonwood-willow bundles at edges of perennial flow where erosion protection needed. 3. Construct perennial channel features (e.g., pools, runs, and riffles).	1. Create tributary aquitard deltas with hydraulic link to perennial flow. 2. Irrigate and plant low terraces with riparian grasses to maintain flood conveyance and discourage colonization by invasive species. 3. Irrigate and plant upper terraces with mesquite/cottonwood-willow.	Hydro Riparian plants do not occur in areas of the floodplain that are not subject to frequent inundation. Even so, measure 3 from the mesoriparian floodplain is carried forward to mitigate greater erosion risks associated with increased channel roughness in combinations where "No Action" is paired with Perennial Flow.

Table 8-2 Alternative Screening

Active Channel	Terraces	Floodplain	Screen Out	Reason
No Action	Xero	Xero	Yes	Fails to provide sufficient habitat diversity
No Action	Xero	Meso	Yes	Not Consistent with Natural Pattern
No Action	Xero	No Action	Yes	Fails to provide sufficient habitat diversity
No Action	Meso	Xero		
No Action	Meso	Meso		
No Action	Meso	No Action	Yes	Fails to provide sufficient habitat diversity
No Action	Hydro	Xero	Yes	Not Consistent with Natural Pattern
No Action	Hydro	Meso	Yes	Not Consistent with Natural Pattern
No Action	Hydro	No Action	Yes	Not Consistent with Natural Pattern
No Action	No Action	Xero	Yes	Fails to provide sufficient habitat diversity
No Action	No Action	Meso	Yes	Fails to provide sufficient habitat diversity
Xero	No Action	No Action	Yes	Fails to provide sufficient habitat diversity
Xero	No Action	Xero	Yes	Fails to provide sufficient habitat diversity
Xero	No Action	Meso	Yes	Not Consistent with Natural Pattern
Xero	Xero	No Action	Yes	Fails to provide sufficient habitat diversity
Xero	Xero	Xero		
Xero	Xero	Meso	Yes	Not Consistent with Natural Pattern
Xero	Meso	No Action	Yes	Not Consistent with Natural Pattern
Xero	Meso	Xero	Yes	Not Consistent with Natural Pattern
Xero	Meso	Meso	Yes	Not Consistent with Natural Pattern
Xero	Hydro	No Action	Yes	Not Consistent with Natural Pattern
Xero	Hydro	Xero	Yes	Not Consistent with Natural Pattern
Xero	Hydro	Meso	Yes	Not Consistent with Natural Pattern
Meso	No Action	No Action	Yes	Fails to provide sufficient habitat diversity
Meso	No Action	Xero	Yes	Not Consistent with Natural Pattern
Meso	No Action	Meso	Yes	Not Consistent with Natural Pattern
Meso	Xero	No Action		
Meso	Xero	Xero		
Meso	Xero	Meso	Yes	Not Consistent with Natural Pattern
Meso	Meso	No Action		
Meso	Meso	Xero		
Meso	Meso	Meso		
Meso	Hydro	No Action	Yes	Not Consistent with Natural Pattern
Meso	Hydro	Xero	Yes	Not Consistent with Natural Pattern
Meso	Hydro	Meso	Yes	Not Consistent with Natural Pattern
Hydro	No Action	No Action		
Hydro	No Action	Xero	Yes	Not Consistent with Natural Pattern
Hydro	No Action	Meso	Yes	Not Consistent with Natural Pattern
Hydro	Xero	No Action		
Hydro	Xero	Xero		
Hydro	Xero	Meso	Yes	Not Consistent with Natural Pattern
Hydro	Meso	No Action	Yes	Too much reduction in conveyence
Hydro	Meso	Xero	Yes	Too much reduction in conveyence
Hydro	Meso	Meso	Yes	Too much reduction in conveyence
Hydro	Hydro	No Action		
Hydro	Hydro	Xero		
Hydro	Hydro	Meso		

9.0 WATER BUDGET FOR PROJECT ALTERNATIVES

The water budget analysis was generated based on total inflow and outflow in ac-ft/yr along the study reach of the Santa Cruz River basin in Township 14 South, Range 13 East, Sections 14, 22, 23, 25, 26, 27, 34 and 35, and Township 15, South, Range 13 East, Sections 2, 3, 10, 11, 14, and 15. A short description of contributing factors in the water budget calculations is provided below.

The 100 feet or more depth to existing groundwater, in combination with insufficient flows to support habitat, result in an existing conditions water budget that is incapable of supporting larger amounts of habitat. More efficient capturing and retention of the existing flood flows within the study area may result in an incremental increase in the amount of habitat that is supportable.

Each of the potential water sources has been evaluated based on the quality, quantity, and seasonality of flow. A few dependable and supplemental sources of water are available to supply the Santa Cruz River Restoration Project. For some of these, there is sufficient information to quantify the potential supply; however, others will require further monitoring to verify the quantity and seasonality of flow. In addition, the Community, CAP, or TRAP could make other water sources available upon institutional commitments. These entities will need to decide if, how much, and when they will commit the water to the Santa Cruz River Restoration Project. The pumped withdrawal is not considered at this point, but it will be described in the future study with project conditions.

Water supply sources are summarized in **Table 9-1**. The total annual volume of secondary effluent produced at the two treatment plants is 74,000 acre-ft (28,000 acre-ft at Ina Road and 46,000 acre-ft at Rogers Road), out of which about 10,000 acre-ft of reclaimed water is currently utilized. Another secondary effluent (100 – 300 acre-ft) form the Avra Valley Wastewater Treatment Facility can be used as a potential water resource with the addition of an NO_3 removal system. Surface water sources available from Santa Cruz River gaging station (09482500) at Tucson (average annual volume of 17,681 acre-ft) and tributaries (average annual volume of 9,020 acre-ft) can also be used as potential water supply sources. Thus, if one considers only the total annual irrigation need (55 to 8978 acre-ft/year) and the total available supply from different sources, it seems that the total irrigation need can be supplied by any one of the supply sources from reclaimed water, Santa Cruz River flows or tributary flows. However, a closer look at the variability of seasonal or monthly flows of the Santa Cruz River and tributaries indicate that, in a given month, the available flow can vary from zero (minimum) to the maximum (which is typically several times mean flow for that month). This monthly variation for the Santa Cruz River is very similar for the tributaries, as can be seen from the available stream flow records in similar watersheds located in the vicinity of the study. Availability of water from Santa Cruz River or tributaries is therefore subject to considerable uncertainty. Based on this consideration, available water supply and irrigation need for each alternative plan are summarized in **Table 9-1** and **Table 9-2**.

The estimate of volume of water that can be harvested from tributaries is approximate and is likely to increase depending on the availability of water at a given time and operation of tributary basins. However, considering the extreme variability of tributary flows as discussed above, it is suggested that an irrigation system be designed to meet all consumptive needs of vegetation using secondary effluent or reclaimed water, and utilize harvested water whenever possible, so that a reliable supply of irrigation water is provided during the initial establishment period. Adequate supply of reclaimed water is available to meet the requirements under this scenario; Roger Road Treatment Plant currently produces 46,000 acre-ft/year, compared to about 55 to 8,978 acre-ft/year of irrigation needed for the alternative plans. Use of groundwater as an alternative source for irrigation is not considered for this project because, according to the regulatory policy of the Arizona Department of Water Resources, groundwater withdrawal for irrigation use is allowed only if "grandfather" rights exist for such withdrawal. An "adaptive management" plan should be developed during the design process and implemented during project operation to maximize the use of harvested water and reduce the use of reclaimed water.

Table 9-1 Summary of Potential Water Resources

Water Supply Sources	Acre-ft/year	MGD
Reclaimed Water	~ 64,000 [1]	~ 57.14
Surface Water: Santa Cruz River	~ 17,681 [2]	~ 15.78
Surface Water: Tributaries	~ 9,020 [3]	~ 8.05
Secondary Effluents	~ 1,343 [4] – 3,577 [5]	~ 1.2 – 3.2
Storm Drains	Unknown [6]	Unknown

[1] Combined capacity of Ina and Rogers Road Treatment Plants (74,000 acre-ft) minus 10,000 acre-ft of Total current usage.

[2] Average annual runoff of Santa Cruz River gaging station at Tucson (09482500), which is, included the runoff (~9,020 acre-ft/year) from tributaries.

[3] Estimated average annual runoff.

[4] Approximate existing Avra Valley WWTF Capacity. Source: Avra Valley Basin Study, Pima County Wastewater management Department (July 2002)

[5] Approximate future (2012) Avra Valley WWTF Capacity. Source: Avra Valley Basin Study, Pima County Wastewater management Department (July 2002)

[6] It is a possible water source; insufficient data to estimate average annual volumes.

Table 9-2 Summary of Draft Water Demands for Alternatives

	GROUP			PRECIP	PERENNIAL CHANNEL			XERORIPARIAN						MESORIPARIAN								HYDRORIPARIAN								TOTAL		
Functional Assessment Tool Name[1]	Active Channel	Terraces	Floodplain	Ann. Avg. Precip. (ft/yr)[2]	AREA (acres)	Evaporation Loss (ft/yr)[3]	Infiltration Loss (ft/yr)[4]	Shrub Scrub Area (acres)	Shrub Scrub Water Demand (ft/yr)	Mesq. (acres)	Mesq. Water Demand (ft/yr)	Emergent Marsh (acres)	Emergent Marsh Water Demand (ft/yr)	Shrub Scrub Area (acres)	Shrub Scrub Water Demand (ft/yr)	Mesq. (acres)	Water Demand (ft/yr)	CWW (acres)	CWW Water Demand (ft/yr)	Emergent Marsh (acres)	Emergent Marsh Water Demand (ft/yr)	Shrub Scrub Area (acres)	Shrub Scrub Water Demand (ft/yr)	Mesq. (acres)	Mesq. Water Demand (ft/yr)	CWW (acres)	CWW Water Demand (ft/yr)	Emergent Marsh (acres)	Emergent Marsh Water Demand (ft/yr)	Area (acres)	Water Demand (acre-feet/yr)	Water Demand (mgd)
NMX	No Action	Meso	Xero	0.93		5.40	321.20	693	1.00	294	1.60		5.00		2.00	122	3.00	10	7.50		6.00		3.00		4.00		8.50		7.00	1119	562.52	0.50
NMM	No Action	Meso	Meso	0.93		5.40	321.20		1.00		1.60		5.00	471	2.00	638	3.00	10	7.50		6.00		3.00		4.00		8.50		7.00	1119	1889.12	1.69
XXX	Xero	Xero	Xero	0.93		5.40	321.20	867	1.00	252	1.60	6	5.00		2.00		3.00		7.50		6.00		3.00		4.00		8.50		7.00	1125	252.73	0.23
MXN	Meso	Xero	No Action	0.93		5.40	321.20	174	1.00	19	1.60		5.00		2.00		3.00		7.50	6	6.00		3.00		4.00		8.50		7.00	199	55.11	0.05
MXX	Meso	Xero	Xero	0.93		5.40	321.20	862	1.00	257	1.60		5.00		2.00		3.00		7.50	6	6.00		3.00		4.00		8.50		7.00	1125	261.73	0.23
MMN	Meso	Meso	No Action	0.93		5.40	321.20		1.00		1.60		5.00		2.00	183	3.00	10	7.50	6	6.00		3.00		4.00		8.50		7.00	199	474.71	0.42
MMX	Meso	Meso	Xero	0.93		5.40	321.20	688	1.00	238	1.60		5.00		2.00	183	3.00	10	7.50	6	6.00		3.00		4.00		8.50		7.00	1125	681.33	0.61
MMM	Meso	Meso	Meso	0.93		5.40	321.20		1.00		1.60		5.00	466	2.00	643	3.00	10	7.50	6	6.00		3.00		4.00		8.50		7.00	1125	1924.53	1.72
HNN	Hydro	No Action	No Action	0.93	19.00	5.40	321.20		1.00		1.60		5.00	69	2.00	122	3.00		7.50		6.00		3.00		4.00	69	8.50	59	7.00	338	7394.19	6.60
HXN	Hydro	Xero	No Action	0.93	19.00	5.40	321.20	181	1.00	14	1.60		5.00	62	2.00	122	3.00	69	7.50	59	6.00		3.00		4.00		8.50		7.00	526	7280.55	6.50
HXX	Hydro	Xero	Xero	0.93	19.00	5.40	321.20	867	1.00	252	1.60		5.00		2.00		3.00		7.50		6.00		3.00		4.00	69	8.50	59	7.00	1266	7296.35	6.51
HHN	Hydro	Hydro	No Action	0.93	19.00	5.40	321.20		1.00		1.60		5.00	69	2.00	122	3.00		7.50		6.00	112	3.00	46	4.00	79	8.50	59	7.00	506	7842.77	7.00
HHX	Hydro	Hydro	Xero	0.93	19.00	5.40	321.20	624	1.00	116	1.60		5.00	69	2.00	122	3.00		7.50		6.00	112	3.00	46	4.00	79	8.50	59	7.00	1246	7963.37	7.11
HHM	Hydro	Hydro	Meso	0.93	19.00	5.40	321.20		1.00		1.60		5.00	465	2.00	466	3.00		7.50		6.00	112	3.00	46	4.00	79	8.50	59	7.00	1246	8977.77	8.01

[1]-Alternatives are designed by combinations of four characters into groups of three. The letter used are N for no action, X for xeroriparian, M for mesoriparian, and H for hydroriparian. Each letter represents a row from the Alternative Features Matrix with the order of letter aligned to the columns.
For example, alternative HMN would be the result of combining hydroriparian active channel features and mesoriparian terrace features with no action in the historic floodplain.

[2]-Average annual precipitation (1894-2002) at Tucson WFO (8815)station

[3]-Environmental Restoration in Pima County/Pima County Administrator's Office/Dec. 1999

[4]-Long term loss (0.88 ft/day), Galyean (1996)

10.0 REFERENCES

Any studies have been conducted pertaining to water and related land resources within the study area. These studies have examined themes including development trends, environmental resources, water supply, groundwater recharge, wastewater management, flooding and erosion, geology, cultural resources, history, and recreation. The following is not intended to be a comprehensive list of previous reports, but to provide a sample of the types of studies that have been completed in the study area.

Cluff C.B., Katz, L.T., and Scovill, G.L., 1987, Effects of Channel Stabilization in Tucson Stream Reaches on Infiltration and Groundwater Recharge, Pima County Department of Transportation and Flood Control District

USGS, Water Resources Data Arizona Water Year (1996-2000)

Paseo de las Iglesias Draft Biological Resources Data, Prepared by Tetra Tech, Inc. for US Army Corps of Engineers

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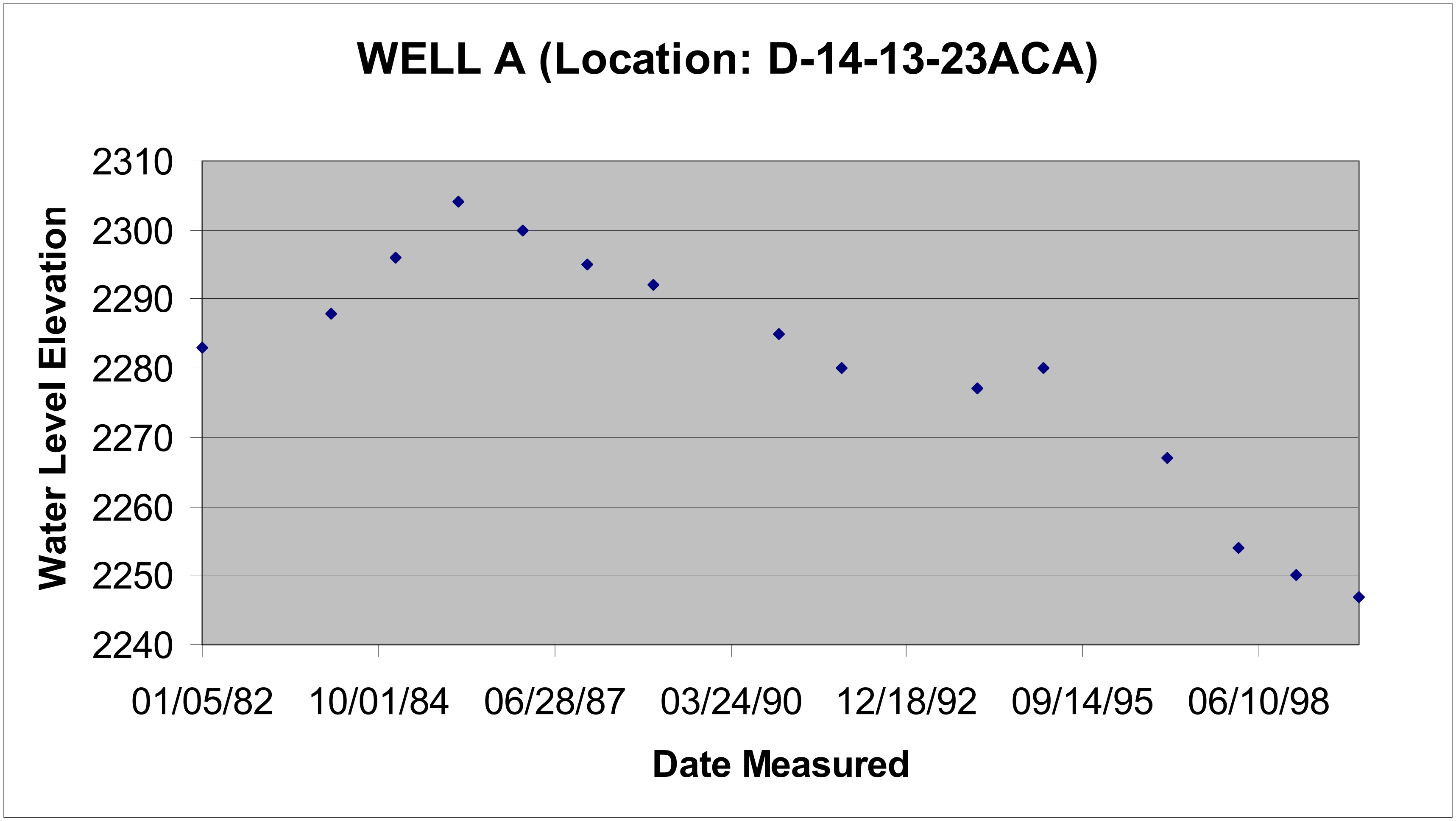
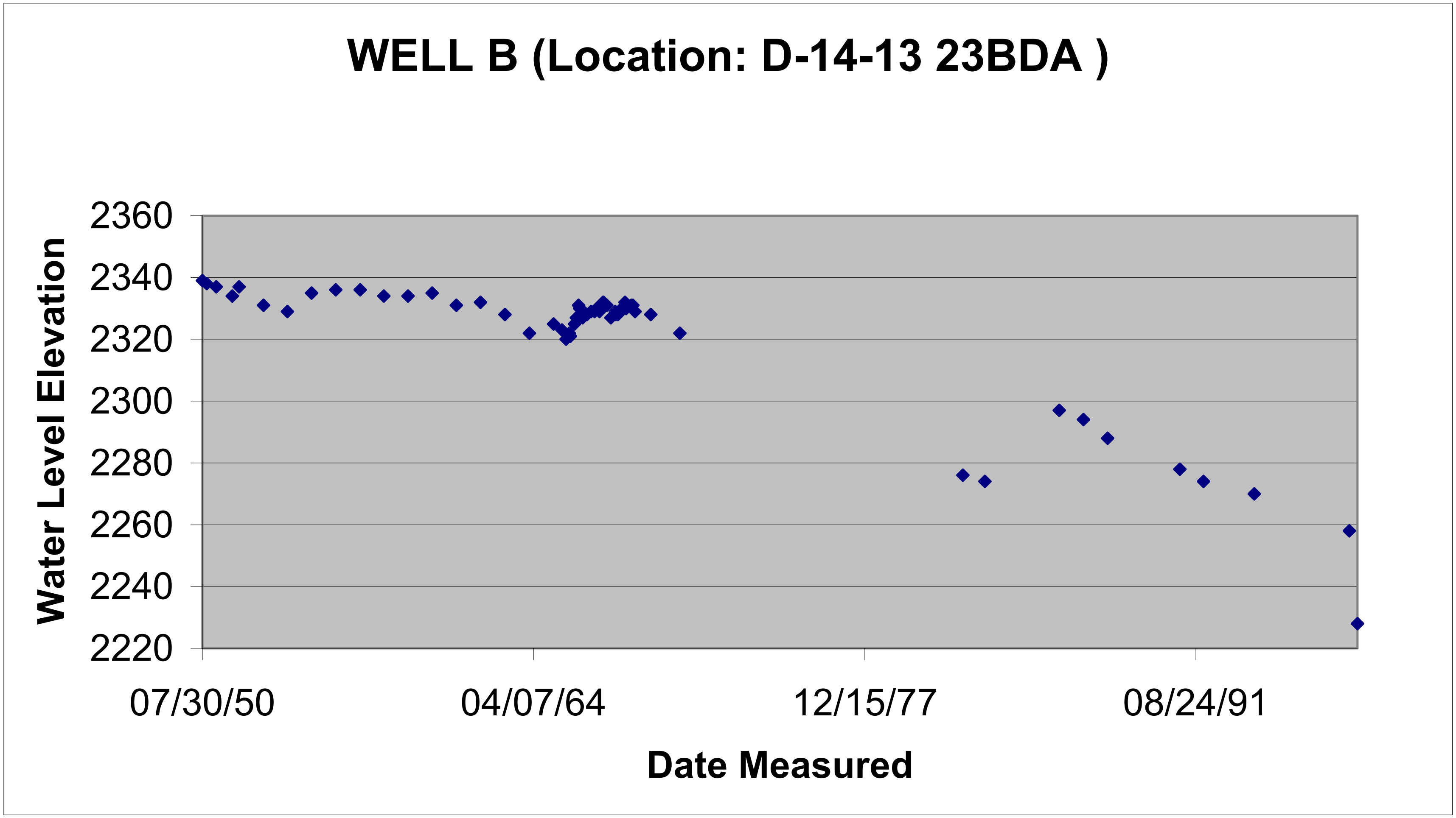
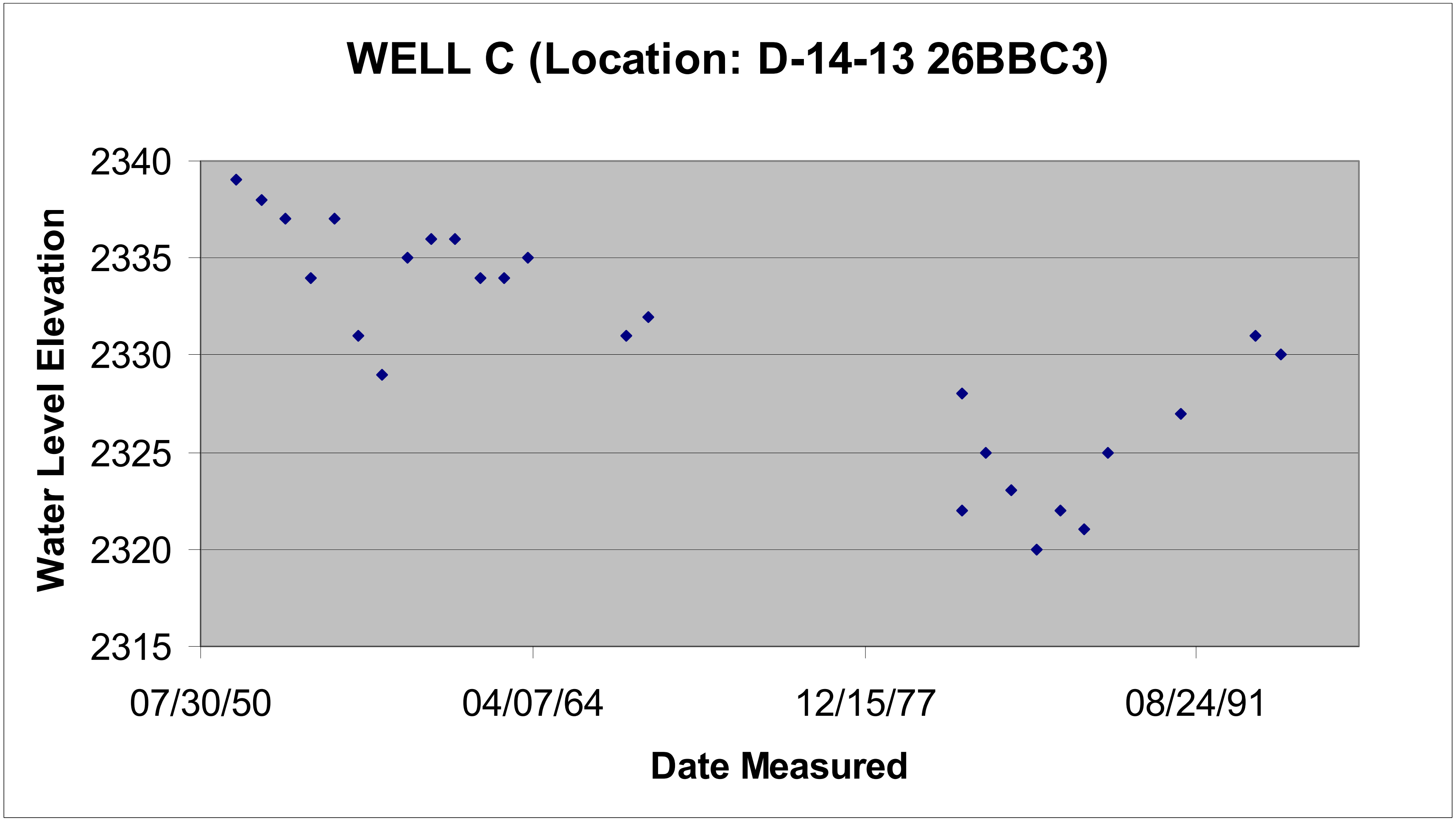
APPENDIX A

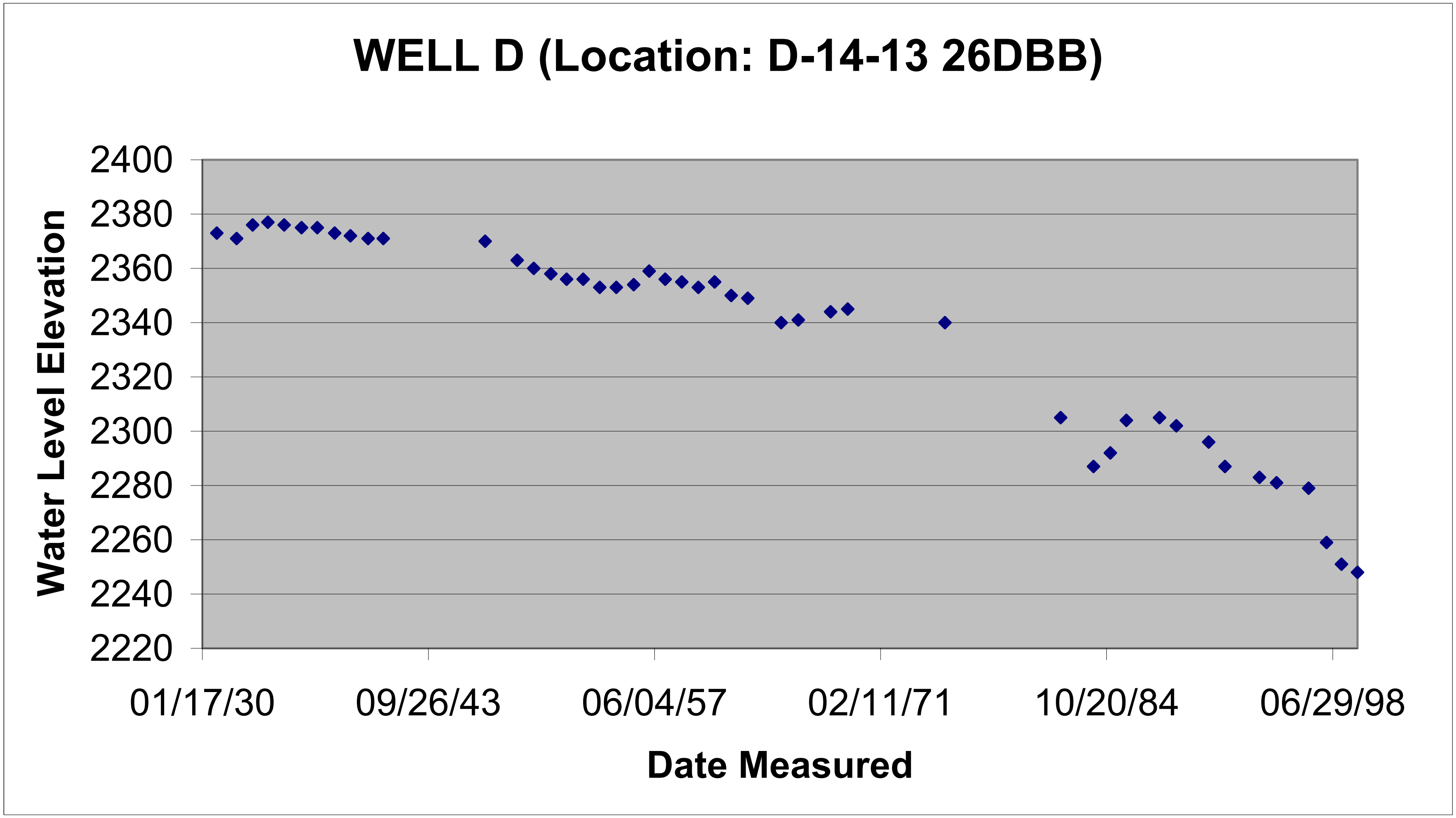
Groundwater Level Elevation



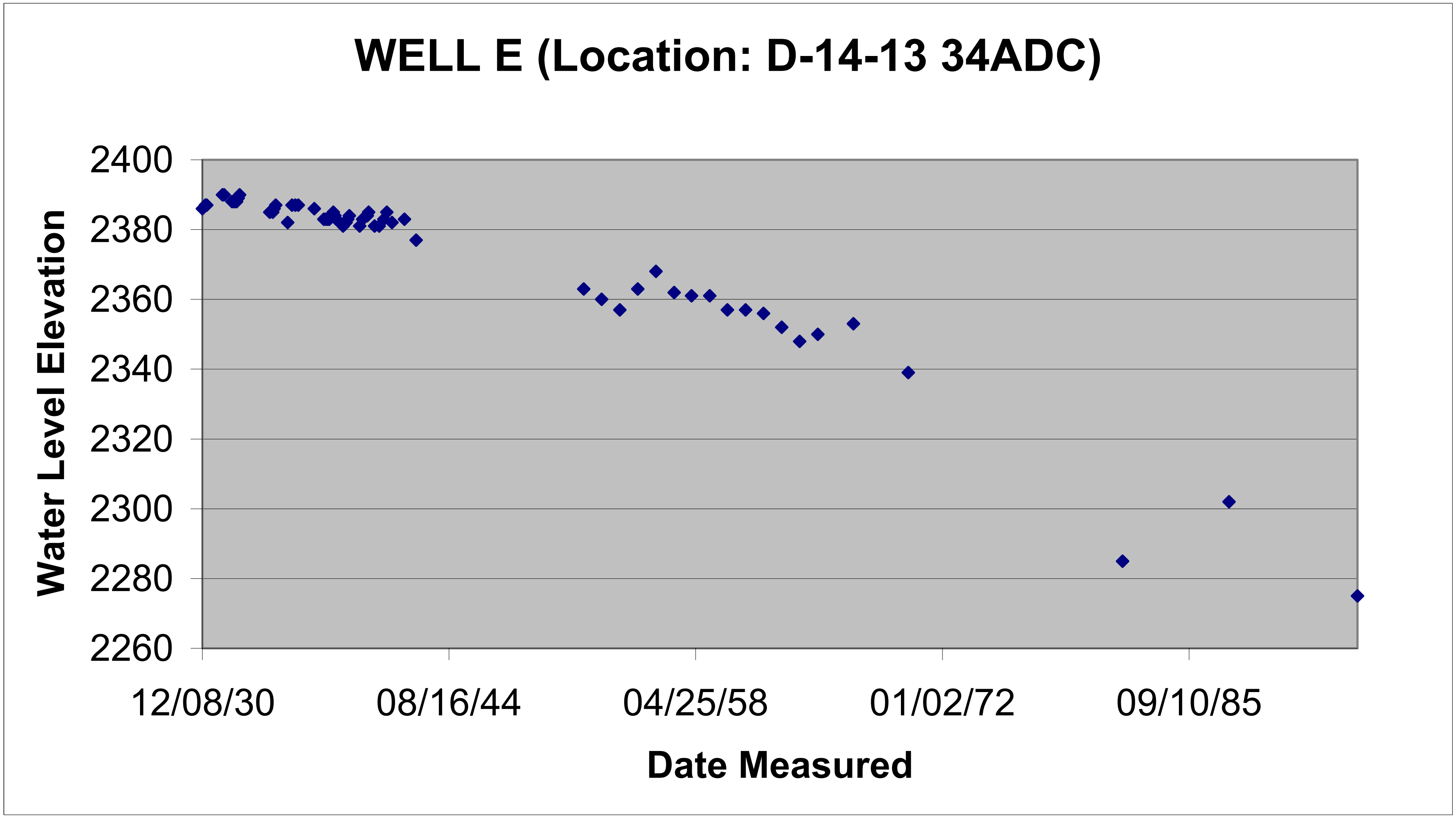
WELL A (Location: D-14-13-23ACA)
Water Level Elevation
2310
2300
2290
2280
2270
2260
2250
2240
01/05/82
10/01/84
06/28/87
03/24/90
12/18/92
09/14/95
06/10/98
Date Measured

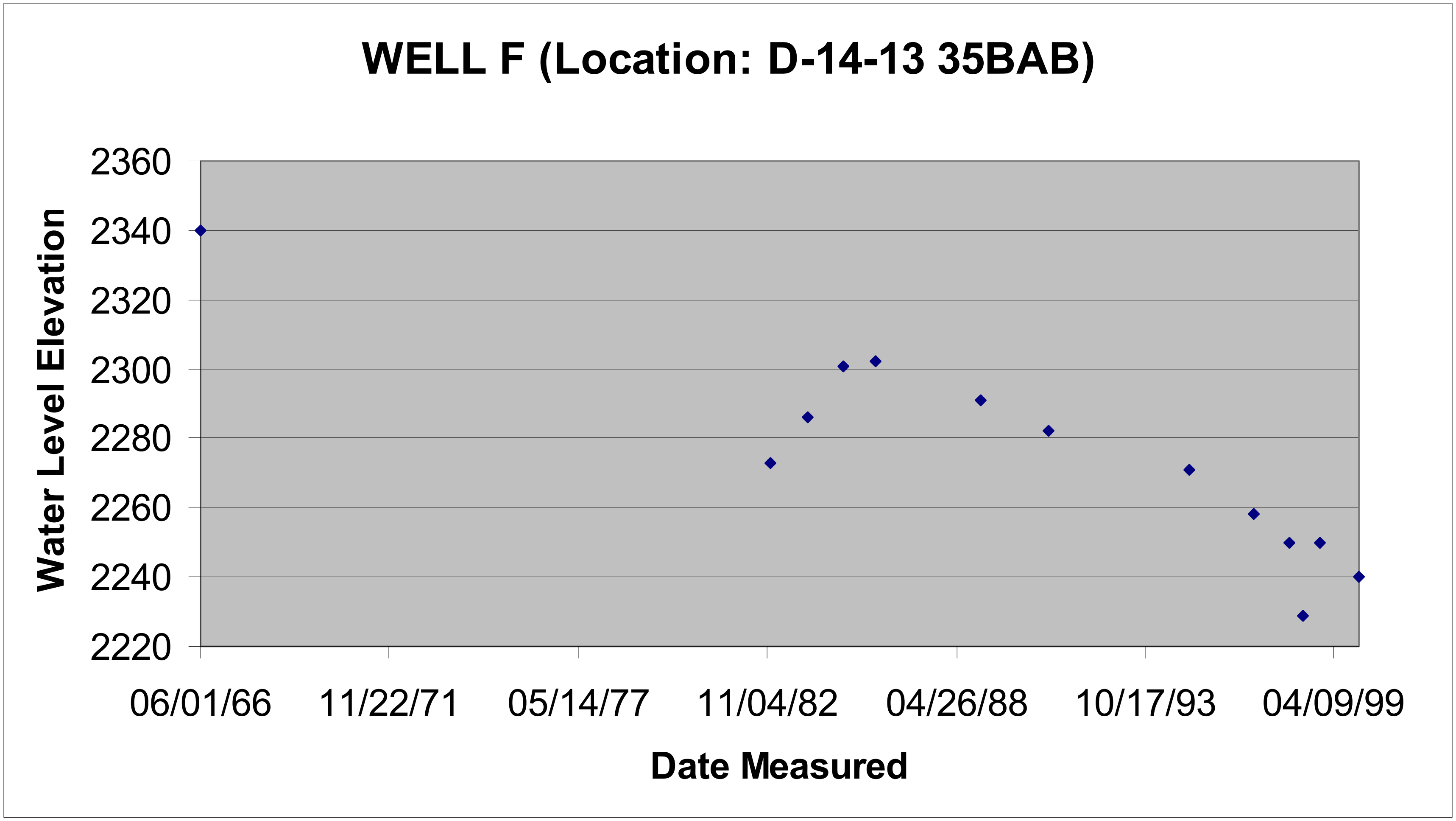

WELL B (Location: D-14-13 23BDA)
Water Level Elevation
2360
2340
2320
2300
2280
2260
2240
2220
07/30/50
04/07/64
12/15/77
08/24/91
Date Measured


WELL C (Location: D-14-13 26BBC3)
Water Level Elevation
2340
2335
2330
2325
2320
2315
07/30/50
04/07/64
12/15/77
08/24/91
Date Measured

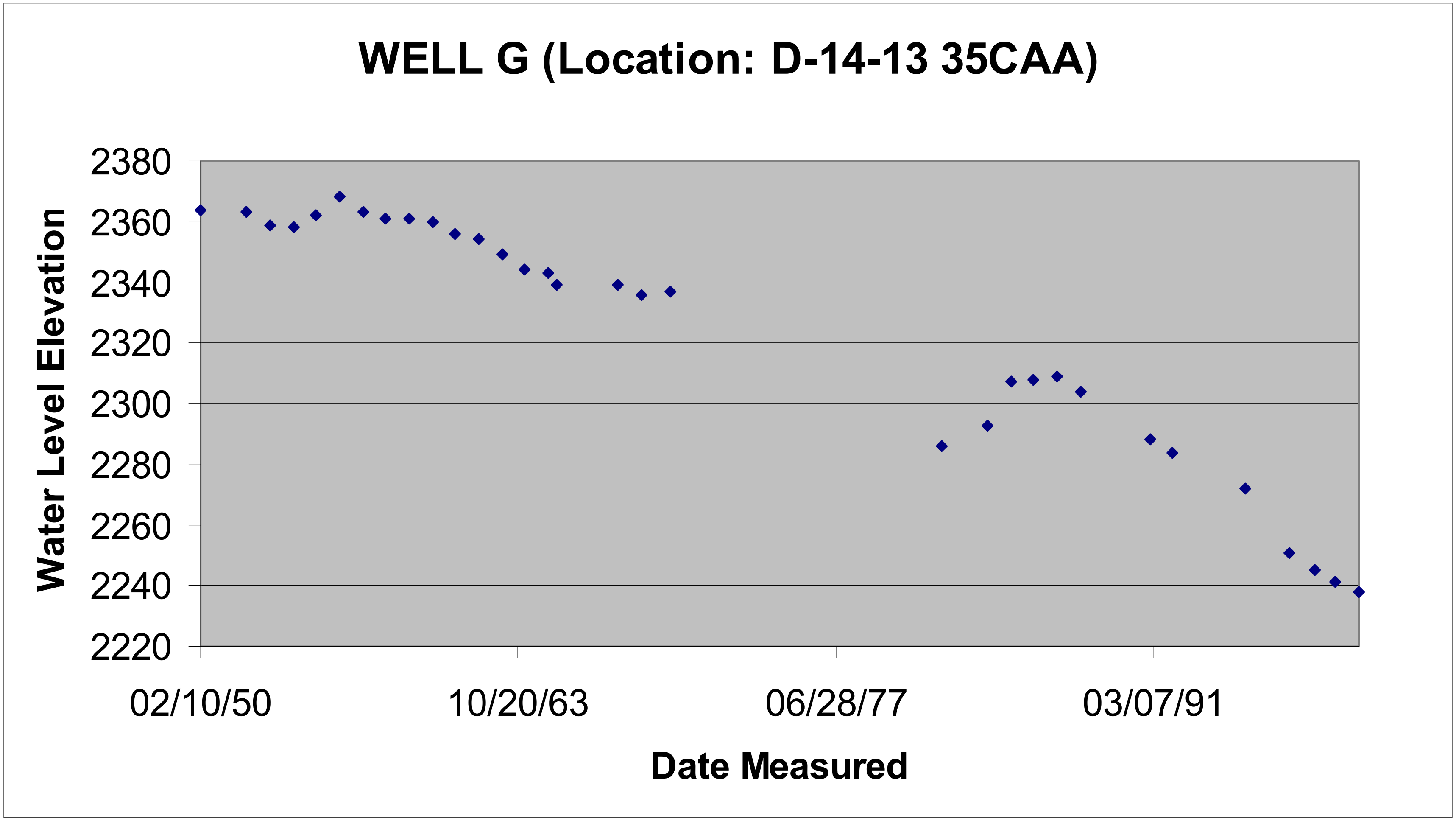


WELL D (Location: D-14-13 26DBB)
Water Level Elevation
2400
2380
2360
2340
2320
2300
2280
2260
2240
2220
01/17/30
09/26/43
06/04/57
02/11/71
10/20/84
06/29/98
Date Measured

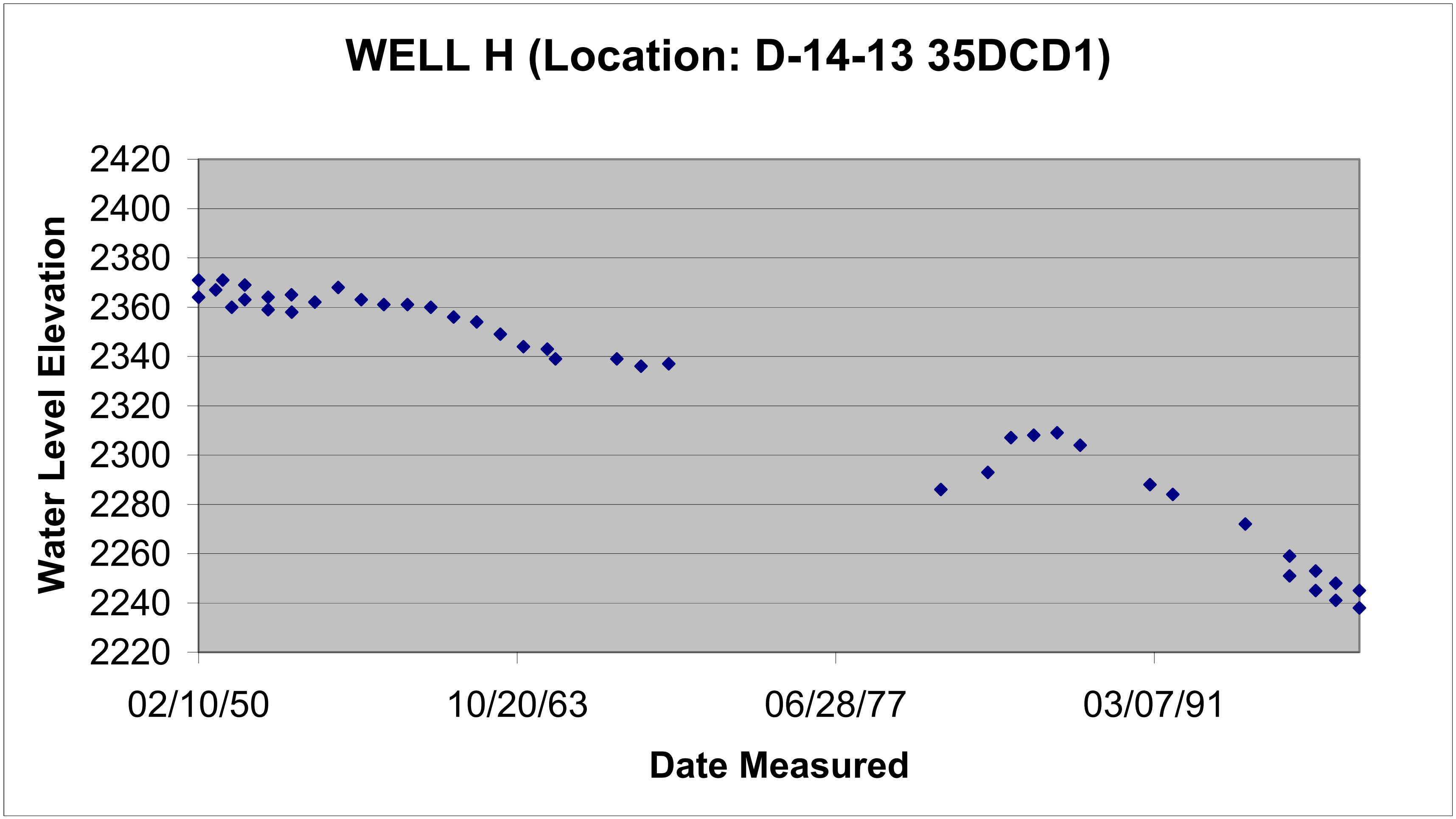

WELL E (Location: D-14-13 34ADC)
Water Level Elevation
2400
2380
2360
2340
2320
2300
2280
2260
12/08/30
08/16/44
04/25/58
01/02/72
09/10/85
Date Measured



WELL F (Location: D-14-13 35BAB)
Water Level Elevation
2360
2340
2320
2300
2280
2260
2240
2220
06/01/66
11/22/71
05/14/77
11/04/82
04/26/88
10/17/93
04/09/99
Date Measured



WELL G (Location: D-14-13 35CAA)
Water Level Elevation
2380
2360
2340
2320
2300
2280
2260
2240
2220
02/10/50
10/20/63
06/28/77
03/07/91
Date Measured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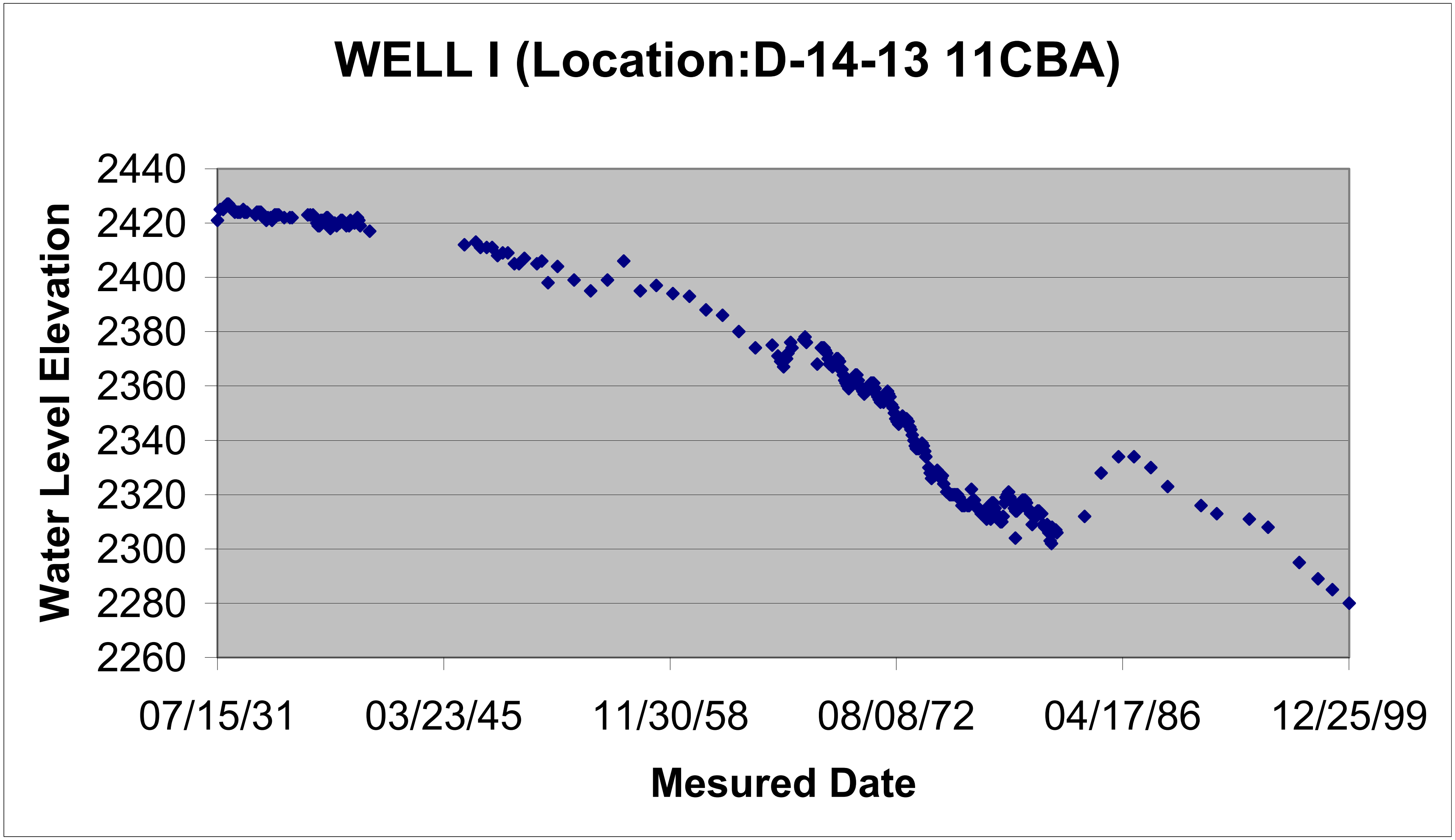
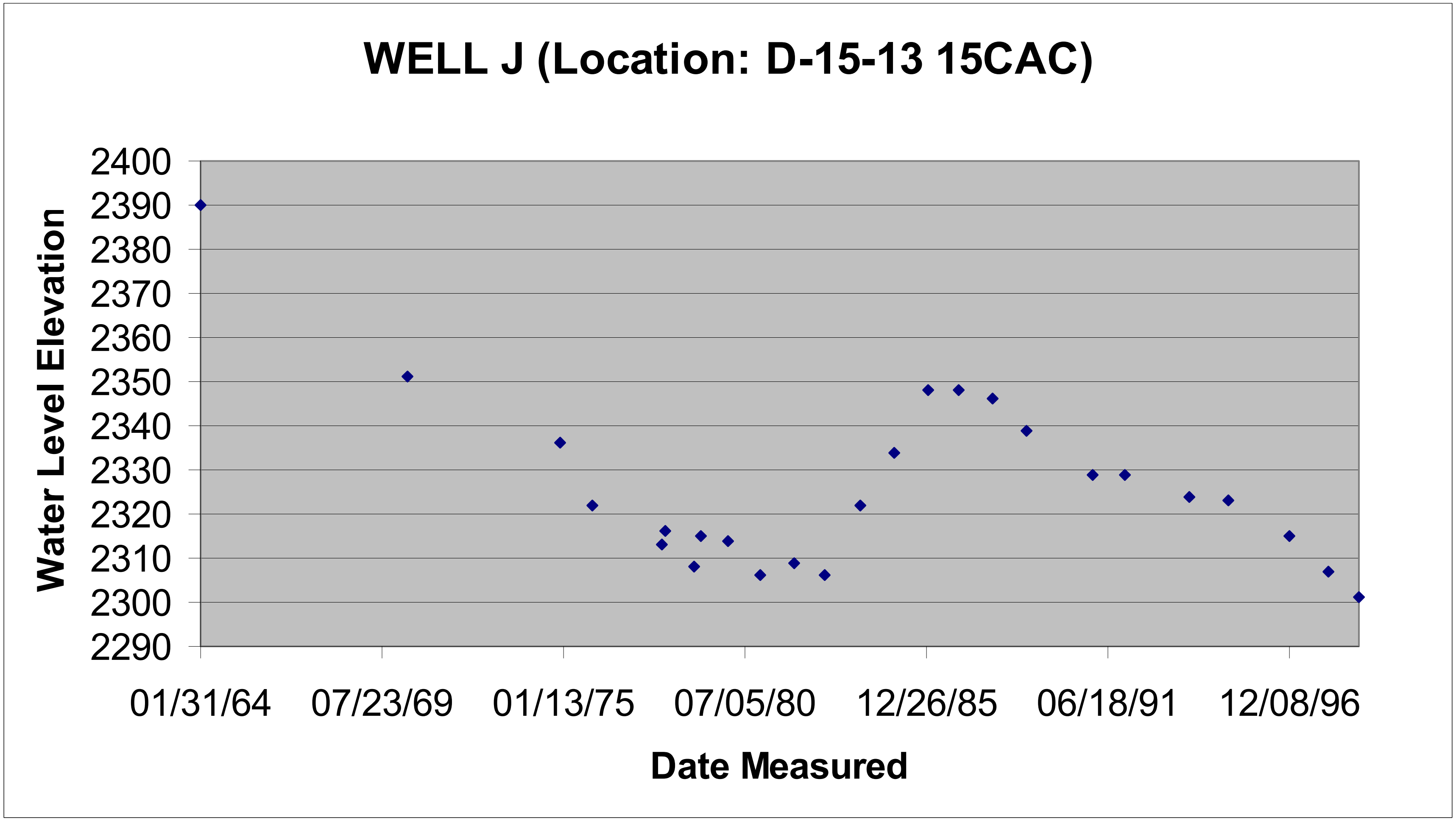
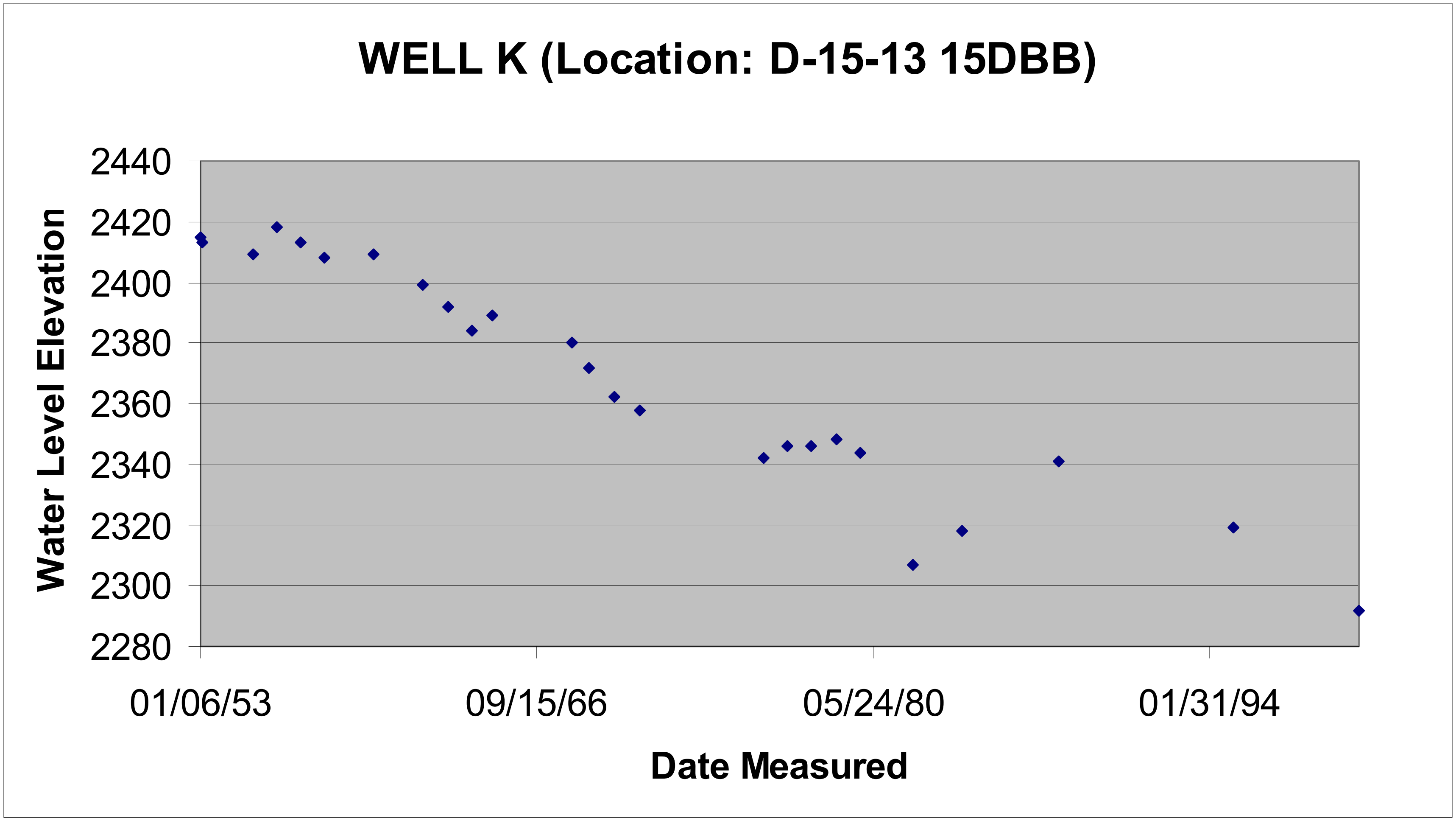
Water Level Elevation
2420
2400
2380
2360
2340
2320
2300
2280
2260
2240
2220
02/10/50
10/20/63
06/28/77
03/07/91
Date Measured


WELL I (Location:D-14-13 11CBA)
Water Level Elevation
2440
2420
2400
2380
2360
2340
2320
2300
2280
2260
07/15/31
03/23/45
11/30/58
08/08/72
04/17/86
12/25/99
Mesured Date



WELL J (Location: D-15-13 15CAC)
Water Level Elevation
2400
2390
2380
2370
2360
2350
2340
2330
2320
2310
2300
2290
01/31/64
07/23/69
01/13/75
07/05/80
12/26/85
06/18/91
12/08/96
Date Measured


WELL K (Location: D-15-13 15DBB)
Water Level Elevation
2440
2420
2400
2380
2360
2340
2320
2300
2280
01/06/53
09/15/66
05/24/80
01/31/94
Date Measured

APPENDIX B

Groundwater Quality Data Table

Groundwater Quality Text Value*

Well ID	Collect data	pH	TDS	Bromide	Chloride	Fluoride	Nitrate as N	Surfate	Bicarbonate Alkalinity	Carbonate Alkalinity	Total Alkalinity	Calcium	Magnesium	Potassium	Sodium
D-14-13 35CAC	2-Mar-00	7.60	892	0.17	70	0.52	7.8	332	237		237	143	28	3.8	99
D-14-13 35CAC	8-May-00	7.30	901	0.14	71	0.45	7.8	334	237		237	143	28	3.9	101
D-14-13 35CAC	20-Nov-01	7.06		0.12	70	0.43	7.7	275	237		237	149	29		98
D-14-13 26ACC	2-Aug-00	8.60	324	0.14	17	1.5	1.3	95	95	<20	111	7.1	0.63	1.2	96
D-14-13 26ACC	13-Dec-00	8.35	326	0.13	12	0.78	2.3	98	119	<20	134	9.4	0.87	1.3	103
D-14-13 26ACC	25-Jun-01	6.92	349	0.13	13	1.2	1.6	98	113	<20	126	8	0.76	0.99	101
D-14-13 26ACC	10-Sep-01	8.16	351	0.14	13	1.1	1.7	95	108	<20	124	8	0.71	0.99	104
D-14-13 26ACC	30-May-02	8.77	320	0.11	14	1.3	1.4	101	102	<20	116	7.2	0.64		
D-14-13 35CAD	23-Feb-00		771	0.53	55	0.74	6.4	286	212		212	124	23	4.1	96
D-14-13 35CAD	16-May-00	7.20	791	0.56	58	0.65	6.6	304	210		210	128	24	4.1	97
D-14-13 35CAD	20-Nov-01	7.12		0.57	60	0.62	6.9	264	208		208	129	24		98
D-14-13 23BAD	2-Mar-00	7.40	674	<0.1	43	0.86	4.6	191	272		272	83	16	3	82
D-14-13 23BAD	12-Apr-00	7.26	675	0.073	41	0.81	4.5	183	276		276	94	18	3.6	95
D-14-13 23BAD	11-Apr-01					0.71	4.9								110
D-14-13 23BAD	31-Oct-01	7.24		0.41	42	0.68	4.6	196	300		300	109	21		96
D-14-13 23BAD	24-Jun-02	7.06					4.6								
D-15-13 02CAA	23-Feb-00	7.20	564	0.45	52	0.62	4.4	149	213		213	85	16	3.1	75
D-15-13 02CAA	8-May-00	7.37	581	0.43	51	0.52	4.4	153	216		216	88	16	3.1	77
D-15-13 02CAA	26-Nov-01	7.20		0.41	49	0.49	4.4	162	214		214	82	17		75
D-14-13 14ABC	30-Mar-00	7.78	712	0.31	38	1.4	2.9	248	246		246	71	11	3.7	151
D-14-13 14ABC	6-Sep-00	7.26	712	0.32	39	1.5	3	258	247		247	73	11	2.7	150
D-14-13 14ABC	12-Dec-00	7.14	699	0.25	37	1.4	2.9	246	240		240	73	11	3.6	146
D-14-13 14ABC	21-Mar-01	7.06	712	0.31	36	1.5	3	235	246		246	76	12	3.1	160
D-14-13 14ABC	12-Jun-01	7.41	703	<0.5	33	1.5	3	247	249		249	74	11	3.2	151
D-14-13 14ABC	3-Jul-01	7.23		0.31	36	1.4	3	245				74	11		154
D-14-13 14ABC	1-Aug-01	7.67		0.31	36	1.3	3	248				75	12		157
D-14-13 14ABC	6-Sep-01	7.61	727	0.29	36	1.2	3	248	245		245	74	11	3	155
D-14-13 14ABC	2-Oct-01	8.24		0.31	36	1.3	3	238				68	10		146
D-14-13 14ABC	5-Nov-01	7.37		0.3	35	1.3	3	242				74	11		155

Groundwater Quality Text Value* (Continue)

Well ID	Collect data	pH	TDS	Bromide	Chloride	Fluoride	Nitrate as N	Surfate	Bicarbonate Alkalinity	Carbonate Alkalinity	Total Alkalinity	Calcium	Magnesium	Potassium	Sodium
D-14-13 14ABC	4-Dec-01			0.3	35	1.3	3	244				73	11		154
D-14-13 14ABC	3-Jan-02	7.51		0.28	35	1.3	3	248				74	11		143
D-14-13 14ABC	4-Feb-02	7.10		0.3	36	1.3	3	244				70	11		139
D-14-13 14ABC	7-Mar-02	7.41		0.32	36	1.3	3	250				74	12		149
D-14-13 14ABC	2-Apr-02	7.23		0.3	36	1.3	3	263				74	12		144
D-14-13 14ABC	13-May-02	7.32		0.3	36	1.3	3	264				81	13		158
D-14-13 14ABC	3-Jun-02	7.27	698	0.3	36	1.3	3	264	247		247	77	12	3.1	149
D-14-13 14ABC	3-Jul-02	7.44		0.3	36	1.3	3	264							
D-14-13 14ACA	30-Mar-00	7.38	476	0.11	16	0.98	3.3	120	225		225	52	8.4	3.5	102
D-14-13 14ACA	6-Sep-00	7.32	458	0.12	16	1.1	3.3	117	223		223	48	6.8	2.4	94
D-14-13 14ACA	12-Dec-00	7.23	438	0.12	16	1	3.2	108	219		219	51	8.2	3.5	100
D-14-13 14ACA	21-Mar-01	7.03	439	<0.1	16	1.1	3.1	104	218		218	51	7.2	2.1	100
D-14-13 14ACA	12-Jun-01	7.80	429	<0.1	15	1	3	106	221		221	47	6.6	2.4	92
D-14-13 14ACA	3-Jul-01	7.34		<0.1	16	1	3.1	102				46	6.4		91
D-14-13 14ACA	1-Aug-01	7.80		<0.1	16	0.97	3	101				48	6.6		90
D-14-13 14ACA	5-Sep-01	7.48	450	<0.1	16	0.95	3	100	220		220	48	6.8	2.6	99
D-14-13 14ACA	2-Oct-01	8.62		<0.1	16	0.95	3.1	99				44	6.2		93
D-14-13 14ACA	5-Nov-01	7.41		<0.1	16	0.93	3	99				45	6.3		94
D-14-13 14ACA	4-Dec-01			<0.1	16	0.96	3	98				46	6.5		95
D-14-13 14ACA	3-Jan-02	7.46		<0.1	16	0.97	3	100				49	6.9		94
D-14-13 14ACA	4-Feb-02	7.10		<0.1	16	0.96	3	101				45	6.2		86
D-14-13 14ACA	7-Mar-02	7.45		<0.1	16	1	3	96				46	6.4		91
D-14-13 14ACA	2-Apr-02	7.27		<0.1	16	1	3	104				46	6.3		90
D-14-13 14ACA	8-May-02	7.38		<0.1	16	1	3	104				45	6.3		89
D-14-13 14ACA	3-Jun-02	7.21	426	<0.1	16	0.98	3	104	218		218	48	6.7	2.6	95
D-14-13 14ACA	3-Jul-02	7.40		<0.1	16	1	2.9	103							

UNITS (mg/l)

Text Value*:This field is the analysis results including the values that are less than (<) the detction limit. The numbers are generated from the database as text because of the inclusion of the "less than symbol" and to use them as numbers they must be

APPENDIX C

Tributary Analysis

I. INTRODUCTION

This appendix presents results of additional analyses for Groundwater and Water Budget Analysis performed in support of the feasibility study for the Paseo de las Iglesias Environmental Restoration Study. The following sections describe the procedures and estimates of average annual and monthly streamflows for the Santa Cruz River and tributaries joining the East and West bank. These results will be used for the water budget analysis of this environmental restoration project.

II. AVERAGE ANNUAL/MONTHLY STREAMFLOW FOR SANTA CRUZ RIVER

The United States Geological Survey (USGS) currently operates a streamflow gaging station at one location along the Santa Cruz River in study area - at Congress St. (#09482500) since 1905. Available long record (1905-2001) from this gaging station (#09482500) was used to estimate average monthly and annual flows for the Santa Cruz River (SCR) Tributaries and summarized in Table 4 of this report. It should be noted here that the variability of monthly flows is large, and for a given month, average monthly flow varies from a minimum of zero to several hundred cubic feet per second. Maximum, minimum and standard deviation of monthly flows are listed in Table 4-3 of this report, to indicate this large variability. Note that standard deviations of monthly flows typically vary.

III. AVERAGE ANNUAL/MONTHLY STREAMFLOW FOR TRIBUTARIES

III. 1. General

There are nineteen major tributaries joining the SCR in the study reach. Twelve tributaries – Hughes Wash, Santa Clara Wash, El Vado Wash, Valencia Wash, Airport Wash, Wyoming Wash, Irvington Wash, Rodeo Wash, Julian Wash, Mission View Wash, 18th Street Wash, Cushing Street– join the East bank, while seven tributaries – Ajo Wash, Enchanted Hills Wash, San Juan Wash, Cholla Wash, Old West Branch at Confluence with SCR, New West Branch at Confluence with SCR, Los Reales Road – join the west bank of the Santa Cruz River. Locations of these tributaries are shown in Figure 1-1 of this report. As a result, available streamflow data from gaged watersheds with similar characteristics are analyzed to provide estimates of average monthly and annual runoff volumes for the twelve tributaries shown in Figure 1-1 of this report.

Watersheds of tributaries joining the east bank are highly urbanized, while west bank tributaries have relatively natural or rural watersheds. Because of this difference in characteristics, two groups of similar watersheds were selected and available streamflow data are analyzed to develop two different relations for average annual runoff volumes.

For the tributary analysis, methodology and stream flow data gaged were used same with the El Rio Antiguo, Rillito River Environmental Restoration, since those are the watersheds in Tucson area with similar physical characteristics.

III. 2. Average Annual Runoff Volume

For the urbanized tributaries, stream flow data from the following six gaged watersheds in Tucson area with similar physical characteristics were utilized: Airport Wash, Railroad Wash, Tucson Arroyo, High School Wash, Arcadia Wash and Atterbury Wash. Table 1 summarizes physical characteristics and runoff data for these six watersheds. Available streamflow data from these watersheds are analyzed to develop a regression relation between the average annual runoff volume and independent variables representing physical characteristics for the watersheds.

From a sensitivity analysis, it was found that drainage area alone was not a good indicator, but drainage area combined with impervious area (in fraction) was the most important explanatory variables. Based on this consideration, the following relation for urban watersheds were obtained from multiple regression analysis:

$$AAR_u = 67.29 + 87.56\,(IA) + 17.30\,(IA)^2 \qquad (1)$$

where AAR_u = Average annual runoff for urban watersheds in acre-ft

A = Drainage area, in sq. miles

I = Impervious area, in fraction

Eq. (1) has a correlation coefficient of 0.985 and a standard deviation of 43.47. Average annual runoff volumes for the eleven urban tributaries are estimated using Eq. (1) and summarized in Table 4-5 of this report.

<u>Table 1</u> Watershed Characteristics

Watershed/Station	Drainage Area (sq. mile)	Mean Basin Elevation (ft)	Forested Area (%)	Impervious Area (%)	Mean Annual Rainfall (in)	Mean Annual Runoff			
						cfs	Inch	Acre-ft	Percent of Rainfall
Airport Wash (9482400)	23.0	2700	1.1	9.1	10.8	0.43	0.25	311.3	2.3
Railroad Wash (9482950)	2.3	2490	0.0	51.6	11.0	0.21	1.24	152.0	11.3
Tucson Arroyo (at Vine Ave) (9483000)	8.2	2510	0.0	45.5	11.0	0.88	1.46	637.1	13.3
High School Wash (9483010)	0.95	2460	0.0	38.5	11.0	0.11	1.57	79.6	14.3
Arcadia Wash at Tucson (9485550)	2.72	2560	0.0	49.8	11.0	0.36	1.80	260.7	16.4
Atterbury Wash at Tucson (9485390)	4.97	-	-	13.3	11.0	0.23	0.63	166.5	5.7
Tanque Verde Creek near Tucson ((9483100)	43.0	4780	21.0	-	17.0	8.90	2.81	6,443.3	16.5
Sabino Creek near Tucson (9484000)	35.5	6300	85.0	-	22.6	14.0	5.35	10,135.5	23.7
Bear Creek near Tucson (9484200)	16.3	5860	82.0	-	20.6	4.7	3.91	3,402.6	19.0
Tanque Verde Creek at Tucson (9484500)	219.0	4340	36.0	-	16.7	33.0	2.04	23,890.9	12.2
Rincon Creek near Tucson (9485550)	44.8	4850	57.0	-	19.2	7.0	2.12	5,067.8	11.0

For West bank tributaries which have relatively natural or rural watersheds, stream flow data from the following five gaged watersheds in Tucson area having similar physical characteristics are utilized: Tanque Verde Creek near Tucson, Sabino Creek near Tucson, Bear Creek near Tucson, Tanque Verde Creek at Tucson and Rincon Creek near Tucson. Physical and runoff characteristics for these watersheds are summarized in Table 1. It was found that drainage area and mean basin rainfall were the most important independent variables for estimating average annual runoff for these watersheds. Based on this consideration, the following relation was developed for rural or natural tributaries using multiple regression analysis:

$$AAR_n = 0.252\ A^{0.924}\ P^{2.291} \qquad (2)$$

where AAR_n = Average annual runoff for natural watersheds, in acre-ft.

A = Drainage area, in sq. miles

P = Mean basin annual rainfall, in inches

Eq. (2) has a correlation coefficient of 0.954. Average annual runoff for the eight rural or natural tributaries are estimated using Eq. (2) and summarized in Table 4-5 of this report. Basin rainfalls for the tributaries in Table 4-5 of this report are estimated as average value of the annual rainfall recorded at stations: # 8820 (Tucson AP). This station is the vicinity to the tributary watersheds.

From the above calculation, the total from the nineteen tributaries in the study reach, on an average annual basis, is **9,020** acre-ft.

III. 3. Average Monthly Runoff Volume

A review of the average monthly flows for the Santa Cruz River and the gaged watersheds used in the analysis in Section III. 2, indicates that variability of monthly flows is very large. As an example, this can be seen from Table 4-3 of this report, which shows that standard deviations of monthly flows are up to seven times the annual mean values. Consequently, any attempt to develop relations for monthly flows similar to Eq. (1) or Eq. (2) is likely to yield unreliable estimates. An alternative approach involves estimating monthly distributions as percent of annual runoff volumes from the available records for the gaged watershed analyzed in Section III. 2, and then apply them to get monthly values from the annual values estimated in Section III.2. This approach, though approximate but relatively more reliable, will be utilized in the following analysis.

From the available stream flow record, average monthly runoff values expressed as percent of average annual runoff are summarized in Table 2 for the eleven urban watersheds used in Section III.2 for developing Eq. (1). Similarly, Table 3 summarizes the corresponding values for the eight rural or natural watersheds. Average values indicated for each month are combined as average annual runoff values given in Tables 2 and 3, respectively, to estimate average monthly values for each of the nineteen watersheds, and the results are summarized in Table 4-6 of this report.

Table 2

Average Monthly Runoff as Percent of Average Annual Runoff for Urban Watersheds

Watershed	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Airport Wash*	1.7	2.6	1.2	0.4	0.1	0.2	38.0	16.0	23.5	10.6	2.0	3.7	100.0
Railroad Wash**	13.3	7.7	3.7	0.4	0.36	2.0	15.4	15.4	20.7	10.9	3.7	7.7	100.0
Tucson Arroyo*	5.4	4.8	3.5	0.8	0.7	1.0	26.4	27.8	10.2	7 .8	4.2	7.5	100.0
High School Wash*	9.5	5.6	7.1	1.2	1.4	1.5	17.8	20.9	17.4	8 .0	4.0	5.7	100.0
Arcadia Wash**	10.1	14.9	9.2	0.3	1.9	2.0	9.7	23.3	18.7	2.6	3.0	4.0	100.0
Atterbury Wash**	12.2	7.0	7.4	0.11	1.6	1.0	11.1	17.0	32.2	2.4	2.1	5.2	100.0
Average	8.7	7.1	5.4	0.5	1.0	1.3	19.7	20.1	20.5	7.1	3.2	5.6	100.0

* Data from Water Resources Investigations Report 98-4225, U.S.G.S., 1998, Ref. 3.

** Data from U.S.G.S. web site: http://waterdata.usgs.gov/az/nwis/monthly/

<u>**Table 3**</u>

Average Monthly Runoff as Percent of Average Annual Runoff for Natural Watersheds

Watershed	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Tanque Verde Creek (near Tucson)	13.8	19.8	14.0	3.2	0.3	0.1	3.0	7.7	9.0	4.3	1.9	23.1	100.0
Sabino Creek	16.5	17.4	21.6	7.7	1.3	0.3	3.6	8.4	6.0	2.7	2.6	11.9	100.0
Baer Creek	18.0	21.8	15.6	3.7	0.4	0.0	1.2	3.2	6.4	5.6	1.8	22.4	100.0
Tanque Verde Creek (at Tucson	42.0	17.0	21.0	4.0	0.27	0.0	0.37	0.78	0.12	0.03	1.0	13.0	100.0
Rincon Creek	23.9	18.2	16.1	3.7	0.2	0.1	4.3	13.6	4.0	1.9	1.3	12.7	100.0
Average	22.8	18.8	17.7	4.5	0.5	0.1	2.5	6.7	5.1	2.9	1.7	16.6	100.0

Data source: Water Resources Investigations Report 98-4225, U.S.G.S., 1998, Ref. 3.

APPENDIX D

Terminology of Monthly Statistics

Monthly Statistics

The Monthly Statistics view displays a suite of summary statistics on a month-by-month basis. This suite summarizes data over the entire period of record, reporting three types of statistics: **daily statistics**, **period statistics** (monthly or annual), and **exceedances**. Daily statistics are calculated against the daily observations. Period statistics are calculated against the population of valid monthly or annual totals or means for each period (month or year). Exceedances are calculated against all non-missing daily observations.

The values are reported by months, using all valid observations that fell within the month indicated. The *Year* column reports daily statistics for all values in the data record, and period statistics based on all of the annual values in the data record.

NOTE: Values which are flagged as accumulated are treated as missing when computing the various statistics.

Monthly Statistics

Station Name: DEATH VALLEY

Parameter: Maximum Temperature

	June	July	August	September	October	November	December	Year
# Days	988	961	991	960	986	956	989	11666
Avg Day	108.70	114.90	112.90	105.30	92.82	76.11	64.57	90.38
# Months	33	31	32	32	32	32	32	28
SDev Month	2.65	2.25	2.61	2.96	3.72	2.76	3.29	1.09
Min Month	104.40	110.30	106.70	98.50	86.19	71.10	56.45	87.71
Max Month	113.70	118.40	117.20	110.10	101.10	81.62	70.61	92.41
Avg Month	108.70	114.90	112.90	105.30	92.76	76.10	64.57	90.28
Skew Month	0.02	-0.35	-0.42	-0.60	0.18	-0.14	-0.39	-0.13
Kurt Month	1.85	2.18	2.75	2.42	2.31	2.16	2.48	2.95
M Min Year	1963	1982	1983	1985	1984	1964	1990	1982
M Max Year	1961	1988	1969	1974	1988	1986	1980	1989
Exceedences								
1%	123.00	125.00	123.00	118.00	110.00	92.44	79.00	122.00
5%	120.00	122.90	121.40	115.00	106.00	88.00	74.00	118.00
10%	118.00	121.00	120.00	114.00	104.00	86.00	72.00	115.00
20%	115.00	119.00	118.00	111.00	100.00	83.00	70.00	110.00
50%	109.00	115.00	114.00	106.00	93.00	76.00	65.00	91.00
80%	103.00	111.00	109.00	100.00	86.00	69.00	60.00	71.00
90%	98.00	108.00	105.00	96.00	82.00	66.00	57.00	65.00
95%	95.00	106.00	103.00	92.00	79.00	64.00	54.00	61.00
99%	89.00	101.00	95.00	85.00	71.86	60.00	47.00	54.66

The first two rows of statistics contain **daily statistics**: *# Days, Avg Day*. The third through eleventh rows of statistics contain **period statistics**: *# Months, SDev Month, Min Month, Max Month, Avg Month, Skew Month, Kurt Month, M Min Year and M Max Year*. Period statistics are based on all of the monthly or annual values in the full data record. The twelfth through twentieth rows of statistics contain **exceedances**.

The **daily statistics** are calculated based on all observations that fell within the month indicated, during the period of record. For example, *Avg Day* in *May* is the average daily value observed in all the months of May over the period of record. The column labeled *Year* expresses the values derived from days in all of the months (the entire data record). So, *Avg Day* in the *Year* column is the average daily value observed over the entire data record.

 # Days is the total number of valid days on which readings were taken during the period of record. Again, it refers to the period of the column in which the count is found. So, *# Days* in the *March* column is the number of days with observations in all of the months of March in the data record. It may not equal 31 times the number of years in the period of record because there may be days on which no observations were recorded ("missing days"). The *# Days* in the *Year* column is the number of days for which there are observations in the period of record. It will be equal to the sum of the monthly values.

The ***Avg Day*** is the average of the valid daily observations for the period

The next grouping is the **period statistics**. These are based on the population of monthly or annual totals or means (period values) for each month or year over the entire period of record.

Data are summarized to period values (month or year) according to the methods that are customary for the parameter. Period values for measurements of mass or volume like precipitation, snow, and evaporation are based on the monthly or annual totals. Period values for rates or state variables like wind speed or temperature are based on the monthly or annual averages.

For example, the *Max Month* for *July* for maximum temperature is the maximum mean July value observed over the period of record and *Max Month* for *Year* is the maximum annual mean observed over the entire data record.

 # Months is the number of valid periods (months or years) upon which the period statistics are based.

NOTE: Hydrosphere follows the National Climatic Data Center convention on valid statistics: a **valid month** cannot have more than 9 missing daily observations to be counted in the period statistics. A **valid year** cannot have a single invalid month.

SDev Month is the standard deviation of the period values: a measure of the distribution of period values about the *Avg Month*. There is a 66% probability that any period value will fall into the range defined by one standard deviation above and below the *Avg Month*.

Avg Month is the average period value in the data record.

Min Month is the minimum period value.

Max Month is the maximum period value.

Skew Month is the coefficient of skewness of the population of period values. Skewness measures the departure of the population of period values from a symmetrical (Gaussian, or bell-curve) distribution. Positive skewness indicates a population tailing off to the right (that is, one with a mode less than the median less than the mean).

Kurt Month is the monthly or period kurtosis. Sometimes known as the fourth moment, kurtosis is defined as the degree of peakedness or flatness of the curve graphing a distribution. It expresses the concentration of points about the mean.

Standard deviation, skewness and kurtosis were calculated in accordance with SPSS procedures (Nye, et al, 1975).

M Min Year is the year in which the *Min Month* occurred.

M Max Year is the year in which the *Max Month* occurred.

Exceedances rank the individual daily values for the entire data record. A value for 1% means that only 1% of the time were values observed that were greater than the value displayed. The 50% value represents the median. Exceedences are calculated using the Weibul formula to determine the plotting position and then locating (interpolating if necessary) the data value at that position.

$$P = M/(N+1)$$

where N is the number of values and M is the position of the value in the list of values ordered by decreasing value.