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WATER BUDGET AND HYDROGEOLOGIC MODEL OF SPRING FLOW AT LIMESTONE HILL, ZZYZX DESERT STUDIES CENTER

A Thesis

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In Partial Fulfillment

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Master of Science

in

Geology

By

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ABSTRACT

This study was performed to determine the source of recharge to MC Spring, which is home to the endangered Mohave tui chub. MC Spring is located at the Zzyzx Desert Studies Center, east of Limestone Hill. The water level in MC Spring is constant year-round, though the groundwater elevation in the adjacent playa aquifer of Soda Lake fluctuates seasonally as much as 1.5 meters and the elevation of the surface of MC Spring and groundwater in the alluvial aquifer is 1 to 2 meters higher than the elevation of the playa aquifer groundwater. The electroconductivity of the water in MC Spring and alluvial aquifer groundwater is an order of magnitude lower than the electroconductivity of the playa aquifer groundwater.

A hydrogeologic model was prepared using monitoring well data, alluvial aquifer recharge, and fracture measurements to determine a flow path to MC Spring. The evapotranspiration of Lake Tuende of 28.5 acre-feet per year was determined by the pumping data and used to calculate a water budget for MC Spring. The balanced water budget supports the observed stability of the surface elevation of MC Spring. Results of this study suggest that the source of water for MC Spring is alluvial and fractures in Limestone Hill provide a path for recharge.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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CHAPTER 1

INTRODUCTION

MC Spring is a modified, naturally occurring pond at the California State University's Desert Studies Center at Soda Springs, commonly referred to as Zzyzx. The spring is the only location known to naturally contain the Mohave tui chub (*Gila bicolor mohavensis*), which is listed as endangered (United States Fish and Wildlife Services 2007). The water level in MC Spring is constant year-round, suggesting that the source of recharge water to the spring balances the effects of evapotranspiration.

It is hypothesized that MC Spring is recharged through fractures in a limestone outcrop called Limestone Hill from the alluvial aquifer west of the hill (which is recharged from the southern extension of the Soda Mountains, known herein as Soda Mountain), rather than from the playa aquifer, which is recharged by the Mojave River system. The purpose of this project is to determine the groundwater recharge capacity in and around Limestone Hill as it impacts MC Spring, near the hill's base.

A comprehensive analysis of the local hydrogeology around Limestone Hill was performed to better understand the impact of local groundwater recharge sources on the spring habitat of the Mohave tui chub. The objective of this

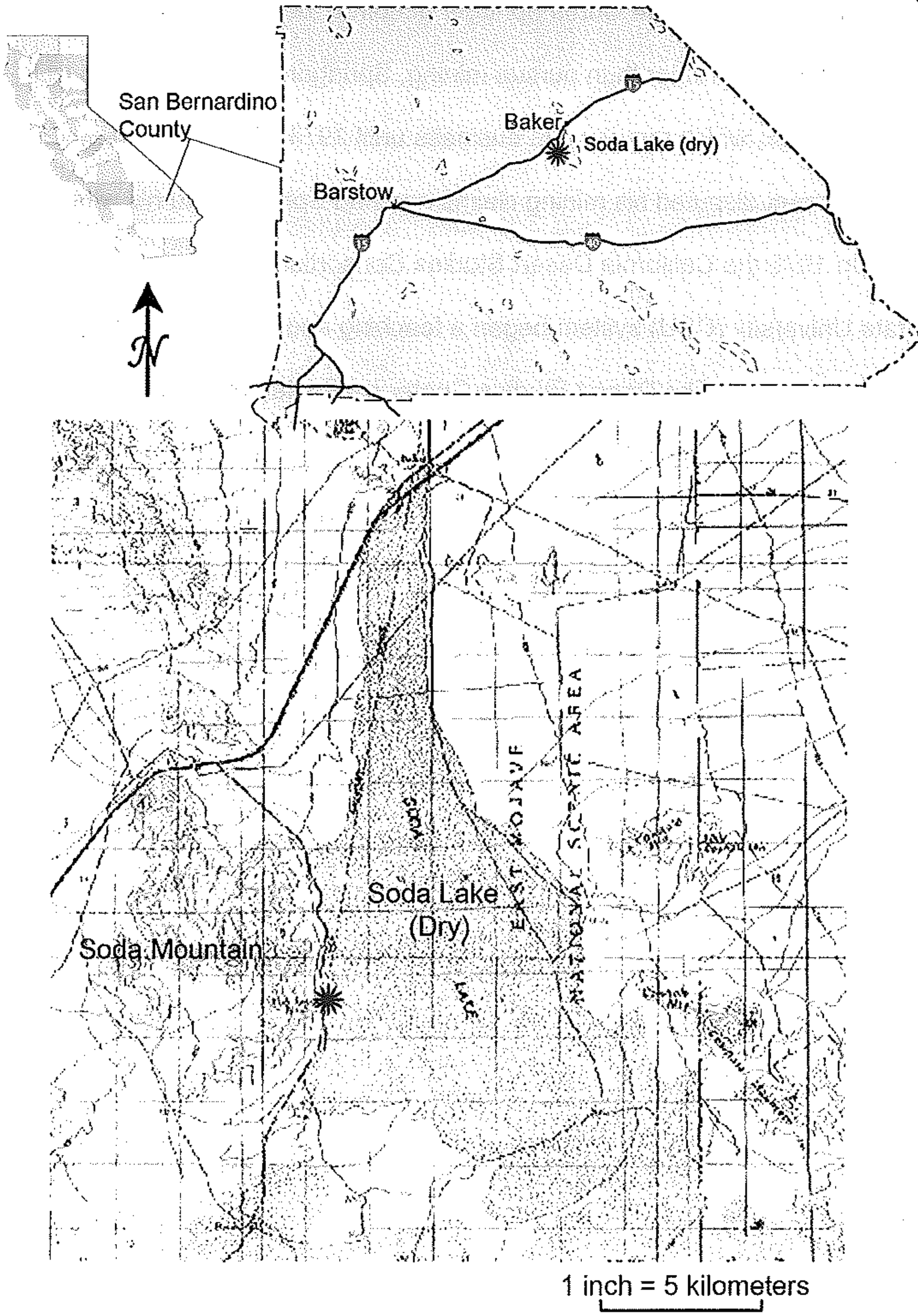


Figure 1. Zzyzx Desert Studies Center Location Map. Zzyzx is located on the western edge of the wedge-shaped Soda Lake (dry) in San Bernardino County, Southern California. Topography map from USGS quadrangle Soda Lake North.

al.1979; Muessig et al. 1957). Subsurface sediments suggest that intermittent lake conditions occurred as early as 22,000 years ago with sufficient flooding of the Mojave River (Enzel et al. 1992; Wells et al. 2003). North of the narrow northern end of Soda Lake, Silver Lake marks the terminus of the Mojave River (Enzel et al. 1992).

As a result of previous thrust faulting on the southern Death Valley Fault Zone (formerly referred to as the Soda-Avawatz fault) the Soda Mountains, which consist of Paleozoic limestone and Triassic to Jurassic granitics and metavolcanics (Grose 1959; Walker et al. 2002), rise steeply on the western edge of Soda Lake. In areas the massive to thinly bedded limestone, including Limestone Hill, are exposed on the surface of the mountains (Figure 2) (Grose 1959; Glazner et al. 2002; Harvey and Wells 2003; Michner 1984). Active alluvial fans occur between the mountains and the lakebed (Harvey and Wells 2003).

Between Soda Mountain and Limestone Hill, alluvial deposits consist of sand and gravel (refer to borehole logs for Wells A1, A8, A12, and JW3 in Appendix A). To the east of Limestone Hill, a thin layer of alluvial silty sand overlies sandy silt playa deposits (refer to borehole log for Well MC in Appendix A). MC Spring is located within the alluvium on the eastern side of Limestone Hill. Figure 3 shows the location of monitoring wells and surface water at Zzyzx. Figures 4 and 5 show the geology of the vicinity of Limestone Hill and MC Spring.

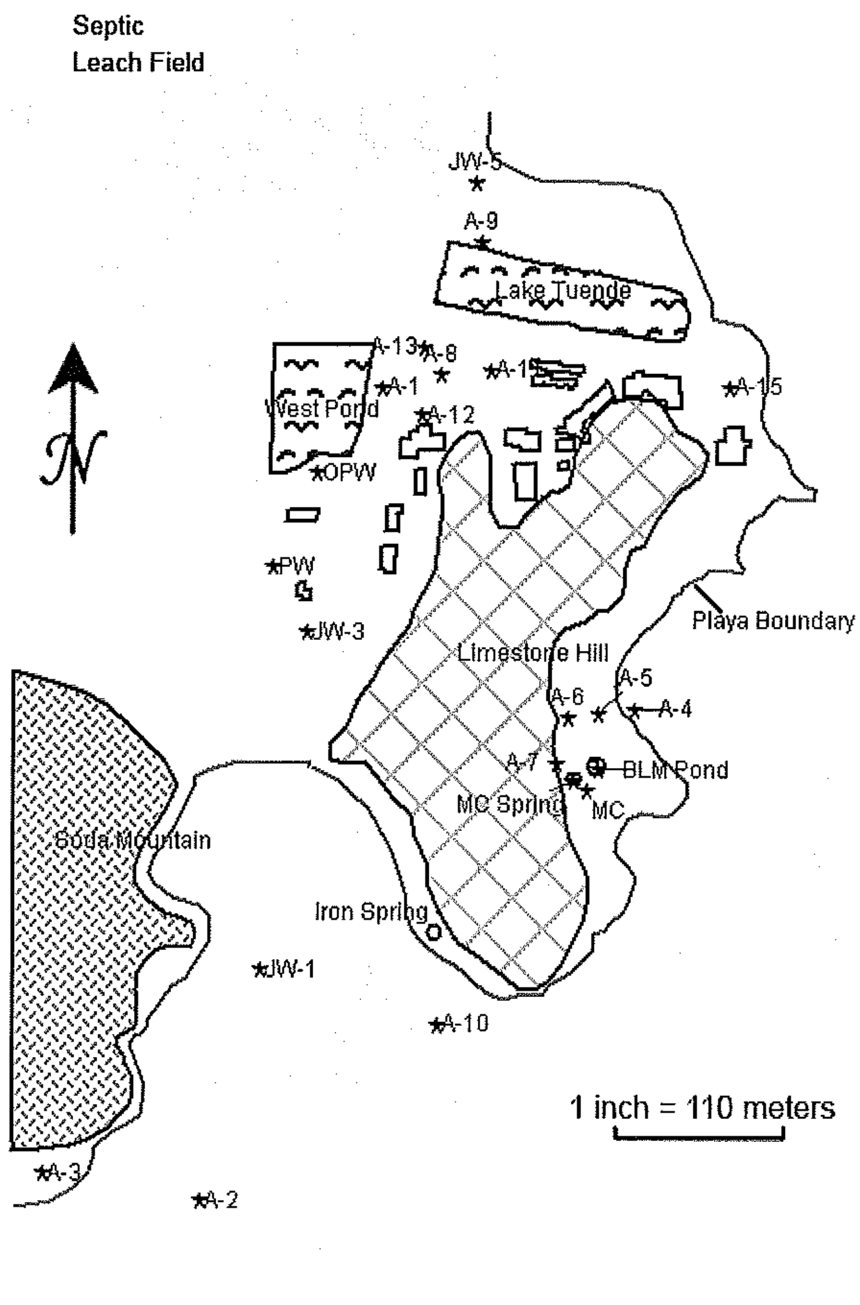


Figure 3. Location of Monitoring Wells and Surface Water at Zzyzx. MC Spring is located on the eastern edge of Limestone Hill. Geology is shown on Figure 4. Borehole logs for Wells A1, A8, A12, and JW3 (Appendix A) show the geology in the alluvial deposits. The borehole log for Well MC shows the contact between alluvial and playa deposits.

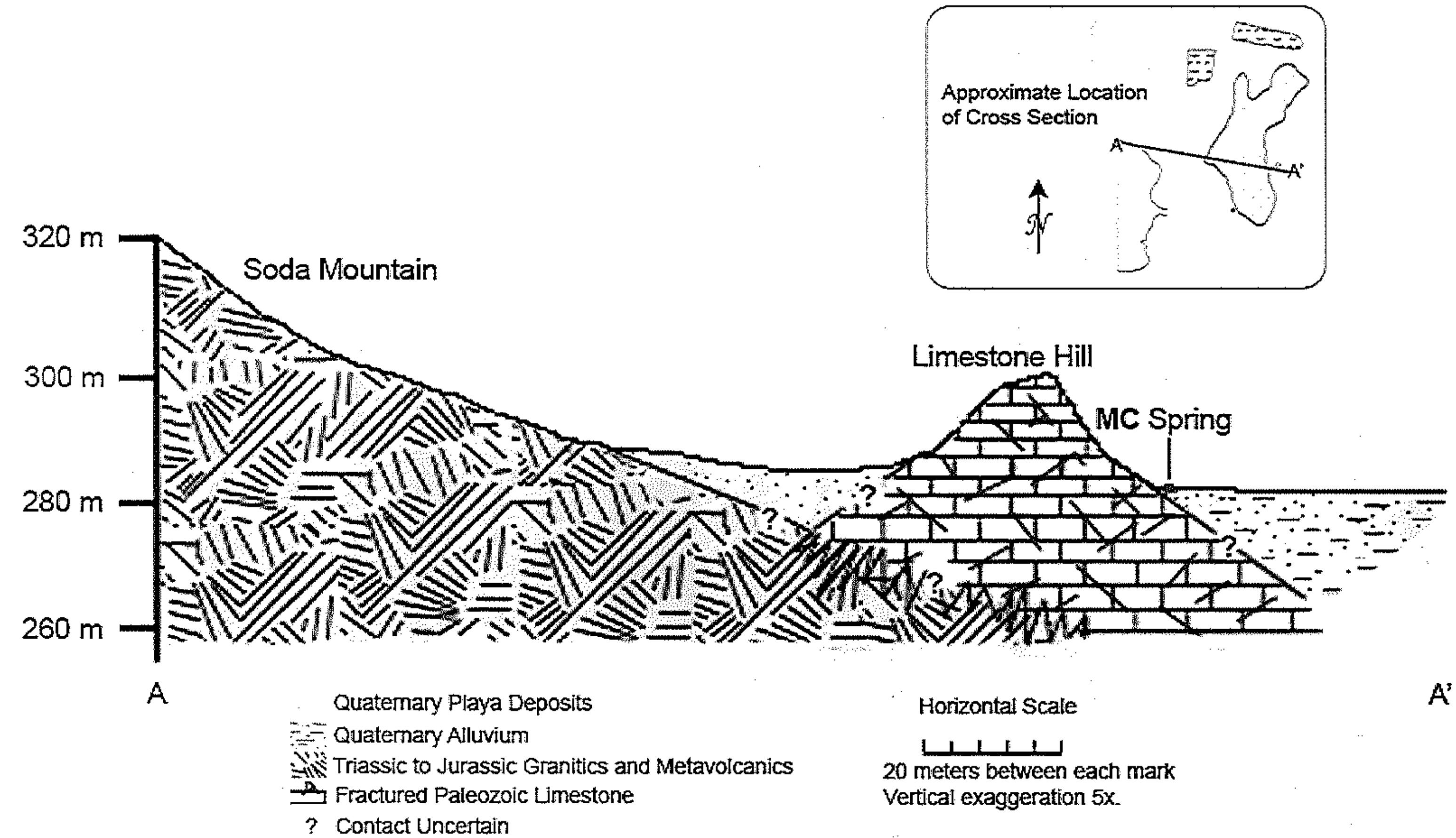


Figure 5. Geologic Cross Section of Zzyzx Desert Studies Center. MC Spring is located in a thin layer of alluvial deposits on the east side of Limestone Hill. Subsurface contacts are uncertain.

In the Mojave Desert, much of the precipitation infiltrates only the upper soil zone and is eventually lost to the atmosphere by evapotranspiration (the loss of water to the atmosphere by evaporation, plus transpiration from plant tissue). Zzyzx is located in the California Irrigation Management Irrigation System (CIMIS) Zone 17, valleys in the high desert near Nevada and Arizona (CIMIS 2007), which is characterized by CIMIS as having an average reference evapotranspiration rate of 169 cm (66.5 in) per year.

Groundwater

The Studies Center at Zzyzx is underlain by a shallow alluvial aquifer between Soda Mountain and Limestone Hill. It is presumed that this aquifer is recharged by precipitation through the alluvial fans on the east side of Soda Mountain. Groundwater and surface water flow follow the surface gradient, from Soda Mountain toward Soda Lake, except where Limestone Hill prevents direct flow to the playa in the vicinity of the Studies Center. Bilhorn and Feldmeth (1985) reported elevations in the water supply well, located in the alluvial aquifer, and of MC Spring to be 1.8 to 3 m (6 to 10 ft) above the elevation of the water table in the playa aquifer.

Groundwater in the Soda Lake playa flows northward toward Silver Lake. The playa aquifer receives drainage from Kelso Valley and the Mojave River and is also fed by percolation of precipitation in the basin (Thompson 1929; Dickey et al. 1979). However, only an estimated five percent of the average 10.62 cm

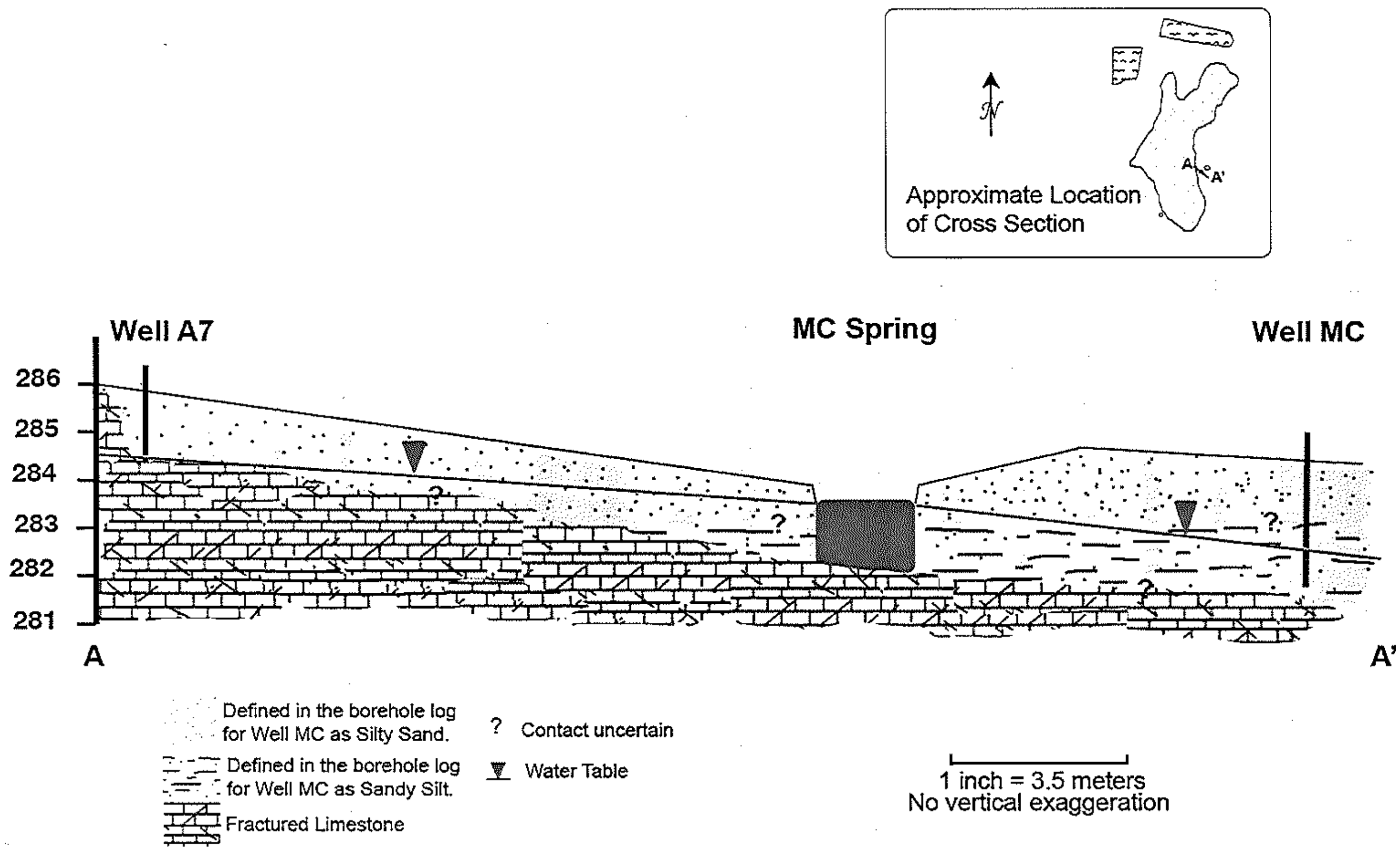


Figure 6. Hydrogeologic Model of MC Spring. Conceptual cross section shows the relationships between Well A7, MC Spring, and Well MC. Subsurface contacts are uncertain.

approximately 150 m by 40 m (490 ft by 130 ft). The bottom of the lake is mud and sand (Fulton personal communication). Discharge from the lake appears to be feeding the wetland area on the northern edge of the lake (Figure 7). The water level in the lake is artificially maintained by the pumping of groundwater from the alluvial aquifer to a fountain near the center of the lake when the water evaporates or percolates into the surrounding ground to approximately 0.6 to 1 m (2 to 3 ft) below the optimal level (Dirling 1997, Fulton personal communication). Archbold (1984) reported maximum depths of 1.3 m (4.3 ft) on the eastern end and 1.6 m (5.4 ft) on the western end, and calculated the average depth to be 1 m (3.1 ft). During a dredging event in 1985 a dam was constructed across the middle of the lake. The western half of the lake could not be completely emptied because of seepage into the lake from the playa aquifer below (Bilhorn and Feldmeth 1985). After the dredging, Bilhorn and Feldmeth reported a maximum depth of 1 m (3.3 ft) in the western end of the lake, and estimated the volume of the lake as 2,240 m^3 (592,000 gal). In 1990 the BLM dredged the eastern end of the lake to a depth of 1 to 2 m (3 to 6 ft). The National Park Service dredged the western end in 2001 to a depth of 2 m (6 ft). The dredging was performed to increase the surface to volume ratio in order to decrease temperature swings and evaporation, to provide an optimal fish habitat (Fulton personal communication).

West Pond was originally excavated by the Tonopah and Tidewater Railroad in 1907 as a borrow pit to provide gravel during construction of the railroad. Curtis Springer likely expanded this pond during his time at Zzyzx. In 1985, the pond had an average depth of 0.3 to 0.45 m (1 to 1.5 ft) and a volume of approximately 2,500 m^3 (660,000 gal) (Bilhorn and Feldmeth 1985). In the late 1980s the BLM expanded the pond to the current shape and depth, as well as forming the islands (Fulton personal communication). This pond is cut into the alluvial aquifer and the water level is not controlled, as is the water level at Lake Tuendae. Archbold (1994) measured depths in West Pond of between 0.03 and 1.9 m (0.3 to 6.1 ft) with an average depth of approximately 1 m (3.4 ft). The bottom of West Pond consists of sandy silt and gravel capped by organic mud and aeolian silt (Fulton personal communication). Between 1981 and 1985, the Mohave chub living in West Pond all died. The suspected cause was an increase in pH and ammonia content, and decreased dissolved oxygen (Dirling 1997). The water in this small lake has a green appearance and often has a sulfurous odor.

CHAPTER 2

PREVIOUS WORK AND DATA GAPS

Although much work has been done in the Mojave Desert, the southern Soda Mountains and the Zzyzx area have not been extensively studied. Reports of the geology, hydrogeology, and geomorphology of Soda Lake and the eastern Soda Mountains (Brown et al. 1990; Butler 1984; Dickey et al. 1979; Enzel et al. 1992; Foster 1984; Grose 1959; Harvey and Wells 2003; HES 1985; Moyle 1967; Muessig et al. 1957; Thompson 1929; Walker and Wardlaw 1989; Wells et al. 2003) were reviewed. These reports are summarized in the Geologic Setting section in Chapter 1.

Thompson (1929) studied the area that was, in his time, called Soda Springs, as part of a report on the water supply potential and basic chemistry of springs throughout the Mojave Desert. He collected samples from a spring and a well at Soda Springs in December 1919. Based on observations of water chemistry at the springs east of Limestone Hill, Thompson noted that the chemical makeup of the water suggested possible sources both through the small limestone outcrop and from the playa.

Michner (1984) and Bilhorn and Feldmeth (1985) also analyzed the chemistry of the groundwater and surface water at Zzyzx. Both reports

Students of the Department of Geological Sciences at CSU Fullerton are among the main students to visit Zzyzx to learn a variety of geologic and hydrologic field analysis techniques. Numerous CSU Fullerton class projects have been conducted on the hydrology and hydrogeology of Zzyzx under the leadership of Dr. Prem K. Saint. Most of these studies were intended as learning tools for specific undergraduate coursework, or as undergraduate or graduate research projects. Students used the data they gathered to complete a specific class project or task. Students working toward their Bachelors or Masters degrees have conducted further studies. For example, Brown (1997) studied the groundwater seeps along the edge of the lakebed at the base of the southern Soda Mountains. Projects reported by Archbold (1994) and Dirling (1997) focused on Mohave tui chub habitat restoration. These reports did not attempt to determine the source of groundwater recharge.

Most of the above-listed studies were accomplished with limited data synthesis or field observations. Because the monitoring wells were installed during several different projects, no comprehensive inventory of the wells was made. Likewise, no survey had been performed to determine the location and elevation of each well. The limited understanding of subsurface geology was based on the available logs of hand-augered boreholes installed under Dr. Saint's leadership.

CHAPTER 3

METHODS

GPS and Map Preparation

The location and elevation of all wells were surveyed with an electronic Total Station and global positioning system (GPS). Various locations within the Zzyzx area were also surveyed. A Trimble Pathfinder Pro-XR Geographic Positioning System was used to determine the location of base stations for the Total Station, other reference locations throughout the area, and wells that were not visible from the Total Station (Wells A3, A10, and A15).

A surface map of the Zzyzx facility including surface features and wells was created using the data from the Total Station and the Pathfinder (Figure 3).

Monitoring Well Inventory

Borehole logs provided by Dr. Saint from previous class and student projects were compiled. Borehole logs are used to interpret subsurface geology. Several attempts have been made to locate the drilling log for Well PW, but to no avail (Fulton personal communication).

A reconnaissance was performed in April 2004 to determine the condition of each well, including whether water was present in the well. Wells that required repair were reported to the site manager, Mr. Rob Fulton.

parts per thousand [ppt]). The Hanna 9913000 was used to measure pH throughout the monitoring period.

Precipitation was compared to groundwater elevations and quality to determine variations between the cold, wet seasons and the hot, dry seasons. These comparisons were also used to better define the water budget of the area.

General ion chemistry, analyzed in March 2005 at CSU Los Angeles, was compared to the field-monitored groundwater quality at several monitoring wells and Well PW. Chemistry data were useful in determining flow paths of groundwater.

Surface Water Survey

Surface water in MC Spring, Lake Tuendae, and West Pond was monitored periodically between March 2005 and June 2006. Beginning in August 2006, monthly monitoring was performed through July 2007. Temperature, pH, EC, and TDS were recorded as described above using a Hanna Model HI 9913000 pH/EC/TDS/temperature waterproof meter, with a limit in EC of 4,000 μS/cm (4 mS/cm) from June 2006 through November 2006. Beginning in December 2006, a Hanna DiST HI98312 EC/TDS/temperature waterproof meter, which can measure EC up to 20 mS/cm, was used. The Hanna 9913000 was used to measure the pH throughout the monitoring period. These water quality parameters were also recorded at Iron Spring in April 2007.

Although there is a gauge in MC Spring, the gauge is not scaled. Photographs (Figure 8) were taken when possible of the gauge to compare the relative water level of the spring. In March 2006, MC Spring was overgrown with vegetation and the rod is difficult to see in the photograph. The level of BLM Pond was monitored by observation only. West Pond has a scaled gauge; readings were recorded periodically through the monitoring period. The level of Lake Tuendae is maintained by pumping; therefore, levels were not recorded.

A data logger in Lake Tuendae monitored temperature, DO, pH, and EC. The data downloaded from the logger between November 2003 and June 2004 were provided by Mr. Rob Fulton of the Desert Studied Center.

General ion chemistry analyzed at CSU Los Angeles was compared to the field-monitored water quality at MC Spring. Relationships in water quality of the spring and of groundwater were evaluated.

Resistivity Survey

An electrical resistivity survey was performed in January 2007 to explore the shallow subsurface. The subsurface was not well understood prior to the survey, other than the alluviual sediments that were logged during hand-augering of the groundwater monitoring wells. The subsurface geology and hydrogeology determined by this survey was used to prepare a hydrogeologic model for the site.

An Advanced Geosciences, Inc. SuperSting R8 Induced Polarization (IP) eight-channel automatic multi-electrode system with a 200-watt transmitter powered by two 12-volt vehicle batteries was used to perform the survey. The line was acquired across Zzyzx Road south of Limestone Hill. Sixty-four

The current transmitted, voltage received, and cycle information recorded by the SuperSting were downloaded to a computer. The resulting files were processed by EarthImager software.

Fracture Survey

In January 2007 the fracture orientations of Limestone Hill were surveyed. The fracture survey was performed to help build the hydrogeologic model and to assist in pinpointing potential areas of recharge. Four survey stations (Stations 1, 4, 5 and 6) were established. At each station, at least 16 and up to 64 measurements were recorded. The orientations of intrusive trends were also recorded in two locations (Stations 2 and 3). The fracture orientations were plotted on a rose diagram using Rockworks 2002 to determine the predominant orientation of fractures in the limestone.

Vegetation Survey

The vegetation at Zzyzx was mapped in April and May 2007. Vegetation patterns are useful, where well coverage is insufficient, in estimating the depth to groundwater. Meinzer (1927) describes plants that indicate the presence of groundwater and defines the tolerance of certain plants (halophytes) to saline or alkaline conditions common in the Mojave Desert. Additionally, the Desert Studies Center provides a list of plants found at Zzyzx (Desert Studies Center 2007).

Zzyzx, vegetation mapping, studies of the geology of the area, and synthesizing previous aquifer test data.

Although CIMIS (2007) characterizes the zone including Zzyzx as having an average reference evapotranspiration rate of 169 cm (66.5 in) per year, a more representative rate was determined by direct observation at Zzyzx. Zxyzx is a closed system, in which water does not enter or leave the area except as listed above. Therefore, by including the average annual precipitation recorded in the area (inflow) and the volume of water pumped into Lake Tuendae to maintain its level for a one-year period (outflow), and by the observation that the pumping prevents variations in the elevation of the surface water in the lake (no change in storage), a water budget for Lake Tuendae was calculated with a high degree of confidence. Likewise, the calculated evapotranspiration rate for Lake Tuendae was used to calculate a water budget for the area influenced by MC Spring.

CHAPTER 4

RESULTS

Zzyzx Map

Figure 3 shows the Zzyzx study site including Limestone Hill and the edge of the southern extent of Soda Mountain, surface water features, the playa boundary, groundwater monitoring well locations, and the Studies Center buildings.

Monitoring Well Inventory

Because the wells at Zzyzx were installed in boreholes that were drilled using hand-augered boreholes, none of the boreholes were advanced into bedrock or limestone. Sediments with varying degrees of sand, silt, and clay are the only subsurface geology reported in the logs. The logs do not state whether the total depth of the wells was determined by contact with groundwater or by auger refusal (which could indicate contact with gravel, bedrock, or limestone). Because of this uncertainty, the borehole logs were generally not used in this study to make inferences regarding subsurface geology. The available borehole logs are presented in Appendix A.

Upon inspection in April 2004, many wells were found without caps. The wells were capped to prevent excess evaporation as well as to prevent dilution water level fluctuated from approximately 0.3 to 0.5 m (1 to 1.5 ft) below the top of casing, but was always above ground surface. The total depth of Well JW5 is 5.3 m (17.3 ft), which is among the deepest of the monitoring wells. Only Well OPW is deeper (6.7 m [22 ft]).

The groundwater levels in all of the monitoring wells follow similar patterns, with more shallow water levels in most wells occurring in March 2005, March 2006, and March 2007 and deeper water levels in August 2005 and August 2006 (Figure 9). In contour maps of groundwater elevations for September 2006, December 2006, March 2007, and June 2007 (Figure 10), wells that were not dry (many wells become dry in the warmer months and were not used in the contouring) show a pattern of higher elevation to the southwest, at the base of the southern extent of Soda Mountain, and to the northwest, also from the direction of the Soda Mountains. In general, the alluvial aquifer wells have a water table elevation higher than the playa aquifer wells. The higher elevation continues through the fracture zone in the southern portion of Limestone Hill; the elevation of the surface of MC Spring is very similar to the elevation in wells in the alluvial aquifer. Elevations are 1 to 2 m (3 to 6 ft) lower toward the east and southeast, in the direction of the playa. Except in December 2006, the lowest elevations were measured in wells east of Limestone Hill. In December 2006 the lowest elevation was at Well A9, north of Lake Tuendae. Elevations were lowest overall (of the 4 months plotted) in September 2006, which is near the end of the particularly rainy 2005-2006 season as well as near the end of the typically hot

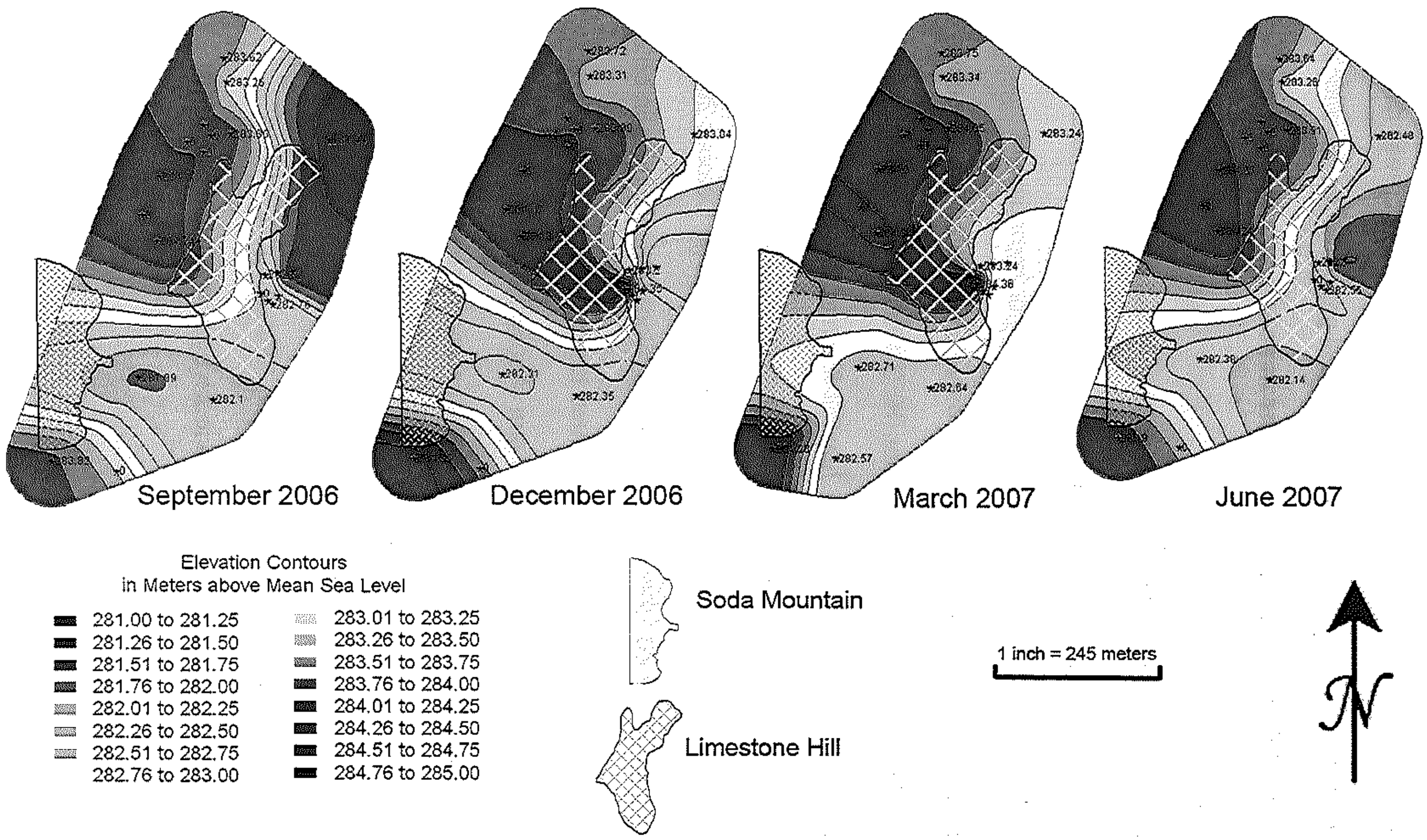


Figure 10. Seasonal Variations in Elevation. Groundwater and surface water elevations in meters above mean sea level at monitoring wells and MC Spring. Wells with an elevation of zero (0) in this figure were dry at the time of measurement, and were not used to determine the contours.

In general, wells that are located on the playa have groundwater elevations that are approximately 1 m (3 ft) below the elevations of alluvial wells when comparing cool-season elevations. The elevation difference is greater in warm-season elevations; there is a greater elevation fluctuation in playa wells than in alluvial wells (Figure 9). Aside from the seasonal fluctuations, groundwater elevations are relatively similar to water levels reported from June 1985 (Bilhorn and Feldmeth 1985) and November 1996 (Dirling 1997).

The greatest water level fluctuations observed during the current study occurred in Wells A4, A5 (which was dry from July to November 2006 and in June and July 2007), A10, A15, and JW1. These wells are located on the playa (A5 is near the playa boundary) (see playa boundary on Figure 3), suggesting that the playa aquifer water table fluctuates to a greater extent than the alluvial aquifer water table.

Groundwater Quality

Table 1 provides a summary of the groundwater and surface water quality recorded from March 2005 through July 2007. All the recorded data are provided in Appendix D.

In general, the temperatures of the groundwater and surface water monitored ranged from 15 to 32 °C (59 to 90 °F). Of the monitoring wells that were measured (all the wells that were not dry) in September 2006, December 2006, March 2007, and June 2007 (Figure 11), the highest temperature was measured in Well OPW in September 2006. The lowest temperature in that

Table 1. Summary of Groundwater and Surface Water Quality
(Page 2 of 3)

Name	TD	December-06				January-07				February-07				March-07			
		WL	Temp	EC	pH	WL	Temp	EC	pH	WL	Temp	EC	pH	WL	Temp	EC	pH
PW	52.25	12.85	19.8	3.25	7.43	-	-	-	-	-	-	-	-	-	-	-	-
A7	5.32	5.05	21.1	7.54	-	4.95	16.2	6.41	6.41	4.95	20.4	5.3	6.82	5.02	-	-	-
JW3	10.12	8.41	22.9	5.16	-	8.33	22.7	5.36	6.87	8.28	23.3	4.94	7.04	8.28	25.1	5.39	6.95
OPW	22	5.4	22.8	3.52	7.11	-	-	-	-	5.48	21.5	3.58	7.05	5.48	24.5	3.41	7.02
A3	6.58	4.01	23.9	5.53	-	3.91	18.8	4.86	6.43	3.96	21.9	4.3	6.78	4.22	24.1	4.49	6.4
A13	9.74	4.87	19.5	15.45	-	4.78	17.8	14.19	6.49	4.74	21.4	12.78	6.49	4.76	24.6	12.2	6.3
A12	8.46	dry	-	-	-	muddy	-	-	-	dry	-	-	-	dry	-	-	-
A8	4.78	muddy	-	-	-	muddy	-	-	-	4.77	22.6	10.77	6.57	4.47	-	-	-
A11	10.58	5.21	19.8	15.18	-	4.96	19.4	13.95	-	4.92	22.5	12.99	6.71	5	23.5	12.94	6.2
JW5	17.32	1.2	18.9	3.22	-	1.11	17.8	3.66	7.26	1.07	17.5	3.071	7.23	1.1	24.7	2.92	7.09
MC Spring			20.1	3.07	-		16.6	3.33	7.14		21.8	3.07	7.35		23.9	2.92	7.09
A9	4.73	4.36	16.4	12.07	-	4.22	14.4	10.62	6.25	4.28	17.8	11.67	6.5	4.25	24.4	8.49	6.61
A6	7.99	5.21	20.0	6.27	-	4.97	NM	5.58	6.39	4.93	20.3	4.48	6.83	5.05	22.6	4.64	6.35
A15	11.85	6.44	22.3	>20	-	5.92	18.5	>20	6.01	8.84	20.4	18.7	6.24	5.78	22.2	11.2	6.41
MC	10.48	5.44	21.7	4.63	-	4.4	15.8	5.01	6.47	4.34	19.9	4.89	6.83	4.55	22.2	3.65	6.52
A5	8.12	4.77	19.0	>20	-	3.02	13.6	16.07	6.76	2.87	17.5	12.75	6.76	3.09	20.3	11.96	6.64
A4	13.5	5.57	20.3	>20	-	3.71	16.5	>20	7	3.27	17.7	>20	7.22	3.13	22.8	>20	7.1
A10	9.94	5.43	22.8	>20	-	5.15	19.1	>20	6.58	4.98	19.8	>20	6.79	4.47	22.7	>20	6.49
JW1	11.96	8.22	23.7	12.54	-	7.34	19.6	13.52	6.37	6.99	21.5	13.81	6.38	6.56	25.1	14.38	6.22
A2	5.72	dry	-	-	-	muddy	-	-	-	5.51	23	>20	6.34	5.31	23.8	>20	7.24
Lake Tuende			14.6	4.29	-		-	-	-		17.9	4.18	7.58		24.1	4.16	7.5
BLM Pond			15.4	3.29	-		12.8	3.47	6.34		16.2	3.23	6.74		20.2	3.6	6.57
West Pond			-	-	-		-	-	-	50	-	-	-	50	25.3	>20	7.98
Iron Spring			-	-	-		-	-	-	-	-	-	-				

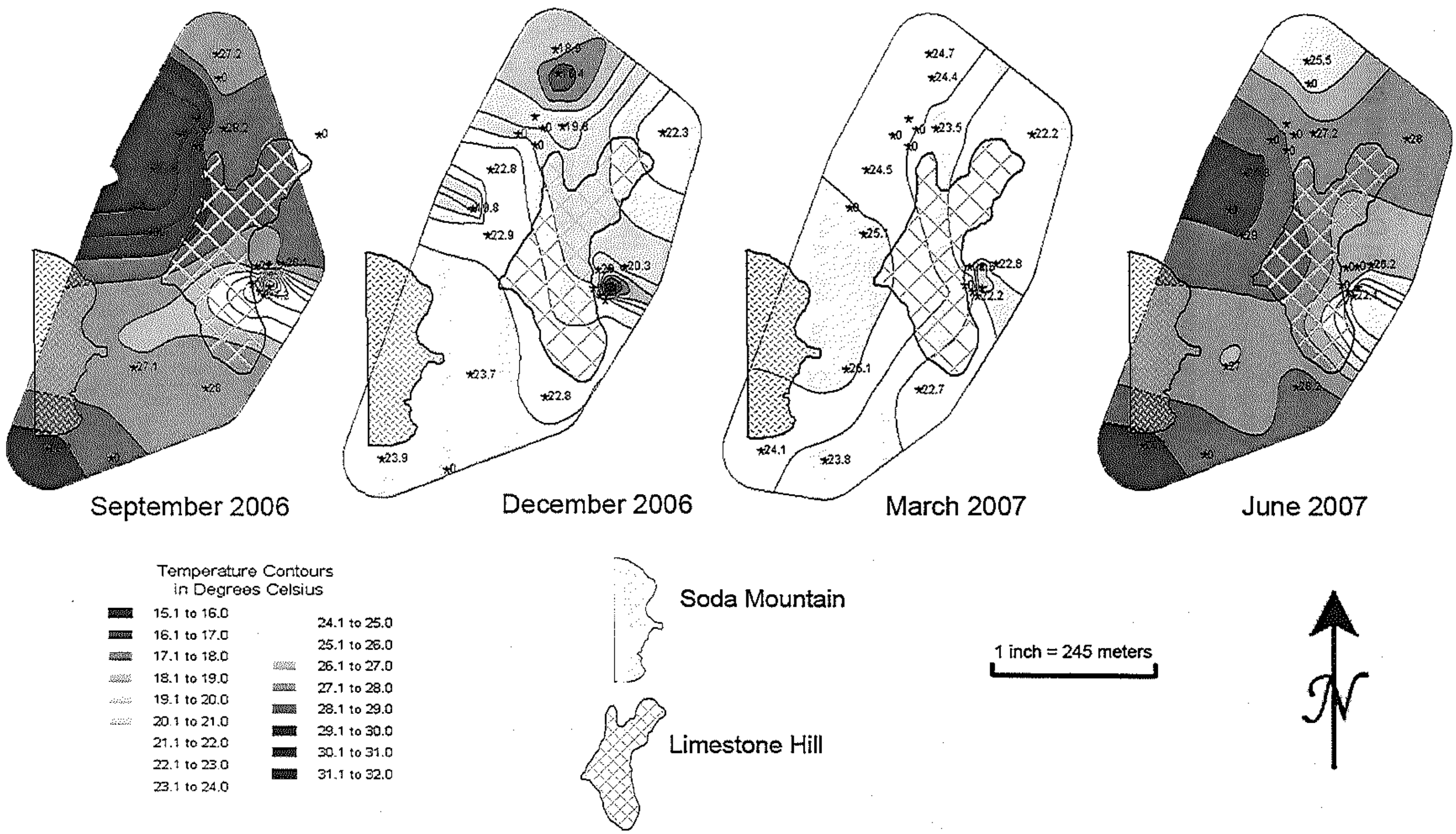


Figure 11. Seasonal Variations in Temperature. Temperature of groundwater in degrees Celsius collected from monitoring wells and surface water in MC Spring. Wells with a temperature of zero (0) in this figure were dry at the time of collection, and were not used to determine the contours.

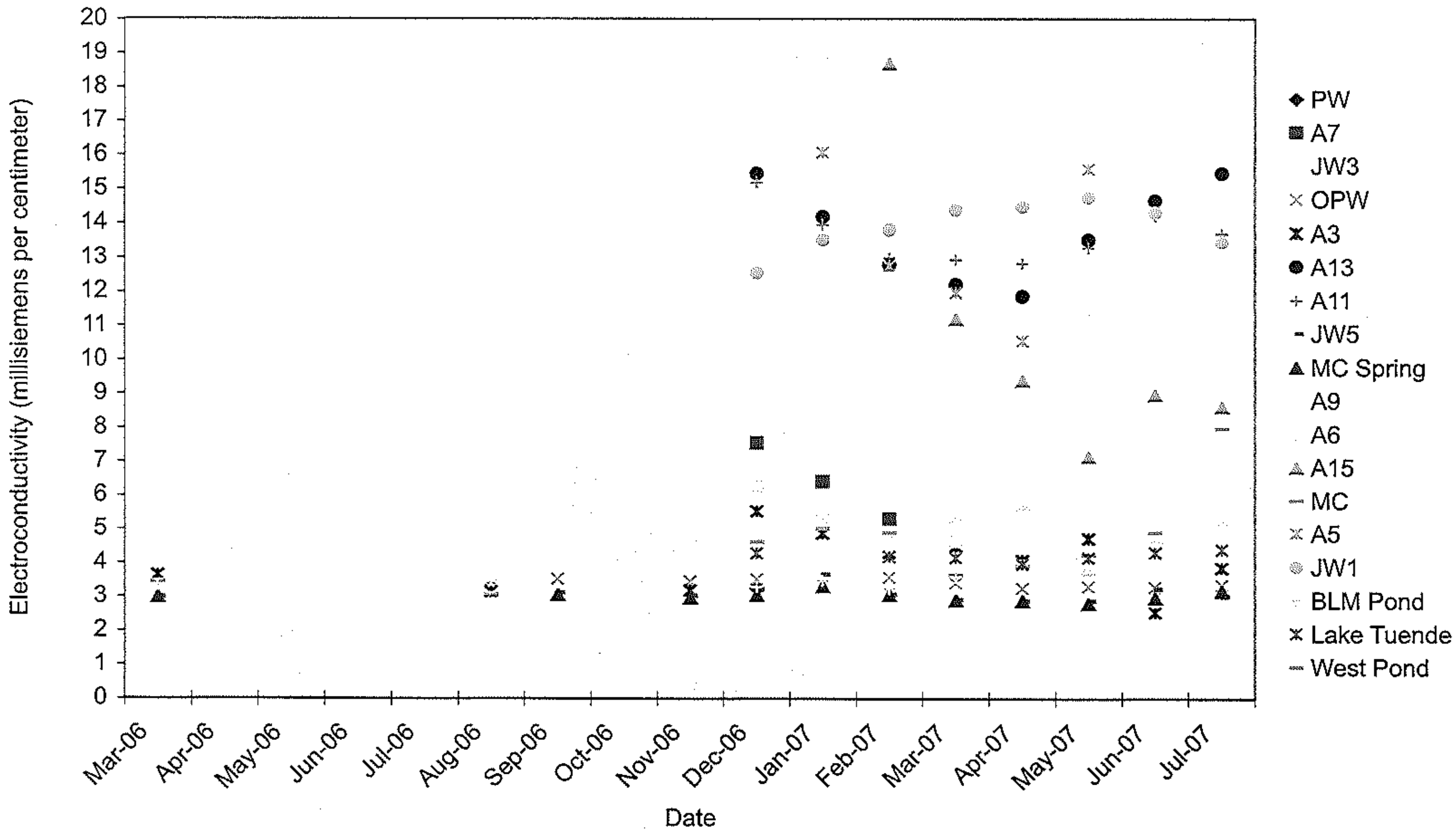


Figure 12. Electroconductivity Fluctuations in Monitoring Wells and MC Spring from March 2006 through July 2007. Values greater than 4 millisiemens per centimeter (mS/cm) through November 2006 and greater than 20 mS/cm beginning December 2006, were beyond the range of the meter and are not included. Wells A1 and A4 had values greater than 20 mS/cm throughout the study period, and are not included.

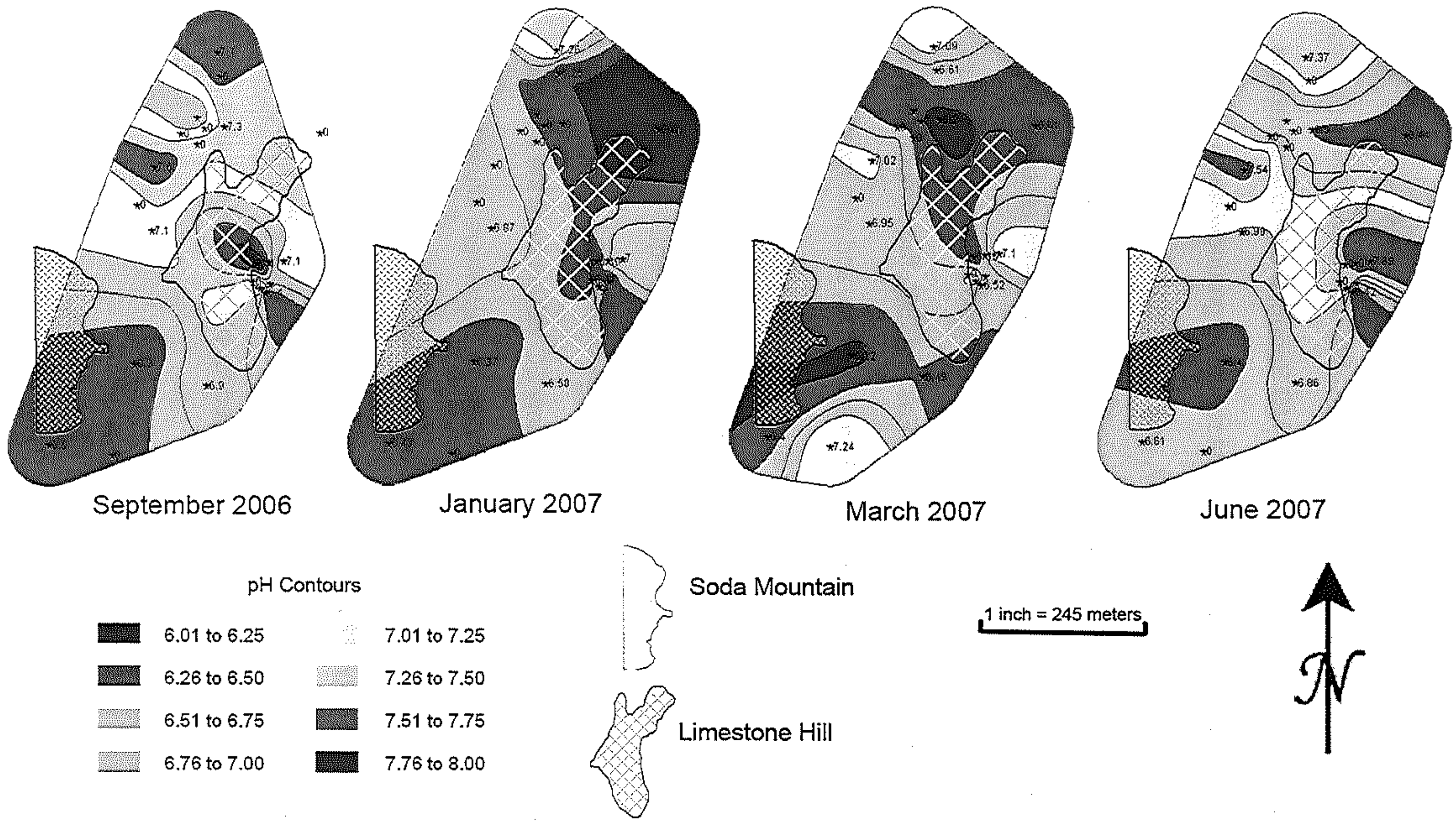


Figure 14. Seasonal Variations in pH. pH of groundwater collected from monitoring wells and surface water in MC Spring. Wells with a pH of zero (0) in this figure were dry at the time of collection, and were not used to determine the contours.

In June 2006, the elevation of the surface of BLM Pond was 282.47 m (926.75 ft) above mean sea level (Figures 9 and 10). Between April and July 2007, BLM Pond became nearly dry. When measured, BLM Pond had among the lowest temperature of all the recorded temperatures (Figure 11); the level in BLM pond was quite low from April to July 2007 and the water was not measured. The EC at BLM pond was slightly higher than that of MC Spring in each monthly measurement collected for both surface water bodies (Figure 12), but lower than wells on or near the playa. The pH at BLM pond measured lower than MC Spring in each month that parameters were recorded (Figure 14).

In April and August 2007, Iron Spring (refer to Figure 3) was a very shallow pool and was nearly hidden in *Typha* (cattails), *Phragmites* (reed grass), and deciduous *Tamarix* (Salt Cedar) trees. Water quality parameters were measured in April 2007. Temperature was 29.7 °C (85.5 °F), EC was 4.95 mS/cm, and pH was 6.61. South of the spring, the ground has a dark quality and there are remnants of cattails. The past presence of cattails indicates that this area at one time had water at the surface. Currently, groundwater is found in Well A10 at approximately 1.2 to 1.5 m (4 to 5 ft) below ground surface (bgs).

Water quality values were recorded during monthly monitoring at Lake Tuendae, although no set location or depth of sampling was chosen. In general the EC of Lake Tuendae ranged slightly higher than that of the alluvial aquifer wells. As described in Chapter 1, Lake Tuende is fed in part by the playa aquifer, and diluted by pumped alluvial aquifer water. Results recorded by a data logger

Table 2. Summary of Laboratory Ion Results for Samples Analyzed in 1919, 1994, 1998, and 2005

	Ca	K	Mg	Na	Cl	F	NO_3	SO_4
<u>1919</u>								
Well	18	see Na	6.3	(+K) 658	688	-	1.0	316
Spring	16	16	5.0	708	736	-	2.2	321
<u>July 1985</u>								
Supply Well	25	16	7	760	765	-	-	18
MC Spring	14	14	6	640	607	-	-	240
Lake Tuende (1982)	25	21	3.2	776	846	10	-	387
West Pond	10	49	5	2,500	2,414	-	-	1,050
<u>June 1994</u>								
Well PW (1989)	39	11	6	89	-	-	5	397
MC Spring	14	13	5	660	690	8.6	5	320
Lake Tuendae	12	15	4	980	1,100	13	<1	450
West Pond	20	72	9	4,200	4,600	51	3	2,000
<u>May 1998</u>								
PW	2.7	11.6	8.1	700	732	8.94	7.1	321

<u>March 2005</u>	Br	Cl	F	NO_2	NO_3	PO_4	SO_4
Well PW	0.7	798.7	9.2	0.8	6.6	0.2	348.5
Well A7	3.1	4,059.7	18.0	3.4	22.9	1.9	2,043.7
Well JW3	1.1	1,348.2	13.2	0.9	2.9	0.4	516.7
Well JW2	2.4	3,013.9	11.7	2.7	0.4	1.4	1,184.8
Well A3	1.3	1,486.5	13.1	1.3	0.0	0.4	701.0
Well A12	1.0	1,315.9	9.0	0.9	26.2	0.4	582.7
MC Spring	0.7	676.6	8.8	0.9	5.5	0.4	308.4
Well A6	1.1	1,339.5	20.5	0.9	0.1	1.1	615.4
Well A15	2.8	3,419.7	17.1	2.0	0.4	4.9	1,596.0
Well MC	0.9	1,061.5	12.0	0.6	0.6	0.5	528.3
Well A5	5.9	7,299.7	10.5	2.3	0.5	6.1	3,865.4
Well A4	13.9	16,742.2	26.6	1.0	8.3	11.5	9,685.3
Well A10	9.4	11,646.6	10.0	0.5	0.8	5.4	4,433.1
Well JW1	10.9	14,170.7	5.9	1.0	1.0	6.1	8,656.2
Well A2	16.0	18,413.5	38.1	1.0	39.8	7.2	6,371.8

Notes:
All results reported in milligrams per liter (mg/L) or the equivalent parts per million (ppm).

Sources:
Thompson 1929 (1919 data)
Bilhorn and Feldmeth 1985 (1985 data)
Archbold 1994 (1994 data)
Mr. Rob Fulton (1998 data)
Dr. Barry Hibbs (2005 data)

(Figure 15). Wells A5 and A10 had lower anion content. Lower still was the anion content of Wells A7, A15, and JW2 (this well was dry during the entire monthly monitoring period). The lowest anion content was found in MC Spring and in Wells A3, A6, A12, JW3, PW, and MC.

Pumping in the Alluvial Aquifer

Well PW is used to provide the center with its water needs. Pumping was monitored from September 2006 through August 2007 (Appendix C). In that time, a total of 10.6 million gal were pumped from the alluvial aquifer. Of this volume, Lake Tuendae received 9.27 million gal; 1.17 million gal were pumped to the reservoir for use in the Studies Center kitchen and bath facilities; and 0.13 million gal were pumped into the pool for use by personnel and visitors during the summer months (the pool received water only during September 2006 and April through August 2007).

Evapotranspiration

Water loss to the atmosphere due to evapotranspiration is a major factor in a desert water budget. The total average annual evapotranspiration reported by CIMIS (2007) is 1.69 m (66.5 in) per year. However, because Zxyzx is a closed system, a more representative rate was calculated based on pumping data recorded at the Studies Center. The calculated evapotranspiration of the 2-acre Lake Tuendae watershed (the lake plus the area of vegetation to the north), based on 9.27 million gal required to maintain the water level in the lake, is 4.34 m (14.25 ft) per year.

Lake Tuendae

Lake Tuendae receives aquifer water to maintain its depth, temperature, and quality so the water remains habitable by the Mohave tui chub. More water was pumped into the Lake during the months in which elevated temperatures cause greater evaporation (September, May, June, July, and August); over a million gallons were added to Lake Tuendae during each of those months (Appendix C). In the same months, the amount of water added to the reservoir was also increased in response to variations in the domestic needs of the Desert Studies Center.

Source for MC Spring

As presented in Chapter 1, two distinct aquifer systems underlie the Zzyzx and Soda Lake area. Besides location, distinct groundwater elevations (Figures 9 and 10), groundwater quality (Figures 12 and 13), and anion chemistry (Figure 15) are most useful in illustrating the differences between the two aquifers. The groundwater elevation, quality, and anion chemistry of MC Spring are more similar to the alluvial aquifer wells than to the playa aquifer wells. These comparisons indicate that although MC Spring is located very close to the edge of the Soda Lake playa, the spring is fed by the alluvial aquifer, not by the playa aquifer.

Recharge Rate

Recharge would be best understood by monitoring water levels for tens of years in this area of highly variable annual precipitation. The recharge rate is

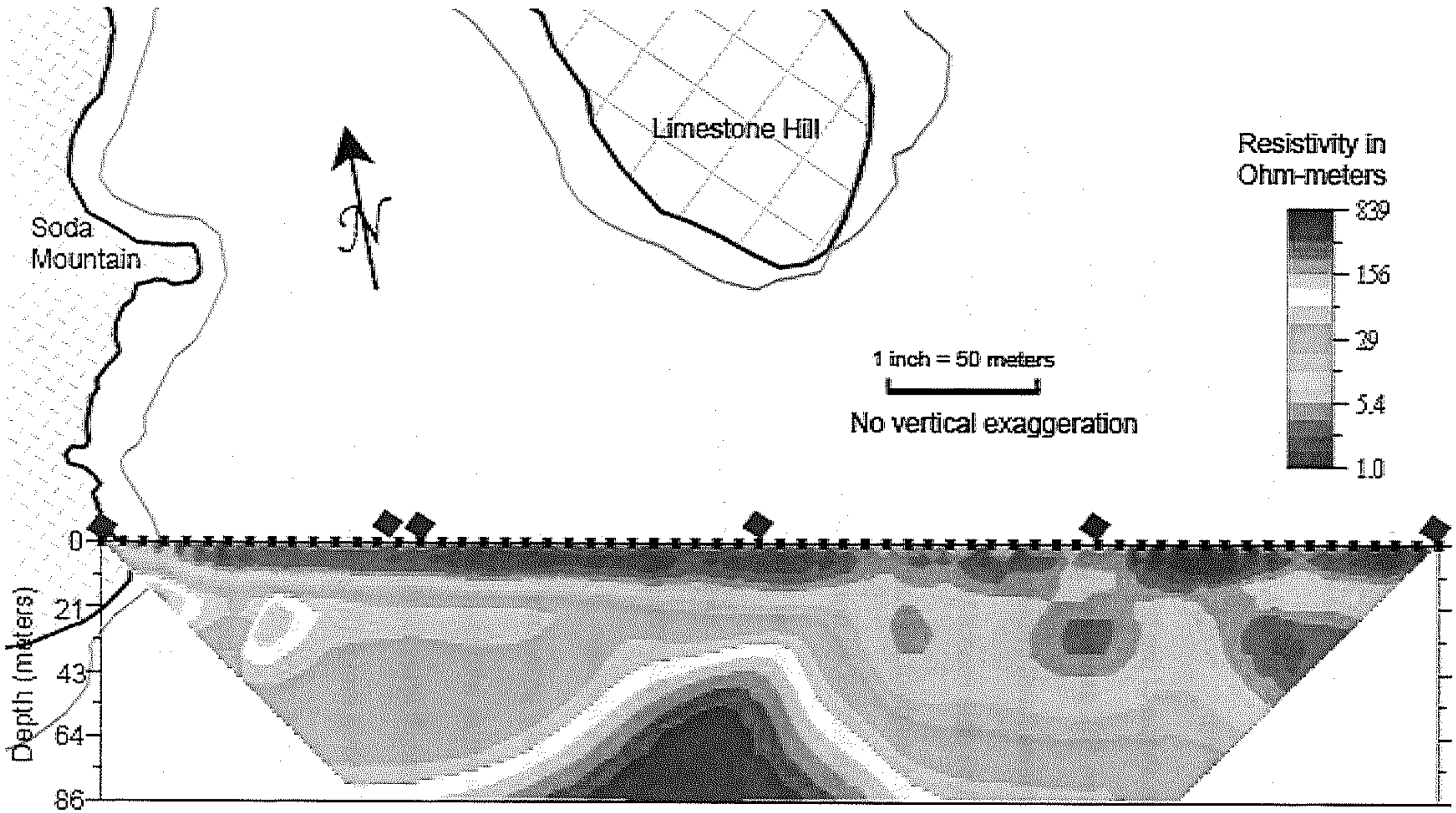


Figure 16. Resistivity South of Limestone Hill. Darker blue areas indicate low resistivity, interpreted as moist to wet sediments. Darker red areas indicate high resistivity, interpreted as dry, slightly fractured rock.

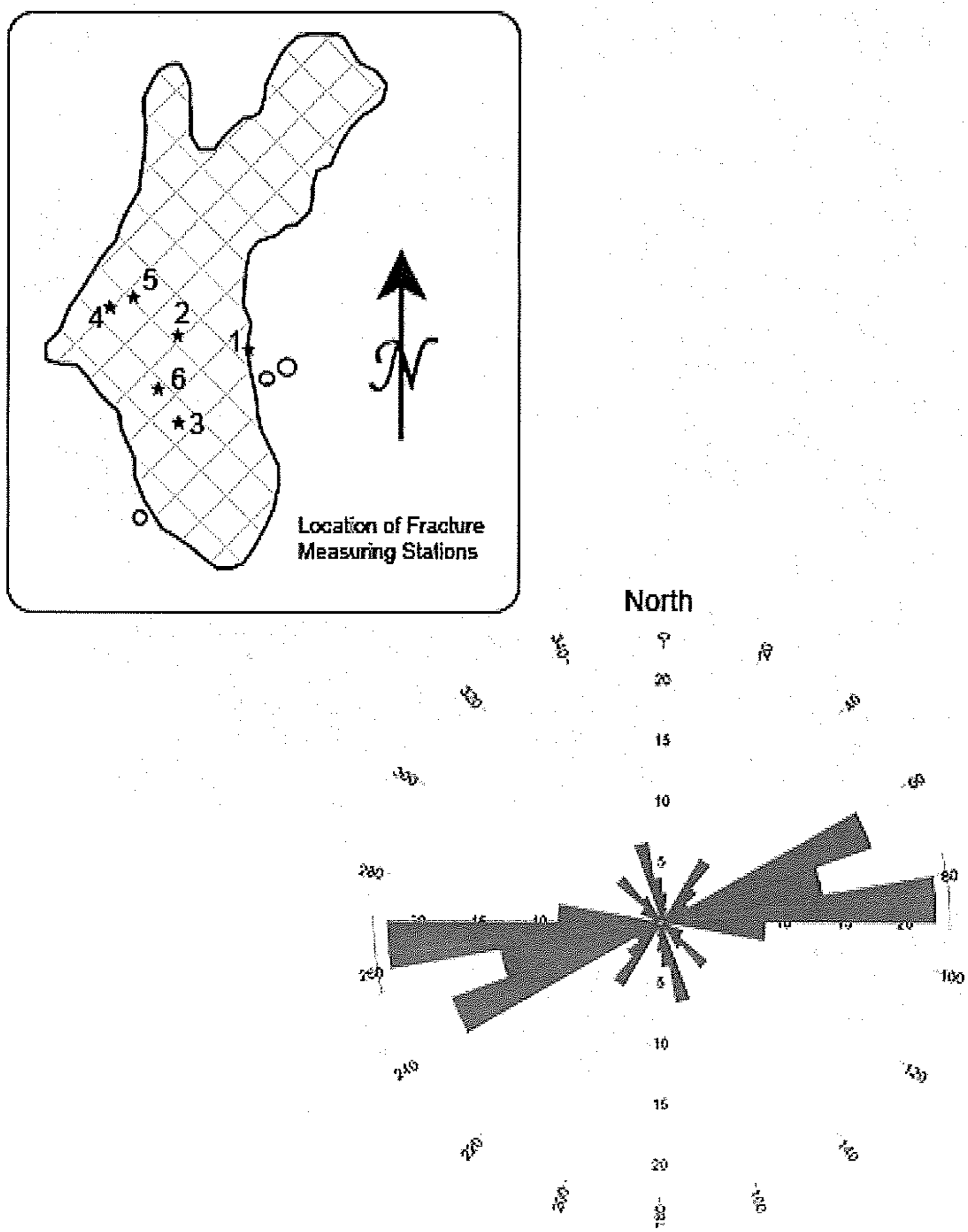


Figure 17. Fracture System in Limestone Hill. This rose diagram shows the dominant fracture direction in Limestone Hill.

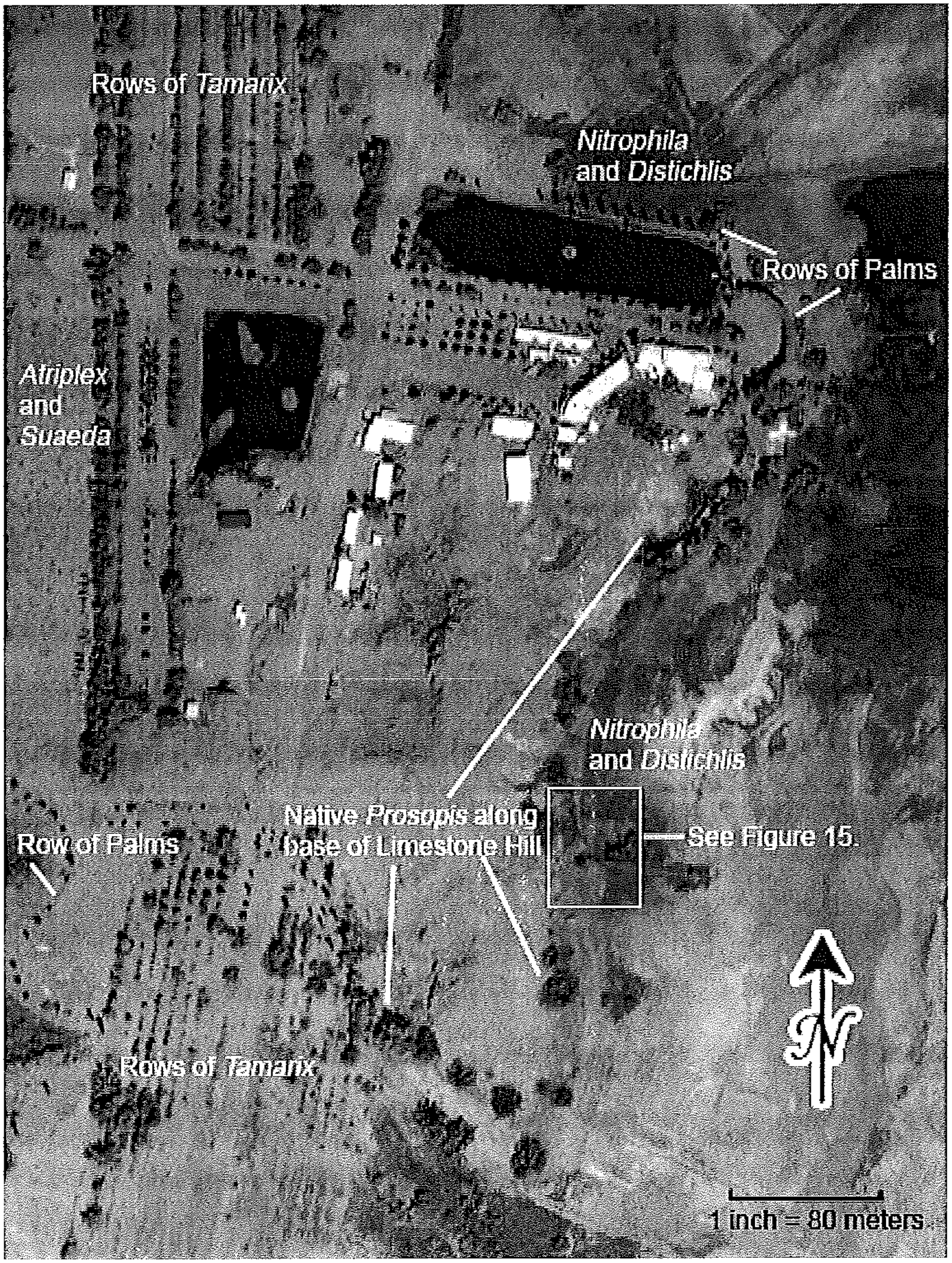


Figure 19. Vegetation at Zzyzx Desert Studies Center. Palm and *Tamarix* are introduced trees. *Nitrophila* and *Distichles* indicate water within 2.5 meters of the ground surface. *Proposis* do not tolerate water of poor quality.

surface (Meinzer 1927). *Anemopsis* is prominent on the eastern side of Limestone Hill between the hill and Soda Lake playa. A few *Anemopsis* were also found at Iron Spring and along the north shore of Lake Tuendae. *Distichlis* (saltgrass) can tolerate fresh or alkaline conditions, and can reach groundwater as far as 2.5 m (8 ft) below the ground surface (Meinzer 1927). *Nitrophila* (Nitrophilia) is commonly associated with *Distichlis* (Meinzer 1927). These two halophytic species are wide-spread throughout Zzyzx, extending from near the surface water locations outward toward the playa. *Atriplex* (salt bush) and *Suaeda* (iodine bush) tolerate alkaline conditions, and generally depend on soil moisture at or near the surface rather than on groundwater (Meinzer 1927). *Suaeda* and two species of *Atriplex* (desert holly and cattle spinach) are common in the alluvial deposits east of the Soda Mountains and west of Limestone Hill, and on Limestone Hill. Two species of *Tamarix* (deciduous Salt Cedar and evergreen Tamarisk, an introduced tree commonly planted as a windbreak or ornamentally) and *Phoenix* and *Washingtonia* Palm trees (also introduced at Zzyzx) are also halophytic and have widespread, shallow root systems that reach downward to the capillary zone above the water table (Meinzer 1927). Rows of *Tamarix* and Palms were planted by Curtis Springer throughout Zzyzx as nursery stock. Most of these trees thrive at Zzyzx. Native *Prosopis* (Mesquite) trees, as well as the introduced *Tamarix*, are also known to send a taproot as deep as 15 m (50 ft) below the ground surface in search of groundwater. *Prosopis* is not tolerant of poor water quality (Meinzer 1927).

Table 3. Summary of Average Hydraulic Conditions at Zzyzx

Aquifer Test Date	pump rate (gpm)	t (minutes)	K (gpd/ft^2)	T (gpd/ft)	S (no units)	Q (gpd)	r_0 (meters)
January 1985[a]	218	1,000	-	1.00E+05	1.30E-01	-	10
November 1993[b]	148	1,000	6.87E+03	3.94E+05	5.50E-03	-	101
April 1995[c]	142	245	-	4.01E+05	3.74E-03	-	61
April 1995[d]	142	240	-	4.74E+05	4.10E-03	3.08E+06	63
November 1996[e]	150	1,200	-	4.98E+05	3.06E+00	5.07E+05	5

Notes:

Values for t, K, T, S, and Q reported by cited authors; r_0 calculated

[a] Bilhorn and Feldmeth 1985; test was performed on OPW. Time of pumping was assumed, not reported.

[b] Archbold 1994

[c] Brown 1995

[d] Dirling 1995

[e] Gardiner 1996

ft foot
ft^2 square foot
gpd gallons per day
gpm gallons per minute
K hydraulic conductivity

Q discharge
r_0 estimated radius of influence
S Storativity
t time
T Transmissivity

seepage. The calculated evapotranspiration of the 2-acre Lake Tuendae watershed is 4.34 m (14.25 ft) per year as described above. Consumption was determined by the amount of water that was pumped into the reservoir for drinking, washing, and other uses at the Studies Center, and into the pool during the hot seasons (Appendix C). Groundwater elevations recorded between 1985 and 2007 show that the water table elevation in Zzyzx monitoring wells has not changed measurably; therefore, the long-term change in storage is negligible.

The steady water surface in the MC Spring indicates there is no overall change in storage in the spring. Therefore, the evapotranspiration (outflow) from the 0.4-acre MC Spring watershed is balanced by the inflow from precipitation and recharge through Limestone Hill.

Hydrogeologic Model

The hydrogeologic model (Figure 21) was prepared with information from synthesis of reference materials along with field observations, including water table elevations and water quality, of monitoring wells at Zzyzx and at MC Spring and Lake Tuendae. The model shows fractures in Limestone Hill consistent with a through-going providing a reasonable pathway for groundwater to recharge MC Spring from the alluvial aquifer west of Limestone Hill.

CHAPTER 5

CONCLUSIONS AND LONG-TERM STUDIES

Conclusions

MC Spring is recharged from the alluvial aquifer west of Limestone Hill, rather than from the playa aquifer. Fractures in Limestone Hill provide a possible mechanism for groundwater in the alluvial aquifer to recharge MC Spring.

The elevation of the water table, determined by field monitoring and the GPS survey, is 1 to 2 m (3 to 6 ft) higher in the alluvial aquifer and in MC Spring than the water table elevation in the playa aquifer.

Lake Tuendae is cut into the playa aquifer and the elevation of water in is maintained by pumping groundwater from the alluvial aquifer (using Well PW) into the lake. West Pond, which is cut into alluvial deposits, is located close to Well PW, yet is not affected (lowered) by pumping from the alluvial aquifer.

Chemical laboratory results and EC measurements imply that the water in MC Spring is very similar chemically to the alluvial aquifer, not to the playa aquifer. The playa aquifer groundwater contains very high concentrations of Cl, SO_4, and other anions. By contrast groundwater in the alluvial aquifer has lower overall concentrations and has a relatively greater concentration of F than the

Recommended Future Studies

A resistivity survey between the southern extent of Soda Mountain and Limestone Hill is recommended to further characterize the relationships between the alluvial aquifer, Soda Mountain, and Limestone Hill. Surveys are also recommended across Limestone Hill in both directions to further study the fractures in Limestone Hill and its subsurface extent.

This study was performed in an extremely dry year at Zzyzx. In order for a valuable study to be carried out, long-term monitoring is necessary, to compare rainfall and water levels on a scale of decades rather than months. The analysis included in this report can be used as a baseline for long-term monitoring of the groundwater and surface water conditions at Zzyzx.

A limited understanding of subsurface geology was gained by the logs of the hand-augered boreholes. Piezometers should be installed in areas where there are gaps in the groundwater and geology data. These should be advanced with drill rigs, rather than by hand-auger, to prevent shallow refusal. Accurate geological logging during drilling of the boreholes would provide a better knowledge of the subsurface geology, and may help determine the subsurface extent of Limestone Hill.

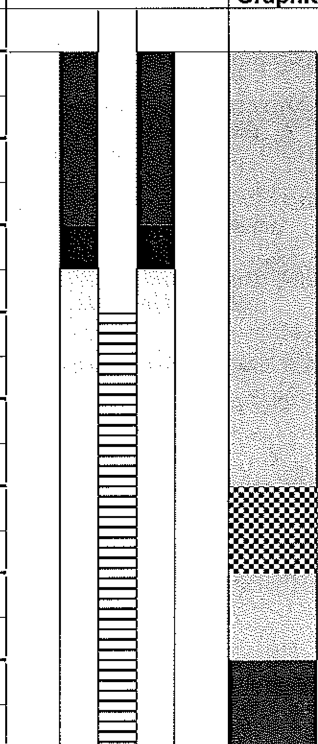
The surface water analysis provides baseline data that can be useful for the preservation and management, and possible expansion, of the habitat of the Mohave tui chub.

APPENDIX A

BOREHOLE LOGS

BOREHOLE/WELL CONSTRUCTION LOG

Project Name: Soda Springs Desert Studies Center		**Borehole Number:**	A1
Borehole Location: Wellfield between Lake Tuende and LS Hill		**Total Depth (bgs):**	8.0 feet
Drilling Agency: CSUF	**Driller:**	**Depth to Bedrock:**	8.0 feet
Drilling Equipment Hand Auger	**Date Started:** 10/16/96	**Depth to Water**	
Drilling Method: Hand Auger	**Date Finished:** 10/16/96	**(Drilling):**	3.92 feet
Drilling Fluid: None	**Number of Samples:**	**(Static):**	feet
Completion Information:	**Borehole Diameter:** 3.5 inches	**Elevation TOC:**	936.13 feet
Completed as a 2" monitoring well	**Logged By:**	**Datum:** msl	
Northing: 2242653	**Easting:** 7128321.36	**Stickup (feet):**	

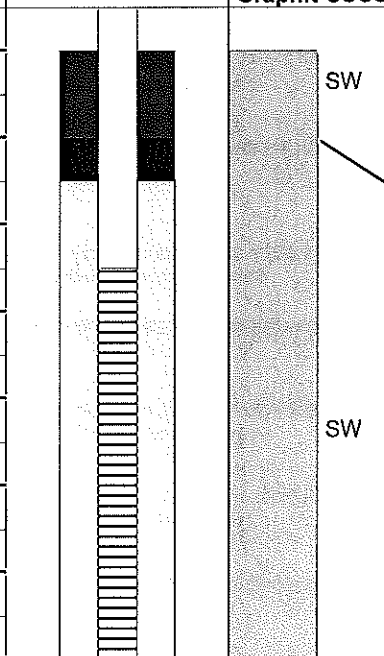


Depth (feet)	Well Design	Log Graphic	USCS	Lithologic Description
0.0				**Round concrete pad installed at surface**
0.5			GW	SANDY GRAVEL; gray brown; subangular to subroun gravel in carbonate-rich matrix; poorly sorted
1.0				
1.5				larger subrounded gravel clsts in limestone-rich matrix
2.0				
2.5				
3.0				
3.5				
4.0				
4.5				
5.0				
5.5			SW	PEBBLY SAND; gray brown; poorly-sorted subangula limestone-rich clasts
6.0				
6.5			GW	SANDY GRAVEL; gray brown; subangular to subroun limestone rich gravel; poorly-sorted
7.0				
7.5			SW	SAND; limestone-rich; coarse; subrounded; moderatel sorted
8.0				
8.5				Total Depth 8.0 feet
9.0				
9.5				
10.0				

Native Backfill
Bentonite Grout
Monterey #3 Sand

BOREHOLE/WELL CONSTRUCTION LOG

Project Name:	Soda Springs Desert Studies Center			**Borehole Number:**	A8
Borehole Location:	wellfield between Lake Tuende and LS Hill			**Total Depth (bgs):**	7.0 feet
Drilling Agency:	CSUF	**Driller:**		**Depth to Bedrock:**	feet
Drilling Equipment	Hand Auger	**Date Started:**	10/16/96	**Depth to Water**	
Drilling Method:	Hand Auger	**Date Finished:**	10/16/96	**(Drilling):**	4.78 feet
Drilling Fluid:	None	**Number of Sample**	5	**(Static):**	feet
Completion Information:		**Borehole Diameter:**	3.5 inches	**Elevation TOC:**	936.99 feet
Completed as a 2" monitoring well		**Logged By:**	Jan and Angie	**Datum:**	**msl**
Northing:	2242651.14	**Easting:**	7128205.54	**Stickup (feet):**	

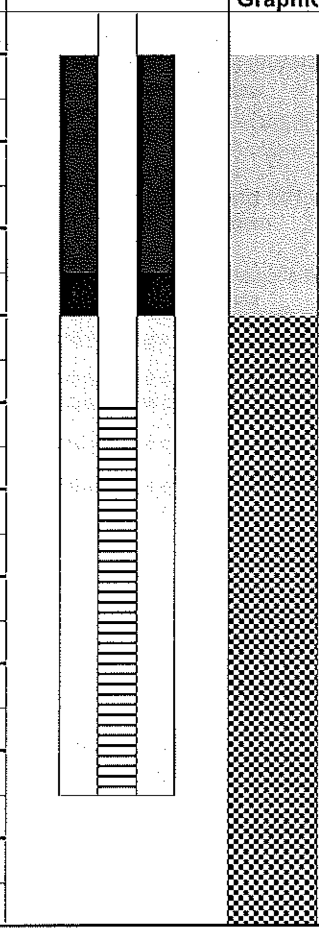


Depth (feet)	Log USCS	Lithologic Description
0.0		**Round concrete pad installed at surface**
0.5	SW	GRAVELLY SILTY SAND; tan; poorly sorted; subangu subrounded, silt to coarse pebble, limestone an fragment clasts; dry; immature texture; pl salty taste; some caliche
1.0		
1.5		at 1' color change to greenish gray
2.0		
2.5		
3.0		
3.5		very fine to coarse pebble size mafic, igneous, sedime fragments
4.0		
4.5	SW	GRAVELLY SAND; tan gray; subangular to subrounde fine sand to coarse pebble; quartz, biotite, lithic dry
5.0		
5.5		
6.0		
6.5		
7.0		
7.5		Total Depth 7.0 feet
8.0		
8.5		
9.0		
9.5		
10.0		

Native Backfill
Bentonite Grout
Monterey #3 Sand

BOREHOLE/WELL CONSTRUCTION LOG

Project Name: Soda Springs Desert Studies Center		**Borehole Number:**	A12
Borehole Location: in caretakers yard		**Total Depth (bgs):**	10.0 feet
Drilling Agency: CSUF	**Driller:**	**Depth to Bedrock:**	feet
Drilling Equipment Hand Auger	**Date Started:** 10/16/96	**Depth to Water**	
Drilling Method: Hand Auger	**Date Finished:** 10/16/96	**(Drilling):**	~7 feet
Drilling Fluid: None	**Number of Samples:**	**(Static):**	feet
Completion Information:	**Borehole Diameter:** 3.5 inches	**Elevation TOC:**	938.03 feet
Completed as a 2" monitoring well	**Logged By:**	**Datum:** msl	
Northing: 2242720.48	**Easting:** 7128258.04	**Stickup (feet):**	

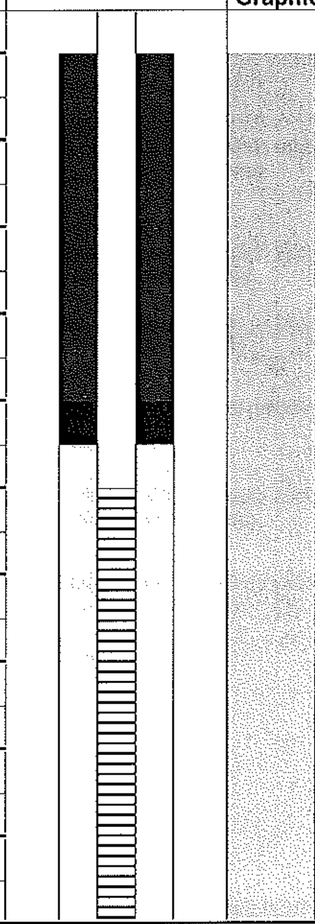


Depth (feet)	Log Graphic USCS	Lithologic Description
0.0		**Round concrete pad installed at surface**
0.5	SM	Dry top soil
1.0		
1.5		SILTY SAND; dark tan; very fine sand to fine pebbles; quartz and dark granite, 5% unconsolidated part sorted; angular
2.0		
2.5		color change to tan; grading to very fine sand to mediu pebbles; chert, quartz, epidote; grading to subro
3.0		
3.5	SW	GRAVELLY SAND; coarse sand to coarse gravel; chlo inclusions in epidote, quartz; poorly sorted; very rounded
4.0		
4.5	SP	SAND; tan; quartz, plagioclase; well sorted; very well rounded
5.0		
5.5	SW	GRAVELLY SAND; coarse sand to fine cobble; chlorit inclusions in epidote, quartz; poorly sorted; angu rounded
6.0		
6.5		
7.0		
7.5		grading to slightly moist
8.0		
8.5		grading to medium sand to medium pebbles; rading to slightly moist
9.0		
9.5		
10.0		Total Depth 10.0 feet

Native Backfill
Bentonite Grout
Monterey #3 Sand

BOREHOLE/WELL CONSTRUCTION LOG

Project Name: Soda Springs Desert Studies Center		**Borehole Number:** JW3
Borehole Location: near diesel storage tank		**Total Depth (bgs):** 10.0 feet
Drilling Agency: CSUF	**Driller:**	**Depth to Bedrock:** feet
Drilling Equipment Hand Auger	**Date Started:** 10/21/96	**Depth to Water**
Drilling Method: Hand Auger	**Date Finished:** 10/21/96	**(Drilling):** 8.2 feet
Drilling Fluid: None	**Number of Samples:**	**(Static):** feet
Completion Information:	**Borehole Diameter:** 3.5 inches	**Elevation TOC:** 941.15 feet
Completed as a 2" monitoring well	**Logged By:**	**Datum:** msl
Northing: 2243075.04	**Easting:** 7128562.2	**Stickup (feet):**

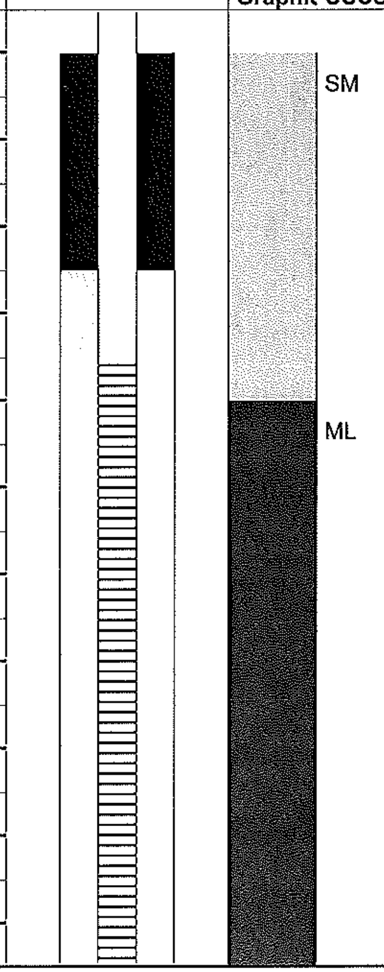


Depth (feet)	Well Design / Log Graphic	USCS	Lithologic Description
0.0			**Round concrete pad installed at surface**
0.5		SM	SILTY SAND; tan; grey quartz, limestone, basalt, cher pebbles; moderalely sorted; angular
1.0			
1.5			grading to poorly sorted; 90% sand; 10% fine to mediu pebbles
2.0			
2.5		GW	SILTY GRAVEL: tan; siltstone, limestone, epidote, qua anbular siltstone pebbles; rounded epidote pebl sorted
3.0			
3.5		SM	SILTY SAND; dark tan; quartz; well sorted; well round moist
4.0			
4.5			grading to poorly sorted; grading to angular; grading v volcanics; 15% pebbles
5.0			
5.5		GW	SANDY GRAVEL; grey-tan; limestone and quartz pebl and cobbles; poorly sorted; angular; dry
6.0			
6.5			grading without cobbles
7.0			
7.5			color change to greenish grey; caliche siltstone cobble pebbles; angular quartz sand; silt
8.0			
8.5			color change to grey
9.0			
9.5			
10.0			Total Depth 10.0 feet

Native Backfill
Bentonite Grout
Monterey #3 Sand

BOREHOLE/WELL CONSTRUCTION LOG

Project Name:	Soda Springs Desert Studies Center			**Borehole Number:**	MC
Borehole Location:	adjacent to MC Spring			**Total Depth (bgs):**	10.5 feet
Drilling Agency:	CSUF	**Driller:**		**Depth to Bedrock:**	feet
Drilling Equipment	Hand Auger	**Date Started:**	11/9/96	**Depth to Water**	
Drilling Method:	Hand Auger	**Date Finished:**	11/9/96	**(Drilling):**	feet
Drilling Fluid:	None	**Number of Samples:**		**(Static):**	feet
Completion Information:		**Borehole Diameter:**	3.5 inches	**Elevation TOC:**	933.01 feet
Completed as a 2" monitoring well		**Logged By:**		**Datum:**	**msl**
Northing:	2242902.56	**Easting:**	7128564.04	**Stickup (feet):**	

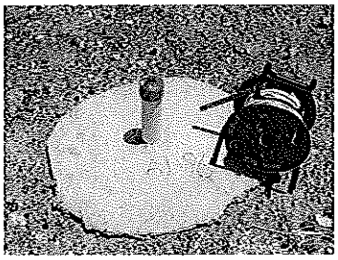


Depth (feet)	Well Design	Log Graphic	USCS	Lithologic Description
0.0				**Round concrete pad installed at surface** SILTY SAND; dark brown (10YR 3.3); well sorted; dry
0.5			SM	
1.0				
1.5				
2.0				
2.5				
3.0				
3.5				color change to dark brown (10YR 3/2); very fine sand moist; plant fragments
4.0				
4.5			ML	SANDY SILT; very dark brown (7.5YR 2.5/3), mottled (4/4); quartz sand; wet; plant roots
5.0				
5.5				color change to brown (10YR 4/3)
6.0				
6.5				
7.0				
7.5				
8.0				
8.5				Noted as rock deposit from 8.5' to total depth. Limest noted at 10.5'
9.0				
9.5				
10.0				at 9.5' color change to mottled green; sulfur smell
10.5				Total Depth 10.5 feet

Native Backfill
Bentonite Grout
Monterey #3 Sand

APPENDIX B

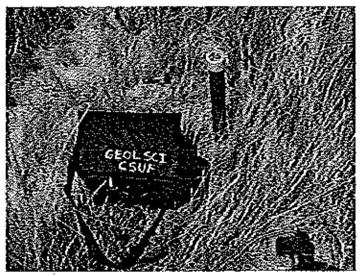
PHOTOGRAPHS OF GROUNDWATER MONITORING WELLS


Well A1


Well A2


Well A3


Well A4



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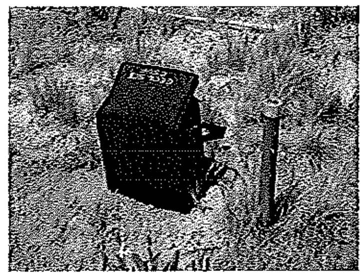
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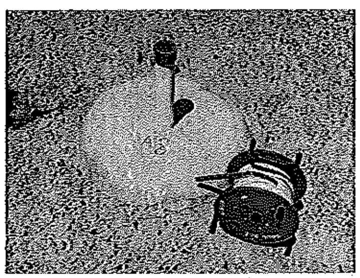
Well A7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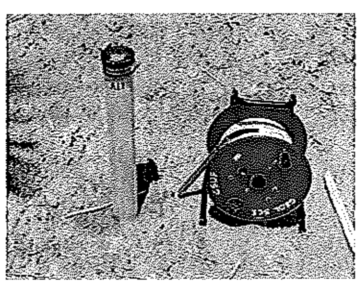
Well A9


Well A10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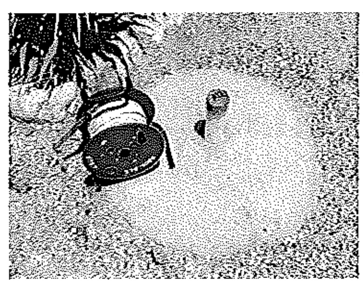

Well A12

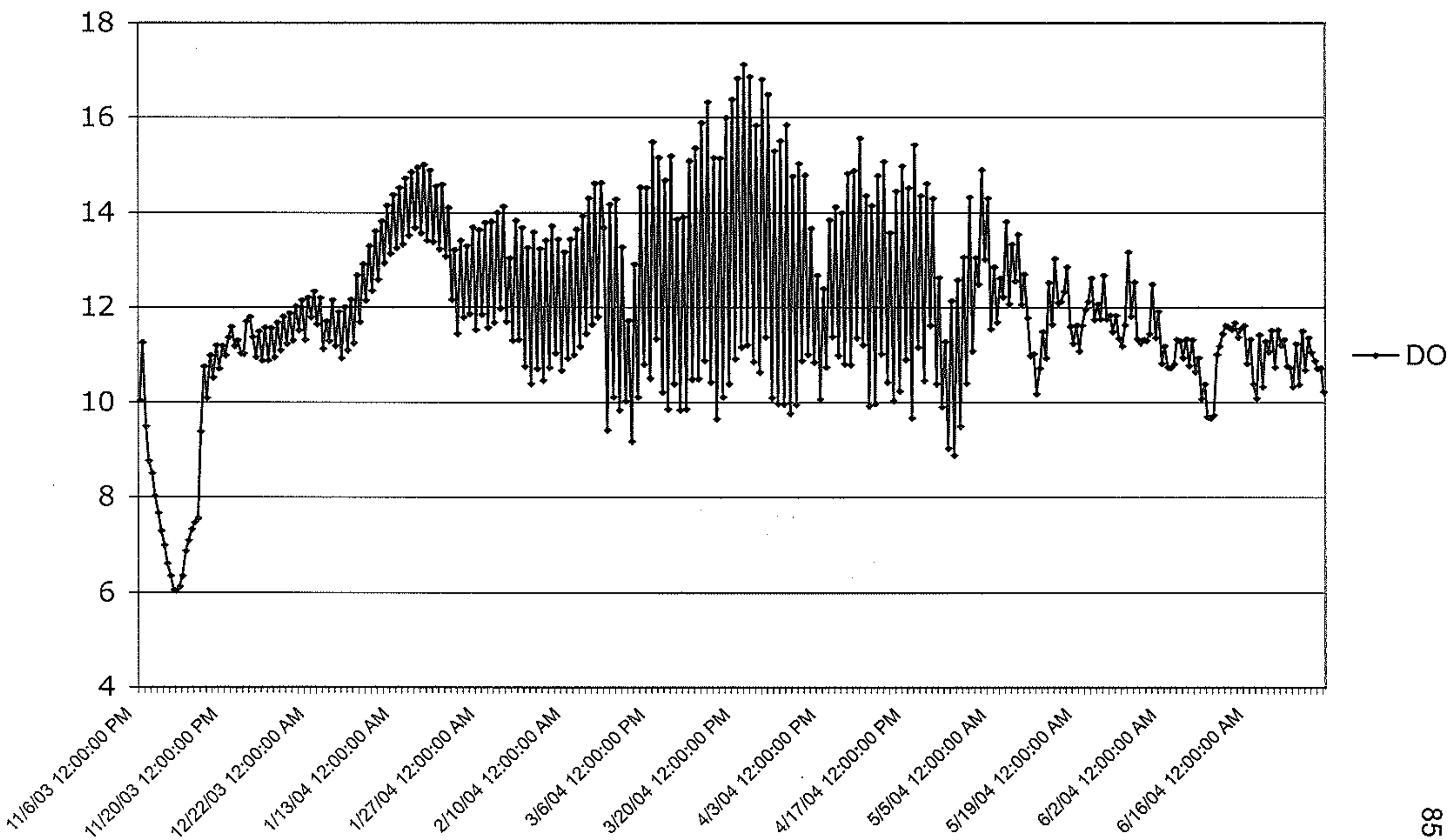
APPENDIX C

EVAPORATION PAN, DATA LOGGER, AND WELL PRODUCTION RECORDS

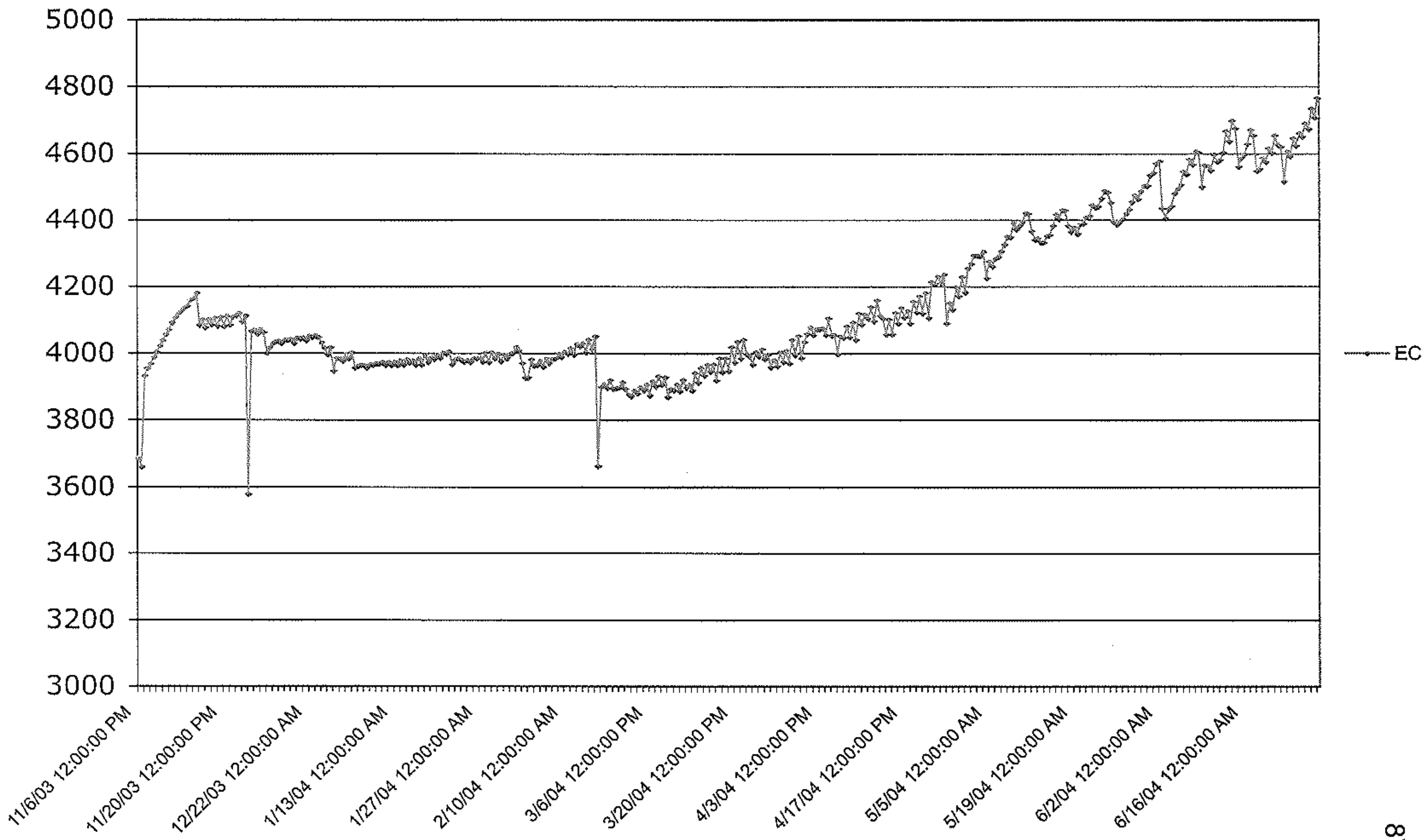
EVAPORATION PAN DATA 1997-1998

INTERVAL	LEVEL DROP (mm)	RAIN (mm)	NET LOSS (mm)	24 HOUR MEAN (mm)
5/27 - 6/3	83	0	83	11.8
6/3 - 6/10	67	2	69	9.8
6/10 - 6/17	63	2	65	9.3
6/17 - 6/24	93	0	93	13.3
6/24 - 7/1	87	0	87	12.4
7/1 - 7/8	87	0	87	12.4
7/8 - 7/15	90	1	91	13
7/15 - 7/22	83	1	84	12
7/22 - 7/29	73	3	76	10.8
7/29 - 8/5	77	1	78	11.1
8/5 - 8/12	80	0	80	11.4
8/12 - 8/20	95	0	95	11.9
8/20 - 8/26	90	0	90	15
8/26 - 9/3	87	1	88	11
9/3 - 9/9	32	16	48	8
9/9 - 9/16	59	4	63	9
9/16 - 9/23	51	0	51	7.3
9/23 - 9/30	15	17	32	4.6
9/30 - 10/14	81	1	82	5.9
10/14 - 10/21	36	0	36	5.1
10/21 - 11/4	61	0	61	4.4
11/4 - 11/18	51	1	52	3.7
11/18 - 12/2	34	0	34	2.4
12/2 - 12/23	46	1.5	47.5	2.3
12/23 - 1/13	33	2	35	1.7
1/13 - 1/27	28	0	28	2
1/27 - 2/3	13	0	13	1.9
2/3 - 3/30	87	51	138	2.5
3/30 - 4/13	77	0.5	77.5	5.5
4/13 - 4/20	41	0	41	5.8
4/20 - 5/4	104	0	104	7.4
5/4 – 5/12	43	0	43	5.4
5/12 – 5/19	45	0	45	6.4
5/19 – 5/26	52	0	52	7.4
1997-98 Total	2144	103	2247	6.2

DO of Lake Tuendae



EC of Lake Tuendae



Well Production September 2006 to August 2007

MONTH/YEAR	RESERVOIR GALLONS	POOL GALLONS	LAKE TUENDAE GALLONS	TOTAL GALLONS	TOTAL ACRE-FEET
Sep-06	135,000	4,400	1,095,900	1,235,300	3.790
Oct-06	60,000	0	559,727	619,727	1.901
Nov-06	82,500	0	391,950	474,450	1.456
Dec-06	30,000	0	263,250	293,250	0.900
Jan-07	37,500	0	627,900	665,400	2.042
Feb-07	45,000	0	374,400	419,400	1.287
Mar-07	97,500	0	645,450	742,950	2.280
Apr-07	52,500	6,600	883,350	942,450	2.892
May-07	210,000	44,000	1,021,020	1,275,020	3.912
Jun-07	105,000	11,000	1,112,670	1,228,670	3.770
Jul-07	180,000	35,200	1,171,170	1,386,370	4.254
Aug-07	135,000	26,400	1,127,880	1,289,280	3.956
Total Gallons	1,170,000	127,600	9,274,667	10,572,267	
					32.438
Total Acre-feet	3.590	0.392	28.457	32.438	

325,920 conversion factor gallons to acre-feet

APPENDIX D

FIELD MONITORING RECORDS

FIELD MEASUREMENTS 1996

Well or Location	TD TOC	Mar-06 WL TOC	Temp °F	°C	pH	EC µS/cm	TDS ppm	Jun-06 WL TOC	Stick Up
A1	3.74	dry	dry		dry	dry	dry	dry	0.64
A10	9.94	4.37	61	16.1	6.37	>4,000	>2,000	5.16	0.90
A11	10.58	4.96	60.3	15.7	6.24	>4,000	>2,000	5.35	1.45
A12	8.46	5.68	62.9	17.2	6.68	3,784	1,879	dry	1.60
A13	9.74	4.66	59.9	15.5	6.37	>4,000	>2,000	4.89	1.67
A15	11.85	6.12	63.3	17.4	5.91	>4,000	>2,000	8.91	0.10
A2	5.72	4.98	59.9	15.5	7.2	>4,000	>2,000	5.52	0.95
A3	6.58	4.08	64.5	18.1	6.36	3,622	1,800	5.39	0.45
A4	13.5	2.67	60	15.6	6.97	>4,000	>2,000	5.47	1.60
A5	8.12	2.73	54.8	12.7	6.21	>4,000	>2,000	6.31	1.60
A6	7.99	4.8	62.1	16.7	6.25	>4,000	>2,000	6.71	1.50
A7	5.32	4.78	61.1	16.2	6.51	>4,000	>2,000	dry	1.55
A8	4.78	dry	dry	dry	dry	dry	dry	dry	2.30
A9	4.73	4.25	55.6	13.1	6.54	>4,000	>2,000	dry	1.23
JW1	11.96	6.38	63.8	17.7	6.19	>4,000	>2,000	7.09	1.50
JW2	3.62	dry	dry	dry	dry	dry	dry	dry	0.84
JW3	10.12	8.19	65.5	18.6	6.64	>4,000	>2,000	8.35	0.22
JW4	6.34	dry	dry	dry	dry	dry	dry	dry	0.10
JW5	17.32	1.03	60	15.6	6.87	2,980	1,490	2.3	1.35
MC	10.48	4.3	60.9	16.1	6.29	3,443	1,717	5.82	1.50
OPW	22							5.49	
PW	52.25							10.08	
Lake Tuende near Well A9			54.1	12.3	7.51	>4,000	>2,000		
Lake Tuende on south side			53.7	12.1	7.61	>4,000	>2,000		
BLM Pond			55	12.8	7	3,315	1,660		
MC Spring			63.6	17.6	7.05	2,995	1,498		
West Pond									
Arrowhead drinking water			59.4	15.2	6.7	468	230		

FIELD MEASUREMENTS 1996

Well or Location	Nov-06 WL TOC	Nov-06 Temp °F	Nov-06 Temp °C	Nov-06 pH	Nov-06 EC µS/cm	Nov-06 TDS ppm	Dec-06 WL TOC	Dec-06 Temp °C	Dec-06 pH	Dec-06 EC mS/cm	Dec-06 TDS ppt	Dec-06 DO mg/L	Dec-06 NO3 mg/L
A1	dry	dry		dry	dry	dry	dry	dry	dry	dry	dry		
A10	5.61	74.9	23.8	7.03	>4,000	>2,000	5.43	22.8	-	>20	>10	3.4	
A11	5.33	76.8	24.9	6.38	>4,000	>2,000	5.21	19.8	-	15.18	7.68		
A12	dry	dry	dry	dry	dry	dry	dry	dry	-	dry	dry		
A13	4.98	79.6	26.4	6.46	>4,000	>2,000	4.87	19.5	-	15.45	7.77	6	
A15	8.01	77.1	25.1	6.15	>4,000	>2,000	6.44	22.3	-	>20	>10		0.5
A2	dry	dry	dry	dry	dry	dry	dry	dry	-	dry	dry		
A3	4.63	78.2	25.7	6.63	3,191	1,597	4.01	23.9	-	5.53	2.84	7.9	
A4	6.13	77.8	25.4	6.86	>4,000	>2,000	5.57	20.3	-	>20	>10	1.4	
A5	dry	dry	dry	dry	dry	dry	4.77	19	-	>20	>10		
A6	5.45	75.2	24.0	5.65	>4,000	>2,000	5.21	20	-	6.27	3.2		
A7	5.3	dry	dry	dry	dry	dry	5.05	21.1	-	7.54	3.83		
A8	dry	dry	dry	dry	dry	dry	muddy	dry	-	dry	dry		
A9	4.53	68.3	20.2	6.26	>4,000	>2,000	4.36	16.4	-	12.07	6.12		
JW1	8.74	77.1	25.1	6.24	>4,000	>2,000	8.22	23.7	-	12.54	6.39		
JW2	dry	dry	dry	dry	dry	dry	dry	dry	-	dry	dry		
JW3	8.62	79.8	26.6	6.71	>4,000	>2,000	8.41	22.9	-	5.16	2.63	5.7	
JW4	dry	dry	dry	dry	dry	dry	dry	dry	-	dry	dry		
JW5	1.34	69.3	20.7	7.18	3,027	1,500	1.2	18.9	-	3.22	1.64		
MC	5.33	71.2	21.8	6.31	>4,000	>2,000	5.44	21.7	-	4.63	2.34		
OPW	5.71	78	25.6	7.11	3,465	1,733	5.4	22.78	7.11	3,520	1,773		
PW							12.85	19.83	7.43	3,253	1,625	4.4	
Lake Tuende near Well A9								14.6	-	4.29	2.19		
Lake Tuende on south side													
BLM Pond								15.4	-	3.29	1.75		
MC Spring		68.4	20.2	6.85	2.988	1,494		20.1	-	3.07	1.57	7.3	
West Pond	44												
Arrowhead drinking water													

FIELD MEASUREMENTS 1997

Well or Location	Mar-07 WL TOC	Temp °C	pH	EC mS/cm	TDS ppt	Apr-07 WL TOC	Temp °C	pH	EC mS/cm	TDS ppt
A1	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
A10	4.47	22.7	6.49	>20	>10	5.03	29.6	6.65	>20	>10
A11	5	23.5	6.2	12.94	6.59	5.22	28.8	6.38	12.82	6.48
A12	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
A13	4.76	24.6	6.3	12.2	6.16	4.99	31.7	6.72	11.87	6.1
A15	5.78	22.2	6.41	11.2	5.73	5.77	23	6.61	9.4	4.75
A2	5.31	23.8	7.24	>20	>10	5.41	33.4	7.43	>20	>10
A3	4.22	24.1	6.4	4.49	2.28	4.95	32	6.53	4.07	2.06
A4	3.13	22.8	7.1	>20	>10	4.02	28.3	7.31	>20	>10
A5	3.09	20.3	6.64	11.96	6.15	4.35	-	6.92	10.54	5.43
A6	5.05	22.6	6.35	4.64	2.37	5.88	29.6	6.33	3.91	1.99
A7	5.02	dry	dry	dry	dry	5.34	dry	dry	dry	dry
A8	4.47	dry	dry	dry	dry	4.94	dry	dry	dry	dry
A9	4.25	24.4	6.61	8.49	4.28	4.34	29.4	6.74	6.82	3.46
JW1	6.56	25.1	6.22	14.38	7.31	6.55	31.2	6.28	14.48	7.47
JW2	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
JW3	8.28	25.1	6.95	5.39	2.77	9.17	33.8	6.88	5.74	2.91
JW4	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
JW5	1.1	24.7	7.09	2.92	1.48	1.29	28.9	7.21	2.88	1.46
MC	4.55	22.2	6.52	3.65	1.86	5.56	28.6	6.59	3.92	1.99
OPW	5.48	24.5	7.02	3.41	1.74	5.9	28.9	6.98	3.25	1.65
PW										
Lake Tuende near Well A9		24.1	7.5	4.16	2.12		28.5	7.84	3.96	2.03
Lake Tuende on south side										
BLM Pond		20.2	6.57	3.6	1.83	WL down				
MC Spring		23.9	7.09	2.92	1.48		32	7.33	2.9	1.47
West Pond	50	25.3	7.98	>20	>10	49				
Iron Spring							29.7	6.61	4.95	2.51

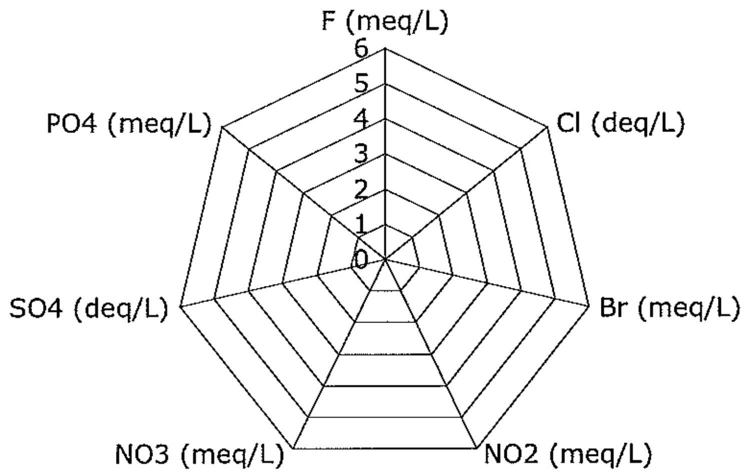
FIELD MEASUREMENTS 1997

Well or Location	Jul-07				
	WL TOC	Temp °C	pH	EC mS/cm	TDS ppt
A1	dry	dry	dry	dry	dry
A10	6.71	25.6	7.07	>20	>10
A11	5.63	28.2	6.94	13.69	6.98
A12	dry	dry	dry	dry	dry
A13	5.14	29.9	7.56	15.45	7.88
A15	10.15	27.4	6.52	8.62	4.36
A2	dry	dry	dry	dry	dry
A3	5.71	27.3	7.35	3.85	1.97
A4	7.19	26.8	8.16	>20	>10
A5	dry	dry	dry	dry	dry
A6	dry	dry	dry	dry	dry
A7	dry	dry	dry	dry	dry
A8	dry	dry	dry	dry	dry
A9	dry	dry	dry	dry	dry
JW1	8.43	26.4	6.83	13.46	6.86
JW2	dry	dry	dry	dry	dry
JW3	9.03	27.7	7.45	5.32	2.71
JW4	dry	dry	dry	dry	dry
JW5	1.66	29.1	8.05	3.02	1.54
MC	5.76	24.9	6.51	7.98	4.05
OPW	5.97	29	8.06	3.36	1.71
PW	pumping				
Lake Tuende near Well A9		27.7	8.91	4.39	2.24
Lake Tuende on south side					
BLM Pond					
MC Spring		25.2	7.98	3.19	1.71
West Pond	38				
Iron Spring					

APPENDIX E

2005 ANION ANALYSIS RESULTS

Scale for Anion Graphs



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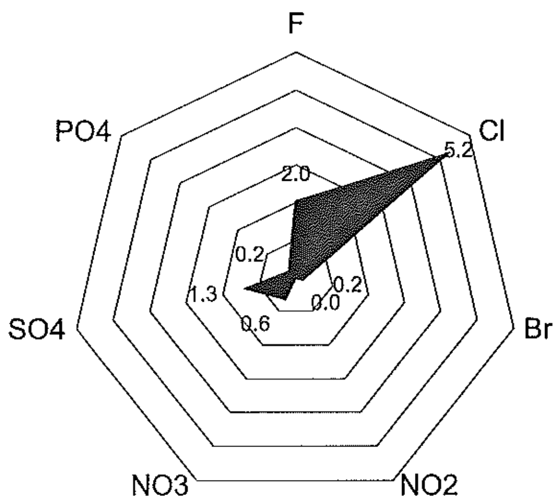

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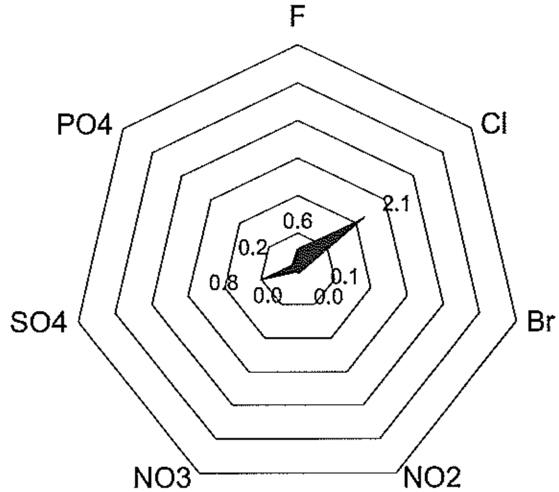

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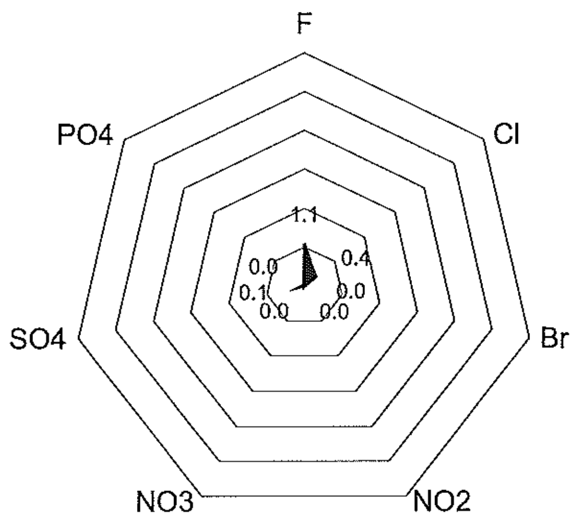

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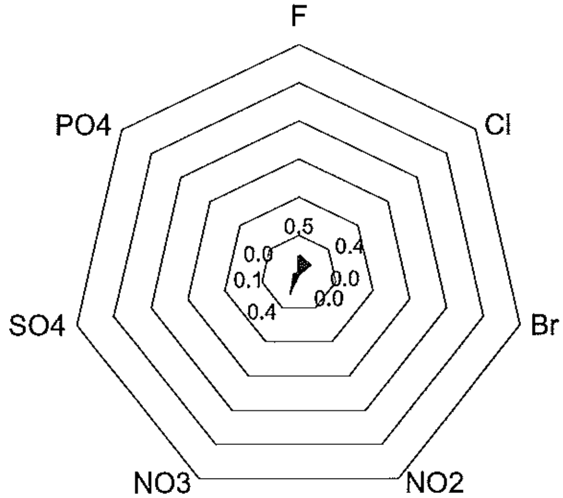

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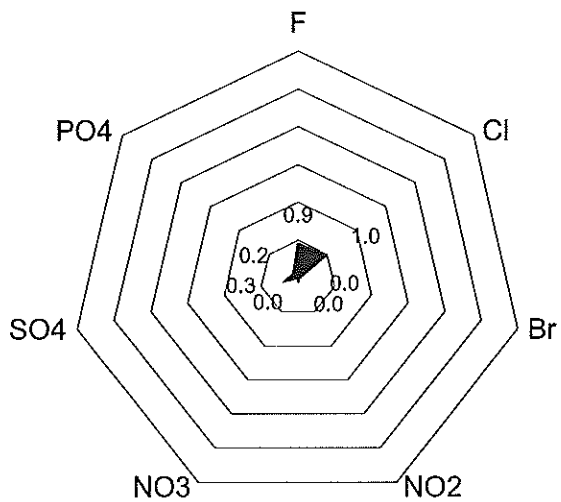
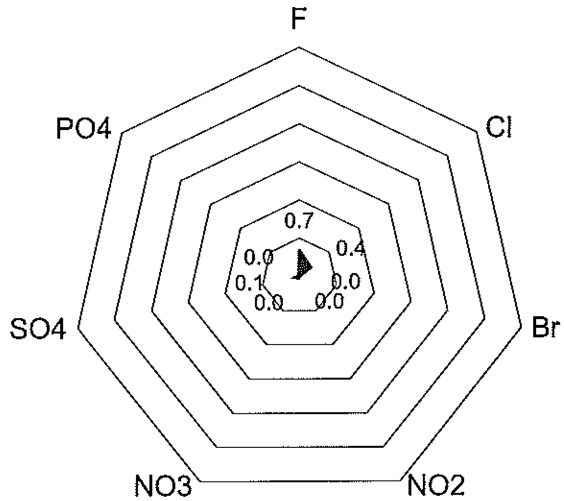
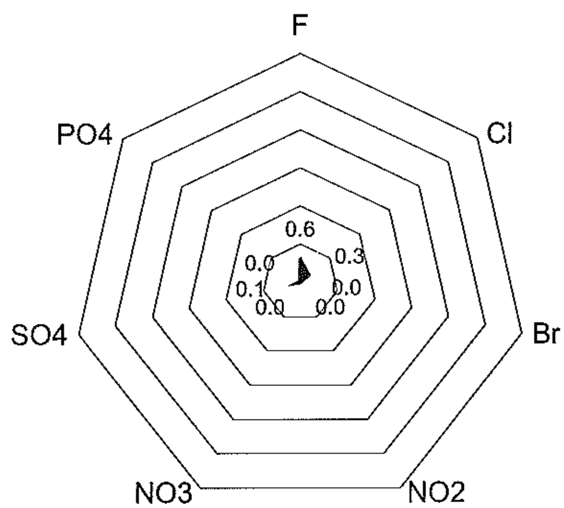


Well JW3



Well MC



APPENDIX F

FRACTURE SURVEY DATA

Fracture Measurements

Station #1

	deg	min	sec
N	35	8	27.2
W	116	6	14.8

Strike	Dip	Strike	Dip
N89W	59 S	S88W	62 S
S82W	75 S	N87W	74 S
S74W	72 S	N89W	57 S
S81W	58 S	N52W	46 S
N89W	57 S	N51W	45 S
N85W	60 S	S84W	67 S
N67W	45 S	N49W	45 S
N89W	70 S	N14W	39 S
N84W	70 S	N16W	38 S
N88W	71 S	N52E	60 N
N89W	62 S	N32W	64 S
N64W	47 S	N34W	66 S
N50W	45 S	N13W	71 S
N58W	47 S	N88W	64 S
N88W	69 S	N86W	60 S
N15W	68 S	S82W	52 S
N55E	58 N	S85W	56 S
N54E	55 N	N12W	32 S
N35W	65 S	S88W	62 S
N35W	65 S	S84W	53 S
N12W	72 S	S87W	52 S
N70W	62 N	S84W	51 S
N85W	64 S	S84W	48 S
S84W	56 S	S80W	50 S
S86W	54 S	S84W	44 S
N5W	31 N	N41W	89 S
N89W	60 S	N47W	84 S
S84W	55 S	N50W	89 S
S86W	51 S	N44W	85 S
S84W	49 S	N42W	81 S
S85W	50 S		
S83W	48 S		
S81W	42 S		
N45W	88 S		

Station #2

	deg	min	sec
N	35	8	27.5
W	116	6	16.6

Intrusive Trend
N60W

Station #3

	deg	min	sec
N	35	8	25.7
W	116	6	16.6

Intrusive Trend
S65W

Station #4

	deg	min	sec
N	35	8	28.1
W	116	6	18.3

Strike	Dip
N65E	90
N65E	89 S
N78E	90
N64E	72 S
N63E	70 S
N66E	54 S
N70E	59 S
N69E	64 S
N64E	89 S
N62E	81 S
N83E	90
N62E	72 S
N65E	73 S
N61E	70 S
N68E	62 S
N70E	63 S

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