FINAL

Basin Conceptual Model and Assessment of Water Supply and Demand

for the Ames Valley, Johnson Valley, and Means Valley Groundwater Basins

April 2007

Kennedy/Jenks/Todd LLC

Basin Conceptual Model
and
Assessment of Water Supply and Demand
for the
Ames Valley, Johnson Valley, and Means Valley
Groundwater Basins

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EXECUTIVE SUMMARY

Bighorn-Desert View Water Agency (BDVWA) is located within the boundaries of the Mojave Water Agency (MWA) and overlies a portion of three High Desert groundwater basins: Ames Valley, Johnson Valley, and Means Valley. MWA, in cooperation with BDVWA and other local water districts, is responsible for managing the water resources of the High Desert region in San Bernardino County to ensure a sustainable water supply for current and future beneficial use. Together, BDVWA and MWA are currently evaluating management options for water resources in the area.

Groundwater has been the sole source of supply for the Ames, Johnson, and Means valleys, but with increasing demand, the long-term sustainability of the resource is uncertain. Management alternatives are being evaluated including conjunctive use projects involving storage of State Water Project (SWP) water in local basins for future extraction and use. In order to develop appropriate management actions for the three basins, a clear understanding is required of the hydrogeologic framework and the water supply and demand conditions.

Kennedy/Jenks/Todd (KJT) was retained for this Study to provide basin conceptual models for the three basins and assess water supply and demand to support groundwater management decisions. This project is being jointly funded by BDVWA, MWA, and a grant under the Local Groundwater Assistance Act (AB303) administered by the California Department of Water Resources (DWR).

Groundwater Basins and Study Area

The Ames Valley, Means Valley, and Johnson Valley groundwater basins cover more than 360 square miles in San Bernardino County. The area is located in the southwestern Mojave Desert (also known as the High Desert) approximately 100 miles east of Los Angeles and just north of Yucca Valley (Figure 1). Groundwater basin boundaries were adopted by DWR in the 2003 update of Bulletin 118 on California's groundwater (DWR, 2003).

Previous studies in this area, which span decades and involve numerous investigators, have resulted in evolving boundaries and nomenclature of basins and subbasins over time. Table 1 summarizes nomenclature and correlates subbasin names used by the U.S. Geological Survey (USGS) to DWR groundwater basins. In order to focus this Study on key areas of interest, a project Study Area was selected that covers about 250 square miles and overlies most of the groundwater basins. Figure 2 shows the Study Area and water providers in the three-basin area. The Morongo Basin Pipeline, which transports SWP water through the area, is also shown.

Project Objectives

The goal of this project is to assimilate data and previous evaluations into a document that provides the technical foundation on which management decisions, including possible conjunctive use projects, can be based. To support this goal, the Study has been divided into two interrelated components: the development of a basin conceptual model that describes physical and hydraulic conditions for each groundwater basin and the analysis of water supply and demand that includes projections of future use. The combination of these two components provides the scientific and engineering basis to support management decisions in the future.

Data Sources

Most of the information used for this study was compiled by BDVWA, MWA, Hi-Desert Water District (HDWD), Joshua Basin Water District (JBWD), and San Bernardino County Special District Area No. 70 (CSA-70). Information was made available on a website-based repository through the MWA file transfer protocol (ftp) site. Data included published articles and reports, hydrogeologic data collected from cooperating water and other governmental agencies, geographic information system (GIS) shapefiles, maps, air photos, and various databases. Key documents and data used in this study are identified on the reference list at the end of this report. Figure 3 shows key wells in the Study Area.

Existing data were supplemented with a field program conducted in October 2006 involving surface geophysics techniques. KJT worked with MWA and Aquifer Science & Technology (AST, a Ruekert & Mielke company) to develop a surface geophysical investigation to evaluate key data gaps, primarily in the Ames Valley where growth and water demand are expected to increase. The scope of work included 15 electrical resistivity transects and 35 time-domain electromagnetic (TEM) surveys (Figure 4). The report summarizing the geophysical field program is attached as Appendix A (Ruekert & Mielke, 2007).

Project Considerations

This report summarizes relevant hydrogeologic and groundwater data to provide the understanding and background for the basin conceptual models. However, the purpose of this document is not only to look back over all of the data generated to date but to also look forward to how the basins might be used in the future. As such, the basin conceptual models focus on components of a groundwater basin relevant to conjunctive use and managed aquifer recharge including the geometry of the basin, available storage, permeability and hydraulic properties of aquifers, boundary conditions, water quality, surface facilities, and the institutional framework for groundwater basin management.

Basin Conceptual Model Development

The Ames Valley, Johnson Valley, and Means Valley groundwater basins are eastward- and northward-sloping alluvial plains located east and north of the San Bernardino Mountains in the Mojave Desert of California (Figure 1). The groundwater basins are sparsely populated with most of the population centers located within the Study Area. The upstream portions of the basin watersheds are located in the San Bernardino Mountains and contribute runoff and recharge to the basins (Figure 5). Lower portions of the watershed are of less importance where very little runoff and essentially no groundwater recharge occurs. Rainfall ranges from almost 16 inches per year in the upper elevations of the watersheds to less than four inches per year in the northeast basin areas. Average potential evapotranspiration (ET) is reported as 66.47 inches per year by DWR for the High Desert region.

Geology

The Mojave Desert was formed in the Tertiary Period from movement along the San Andreas Fault to the south and the Garlock Fault to the north, creating the Mojave structural block (Norris and Webb, 1990). The San Bernardino Mountains and bedrock underlying the groundwater basins consist mainly of Jurassic and Cretaceous granitic rocks. The bedrock surface dips steeply to the north and east, providing a large thickness of alluvial sediments a short distance from the mountain front. The Tertiary and Quaternary age alluvial sediments are the main aquifers in the groundwater basin. The Mojave structural block is dominated by extensive northwest-trending faults that appear to terminate regionally near the Garlock Fault outside of the Study Area. A re-evaluation of certain faults in the Pipes and Reche subbasins of the Ames Valley was conducted in the surface geophysics program associated with this Study (Ruekert & Mielke, 2007).

Groundwater Use

Groundwater has served as the sole source of supply historically for the three groundwater basins. Service areas for four water agencies overlie portions of the Study Area including BDVWA, CSA No. 70, HDWD, and JBWD (Figure 2). In addition to the water service providers, a small amount of groundwater is pumped from private wells. Several commercial water haulers purchase water from BDVWA and serve outlying areas.

Groundwater for municipal use is pumped from approximately 12 active wells operated by BDVWA, HDWD, and CSA-70 in the Study Area. With the exception of one well, all pumping is located within the Ames Valley Groundwater Basin. One well, operated by BDVWA, is in Johnson Valley. Over the last 35 years, Study Area pumping has ranged from about 80 AFY in 1970 to more than 2,000 AFY in 1996 and 1997. Municipal pumping has averaged 1,197 AFY over the last six years.

Institutional Framework

Various water supply agreements are applicable to groundwater management in the Study Area, including a semi-adjudication in a portion of the Ames Valley basin and an agreement for the users of the Morongo Basin Pipeline. The purpose of the agreement is to improve reliability of the shared groundwater supply by limiting extractions.

The Ames Valley Basin Water Agreement is an Agreement between HDWD and BDVWA for the construction and operation of the HDWD Mainstream Well in the Ames Valley basin. At the time the Agreement and Judgment were entered, the HDWD service area included areas within the Ames Valley basin and the Warren Valley basin.

The Morongo Basin Pipeline Agreement of 1991 is an agreement between BDVWA, HDWD, JBWD, CSA No. 70, and MWA for construction, operation, and financing of the Morongo Basin Pipeline Project. Of these users, only BDVWA and CSA No. 70 Zone W-1 can be delivered water in the Study Area, accounting for 13 percent of the project capacity.

The Warren Valley Basin Agreement is an agreement between MWA, HDWD, and the Warren Valley Basin Watermaster. This agreement affects the use of the Morongo Basin Pipeline, including pipeline users in the Study Area. The primary purpose of the agreement is to more efficiently use available water supply and to provide supplemental water to the Watermaster in the event that water levels drop too low to support the adjudicated water rights.

Basin Conceptual Model – Ames Valley Groundwater Basin

The Ames Valley Groundwater Basin covers 110,000 acres of a sloping alluvial plain, extending from the San Bernardino Mountains on the west to Emerson Dry Lake in the northeast. Known and inferred northwest-trending faults slice the basin into four subbasins: Pipes, Reche, Giant Rock and Emerson (Figure 6). An upland area characterized by shallow bedrock and thin saturated sediments defines a fifth subbasin, Pioneertown. Shallow bedrock ridges interrupt the basin with bedrock outcrops and redirect groundwater flow in the shallow subsurface in some areas (Figures 7 through 13).

Natural recharge to the groundwater basin is from runoff generated in the upland areas of the adjacent mountains where precipitation is higher than on the basin floor. Average precipitation in the 58,551 acres of the contributing watershed is about 7.5 inches per year (Figure 5). Runoff is confined primarily to four major drainageways (Antelope Creek, Whalen's Wash, Ruby Mountain Creek, and Sand Hill Wash), which transport surface water to the basin edge where it is subject to evaporation and infiltration (Figure 14). Recharge is estimated to be two percent of average rainfall generated in the contributing watershed. Recharge from precipitation that falls directly on the groundwater basin area is considered negligible due to low precipitation and high evaporation. The two percent factor relating recharge to upland rainfall was calibrated to data in the Flamingo Heights/Pipes Subbasin including observed changes in storage, runoff catchment areas, septic return flows, and pumping data. Using this factor, natural recharge for the basin is estimated at 686 AFY on an average basis, a value consistent with previous estimates (500 AFY and 700 AFY).

Recharge occurs mainly in incised washes and alluvial fans and percolates to groundwater through relatively coarse-grained sediments near the mountain front. Basin groundwater appears to be unconfined to semi-confined throughout the basin. Groundwater generally flows from western recharge areas to the northeast toward the groundwater basin discharge areas at the boundary with the Surprise Spring basin and beneath Emerson Dry Lake (Figures 17 through 20). Groundwater flowpaths from recharge areas to discharge areas are impacted by faulting and shallow bedrock. Clay gouge and low permeability zones associated with fault planes impede groundwater flow from subbasin to subbasin, although groundwater apparently does seep through the zones. Shallow bedrock ridges re-direct flow and funnel groundwater to specific areas along the faults where most of the crossflow likely occurs.

Groundwater quality is good, as represented by total dissolved solids (TDS), with levels generally below 500 milligrams per liter (mg/L) (Figure 31). No elevated concentrations of constituents of concern were identified from available data.

Groundwater storage in the basin is estimated at 1.45 million AF, although most of this cannot be developed economically through wells. Available storage capacity in the unsaturated zone is estimated to be more than 3.14 million AF. Topography and other constraints limit the use of the entire unsaturated zone for storage, but the high value indicates that storage of imported water in the basin could be accomplished. Saturated thickness and depth to water are highly variable in the basin (Figures 21 through 24 and Figure 27).

Current (2005) pumping of about 1,000 AFY supports a population of about 8,300 persons (Figure 28). Since most of the water use is indoors and none of the Study Area is sewered, return flows from septic systems represent a significant component of inflows to the groundwater basin. Return flows from septic systems are calculated using formulas derived by other investigators in the Mojave Desert area and represent 651 AFY for the Ames Valley in 2005.

A preliminary water balance for the basin indicates that the basin is close to balance under average conditions. This balance is supported by water levels in the basin, which have stabilized under current pumping conditions (Figures 25 and 26). The negative change in storage (-12 AFY) suggests slight overdraft conditions, but the value is likely within the uncertainty of the water balance components. Nonetheless, the water balance warrants investigation of additional supplies to supplement the groundwater basin.

Water Balance for
Ames Valley Groundwater Basin

Basin Inflows	**Volume (AFY)**
Rainfall	686
Septic Return Flow	651
Subsurface Inflow	0
Total Inflow	*1337*
Basin Outflows	**Volume (AFY)**
Pumping	1186
Subsurface Outflow	128
Evapotranspiration	35
Total Outflow	*1349*
Groundwater Storage Change	**-12**

Basin Conceptual Model – Johnson Valley Groundwater Basin

The Johnson Valley Groundwater Basin covers 111,630 acres of a sloping alluvial plain, extending from the San Bernardino Mountains on the south to Melville and Soggy dry lakes to the north. The basin size is similar to Ames Valley. Known and inferred northwest-trending faults divide the basin into two subbasins referred to as Upper Johnson and Soggy Lake by DWR. USGS further divides the Soggy Lake Subbasin into two areas, Johnson and Fry (Figure 6). Shallow bedrock ridges and peaks from historical and recent faulting interrupt the basin with bedrock outcrops and redirect groundwater flow in the shallow subsurface in some areas.

Natural recharge to the groundwater basin is from runoff generated in the upland areas of the adjacent mountains where precipitation is higher than on the basin floor. Average precipitation in the 64,428 acres of the contributing watershed is about 9.2 inches per year (Figure 5). Runoff is confined primarily to three major drainageways, Ruby Canyon, Two Holes Spring, and Arrastre Creek, which transport surface water to the basin edge where it is subject to evaporation and infiltration. Consistent with a methodology developed in the Ames Valley for this Study, recharge is estimated to be two percent of average rainfall generated in the contributing watershed. This method results in an average recharge of 921 AFY to the Johnson Valley basin. Average recharge is higher than in Ames Valley due to the slightly larger watershed and higher average precipitation. Recharge from precipitation that falls directly on the basin floor is considered negligible due to low precipitation and high evaporation.

Recharge occurs mainly in incised washes and alluvial fans and percolates to groundwater through relatively coarse-grained sediments near the mountain front. Basin groundwater appears to be unconfined to semi-confined throughout the basin. Groundwater generally flows from southern recharge areas to the north toward the groundwater basin discharge areas at the Means Valley Groundwater Basin and Melville and Soggy dry lakes (Figures 17 through 20). Groundwater leaves the basin as subsurface outflow and evaporation beneath the dry lakes. Groundwater flowpaths from recharge areas to discharge areas are impacted by faulting and shallow bedrock. Low permeability zones associated with faults impede groundwater flow across basin and subbasin boundaries, although groundwater apparently does seep through fault zones at certain locations. Shallow bedrock ridges re-direct flow and funnel groundwater to specific areas along the faults where most of the crossflow likely occurs.

Groundwater quality, as characterized by TDS, is better in the southern portion of the basin where levels are lower than 500 mg/L (Figure 31). Water quality deteriorates significantly in wells to the north with TDS concentrations exceeding 1,000 mg/L.

Groundwater storage in the basin is estimated at 2.27 million AF, although most of this cannot be accessed economically with wells. Available storage capacity in the unsaturated zone is estimated to be more than 2.4 million AF. Topography and other constraints limit the use of the entire unsaturated zone for storage, but the high value indicates that storage of imported water in the basin could be accomplished. Saturated thickness and depth to groundwater are highly variable in the basin (Figures 34 through 36).

Current (2005) pumping of about 10 AFY is reported by BDVWA, an amount predicted to provide water to about 70 to 100 persons (based on water use in Ames Valley) (Figure 38). Population in the Johnson Valley is reported to be about 400 persons, indicating possible use of private wells. Water distribution by BDVWA is accomplished by pumping water from one active well to a storage tank, providing water to private users and commercial water haulers. The increased use of private wells in Johnson Valley compared to Ames Valley seems reasonable, given the lack of a local distribution system. Since most of the water use is indoors and none of the Study Area is sewered, return flows from septic systems are estimated at 31 AFY of groundwater recharge (based on population).

Stable water levels and a preliminary water balance for the basin indicate that the basin is in balance with significant subsurface outflows and losses to evaporation at dry lakes. If actual pumping is higher due to private well use, then subsurface outflow and ET would likely decrease. This conclusion is based on water level trends, indicating no significant change in groundwater storage. Although future population and water demand are expected to increase in the Johnson Valley basin, projected increases are small. Evaluation of a single dry year, multiple dry years, and average conditions indicate that the basin is capable of meeting future demands as needed. If increasing demand in the valley is addressed through additional wells, pumping could likely be placed to intercept groundwater that would otherwise be lost to subsurface outflow and ET.

Water Balance
Johnson Valley Groundwater Basin

Basin Inflows	**Volume (AFY)**
Rainfall	921
Septic Return Flow	31
Subsurface Inflow	0
Total Inflow	*952*
Basin Outflows	**Volume (AFY)**
Pumping	11
Subsurface Outflow	273
Evapotranspiration	668
Total Outflow	*952*
Groundwater Storage Change	**0**

Basin Conceptual Model – Means Valley Groundwater Basin

The Means Valley Groundwater Basin covers 15,000 acres of an alluvial plain, situated between Johnson Valley and Ames Valley basins. The basin is small compared to the adjacent basins and is defined by two bounding faults, the Johnson Valley Fault to the southwest and the Homestead Valley Fault to the east (Figure 6). Bedrock is relatively shallow, especially in the southern portion of the basin and the alluvial sediments are less than 500 feet thick and much thinner in some areas (Figure 13).

Natural recharge is provided by runoff from adjacent mountains where rainfall does not infiltrate significantly into the bedrock. Average precipitation in the 3,164 acres of the contributing watershed is about 5.1inches per year (Figure 5). Runoff is confined to only one major drainageway, Means Wash, which transports surface water to the basin edge where it is subject to evaporation and infiltration. Consistent with a methodology developed in the Ames Valley for this study, recharge is estimated to be two percent of average rainfall generated in the contributing watershed. This method results in an average recharge of only 25 AFY to the Means Valley basin. Average recharge is much lower than in Ames Valley or Johnson Valley because of the smaller watershed, limited surface water in Means Wash, and lower average precipitation (associated with lower elevations for the watershed). Recharge from precipitation that falls directly on the basin is considered negligible.

Recharge occurs mainly in the southern portions of the alluvial plain and percolates to groundwater through relatively coarse-grained sediments near the mountain front. Groundwater generally flows from the southern recharge area to the north where it evaporates from Means Dry Lake. Low permeability associated with the Johnson Valley Fault impedes groundwater flow into the Means Valley basin from Johnson Valley basin, although some groundwater apparently does seep through the fault zone (Figures 17-20). Shallow bedrock ridges are present around much of the basin and funnel groundwater through a relatively narrow area where Johnson Valley and Means Valley connect.

Groundwater storage in the basin is estimated at 89,600 AF, although most of this cannot be developed economically through wells. In addition, the basin is characterized by relatively poor water quality and groundwater use from the basin is limited. Available storage in the unsaturated zone is estimated to be about 202,600 AF. Topography and water quality constraints limit the use of the unsaturated zone for storage.

There is currently no pumping by water agencies in the basin. Groundwater use by private wells may occur in the basin, but the numbers are estimated to be small due to the sparse population.

A preliminary water balance for the basin indicates that the basin is in balance with evaporative loss at Means Dry Lake roughly equivalent to natural recharge and subsurface inflow.

Water Balance
Means Valley Groundwater Basin

Basin Inflows	**Volume (AFY)**
Rainfall	25
Septic Return Flow	0
Subsurface Inflow	273
Total Inflow	*298*
Basin Outflows	**Volume (AFY)**
Pumping	0
Subsurface Outflow	0
Evapotranspiration	298
Total Outflow	*298*
Groundwater Storage Change	**0**

Basin Supply and Demand Assessment

An assessment of the current and future demands and a comparison of demand and supply have been conducted to assist basin managers with decisions on providing a supplemental water supply to the Study Area. The assessment evaluates water use per person, projected changes in population, and the amount of additional supply that may be extracted from the groundwater basins incorporating the water balance information provided above. The assessment also examines the availability of SWP water as a supplemental supply as well as potential restrictions on delivery by the Morongo Basin Pipeline. A comparison of supply and demand is conducted for three different hydrologic conditions: average, a single dry year, and multiple dry years.

Population projections were provided in the MWA Urban Water Management Plan (MWA, 2005). Population was not separated between Ames and Means Valley since water service to the Means Valley is negligible.

Population Projections

	2005	2010	2015	2020	2025	2030
Ames/Means	8,300	9,300	10,400	11,700	12,400	13,900
Johnson	400	500	500	600	600	700
Study Area	**8,700**	**9,800**	**10,900**	**12,300**	**13,000**	**14,600**

Source: Source- MWA 2005 UWMP. Values represent the population served in each basin.

Water supply for the Study Area is currently available from the groundwater basins and may be available in the future from imported SWP water. Supply from the groundwater basins is approximated by the amount of recharge from rainfall and runoff originating in the upland portions of the watershed. Although it is recognized that water supply wells may not be able to effectively capture all of this supply, the natural recharge amount is considered an adequate estimation for the basin-wide scale of this Study. For the purposes of this Study, it is further assumed that the groundwater supply conditions will remain unchanged through 2030. A summary of groundwater and imported supplies available for the Study Area is shown below.

Current and Planned Water Supplies (AFY)

Water Supply Sources (Long-term Average)	2005	2010	2015	2020	2025	2030
Groundwater	*1,632*	*1,632*	*1,632*	*1,632*	*1,632*	*1,632*
Ames Valley	686	686	686	686	686	686
Johnson Valley	921	921	921	921	921	921
Means Valley	25	25	25	25	25	25
Imported Water to Study Area						
Total SWP[(a)]		1,340	1,380	1,410	1,450	1,450
Total	1,632	2,972	3,012	3,042	3,082	3,082

(a) SWP water delivery at 69 to 77 percent of Morongo Basin Pipeline Capacity.

As shown above, the supply from the Means Valley Groundwater Basin is small and its use is limited due to poor water quality. As such, the supply from the Means Valley is not included in the comparisons of supply and demand described below.

Current pumping in each of the basins has been documented in the basin conceptual models, representing a total water demand. For the purposes of this Study, an estimate of net demand is used, which accounts for the water actually consumed by correcting total demand for estimated return flows (primarily from septic systems). This net demand is referred to as consumptive use. The incorporation of return flows into the demand analysis is adopted for consistency with the water balance, which is based on the entire groundwater basin. A consumptive use of 50 percent of the total pumping was adopted for this analysis, consistent with the MWA 2004 Regional Management Plan and other studies (Albert A. Webb and Associates, 2000).

To estimate future demand or consumptive use, a consumptive use coefficient was used based on current pumping and population data in Ames Valley. The coefficient of 0.071 AFY per person was applied to future population projections to estimate demand into the future. Demand estimates shown below are based on the consumptive use projection and include MWA's conservation goal of five percent of consumptive use by 2015.

Population Based Water Demand Projections (Consumptive Use, AFY)

	2005	2010	2015	2020	2025	2030
Ames/Means	589	660	701	789	836	938
Johnson	28	36	34	40	40	47
Study Area	**617**	**696**	**735**	**829**	**876**	**985**

Supply and demand data were compared for average hydrologic conditions, single dry year conditions, and multiple dry year conditions as summarized below.

Average Water Year Supply and Demand Comparison (AFY)

Water Supply Sources	2005	2010	2015	2020	2025	2030
Ames Valley GW Supply	686	686	686	686	686	686
Ames Valley Demand	589	660	701	789	836	938
Ames Valley Surplus/(Deficit)	97	26	(15)	(103)	(150)	(252)
Johnson Valley GW Supply	921	921	921	921	921	921
Johnson Valley Demand	28	36	34	40	40	47
Johnson Valley Surplus/(Deficit)	893	885	887	881	881	874
GW Surplus/(Deficit) to Study Area	990	911	872	778	731	622
Imported Water to Study Area	1,300	1,340	1,380	1,410	1,450	1,450
Total Surplus/(Deficit) to Study Area	2,290	2,251	2,252	2,188	2,181	2,072

Note: Demand totals reflect an average consumptive use coefficient of 0.071 AFY/persons.

As shown by the comparison above, Ames Valley appears to be capable of handling only current demand, with perhaps a small increase in demand under average conditions. According to the water balance, the basin is estimated to be very near or already in overdraft conditions, assuming that increased pumping would not be able to access current amounts of subsurface outflow or evaporation. The small surplus listed for 2005 and 2010 is likely within the uncertainty range of the water balance. A deficit is indicated in 2015 and beyond. After about 2010, demand would have to be met with either groundwater storage or an imported supply.

Johnson Valley, in contrast, has very little current or future demand and, as such, indicates a surplus of water through 2030 under average conditions. This surplus assumes that additional wells would be capable of capturing groundwater that would otherwise be lost to subsurface outflow or ET. Using the indicated surplus in Johnson Valley to offset the need for additional supplies in Ames Valley may not be practical, given the lack of infrastructure in Johnson Valley and the uncertainties in the water balance.

A comparison of supply and demand conditions for a single dry water year (1989-1990) is shown below. The analysis does not account for the availability of groundwater storage that could be used during one year.

Single Dry Water Year Supply and Demand Comparison (AFY)

Water Supply Sources	2005	2010	2015	2020	2025	2030
Ames Valley GW Supply	176	176	176	176	176	176
Ames Valley Demand	589	660	701	789	836	938
Ames Valley Surplus/(Deficit)	(413)	(484)	(525)	(613)	(660)	(762)
Johnson Valley GW Supply	236	236	236	236	236	236
Johnson Valley Demand	28	36	34	40	40	47
Johnson Valley Surplus/(Deficit)	208	200	202	196	196	189
GW Surplus/(Deficit) to Study Area	(205)	(284)	(323)	(417)	(464)	(573)
Imported Water to Study Area	95	95	95	95	95	95
Total Surplus/(Deficit) to Study Area	(110)	(189)	(228)	(322)	(369)	(478)

As shown by the comparison above, recharge to the Ames Valley Groundwater Basin in a single dry year is not sufficient to meet current or future single dry year demand without using groundwater storage or SWP water. Recharge to the Johnson Valley basin appears to be sufficient to meet single dry year demand through 2030. If the indicated surplus in Johnson Valley is used to offset the deficit in the Ames Valley, the overall deficit for the Study Area is reduced but not eliminated. Even if imported water supply is added to these conditions, deficits remain for single dry year demand now and into the future. This is due, in part, to the small amount of imported water that may be available in a single dry year.

Multiple dry-year reliability for each groundwater basin and the Study Area as a whole was analyzed using recharge data from 1999-2001, when rainfall was approximately 50 percent of the long-term average (Table 3).

Multiple Dry Water Year Supply and Demand Comparison (AFY)

Water Supply Sources	2005	2010	2015	2020	2025	2030
Ames/Means Valley GW Supply	386	386	386	386	386	386
Ames/Means Valley Demand	589	660	701	789	836	938
Ames/Means Valley Surplus/(Deficit)	**(203)**	**(274)**	**(315)**	**(403)**	**(450)**	**(552)**
Johnson Valley GW Supply	518	518	518	518	518	518
Johnson Valley Demand	28	36	34	40	40	47
Johnson Valley Surplus/(Deficit)	**490**	**482**	**484**	**478**	**478**	**471**
GW Surplus/(Deficit) to Study Area	287	208	169	75	28	(81)
Imported Water to Study Area	790	790	790	790	790	790
Total Surplus/(Deficit) to Study Area	**1,077**	**998**	**959**	**865**	**818**	**709**

As shown by the multiple dry year comparison, the Ames Valley groundwater supply is not sufficient to meet current or future multiple dry-year demand without imported water. Johnson Valley, on the other hand, has sufficient groundwater to meet its multiple dry year demand through 2030. Similar to previous evaluations, the indicated surplus in Johnson Valley assumes that additional wells would be capable of capturing groundwater that would otherwise be lost to subsurface outflow or ET.

Overall, the Study Area appears to have sufficient groundwater supply for multiple dry-year demands until after 2025, when a deficit is indicated. Again, applying the Johnson Valley surplus to the deficit in the Ames Valley basin may not reflect a reasonable approach to water supply due to infrastructure considerations. As in the single-dry year analysis, SWP water would be required eventually to meet the Study Area deficit.

The analysis of water supply and demand in the basin through 2030 indicates that demand in Ames Valley exceeds supply in all single and multiple dry-year hydrologic conditions analyzed. The basin is very near or already in overdraft under average conditions and cannot support additional projected demand without a supplemental supply. Although a surplus is indicated in Johnson Valley, it is unclear whether wells could be economically sited to capture most of the surplus. In addition, no infrastructure exists to transport groundwater from Johnson Valley to meet Ames Valley demand.

Findings and Conclusions

Ames Valley Groundwater Basin

Findings from the basin conceptual model development and water demand and supply assessment for the Ames Valley Groundwater Basin indicate that a managed aquifer recharge project is technically feasible and, if implemented, would meet the objectives of BDVWA and MWA to manage groundwater resources conjunctively in the Study Area. Findings from the evaluation with respect to project considerations are summarized below:

- The area bounded by the Flamingo Heights Fan, Whalen's Wash, and Pipes Wash represents the deepest portion of the basin. This area would provide adequate groundwater storage and available storage capacity to support sustainable managed aquifer recharge.

- Coarse-grained sediments in the unsaturated zone beneath Pipes Wash and Whalen's Wash (as identified by electrical resistivity surveys) are ideal for the sustainable infiltration and percolation of imported SWP water in the basin.

- The highest specific capacities (which correlate to the highest aquifer T and K values) were calculated for wells located in three areas: 1) in the Flamingo Heights Fan just west of the Johnson Valley Fault, 2) along Pipes Wash and Whalen's Wash in the Pipes and Reche subbasins, and 3) near BDVWA 6, 7, and 9 in the Reche Subbasin.

- Lithologic data and resistivity surveys indicate that coarse-grained sediments associated with the proximal portions of the Flamingo Heights Fan do not extend sufficient distances downgradient to support a conjunctive use project on the upper slope of the fan.

- The Pioneertown Subbasin, the area in the Reche Subbasin north of BDVWA 6, 7, and 9, and the areas in the Pipes and Reche subbasins southeast of Pipes Wash are defined by shallow bedrock overlain by thin saturated sediments with low permeability. Such conditions are likely insufficient with respect to groundwater storage, available storage capacity, or aquifer permeability to sustain a conjunctive use project in the basin.

- Although groundwater flow occurs across the Pipes Barrier, and Johnson Valley and Homestead Valley faults, infiltrating water from a conjunctive use project located hydraulically upgradient of these faults may be impeded.

- Groundwater quality in monitoring wells meets MCLs in the Pipes, Reche and Giant Rock subbasins. Groundwater quality is generally poor in the Emerson Subbasin, where elevated concentrations of chloride, sulfate, fluoride, and TDS exceed MCLs.

- The extent and concentrations of naturally occurring nitrate and high-nitrate septic tank discharge in the unsaturated zone are unknown in the basin, but are a concern.

- Areas in the basin that are characterized by favorable hydrogeologic conditions (i.e. sufficient groundwater storage and available storage capacity, downgradient of major hydraulic barriers, high well specific yield, and good water quality) and are also located close to the MWA Morongo Basin Pipeline include 1) Whalen's Wash west of the Pipes Barrier up to BDVWA 6, 7, and 9 in the Reche Subbasin and 2) Pipes Wash east of the Inferred Pipes Barrier in the Reche Subbasin.

Johnson Valley Groundwater Basin

Findings from the basin conceptual model development and water supply and demand assessment for the Johnson Valley Groundwater Basin indicate that a managed aquifer recharge project in the basin is technically feasible, but – due to the lack of projected growth in this area – does not directly meet the objectives of BDVWA and MWA. Conclusions from the evaluation of the Johnson Valley Groundwater Basin with respect to project considerations are summarized below:

- The thickness of saturated and unsaturated sediments from the southern to central portions of Soggy Lake Subbasin would provide adequate groundwater storage and available storage capacity for a conjunctive use project.

- Lithologic data indicate that basin fill sediments are generally coarse-grained in the southern to central portions of the Soggy Lake Subbasin, becoming finer-grained to the northwest. Sediments in the Upper Johnson Valley subbasin are generally coarse-grained but become finer-grained near Melville Dry Lake.

- Available hydraulic data for the calculation of specific capacities and aquifer parameters are limited but indicate that aquifer permeability in the basin may be sufficient to support a conjunctive use project.

- Although groundwater flow occurs across the Old Woman Springs, Lenwood, West Johnson Valley, and Johnson Valley faults, infiltrating surface water from a conjunctive use project located hydraulically upgradient of these faults may be impeded.

- Groundwater quality in the southern portion of the basin meets primary and secondary MCLs. North of Highway 247, groundwater quality generally worsens and exceeds MCLs for sulfate, chloride, and TDS.

- Projected growth in the Johnson Valley basin is small, indicating that the Johnson Valley basin would not be a candidate for a conjunctive use project.

Means Valley Groundwater Basin

Findings from the basin conceptual model development and water demand and supply assessment for the Means Valley Groundwater Basin indicate that a managed aquifer recharge project in the basin was judged to have severe technical issues and does not meet the management objectives of BDVWA and MWA. Conclusions from the evaluation of the Ames Valley Groundwater Basin with respect to project considerations are summarized below:

- Although groundwater storage and available storage in the Means Valley basin is significant, groundwater quality is poor and subsurface lithology is relatively fine-grained compared to the Ames Valley and Johnson Valley basins. Such hydrogeologic conditions would not likely support sustainable managed aquifer recharge in the basin. Additionally, the relatively long distance between the Means Valley basin and the Morongo Basin Pipeline and the fact the projected growth in the basin is small allows for the conclusion that the Means Valley Basin should not be considered for a conjunctive use project.

Recommendations

Based on project findings, the following recommendations can be made:

- Given the favorable hydrogeologic conditions, and considering that major groundwater production, historic water level declines, and projected growth in water demand is concentrated in the central portion of the Pipes and Reche subbasins, additional hydrogeologic investigations along Whalen's Wash and Pipes Wash downgradient of the inferred Pipes Barrier are recommended.

- Although groundwater does flow across the Johnson Valley Fault, Pipes Barrier, and Homestead Valley Fault, implementation of a managed recharge project hydraulically upgradient of these structures is not recommended without further investigation.

- Additional investigation is recommended to understand the geochemical compatibility of imported SWP water, native groundwater, and subsurface mineralogy in locations deemed promising for conjunctive use.

- Additional shallow monitoring wells are recommended to assist in characterizing groundwater in the upper aquifers. Most wells provide data only in deeper zones.

- Consistent with the BDVWA Draft Water System Master Plan, new wells for recovery of water from a conjunctive use project in Reche Subbasin should be integrated into the current BDVWA conveyance system.

- Areas better than the area of BDVWA 10 should be investigated for groundwater development in the Johnson Valley basin if additional production is needed in the future.

- A survey of private wells is recommended for the Johnson Valley.

- Test wells should be drilled and constructed at recommended recharge sites, including geophysical logging and pumping tests to confirm lithology, aquifer parameters, and discharge boundary (fault) locations, and to assess impacts of faults on groundwater and recharge flow pathways.

- A Groundwater Management Plan should be prepared for the Ames Valley Groundwater Basin that envisions potential conjunctive use projects involving the storage of SWP water and plans for storage, extraction, and the institutional framework to allow efficient operation of the basin.

1 INTRODUCTION

Bighorn-Desert View Water Agency (BDVWA) is located within the boundaries of the Mojave Water Agency (MWA) and overlies a portion of three High Desert groundwater basins, Ames Valley, Means Valley, and Johnson Valley. Groundwater is the primary source of supply, but increasing demand is expected to stress limited groundwater resources in the future. In addition, groundwater underlying a portion of the Agency is semi-adjudicated under the Ames Valley Water Basin Water Agreement (1991). In order to fulfill its responsibilities in the management of local resources from these three basins and to ensure compliance with its legal agreements, BDVWA requires a technical understanding of the groundwater basins to serve as a foundation for future management activities.

The Mojave Water Agency (MWA), in cooperation with local water districts, is responsible for managing the water resources of the High Desert region in San Bernardino County to ensure a sustainable water supply for current and future beneficial use. As one of twenty-nine State Water Contractors, MWA has access to State Water Project (SWP) water to supplement local groundwater supplies. One of the primary goals of MWA is to manage imported and groundwater conjunctively while maintaining primary reliance on local supplies during periods of water shortage. Imported water is and will remain a critical component of the area's water supply. Regional overdraft conditions have been documented since the 1950s and measurable groundwater level declines have been documented in several groundwater basins.

BDVWA and MWA are currently evaluating management options for water resources in the area. The existing Morongo Basin Pipeline conveys SWP water across portions of these basins and could be used to provide water for conjunctive use projects. Such projects would consist of recharging excess SWP water at the surface and storing it in the groundwater basin for future extraction and use.

In order to develop appropriate management actions for the three basins, a clear understanding is required of the hydrogeologic framework and the water supply and demand conditions. The current understanding of the groundwater basins has evolved from decades of scientific study by the U.S. Geological Survey (USGS), BDVWA, MWA, and others. The objectives of this study are to assimilate previous evaluations into a coherent conceptual model, address data gaps with a geophysical investigation, document water supply and demand for the region, and integrate these components into a comprehensive document on which future management decisions can be based.

To support this project, BDVWA, with assistance from the MWA, prepared a successful grant application under the Local Groundwater Assistance Act (AB303). The grant, being administered by the California Department of Water Resources (DWR), funds a portion of the project along with contributions from BDVWA and MWA. Following a public Request for Proposal and consultant selection process, BDVWA and MWA retained Kennedy/Jenks/Todd, LLC (KJT) to evaluate the basin hydrogeology and the current and projected water demand within the Ames Valley, Means Valley, and Johnson Valley groundwater basins.

1.1 Groundwater Basins and Study Area

The three groundwater basins cover more than 360 square miles in San Bernardino County. The area is located in the southwestern Mojave Desert (also known as the High Desert) approximately 100 miles east of Los Angeles and just north of Yucca Valley (Figure 1). The basins are northeast of the San Bernardino Mountains and overlie portions of the southeastern MWA service area (Figure 1).

The groundwater basins that are shown by color on Figure 1 were adopted by DWR in the 2003 update of Bulletin 118 on California's groundwater (DWR, 2003). The open areas within the basins represent outcrops of bedrock that interrupt the alluvial basin fill deposits. The DWR numerical designations for each basin are also shown on Figure 1 and include 7-16, 7-17, and 7-18 for the Ames Valley, Means Valley, and Johnson Valley basins, respectively. The larger Johnson Valley basin is subdivided into two subbasins, Soggy Lake (7-18.01) and Upper Johnson Valley (7-18.02).

Previous studies in this area, which span decades and involve numerous investigators, have resulted in evolving boundaries and nomenclature of basins and subbasins over time that are not always coincident with DWR boundaries and nomenclature. In a recent publication, USGS refers to all three DWR basins and some of the surrounding subbasins collectively as the Morongo groundwater basin (Stamos, et al., 2004). Two previous studies by USGS have subdivided the Morongo basin into numerous subbasin boundaries (Stamos, et al., 2004; Lewis, 1972). The most recent USGS subbasin boundaries are included on Figure 1 for comparison to DWR basin boundaries (Stamos, et al., 2004). Table 1 compiles the basin and subbasin nomenclature to facilitate correlation to DWR designations.

Although corresponding subbasin boundaries differ somewhat from DWR basin boundaries, the USGS subbasins provide a useful construct for referring to certain portions of the DWR basins, especially in the Ames Valley basin. As such, USGS subbasin nomenclature corresponding to Ames Valley is used in this report including the Pioneertown, Pipes, Reche, Giant Rock, and Emerson subbasins. The Means Valley groundwater basin is sufficiently small to not require subdivision in this report. DWR subbasins already exist for the Johnson Valley basin (Soggy Lake Subbasin and Upper Johnson Valley Subbasin) (Figure 1). Since only minimal data are available for these two subbasins, this entire basin is simply referred to as the Johnson Valley basin in this document.

In order to focus this study on key areas of interest, a project Study Area was defined, covering about 250 square miles and overlying most of the groundwater basins (Figure 1). The Study Area was selected based on groundwater use, the occurrence of key data, and surface water conveyance facilities. The Study Area includes all or portions of the service areas for the four major water purveyors in the area: BDVWA, Hi-Desert Water District (HDWD), San Bernardino County Service Area 70-W1 (CSA 70-W1), and Joshua Basin Water District (JBWD) (Figure 2). The Study Area also includes most of the area where the Morongo Basin Pipeline crosses the groundwater basins of interest (Figure 2).

1.2 Project Objectives

The goal of this project is to assimilate data and previous evaluations into a document that provides the technical foundation on which management decisions, including possible conjunctive use projects, can be based. In order to support this goal, the following technical components of the groundwater basins and water demand conditions have been identified as project objectives:

- Describe the geometry, geology, and hydrogeology of the groundwater basins
- Evaluate groundwater occurrence, movement, and storage, including available unsaturated zone storage for conjunctive use projects
- Develop a groundwater basin water balance
- Document groundwater use
- Locate surface facilities and engineering limitations
- Assess current and future water demand in the Study Area

1.3 Scope of Work

To support project objectives, the study has been divided into two interrelated components: the development of a basin conceptual model that describes physical and hydraulic conditions for each groundwater basin and the analysis of water supply and demand that includes projections of future conditions. The combination of these two components will provide the scientific and engineering basis for informed management decisions in the future.

Specific tasks developed for the scope of work included the following:

Task 1: Develop a hydrogeologic conceptual model of the Study Area that identifies the extent and character of basin fill deposits, occurrence and movement of groundwater, location and influence of geologic faults on groundwater flow, chemical quality of groundwater, and a preliminary water budget for each of the groundwater basins.

Task 2: Assess current and future water supply and demand conditions in the Study Area and estimate the market for imported water.

Task 3: Design a surface geophysical investigation, including multi-array electrical resistivity and time-domain electromagnetics methods, to fill knowledge gaps identified during the development of the basin conceptual model, considering areas of high future growth potential and potential areas for artificial recharge.

Task 4: Prepare a project report summarizing the basin conceptual models and water supply and demand assessment.

Task 5: Perform project management activities and participate in meetings and presentations.

1.4 Data Sources

Most of the information used for this study was compiled by BDVWA, MWA, HDWD, JBWD, and CSA 70-W1 and made available on a website-based repository through the MWA file transfer protocol (ftp) site. Data included published articles and reports, hydrogeologic data collected from cooperating water and other governmental agencies, geographic information system (GIS) shapefiles, maps, air photos, and various databases. Key documents and data used in this study are identified on the reference list at the end of this report.

Although more than 100 wells have been drilled in the Study Area, data from most of them are inadequate for contributing significantly to the basin conceptual models. Available driller's logs provided some information on general lithology, well construction, and aquifer testing. However, water levels and other data were generally available for only production wells of the major water providers and key monitoring wells in the area. Many of these wells are part of the Ames Valley Water Basin Agreement monitoring program and are clustered in the Agreement Area of Ames Valley basin (Figure 3). Key wells are also located relatively close to the Morongo Basin Pipeline and provide data in potential conjunctive use project areas.

Relevant information and data were also available from a Water System Master Plan being prepared for BDVWA by their consultant, Don Howard Engineering. The Water System Master Plan involves an agency-wide evaluation of supply and demand, along with system and facility requirements for the future. Preliminary findings and a draft Water System Master Plan was provided to KJT for consideration and use in this report.

Available data were supplemented with a field program involving surface geophysics techniques. Details of the geophysical program are described in the following section.

1.5 Geophysical Investigation

KJT worked with MWA and Aquifer Science & Technology (AST, a Ruekert & Mielke company) to develop a surface geophysical investigation to evaluate key data gaps, primarily in the Ames Valley where growth and water demand are expected to increase. The investigation was also focused on areas where conjunctive use projects may be feasible based on pipeline location and preliminary evaluations of geology. Specifically, the geophysical investigation was conducted to provide a better understanding of subsurface lithology, and fault and barrier locations and their impacts on groundwater flow. With these objectives in mind, geophysical lines were located across fault traces (including the Johnson Valley Fault, Homestead Valley Fault, and Pipes Barrier fault), in the major washes (Whalen's Wash and Pipes Wash), and in areas where water level anomalies were thought to occur (e.g., near HDWD #20 and #6).

Figure 4 shows the location of the surface geophysics investigations. The scope of work included 15 electrical resistivity transects (1,800 feet in length) and 35 time-domain electromagnetic (TEM) surveys. The field program was conducted from October 17 through October 23, 2006. The report produced by AST (referenced as Ruekert & Mielke, or R&M, 2007) that documents the methods and findings of the field program is provided as Appendix A to this document.

1.6 Project Considerations

More than 100 reports, studies, plans, and documents have been generated on this area, providing a wealth of information on basin hydrogeology and water supply. This document attempts to pull together and summarize as much relevant data as possible to provide the understanding and background for the basin conceptual models. This document is intended to be a reference and summary document that allows basin managers to assess the hydrogeologic conditions of the basins.

However, the purpose of this document is not only to look back over all of the data generated to date but to also look forward to how the basins might be used in the future. If the basins are to be managed conjunctively, what special considerations need to be addressed? Goals of a conjunctive use project are relatively straightforward: percolate a sufficient amount of water to groundwater for storage, understand the subsurface movement of the water to account for any losses from the system, and extract the stored water efficiently for future use. To focus our evaluation in this project, we have prepared the following list of items and components of the groundwater basins that support these goals and are relevant to managed aquifer recharge projects. Our basin conceptual model considers these items:

- Geometry of the sediment filled valley including occurrence of shallow bedrock
- Sufficient total thickness of alluvial sediments
- Adequate storage available
- Permeable sediments for infiltration
- Groundwater occurrence and confining layers
- Groundwater flow directions
- Subsurface impediments to groundwater flow
- Basin boundary conditions including faults and shallow bedrock
- Acceptable native groundwater quality
- Compatible imported groundwater quality
- Potential of chemicals of concern to leach in the unsaturated zone
- Conditions of subsurface outflow in the basin
- Local pumping depressions
- Aquifer parameters and variability with location and depth
- Permeable aquifers for water recovery
- High specific capacity for production wells
- Accessibility to imported water
- Location of surface facilities and infrastructure
- Institutional framework for basin management incorporating conjunctive use projects

1.7 Report Organization

The first section of the report provides an **Introduction** that summarizes the project, objectives, scope, and data. Section 2 provides information on the **Physical Setting, Groundwater Use,** and **Institutional Framework** for the project. The **Physical Setting** introduces the climate, geology, and hydrology and provides background information for the Study Area. The section on **Groundwater Use** provides information on local water agencies and groundwater pumping in the Study Area. The **Institutional Framework** summarizes some of the key legal and management documents under which the basins are managed.

The **Basin Conceptual Models for the Ames Valley, Johnson Valley, and Means Valley Groundwater Basins** are provided in Sections 3, 4, and 5, respectively. Each section contains basin-specific information on faults and hydraulic barriers, basin fill deposits and aquifer parameters, groundwater occurrence and flow, groundwater level trends, groundwater storage and available storage, a groundwater basin water balance, and groundwater quality. The **Water Supply and Demand** section summarizes supply information from the basin conceptual model water balances and considers additional supply from the Morongo Basin Pipeline. These data on water supply are compared to current and projected water demands for each basin.

Conclusions and Recommendations are provided in the Section 7 and a list of **References** is included at the end of the report. A report prepared by Ruekert & Mielke, *Report on the Geophysical Investigations for the Ames, Means, and Johnson Valleys, Near Yucca Valley California, 2007* summarizes the surface geophysics program and is provided as **Appendix A** of this report.

1.8 Accuracy of Values in this Report

Throughout this report values for areas are rounded to the nearest acre or acre-foot (AF) as needed. As such, large numbers may appear accurate to several digits, which is not the case. Values for data that are measured directly are more accurate, perhaps to two or three significant digits. Values that are estimated are much less accurate, possibly to only one or two significant digits. However, all digits are retained in the text and tables to prevent small numbers from being rounded to zero, to preserve correct column totals in tables, and to maintain as much accuracy as possible when numbers are used for subsequent calculations.

2 BASIN CONCEPTUAL MODEL DEVELOPMENT

A large amount of geologic and engineering work has been conducted in the Ames Valley, Johnson Valley, and Means Valley groundwater basins spanning several decades. One of the primary objectives of this study was to assimilate all of the available hydrogeologic information (including results of a geophysical survey conducted for this study) for development of a comprehensive conceptual model for each of the three groundwater basins. These models are intended to provide a foundation of knowledge that can guide and support science-based groundwater management. A description of the physical setting, provided below, contains background information on the environment where the basins are located. Information on the water agencies and groundwater use in the Study Area is also provided. The institutional framework, which involves a variety of agreements that affect groundwater management, is summarized. Collectively, the information on physical setting, groundwater use, and institutional framework sets the stage for the development of the basin conceptual models.

2.1 Physical Setting

The Ames Valley, Johnson Valley, and Means Valley groundwater basins are eastward- and northward-sloping alluvial plains located east and north of the San Bernardino Mountains in the Mojave Desert of California (Figure 1). The area is characterized by arid conditions, desert vegetation, relatively sparse population, and a reliance on groundwater resources. Surface water drainages are fed by rainfall in the adjacent mountains and transport water onto alluvial fans at the mountain front and through major washes entering the groundwater basins. Most of the available water evaporates or percolates into the basin a short distance from the mountain source. Surface drainage is internal and ephemeral washes drain toward dry lakes, including Melville Dry Lake (Johnson Valley), Means Dry Lake (Means Valley), and Emerson Dry Lake (Ames Valley) (Figure 5).

Surface elevations within the groundwater basins range from about 3,500 feet above mean sea level (msl) to about 2,300 feet msl near Emerson Dry Lake. The higher elevations are associated with the upper portions of alluvial fan deposits along the mountain front. The desert alluvial sediments have infilled down-dropped areas within the mountainous topography and, as such, bedrock hills and ridges interrupt the alluvial valley floor. These inter-valley hills and ridges range in elevation up to about 4,000 feet msl.

Much higher surface elevations are associated with the adjacent San Bernardino Mountains. Elevations rise above 4,000 feet along the groundwater basin boundaries. Portions of the San Bernardino Mountains southwest of the Study Area but within the basin watersheds rise above 9,000 feet msl. The Digital Elevation Model (DEM) background on Figure 5 illustrates the mountainous terrain and buried bedrock ridges within and southwest of the groundwater basins.

2.1.1 Land Use and Population

The High Desert environment of the Study Area consists mostly of open undeveloped land. Most of the land is owned by various governmental agencies including the U.S. Bureau of Land

Management (BLM). Private (non-government) land is mostly urban, containing residential and commercial development as well as undeveloped acreage. The community of Landers is the largest population center in the Study Area.

The groundwater basins are sparsely populated with most of the population centers located within the Study Area. Population data were provided in the MWA Urban Water Management Plan (UWMP) (2005) for the portion of the population served by water agencies. Although there are some homeowners with private wells in the area, the numbers are difficult to determine accurately and assumed to be negligible. Using the population served by water agencies as representative of total population was determined to be sufficient for the purposes of this study. In addition, the population served in the Means Valley basin was combined with the Ames Valley basin since the Means Valley population was determined to be small. For the purpose of this report, the population served in Means Valley would only affect the demand analysis by basin and since population and demand are not expected to grow significantly in Means Valley, the population to be included in the analysis was determined to be negligible. Estimated 2005 population and private acreage in each of the three groundwater basins are as follows:

Population and Private Land by Groundwater Basin

Basin	2005 Population[1] Served by Water Agencies	Private Land[2] (acres)	Total Basin Area[3] (acres)
Ames Valley	8,300	32,000	110,000
Means Valley	0	1,500	15,000
Johnson Valley	400	11,003	111,630

[1] Population served by water agencies only; Means population unknown but assumed to be negligible for population served by water agencies; MWA UWMP, 2005
[2] Estimated from land use coverage in GIS
[3] DWR Groundwater Basin descriptions

2.1.2 Watersheds

Figure 5 shows the entire watershed for each of the three groundwater basins. Watershed boundaries are based on the California Watershed Portal developed by the California Resources Agency and California Environmental Protection Agency (Cal-EPA) and were judged adequate for the regional-scale work of this project. The watersheds for the Ames Valley, Means Valley, and Johnson Valley basins are designated by Cal-EPA as Emerson, Means, and Johnson, respectively.

The upstream portions in the San Bernardino Mountains contribute runoff and recharge to the basins and are defined as the contributing watersheds in the study. Lower portions of the watershed are of less importance in that very little runoff and essentially no groundwater recharge occurs in those areas. The contributing watersheds and main surface water drainages for the three groundwater basins are shown on Figure 5 and summarized on the following table.

Contributing Watershed for the Groundwater Basins

Basin	Watershed Designation (Cal-EPA)	Contributing Watershed Area[1] (acres)
Ames Valley	Emerson	58,551
Means Valley	Means	3,164
Johnson Valley	Johnson	64,428

[1] Contributing watershed areas measured using project GIS

As shown on the table above, contributing watersheds for the Ames Valley and the Johnson Valley basins are similar in size. The watershed providing runoff and recharge to the Means Valley basin is significantly smaller.

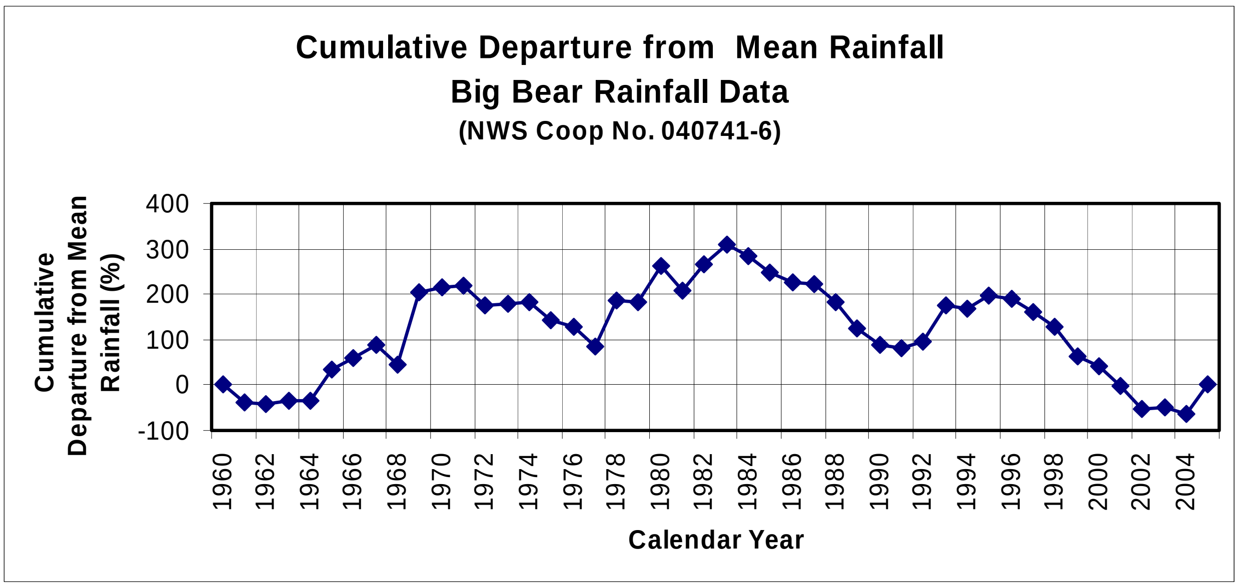
The main surface water drainageways in the contributing watersheds are also identified on Figure 5. These are the principal pathways by which runoff is transported to the three basins. Although maps and documents refer to these features by various names, nomenclature from the USGS topographic maps was used. For unnamed drainages, local nomenclature or other documents were used. As shown on Figure 5, Antelope Creek, Pipes Wash, and their tributaries are the principal drainages contributing runoff to the Ames Valley basin. Three main drainages, Arrastre Creek, Two Holes Spring, and Ruby Canyon, contribute to the Johnson Valley basin. In contrast, Means Valley basin is fed by only one small drainageway, Means Wash (Figure 5).

2.1.3 Precipitation

The groundwater basins and Study Area are characterized by low precipitation and high evaporation, both of which limit natural recharge to groundwater. Average annual rainfall is indicated by contours of equal rainfall, or isohyets, shown on Figure 5. The isohyetal map was provided by MWA (from James, 1992) and represents annual rainfall data from 1960 to 1991. As shown by the isohyets, rainfall ranges from almost 16 inches per year in the upper elevations of the watersheds to less than four inches per year in the northeast basin areas. Rainfall is between four and six inches per year at the upper portions of the valley floor. These data are consistent with three rainfall stations south of the Study Area near Yucca Valley and Joshua Tree. At the closest station, Yucca Valley, long-term average annual precipitation is reported as 4.97 inches per year (Don Howard, 2007). Most of the Johnson Valley and Ames Valley basins and the entire Means Valley basin receive less than four inches per year (Figure 5)

Average potential evapotranspiration (ET) is reported as 66.47 inches per year by DWR for the High Desert region. The maximum daily ET is 0.32 inches per day (July). Even during the winter months, ET ranges from 0.06 inches per day to about 0.15 inches per day. For an average annual rainfall of about 8 inches per year, daily precipitation in the region exceeds 0.2 inches per day only about 10 days per year. These data suggest that rainfall on the valley floor does not contribute significantly to groundwater recharge. Under the empirical Maxey-Eakin Method (1949) for estimating recharge from rainfall (calibrated to Nevada desert conditions), an area with an average annual rainfall less than 8 inches per year would not produce any groundwater recharge. Previous investigators also indicate that average annual rainfall of less than 8 inches per year is insignificant with respect to groundwater recharge (Boyle, 1993).This indicates that runoff generated in the upper reaches of the contributing watersheds is the primary source of water for natural recharge to the basins.

To further evaluate rainfall in the upper reaches of the watersheds, rainfall data in the San Bernardino Mountains were reviewed. The closest station with a relatively long record (1949 to present) was at Big Bear Community Services District (CSD). Data from this station provided information on applicable wet and dry periods for the Study Area. To examine hydrologic periods and identify trends, data were plotted using the accumulated departure method. This method of plotting shows alternating wet, average, and dry periods of various durations, which are indicated by the slope of the cumulative departure curve. An upward slope indicates a wet period, and a downward slope indicates a dry period, but actual rainfall totals are not shown. The cumulative departure curve for Big Bear data is provided below.



A review of these rainfall data indicates that a recent time period of 1989-2001 contains representative wet and dry cycles and an average rainfall consistent with long-term rainfall. This baseline period, along with the average annual rainfall data for the contributing watersheds, was used to evaluate runoff and recharge for the three groundwater basins.

2.1.4 Runoff and Recharge

The relatively high precipitation in the upper reaches of the San Bernardino Mountains watersheds generates runoff that is funneled into drainageways and flows downstream to the groundwater basins. Runoff is variable and does not occur at the same rate with each precipitation event. Rainfall in the mountains is expected to result in very little deep percolation in the upland bedrock areas; however, some rainfall may be lost by infiltration where upland topography is relatively flat. In addition some rainfall is lost to evapotranspiration (ET). There are no stream gages or other flow estimates available in the Study Area (Stamos et al, 2001). In the absence of streamflow data, it is difficult to provide quantitative estimates of water budget components such as runoff and ET in each portion of the contributing watershed.

In the more thoroughly gaged and studied Mojave River Basin, 92 percent of groundwater recharge is attributed to mountain runoff (Hardt, 1971). Because of the ephemeral nature of arid-zone streams, runoff is highly variable and may not occur every year, or with every storm. The best locations for runoff to recharge groundwater likely occur where flow in the main drainageways (shown in Figure 5) crosses the "mountain front" onto the upper portions of the groundwater basins. Runoff percolates in this area where alluvial sediments are coarse and deep and where more frequent high volume flows occur. Here, the unsaturated zone can exhibit relatively high percolation rates, and recharge can occur with less evaporation. As flow progresses downstream, the slopes become flatter and the alluvial sediments become finer, forcing the recharge pattern to widen. Because the finer sediments reduce downward velocities, recharge is more subject to evaporation.

On the lower valley floor, fine grained sediments absorb rainfall and any available soil moisture is used by the desert vegetation or evaporates. The average annual rainfall over the basin floor is less than four inches, and while individual storms may have more rainfall, water tends to collect and evaporate in normally dry lakebeds. The dry lakebeds have a thick layer of sediment that promotes evaporation and limits recharge. Because of the reasons stated above, for this analysis, deep percolation of precipitation (effective precipitation) is considered negligible for both the mountains and the basin floor.

Although recharge from direct percolation on the valley floor is not considered significant for rainfall amounts less than eight inches per year, runoff is generated from the upland portion of the watersheds at these rainfall amounts. This runoff serves as potential recharge to the groundwater basin. To estimate the runoff source areas and associated average annual rainfall, the catchment areas for the main drainages were determined using the project GIS. Then a raster surface of the isohyetal map (James, 1992) was constructed in GIS and the average annual rainfall for each catchment area was determined. Data are summarized below:

Surface Water Contributions to the Groundwater Basins

Groundwater Basin	Surface Water Source	Average Annual Rainfall [1] (inches)	Catchment Areas [2] (acres)
Ames Valley			***58,551***
	Antelope Creek	8.54	35,423
	Hondo Road	6.35	13,434
	Ruby Mountain	5.39	8,581
	Sand Hill Wash	4.52	1,113
Means Valley			***3,164***
	Means Wash	5.11	3,164
Johnson Valley			***64,428***
	Ruby Canyon	6.47	13,389
	Two Holes Spring	8.41	26,142
	Arrastre Creek	11.38	24,896
Total for Study Area			***126,143***

[1] Based on a computer-generated average from a raster surface of isohyetal map by James (1992)
[2] Drainage catchment area within contributing watershed upstream of the groundwater basin (estimated from GIS).

As shown on the table above, the sum of the catchment areas (in the contributing watersheds) for the Ames Valley basin and the Johnson Valley basin are similar (58,551 acres and 64,428 acres, respectively). However, the average annual rainfall to Johnson Valley is higher (up to 11.38 inches) due to the higher elevations in the contributing watershed for that basin. In contrast, the catchment area for the only drainage contributing to Means Valley is much smaller (3,164 acres) and is associated with much lower average annual rainfall (5.11 inches) than Johnson Valley.

The absence of streamflow data and site-specific information made it difficult to quantify runoff for the contributing watersheds. Lines (1996) developed a coefficient relating runoff to channel geometry for washes in the Mojave Desert region. However, Lines did not work in the Study Area and a field determination of local channel geometry was outside of the scope for this study. To overcome this data gap, we combined a series of methodologies to calibrate inflows and outflows to observations of groundwater storage changes using data from the Pipes Subbasin. This methodology was then applied to each of the three basins and is described in detail in the water balance section for each basin.

2.1.5 Geology

The Mojave Desert was formed in the Tertiary Period from movement along the San Andreas Fault to the south and the Garlock Fault to the north, creating the Mojave structural block (Norris and Webb, 1990). Tectonic activity associated with the Mojave structural block was superimposed onto the previously-formed Basin and Range terrain, which was characterized by substantial faulting. The San Andreas and related faults created a horst-like block, uplifting the San Bernardino Mountains on the southwestern edge of the Study Area. Since then, deposition from the San Bernardino Mountains has created coalescing alluvial fans along the mountain front, alluvial deposits along ephemeral washes, and basin-fill deposits in the down-dropped valleys of the groundwater basins. These sediments have been deposited onto hilly topography, essentially burying hills and ridges formed from previous tectonic events. This depositional environment has resulted in groundwater basins with local shallow bedrock highs, intervening outcrops of bedrock, and a complex geometry along the base of the alluvial fill. The geometry of the basins has been altered further by movement along more recent faults that have displaced alluvial sediments and bedrock at depth.

The San Bernardino Mountains and bedrock underlying the groundwater basins consist mainly of Jurassic and Cretaceous granitic rocks. Because of relatively low permeability, the consolidated bedrock is considered to be non-water bearing for the purposes of groundwater basin storage. Domestic wells drilled into these rocks, however, can yield water supplies sufficient for domestic use (Lewis, 1972). Numerous wells have encountered bedrock at various depths, providing data for the interpretation of the alluvial basin bottom developed for this study.

The San Bernardino Mountains dip steeply to the north and east, providing a large thickness of alluvial sediments a short distance from the mountain front. In the Pipes Subbasin, bedrock dips steeply towards the east, extending to depths of about 1,500 feet in the eastern portion of the Flamingo Heights alluvial fan in Pipes Subbasin. Similarly, bedrock dips steeply to the north in the Johnson Valley basin to depths likely reaching 1,000 feet.

The Tertiary and Quaternary age alluvial sediments are the main aquifers in the groundwater basin. The aquifers are the coarse-grained layers of sands and gravels with interbedded layers of silts and clays. The geometry of the basins suggests that basin-fill units were deposited in alluvial fan and fluvial wash environments and sourced from erosion of rocks in the higher elevations of the San Bernardino Mountains. These deposits interfinger in the subsurface, making differentiation of discrete aquifer packages difficult on a regional basis. This phenomenon also results in variable aquifer properties across each groundwater basin.

The Mojave structural block is dominated by extensive northwest-trending faults that appear to terminate regionally near the Garlock Fault outside of the Study Area. Figure 6 shows the location of major faults in the Study Area, illustrating the northwest trends. As shown on the figure, many of these faults coincide with groundwater basin and subbasin boundaries because displacement along the faults has created low permeability zones that often impede groundwater flow. Faults that form basin and subbasin boundaries as shown on Figure 6 are summarized below.

Study Area Faults that Serve as Basin or Subbasin Boundaries

Fault	Basin/Subbasin Boundaries
Johnson Valley Fault	Separates Johnson (Soggy Lake) and Upper Johnson subbasins; Separates Johnson Valley and Means Valley basins; Separates portions of Pipes and Reche subbasins
Pipes Barrier	Separates portions of Pipes and Reche subbasins
Homestead Valley Fault	Separates Reche and Giant Rock subbasins; Separates Means Valley and Ames Valley basins
Emerson Fault	Separates Giant Rock and Emerson subbasins

Because of the obvious structural complexity in the Pipes and Reche subbasins (Figure 6), along with the concentration of groundwater production and population in the area, a re-evaluation of faulting here was conducted for this study. A surface geophysical study (provided in Appendix A) was scoped to provide additional information on several faults in the area including the Pipes Barrier. The Johnson Valley Fault had been mapped in detail after the Landers 1992 earthquake. The geophysical study and evaluation of existing data resulted in a modification to the trace of the Pipes Barrier as shown on Figure 6 and described in more detail in the basin conceptual model for the Ames Valley Groundwater Basin.

2.2 Groundwater Use

Because groundwater is currently the sole source of supply to the area, information on water agencies, groundwater pumping, and distribution systems provides a backdrop to the groundwater basin setting. Summary information on groundwater use is provided in the sections below.

2.2.1 Local Water Agencies

As previously mentioned, service areas for four water agencies overlie portions of the Study Area and groundwater basins as shown on Figure 2. Agencies include Bighorn-Desert View Water Agency (BDVWA), San Bernardino County Special District Area No. 70 (CSA No. 70), Hi-Desert Water District (HDWD), and Joshua Basin Water District (JBWD). Since production in JBWD is outside of the groundwater basins, the district is not examined further in this study. HDWD has historically pumped from the Ames Valley basin and currently maintains one well in the Study Area.

2.2.1.1 Bighorn-Desert View Water Agency

The BDVWA encompasses 45 square miles of desert area serving the communities of Flamingo Heights, Landers, and Johnson Valley. It has approximately 1,880 metered services. The BDVWA operates eight deep wells and ten above-ground reservoir tanks, and maintains about 600 fire hydrants and 130 miles of water main pipelines. The Bighorn-Desert View Intertie pipeline allows export of water pumped from the Ames Valley basin to HDWD service areas in the adjacent Copper Mountain Valley and Warren Valley basins. According to the draft 2007 Water System Master Plan, BDVWA plans to annex an additional 640 acres (Section 35 of 2N/5E) for development of approximately 250 homes. The demand from this development has been considered in the projected demands of this study.

2.2.1.2 Hi-Desert Water District

HDWD provides water to the town of Yucca Valley and portions of unincorporated areas of San Bernardino County. HDWD serves approximately 25,000 people (with close to 10,000 connections) in their 50 square mile service area. HDWD maintains approximately 274 miles of pipeline ranging from a diameter of 2 inches to 12 inches. There are 16 storage tanks with a total storage of 12.66 million gallons. With 17 wells in operation, HDWD is able to produce a maximum of 7,000 gallons per minute (gpm) from the Warren Valley Basin. There are four HDWD wells in the Ames Valley basin, but only one is operational and is used to serve HDWD customers in the basin. HDWD also operates three recharge ponds in the Warren Valley Basin, each of which percolates SWP water delivered by the Morongo Basin Pipeline. HDWD is currently considering construction of a wastewater treatment plant. Treated effluent from the plant is expected to be used to recharge the Warren Valley basin.

2.2.1.3 San Bernardino County Special District

CSA No. 70 is a water district within the Special Districts Department of the Water and Sanitation Division. It provides water services to a community of approximately 2,030 customers with 615 meters. The water system consists of three wells in the Ames Valley basin and three storage tanks with a combined capacity of 620,000 gallons.

2.2.1.4 Water Haulers

In addition to groundwater service through their distribution system, BDVWA provides groundwater to bulk haulers for offsite use. BDVWA currently has 80 active bulk water hauling metered accounts from four water drop locations within the Study Area. A water drop location is a tank filled with water from the BDVWA distribution system for haulers to drive up to, fill up their truck tank, and haul to an end user. The source of the water is BDVWA groundwater wells. Water hauling is used in areas where a pipeline distribution system has not been developed. Water is delivered to construction, commercial, and residential users in Johnson Valley, Landers, Pipes Canyon, Pioneertown, and other locations.

Of the 80 accounts, 73 are held by private residents and 7 are held by commercial water haulers. Since the amounts delivered by the commercial haulers represent the largest accounts, a summary of the commercial water hauler deliveries is provided in the following table.

Bulk Water Delivered by Commercial Water Haulers

Hauler	Estimated No. of Locations or Households Served	Total Average Delivery (AFY)	Location of Deliveries, Comments
Commercial Hauler 1	35	2.17	Johnson Valley and Landers area
Commercial Haulers 2 and 3	47	6.15	Johnson Valley and Landers area; 2 commercial customers
Commercial Hauler 4	45	1.93	Households estimate based on similar consumption to Hauler 2 and 3
Commercial Hauler 5	5	2.14	Mostly construction sites
Commercial Hauler 6	40	0.72	Pipes Canyon and Johnson Valley area
Commercial Hauler 7	7	0.19	Pioneertown and Pipes Canyon area
Total	**179**	**13.29**	

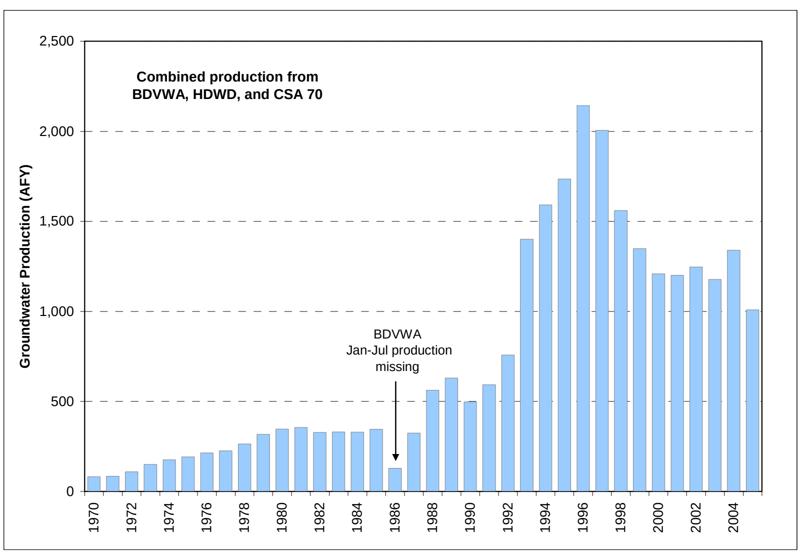
Source: Bighorn-Desert View Water Agency memorandum dated July 26, 2006.

As shown on the table, water haulers delivered about 13 AFY to about 191 locations. The water associated with water hauling accounts is included in the total system production for BDVWA.

2.2.2 Groundwater Pumping

Groundwater is pumped from 12 active wells operated by BDVWA, HDWD, and CSA-70 in the Study Area. With the exception of one well, all pumping is located within the Ames Valley Groundwater Basin. One well, operated by BDVWA, is in Johnson Valley. There is no known pumping in the Means Valley basin. Pumping data in the Study Area were provided by BDVWA. Almost all of the pumping provides water for residential and commercial use; there is no agricultural or industrial pumping in the Study Area. Annual groundwater production from 1970 to 2005 in the Study Area is shown on the following graph.

Groundwater Pumping in the Study Area 1970-2005



As shown above, pumping increased gradually in the Study Area from about 80 AFY in 1970 to about 325 AFY in 1987. Pumping averaged more than 600 AFY for the next five years and increased significantly in the period 1993-1999 as a result of export from the Ames Valley basin to the adjacent Copper Mountain Valley and Warren Valley basins occurring at the BDVWA Intertie. During that time period, annual pumping averaged about 1,700 AFY. Pumping decreased to about 1,200 AFY in 2000 and has averaged 1,197 AFY over the last six years.

Production from three private production wells in the Ames Valley basin (two wells owned by Gubler Farm and one well owned by Patty Karaqcizyk) is unknown (Don Howard, 2007).

2.3 Institutional Framework

Various water supply agreements are applicable to the groundwater management in the Study Area, including a semi-adjudication in a portion of the Ames Valley basin and an agreement for the users of the Morongo Basin Pipeline. These agreements guide the distribution of water and operation of water supply infrastructure and are summarized in the sections below.

2.3.1 Ames Valley Basin Water Agreement

The Ames Valley Basin Water Agreement is an Agreement between HDWD and BDVWA for the construction and operation of the HDWD Mainstream Well in the Ames Valley basin. The purpose of the agreement is to improve reliability of the shared groundwater supply by limiting extractions. The new well, Mainstream Well (referred to in this study as HDWD 24) was constructed on BLM land between the HDWD and BDVWA service areas. The Agreement was filed in January 10, 1991 and followed by a Stipulation for Judgment (Judgment) filed on June 3, 1991.

At the time the Agreement and Judgment were entered, the HDWD service area included areas within the Ames Valley basin and the Warren Valley basin. Section 2 of the Agreement specifically states that water diverted from wells within the Ames Valley basin will be used only within the basin. Although the Judgment provides for an increase in the amount pumped by HDWD, it states that the increased production must be for water needs within the Ames Valley basin. The Judgment further provides that HDWD Mainstream Well is limited to a maximum pumping of 800 AFY. However, production may be increased by 0.5 AFY for each new connection within the Ames Valley basin. A Motion for Relief was submitted by HDWD to include an expanded “Yucca Mesa Area” and to strike Section 2 of the Agreement in order to use the Mainstream Well to serve areas outside of the Ames Valley basin; however, this motion was denied.

2.3.2 Morongo Basin Pipeline Agreement

The Morongo Basin Pipeline Agreement of 1991 is an agreement between BDVWA and MWA for construction, operation, and financing of the Morongo Basin Pipeline Project. Other participants in the contract are CSA No. 70, HDWD, and JBWD. Exhibit A of this Agreement defines the percent capacity of the pipeline allotted to BDVWA, CSA No. 70, HDWD, and JBWD.

Percent allotment of project capacity is as follows:

- BDVWA: 9 percent
- CSA No. 70, Improvement Zone W-1: 4 percent
- CSA No. 70, Improvement Zone W-4: 1 percent
- HDWD: 59 percent
- JBWD: 27 percent

Of these users, only BDVWA and CSA No. 70 Zone W-1 can be delivered water in the Study Area, accounting for 13 percent of the project capacity. Unused capacity in the pipeline may be used by the participants for any additional water made available by MWA, subject to additional costs for operation and maintenance.

2.3.3 Warren Valley Basin Agreement

The Warren Valley Basin Agreement is an agreement between MWA, HDWD, and the Warren Valley Basin Watermaster. This agreement affects the use of the Morongo Basin Pipeline, including pipeline users in the Study Area. The primary purpose of the agreement is to more efficiently use available water supply and to provide supplemental water to the Watermaster in the event that water levels drop too low to support the adjudicated water rights in the basin. Additionally, SWP water delivered to the Warren Valley basin as part of this Agreement will be credited to a “MWA storage water account” without limitations if no adverse effects are observed. The agreement allows for MWA to store excess SWP water in the basin as long as the deliveries do not interfere with rights of other water users within MWA. Before MWA can withdraw water from the Storage account, delivery of at least 2,500 AFY plus the 1,935 AF of Shrinkage Water (potential water loss) must be credited to the account.

3 BASIN CONCEPTUAL MODEL OF THE AMES VALLEY GROUNDWATER BASIN

The DWR Ames Valley Groundwater Basin covers 110,000 acres (169.7 square miles) of the High Desert region (DWR, 2003). The basin is bounded by the San Bernardino Mountains to the west, non-water bearing rocks to the north and northeast, northwest trending faults to the east, and a surface drainage divide to the south. As shown in Figure 1, the basin overlies the Pipes, Reche, Giant Rock, southern portion of the Emerson, and northern tip of the Surprise Spring subbasins of the greater Morongo Groundwater Basin (Stamos et al., 2004). Additionally, the Ames Valley Groundwater Basin includes the Pioneertown Subbasin (Lewis, 1972).

This section presents a hydrogeologic conceptual model for the Ames Valley Groundwater Basin. The conceptual model was developed using information from existing hydrogeologic reports and available geologic, geophysical, and groundwater data. Data sources are summarized in Section 1.4, and key references are provided at the end of this report. Hydrogeologic components of the basin are described including basin geometry, major faults and hydraulic barriers, distribution of basin fill deposits, aquifer parameters, groundwater levels and trends, and groundwater quality. A preliminary groundwater basin water balance is also provided including an analysis of basin inflows (runoff from the mountains, subsurface groundwater inflow, and septic system returns), outflows (groundwater pumping, subsurface groundwater outflow, and evapotranspiration), and change in storage. This water balance is used to estimate the perennial yield of the basin.

3.1 Faults and Hydraulic Barriers

The Ames Valley Groundwater Basin lies within the Eastern California Shear Zone, a region of concentrated seismic activity that stretches north-northeast from the San Andreas Fault across the Mojave Desert and into the Owens Valley. Major geologic structures in the Ames Valley Groundwater Basin are shown on Figure 6 and include Pipes Barrier and the Johnson Valley, Kickapoo, Homestead Valley, and Emerson faults. Previous researchers have identified these structures as partial barriers to groundwater flow using primarily groundwater level data (Lewis, 1972; Trayler and Koczot, 1995; GSI, 2000). The following sections describe the historic and current understanding of each structure with respect to its location and influence on groundwater flow. Interpretations are based on a literature review, groundwater level data, and results of recent geophysical (electrical resistivity and TEM) surveys conducted by Ruekert & Mielke (2007). Figure 4 shows the locations of the geophysical surveys and the full report is attached as Appendix A.

3.1.1 Pipes Barrier

The Pipes Barrier is an inferred fault roughly coincident with a portion of the Pipes/Reche subbasin boundary. A steep groundwater gradient across Pipes Barrier was first identified by Lewis (1972) from 1969 groundwater level data. Because figures depicting Pipes Barrier covered a very large area, and groundwater levels for individual wells were not presented, the Lewis report cannot be used to locate precisely the trace of Pipes Barrier. Using 1994 groundwater level data, Trayler and Koczot (1995) documented a steep groundwater gradient southeast of Pipes Wash confirming the location of Pipes Barrier in this area. Although the steep groundwater gradient could not be identified northwest of Pipes Wash with groundwater level data, Trayler and Koczot inferred a single northwest-trending trace for Pipes Barrier towards its intersection with the Johnson Valley Fault. GSI (2000) later re-interpreted the trace of Pipes Barrier using gravity survey data and included two traces, one on each side of the Trayler and Koczot trace of Pipes Barrier.

Due to the significance of Pipes Barrier with respect to potential conjunctive use projects and the uncertainty surrounding its location and impact on groundwater flow, geophysical surveys (electrical resistivity and TEM) were conducted to help refine the trace of Pipes Barrier and to determine the degree to which groundwater flow is impeded along this geologic structure (in both horizontal and vertical directions). Figure 4 shows the location of the geophysics program and Figure 6 shows the new interpreted trace of Pipes Barrier based on the results of electrical resistivity surveying (see Ruekert & Mielke, 2007 in Appendix A). Modeled resistivity profiles generated along Resistivity Lines 4, 7, 8, and 14 reveal a high resistivity anomaly dipping approximately 70 degrees to the west. This anomaly is interpreted as clay gouge along Pipes Barrier (Ruekert & Mielke, 2007). Displacement is observed along two planes through Pipes Wash (Lines 7 and 8 on Figure 4), and no anomaly is observed in the profile generated along Resistivity Line 9, indicating that the displacement planes in Pipes Wash likely trend along either side of Resistivity Line 9 (Figure 4). The occurrence of multiple displacement planes is not surprising, considering the high degree of *en echelon* faulting (staggered or overlapping arrangement of fault traces within a fault zone) associated with the nearby Johnson Valley Fault.

Profiles along Resistivity Lines 4, 7, 8, and 14 (Figure 4) reveal a clearly defined boundary between a shallow, high-resistivity unit and a deeper, low-resistivity unit at a depth of between 150 and 200 feet (Ruekert & Mielke, 2007 in Appendix A). This boundary coincides with the estimated location of the water table, indicating that the boundary reflects a change in saturation and possibly lithology as well. In each profile a dipping high resistivity anomaly can be seen within a deeper, low-resistivity unit beneath Pipes Wash and Whalen’s Wash. The anomaly does not extend into the shallow, high-resistivity unit, indicating that clay gouge may not exist in shallow sediments beneath the washes. There are currently insufficient data to confirm if 1) the lithology of the high resistivity unit is too coarse-grained to develop clay gouge, 2) the lithology of the high resistivity unit is too coarse-grained for clay gouge to be measured, or 3) the most recent displacement along Pipes Barrier occurred prior to the deposition of the shallow, high resistivity unit beneath the washes.

Regardless of which explanation is correct, the horizontal resistivity boundary appears to be vertically offset and uplifted on the west side of Pipes Barrier between 40 and 60 feet in the profiles. This vertical offset suggests groundwater is being restricted by and builds up along Pipes Barrier. Results of resistivity surveys and DWR well completion reports indicate that basin fill sediments located outside of the washes along Pipes Barrier generally have higher clay content than inside the washes. Therefore, it is reasonable to expect that clay gouge along Pipes Barrier also impedes groundwater flow outside of Pipe Wash and Whalen’s Wash.

3.1.2 Johnson Valley Fault

Due to its recent rupture history and possible influence on groundwater flow, the Johnson Valley Fault has been well studied and mapped (Riley and Worts, Jr. 1953; Lewis, 1972; Rockwell, et al., 2000; GSI, 2000). Figure 6 shows that the Johnson Valley Fault extends the length of the Pipes Subbasin in the Ames Valley Groundwater Basin. North of the junction between Pipes Barrier and Johnson Valley Fault, the Johnson Valley Fault is oriented to the northwest and represents the eastern boundary of Pipes Subbasin. South of this junction, the alignment of the main trace of Johnson Valley Fault is north-south and generally coincides with Highway 247. Riley and Worts, Jr. (1953) observed that uplift occurs on the west side of Johnson Valley Fault north of Whalen's Wash (see Figure 5 for location), while south of Whalen's Wash, topography along Johnson Valley Fault is characterized by a low west-facing scarp, indicating uplift occurs on the east side of the fault. Surface rupturing along the fault has been mapped with multiple planes of displacement, particularly west of Highway 247 in the Flamingo Heights area, where *en echelon* faulting is prevalent. Surface rupture along the Johnson Valley Fault during the 1992 Landers Earthquake has led previous investigators to conclude that the fault probably impedes groundwater flow (GSI, 2000 and Rasmussen, 2000). However, historic groundwater level, pumping test, and geophysical data have been insufficient to confirm this theory.

Geophysical surveys (electrical resistivity and TEM) were conducted to confirm whether the Johnson Valley Fault impedes groundwater flow through the Pipes Subbasin specifically in the Flamingo Heights area (Lines 10 and 11 on Figure 4). Resistivity profiles along Resistivity Lines 10 and 11 indicate that the Johnson Valley Fault dips about 45 degrees to the west in this vicinity. Displacement is evident along two planes in each profile (Ruekert & Mielke, 2007). Resistivity anomalies interpreted as clay gouge are evident and extend from the base of the profile to the ground surface. Similar to surveys across Pipes Barrier, a boundary between the shallow, high-resistivity unit and deeper, low-resistivity unit is observed. Vertical offset of the low resistivity unit across the two fault planes in Line 11 can also be seen. However, the resistivity contrast and degree of vertical offset are not as clear compared to profiles across Pipes Barrier beneath the washes, making it difficult to confirm to what degree the Johnson Valley Fault impedes groundwater flow at these locations. The dampened resistivity contrast across Johnson Valley Fault may be attributable to the presence of more heterogeneous sediments located near the fault compared to the washes. Overall, the results of electrical resistivity surveys are consistent with the presence of clay gouge along the Johnson Valley Fault and provide evidence that groundwater flow in the Pipes Subbasin is impeded by the fault. Additional groundwater monitoring wells east of Johnson Valley Fault would help verify the degree to which the fault impedes groundwater flow.

3.1.3 Homestead Valley Fault

The Homestead Valley Fault generally correlates to the boundary between the Reche and Giant Rock Subbasins within the Ames Valley Groundwater Basin. A groundwater level drop of 200 to 250 feet from the Reche Subbasin to the Giant Rock Subbasin was first identified by Riley and Worts Jr. (1953), indicating that the Homestead Valley Fault significantly impedes groundwater flow. However, because the location of the Homestead Valley Fault through the central portion of the Reche Subbasin is unclear, geophysical surveys were conducted across the fault in this area (see Lines 12 and 13 on Figure 4).

Resistivity Lines 12 and 13 indicate clay gouge occurs along two planes across the inferred location of the Homestead Valley Fault in this area. A clearly defined boundary between a shallow, high resistivity unit and deeper, low resistivity unit is seen in both profiles and coincides with the estimated groundwater level in this location. The vertical offset of the boundary between the high and low resistivity units across the displacement plane in the profile generated along Resistivity Line 12 coincides closely with the large groundwater level drop from Reche Subbasin to Giant Rock Subbasin. Even though groundwater flow is impeded in this area, some cross flow likely occurs. Outcrops of bedrock to the north and south likely funnel groundwater flow to this area.

3.1.4 Kickapoo Fault

The Kickapoo Fault is located in the northern portion of the Reche Subbasin and represents a restraining bend between the Johnson Valley and Homestead Valley faults (Sowers, et al., 1994). Investigation of the surface rupture along the Kickapoo Fault after the 1992 Landers Earthquake indicates that it is structurally linked to both the Johnson Valley and Homestead Valley Faults but has a different rupture history (Rockwell, et al., 2000). Alluvial sediments have been uplifted and pressure ridges exist along the Kickapoo Fault, indicating a compressional feature (Sowers, et al., 1994). The thickness of saturated basin fill deposits is small in this area and groundwater water level data indicate that the Kickapoo Fault impedes groundwater flow from west to east.

3.1.5 Emerson Fault

In the eastern portion of the Study Area, the Emerson Fault separates the Giant Rock Subbasin from the southern portion of the Emerson Subbasin and northern portion of the Surprise Spring Subbasin. Previous investigators identified a groundwater level drop of approximately 50 feet from Giant Rock Subbasin to the Surprise Spring and Emerson Subbasins, indicating groundwater flow is impeded by the Emerson Fault (Schaefer, 1978; Londquist and Martin, 1991).

3.2 Basin Geometry

Consolidated pre-Tertiary rocks, including quartz monzonite/diorite and schist, comprise the bedrock underlying the basin fill deposits of the Ames Valley Groundwater Basin. Although small quantities of groundwater for domestic use can be extracted from fractures, bedrock is generally considered to be non water-bearing and constitutes the basin floor. As a result of historical faulting in the area, the elevation of bedrock across the basin is highly variable.

Depths to bedrock (in feet below ground surface or bgs) in the western Ames Valley basin were mapped for this study using lithologic logs in well completion reports, borehole geophysical logs, and geophysical (gravity and TEM) data. Data were incorporated into a GIS database and calibrated to the DEM for the Study Area. A raster surface representing the bedrock surface across the Pioneertown, Pipes and Reche Subbasins was generated, as shown in Figure 7. The gradational shading on Figure 7 illustrates that the deepest portions of the Ames Valley basin are in southern Pipes and Reche subbasins. Bedrock is shallow in Pioneertown as indicated by the light shading. Data were insufficient to determine depths to bedrock in the Giant Rock and Emerson Subbasins.

Five hydrogeologic cross-sections across the Ames Valley basin were prepared to evaluate and illustrate bedrock elevations and basin geometry. Cross sections, shown on Figure 8, were located to incorporate the maximum amount of hydrogeologic data in the basin. Cross sections covering portions of the Ames Valley Groundwater Basin, A-A' through E-E', are presented on Figures 9 through 13, respectively and are discussed in more detail by subbasin below.

3.2.1 Pipes Subbasin

Depth to bedrock in the Pipes Subbasin is illustrated on west to east Cross Sections A-A', B-B', and D-D' (Figures 9, 10, and 12). Cross Section A-A' shows that bedrock in the Pipes Subbasin slopes from the surface along the western margin of the basin to approximately 1,300 feet deep in the vicinity of Flamingo Heights near Johnson Valley Fault (Figure 9). Cross Section B-B', crosses the Flamingo Heights Fan to the south and turns east, showing the bedrock geometry south of A-A' (Figure 8). As shown on B-B', bedrock rises in the subsurface to the east towards Pipes Barrier (Figure 10). Uplift due to historical fault activity has apparently created a northeast-trending bedrock ridge at the Pipes/Reche subbasin boundary as illustrated on B-B' (GSI, 2000). The ridge is encountered in the subsurface at 354 and 406 feet bgs in HDWD 6 and HDWD 20, respectively, which are located on the northwest side of this bedrock ridge. The ridge rises to the surface and crops out south of the section (Figure 8). Shallow bedrock is also encountered on the eastern edge of B-B' as the section leaves the Reche Subbasin (Figure 10). On Cross Section D-D', north of the other sections and Whalen's Wash, bedrock in the Pipes Subbasin is generally shallower and is encountered at 140 feet bgs in Well 2N/5E-10Q2 (Figure 12).

3.2.2 Reche Subbasin

Portions of Reche Subbasin are shown on Cross Sections A-A' through E-E' (Figures 9 through 13) with Cross Section C-C' extending north-south through most of the subbasin (Figure 11). On these sections, bedrock depths generally range from 300 to 600 feet. As shown on cross sections A-A' and B-B' (Figures 9 and 10) and discussed above, uplifted bedrock on the east side of Pipes Barrier has resulted in shallower bedrock elevations in Reche Subbasin relative to Pipes Subbasin. Near the intersection of Pipes Wash and Whalen's Wash, bedrock was encountered in HDWD 24 (2N/5E-24H1) at 595 feet (Figure 9). The variability of bedrock and basin fill in the Reche Subbasin is best illustrated on north-south Cross Section C-C' (Figure 11). As shown on the section, bedrock was encountered at 462 feet in Well 2N/5E-12N1 and at 485 feet in BDVWA 9 (2N/5E-12C2) just north of Whalen's Wash (Figure 11). Shallow bedrock north of BDVWA 9 limits the saturated thickness of sediments and generally ranges from 100 to 250 feet deep (Figure 11). Numerous wells in this area encountered shallow bedrock and mostly clay and decomposed granite above the bedrock surface (Figure 11). The condition of shallow bedrock and thin saturated sediments continues to the northern edge of the Reche Subbasin as shown on Cross Section E-E' (Figure 13). At the eastern edge of Reche Subbasin, bedrock was encountered in well 2N/6E-07Q3 at 346 feet (Cross Section D-D' on Figure 12).

3.2.3 Pioneertown, Giant Rock, and Emerson Subbasins

No hydrogeologic cross sections were developed through the Pioneertown Subbasin due to the shallow bedrock conditions documented in driller's logs. Of 58 wells drilled in the Pioneertown Subbasin, bedrock was encountered in 39 wells within the first 20 feet. The maximum encountered depth to bedrock in the basin was 80 feet (1N/5E- 06N1). These shallow bedrock conditions are also evident on the Depth to Bedrock map on Figure 7.

Geologic data for determining the bedrock surface in the Giant Rock Subbasin were limited. Here, depth to bedrock appears to range from about 340 to about 400 feet, as indicated by wells 2N/6E-07H1 and 2N/6E-05N1 (Cross Section D-D' on Figure 12). Bedrock becomes shallower to the east and crops out as prominent peaks, including Goat Mountain, as shown on Figure 12.

No well or gravity data were available for determining bedrock elevations in the Emerson Subbasin. However, in the development of a calibrated, steady-state groundwater model for the Surprise Spring Subbasin, bedrock in the southern portion of the Emerson Subbasin at the Surprise Spring boundary was thought to be deeper than 1,000 feet (Londquist and Martin, 1991). Bedrock is much shallower north of this area toward Emerson Dry Lake.

3.3 Basin Fill Deposits and Aquifer Parameters

In order to resolve the complex distribution of basin fill deposits in the Ames Valley Groundwater Basin, an understanding of the evolution of the major geomorphic features (representing geologic units) is essential, including key alluvial washes, fans, and dry lakes. Basin fill deposits are derived principally from eroded rocks of the San Bernardino Mountains, (quartz monzonite/diorite, schists, and basalts), and consist of intercalated lenses of Tertiary and Quaternary clay, silt, sand, and gravel. Sediments were transported from the mountains by alluvial washes through the narrow canyons in the mountains and created alluvial fans when they were deposited on the basin floor. The locations of major washes and fans including Pipes Wash, Whalen's Wash, Ruby Mountain Wash, Yucca Mesa Fan, Flamingo Heights Fan, and Ruby Mountain Fan are shown on Figure 14 and described in more detail below.

3.3.1 Pipes Wash

Pipes Wash is a fluvial channel representing the confluence of Antelope Creek and its tributaries in the Pioneertown Subbasin (Figure 14). Pipes Wash enters the southern portion of Pipes Subbasin through a narrow gorge eroded in granite east of Highway 247 and traverses the Pipes, Reche, and Giant Rock Subbasins generally as a 2,000-foot wide, flat-floored wash (Rasmussen, 2000). Previous investigators concluded that the Yucca Mesa Fan to the south of the Study Area was created by sediments transported through Pipes Wash. Historical fault activity, resulting in bedrock uplift, re-oriented Pipes Wash to its existing location to the north (GSI, 2000). This interpretation is based on a gravimetric investigation, in which an anomaly (interpreted as a bedrock ridge) appears to extend from a bedrock outcrop southwest of Pipes Wash to the northeast through the Pipes and Reche Subbasins.

All of the major washes in the basin are comprised primarily of arkosic sediments, derived from eroded granitic rocks of the San Bernardino Mountains. Resistivity surveys (Lines 7, 8, 14, and

15 on Figure 4) indicate that Pipes Wash is underlain by a shallow, high resistivity (coarse-grained) unit down to a depth of 200 to 250 feet, with a low resistivity (fine-grained) unit occurring at greater depth within the Pipes and Reche Subbasins (see Ruekert & Mielke, 2007 in Appendix A). Pipes Wash is deeply incised though the landscape, indicating that the wash has not migrated significantly from its current position in a relatively long time. The southeastern banks of Pipes Wash are comprised of older alluvium and recent sand dunes deposited by prevailing westerly winds and rise up to 150 feet above the wash floor.

3.3.2 Whalen's Wash and Flamingo Heights Fan

Whalen's Wash originates in the Pipes Subbasin and traverses the Pipes and Reche subbasins as a 1,000-foot wide flat-floored wash (Figure 14). The wash merges with Pipes Wash in the Reche Subbasin. Whalen's Wash is currently bounded along the northern edge of the Flamingo Heights Fan by its incised banks, which are comprised of older alluvium and rise up to 80 feet above the wash floor. Nonetheless, it is apparent that sediments transported by Whalen's Wash formed the Flamingo Heights Fan south of the current alignment of the wash (Figure 14).

Resistivity surveys (Lines 3 and 4, Figure 4) indicate that Whalen's Wash is underlain by coarse-grained sediments to a depth greater than 450 feet west of Highway 247 and 200 to 250 feet east of Highway 247, with progressively finer-grained sediments occurring at increasing depths (Ruekert & Mielke, 2007).

The largest and steepest alluvial fan in the western portion of the basin is the Flamingo Heights Fan, which is located along and south of Whalen's Wash. The width of the fan is about two miles as it crosses Highway 247 and the Johnson Valley Fault. As mentioned above, sediments of the Flamingo Heights Fan were probably deposited by Whalen's Wash in a predominantly eastern direction. Evaluation of lithologic logs, supported by resistivity surveys (Lines 1 and 2 on Figure 4), indicate that shallow sediments (upper 450 feet) are coarse-grained in the upper fan area but grade quickly to silty sands down the fan axis, a depositional pattern expected for alluvial fans (Ruekert & Mielke, 2007).

Some data indicate that the coarse-grained portion of the Flamingo Heights Fan extends further away from the mountain front with depth. Coarse-grained sediments were encountered during drilling of the USGS Monitoring Well (2N/5E-27A1) and BDVWA 8 (2N/5E-22J1) at depths of around 800 feet. Gravity surveys indicate that the thickness of basin fill sediments may be as much as 1,300 feet in this area. However, the driller's log for BDVWA 8 indicates that "hard rock" was encountered from 838 to 871 feet, indicating that matrix porosity at these depths is probably somewhat lower due to increased cementation.

3.3.3 Ruby Mountain Wash and Ruby Mountain Fan

Ruby Mountain Wash originates in the Pipes Subbasin and is located north of Whalen's Wash (Figure 14). Unlike the other major washes in the basin, Ruby Mountain Wash does not create a deep incision in the landscape as it crosses Pipes and Reche subbasins. Thus, the fan that Ruby Mountain Wash creates (Ruby Mountain Fan) is actively growing or prograding.

Ruby Mountain Fan is prograding in a northeasterly direction. Cross-section D-D', which crosses the southern portion of the fan, indicates that thickness of basin fill sediments increases eastward to approximately 500 feet (Figure 12). The driller's log for Well 2N/5E-12N1 indicates that coarse-grained sediments down to 271 feet are underlain by progressively finer-grained sediments at increasing depth before reaching granitic bedrock at 462 feet.

3.3.4 Emerson Dry Lake

An additional geomorphic feature of importance to groundwater flow in the Ames Valley Groundwater Basin is Emerson Dry Lake, a playa located in the central portion of the Emerson Subbasin (Figure 14). Because of the high evaporative potential on the basin floor and relatively shallow groundwater occurrence near the playa (about 40 feet), Emerson Dry Lake serves as a natural discharge point for groundwater flow including underflow along Pipes Wash (Lewis, 1972).

3.3.5 Aquifer Parameters

For this study, well data were reviewed and compiled to generate aquifer parameters for the Ames Valley Groundwater Basin. Specific capacity data derived from aquifer pumping tests were evaluated to estimate and identify the distribution of aquifer transmissivity (T) values and hydraulic conductivity (K) values within the Study Area. Available hydraulic data sources for this evaluation included step-drawdown pumping test results for BDVWA and HDWD production wells and DWR driller's logs. Table 2 shows the calculated specific capacity and estimated aquifer parameters for wells in the Study Area, although most of the data are from the Ames Valley Groundwater Basin. Wells are grouped by groundwater basin/subbasin. For major production wells with multiple pumping tests results, average hydraulic data and aquifer parameters are presented.

Specific Capacity. The specific capacity is a normalized property of a well that is defined as the discharge of the well in gallons per minute (gpm) divided by the water level drawdown in feet. This normalized parameter represents the productivity of the well. The drawdown is the vertical distance between the static water level (SWL) and the pumping water level. The specific capacity is time and discharge dependent: the greater the elapsed time of pumping the smaller the specific capacity, and the greater the discharge for a given time the smaller the specific capacity. The specific capacity for each period of continuous undisturbed pumping was computed by dividing the discharge rate by the maximum water level drawdown in the pumping well.

Specific capacity data for wells in the Ames Valley Groundwater Basin range from less than 0.1 up to 52.2 gallons per minute per foot of drawdown (gpm/ft of dd). Specific capacities of active municipal production wells range from 16.7 to 52.2 gpm/ft of dd in the Pipes Subbasin and from 25.9 to 48.4 gpm/ft of dd in the Reche Subbasin. Wells screened in low permeability sediments have low specific capacities. For instance, specific capacities of wells screened in bedrock within the Pioneertown Subbasin are significantly lower and range from less than 0.1 to 0.5 gpm/ft of dd. Wells located in 3N / 5E of the Reche Subbasin are screened in cemented sediments and bedrock (see Cross Section C-C', Figure 11) and have low specific capacities, ranging from less than 0.1 to 3.0 gpm/ft of dd. Specific capacities of wells in the Giant Rock and Surprise Spring subbasins are all less than 1.0 gpm/ft of dd.

Transmissivity (T) Values. The transmissivity (T) of an aquifer represents the ease with which groundwater flows through an aquifer and can be measured from a constant-discharge pumping test. Large T values (greater than 10,000 gpd/ft) indicate prolific aquifers that can be pumped for several hundreds or thousands of gpm; small T values (less than 1,000 gpd/ft) represent low-yield aquifers that are used primarily for relatively small water supplies, such as livestock watering or domestic use. Empirically, the T value is directly proportional to the specific capacity and is estimated by multiplying the specific capacity by a coefficient of 1,500 for an unconfined aquifer (Appendix 16D in Driscoll, 1986). Because the empirical method depends on the specific capacity of the pumping well (and hence the well efficiency, which is commonly less than 100 percent), the empirically derived T value is considered a conservative estimate of the actual T value of the aquifer. A more reliable estimate of the T value can be derived from time-drawdown analysis and can be compared to the empirical T value to determine the well efficiency. Hydraulic data collected from historical pumping tests of Study Area wells did not allow for reliable time-drawdown analysis.

To estimate the T value for each well, the specific capacity was multiplied by the constant relating to unconfined conditions (1,500) (Table 2). Figure 15 shows the spatial distribution of high and low T values for wells in the Ames Valley Groundwater Basin. T value calculations for each well (grouped by Subbasin) are presented in Table 2 and summarized below.

Aquifer Transmissivity
Ames Valley Groundwater Basin

USGS Morongo Subbasin	Number of Wells	Transmissivity (gpd/ft)	
		Geometric Mean	High
Giant Rock	2	758	1,500
Pioneertown	16	104	808
Pipes	13	2,049	78,375
Reche	19	2,118	72,664

Figure 15 and the summary table above show that the highest estimated T values are located in the Reche and Pipes Subbasins. The mean T value in the Pipes Subbasin based on the evaluation of 13 wells is 2,049 gpd/ft. The highest T values were calculated for BDVWA Wells 2, 3, 4, and 8 near the Johnson Valley Fault indicating that permeable sediments exist in the Flamingo Heights Fan possibly to depths of 700 and 800 feet. The highest T value in the Pipes Subbasin was calculated for BDVWA 8 (78,375 gpd/ft). In the Reche Subbasin, the mean T value based on the evaluation of 19 wells is 2,118 gpd/ft. High-yielding units in the Reche Subbasin are located near the confluence of Whalen’s Wash and Pipes Wash, where coarser-grained sediments are expected. The highest T value in the Reche Subbasin was calculated for HDWD 24 (72,664 gpd/ft) (Table 2).

Wells located north of BDVWA 6, 7, and 9 in the Reche Subbasin have relatively low T values ranging from 58 to 4,500 gpd/ft. Cross Section C-C’ (Figure 11) indicates that aquifer units in this area are comprised of weathered granite and cemented sands and gravel. The average saturated screen length of wells in this area is only about 60 feet.

Hydraulic Conductivity (K) Values. Hydraulic conductivity (K) of an aquifer is a normalized quantity of the aquifer permeability and is a more fundamental property of the permeability than the T value. The K value in gallons per day per square foot (gpd/ft^2) is computed as the T value (in gpd/ft) divided by the aquifer thickness (in feet). For this study, two methods were used to estimate the aquifer thickness, which provided the full range of possible K values for each well. For the first method, the aquifer thickness was represented by the total saturated screen length. For the second method, the aquifer thickness was represented by the vertical distance between the static water level and the bottom of the lowest well screen. Using the saturated screen length as the aquifer thickness provides the upper K value boundary, while using the vertical distance between the SWL and bottom of the lowest well screen as the aquifer thickness provides the lower K value boundary. Figure 16 shows the spatial distribution of the estimated K values for wells in the Ames Valley Groundwater Basin. K value calculations for each well grouped by USGS Morongo Subbasin are presented in Table 2 and summarized below.

Hydraulic Conductivity for
Ames Valley Groundwater Basin

USGS Morongo Subbasin	Number of Wells	Hydraulic Conductivity (gpd/ft^2)	
		Geometric Mean[a]	High
Giant Rock	2	1	13
Pioneertown	16	<1	18
Pipes	13	12 - 16	654
Reche	19	19 - 23	545

[a] Higher K-value corresponds to b = total saturated screen length.
Lower K-value corresponds to b = bottom of well screen minus depth to SWL

Figure 16 and the summary table above show that, similar to the distribution of T values, the highest estimated K values are located in the Reche and Pipes Subbasins. The mean K values in the Pipes Subbasin based on the evaluation of 13 wells range from 12 to 16 gpd/ft^2. The highest K values in the Pipes Subbasin were calculated for BDVWA 2 and 3 (479 to 515 gpd/ft^{2}and 515 to 654 gpd/ft^2, respectively). In the Reche Subbasin, the mean K value based on the evaluation of 19 wells ranged from 19 to 23 gpd/ft^2. The highest K value in the Reche Subbasin was calculated for CSA 1 and 3 (379 to 545 gpd/ft^{2}and 326 to 329 gpd/ft^2, respectively). The mean K value in Giant Rock Subbasin based on evaluation of two wells is 1 gpd/ft^2 (Table 2).

In addition to the findings above, results from a packer test conducted in 1991 on HDWD 24 as reported by GSI (2000), were analyzed. Data indicated that estimated K values of the screened shallow unit (220 to 310 feet depth) and deep unit (310 to 580 feet depth) were relatively similar.

Storativity (S) Values. Storativity (S) is a unitless number that represents the relative confinement of the aquifer and, in the case of an unconfined aquifer, is the specific yield (effective porosity) of the aquifer. A constant-discharge pumping test with a nearby observation well is necessary to estimate the S value. An absence of observation well data prevented direct derivations of S values for this study. A literature review indicates that the average S value of aquifer units for each of the USGS Morongo Subbasins within the Ames Valley Groundwater Basin ranges from 12 percent to 14 percent (Lewis, 1972).

3.4 Groundwater Occurrence and Flow

A comprehensive groundwater level database was developed to evaluate groundwater flow within the Ames Valley, Johnson Valley, and Means Valley groundwater basins. For the Ames Valley Groundwater Basin, groundwater level data were sourced from the USGS National Water Information System (USGS, 2006) and the latest Ames Valley Water Basin Monitoring Program Annual Report (Hanson, 2006). Groundwater level measurements for 1969, 1975, 1994, and 2004 were calibrated to a DEM provided by MWA to produce groundwater level contour maps (Figures 17 through 20) and depth to groundwater maps (Figures 21 through 24). Groundwater level contour maps are used to analyze groundwater flow directions from subbasin to subbasin and through time. Depth to water maps summarize the water table depth in various portions of the basin and were used in the analysis of available storage capacity in the unsaturated zone. All of these maps are included for completeness, although changes through time are relatively minor. Contour intervals on the water level maps are 100 feet for most areas, but are variable in some places to allow analysis of sparse data and areas of anomalies. The 2004 groundwater levels are also depicted on Hydrogeologic Cross Sections A-A' through E-E' (Figures 9 through 13).

Current groundwater elevations in the Ames Valley Groundwater Basin range from about 3,400 ft msl in the western portion of Pipes Subbasin to less than 2,300 ft msl in the Emerson Subbasin (Figure 20). As shown on the maps, groundwater flows in an east-northeast direction across the Pipes and Reche subbasins. Trayler and Koczot (1995) noted a steep groundwater gradient southeast of Pipes Wash at the location of Pipes Barrier using 1994 groundwater level data in three wells (labeled 36C1, 31D1, and 30N1 on Figure 19).Results of recent geophysical surveys indicate that groundwater flow within the Pipes and Reche Subbasins is impeded by Pipes Barrier, the Johnson Valley Fault, and the Kickapoo Fault (see Ruekert & Mielke, 2007 in Appendix A).

Groundwater enters the Giant Rock Subbasin at two locations corresponding to bedrock lows along the Homestead Valley Fault. A groundwater level drop of between 150 to 200 feet from Reche Subbasin to Giant Rock Subbasin in those two areas indicates that groundwater is significantly impeded by the Homestead Valley Fault. However, outflow apparently occurs in these areas as evidenced by water level data and bedrock outcrops. Groundwater flow to alternative outlets in the north or south is not indicated by the data.

Groundwater flow within Giant Rock Subbasin is generally toward the east and northeast as indicated by limited data. Groundwater flows from the Giant Rock Subbasin into the Emerson Subbasin across the Emerson fault. Data indicate that flow is impeded by the fault with a water level drop across the fault of perhaps more than 100 feet. However, the shape of water level contours indicates that cross-flow does occur in this area. Once in the Emerson Subbasin, shallow bedrock diverts groundwater toward the basin discharge area near Emerson Dry Lake. Here, shallow groundwater is subject to evapotranspiration (ET).

3.5 Groundwater Level Trends

Figures 25 and 26 show water level hydrographs for production and monitoring wells within the Study Area of the Ames Valley Groundwater Basin. A discussion of water level trends by subbasin is presented below.

Pipes Subbasin. Figure 25 shows water level hydrographs for 14 wells including six key wells in the Pipes Subbasin clustered near the bottom of the figure (BDVWA 8, BDVWA 1, USGS Monitoring Well, BDVWA 3, 1N/5E-2N1, and HDWD 20). The hydrograph for BDVWA 2 is not included on the figure, as it closely resembles the hydrograph for BDVWA 3. Hydrographs indicate that BDVWA groundwater production in the Pipes Subbasin since the 1970s has resulted in groundwater level declines in several wells located in the Flamingo Heights area (western Pipes Subbasin). The table below summarizes changes in water levels for certain time periods and shows that since 1990 groundwater level declines in the Flamingo Heights production wells (BDVWA 2, 3, 4, and 8) and the nearby USGS Monitoring Well have ranged from 38 to 43 feet, with most of the decline occurring from 1992 to 1997. This six-year period coincided with the peak of groundwater pumping in Pipes Subbasin, when average annual pumping was equal to 718 AFY. Since 1997, groundwater pumping has significantly decreased, with average annual production from 1998 through 2005 of 189 AFY. Correspondingly, the rate of groundwater level declines in the Flamingo Heights wells has decreased to generally less than one foot per year for monitored wells.

Groundwater Level Trends in Pipes Subbasin Wells

State Well Number	Well Name	Well Type	Ave. Annual Prod. 1990-05	Change in Groundwater Level (feet)			
				1990-06	1990-91	1992-97	1998-06
2N/5E-27K2	BDVWA #2	Prod	64.8	-42	-2	-33	-7
2N/5E-27K3	BDVWA #3	Prod	86.3	-38	-2	-33	-3
2N/5E-27R1	BDVWA #4	Prod	107.5	-43	-3	-32	-8
2N/5E-22J1	BDVWA #8	Prod	137.8	-43	-8	-22	-13
2N/5E-23M1	BDVWA #1	Monitor	0.0	> -29	-1	> -28	-
2N/5E-27A1	USGS Mon.	Monitor	0.0	-42	-2	-33	-7
2N/5E-36C1	HDWD #20	Monitor	0.0	-3	±0	±0	-3
1N/5E-02N1		Monitor	0.0	-12	-5	+22	-29

Exceptions to the overall declining groundwater level trend in Pipes Subbasin include HDWD 20 and Well 1N/5E- 02N1 (eastern and southern Pipes Subbasin). Groundwater levels in HDWD 20 have historically been flat and even rose slightly from 1996 to 1999. No municipal production wells are located near HDWD 20 and the area appears to be unaffected by groundwater pumping in the Pipes Subbasin. In addition, the area likely benefits from most of the recharge along Pipes Wash. Well 1N/5E- 02N1 is located along the southern banks of Pipes Wash and may be directly influenced by local recharge. Groundwater levels in Well 1N/5E- 02N1appear to reflect annual rainfall patterns with an approximate lag time of one year. For example, groundwater levels in Well 1N/5E- 02N1 rose 31 feet from 1992 to 1996 when rainfall from 1991 to 1995 was 124 percent of average annual rainfall. From 1996 to 2002, groundwater levels fell 25 feet when rainfall from 1995 to 2001 was 80 percent of average annual rainfall.

Reche Subbasin. Figure 25 also shows groundwater level hydrographs for eight key wells in the Reche Subbasin (Gubler Farm, 2N/5E-12N1, HDWD 24, BDVWA 9, BDVWA 7, CSA 70 W-1, Moran, and HDWD 6). No groundwater elevation data have been collected for CSA 3, and the hydrograph for CSA 2 is not presented, as it closely resembles the hydrograph for CSA 1 and has a shorter record. Similar to the Pipes Subbasin, hydrographs indicate groundwater level declines in most of the production wells and monitoring wells, although declines are generally smaller for wells in the Reche Subbasin. Groundwater level declines are attributed to groundwater pumping in the Reche Subbasin by BDVWA (Wells 6, 7, 9), HDWD (Well 24), and San Bernardino County Service Area 70 W-1 (Wells CSA 1, 2, and 3) since 1988. As summarized in the table below, declines in wells in the Reche Basin since 1990 range from -2 to greater than -20 feet for key wells.

Groundwater Level Trends in Reche Subbasin Wells

State Well Number	Well Name	Well Type	Ave. Annual Prod. 1990-05	Change in Groundwater Level (feet)			
				1990-06	1990-92	1993-99	2000-06
2N/5E-12B1	BDVWA #6	Prod	76.9	> -12	-	-	-
2N/5E-12B2	BDVWA #7	Prod	69.1	-2	+10	-5	-7
2N/5E-12C2	BDVWA #9	Prod	94.6	-18	-2	-9	-7
2N/5E-24H1	HDWD #24	Prod	483.2	-24	+1	-24	-1
2N/6E-18B1	CSA #1	Prod	64.6	-23	±0	-12	-11
2N/6E-18B2	CSA #2	Prod	49.6	-11	+2	-12	-1
2N/6E-30N1	HDWD #6	Monitor	0.0	-32	-29	-3	±0
2N/5E-01G1	Gubler Farm	Monitor	0.0	-4	+1	+1	-6
2N/5E-13A1	Moran	Monitor	0.0	> -17	+2	-11	> -8
2N/5E-12N1		Monitor	0.0	-11	-	-7	-4

The summary table above generally shows that most of the total groundwater level decline in each well occurred during the period from 1993 to 1999. This decline was likely related to the increase in pumping that occurred in the subbasin during those years. Average annual groundwater pumping in the subbasin from 1990 to 1992 was only 238 AFY. In the following years, subbasin production increased significantly from less than 400 AFY in 1993 to more than 1,500 AFY in 1997. From 1993 through 1999, average annual subbasin pumping was 1,122 AFY with significant increases in 1996 and 1997, accounting for most of the water level declines. Since 1999, groundwater pumping has decreased slightly, with average production from 2000 through 2005 equal to 1,006 AFY. Correspondingly, the rate of groundwater level declines in the Reche Subbasin has decreased to about one foot per year on average in monitored wells.

One exception to the trends exhibited by most Reche Subbasin wells is HDWD 6, in which groundwater levels exhibited a dramatic drop of 29 feet from 1990 to 1992, occurring mostly in 1992. The cause of this decline is unresolved, as there is no groundwater production nearby and no problem with well construction indicated. Given the timing and relative suddenness of the decline, it is suspected that seismic movement along the Pipes Barrier during the 1992 Landers earthquake may be involved.

Giant Rock and Emerson Subbasins. Figure 26 shows groundwater level hydrographs for key wells in the Giant Rock and Emerson subbasins. As shown in the figure, the hydrographs indicate groundwater levels have been historically steady in both subbasins. This is attributable to the fact that no major groundwater pumping occurs in either basin. Further, if subsurface outflow from Reche Subbasin to Giant Rock Subbasin has been decreased due to pumping in Reche, levels do not reflect the change.

3.6 Groundwater Storage and Available Storage

The amount of groundwater in storage (groundwater storage) in the Pipes, Reche, and Giant Rock Subbasins was previously estimated by Lewis (1972) to be 120,000, 240,000, and 180,000 acre-feet (AF), respectively. Due to insufficient data and the limited area of investigation, groundwater storage in the Pioneertown and Emerson Subbasins was not calculated. Lewis' methodology involved a single value for the average thickness of saturated sediments in each subbasin, a value determined from 1969 groundwater levels and bedrock elevations from available driller's logs. Saturated thickness values ranged from 100 feet for the Reche and Giant Rock subbasins to 150 feet in Pipes Subbasin. A single value representing the average specific yield of basin fill deposits for each subbasin was estimated from sediment descriptions on driller's logs. The representative specific yields for the Pipes, Reche, and Giant Rock Subbasins were 0.14, 0.12, and 0.12, respectively.

Groundwater storage in each subbasin of the Ames Valley Groundwater Basin was re-calculated for this study, because 1) subbasins defined by Lewis differ from the subbasins in this study, 2) additional subsurface data has become available since the Lewis report, and 3) historic groundwater pumping in the basin over the past 35 years has significantly impacted groundwater levels. For this study, 2004 groundwater levels (Figure 20) and bedrock elevations (Figure 7) interpreted from gravity data (GSI, 2000) and driller's logs were imported into the project GIS database. The thickness of saturated basin fill sediments was determined electronically by computing the differences in elevation between raster surfaces generated from each dataset. In areas where bedrock data were limited, bedrock elevations were estimated based on nearby known bedrock elevations and observed trends of bedrock slopes beneath the basin. Data were insufficient to estimate the average saturated thickness for Giant Rock and Emerson Subbasins. For these subbasins, average saturated thicknesses estimated by Lewis were used and applied to re-calculated areas for the subbasins. A specific yield of 0.12 was applied to each subbasin, consistent with the lower estimate of specific yield used by Lewis (1972). Groundwater storage estimates for subbasins in the Ames Valley Groundwater Basin are summarized below.

Groundwater in Storage
Ames Valley Groundwater Basin

USGS Subbasin	Surface Area[a]		Average Specific Yield[b]	Average Thickness of Saturated Basin Fill Sediments[c]	Groundwater in Storage
	mi²	acres		feet	acre-feet
Pioneertown	13.4	8,600	0.12	4	4,400
Pipes	21.4	13,700	0.12	217	356,100
Reche	24.4	15,600	0.12	129	242,300
Giant Rock	65.0	41,600	0.12	100	499,200
Emerson	45.3	29,000	0.12	100	348,000
Total	**169.5**	**108,500**			**1,450,000**

[a] All DWR Basin areas assigned to a USGS Morongo Subbasin
[b] Based on specific yields calculated by Lewis for subbasins in the Ames Valley Groundwater Basin
[c] Calculated from raster surfaces representing 2004 groundwater level and bedrock elevations

The table shows that total groundwater storage in the Ames Valley Groundwater Basin is estimated to be 1,450,000 AF. Of the total storage volume, about 600,000 AF (41 percent) is stored in the Pipes and Reche Subbasins, and about 850,000 (58 percent) is stored in the Giant Rock and Emerson subbasins, and 4,400 AF (0.3 percent) is stored in the Pioneertown Subbasin. These totals are likely on the high end of storage estimates and are higher than the amount that could be economically pumped with wells. In addition, some areas likely have lower specific yields, especially with depth. Nonetheless, these totals provide a more rigorous estimate of the total amount of groundwater in storage than past evaluations.

These totals are much different from Lewis' previous estimates, especially for Pipes and Giant Rock subbasins. However, the numbers cannot be compared directly because the areas used by Lewis were significantly smaller than current subbasin acreages in this study. For example, Lewis notes that lack of data on water levels, bedrock elevation, and average thickness, limit his estimates to only about 22 square miles of the Giant Rock Subbasin (which extends over about 65 square miles). In addition, Lewis used an average depth to bedrock that did not account for the high variability and localized deep areas of the basin. This study considered the variation in depth and the entire area of each subbasin.

For groundwater basin management and conjunctive use studies, the amount of storage space available in the unsaturated zone is also an important component of the groundwater basin. Available storage capacity in the Ames Valley Groundwater Basin was calculated by computing the difference in elevation between the DEM and the raster surface representing 2004 groundwater elevations (Figure 20). This surface is represented by gradational shading shown on Figure 27. Also posted on Figure 27 are the depths to water for individual wells during 2004. Similar to the groundwater storage estimates, a specific yield of 0.12 was used for unsaturated basin fill sediments.

Available groundwater storage capacity for the Ames Valley Groundwater Basin is summarized below.

Available Storage Capacity
Ames Valley Groundwater Basin

USGS Subbasin	Surface Area[a]		Average Specific Yield[b]	Average Thickness of Unsaturated Basin Fill Sediments[c]	Available Storage Capacity
	mi^2	acres		feet	acre-feet
Pioneertown	13.4	8,600	0.12	173	178,200
Pipes	21.4	13,700	0.12	216	355,100
Reche	24.4	15,600	0.12	223	417,500
Giant Rock	65.0	41,600	0.12	337	1,682,300
Emerson	45.3	29,000	0.12	146	508,100
Total	**169.5**	**108,500**			**3,141,200**

[a] All DWR Basin areas assigned to a USGS Morongo Subbasin
[b] Based on specific yields calculated by Lewis for subbasins in the Ames Valley Groundwater Basin
[c] Calculated from DEM and raster surface representing 2004 groundwater elevation

The table shows that total available storage capacity in the Ames Valley Groundwater Basin is estimated to be 3,141,200 AF. Available capacity in the Pipes and Reche subbasins is about 772,600 AF. Although the total estimated available storage in the basin could not be utilized due to variability in topography across the basin, for perspective, the volume of available storage is larger than the amount of groundwater currently in storage in the basin.

3.7 Water Balance

A water balance was developed for the Ames Valley Groundwater Basin to estimate the perennial yield of the basin. Major basin inflows accounted for in the water balance include recharge of runoff from the San Bernardino Mountains, septic return flows, and groundwater inflows from other basins (subsurface inflow). Major basin outflows include groundwater pumping, groundwater outflows to other basins (subsurface outflow), and evapotranspiration.

3.7.1 Recharge from Rainfall

The principal source of natural groundwater recharge to the basin is the runoff of rainfall in the San Bernardino Mountains. Direct recharge from rainfall on the basin is negligible given the low amounts of precipitation on the valley floor. Subsurface inflow through fractured bedrock is unknown, but is also considered to be negligible for this balance. Figure 5 shows the contributing watershed area and annual rainfall isohyets for the Ames Valley Groundwater Basin. The contributing watershed area is divided into four major drainages. The surface areas and average annual rainfall in the four catchment areas are summarized below.

Major Drainages in the Ames Valley Groundwater Basin

Major Drainage	Antelope Creek	Whalen's Wash	Ruby Mountain	Sand Hill Wash	Total
Catchment Area (mi^2)	55.3	21.0	13.4	1.7	**91.4**
Catchment Area (acres)	35,423	13,434	8,581	1,113	**58,551**
Average Annual Rainfall (in)	8.54	6.35	5.39	4.52	**7.50**

The table shows that Antelope Creek (tributary to Pipes Wash) has the largest contributing catchment area to the basin, representing 60 percent of the overall contributing watershed area. Following Antelope Creek in order of decreasing catchment area and average annual rainfall are Whalen's Wash, Ruby Wash, and Sand Hill Wash.

Because Antelope Creek (and ultimately Pipes Wash) is the largest contributor of runoff to the subbasin, Lewis (1972) used it to represent natural recharge to the basin. Assuming that most of the recharge enters the basin as subsurface inflow along Pipes Wash, Lewis calculated this inflow using the groundwater gradient, hydraulic conductivity, and cross-sectional area of the aquifer where Antelope Creek enters the Ames Valley Groundwater Basin. From this methodology, Lewis estimated that average annual groundwater recharge from rainfall in the Antelope Creek Catchment is between 100 and 1,000 AFY, and probably around 500 AFY. DWR later estimated that recharge from rainfall to the entire basin is approximately 700 AFY (RWMP, 2003); however, a description of the method used is not reported. Recharge estimates by Lewis and DWR correlate to 2.04 percent and 2.12 percent of rainfall, respectively, for the contributing watershed area of the Ames Valley Groundwater Basin. However, because recharge estimates by Lewis and DWR do not consider the variability associated with wet and dry cycles, an analysis of dry year water supply could not be conducted with their estimates.

For this study, a more detailed methodology was developed to estimate annual recharge from rainfall to the Ames Valley Groundwater Basin over wet, average, and dry conditions. The methodology re-affirmed that reasonable estimates of natural groundwater recharge were equivalent to about 2.0 percent of rainfall in the contributing watershed area. The methodology used to establish this percentage involved the calibration of average inflows and outflows to observed groundwater storages changes (as indicated by groundwater levels) for a small portion of the basin where adequate data were available. Estimates of basin inflows and outflows and their application of this methodology are described below.

3.7.2 Septic Return Flows

Septic tanks represent the sole method of wastewater treatment and disposal in the Ames Valley Groundwater Basin. The total volume of septic return flow infiltrating into the groundwater system was estimated using population for the basin and applying a per-capita septic system return factor of 70 gallons per day (Umari, et al., 1993 and Nishikawa et al., 2003). The factor was determined applicable for two studies conducted by USGS in the Apple Valley and Warren Basin areas. The distribution of septic return flows is correlated directly to population density. With a current population of 8,300 in the Ames Valley Groundwater Basin, the total amount of groundwater recharge in the form of septic return flow is estimated at 651 AFY.

3.7.3 Subsurface Inflow

Groundwater generally flows to the east and northeast through the Ames Valley Groundwater Basin. Because Ames Valley Groundwater Basin lies adjacent to consolidated bedrock along its eastern boundary, some subsurface inflow likely occurs along this surface, but the amount is unknown. Given the low permeability of bedrock, especially at depth, the subsurface inflow for the purposes of this water balance is considered negligible. Additionally, because the northern and southern boundaries of the basin represent groundwater divides, subsurface inflow from neighboring groundwater basins is considered negligible.

3.7.4 Groundwater Pumping

Since 1970, groundwater pumping by BDVWA, HDWD, and the County has represented most of the pumping in the basin. Although there are numerous private wells in the Study Area, pumping from these wells is primarily for domestic purposes and is considered to be sufficiently small to be excluded from this preliminary water balance. Annual groundwater production for the Ames Valley Groundwater Basin is shown in Figure 28. The figure shows that most of the production in the basin occurs in the Pipes and Reche subbasins. Beginning in 1970, groundwater pumping by BDVWA in the Pipes and Reche subbasins steadily increased from approximately 100 AFY to 600 AFY in 1989. In 1991, San Bernardino County began pumping in the Reche Subbasin, and was joined by HDWD in 1993. Groundwater production in the basin peaked at 2,143 AFY in 1996 but has since decreased by about 50 percent. Average annual groundwater pumping in the basin from 2000 to 2005 was about 1,200 AFY (Figure 28).

Pipes Subbasin. The top of Figure 29 shows groundwater pumping in the Pipes Subbasin. As shown in the figure, pumping in Pipes Subbasin began in 1970 when 82 AF was pumped from BDVWA 2. Groundwater pumping in Pipes Subbasin peaked in 1993 at 1,047 AF with export from the basin occurring at the BDVWA Intertie. However, since 1998, groundwater pumping has decreased more than 80 percent in response to the Ames Valley Agreement and has been relatively steady in recent years. Average annual groundwater pumping from 2000 to 2005 was 198 AFY.

Reche Subbasin. The bottom of Figure 29 also shows groundwater pumping in the Reche Subbasin. As shown in the figure, pumping in the Reche Subbasin began in 1988 when 243 AF was pumped from BDVWA 6 and 7. Subsequently, total groundwater pumping in the Reche Subbasin increased dramatically, peaking in 1997 at 1,517 AF. Since 2000, groundwater pumping has decreased by about 30 percent and has been relatively steady in recent years. Average annual production from 2000 to 2005 was 988 AFY.

3.7.5 Subsurface Outflow

A portion of groundwater in the Ames Valley Groundwater Basin flows from Giant Rock Subbasin across the Emerson Fault and into the Surprise Spring Subbasin (Akers, 1986 and Londquist and Martin, 1991). Although the Emerson Fault significantly impedes groundwater flow, calibration of a steady-state groundwater model for the Surprise Spring Subbasin indicated that 128 AFY of groundwater flows out of the Giant Rock into Surprise Spring (Londquist and Martin, 1991). Of the 128 AFY, 64 AFY represents discharge from Pipes Wash, 11 AFY represents groundwater discharge from the Sand Hill Wash catchment area, and 53 AFY represents groundwater discharge between Pipes Wash and Sand Hill Wash.

3.7.6 Evapotranspiration

Although Emerson Dry Lake represents a discharge point for groundwater flowing north in Emerson Subbasin, comparison of groundwater level data to ground surface elevations indicate that the depth to groundwater closest to the dry lake is 40 feet or greater. However, data are limited and discharge by evaporation is assumed to occur, although amounts may be small. To estimate ET of groundwater at the lake, a calculation was made based on the size of the playa, potential ET, and a small actual ET calibrated to evaporation estimates at the other dry lakes. Applying this method, ET at Emerson Dry Lake is estimated to be approximately 35 AFY.

3.7.7 Change in Storage and Perennial Yield

To estimate the perennial yield of the Ames Valley Groundwater Basin, a methodology was developed for this Study that first calibrated average inflows, outflows, and changes in groundwater storage for a small area of the Pipes Subbasin (Flamingo Heights area) where more complete data are available. In that area, groundwater levels indicate that the change in groundwater storage from 1998 to 2005 has been minimal. Using the assumption that inflows minus outflows equals change in storage, the major inflows and outflows were balanced for the Flamingo Heights area during a period when change in groundwater storage is assumed to be negligible. Details of this methodology are provided in the following sections.

Septic return flows and recharge from rainfall represent the major sources of groundwater recharge to the Pipes Subbasin. A preliminary evaluation of population data by MWA indicates that roughly 1,000 persons in the Ames Valley Groundwater Basin live in the Pipes Subbasin. Applying a per capita septic system return factor of 70 gal/day to 1,000 people results in an annual septic system return of 78 AFY for Pipes Subbasin alone.

The estimate of recharge from rainfall for the calibration area of Pipes Subbasin involved an assessment of the drainages that contribute recharge to the subbasin. Groundwater flow data indicate that runoff from Whalen's Wash is the only source of natural groundwater recharge to the Pipes Subbasin in the Flamingo Heights area. Groundwater level contours indicate that recharge from the Pipes Wash (Antelope Creek) flows northeast to the Reche Subbasin and is not captured by Pipes Subbasin pumping. By applying varying percentages to rainfall in the Whalen's Wash catchment area, it was determined that 2.00 percent of average rainfall results in a reasonable recharge estimate that balances outflows and observed water levels. In the Whalen's Wash catchment, 2 percent of rainfall equates to 133 AFY. Adding estimated septic returns results in a total estimated groundwater recharge of 211 AFY for the Pipes Subbasin. This amount is very close to recent production that has produced relatively stable water levels in the Flamingo Heights area (see Pipes Subbasin pumping on Figure 29). The average annual inflows of 211 AFY to Pipes Subbasin are slightly greater than groundwater pumping (average 198 AFY from 2000 through 2005), a condition judged appropriate since BDVWA production wells in Pipes Subbasin are unlikely to capture 100 percent of the groundwater recharge flowing east across the Flamingo Heights. This analysis confirmed that applying a factor of 2.0 percent to rainfall for estimating recharge produced reasonable values for the Pipes Subbasin. Therefore, this factor was applied to rainfall for the other catchments to estimate recharge for the entire groundwater basin.

The left side of Table 3 presents the natural groundwater recharge from rainfall in the Ames Valley Groundwater Basin over a 12-year study period from water years 1989-1990 through 2000-2001. The drainages contributing runoff that results in basin recharge are summarized in the top portion of the table. The percentage of average rainfall, using data from the Big Bear rainfall station, is shown next to each year in the study period. These data are applied to average annual rainfall derived from the isohyets on Figure 5 and listed for each catchment on Table 3. Using the calibration methodology described previously, recharge is estimated at 2 percent of rainfall.

Table 3 shows that average annual recharge from rainfall for the Ames Valley Groundwater Basin is 686 AFY. The Antelope Creek Catchment is the largest contributor of recharge (472 AFY) followed by Whalen's Wash (133 AFY), Ruby Mountain Wash (72 AFY), and Sand Hill Wash (8 AFY). The largest annual recharge (1,347 AF) was generated in 1992-1993 when rainfall was 184 percent of the long-term average, and the smallest amount was generated in 1989-1990 when rainfall was 24 percent of the long-term average. The table also shows the annual recharge from rainfall to the basin for a single dry year (176 AF in 1989-1990) and multiple dry years (386 AFY from 1998 to 2001).

The water balance for the Ames Valley Groundwater Basin, as summarized in the following table, shows that the Ames Valley Groundwater Basin is currently near balance under average climatic conditions. The negative value suggests a slight overdraft that warrants consideration for future management.

Water Balance for
Ames Valley Groundwater Basin

Basin Inflows	**Volume (AFY)**
Rainfall	686
Septic Return Flow	651
Subsurface Inflow	0
Total Inflow	*1337*
Basin Outflows	**Volume (AFY)**
Pumping	1186
Subsurface Outflow	128
Evapotranspiration	35
Total Outflow	*1349*
Groundwater Storage Change	**-12**

Basin inflow estimates indicate almost equal contributions from rainfall and septic return flows under average conditions. Groundwater pumping represents 88 percent of the groundwater outflow from the basin. Additional outflows include subsurface outflow into the Surprise Spring Subbasin and ET at the Emerson Dry Lake. The small amount of negative groundwater storage change (-12 AFY) is judged to be within the error of the basin balance and is sufficiently small to assume that the basin is nearly in balance.

3.8 Groundwater Quality

Groundwater quality data sources for this study included the California Department of Health Services (DHS) Drinking Water Program database (DHS, 2006), the USGS National Water Information System (USGS, 2006), and laboratory groundwater quality reports for production wells in the Study Area provided by MWA and BDVWA. Groundwater quality data were combined into a comprehensive database and used to identify the chemical signature of groundwater and concentrations of dissolved constituents of concern within the Study Area.

Major Inorganic and TDS. Table 4 summarizes the inorganic water quality with concentrations of major cations and anions for 31 wells in the Ames Valley Groundwater Basin grouped by subbasin. Sample dates and concentrations represent the latest reported groundwater quality data for each well.

These data were evaluated using a geochemical plotting technique known as a Trilinear Diagram (Piper, 1956). This technique plots the major anions and cations in percent milliequivalents per liter (% meq/L) to characterize groundwater and differentiate samples of varying water quality. Figure 30 shows a Trilinear Diagram for wells in the Ames Valley Groundwater Basin grouped into subbasins by color. Cations in % meq/L are plotted on the lower left triangle and anions in % meq/L are plotted in the lower right triangle. Data are projected onto the central diamond to evaluate overall water type. Water samples of similar quality plot together in a cluster.

As shown on Figure 30, groundwater in most of the wells cluster in the central portion of the diamond, indicating primarily a sodium/calcium-bicarbonate water type. The wide variability of water type for many basin wells can be correlated to specific locations (e.g., near dry lakes or along a fault) or geologic units (e.g., wells screened in bedrock). Wells are color-coded by subbasin with most of the data coming from the Pipes and Reche subbasins.

As shown by the cluster of most basin wells, groundwater in Pipes and Reche subbasins is primarily a sodium/calcium-bicarbonate type. However, wells in Pipes Subbasin generally have a higher ratio of calcium to sodium than wells in the Reche Subbasin. This may be indicative of different recharge sources and/or cation exchange between calcium and sodium along groundwater flow paths. One exception to this trend is BDVWA 8, which has a much higher ratio of sodium to calcium than other wells in Pipes Subbasin, indicating that the flowpath of groundwater recharge to BDVWA 8 is different compared to groundwater recharge pumped by BDVWA 2, 3, and 4. This is expected given the relatively deep screen in BDVWA 8 compared to the other wells. Four wells located in the Pipes Subbasin along the Johnson Valley Fault, (2N/5E-03G1, 2N/5E -10A1, 2N/5E -27H1, and 2N/5E -27J1), have higher ratios of calcium to sodium than all other wells in the basin. Although it cannot be confirmed with existing data, the unique chemistry observed in these four wells may be associated with fluid movement along the Johnson Valley Fault.

Wells falling outside of these clusters represent areas of sparse data or unique conditions, limiting the amount of interpretation that can be made with respect to changing groundwater quality. Some additional observations include: Well 2N/6E-30L1 is completed in bedrock and has a different signature; two wells in Emerson Subbasin plot in the area of high sodium-chloride, perhaps indicating evaporative conditions; and wells in the Giant Rock Subbasin appear to have the most variable water quality.

An additional geochemical plotting technique, known as a Stiff Diagram, was used to illustrate the distribution of groundwater quality across the basin. Stiff Diagrams characterize water quality visually by plotting major anions and cations along four parallel horizontal axes for each water sample. Connecting the points for each ion creates a polygon, the distinctive shape of which allows for a visual comparison of groundwater quality data across the basin. Groundwater samples with similar inorganic water quality will plot as similar shapes.

Figure 31 shows the Stiff Diagrams for Ames Valley wells using the same data presented in Table 4. Additionally, the size of the diagram correlates to the concentration of total dissolved solids (TDS) for the well, which is indicated by the color of the Stiff diagram in the figure. A blue-colored Stiff diagram represents a relatively low concentration TDS, whereas a red-colored Stiff diagram represents a high TDS concentration. Total dissolved solids (TDS) concentrations shown on the figure are also presented in Table 5 and represent the latest reported concentrations for each well. In cases where TDS concentrations were not reported, the measured electrical conductivity (EC) in units of μmhos/cm were converted to TDS concentrations in mg/L using a conversion factor of 0.6. The conversion factor was the average factor for eleven (11) analyses that reported both EC and TDS concentrations and is consistent with published values for the relationship between the two parameters.

Figure 31 and Tables 4 and 5 indicate that groundwater in the Ames Valley Groundwater Basin generally meets drinking water standards for TDS, reported as a secondary maximum contaminant level (MCL) of 500 mg/L. TDS concentrations, as summarized below, show that the MCL for drinking water is exceeded only in the Emerson Subbasin.

Total Dissolved Solids for
Ames Valley Groundwater Basin

USGS Morongo Subbasin	Number of Wells	TDS (mg/L)	
		Range	Geometric Mean
Emerson	4	690 - 13,260	1,630
Giant Rock	5	198 - 372	288
Pipes	10	152 - 340	274
Reche	13	135 - 421	251

A comparison of Stiff diagrams on Figure 31 indicates that most of the wells in the Pipes Subbasin have similar shapes, representing similar water quality. The water type indicated is calcium bicarbonate. More variability exists in the Reche Subbasin, mainly due to the relative concentrations of sodium and calcium. Stiff diagrams in Giant Rock Subbasin appear similar to many of the diagrams in Reche, but with a less distinct water quality type (indicated by the more rectangular shapes). Wells in all three subbasins have TDS concentrations below 500 mg/L, as shown by the blue color. Water quality in Emerson Subbasin is significantly different and contains elevated relative concentrations of sodium and chloride. The increase in sodium and chloride is most pronounced at a well near Emerson Dry Lake. TDS is also elevated throughout the subbasin and highest at Emerson Dry Lake as indicated by the green, yellow, and red colors of the diagrams.

Nitrate. Given the significance of septic tank return flows to the groundwater basin and the association of elevated nitrate concentrations with septic discharges, groundwater nitrate concentrations were reviewed. The latest reported nitrate concentration (as NO_3) for 11 wells in the Ames Valley Groundwater Basin are shown on Figure 32. Data indicate that nitrate concentrations range from 5.2 to 11 mg/L as NO_3 in the Pipes and Reche subbasins, significantly below the primary MCL of 45 mg/L. Although current nitrate concentrations in monitored wells within the Ames Valley Groundwater Basin do not pose a health risk, implementation of conjunctive use projects must consider the locations of septic tank discharge in the unsaturated zone to prevent transporting additional nitrate to groundwater. Recent investigations in the Warren Valley basin revealed that septic return flows are the primary cause of elevated nitrate concentrations in groundwater. The timing of nitrate concentration increases was found to be directly correlated to the distance from a surface recharge pond. Increased groundwater levels resulting from the managed aquifer recharge program allowed for large volumes of high-nitrate septic tank discharge stored in the unsaturated zone to be transported to groundwater.

Fluoride. The latest reported fluoride concentration for wells in the Ames Valley Groundwater Basin are shown on Figure 33. Of the 29 wells monitored for fluoride in Ames Valley, fluoride concentrations in 25 wells are below the primary MCL for fluoride (2 mg/L). Fluoride concentrations for one well in Reche Subbasin, 2N/5E-12N1, is 2.5 mg/L, respectively. Data indicate that fluoride concentrations in the Emerson Subbasin generally exceed drinking water standards. Concentrations for three monitored wells in the Emerson Subbasin, 4N/6E-18L1, 4N/6E-27F1, and 4N/6E-27D1 are 84, 37, and 5.1 mg/L, respectively.

4 BASIN CONCEPTUAL MODEL OF THE JOHNSON VALLEY GROUNDWATER BASIN

The Johnson Valley Groundwater Basin, Groundwater Basin Number 7-18, is separated into two subbasins as defined by DWR. Groundwater basin 7-18.01 is called the Soggy Lake Subbasin, and 7-18.02 is called the Upper Johnson Valley Subbasin. The Soggy Lake Subbasin covers 76,800 acres and is bounded by the San Bernardino Mountains to the south, Fry mountains to the north, Johnson Valley Fault and bedrock outcrops to the east, and a groundwater divide to the west. The Soggy Lake Subbasin includes the Fry and Johnson subbasins of the USGS Morongo Groundwater Basin. The Upper Johnson Valley Subbasin covers 34,830 acres and is bounded by mountains to the north, south, and east and the Johnson Valley Fault and bedrock outcrops to the west. The boundaries of the Upper Johnson Valley Subbasin generally coincide with the Upper Johnson Subbasin of the USGS Morongo Groundwater Basin.

This section presents the conceptual hydrogeologic model for the Johnson Valley Groundwater Basin. The conceptual model was developed using information from existing hydrogeologic reports and available geologic, geophysical, and groundwater data (data sources are provided in Section 1.4). A summary of the basin geometry, major faults and hydraulic barriers, distribution of basin fill deposits, aquifer parameters, groundwater levels and trends, and groundwater quality is presented. A comparison of major basin inflows (runoff from the mountains, subsurface groundwater inflow, and septic system returns) and outflows (groundwater pumping, subsurface groundwater outflow, and evapotranspiration) and the estimated perennial yield of the basin are also presented.

4.1 Faults and Hydraulic Barriers

The Johnson Valley Groundwater Basin lies within the Eastern California Shear Zone, a region of concentrated seismic activity that stretches north-northeast from the San Andreas Fault across the Mojave Desert and into the Owens Valley. Major geologic structures in the Johnson Valley Groundwater Basin are shown in Figure 6 and include the Old Woman Springs, Lenwood, West Johnson Valley and Johnson Valley faults. Each of the faults is oriented in a northwest direction and is characterized by right-lateral, strike-slip displacement. Previous researchers have identified these structures as partial barriers to groundwater flow using primarily groundwater level data (French, 1978; Trayler and Koczot, 1995). A description of the historic and current understanding of each structure with respect to its location and influence on groundwater flow is presented below.

4.1.1 Old Woman Springs Fault

The Old Woman Springs Fault is located in the southern most portion of the basin. No groundwater level data exist south of the fault. However, springs located along the central portion of the fault suggest that the fault impedes groundwater flow.

4.1.2 Lenwood Fault

The Lenwood Fault forms the boundary between the Fry and Johnson Valley subbasins defined by USGS. A groundwater level drop of about 20 feet across the fault was identified by French (1978) and re-confirmed by Traylor and Koczot (1995), indicating that the fault impedes groundwater flow.

4.1.3 West Johnson Valley Fault

The West Johnson Valley Fault extends across the central portion of the Johnson Subbasin and is parallel to the Johnson Valley Fault to the east. A groundwater level drop of between 30 and 35 feet across the fault was identified by French (1978) and re-confirmed by Traylor and Koczot (1995), indicating that the fault impedes groundwater flow. Although not shown in Figure 6, French interpreted a single trace of the West Johnson Valley Fault south of Highway 247 towards the San Bernardino Mountains. Additional investigations are needed to confirm the location of this fault trace and its impact on groundwater flow.

4.1.4 Johnson Valley Fault

The Johnson Valley Fault separates the Johnson Subbasin from the Upper Johnson and Means subbasins. A groundwater level drop of 30 feet is observed across the Johnson Valley Fault between the Johnson and Upper Johnson subbasins, while a groundwater level drop of 120 feet is observed across the fault between the Johnson and Means subbasins, indicating that the fault impedes groundwater flow at each location.

4.2 Basin Geometry

Consolidated pre-Tertiary rocks, including quartz monzonite/diorite and schist, comprise the bedrock underlying the basin fill deposits of the Johnson Valley Groundwater Basin. Although small quantities of groundwater for domestic use can be extracted from fractures, bedrock is generally considered to be non water-bearing and constitutes the basin floor. As a result of historic faulting in the area, the elevation of bedrock across the basin is highly variable.

Bedrock elevations in the basin were determined using lithologic logs in well completion reports, borehole geophysical logs, and geophysical (gravity and TEM) data. Data were incorporated into a GIS database and calibrated to the DEM for the Study Area. Three hydrogeologic cross-sections across the basin (F-F’ through H-H’) were developed and are presented on Figures 34 through 36. Cross section locations were selected to show the maximum amount of hydrogeologic data in the basin and are shown on Figure 8.

Cross sections F-F’ and G-G’ show that depth to bedrock in the Johnson Valley Groundwater Basin increases from 100 feet along the southern margins of the basin to about 1,000 feet south of Highway 247 in the Johnson Subbasin. A previously unidentified northeast trending fault associated with the North Frontal Thrust System was identified between Well 3N/4E-15J1 and 3N/4E-15G1. Movement along this fault has uplifted bedrock to the south by about 500 feet (Figures 34 and 35). Depth to bedrock gradually decreases north of Highway 247, as indicated by gravity data (Figure 35). Bedrock in the northern portion of Johnson Subbasin was encountered in Wells 4N/3E-22C1 and 4N/3E-24N1 at 285 and 232 feet (Figure 36). Bedrock in the Upper Johnson Subbasin was encountered in Well 4N/4E-08J1 at 290 feet.

4.3 Basin Fill Deposits and Aquifer Parameters

4.3.1 Basin Fill Deposits

Basin fill deposits are derived principally from eroded rocks of the San Bernardino Mountains, which include quartz monzonite/diorite, schists, and basalts, and consist of intercalated lenses of Tertiary and Quaternary clay, silt, sand, and gravel. Sediments were transported from the mountains by alluvial washes through the narrow canyons in the mountains and created alluvial fans when they were deposited on the basin floor. Major washes in the Johnson Valley Groundwater Basin include Arrastre Creek, Two Holes Spring, and Ruby Canyon. Alluvial fans associated with these washes are generally flatter and broader than alluvial fans in the Ames Valley Groundwater Basin.

A review of well driller's logs indicates that subsurface lithology is variably packaged across the basin. The area between the West Johnson and Johnson Valley faults is predominantly underlain by coarse-grained deposits, while south of Highway 247 and west of the West Johnson Valley Fault, deposits are comprised of thin lenses (20 to 50 feet) of coarse-grained and fine-grained sediments. West of the West Johnson Valley Fault in the northern portion of the Johnson Subbasin, higher silt/clay-to-sand ratios occur. In the Upper Johnson Subbasin, sediments are primarily coarse-grained down to 300 feet. Sediments beneath Melville Dry Lake are comprised of silty and sandy clays. Overall, the basin is underlain by relatively permeable sediments.

4.3.2 Aquifer Parameters

Hydraulic data in the Johnson Valley Groundwater Basin were limited to two wells, 3N/4E-17R3 (BDVWA 10) and 3N/4E-06N1. Well specific capacities calculated from aquifer pumping tests were evaluated to estimate the aquifer transmissivity (T values) and hydraulic conductivity (K values) in the Johnson Valley Groundwater Basin. The calculated specific capacity and estimated aquifer parameters for the two wells are presented in Table 2 and summarized below. As shown in the table, three step-drawdown pumping tests were conducted for BDVWA 10 from 1996 to 1998.

**Summary of Aquifer Parameters for
Johnson Valley Groundwater Basin**

Well Name	Date	Specific Capacity	T value	K value
		gpm/ft of dd	gpd/ft	gpd/ft^2
3N/4E-17R3 (BDVWA 10)	4/10/1996	0.7	1,096	3.7 - 7.3
	4/11/1996	0.8	1,152	3.9 - 7.7
	7/31/1998	0.9	1,296	4.5 - 8.6
3N/4E-06N1	12/26/1973	5.7	8,571	79.4 - 88.4

The table shows that the specific capacity and T and K values for the two wells are significantly different. Review of the well driller's and borehole resistivity logs for BDVWA 10 indicates that the well is screened opposite clay sediments. Pumping tests indicate that BDVWA 10 is capable of producing 85 gpm with 100 feet of drawdown. The fine-grained lithology encountered in BDVWA 10 is unique relative to other driller's logs in the vicinity and indicates that the well may be located along a fault associated with the southern extension of the West Johnson Valley Fault. The estimated T value for Well 3N/4E-06N1 is 8,571 gpd/ft, which indicates that the aquifer is relatively prolific at this location. Additional pumping tests are needed to estimate more reliably the aquifer parameters and water supply potential of the Johnson Valley Groundwater Basin.

4.4 Groundwater Occurrence and Flow

Groundwater level measurements for 1969, 1975, 1994, and 2004 were calibrated to a DEM provided by MWA to produce groundwater level contour maps (Figures 17 through 20) and depth to groundwater maps (Figures 21 through 24) for the Johnson Valley Groundwater Basin. 2004 groundwater levels are depicted on Hydrogeologic Cross Sections F-F' through H-H' (Figures 34 through 36).

Current groundwater elevations in the Johnson Valley Groundwater Basin range from about 3,100 ft msl in the southeast portion of Johnson Subbasin to less than 2,700 ft msl at Melville Lake in the Upper Johnson Subbasin. Groundwater gradients are relatively flat across the basin. Depth to groundwater decreases northward in the Johnson Subbasin from 300 to 400 feet bgs south of Highway 247 to less than 40 feet in the northeast portion near the Johnson Valley Fault. Depth to water near Melville Dry Lake is about 15 ft bgs.

Recharge from rainfall entering the Johnson Subbasin through Arrastre Creek, Two Holes Spring, and Ruby Canyon flows in a north-northeast direction across the basin. Groundwater flow in Fry and Johnson subbasins is impeded by the Lenwood, West Johnson Valley and Johnson Valley faults, as indicated by groundwater level drops across these features. Although not shown in Figure 6, the West Johnson Valley Fault probably extends to the southeast and impedes groundwater flow in the southern portion of the Johnson Subbasin (French, 1978). A portion of groundwater in the Fry Subbasin discharges to Soggy Dry Lake (northwest of the Study Area), while a portion crosses the Lenwood Fault into the Johnson Subbasin. Groundwater flows out of the Johnson Subbasin through two bedrock lows along the Johnson Valley Fault into the Upper Johnson and Means subbasins. Groundwater in the Upper Johnson Subbasin exits the basin via evaporation at Melville Dry Lake.

4.5 Groundwater Level Trends

Figure 37 shows groundwater level hydrographs for 13 wells in the Johnson Valley Groundwater Basin. Groundwater levels in the basin have been relatively steady over the last 50 years. This is attributable to the fact that groundwater pumping in the basin has been relatively small to date. One exception is Well 3N/4E-12N1, in which groundwater levels have declined by about 23 feet since 1994. Groundwater level data for BDVWA 10 (3N/4E-17R3) declined by 6 feet from 1996 to 1998. More recent groundwater level data for BDVWA 10 are not available to determine if water level declines have continued as a result of recent pumping.

4.6 Groundwater Storage and Available Storage

Groundwater storage in the Johnson Valley Groundwater Basin was previously estimated by French (1978) to be 250,000 AF. Of this volume, 150,000 AF was estimated for the area between the Lenwood and West Johnson Valley faults, and 100,000 AF was estimated for the area between the West Johnson and Johnson Valley faults. Estimates assumed an operational storage depth of 400 feet bgs over a basin area of 54 square miles. The thickness of saturated sediments was determined by comparing 1975 groundwater levels to bedrock elevations based on interpretation of available well driller's logs and gravity data. Saturated thickness values ranged from 0 to 400 feet across the basin. A single value representing the average specific yield of basin fill deposits for each subbasin was calculated by applying generalized specific yield values to sediment descriptions in well driller's logs. However, the average saturated thickness and specific yield are not presented in the French report.

Groundwater storage in the Johnson Valley Groundwater Basin was re-calculated for this study, because the boundaries of the basin defined by French differ slightly from the boundaries defined by DWR, and additional subsurface data has become available. For the Fry and Johnson subbasins, an average saturated thickness of 200 feet was estimated based on well driller's logs, gravity data, and saturated thickness contours estimated by French (1978). For the Upper Johnson Subbasin, an average saturated thickness of 100 feet was estimated. Similar to the specific yield used for calculating groundwater storage in the Ames Valley Groundwater Basin, a specific yield of 0.12 was applied, which is conservative relative to the average specific yield for the Johnson Valley Groundwater Basin estimated by Lewis (0.13).

Groundwater storage estimates are summarized below for the Johnson Valley Groundwater Basin (divided into USGS Morongo Subbasins).

Groundwater in Storage
Johnson Valley Groundwater Basin

USGS Subbasin	Surface Area[a]		Average Specific Yield[b]	Average Thickness of Saturated Basin Fill Sediments[c]	Groundwater in Storage
	mi^2	acres		feet	acre-feet
Johnson	65.8	42,100	0.12	200	1,010,400
Upper Johnson	54.3	34,800	0.12	100	417,600
Fry	55.0	35,200	0.12	200	844,800
Total	**175.1**	**112,100**			**2,272,800**

[a] All DWR Basin areas assigned to a USGS Morongo Subbasin
[b] Based on specific yields calculated by Lewis for subbasins in the Ames Valley Groundwater Basin
[c] Estimated from bedrock elevations and raster surfaces representing 2004 groundwater levels

The table shows that total groundwater storage in the Johnson Valley Groundwater Basin is equal to 2,272,800 AF. Of the total storage volume, about 1,000,000 AF (45 percent) is stored in the Johnson Subbasin, 850,000 AF (37 percent) in the Fry Subbasin, and 420,000 AF (18 percent) in the Upper Johnson Subbasin. Because the surface area of the Johnson Valley Groundwater Basin is more than three times the area of investigation of French's study, total groundwater storage estimates are much larger in this study.

Available groundwater storage capacity (thickness of the unsaturated zone) in the Johnson Valley Groundwater Basin was also calculated for this study. Available storage capacity (referred to in this document as available storage) was determined by computing the difference in elevation between the DEM and the raster surface representing 2004 groundwater elevations in the basin. Similar to the estimation of groundwater storage, a specific yield of 0.12 was used for unsaturated basin fill sediments. Available storage capacity estimates are summarized below for the Johnson Valley Groundwater Basin (divided into USGS Morongo Subbasins).

Available Storage Capacity
Johnson Valley Groundwater Basin

USGS Subbasin	Surface Area[a]		Average Specific Yield[b]	Average Thickness of Unsaturated Basin Fill Sediments[c]	Available Storage Capacity
	mi^2	acres		feet	acre-feet
Johnson	65.8	42,100	0.12	214	1,081,100
Upper Johnson	54.3	34,800	0.12	68	284,000
Fry	55.0	35,200	0.12	250	1,056,000
Total	**175.1**	**112,100**			**2,421,100**

[a] All DWR Basin areas assigned to a USGS Morongo Subbasin
[b] Based on specific yields calculated by Lewis for subbasins in the Ames Valley Groundwater Basin
[c] Calculated from DEM and raster surface representing 2004 groundwater elevation

The table shows that total available storage in the Ames Valley Groundwater Basin is equal to 2,421,100 AF. Available storage in the Johnson Subbasin is about 1,000,000 AF. It is noted that the total estimated available storage capacity in the basin cannot be utilized due to variability in topography across the basin. For example, increased recharge on the upper reach of a small slope may result in recharged water day lighting downgradient.

4.7 Water Balance

4.7.1 Recharge from Rainfall

The principal source of natural groundwater recharge to the basin is the subsurface runoff of rainfall in the San Bernardino Mountains. Areal recharge through basin fill deposits and subsurface inflow through fractured bedrock is considered to be negligible. Figure 5 shows the contributing watershed area and annual rainfall isohyets for the Johnson Valley Groundwater Basin. The contributing watershed area is divided into three major drainages. The surface area and average annual rainfall in the three drainage catchments is presented in the table below.

Major Drainages in the Johnson Valley Groundwater Basin

Major Drainage	Ruby Canyon	Two Holes Spring	Arrastre Creek	Total
Catchment Area (mi^2)	20.9	40.8	38.9	**100.7**
Catchment Area (acres)	13,389	26,142	24,896	**64,428**
Average Annual Rainfall (in)	6.47	8.41	11.38	**9.16**

The table shows that Two Holes Spring and Arrastre Creek have the largest contributing catchment areas, with each representing about 40 percent of the overall contributing watershed area. The catchment area for Ruby Canyon represents about 20 percent of the overall contributing watershed area.

Annual groundwater recharge to the Johnson Valley Groundwater Basin has been previously estimated to be about 2,300 AFY (DWR, 1975). The method used to estimate annual recharge is, however, not explained. For this study, it was determined that 2.00 percent of rainfall in the contributing catchment areas for each basin in the Study Area represents groundwater recharge.

Table 3 shows the annual recharge from rainfall generated by contributing catchments over the 12-year study period from water years 1989-1990 through 2000-2001. The table shows that average annual recharge from rainfall for the Johnson Valley Groundwater Basin is 921 AFY. The Arrastre Creek Catchment is the largest contributor of recharge (442 AFY) followed by Two Holes Spring (343 AFY), and Ruby Canyon (135 AFY). The largest amount of recharge from rainfall (1,809 AF) was generated in 1992-1993 when rainfall was 184 percent of the long-term average rainfall, and the smallest amount of recharge (236 AF) was generated in 1989-1990 when rainfall was 24 percent of the long-term average rainfall. The table also shows the annual recharge from rainfall to the basin for a single dry year (236 AF in 1989-1990) and multiple dry years (518 AFY from 1999 to 2001).

4.7.2 Septic Return Flows

Septic tanks represent the sole method of wastewater treatment in the Johnson Valley Groundwater Basin. The total volume of septic return flow infiltrating into the groundwater system was estimated using population figures for the basin and applying a per-capita septic system return factor of 70 gallons per day (Umari, et al., 1993 and Nishikawa et al., 2003). The distribution of septic return flows is correlated to population density. With a current population of 400 in the Johnson Valley Groundwater Basin, the amount of groundwater recharge in the form of septic return flow can be estimated at 31 AFY.

4.7.3 Subsurface Inflow

Groundwater generally flows to the north and northeast through the Johnson Valley Groundwater Basin. Because the basin lies adjacent to consolidated bedrock along its southern boundary, and because the western boundary of the basin is represented by a groundwater divide, subsurface inflow from neighboring groundwater basins is considered negligible.

4.7.4 Groundwater Pumpage

Municipal pumping occurs in the basin in only one well, BDVWA 10. Since coming on line in 1998, BDVWA 10 represents the total documented groundwater production for the Johnson Valley Groundwater Basin. Pumping from BDVWA 10 is shown on Figure 38 and has ranged from 7.7 to 13.6 AFY. Average annual groundwater pumping is 10.5 AFY.

Population and water use data indicate that pumping from BDVWA 10 is insufficient to support all of the valley residents (estimated at 400 persons). Using per capita water use data from Ames Valley, BDVWA is only capable of supporting about 70 to 100 persons, indicating additional water supply from private wells or another source. Pumping from private wells is likely significant relative to municipal pumping in this basin. Private groundwater pumping for Johnson Valley was estimated to be about 62 AFY in 1952 (DWR, 1975). Current private well pumpage is unknown, and as such, it is not included on Figure 38 or in the current water balance. However, if pumping from private wells is later shown to be significant, the amount of groundwater lost to subsurface outflow or ET would be reduced in the water balance. For the assessment of supply and demand in Section 6, demand is based on per capita water use instead of documented pumping from BDVWA 10.

4.7.5 Subsurface Outflow

A portion of groundwater flows out of the basin through the Johnson Valley Fault into the Means Valley Groundwater Basin. Applying a hydraulic conductivity of 5.0 ft/day, a cross-sectional area of 600,000 square feet (assuming average saturated thickness of 100 feet multiplied by aquifer width of 6,000 feet) and a measured hydraulic gradient of 0.011 ft/ft, subsurface outflow from the Johnson Valley Groundwater Basin to the Means Valley Groundwater Basin is estimated to be 273 AFY.

4.7.6 Evapotranspiration (ET)

Old Woman Springs, Soggy Dry Lake and Melville Dry Lake represent groundwater discharge areas for the Johnson Valley Groundwater Basin. Depth to groundwater is approximately 80 feet near Soggy Dry Lake and 15 feet near Melville Dry Lake. Under these conditions, the volume of groundwater lost to evaporation is likely to be much greater at Melville Dry Lake compared to Soggy Dry Lake. It is difficult to measure reliably the volume of groundwater lost from the basin to ET. However, because groundwater storage has remained unchanged in the basin as indicated by groundwater level trends (i.e. annual change in groundwater storage is equal to zero), the volume of groundwater lost to ET can be determined from the water balance as described in the following section.

4.7.7 Change in Storage and Perennial Yield

The water balance for the Johnson Valley Groundwater Basin, as summarized in the table below, shows that the basin is generally in balance under average climatic conditions.

Water Balance
Johnson Valley Groundwater Basin

Basin Inflows	**Volume (AFY)**
Rainfall	921
Septic Return Flow	31
Subsurface Inflow	0
Total Inflow	*952*
Basin Outflows	**Volume (AFY)**
Pumping	11
Subsurface Outflow	273
Evapotranspiration	668
Total Outflow	*952*
Groundwater Storage Change	**0**

The table above shows that recharge from rainfall (921 AFY) represents 97 percent of total average annual groundwater recharge to the basin (952 AFY), while septic return flows represent the remaining 3 percent of groundwater recharge. Estimated actual evapotranspiration from the basin (668 AFY) represents 70 percent of total average annual basin outflow. Subsurface outflow to the Means Valley Groundwater Basin (273 AFY) represents 29 percent of total average annual basin outflows, and pumping represents 1 percent of annual basin outflows. Overall, the Johnson Valley Groundwater Basin is in balance.

4.8 Groundwater Quality

Groundwater quality data were evaluated to determine the chemical signature of groundwater and concentrations of dissolved constituents of concern in groundwater in the Johnson Valley Groundwater Basin. Data sources included the USGS NWIS database, French (1978), and laboratory water quality results for BDVWA 10.

Major Inorganic and TDS. Table 4 shows the general inorganic water quality for eleven wells in the Johnson Valley Groundwater Basin. Ten wells are located in the Soggy Lake Subbasin, and one well is located in the Upper Johnson Subbasin. Sample dates and concentrations represent the most recent groundwater quality data reported. Figure 39 shows the general inorganic water quality data plotted on a Trilinear Diagram. The figure shows that while the character of groundwater varies across the basin, calcium and sodium generally represent the dominant cations, and sulfate represents the dominant anion. Groundwater in BDVWA 10 is a sodium-sulfate/bicarbonate type.

To illustrate the distribution of groundwater quality across the basin, the same data presented in Table 4 were plotted as Stiff diagrams as shown on Figure 31. TDS concentrations are also shown on the figure and are summarized in Table 5. Water quality data indicate that groundwater south of Highway 247 meets the secondary MCL for TDS (500 mg/L). However, groundwater in several wells north of Highway 247 exceeds the secondary MCL and ranges from 360 up to 1,887 mg/L TDS in the Soggy Lake Subbasin. TDS concentrations of groundwater from 4N/4E-05G1 in the Upper Johnson Valley Subbasin was measured at 2,990 mg/L. Five of the eight wells north of Highway 247 in the basin exceed the secondary MCLs for chloride and sulfate (250 mg/L).

Nitrate. Nitrate (as NO_3) concentrations for 8 wells in the Johnson Valley Groundwater Basin are shown Figure 32. Nitrate concentrations range from 1.0 to 28.0 mg/L across the basin and meet the primary MCL of 45 mg/L. The nitrate concentration of a groundwater sample collected from BDVWA 10 in 2004 was 6.6 mg/L. Although current nitrate concentrations in monitored wells within the Johnson Valley Groundwater Basin do not pose a health risk, implementation of a managed aquifer recharge program in the basin must consider where septic tank discharge exists in the unsaturated zone and locate recharge operations away from these areas to prevent nitrate contamination of groundwater.

Fluoride. Fluoride concentrations were available for 7 wells in the Johnson Valley Groundwater Basin as shown on Figure 33. Fluoride concentrations are generally below the primary MCL for fluoride (2.0 mg/L), with the exception of one well (3N/4E-06N1), in which the fluoride concentration was measured at 4.3 mg/L in 1996. The fluoride concentration of groundwater in BDVWA 10 was measured at 0.8 mg/L in 1998.

5 BASIN CONCEPTUAL MODEL OF THE MEANS VALLEY GROUNDWATER BASIN

The Means Valley Groundwater Basin, Groundwater Basin Number 7-17 as defined by DWR, covers 15,000 acres (23.4 square miles). The basin is partially bounded by mountains uplifted along the Johnson Valley and Homestead Valley faults to the northwest and northeast, the Johnson Valley Fault to the southwest, and the Homestead Valley Fault to the east. Elevated bedrock to the south creates a groundwater divide between the Means Valley Groundwater Basin and Ames Valley Groundwater Basin. The Means Valley basin generally overlies the Means Subbasin of the USGS Morongo Groundwater Basin.

This section presents the conceptual hydrogeologic model for the Means Valley Groundwater Basin. The conceptual model was developed using information from existing hydrogeologic reports and available geologic, geophysical, and groundwater data (data sources are provided in Section 1.4). A summary of the basin geometry, major faults and hydraulic barriers, distribution of basin fill deposits, aquifer parameters, groundwater levels and trends, and groundwater quality is presented. A comparison of major basin inflows (runoff from the mountains, lateral groundwater inflow, and septic system returns) and outflows (groundwater pumping, lateral groundwater outflow, and evapotranspiration) and the estimated perennial yield of the basin are also presented.

5.1 Faults and Hydraulic Barriers

Major geologic structures in the Means Valley Groundwater Basin are shown in Figure 6 and include the Johnson Valley and Homestead Valley faults. Both faults are oriented in a northwest direction and characterized by right-lateral, strike-slip displacement. Previous researchers have identified the Johnson Valley Fault as a partial barrier to groundwater flow using groundwater level data (French, 1978; Trayler and Koczot, 1995). A description of the historic and current understanding of each structure with respect to its location and influence on groundwater flow is presented below.

5.1.1 Johnson Valley Fault

The Johnson Valley Fault represents a portion of the boundary between the Means Valley and Johnson Valley groundwater basins. Groundwater levels are 120 feet lower in the Means Valley Groundwater Basin on the eastern side of the fault, indicating that the fault impedes groundwater flow from the Johnson Valley Groundwater Basin into the Means Valley Groundwater Basin.

5.1.2 Homestead Valley Fault

Uplifted bedrock on the eastern side of the Homestead Valley Fault forms the eastern boundary of the Means Valley Groundwater Basin. Although groundwater level data across the basin are limited, groundwater in the eastern portion of the basin presumably flows west towards Means Dry Lake. Therefore, the Homestead Valley Fault does not impede groundwater flow significantly in the Means Valley Groundwater Basin.

5.2 Basin Geometry

Cross Section E-E' (Figure 13) shows that the estimated depth to bedrock along the central north-south axis of the Ames Valley Groundwater Basin ranges from 250 to 500 feet, with bedrock generally shallower in the southern portion of the basin. Bedrock was encountered at 385 feet bgs in 3N/5E-08H1. Along the southeastern margin of the basin, bedrock was encountered at 80 feet in 3N/5E-07H1.

5.3 Basin Fill Deposits and Aquifer Parameters

The driller's logs for 2N/5E-09N1 and 3N/5E-08H1 indicate that the southern portion of the basin is predominantly underlain by clay and shale down to 150 to 200 feet in depth, which is underlain by decomposed granite to competent bedrock. The driller's logs for 4N/4E-26E1 and 4N/4E-24J1 indicate that basin fill sediments from the Johnson Valley Fault towards Means Dry Lake are comprised primarily of sandy and silty clay.

There are no wells with sufficient data for estimating T or K values for the Means Valley basin. For calculation of subsurface inflow from the Johnson Valley basin, a K value of 5 gpd/ft^2 was assumed based on values used by Lewis (1972).

5.4 Groundwater Occurrence and Flow

Groundwater level measurements for 1969, 1975, 1994, and 2004 were calibrated to a DEM provided by MWA to produce groundwater level contour maps (Figures 17 through 20) and depth to groundwater maps (Figures 21 through 24) for the Ames Valley Groundwater Basin. 2004 groundwater levels are depicted on Hydrogeologic Cross Section E-E' (Figure 13).

Groundwater recharge from rainfall entering the basin through Means Wash and subsurface inflow from the Johnson Valley Groundwater Basin flows towards Means Dry Lake in the central portion of the basin. Groundwater levels along the eastern side of Johnson Valley Fault are approximately 120 feet lower relative to the Johnson Valley Groundwater Basin. Groundwater in the southern portion of the basin also flows towards Means Dry Lake.

Current groundwater elevations in the basin range from 2,600 to 2,570 ft msl, indicating that groundwater gradients are relatively flat across the entire basin. Depth to groundwater decreases towards the Means Dry Lake. In 1975, depth to groundwater was measured at 63 feet bgs in 4N/4E-36B1 and 17 feet bgs in 4N/4E-24J1, located adjacent to the lake.

5.5 Groundwater Level Trends

Hydrographs for wells located in the Means Valley Groundwater Basin were not generated due to insufficient data. Given that there is no municipal groundwater pumping in the basin, and groundwater levels in 4N/4E-36B1 dropped by only 1 foot from 1975 to 2004, groundwater levels are assumed to be steady across the basin.

5.6 Groundwater Storage and Available Storage

To date, groundwater storage in the Means Valley Groundwater Basin has not been estimated. For this study, groundwater storage in the Means Valley Groundwater Basin was calculated assuming an average saturated thickness of 100 feet and specific yield of 0.06 (based on lithologic descriptions presented in well driller's logs and 2004 groundwater levels).

Groundwater storage estimated in the Means Valley Groundwater Basin is summarized below.

Groundwater in Storage
Means Valley Groundwater Basin

USGS Subbasin	Surface Area[a]		Average Specific Yield[b]	Average Thickness of Saturated Basin Fill Sediments[c]	Groundwater in Storage
	mi^2	acres		feet	acre-feet
Means	23.3	14,940	0.06	100	89,600
Total	**23.3**	**14,940**			**89,600**

[a] All DWR Means Valley Basin area assigned to USGS Morongo Subbasin
[b] Based on well driller's logs
[c] Calculated from bedrock elevations and 2004 groundwater levels

The table shows that total groundwater storage in the Means Valley Groundwater Basin is estimated to be 89,600 AF.

Available storage in the Means Valley Groundwater Basin was also calculated for this study. Available storage was determined by computing the difference in elevation between the DEM and the raster surface representing 2004 groundwater elevations in the basin. Similar to the estimation of groundwater storage, a specific yield of 0.06 was used for unsaturated basin fill sediments. Available storage estimated in the Means Valley Groundwater Basin is summarized below.

Available Storage Capacity
Means Valley Groundwater Basin

USGS Subbasin	Surface Area[a]		Average Specific Yield[b]	Average Thickness of Unsaturated Basin Fill Sediments[c]	Available Storage Capacity
	mi^2	acres		feet	acre-feet
Means	23.3	14,940	0.06	226	202,600
Total	**23.3**	**14,940**			**202,600**

[a] All DWR Means Valley Basin area assigned to USGS Morongo Subbasin
[b] Based on well driller's logs
[c] Calculated from DEM and raster surface representing 2004 groundwater elevation

The table shows that total available storage in the Means Valley Groundwater Basin is estimated to be 202,600 AF. It is noted that the total estimated available storage in the basin cannot be utilized due to variability in topography across the basin.

5.7 Water Balance

5.7.1 Natural Recharge and Discharge

A primary source of groundwater recharge to the basin is the subsurface runoff of rainfall in the San Bernardino Mountains. Areal recharge through basin fill deposits and lateral inflow through fractured bedrock is considered to be negligible. Figure 5 shows the contributing watershed area and annual rainfall isohyets for the Means Valley Groundwater Basin. The contributing watershed area is represented by Means Wash. The surface area and average annual rainfall in the Means Wash Catchment is presented in the table below.

Major Drainage in the Means Valley Groundwater Basin

Major Drainage	Means Wash	Total
Catchment Area (mi^2)	4.9	**4.9**
Catchment Area (acres)	3,200	**3,200**
Average Annual Rainfall (in)	5.11	**5.11**

The table shows that the contributing catchment area of the basin is 4.9 square miles, or approximately five percent of the contributing watershed area of the Ames Valley or Johnson Valley groundwater basins.

Annual groundwater recharge to the Means Valley Groundwater Basin has been previously estimated to be about 100 AFY (DWR, 1975). For this study, it was determined that 2.00 percent of rainfall in the contributing catchment areas for each basin in the Study Area represents groundwater recharge.

Table 3 shows the annual recharge from rainfall generated by contributing catchments over the 12-year study period from water years 1989-1990 through 2000-2001. The table shows that average annual recharge from rainfall for the Means Valley Groundwater Basin is 25 AFY. The largest amount of recharge from rainfall (50 AF) was generated in 1992-1993 when rainfall was 184 percent of the long-term average rainfall, and the smallest amount of recharge (6 AF) was generated in 1989-1990 when rainfall was 24 percent of the long-term average rainfall. The table also shows the annual recharge from rainfall to the basin for a single dry year (6 AF in 1989-1990) and multiple dry years (14 AFY from 1999 to 2001).

5.7.2 Septic return flows

Considering the current population in the basin is zero or near zero, septic return flows are considered to be negligible in the Means Valley Groundwater Basin.

5.7.3 Subsurface inflow

Subsurface inflow from the Means Valley Groundwater Basin across the Johnson Valley Fault represents a source of groundwater recharge to the Means Valley Groundwater Basin. Average annual subsurface inflows are estimated to be 273 AFY.

5.7.4 Evapotranspiration

Groundwater evapotranspiration rates (normalized to total surface area) at Means Dry Lake and Melville Dry Lake (in Johnson Valley) are likely to be similar, considering that groundwater levels at each dry lake are about 15 feet bgs. For the Johnson Valley water balance, almost all of the 668 AFY of groundwater lost to evapotranspiration is believed to occur at Melville Dry Lake, while little evapotranspiration occurs at Soggy Lake, where depth to groundwater is 80 feet bgs. Means Dry Lake covers about 280 acres, or 44.4 percent of the surface area of Melville Dry Lake (630 acres). Applying this percentage to 668 AFY results in an estimated ET at Means Dry Lake of 298 AFY.

5.7.5 Groundwater Pumpage

There is currently no municipal groundwater pumping in the Means Valley Groundwater Basin. Although there may be some private well production, pumping from these wells is primarily for domestic purposes and is negligible considering the small population in the basin.

5.7.6 Subsurface outflow

Groundwater level contours indicate that groundwater flow is generally towards Means Dry Lake in the central portion of the basin. Because a groundwater divide separates the Means Valley and Ames Valley groundwater basins, subsurface outflow is considered negligible.

5.7.7 Change in Storage and Perennial Yield

The water balance for the Means Valley Groundwater Basin, as summarized in the table below, shows that the basin is in balance under average climatic conditions.

Water Balance
Means Valley Groundwater Basin

Basin Inflows	**Volume (AFY)**
Rainfall	25
Septic Return Flow	0
Subsurface Inflow	273
Total Inflow	*298*
Basin Outflows	**Volume (AFY)**
Pumping	0
Subsurface Outflow	0
Evapotranspiration	298
Total Outflow	*298*
Groundwater Storage Change	**0**

The table above shows that subsurface inflow from the Means Valley Groundwater Basin (273 AFY) represents 92 percent of average annual groundwater recharge to the basin (298 AFY), while recharge from rainfall (25 AFY) represents the remaining 8 percent of groundwater recharge. Average annual outflow from the basin is represented solely by ET from the basin (298 AFY). Overall, the Means Valley Groundwater Basin is in balance.

5.8 Groundwater Quality

Groundwater quality data were evaluated to determine the chemical signature of groundwater and concentrations of dissolved constituents of concern in groundwater in the Means Valley Groundwater Basin.

Major Inorganic and TDS. General inorganic water quality data for two wells in the Means Valley Groundwater Basin are shown in Table 4. Figures 31 and 40 shows the same data plotted as Stiff Diagrams and on a Trilinear Diagram. TDS concentrations for the two wells are presented in Table 5. Data indicate that water quality in the basin varies from a calcium-bicarbonate type to sodium-bicarbonate/chloride type. Variability in inorganic composition and TDS concentration is likely to be correlated to the distance between the well and Means Dry Lake. The TDS sample collected from 4N/4E-24Q1 (1270 mg/L), close to Means Dry Lake, exceeds the secondary MCL for TDS (500 mg/L).

Nitrate. Nitrate (as NO_3) concentrations for groundwater collected from 4N/4E-24Q1 and 4N/4E -36B1 are shown on Figure 33. The nitrate concentration of the 2004 sample collected from 4N/4E-26B1 was 6.7 mg/L, which meets the primary MCL for nitrate (45 mg/L). The nitrate concentration of the 1955 sample collected from 4N/4E-24Q1, close to Means Dry Lake, was 92.0 mg/L, which exceeds the primary MCL for nitrate. Nitrate concentrations are expected to decrease with distance from the Dry Lake.

Fluoride. Fluoride concentrations in groundwater have only been measured in one well in the Means Valley Groundwater Basin, as shown on Figure 33. The fluoride concentration for a 1999 sample collected from 4N/4E-26B1 was 0.2 mg/L, which is below the primary MCL for fluoride (2.0 mg/L). Based on observed TDS and nitrate trends, fluoride concentrations in groundwater are likely to be elevated near the Dry Lake.

6 WATER SUPPLY AND DEMAND ASSESSMENT

The Ames Valley, Johnson Valley, and Means Valley groundwater basins have provided a reliable supply for historical demands. However, the basins may not be capable of providing for increased demand in the future. Data indicate that the Ames Valley Groundwater Basin, while currently close to being in balance, has exhibited overdraft conditions in the recent past associated with increased pumping. As such, an assessment of the current water supply, (including sources other than groundwater), along with current and future demands is necessary to ensure future reliability. This assessment is also provided to assist basin managers with decisions on providing a supplemental water supply to the basin.

6.1 Water Supply

To summarize and assess the potential water supply in the Study Area, both groundwater and the potential importation of SWP water are considered.

6.1.1 Groundwater Supply

As a preliminary estimate of groundwater supply, the current volume of inflows, or recharge to the groundwater basin, is considered. However, it should be noted that the amount of recharge is not equivalent to the amount of water that can be efficiently captured by wells and used in the basin even if the basin is in balance. Pumping wells will draw from groundwater storage, lowering water levels locally and producing cones of depression. These cones expand to hydrologic boundaries and often alter boundary conditions. From a practical standpoint, it is not possible to locate wells to effectively capture *all* of the natural recharge; in addition subsurface outflow and other boundary conditions may provide more or less water to the basin as groundwater conditions change.

With these limitations in mind, the water balance for each basin does provide a limiting set of parameters for groundwater use given the management goal to avoid depletion of groundwater storage on a basin-wide basis. As such, current estimates of recharge – which consider wet, dry, and average periods – provide upper limits for overall groundwater supply.

The primary natural source of supply to the basin is recharge from precipitation. As discussed in the basin conceptual models, the estimated natural recharge from precipitation has been quantified for each basin in the Study Area as provided on Table 3. In that table, the average recharge amount for each basin is estimated for the 12-year study period. Recharge estimates for a single dry year and multiple dry years are also provided. The representative single dry year is water year 1989-1990 when average rainfall was only 24 percent of normal. Multiple dry years are represented by water years 1998-1999 to 2000-2001, when rainfall averaged 53 percent of the long-term average rainfall. The groundwater supply estimates for the three basins are summarized on the following table.

Local Groundwater Water Supply for the Study Area (AFY)

Basin	Net Average Annual Supply (AFY)	Single Dry-Year Supply (1989-1990)	Multi-Dry Year Supply (1999-2001)
Ames Valley	686	176	386
Johnson Valley	921	236	518
Means Valley	25	6	14
Study Area Total	**1,632**	**418**	**918**

6.1.2 Imported Water Supplies

Future imported water supplies to the Study Area will consist of SWP supply purchased by MWA. The SWP is the nation's largest state-built water and power development and conveyance system. It includes pumping and power plants, reservoirs, lakes, storage tanks, canals, tunnels, and pipelines that capture, store, and convey water to 29 water contractors.

The SWP is operated by DWR for the benefit of the SWP contractors. The SWP includes 660 miles of aqueduct and conveyance facilities, from Lake Oroville in the north to Lake Perris in the south. The SWP is contracted to deliver a maximum 4.17 million AFY of Table A amounts to the 29 contractors. Table A Amount is a reference to the amount of water listed in "Table A" of the contract between DWR and the contractor and represents the maximum amount of water that each contractor may request each year.

MWA has a contractual Table A amount of 75,800 AFY of SWP water. This includes 25,000 AFY of Table A purchased (transferred) from the Berrenda Mesa Water District in 1998. Imported SWP water has historically been supplied to the MWA through the Mojave River and Morongo Basin pipelines and by releases from Silverwood Lake. The Morongo Basin Pipeline, completed in 1995, extends from the East Branch of the California Aqueduct near the City of Hesperia to the Town of Yucca Valley. The SWP has delivered approximately 150,000 AF of water to MWA from 1972 through 2001. All MWA deliveries were distributed in the Mojave River Basin (Alto sub-area) or to the HDWD for recharge in the Warren Valley basin. No SWP deliveries have thus far been distributed to the Study Area.

Internal allocation of SWP water within the MWA service area is for a maximum of 7,257 AFY to Improvement District M (IDM) located in the Morongo/Johnson Valley Area. These allocation deliveries may be limited to the same percentage of total Table A amounts that MWA is approved to receive from the SWP. Limitations have not occurred to date because neither MWA nor the IDM member entities have approached maximum delivery capability.

MWA also has an existing agreement to transfer up to 2,250 AFY to the Antelope Valley East Kern Water Agency (AVEK). The water is delivered to AVEK for a power plant located near Kramer Junction within the MWA. One of the major issues raised by MWA stakeholders is how the remaining SWP Table A water will be distributed.

Each year by October 1, the contractors provide DWR with requests for water deliveries up to their full Table A amounts. Actual deliveries from DWR may vary from the requests due to variances in supply availability resulting from hydrology, storage availability, regulatory or operating constraints, and other factors.

In addition to fluctuations in the availability of SWP water, MWA's ability to use SWP water in the Study Area is limited by the lack of transmission facilities. Currently, the only distribution pipeline to the Study Area is the Morongo Basin Pipeline. The Morongo Basin Pipeline has a capacity of 14,500 AFY, of which only 13 percent or 1,885 AFY is dedicated for use in the Ames Basin (BDVWA and CSA No. 70 turnouts in the Study Area). Therefore, the maximum amount of SWP water available to the Study Area is assumed to be 1,855 AFY. Two recharge sites have been developed in HDWD to take water from this facility; these are receiving some SWP water to recharge the Warren Valley basin previously in overdraft.

6.1.2.1 <u>Source Characteristics and Water Quality</u>

The SWP's watershed, encompassing the mountains and waterways around the Feather River, provides rainfall runoff and snowmelt to Lake Oroville. This reservoir in Butte County is the starting point of a complex that includes three power plants, a forebay, and an afterbay.

As needed, water is released from Lake Oroville into the Feather River and hence into the Sacramento River and Sacramento-San Joaquin Delta. From the Delta, water is pumped into the California Aqueduct. Typical SWP water quality is summarized below.

SWP Water Quality Summary

Constituents	Maximum Contamination Level	Public Health Goal	Average	Range	Units
Inorganics:					
Arsenic	10	4	2	1.0 - 3.0	ppb
Nitrate/Nitrite as N	10,000	NA	482	240 – 780	ppb
Iron	300	NA	84	0 – 220	ppb
Secondary Standards:					
Total Dissolved Solids*	500	NA	273	267 - 293	ppm
Sulfate	250	NA	47.6	33 – 97	ppm
Additional Analytes:					
Hardness	NA	NA	72	57 - 77	ppm
Sodium	NA	NA	30	21 – 38	ppm

Source: DWR Operations and Maintenance Website.
*Water Quality Report for State Water Project Silverwood Lake Station 2006.

A potential water quality issue facing the Study Area is the accumulation of salt in groundwater. Because the Morongo/Johnson Valley basin is a closed basin, salt contained in wastewater and SWP supplies stays in the basin. The Study Area has no importation of recycled water, so salt sources would include septic systems, SWP water, and the natural solution and mobilization by runoff and groundwater of salts in geologic sediments.

6.1.2.2 Distribution System – Morongo Basin Pipeline

As previously mentioned, the Morongo Basin Pipeline currently delivers SWP water to the Alto sub-area of the Mojave River groundwater basin and to HDWD for recharge of the Warren Valley groundwater basin. HDWD has received approximately 37,000 AF since SWP deliveries through the Morongo Basin Pipeline began in 1995. To date, no deliveries have been made to the Study Area from the Morongo Basin Pipeline. The Pipeline has capacity to deliver water for the benefit of BDVWA, JBWD, and County of San Bernardino special districts. According to the *Agreement for Construction, Operation, and Financing of the Morongo Basin Pipeline Project* (March 1991) allotment of project capacity is as follows:

- BDVWA: 9 percent
- CSA No. 70, Improvement Zone W-1: 4 percent
- CSA No. 70, Improvement Zone W-4: 1 percent
- HDWD: 59 percent
- JBWD: 27 percent

Of these users, only BDVWA and CSA No. 70 W-1 can receive pipeline water in the Study Area, or 13 percent of the project capacity.

The Morongo Basin Pipeline can deliver a maximum of 14,500 AFY through 70 miles of variable-diameter concrete and mortar-lined steel pipe. The pipeline, which begins at the Antelope Siphon at the SWP aqueduct near Hesperia, continues northeasterly for approximately 7 miles as a 54-inch diameter pipe to a “T” intersection. At the “T” intersection, a 48-inch pipeline extends to a sleeve valve for recharge into the Mojave River from an outlet at Rock Springs Road near Hesperia. From the other side of the “T”, the pipeline extends east, as a 30-inch pipeline, approximately 26 miles to the Lucerne Valley pump station. From there, the pipeline extends 14 miles to Johnson Valley pump station. It continues southeasterly approximately 12 miles to the CSD turnout at Linn Road and Highway 247 in Landers, then approximately 8 more miles to the BDVWA turnout on Winters Road. From the Winters Road turnout the 20-inch pipeline continues southeasterly for approximately 3 miles to the 5 million gallon HDWD Yucca Valley regulating reservoir, located on Warren Vista Avenue. The original Morongo Basin Pipeline ended at the Yucca Valley reservoir. The location of the pipeline through the Study Area is shown on Figure 2.

Reach 1 of a 24-inch extension to the Morongo Basin Pipeline goes approximately 6 miles south from the reservoir to a “T” intersection north of Yucca Creek. Reach 2 extends west approximately 2 miles to the intersection of Highway 247 and Yucca Creek Wash. The extension continues approximately ¼ of a mile westerly to a second HDWD recharge basin, located along Yucca Creek Wash at Sunnyslope Drive. Ultimately, the Morongo Basin Pipeline supplies three separate recharge ponds in the HDWD service area and terminates west of Yucca Creek Wash.

6.1.2.3 Availability of Supply

DWR states in their *SWP Delivery Reliability Report 2005* (*Reliability Report*) that existing SWP facilities will on average receive 69 percent of their full Table A amount for current demand conditions and 77 percent of their full Table A amount for 2025 demand conditions.

Availability of SWP water varies from year to year (depending on precipitation, regulatory restrictions, legislative restrictions, and operational conditions) and is especially limited during dry years. The DWR *Reliability Report* anticipates a minimum delivery of 5 percent of full Table A amounts for single dry year 2025 demand conditions and 42 percent of full Table A amounts for multi-dry year 2025 demand conditions.

The following table summarizes the availability of wholesale water for average, single dry, and multiple dry water years. These tables assume that the amount of SWP water available to the Study Area is limited to the capacity of the local Morongo Basin Pipeline turnouts (13 percent of 14,500 AFY or 1,885 AFY) because this is the only existing means of delivery. In dry years, MWA may reallocate their SWP supply, so the values summarized below represent the maximum that could be delivered to the Study Area.

Wholesaler Identified and Quantified Existing and Planned Sources of Water Available to the Study Area for Average/Normal Water Years

Wholesaler (Supply Source)	2010	2015	2020	2025	2030
MWA (SWP)					
Table A Supply (AF)[(a)]	1,340	1,380	1,410	1,450	1,450
Percent of Table A Amount for Study Area	71	73	75	77	77

Note: (a) The percentages of Table A amount projected to be available are from Table 6-5 of DWR's *Reliability Report*. Supplies are calculated by multiplying the Morongo Basin Pipeline capacity with turnouts to the Study Area (1,885 AFY) by these SWP reliability percentages. All quantities are rounded to the nearest 10 AF.

Wholesaler Water Reliability

Wholesaler	Single Dry Year	Multiple Dry Years
MWA (SWP Supply)		
2005		
Table A Supply to Study Area (AF)[(a)]	95	790
Percent of Table A Amount	5	42
2025/2030		
Table A Supply to Study Area (AF)[(a)]	95	790
Percent of Table A Amount	5	42

Note: (a) The percentages of Table A amount projected to be available are from Table 5-4 of DWR's *Reliability Report*. Supplies are calculated by multiplying the Morongo Basin Pipeline capacity to the Study Area (1,885 AFY) by these percentages. All numbers rounded to the nearest 10 AF.

6.1.3 Summary of Projected Supplies for the Study Area

It is assumed for the purposes of this Study that the amount of water supply available to the Study Area will not change significantly between now and 2030. In addition to its net average annual groundwater supply of 1,632 AFY, the Study Area has an average annual SWP Table A supply of up to 1,885 AFY. The availability of each water type in five-year increments through 2030 is summarized on the following table.

Current and Planned Water Supplies (AFY)

Water Supply Sources (Long-term Average)	2005	2010	2015	2020	2025	2030
Groundwater	*1,632*	*1,632*	*1,632*	*1,632*	*1,632*	*1,632*
Ames Valley	686	686	686	686	686	686
Johnson Valley	921	921	921	921	921	921
Means Valley	25	25	25	25	25	25
Imported Water to Study Area						
Total SWP[a]		1,340	1,380	1,410	1,450	1,450
Total	1,632	2,972	3,012	3,042	3,082	3,082

Notes: All numbers rounded to the nearest 10 AF.
(a) SWP water delivery at 69 to 77 percent of Morongo Basin Pipeline Capacity.

6.2 Water Demand

Current demand in each of the basins has been documented in the basin conceptual models (Sections 3, 4, and 5). For the purposes of this study, demand is first approximated by pumping amounts and subsequently corrected for estimated return flows, primarily from septic systems. This total represents the net demand or consumptive use in the basins. The incorporation of return flows into demand is adopted for consistency with the water balance, which is based on the entire groundwater basin. The following sections describe the methodologies used to estimate consumptive use and current water demand, and to project future demands within the water purveyors' service areas.

6.2.1 Consumptive Use

In the absence of agricultural land use, golf courses, or other large landscaped areas requiring significant water use, most of the water produced is for indoor use and personal consumption. A portion of the water used is returned to the groundwater basin, referred to as return flows. The largest component of return flows in the Study Area is septic system discharge. USGS studies in Apple Valley and the Warren Basin have estimated return flows from septic tanks at 70 gallons per person per day. Septic system return flows were estimated for the water balances for Ames Valley and Johnson Valley basins (Sections 3 and 4 of this report). Return flows in Means Valley were assumed to be negligible. Using this methodology, average return flows were estimated to be between 50 and 60 percent of pumping, indicating that consumptive use (the water actually consumed) is between 40 and 50 percent of total pumping.

For the region, the MWA 2004 RWMP estimates a consumptive use factor of 50 percent (i.e. 50 percent of applied domestic water is returned to the groundwater basin). This consumptive use factor was reviewed and validated in the 2000 *Consumptive Water Use Study and Update of Production Safe Yield Calculations for the Mojave Basin Area* (Albert A. Webb and Associates, 2000), and agreed with estimates used in the Mojave Basin Area Adjudication Study. The amount is also consistent with the results for septic return flows discussed above, which used a different methodology. Accordingly, consumptive use was assumed to be 50 percent of pumping for this portion of the study.

6.2.2 Historic/Current Water Use

Historical groundwater production by basin over a 12-year Study Period is summarized in Table 6 and averages about 1,257 AFY for the Study Area. Volumes for the Ames Valley basin in this report do not include production from HDWD 10. However, the 12-year Study Period contains changes in pumping that are not representative of more recent conditions, especially for the Ames Valley where most of the pumping has occurred. Water has been exported historically from Ames Valley for use outside the Study Area, as discussed below.

6.2.2.1 Ames Valley Groundwater Basin

Groundwater production from Ames Valley basin has been highly variable as shown in Figure 28 and Table 6. Increases in pumping between 1993 and1997 were attributable to increased pumping by HDWD and the operation of the Bighorn-Desert View Intertie pipeline. HDWD, through operation of the Mainstream Well 24 and the intertie pipeline, exported groundwater pumped from the Ames Valley for use outside the Study Area. In 1996, the Ames basin production peaked when 39 percent of all HDWD pumping occurred in the basin, and an additional 700 AF was transferred to HDWD by the Intertie. From 1997 to 1999 the Bighorn Desert View Intertie did not operate, and only 27 AF were transferred in 2000. The Intertie has not been in operation since the 2000 transfer and in 1997, 1999, and 2000, less than 30 percent of the HDWD's production was from the Ames Valley basin. Exports outside the Ames Valley have been discontinued.

Due to a 1991 settlement agreement, HDWD pumping in the Ames basin has been limited to 800 AFY plus 0.5 AF per new residential connection. Additionally, groundwater pumped from the HDWD Mainstream Well 24 can only serve HDWD customers within the Ames Basin. HDWD has planned only 650 AFY to be pumped from the Ames Valley for 2006 through 2030, as stated in their 2005 UWMP. Because of these agreements, fluctuations in HDWD consumptive use for this basin will be limited and less volatile in the future.

Water demand in the Ames Valley basin consists entirely of domestic users, all served by HDWD, BDVWA, and CSA No. 70. It is assumed that all municipal production will be applied within the basin and that return flows are approximately 50 percent of the applied production (based on the MWA 2004 RWMP). Accordingly, consumptive use equals total pumping minus return flows. Pumping, return flows and consumptive use are shown for the last six years on the following table.

Historic and Current Water Use Ames Valley Groundwater Basin (AFY)

Year	Total Pumping	Return Flows[1]	Consumptive Use[2]
2000	1,203	601	601
2001	1,191	595	595
2002	1,233	616	616
2003	1,164	582	582
2004	1,328	664	664
2005	997	498	498
Average	*1,186*	*593*	*593*

[1] Equal to 50 percent of the applied production
[2] Equal to the pumping minus return flows.

6.2.2.2 Johnson Valley Groundwater Basin

Documented municipal water production for the Johnson Valley basin is relatively small and does not appear to be sufficient for the estimated population in the valley of 400 persons. BDVWA has only one well in the basin and production from that well flows into a tank where private users or commercial water haulers purchase water for primarily residential use. Since there is no distribution system in the valley, it is assumed that private wells or other water sources supplement the supply from BDVWA. However, the amount and exact source of the additional water supply is unknown.

As defined for this Study, consumptive use equals the municipal production minus the return flow. However, for Johnson Valley, since the municipal production seems too low for the estimated 2005 population, a per capita water use factor determined for Ames Valley (0.071 AFY/person) is applied to the 2005 population as shown below.

Historic and Current Water Use for Johnson Valley Groundwater Basin (AFY)

Year	Documented Pumping[1]	Return Flows[2]	Consumptive Use from Pumping[3]	Consumptive Use with Ames Valley coefficient[4]
2000	6.2	3.1	3.1	
2001	9.9	4.9	4.9	
2002	13.6	6.8	6.8	
2003	13.6	6.8	6.8	
2004	12.2	6.1	6.1	
2005	11.6	5.8	5.8	28.4
Average	*11.2*	*5.6*	*5.6*	

[1] Municipal pumping in Johnson Valley
[2] Equal to 50 percent of the applied production.
[3] Equal to pumping minus return flows.
[4] Equal to 0.071 AFY/person for 400 persons.

Since the alternative consumptive use number above is based on population and is consistent with per capita demand values for Ames Valley (where private well use is negligible), the alternative method of estimating consumptive use for the Johnson Valley is applied in this Study.

6.2.3 Factors Affecting Water Demand

Two major factors that affect water demand are weather and water conservation. In general, when the weather is hot and dry, water usage increases, while in cool-wet years, water usage decreases, mostly reflecting less water demand for landscaping. Water conservation measures employed within the Study Area have a direct long-term effect on water demand.

6.2.3.1 Weather Effects on Historical Water Demand

While landscaping is limited in the Study Area, water demand increases in response to hot, dry weather. However, in recent years, conservation efforts have limited increases in demand due to the dry weather and often reduce overall demand compared to wet or average weather. Further effects on demand due to global warming may also begin to influence future water usage and planning efforts.

In the update of the California Water Plan (2005), DWR provides an assessment of the impacts of global warming on the State's water supply based on a series of computer models derived from decades of scientific research. Model results indicate increased temperature, reduction in Sierra snow depth, early snow melt, and a rise in sea level. These changing hydrological conditions could affect future planning efforts but have not been defined in enough detail too influence this study. DWR will continue to provide updated results from these models as further research is conducted and more information becomes available.

6.2.3.2 Conservation Effects on Water Usage

In recent years, water conservation has become an increasingly important factor in water supply planning in California. The California plumbing code has instituted requirements for new construction that mandate the installation of ultra low-flow toilets and low-flow showerheads. As signatories to the Memorandum of Understanding (MOU) for Urban Water Conservation in California, MWA and HDWD participate in water conservation measures that include public information and education programs and the implementation of water efficient Best Management Practices. Although BDVWA is not a signatory to the MOU, it is a member agency of the Alliance for Water Awareness and Conservation (AWAC), which focuses water conservation efforts in the Mojave Desert region. MWA and HDWD are also AWAC members. The water demand estimates in the following sections include the AWAC's goal for five percent reduction in consumptive use in the Morongo Basin by 2015.

6.2.4 Comparative Methods of Estimating Demand

There are several methods typically used to determine water demand projections, including: population, service connections, trend-line, land use, and consumptive use. Advantages and disadvantages for each method are discussed briefly below.

6.2.4.1 Population Based Demand Projection

A population based method to determine projected water demand consists of applying an average water demand (typically based on historic water use) to projected population. The growth in population is usually determined from such agencies as the Southern California Association of Governments (SCAG), California Department of Finance, or the U.S. Census Bureau; however, growth rates may also be determined from historic population changes. Population-based water use projections are often the most straightforward to develop. However, they may mask economic trends, changes in land use, and non-population based water demands. Population-based estimates can be improved by incorporating any known future developments when determining the growth rates. This method is the most appropriate for this study.

6.2.4.2 Other Methods

The simplest method uses a simple trend line extension of historic water usage. However, it is limited in that it does not consider climatic changes, new developments, new water conservation, or annexations. However, it may be fairly accurate for near-term forecasts.

Consumptive use-based demand projections tend to be similar to the historic trend-line method but with the added benefit of considering return flow to the basin. This method is beneficial when a detailed determination of the recharge to a basin is being developed.

Another method used to project future water usage is to base the water use on the number of service connections or meters. This method involves an extrapolation of historic service connection trends and is fairly accurate for near-term forecasts. The BDVWA Water System Master Plan being developed by Don Howard Engineering uses this approach to estimate the projected water demand. This approach is limited to the service area boundaries of the water agency and is not broken down by groundwater basin. Since this Study's objective is to compare supply and demand for each basin, this approach was not utilized.

Land-use based water use projections tend to be the most accurate for long-term forecasts (such as build-out) but don't predict a time frame for development and thus can be inaccurate for near-term forecasts. This method requires the most time and money to develop and can provide water use projections per water use class, which can be a great benefit for planning. However, the accuracy of land-use projections is limited by the availability and quality of land-use data for the Study Area.

6.2.5 Population Projection

The population projections for the Study Area are summarized below. Population was not separated between Ames Valley and Means Valley since water service to the Means Valley area is negligible. Therefore the two basins are combined below.

A 2.0 percent annual increase in population was assumed for the Johnson Valley basin for the years 2005 through 2020, consistent with the MWA 2004 RWMP. Using the RWMP increases for the Means/Ames basin results in 2.2 percent annual increase in population for 2005 through 2020. An average growth rate of 1.8 percent per year was assumed for 2020 through 2030, which reflects the San Bernardino County growth rate for this time period as determined by the California State Department of Finance. To remain consistent with the approach of the 2004 RWMP, these population estimates are based on the population served and not the entire population that overlies the basin. Some people have private wells or are served by water haulers.

Population Projections

	2005	2010	2015	2020	2025	2030
Ames/Means	8,300	9,300	10,400	11,700	12,400	13,900
Johnson	400	500	500	600	600	700
Study Area	**8,700**	**9,800**	**10,900**	**12,300**	**13,000**	**14,600**

Source: Source- MWA 2005 UWMP. Values represent the population served in each basin.

6.2.6 Summary of Projected Demand

Population projections are often used to determine future demand by using an average water demand (typically based on historic water use). Based on average 2000 to 2005 water use data, an average consumptive water use per person can be calculated for the Ames Valley. By translating the average pumping amount of 1,186 AFY into an average consumptive use of 593 AFY (one half of pumping as explained previously), and using the 2005 population of 8,300 persons, the consumptive use coefficient is approximately 0.071 AFY per person (593/8,300).

The same consumptive water use coefficient is also applied to Johnson Valley population data (0.071 AFY for 400 persons in 2005). Although municipal groundwater production data were available for Johnson Valley, pumping did not appear sufficient to support the documented population. It is suspected that private well use is significant in the valley since there is no water distribution system. As such, Johnson Valley municipal production seems less appropriate than data from Ames Valley for estimating a per capita consumptive use coefficient.

Using the Ames Valley consumptive use coefficient and population projections for the basins above, the estimated future water usage is presented on the following table. Since Means Valley represents a small unknown number in the population projections and does not receive current water service, the small additional supply from the Means Valley Groundwater Basin was not included in the supply and demand analysis. The following values below include the MWA's goal of five percent consumptive use reductions by the year 2015 for the Study Area. Consumptive use reductions for water conservation were assumed linear between 2005 and 2015.

Population Based Water Demand Projections (Consumptive Use, AFY)

	2005	2010	2015	2020	2025	2030
Ames/Means	589	660	701	789	836	938
Johnson	28	36	34	40	40	47
Study Area	**617**	**696**	**735**	**829**	**876**	**985**

6.3 Summary of Water Supply and Demand Situation

This subsection provides a discussion of the reliability of the water supply within the Study Area. A comparison between the water supply and demand for an average water year, single-dry water year, and multiple dry water years is also provided.

6.3.1 Adequacy of Supply in Normal, Dry, and Multiple Dry Years

A comparison of water supply and demand for an average water year, single dry water year, and multiple dry water years is presented below from 2005 to 2030 in five-year increments. Groundwater (GW) supply is defined in the tables as the annual recharge to the basin.

6.3.1.1 <u>Normal Year (Average) Conditions</u>

The following table provides a summary of the average water year reliability for each of the water basins and the Study Area as a whole. Demand estimates are based on the consumptive use projection and include MWA's conservation goal of five percent of consumptive use by 2015.

Average Water Year Supply and Demand Comparison by Basin (AFY)

Water Supply Sources	2005	2010	2015	2020	2025	2030
Ames Valley GW Supply	686	686	686	686	686	686
Ames Valley Demand	589	660	701	789	836	938
Ames Valley Surplus/(Deficit)	97	26	(15)	(103)	(150)	(252)
Johnson Valley GW Supply	921	921	921	921	921	921
Johnson Valley Demand	28	36	34	40	40	47
Johnson Valley Surplus/(Deficit)	893	885	887	881	881	874
GW Surplus/(Deficit) to Study Area	990	911	872	778	731	622
Imported Water to Study Area	1,300	1,340	1,380	1,410	1,450	1,450
Total Surplus/(Deficit) to Study Area	2,290	2,251	2,252	2,188	2,181	2,072

Note: Demand totals reflect an average consumptive use coefficient of 0.071 AFY/persons.

As shown by the comparison, Ames Valley appears to be capable of handling only current demand, with perhaps a small increase in demand under average conditions. According to the water balance in Section 3, the basin is estimated to be very near or already in overdraft conditions, assuming that increased pumping would not be able to access current amounts of subsurface outflow or evaporation. The small surplus listed below for 2005 and 2010 is likely within the uncertainty range of the water balance. A deficit is indicated in 2015 and beyond. After about 2010, demand would have to be met with either groundwater storage or an imported supply.

Johnson Valley, in contrast, has very little current or future demand and, as such, indicates a surplus of water through 2030 under average conditions. This surplus assumes that additional wells would be capable of capturing groundwater that would otherwise be lost to subsurface outflow or ET. Using the indicated surplus in Johnson Valley to offset the need for additional supplies in Ames Valley may not be practical, given the lack of infrastructure in Johnson Valley and the uncertainties in the water balance.

6.3.1.2 Single Dry-Year Conditions

A comparison of supply and demand conditions for a single dry water year (1989-1990) has also been conducted. This does not account for the availability of groundwater storage that could be used during one year. Availability of SWP water was taken from previous discussions and is five percent of Table A amounts. Demand estimates were based on consumptive use projections above, and include MWA's five percent conservation rate by 2015.

Single Dry Water Year Supply and Demand Comparison by Basin (AFY)

Water Supply Sources	2005	2010	2015	2020	2025	2030
Ames Valley GW Supply	176	176	176	176	176	176
Ames Valley Demand	589	660	701	789	836	938
Ames Valley Surplus/(Deficit)	(413)	(484)	(525)	(613)	(660)	(762)
Johnson Valley GW Supply	236	236	236	236	236	236
Johnson Valley Demand	28	36	34	40	40	47
Johnson Valley Surplus/(Deficit)	208	200	202	196	196	189
GW Surplus/(Deficit) to Study Area	(205)	(284)	(323)	(417)	(464)	(573)
Imported Water to Study Area	95	95	95	95	95	95
Total Surplus/(Deficit) to Study Area	(110)	(189)	(228)	(322)	(369)	(478)

As shown by the comparison above, recharge to the Ames Valley Groundwater Basin in a single-dry year is not sufficient to meet current or future single-dry year demand without using groundwater storage or SWP water. Recharge to the Johnson Valley basin appears to be sufficient to meet single-dry year demand through 2030 without using additional groundwater in storage or imported supply. If the indicated surplus in Johnson Valley is used to offset the deficit in the Ames Valley, the overall deficit for the Study Area is reduced but not eliminated. Even if imported water supply is added to these conditions, deficits remain for single dry year demand now and into the future. This is due, in part, to the small amount of imported water that may be available in a single dry year. Alternatively, groundwater storage could be used to provide drought-time supply, providing that the long-term average demand does not exceed the long-term average recharge.

6.3.1.3 Multiple Dry-Year Conditions

Multiple dry-year reliability for each groundwater basin and the Study Area as a whole was analyzed using recharge data from 1999-2001, when rainfall was approximately 50 percent of the long-term average (Table 3). Availability of SWP water is assumed to be 790 AFY as previously discussed (42 percent of Table A amounts). Demand estimates were based on consumptive use projections and include MWA's five percent conservation rate by 2015.

Multiple Dry Water Year Supply and Demand Comparison (AFY)

Water Supply Sources	2005	2010	2015	2020	2025	2030
Ames/Means Valley GW Supply	386	386	386	386	386	386
Ames/Means Valley Demand	589	660	701	789	836	938
Ames/Means Valley Surplus/(Deficit)	**(203)**	**(274)**	**(315)**	**(403)**	**(450)**	**(552)**
Johnson Valley GW Supply	518	518	518	518	518	518
Johnson Valley Demand	28	36	34	40	40	47
Johnson Valley Surplus/(Deficit)	**490**	**482**	**484**	**478**	**478**	**471**
GW Surplus/(Deficit) to Study Area	287	208	169	75	28	(81)
Imported Water to Study Area	790	790	790	790	790	790
Total Surplus/(Deficit) to Study Area	**1,077**	**998**	**959**	**865**	**818**	**709**

As shown by the comparison above, the Ames Valley groundwater supply is not sufficient to meet current or future multiple dry-year demand without imported water. Johnson Valley, on the other hand, has sufficient groundwater to meet its multiple dry year demand through 2030. Similar to previous evaluations, the indicated surplus in Johnson Valley assumes that additional wells would be capable of capturing groundwater that would otherwise be lost to subsurface outflow or ET.

Overall, the Study Area has sufficient groundwater supply until after 2025 when a deficit is indicated. Again, applying the Johnson Valley surplus to the deficit in the Ames Valley basin may not reflect a reasonable approach to water supply due to infrastructure considerations. As in the single-dry year analysis, SWP water would be required eventually to meet the Study Area deficit.

6.3.2 Water Supply Recommendations

Two recommendations are proposed for consideration in balancing the water supply and demand in average and dry years:

- Develop groundwater banking in the Ames Valley Groundwater Basin, and begin to pre-deliver water for recharge there by using the excess capacity of the Morongo Basin Pipeline.

- If water banking in the Ames Valley Groundwater Basin cannot be conducted or does not meet the reliability needed, seek arrangements to supplement supply in the Ames Valley Basin with groundwater from Johnson Valley. This would involve construction of wells and water conveyance systems. Since the Morongo Basin Pipeline has untreated water, consideration could be given to using the Morongo Basin Pipeline to deliver Johnson Valley water to Ames Valley Groundwater Basin.

7 FINDINGS AND RECOMMENDATIONS

7.1 Findings

The findings of this study are presented below, organized by groundwater basin. A synopsis of each basin conceptual model and considerations for conjunctive use in the basin are included.

7.1.1 Ames Valley Groundwater Basin

<u>Basin Conceptual Model – Ames Valley</u>

The Ames Valley Groundwater Basin covers 110,000 acres of a sloping alluvial plain, extending from the San Bernardino Mountains on the west to Emerson Dry Lake in the northeast. Known and inferred northwest-trending faults slice the basin into four subbasins: Pipes, Reche, Giant Rock and Emerson. An upland area characterized by shallow bedrock and thin saturated sediments defines a fifth subbasin, Pioneertown. Shallow bedrock ridges interrupt the basin with bedrock outcrops and redirect groundwater flow in the shallow subsurface in some areas.

Natural recharge to the groundwater basin is from runoff generated in the upland areas of the adjacent mountains where precipitation is higher than on the basin floor. Average precipitation in the 58,551 acres of the contributing watershed is about 7.5 inches per year. Runoff is confined primarily to four major drainageways (Antelope Creek, Whalen's Wash, Ruby Mountain Creek, and Sand Hill Wash), which transport surface water to the basin edge where it is subject to evaporation and infiltration. Recharge is estimated to be two percent of average rainfall generated in the contributing watershed. Recharge from precipitation that falls directly on the groundwater basin area is considered negligible due to low precipitation and high evaporation. The two percent factor relating recharge to upland rainfall was calibrated to data in the Flamingo Heights/Pipes Subbasin including observed changes in storage, runoff catchment areas, septic return flows, and pumping data. Using this factor, natural recharge for the basin is estimated at 686 AFY on an average basis, a value consistent with estimates by previous investigators (500 AFY by Lewis and 700 AFY by DWR).

Recharge occurs mainly in incised washes and alluvial fans and percolates to groundwater through relatively coarse-grained sediments near the mountain front. Basin groundwater appears to be unconfined to semi-confined throughout the basin. Groundwater generally flows from western recharge areas to the northeast toward the groundwater basin discharge areas at the boundary with the Surprise Spring basin and beneath Emerson Dry Lake. Groundwater flowpaths from recharge areas to discharge areas are impacted by faulting and shallow bedrock. Clay gouge and low permeability zones associated with fault planes impede groundwater flow from subbasin to subbasin, although groundwater apparently does seep through the zones. Shallow bedrock ridges re-direct flow and funnel groundwater to specific areas along the faults where most of the crossflow likely occurs.

Groundwater quality is good, as represented by total dissolved solids (TDS) with levels generally below 500 mg/L. No elevated concentrations of constituents of concern were identified from available data.

Groundwater storage in the basin is estimated at 1.45 million AF, although most of this cannot be developed economically through wells. Available storage capacity in the unsaturated zone is estimated to be more than 3.41 million AF. Topography and other constraints limit the use of the entire unsaturated zone for storage, but the high value indicates that storage of imported water in the basin could be accomplished. Saturated thickness and depth to water are highly variable in the basin.

Current (2005) pumping of about 1,000 AFY supports a population of about 8,300 persons. Since most of the water use is indoors and none of the Study Area is sewered, return flows from septic systems represent a significant component of inflows to the groundwater basin. Return flows from septic systems are calculated using formulas derived by other investigators in the Mojave Desert area and represent 651 AFY for the Ames Valley in 2005.

A preliminary water balance for the basin indicates that the basin is close to balance under average conditions. The negative change in storage (-21AFY) suggests slight overdraft conditions, but the value is likely within the uncertainty of the water balance components. Nonetheless, the water balance warrants investigation of additional supplies to supplement the groundwater basin. Population and water demand are expected to increase significantly in the Ames Valley basin. Evaluation of a single dry year, multiple dry years, and average conditions indicate that the basin cannot supply any of the dry years without impacting groundwater storage and cannot supply average conditions beyond about 2010.

Project Considerations – Ames Valley

Findings from the basin conceptual model development and water demand and supply assessment for the Ames Valley Groundwater Basin indicate that a managed aquifer recharge project is technically feasible and, if implemented, would meet the objectives of BDVWA and MWA to manage groundwater resources conjunctively in the Study Area. Findings from the evaluation with respect to project considerations are summarized below:

- The Flamingo Heights Fan, generally south of Whalen's Wash and west of Pipes Wash represents the deepest portion of the basin. This area would provide adequate groundwater storage and available storage capacity to support sustainable managed aquifer recharge.

- Coarse-grained sediments in the unsaturated zone beneath Pipes Wash and Whalen's Wash as identified by electrical resistivity surveys are ideal for the sustainable infiltration and percolation of imported SWP water in the basin.

- The highest specific capacities (which correlate to the highest aquifer T and K values) were calculated for wells located in three areas: 1) in the Flamingo Heights Fan just west of the Johnson Valley Fault, 2) along Pipes Wash and Whalen's Wash in the Pipes and Reche subbasins, and 3) near BDVWA 6, 7, and 9 in the Reche Subbasin.

- Lithologic data and resistivity surveys indicate that coarse-grained sediments associated with the proximal portions of the Flamingo Heights Fan do not extend sufficient distances downgradient to support a conjunctive use project on the upper slope of the fan.

- The Pioneertown Subbasin, the area in the Reche Subbasin north of BDVWA 6, 7, and 9, and the areas in the Pipes and Reche subbasins southeast of Pipes Wash are defined by shallow bedrock overlain by thin saturated sediments with low permeability. Such conditions are likely insufficient with respect to groundwater storage, available storage capacity, or aquifer permeability to sustain a conjunctive use project in the basin.

- Although groundwater flow occurs across the Pipes Barrier, and Johnson Valley and Homestead Valley faults, infiltrating water from a conjunctive use project located hydraulically upgradient of these faults may be impeded.

- Groundwater quality in monitoring wells meets MCLs in the Pipes, Reche and Giant Rock subbasins. Groundwater quality is generally poor in the Emerson Subbasin, where elevated concentrations of chloride, sulfate, fluoride, and TDS exceed MCLs.

- The extent and concentrations of naturally occurring nitrate and high-nitrate septic tank discharge in the unsaturated zone are unknown in the basin, but are a concern.

- Areas in the basin that are characterized by favorable hydrogeologic conditions (i.e. sufficient groundwater storage and available storage capacity, downgradient of major hydraulic barriers, high well specific yield, and good water quality) and are also located close to the MWA Morongo Basin Pipeline include 1) Whalen's Wash east of the Pipes Barrier up to BDVWA 6, 7, and 9 in the Reche Subbasin and 2) Pipes Wash east of the Inferred Pipes Barrier in the Reche Subbasin.

7.1.2 Johnson Valley Groundwater Basin

<u>Basin Conceptual Model – Johnson Valley</u>

The Johnson Valley Groundwater Basin covers 111,630 acres of a sloping alluvial plain, extending from the San Bernardino Mountains on the south to Melville and Soggy dry lakes to the north. The basin size is similar to Ames Valley. Known and inferred northwest-trending faults slice the basin into two subbasins referred to as Upper Johnson and Soggy Lake by DWR. USGS further divides the Soggy Lake Subbasin into two areas, Johnson and Fry. Shallow bedrock ridges and peaks from historical and recent faulting interrupt the basin with bedrock outcrops and redirect groundwater flow in the shallow subsurface in some areas.

Natural recharge to the groundwater basin is from runoff generated in the upland areas of the adjacent mountains where precipitation is higher than on the basin floor. Average precipitation in the 64,428 acres of the contributing watershed is about 9.2 inches per year. Runoff is confined primarily to three major drainageways, Ruby Canyon, Two Holes Spring, and Arrastre Creek, which transport surface water to the basin edge where it is subject to evaporation and infiltration. Consistent with a methodology developed in the Ames Valley for this study, recharge is estimated to be two percent of average rainfall generated in the contributing watershed. This method results in an average recharge of 921 AFY to the Johnson Valley basin. Average recharge is higher than in Ames Valley due to the slightly larger watershed and higher average precipitation. Recharge from precipitation that falls directly on the basin floor is considered negligible due to low precipitation and high evaporation.

Recharge occurs mainly in incised washes and alluvial fans and percolates to groundwater through relatively coarse-grained sediments near the mountain front. Basin groundwater appears to be unconfined to semi-confined throughout the basin. Groundwater generally flows from southern recharge areas to the north toward the groundwater basin discharge areas at the Means Valley Groundwater Basin and Melville and Soggy dry lakes. Groundwater leaves the basin as subsurface outflow and evaporation beneath the dry lakes. Groundwater flowpaths from recharge areas to discharge areas are impacted by faulting and shallow bedrock. Low permeability zones associated with faults impede groundwater flow across basin and subbasin boundaries, although groundwater apparently does seep through fault zones at certain locations. Shallow bedrock ridges re-direct flow and funnel groundwater to specific areas along the faults where most of the crossflow likely occurs.

Groundwater quality, as characterized by TDS, is better in the southern portion of the basin where levels are lower than 500 mg/L. Water quality deteriorates significantly in wells to the north with TDS concentrations exceeding 1,000 mg/L.

Groundwater storage in the basin is estimated at 2.27 million AF, although most of this cannot be accessed economically with wells. Available storage capacity in the unsaturated zone is estimated to be more than 2.4 million AF. Topography and other constraints limit the use of the entire unsaturated zone for storage, but the high value indicates that storage of imported water in the basin could be accomplished. Saturated thickness and depth to groundwater are highly variable in the basin.

Current (2005) pumping of about 10 AFY supports a population of about 400 persons. Water distribution is accomplished by pumping water from one active well to a storage tank and providing water to private users and commercial water haulers. Since most of the water use is indoors and none of the Study Area is sewered, return flows from septic systems provide about 31 AFY of groundwater recharge using a current population of 400 persons and the same methodology for estimating return flows in Ames Valley.

A preliminary water balance for the basin indicates that the basin is in balance with significant subsurface outflows and losses to evaporation at dry lakes. Although future population and water demand are expected to increase in the Johnson Valley basin, projected increases are small. Evaluation of a single dry year, multiple dry years, and average conditions indicate that the basin is capable of meeting future demands as needed. This demand could be met by additional production wells. Depending on the location and production volume of additional wells, the pumping could intercept groundwater that would have been lost to subsurface outflow and ET.

Project Considerations – Johnson Valley

Findings from the basin conceptual model development and water supply and demand assessment for the Johnson Valley Groundwater Basin indicate that a managed aquifer recharge project in the basin is technically feasible, but due to the lack of projected growth in this area does not directly meet the objectives of BDVWA and MWA. Conclusions from the evaluation of the Johnson Valley Groundwater Basin with respect to project considerations are summarized below:

- The thick saturated and unsaturated sediments in the southern to central portions of Soggy Lake Subbasin would provide adequate groundwater storage and available storage capacity for a conjunctive use project.

- Lithologic data indicate that basin fill sediments are generally coarse-grained in the southern to central portions of the Soggy Lake Subbasin, becoming finer-grained to the northwest. Sediments in the Upper Johnson Valley Subbasin are generally coarse-grained but become finer-grained near Melville Dry Lake.

- Available hydraulic data for the calculation of specific capacities and aquifer parameters are limited but indicate that aquifer permeability in the basin may be sufficient to support a conjunctive use project.

- Although groundwater flow occurs across the Old Woman Springs, Lenwood, West Johnson Valley, and Johnson Valley faults, infiltrating surface water from a conjunctive use project located hydraulically upgradient of these faults may be impeded.

- Groundwater quality in the southern portion of the basin meets primary and secondary MCLs. North of Highway 247, groundwater quality generally worsens and exceeds MCLs for sulfate, chloride, and TDS.

- Projected growth in the Johnson Valley basin is small, indicating that the Johnson Valley basin would not be a candidate for a conjunctive use project.

7.1.3 Means Valley Groundwater Basin

Basin Conceptual Model – Means Valley

The Means Valley Groundwater Basin covers 15,000 acres of an alluvial plain, situated between Johnson Valley and Ames Valley basins. The basin is small compared to the adjacent basins and is defined by two bounding faults, the Johnson Valley Fault to the southeast and the Homestead Valley Fault to the west. Bedrock is relatively shallow, especially in the southern portion of the basin and the alluvial sediments are less than 500 feet thick and much thinner in some areas.

Natural recharge is provided by runoff from adjacent mountains where rainfall does not infiltrate significantly into the bedrock. Average precipitation in the 3,164 acres of the contributing watershed is about 5.1inches per year. Runoff is confined to only one major drainageway, Means Wash, which transports surface water to the basin edge where it is subject to evaporation and infiltration. Consistent with a methodology developed in the Ames Valley for this study, recharge is estimated to be two percent of average rainfall generated in the contributing watershed. This method results in an average recharge of only 25 AFY to the Means Valley basin. Average recharge is much lower than in Ames Valley or Johnson Valley because of the smaller watershed, limited surface water in Means Wash, and lower average precipitation (associated with lower elevations for the watershed). Recharge from precipitation that falls directly on the basin is considered negligible.

Recharge occurs mainly in the southern portions of the alluvial plain and percolates to groundwater through relatively coarse-grained sediments near the mountain front. Groundwater generally flows from the southern recharge area to the north where it evaporates from Means Dry Lake. Low permeability associated with the Johnson Valley Fault impedes groundwater flow into the Means Valley basin from Johnson Valley basin, although some groundwater apparently does seep through the fault zone. Shallow bedrock ridges are present around much of the basin and funnel groundwater through a relatively narrow area where Johnson Valley and Means Valley connect. A preliminary water balance for the basin indicates that the basin is in balance with evaporative loss at Means Dry Lake roughly equivalent to natural recharge and subsurface inflow.

Groundwater storage in the basin is estimated at 89,600 AF, although most of this cannot be developed economically through wells. In addition, the basin is characterized by relatively poor water quality and groundwater use from the basin is limited. Available storage in the unsaturated zone is estimated to be about 202,600 AF. Topography and water quality constraints limit the use of the unsaturated zoned for storage.

There is currently no pumping by water agencies in the basin. Groundwater use by private wells may occur in the basin, but the numbers are estimated to be small due to the sparse population. In addition, current and future water demand in the basin is uncertain because data sources combine Means Valley and Ames Valley for population projections. For purposes of this study, it is assumed that Means Valley population and water demand will not increase to significant numbers (greater than Johnson Valley, for example) through 2030.

<u>Project Considerations – Means Valley</u>

Findings from the basin conceptual model development and water demand and supply assessment for the Means Valley Groundwater Basin indicate that a managed aquifer recharge project in the basin was judged to have severe technical issues and does not meet the management objectives of BDVWA and MWA. Conclusions from the evaluation of the Ames Valley Groundwater Basin with respect to project considerations are summarized below:

- Although groundwater storage and available storage in the Means Valley basin is significant, groundwater quality is poor and subsurface lithology is relatively fine-grained compared to the Ames Valley and Johnson Valley basins. Such hydrogeologic conditions would not likely support sustainable managed aquifer recharge in the basin. Additionally, the relatively long distance between the Means Valley basin and the Morongo Basin Pipeline and the fact the projected growth in the basin is small allows for the conclusion that the Means Valley Basin should not be considered for a conjunctive use project.

7.2 Recommendations

Based on project findings, the following recommendations can be made:

- Given the favorable hydrogeologic conditions, and considering that major groundwater production, historic water level declines, and projected growth in water demand is concentrated in the central portion of the Pipes and Reche subbasins, additional hydrogeologic investigations along Whalen's Wash and Pipes Wash downgradient of the Pipes Barrier is recommended.

- Although groundwater does flow across the Johnson Valley Fault, Pipes Barrier, and Homestead Valley Fault, implementation of a managed recharge project hydraulically upgradient of these structures is not recommended without further investigation.

- Additional investigation is required to understand the geochemical compatibility of imported SWP water, native groundwater, and subsurface mineralogy in promising locations.

- Additional shallow monitoring wells would assist in characterizing groundwater in the upper aquifers. Most wells provide data only in deeper zones.

- BDVWA Draft Water System Master Plan indicates that new wells for recovery of water from a conjunctive use project in Reche Subbasin would be integrated easily into the current BDVWA conveyance system.

- Better areas may exist for groundwater development in the Johnson Valley basin than the area of BDVWA 10 if additional production is needed in the area in the future.

- Drill and construct test wells at recommended recharge sites. Conduct geophysical logging and pumping tests to confirm lithology, aquifer parameters, and discharge boundary (fault) locations; assess impacts of faults on groundwater and recharge flow pathways.

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Table 1
DWR and USGS Groundwater Basin and Subbasin Nomenclature

DWR Bulletin 118 Groundwater Basin / *Subbasin* (No.)	USGS Groundwater Basin / *Subbasin*	
	2004[a]	1972[b]
Ames Valley (7-16)	Morongo	Means Valley
	Pipes	*Pipes*
	Reche	*Reche*
		Pioneertown
		Copper Mountain Valley
	Giant Rock	*Giant Rock*
		Deadman Valley
	Emerson	*Surprise Spring* [c]
Means Valley (7-17)	Morongo	Means Valley
	Means	*Reche* [d]
Johnson Valley (7-18)	Morongo	Johnson Valley
Soggy Lake (7-18.01)	*Johnson*	*(Lower) Johnson Valley*
	Fry	
Upper Johnson Valley (7-18.02)	*Upper Johnson*	*(Upper) Johnson Valley*

[a] Stamos, C. L. et al. (2004) Regional Water Table (2004) and Water-Level Changes in the Mojave River and Morongo Ground-Water Basins, Southwestern Mojave Desert, California. USGS Scientific Investigation Report 2004-5187.
[b] Lewis, R.E. (1972) Groundwater Resources of the Yucca Valley-Joshua Tree Area. USGS Open File Report.
[c] Northern portion of Surprise Spring subbasin (1972) overlaps southern portion of Emerson subbasin (2004) south of Emerson Lake and the Hidalgo Mountains
[d] Reche subbasin (1972) includes DWR Means Valley Groundwater Basin and USGS Means subbasin (2004). Later, USGS (French, 1978) identified a bedrock outcrop separating the current Means and Reche subbasins (2004).

Table 2
Estimated Aquifer Parameters for Study Area Wells

DWR BASIN USGS Morongo Subbasin	State Well Number	Common Name	Depth to SWL	Depth to Top of Well Screen	Depth to Bottom of Well Screen	Total Saturated Screen Length	Well Yield	Water Level Drawdown	Pumping Duration	Specific Capacity	Transmissivity[a]	Hydraulic Conductivity[b] b = sat. screen length	Hydraulic Conductivity[b] b = SWL - screen bottom	Data Source[e]
			feet bgs	feet	feet	feet	gpm	feet	hours	gpm/ft dd	gpd/ft	gpd/ft^2	gpd/ft^2	
AMES VALLEY														
Giant Rock	2N6E 23H1		720	365	835	115	10.0	10.0	1.0	1.0	1,500	13.0	13.0	Driller's log
Giant Rock	2N6E 28J1		420	400	600	180	2.0	180.0	1.0	0.0	17	0.1	0.1	Driller's log
Pioneertown	1N4E 01K5		N/A	100	422	322	2.5	200.0	2.0	0.0	19	0.1	N/A	Driller's log
Pioneertown	1N4E 01N3		23	60	100	40	7.0	137.0	1.0	0.1	77	1.9	1.0	Driller's log
Pioneertown	1N4E 01R4		69	225	325	100	5.0	200.0	4.0	0.0	38	0.4	0.1	Driller's log
Pioneertown	1N4E 02B5		70	120	280	160	10.0	40.0	2.0	0.3	375	2.3	1.8	Driller's log
Pioneertown	1N4E 02H2		38	66	305	239	4.0	150.0	2.0	0.0	40	0.2	0.1	Driller's log
Pioneertown	1N4E 02J3		50	100	205	105	5.0	40.0	2.0	0.1	188	1.8	1.2	Driller's log
Pioneertown	1N4E 11A1		45	350	370	20	0.5	195.0	0.8	0.0	4	0.2	<0.1	Driller's log
Pioneertown	1N4E 11B1		30	311	358	47	1.0	327.0	5.0	0.0	5	0.1	<0.1	Driller's log
Pioneertown	1N4E 11H1		22	60	360	300	3.0	300.0	4.0	0.0	15	0.1	<0.1	Driller's log
Pioneertown	1N4E 12D2		50	143	188	45	7.0	13.0	1.0	0.5	808	17.9	5.9	Driller's log
Pioneertown	1N5E 06B2		20	68	460	392	1.0	460.0	2.0	0.0	3	<0.1	<0.1	Driller's log
Pioneertown	1N5E 06C1		32	80	385	305	5.0	240.0	4.0	0.0	40	0.1	0.1	Driller's log
Pioneertown	1N5E 06D3		40	224	264	40	1.0	224.0	4.0	0.0	7	0.2	<0.1	Driller's log
Pioneertown	1N5E 06Q1		41	240	300	20[c]	0.5	259.0	3.0	0.0	3	0.1	<0.1	Driller's log
Pioneertown	1N5E 06R1		405	0	665	260	0.8	250.0	12.0	0.0	5	<0.1	<0.1	Driller's log
Pioneertown	1N5E 07G1		57	150	422	272	7.0	250.0	3.0	0.0	42	0.2	0.1	Driller's log
Pipes	2N5E 36C1	HDWD #20	274	260	460	186	220.0	10.4	24.0	21.2	31,731	170.6	171.0	Pumping Test
Pipes	1N5E 09P1		88	192	272	80	7.0	60.0	2.0	0.1	175	2.2	1.0	Driller's log
Pipes	1N5E 10F2		115	110	240	125	1.0	240.0	6.0	0.0	6	0.1	0.1	Driller's log
Pipes	1N5E 10F3		125	220	320	100	4.0	5.0	3.0	0.8	1,200	12.0	6.2	Driller's log
Pipes	2N5E 10Q1		253	195	385	132	3.0	104.0	30.0	0.0	43	0.3	0.3	Driller's log
Pipes	2N5E 22J1	BDVWA #8	269	250	775	506	632.0	12.1	N/A	52.2	78,375	154.9	154.9	Pumping Tests
Pipes	2N5E 23K1		229	88	450	221	50.0	180.0	4.0	0.3	417	1.9	1.9	Driller's log
Pipes	2N5E 23K3		227	225	300	73	22.0	5.0	7.0	4.4	6,600	90.4	90.4	Driller's log
Pipes	2N5E 27K2	BDVWA #2	195	184	319	109	406.5	11.3	N/A	36.3	54,500	514.6	479.1	Pumping Tests
Pipes	2N5E 27K3	BDVWA #3	181	208	316	103	453.9	10.6	N/A	45.1	67,640	653.9	515.4	Pumping Tests
Pipes	2N5E 27R1	BDVWA #4	212	260	470	72[c]	409.7	25.1	N/A	16.7	25,083	348.4	97.1	Pumping Tests
Pipes	2N5E 34H2		247	238	418	171	13.0	7.0	2.0	1.9	2,786	16.3	16.3	Driller's log
Pipes	1N5E 02A1	HDWD #21	400[d]	300	600	120[c]	15.0	200.0	N/A	0.1	113	0.9	0.6	HDWD
Reche	2N5E 12B1	BDVWA #6	145	144	384	239	344.8	11.3	N/A	30.4	45,598	190.8	190.7	Pumping Tests
Reche	2N5E 12B2	BDVWA #7	143	180	400	220	400.9	9.6	N/A	41.8	62,695	285.0	244.6	Pumping Tests
Reche	2N5E 12C2	BDVWA #9	170	200	490	290	799.4	21.6	N/A	37.2	55,813	192.5	174.6	Pumping Tests
Reche	2N5E 12E1		206	200	260	54	32.0	5.0	1.0	6.4	9,600	177.8	177.8	Driller's log
Reche	2N5E 23J1		227	225	300	73	22.0	5.0	7.0	4.4	6,600	90.4	90.4	Driller's log
Reche	2N5E 24H1	HDWD #24	251	220	580	329	1400.0	28.9	2.0	48.4	72,664	220.9	220.9	Pumping Test
Reche	2N6E 07Q3	CSA Well #3	209	253	353	100	400.0	11.0	39.0	36.4	54,545	545.5	378.8	Driller's log
Reche	2N6E 18B1	CSA Well #1	186	187	305	118	517.0	20.0	26.0	25.9	38,775	328.6	325.8	Driller's log
Reche	2N6E 30L1		285	365	375	10	2.0	20.0	6.0	0.1	150	15.0	1.7	Driller's log
Reche	2N6E 30N1	HDWD #6	256	300	920	620	160.0	254.0	71.0	0.6	945	1.5	1.4	Driller's log
Reche	3N5E 21A1		249	285	323	38	10.0	51.0	2.0	0.2	294	7.7	4.0	Driller's log
Reche	3N5E 23C2		243	277	345	68	26.0	30.0	1.0	0.9	1,300	19.1	12.7	Driller's log
Reche	3N5E 23M1		230	190	270	40	10.0	260.0	8.0	0.0	58	1.4	1.4	Driller's log
Reche	3N5E 23M2		191	200	300	100	7.0	20.0	2.0	0.4	525	5.3	4.8	Driller's log
Reche	3N5E 23N1		208	220	280	60	6.0	62.0	12.0	0.1	145	2.4	2.0	Driller's log
Reche	3N5E 26E1		86	95	126	31	10.0	20.0	2.0	0.5	750	24.2	18.8	Driller's log
Reche	3N5E 35J2		175	175	261	86	5.0	78.0	12.0	0.1	96	1.1	1.1	Driller's log
Reche	3N5E 35R1		150	149	192	42	15.0	5.0	8.0	3.0	4,500	107.1	107.1	Driller's log
Reche	3N5E 35M1		178	170	238	60	10.0	50.0	2.0	0.2	300	5.0	5.0	Driller's log
JOHNSON VALLEY SOGGY LAKE														
Johnson	3N4E 06N1		137	148	245	97	40.0	7.0	0.0	5.7	8,571	88.4	79.4	Driller's log
Johnson	3N4E 17R3	BDVWA #10	505	650	800	150	85.3	109.1	N/A	0.8	1,181	7.9	4.0	Pumping Tests

[a]Equals 1500 * Specific Capacity (Driscoll (1986) Appendix 16D for unconfined aquifers)

[b]Equals Transmissivity / effective aquifer thickness (b)

[c]Screen length is less than depth to top of screen minus depth to bottom of screen, b/c of blank screen intervals

[d]Based on historic SWL at ~400 ft bgs and assumed PWL at bottom of screen

[e]For "pumping tests" sources, well yield, SWL, and drawdown represent average values from historic pumping tests; Specific Capacity may not equal Well Yield divided by Water Level Drawdown, and Hydraulic Conductivity may not equal Transmissivity divided by thickness, b

HDWD = Memorandum RE: HDWD 21 Pumping Test Results. From Marsh Goldblatt (General Manager HDWD) to Steve Winke

Table 3
Estimated Recharge from Rainfall

Ames Valley Groundwater Basin

Major Drainage		Antelope Creek	Whalen's Wash	Ruby Mountain	Sand Hill Wash	**Total**
Catchment Area (mi^2)		55.3	21.0	13.4	1.7	**91.5**
Catchment Area (acres)		35,400	13,400	8,600	1,100	**58,600**
Average Annual Rainfall (in)		8.54	6.35	5.39	4.52	**7.49**
Water Year	Average Rainfall	Recharge from Rainfall (AFY)				
1989-1990	24%	121	34	19	2	**176**
1990-1991	113%	570	160	87	9	**826**
1991-1992	103%	519	146	80	9	**753**
1992-1993	184%	927	261	142	15	**1,346**
1993-1994	81%	408	115	63	7	**592**
1994-1995	139%	701	197	107	12	**1,017**
1995-1996	94%	474	133	73	8	**688**
1996-1997	82%	413	116	63	7	**600**
1997-1998	146%	736	207	113	12	**1,068**
1998-1999	47%	237	67	36	4	**344**
1999-2000	42%	212	60	32	3	**307**
2000-2001	69%	348	98	53	6	**505**
Average		472	133	72	8	**685**
Maximum		927	261	142	15	**1,346**
Minimum		121	34	19	2	**176**
Single Year Drought(1989-1990)		121	34	19	2	**176**
Multiple Year Drought (1999-2001)		265	75	41	4	**385**

Johnson Valley Groundwater Basin

Major Drainage		Ruby Canyon	Two Hole Spring	Arrastre Creek	**Total**
Catchment Area (mi^2)		20.9	40.8	38.9	**100.7**
Catchment Area (acres)		13,400	26,100	24,900	**64,428**
Average Annual Rainfall (in)		6.47	8.41	11.38	**9.15**
Water Year	Average Rainfall	Recharge from Rainfall (AFY)			
1989-1990	24%	35	88	113	**236**
1990-1991	113%	163	413	534	**1,111**
1991-1992	103%	149	377	486	**1,012**
1992-1993	184%	266	673	869	**1,808**
1993-1994	81%	117	296	383	**796**
1994-1995	139%	201	509	657	**1,366**
1995-1996	94%	136	344	444	**924**
1996-1997	82%	119	300	387	**806**
1997-1998	146%	211	534	690	**1,435**
1998-1999	47%	68	172	222	**462**
1999-2000	42%	61	154	198	**413**
2000-2001	69%	100	252	326	**678**
Average		135	343	442	**921**
Maximum		266	673	869	**1,808**
Minimum		35	88	113	**236**
Single Year Drought(1989-1990)		35	88	113	**236**
Multiple Year Drought (1999-2001)		76	193	249	**518**

Means Valley Groundwater Basin

Major Drainage		Means Wash	**Total**
Catchment Area (mi^2)		4.9	**4.9**
Catchment Area (acres)		3,200	**3,164**
Average Annual Rainfall (in)		5.11	**5.11**
Water Year	Average Rainfall	Recharge from Rainfall (AFY)	
1989-1990	24%	6	**6**
1990-1991	113%	30	**30**
1991-1992	103%	28	**28**
1992-1993	184%	50	**50**
1993-1994	81%	22	**22**
1994-1995	139%	37	**37**
1995-1996	94%	25	**25**
1996-1997	82%	22	**22**
1997-1998	146%	39	**39**
1998-1999	47%	13	**13**
1999-2000	42%	11	**11**
2000-2001	69%	19	**19**
Average		25	**25**
Maximum		50	**50**
Minimum		6	**6**
Single Year Drought(1989-1990)		6	**6**
Multiple Year Drought (1999-2001)		14	**14**

Table 4
General Inorganic Water Quality for Wells in Ames Valley, Johnson Valley, and Means Valley Basins

DWR BASIN USGS Morongo Subbasin	State Well Number	Well Name	Sample Date[a]	Na	K	Ca	Mg	Cl	HCO_3	CO_3	SO_4	Data Source[b]
				mg/L								
AMES VALLEY												
Emerson	4N6E 18L1		31-Aug-82	6,900.0	23.0	14.0	27.0	6,300.0	3,560.0	0.0	2,400.0	USGS NWIS
Emerson	4N6E 27D1		22-Aug-84	190.0	2.0	39.0	14.0	240.0	180.0	0.0	79.0	USGS NWIS
Emerson	4N6E 34E1		31-Aug-82	87.0	3.8	120.0	19.0	330.0	34.0	0.0	61.0	USGS NWIS
Emerson	4N6E 28R1		19-Feb-76	140.0	4.2	150.0	41.0	360.0	40.0	0.0	330.0	USGS NWIS
Giant Rock	2N6E 24C1		27-Oct-80	61.0	3.4	9.3	0.4	17.0	97.0	0.0	30.0	USGS NWIS
Giant Rock	3N6E 04P2		19-Feb-76	67.0	10.0	58.0	8.6	61.0	111.0	0.0	93.0	USGS NWIS
Giant Rock	3N6E 16A1		11-Aug-94	47.0	2.9	42.0	6.5	26.0	114.0	0.0	38.0	USGS NWIS
Giant Rock	3N6E 27B1		14-Sep-00	43.7	2.5	40.8	6.9	16.6	160.0	0.0	29.4	USGS NWIS
Pipes	1N5E 10C1		16-Sep-94	29.0	1.2	45.0	9.4	9.6	190.0	0.0	17.0	USGS NWIS
Pipes	2N5E 3G1		17-Oct-01	13.0	1.9	66.0	30.0	8.8	270.0	0.0	82.0	MWA
Pipes	2N5E 10A1		15-Aug-01	14.0	4.3	76.0	10.0	7.4	230.0	0.0	50.0	MWA
Pipes	2N5E 22J1	BDVWA #8	09-Nov-05	81.0	2.2	20.0	1.9	33.0	160.0	0.0	47.0	Lab WQ Report
Pipes	2N5E 27H1		06-Apr-01	13.0	2.2	71.0	11.0	7.1	220.0	0.0	44.0	MWA
Pipes	2N5E 27J1		06-Apr-01	12.0	1.9	74.0	11.0	7.6	230.0	0.0	52.0	MWA
Pipes	2N5E 27K2	BDVWA #2	09-Nov-05	46.0	3.6	59.0	13.0	30.0	240.0	0.0	39.0	Lab WQ Report
Pipes	2N5E 27K3	BDVWA #3	29-Oct-01	40.0	2.0	65.0	9.0	41.0	200.0	0.0	53.0	Lab WQ Report
Pipes	2N5E 27R1	BDVWA #4	09-Nov-05	49.0	2.7	57.0	11.0	21.0	260.0	0.0	34.0	Lab WQ Report
Pipes	2N5E 36C1	HDWD #21	18-Aug-97	39.0	4.0	43.0	8.5	15.0	172.0	0.0	24.1	Landers Landfill
Reche	2N5E 12B1	BDVWA #6	09-Nov-05	45.0	2.6	41.0	6.5	19.0	200.0	0.0	33.0	Lab WQ Report
Reche	2N5E 12B2	BDVWA #7	09-Nov-05	50.0	2.8	42.0	7.3	19.0	200.0	0.0	33.0	Lab WQ Report
Reche	2N5E 12C2	BDVWA #9	09-Nov-05	53.0	2.6	40.0	7.1	26.0	170.0	0.0	51.0	Lab WQ Report
Reche	2N5E 12N1		21-Aug-96	120.0	2.7	11.0	1.8	41.0	57.0	0.0	190.0	USGS NWIS
Reche	2N5E 13A1	Moran	19-Jun-96	43.0	2.5	33.0	6.3	20.0	124.0	0.0	40.0	USGS NWIS
Reche	2N5E 24H1	HDWD #24	30-Nov-04	41.0	2.1	50.0	7.0	14.0	220.0	0.0	23.0	Lab WQ Report
Reche	2N6E 07Q3	CSA 70 W-1 #3	16-Feb-05	42.0	2.6	40.0	4.7	19.0	170.0	0.0	28.0	Lab WQ Report
Reche	2N6E 18B1	CSA 70 W-1 #1	16-Feb-05	40.0	2.1	29.0	3.7	19.0	150.0	0.0	28.0	Lab WQ Report
Reche	2N6E 18B2	CSA 70 W-1 #2	16-Feb-05	47.0	2.6	47.0	4.9	30.0	170.0	0.0	36.0	Lab WQ Report
Reche	2N6E 30L1		05-Jul-78	48.0	2.4	23.0	0.9	20.0	75.0	0.0	46.0	USGS NWIS
Reche	2N6E 30N1	HDWD #6	18-Aug-97	39.0	7.0	27.0	3.8	22.5	96.0	0.0	16.5	Landers Sanitary Landfill
Reche	3N5E 13G1		15-Aug-96	46.0	4.3	34.0	5.1	34.0	81.0	0.0	79.0	USGS NWIS
Reche	3N5E 23D2		15-Aug-96	80.0	3.3	17.0	3.7	36.0	95.0	0.0	85.0	USGS NWIS
JOHNSON VALLEY, SOGGY LAKE												
Johnson	3N4E 03C1		11-Apr-80	210.0	13.0	260.0	110.0	510.0	75.0	0.0	700.0	USGS NWIS
Johnson	3N4E 06N1		27-Aug-96	360.0	7.1	43.0	24.0	210.0	78.0	0.0	640.0	USGS NWIS
Johnson	3N4E 15E1		10-Jun-66	93.0	5.0	22.0	3.0	39.0	140.0	0.0	100.0	French, 1978
Johnson	3N4E 17F2		22-Aug-96	65.0	5.4	18.0	5.5	39.0	59.0	0.0	100.0	USGS NWIS
Johnson	3N4E 17R3	BDVWA #10	09-Nov-05	110.0	5.9	23.0	5.6	43.0	150.0	0.0	97.0	Lab WQ Report
Johnson	4N3E 22C1		11-Apr-80	170.0	6.5	190.0	74.0	230.0	160.0	0.0	630.0	USGS NWIS
Johnson	4N3E 23G1		20-Feb-69	98.0	6.0	100.0	73.0	133.0	136.0	0.0	437.0	French, 1978
Johnson	4N3E 24Q1		22-Aug-96	60.0	4.6	43.0	25.0	41.0	77.0	0.0	220.0	USGS NWIS
Johnson	4N4E 19E1		11-Jun-74	200.0	6.5	174.0	144.0	615.0	138.0	0.0	461.0	French, 1978
Johnson	4N4E 19N1		04-Jul-78	73.0	4.8	41.0	23.0	41.0	84.0	0.0	200.0	USGS NWIS
JOHNSON VALLEY, UPPER JOHNSON VALLEY												
Upper Johnson	4N4E 5G1		13-Jan-54	880.0	15.4	127.0	2.0	895.0	61.0	0.0	965.0	French, 1978
MEANS VALLEY												
Means	4N4E 24Q1		11-Mar-55	440.0	19.5	47.0	14.0	355.0	649.0	0.0	102.0	French, 1978
Means	4N4E 36B1		15-Sep-99	14.5	1.5	26.3	5.5	14.8	89.0	0.2	16.1	MWA

[a]Most recent sample date

[b]NWIS = National Water Information System; CSA 2005 = CSA water quality results

Table 5
Total Dissolved Solids for Wells in Ames Valley, Johnson Valley, and Means Valley Groundwater Basins

DWR BASIN USGS Subbasin	State Well Number	Well Name	Sample Date[a]	TDS mg/L	E.C. μmhos/cm	TDS estimated from E.C.[b]	Data Source[c]
AMES VALLEY							
Emerson	4N6E 18L1		31-Aug-82	13260	22100	yes	USGS NWIS
Emerson	4N6E 27D1		22-Aug-84	690	1150	yes	USGS NWIS
Emerson	4N6E 28R1		19-Feb-76	1020	1700	yes	USGS NWIS
Emerson	4N6E 34E1		31-Aug-82	756	1260	yes	USGS NWIS
Giant Rock	2N6E 24C1		27-Oct-80	198	330	yes	USGS NWIS
Giant Rock	3N5E 13G1		15-Aug-96	277	461	yes	USGS NWIS
Giant Rock	3N6E 04P2		19-Feb-76	372	620	yes	USGS NWIS
Giant Rock	3N6E 16A1		12-Sep-00	287	478	yes	USGS NWIS
Giant Rock	3N6E 27B1		14-Sep-00	262	436	yes	USGS NWIS
Pipes	1N5E 10C1		16-Sep-94	256	426	yes	USGS NWIS
Pipes	2N5E 03G1		17-Oct-01	340			MWA
Pipes	2N5E 10A1		15-Aug-01	280			MWA
Pipes	2N5E 22J1	BDVWA #8	09-Nov-05	270	460	no	AVBMP
Pipes	2N5E 27H1		06-Apr-01	260			MWA
Pipes	2N5E 27J1		06-Apr-01	280			MWA
Pipes	2N5E 27K2	BDVWA #2	09-Nov-05	320	550	no	AVBMP
Pipes	2N5E 27K3	BDVWA #3	29-Oct-01	320	570	no	AVBMP
Pipes	2N5E 27R1	BDVWA #4	09-Nov-05	310	520	no	AVBMP
Pipes	2N5E 36C1	HDWD #21	18-Aug-97	152			Landers Sanitary Landfill
Reche	2N5E 12B1	BDVWA #6	09-Nov-05	260			AVBMP
Reche	2N5E 12B2	BDVWA #7	09-Nov-05	260	440	no	AVBMP
Reche	2N5E 12C2	BDVWA #9	09-Nov-05	270	470	no	AVBMP
Reche	2N5E 12N1		21-Aug-96	421	702	yes	USGS NWIS
Reche	2N5E 13A1		19-Jun-96	256	426	yes	USGS NWIS
Reche	2N5E 24H1	HDWD #24	30-Nov-04	250	400	no	AVBMP
Reche	2N6E 07Q3	CSA 70 W-1 #3	16-Feb-05	240	370	no	CSA, 2005
Reche	2N6E 18B1	CSA 70 W-1 #1	16-Feb-05	210	340	no	CSA, 2005
Reche	2N6E 18B2	CSA 70 W-1 #2	16-Feb-05	260	420	no	CSA, 2005
Reche	2N6E 30L1		05-Jul-78	135	225	yes	USGS NWIS
Reche	2N6E 30N1	HDWD #6	18-Aug-97	244			Landers Sanitary Landfill
Reche	3N5E 23D2		15-Aug-96	308	513	yes	USGS NWIS
JOHNSON VALLEY, SOGGY LAKE							
Johnson	3N4E 03C1		11-Apr-80	1800	3000	yes	USGS NWIS
Johnson	3N4E 06N1		27-Aug-96	1308	2180	yes	USGS NWIS
Johnson	3N4E 15E1		10-Jun-66	343			FRENCH, 1978
Johnson	3N4E 17F1		10-Jun-66	338			FRENCH, 1978
Johnson	3N4E 17R3	BDVWA #10	09-Nov-05	340			Lab WQ Report
Johnson	4N3E 22C1		11-Apr-80	1320	2200	yes	USGS NWIS
Johnson	4N3E 23G1		20-Feb-69	988			FRENCH, 1978
Johnson	4N3E 24Q1		22-Aug-96	443	738	yes	USGS NWIS
Johnson	4N4E 19E1		11-Jun-74	1887			FRENCH, 1978
Johnson	4N4E 19N1		04-Jul-78	360	600	yes	USGS NWIS
JOHNSON VALLEY, UPPER JOHNSON VALLEY							
Upper Johnson	4N4E 5G1		13-Jan-54	2990		no	FRENCH, 1978
MEAN VALLEY							
Means	4N4E 24Q1		11-Mar-55	1270		no	FRENCH, 1978
Means	4N4E 36B1		15-Sep-99	140		no	MWA

[a]Most recent sample date

[b]Conversion factor of 0.6 was used and represents average for 11 wells with both TDS and E.C. measurements (designated by "no"); STDEV = 0.03

[c]NWIS = National Water Information System; CSA 2005 = CSA water quality results

Table 6
Annual Groundwater Production (1989-2005)

Calendar Year	Basin Groundwater Production (AFY)		
	Ames Valley	Johnson Valley	Means Valley
1989	631	0	0
1990	498	0	0
1991	593	0	0
1992	758	0	0
1993	1,401	0	0
1994	1,592	0	0
1995	1,736	0	0
1996	2,143	0	0
1997	2,006	0	0
1998	1,553	7.7	0
1999	1,340	9.2	0
2000	1,203	6.2	0
2001	1,191	9.9	0
2002	1,233	13.6	0
2003	1,164	13.6	0
2004	1,328	12.2	0
2005	997	11.6	0
Total	**21,367**	**84**	**0**
Average	**1,257**	**5**	**0**

Data Sources: Ames Valley Basin Monitoring Program and BDVWA

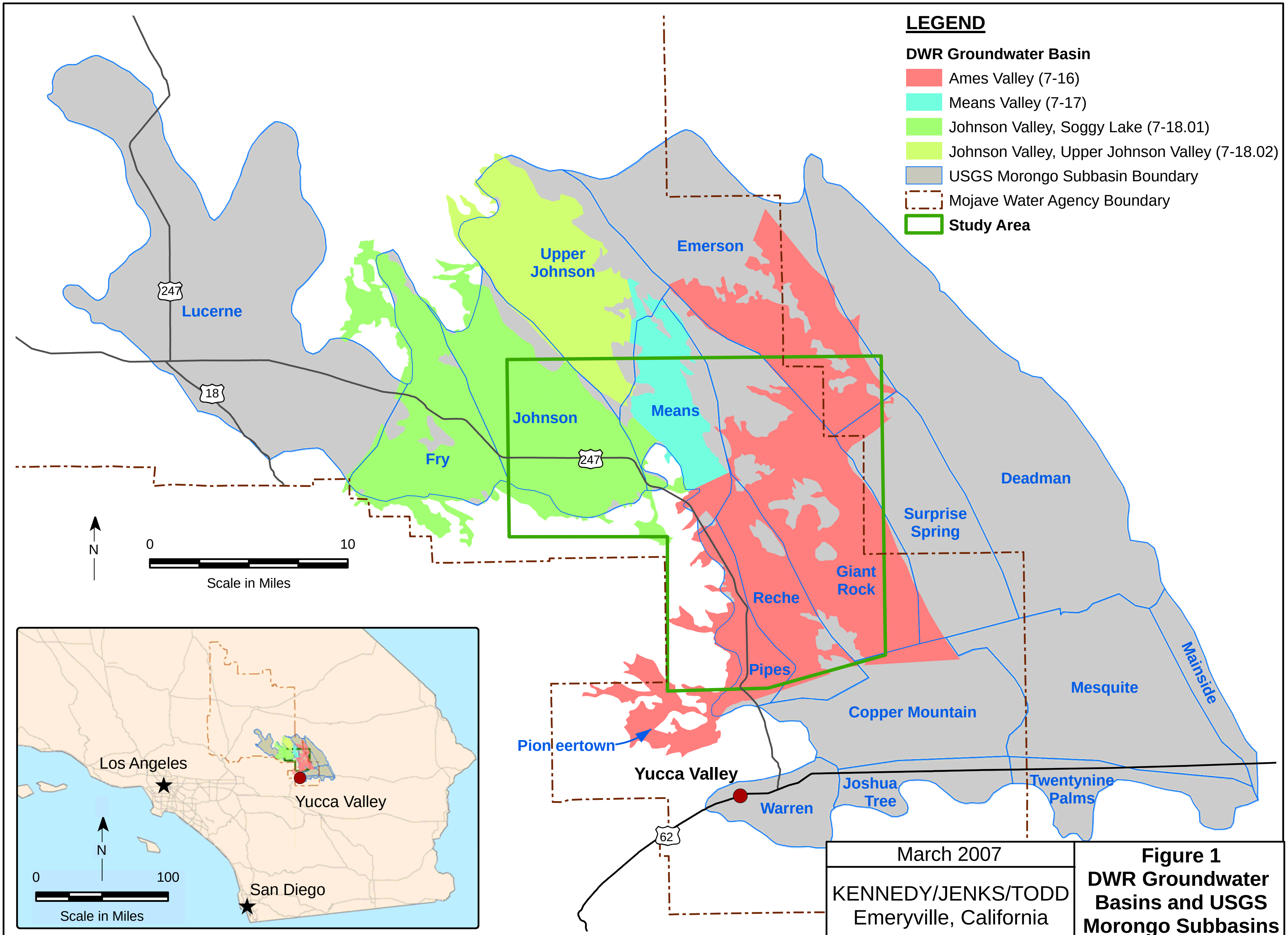

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Figure 1
DWR Groundwater Basins and USGS Morongo Subbasins

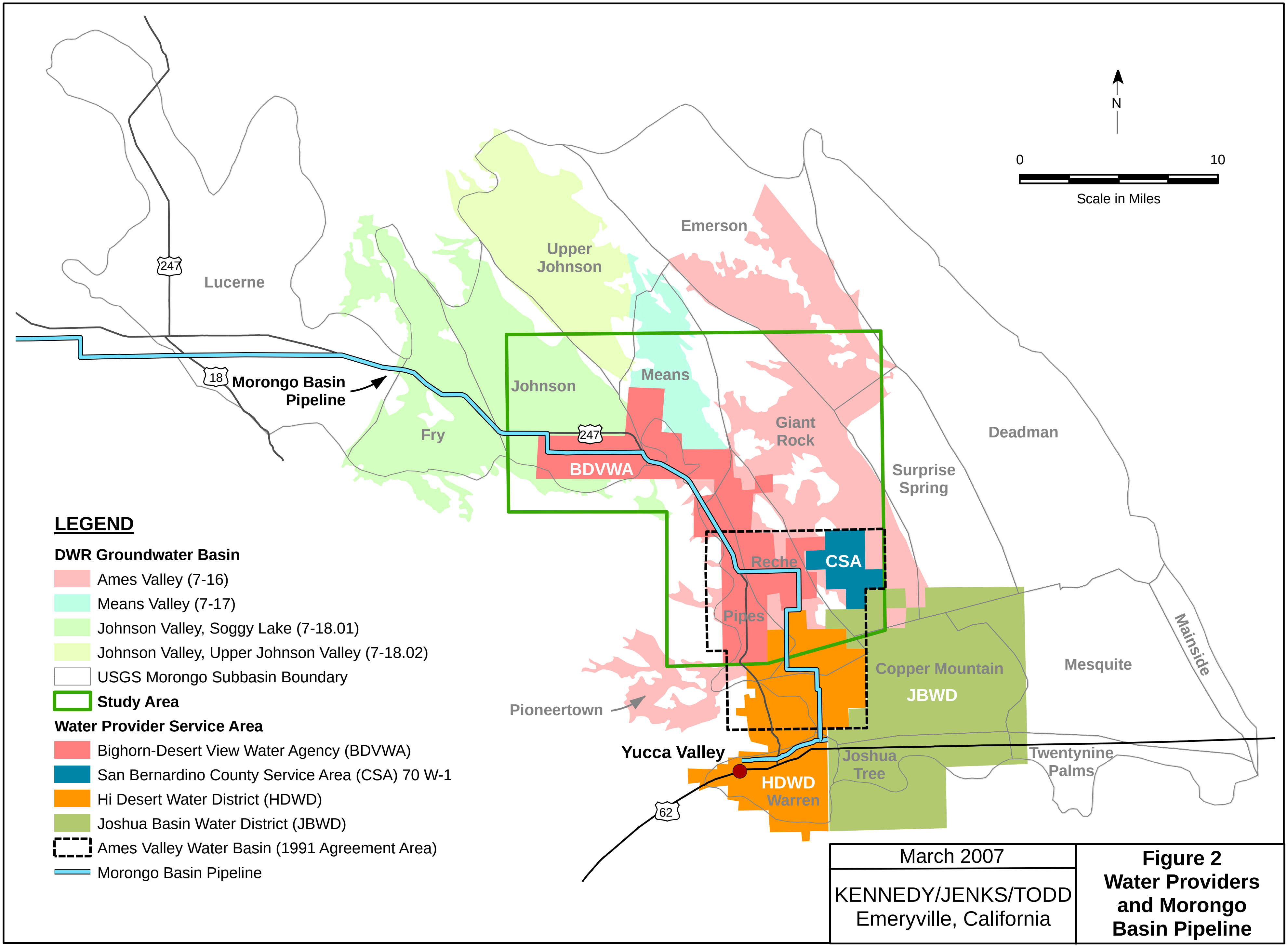

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Figure 2
Water Providers and Morongo Basin Pipeline

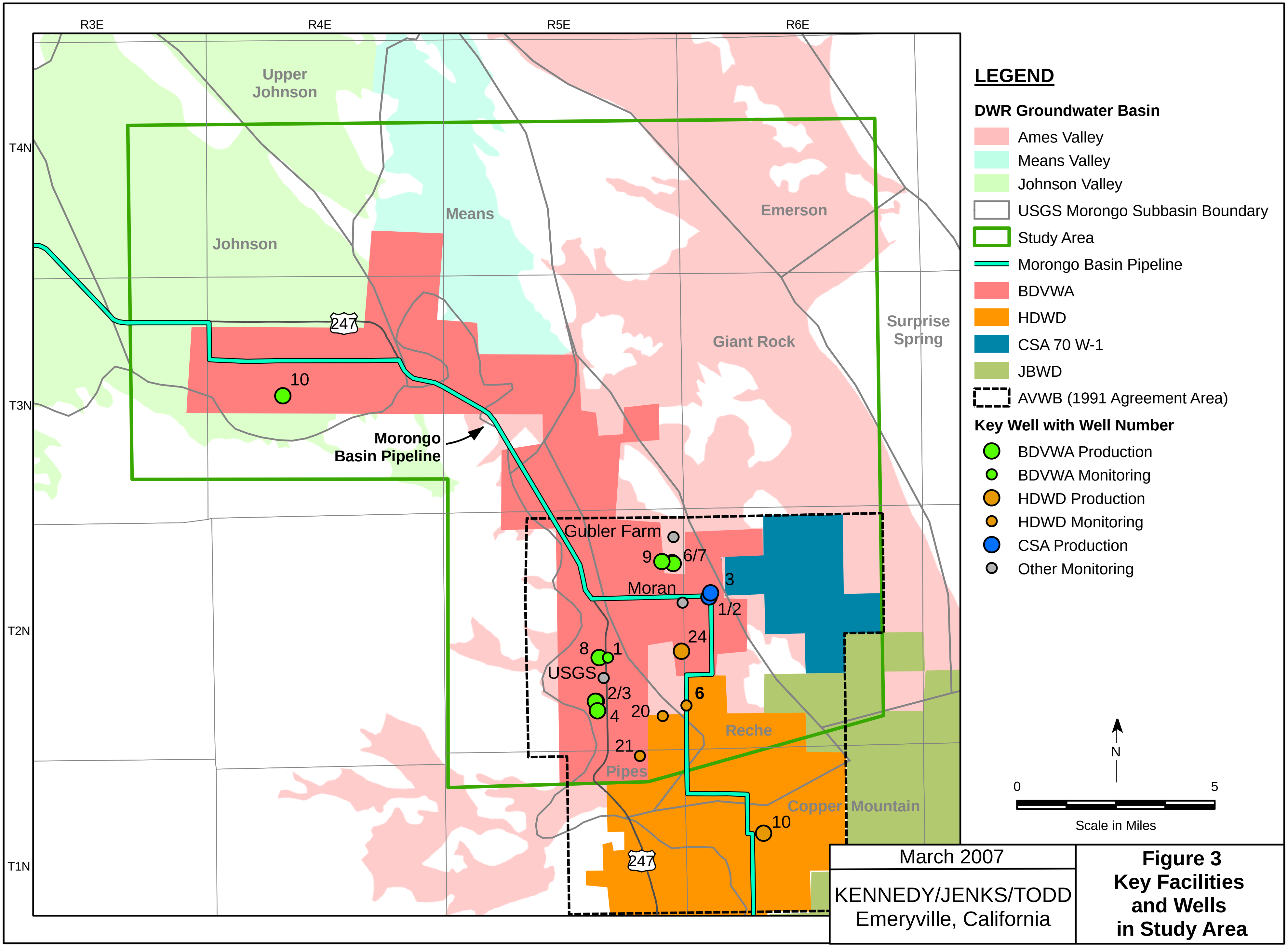

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Figure 3
Key Facilities and Wells in Study Area

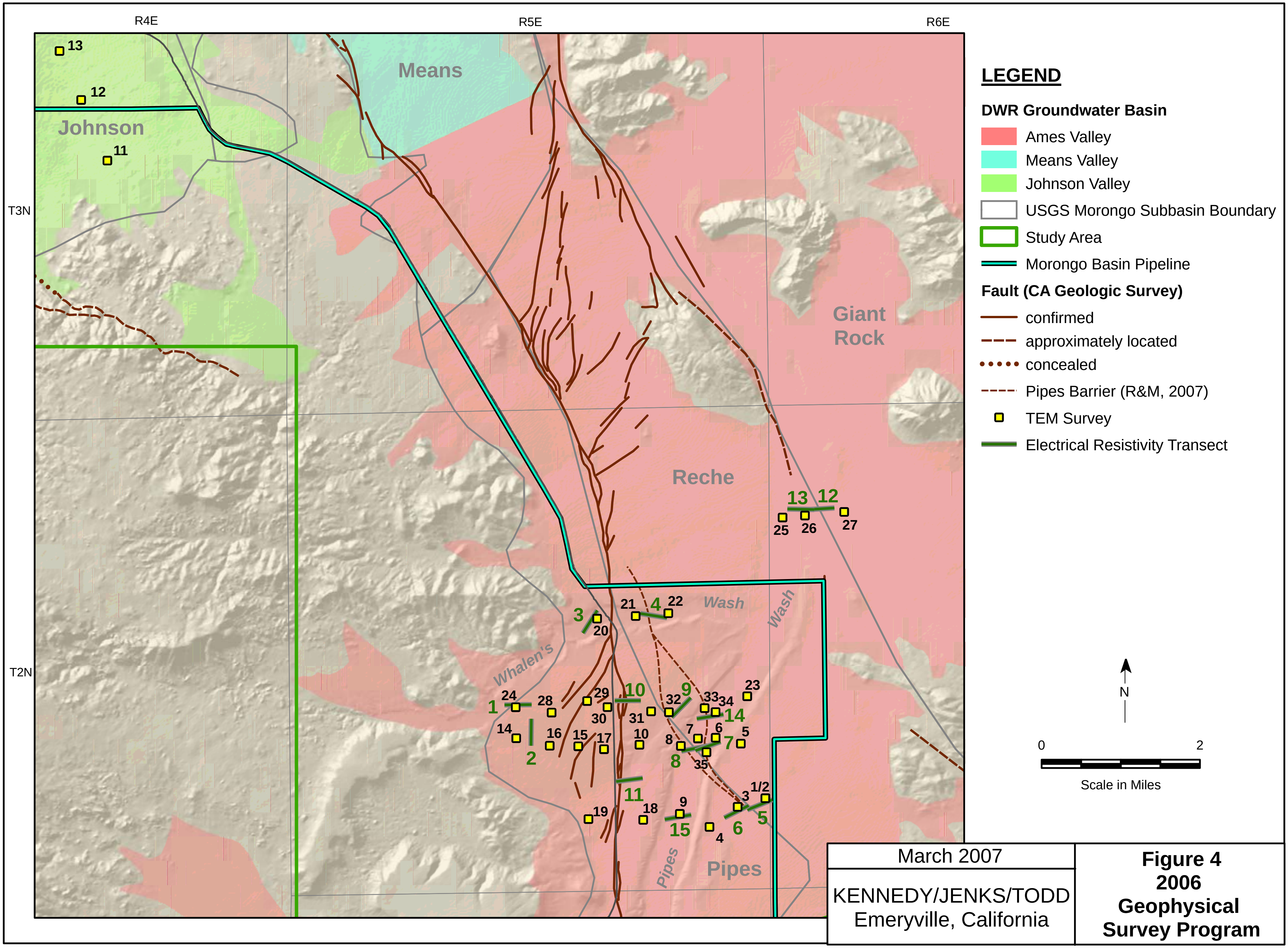

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Figure 4
2006
Geophysical
Survey Program

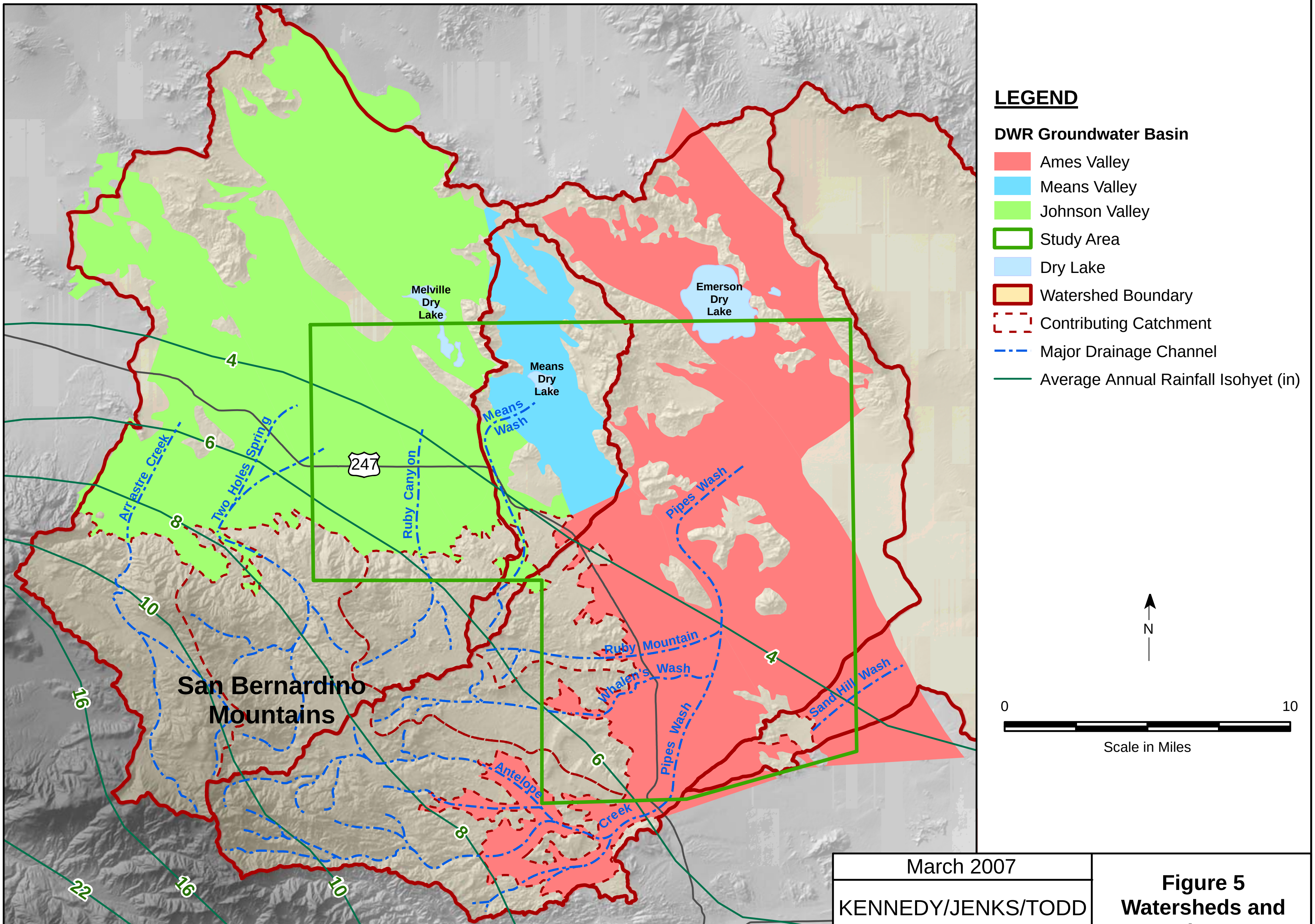

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Figure 5
Watersheds and Drainages

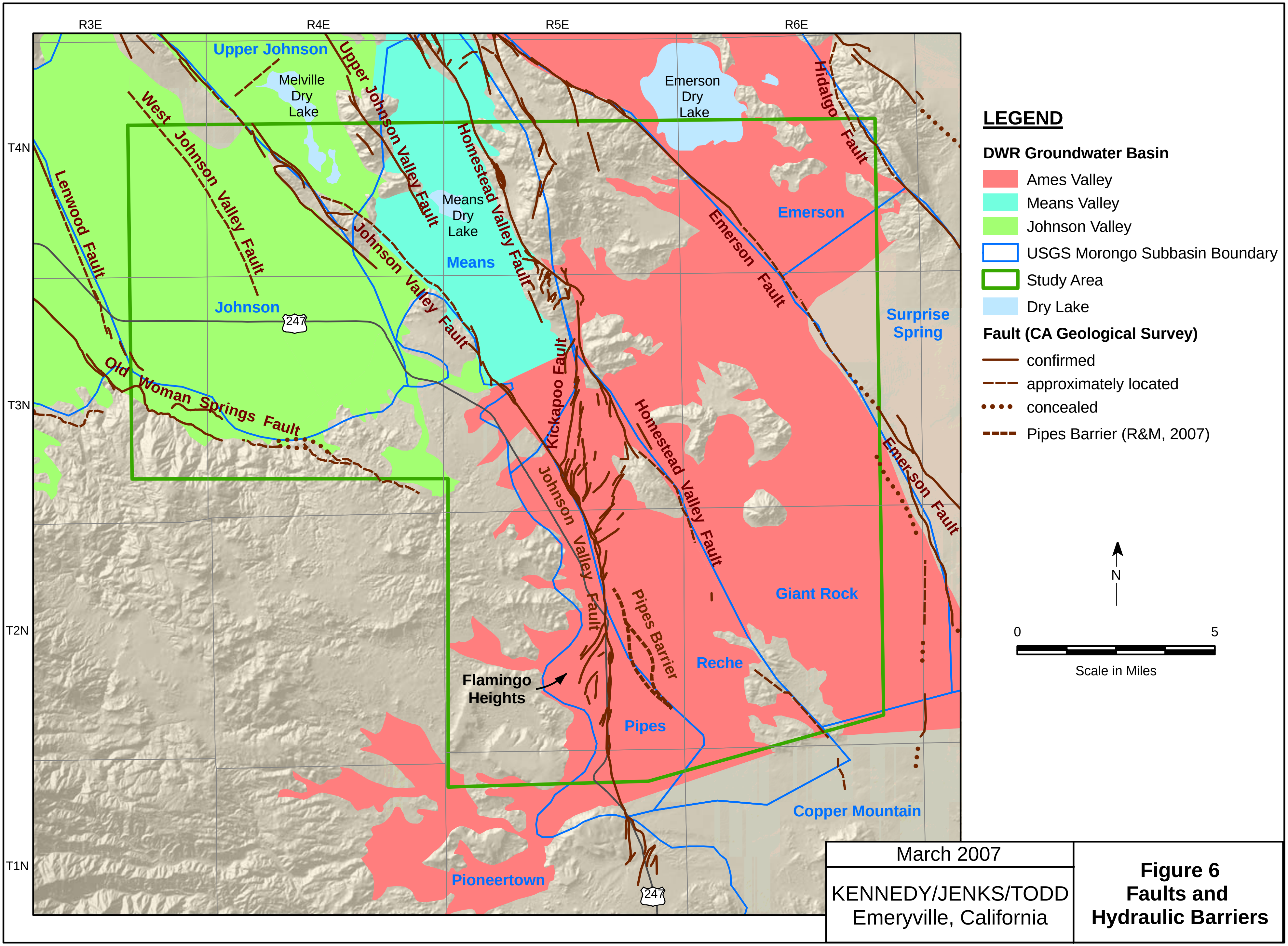

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Figure 6
Faults and Hydraulic Barriers

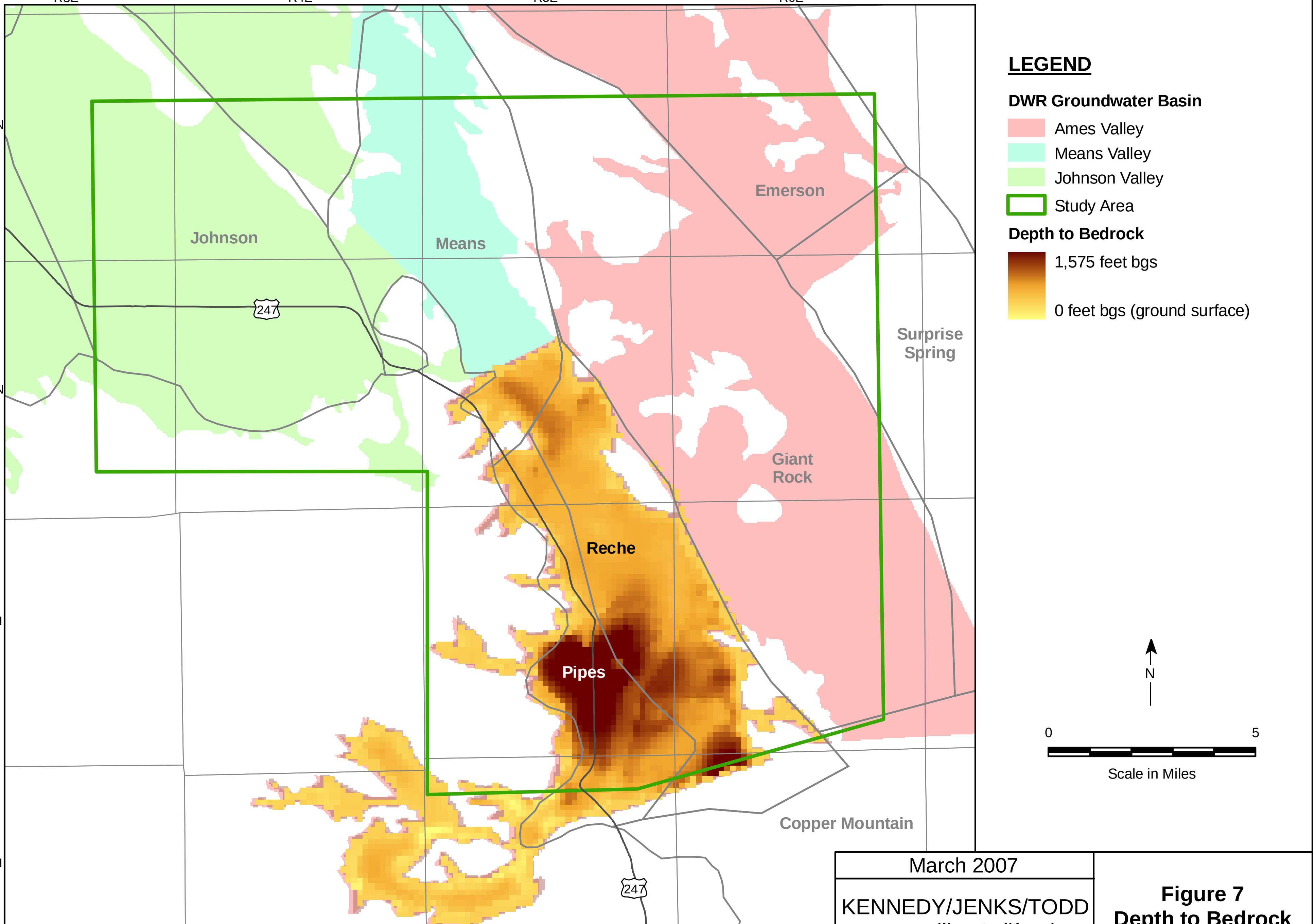

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Figure 7
Depth to Bedrock

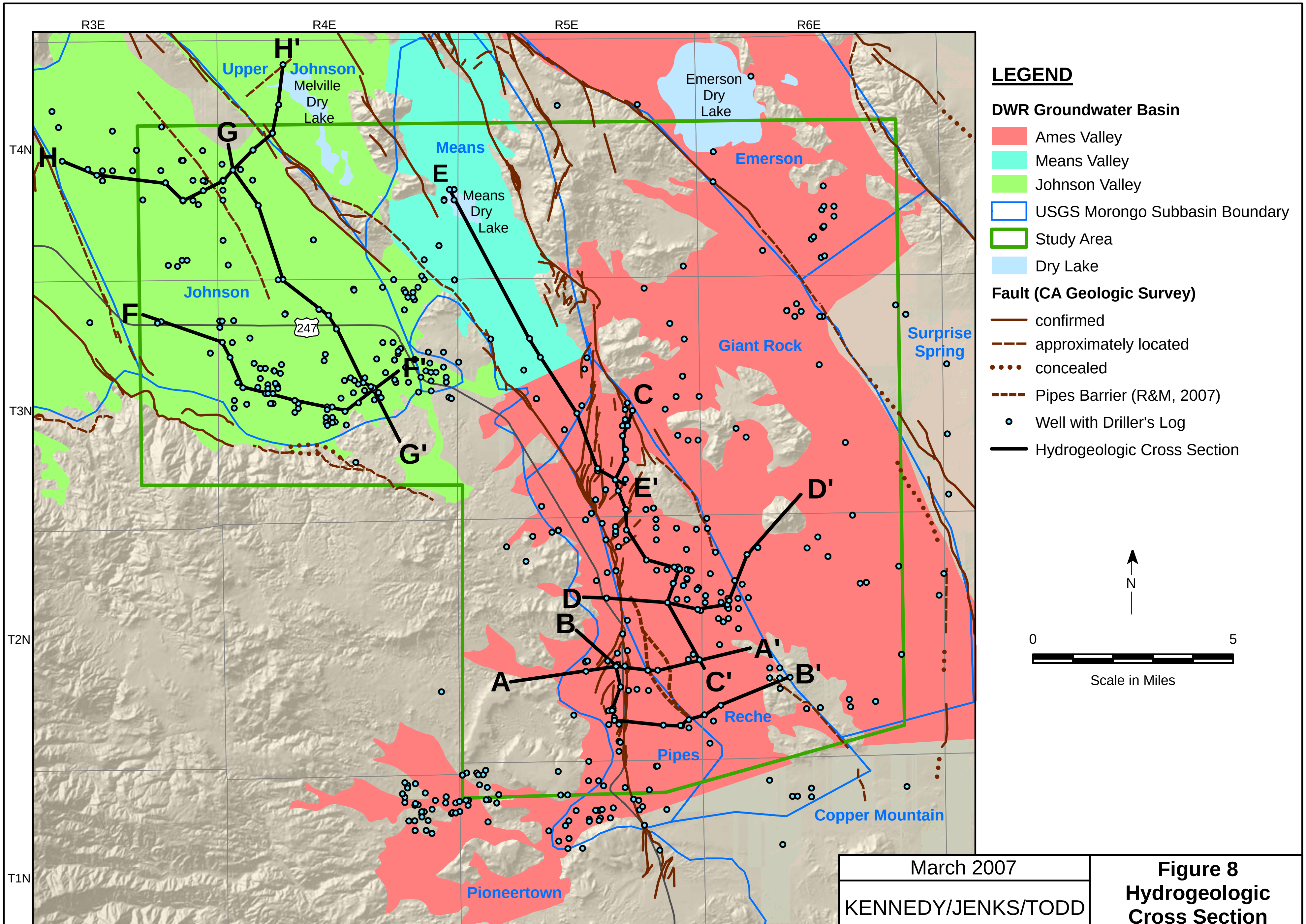

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Figure 8
Hydrogeologic Cross Section Locations

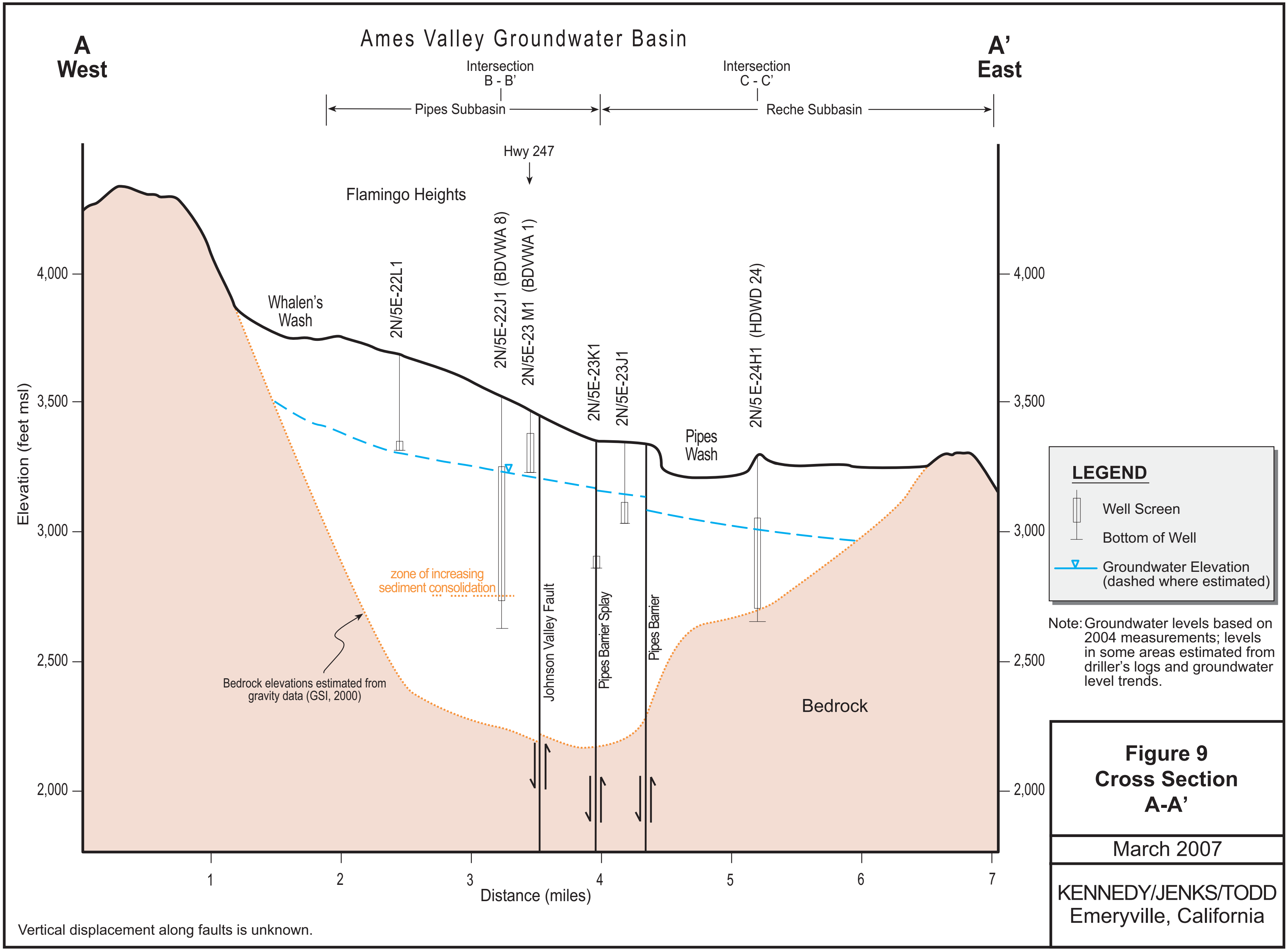

Figure 9
Cross Section
A-A'

March 2007

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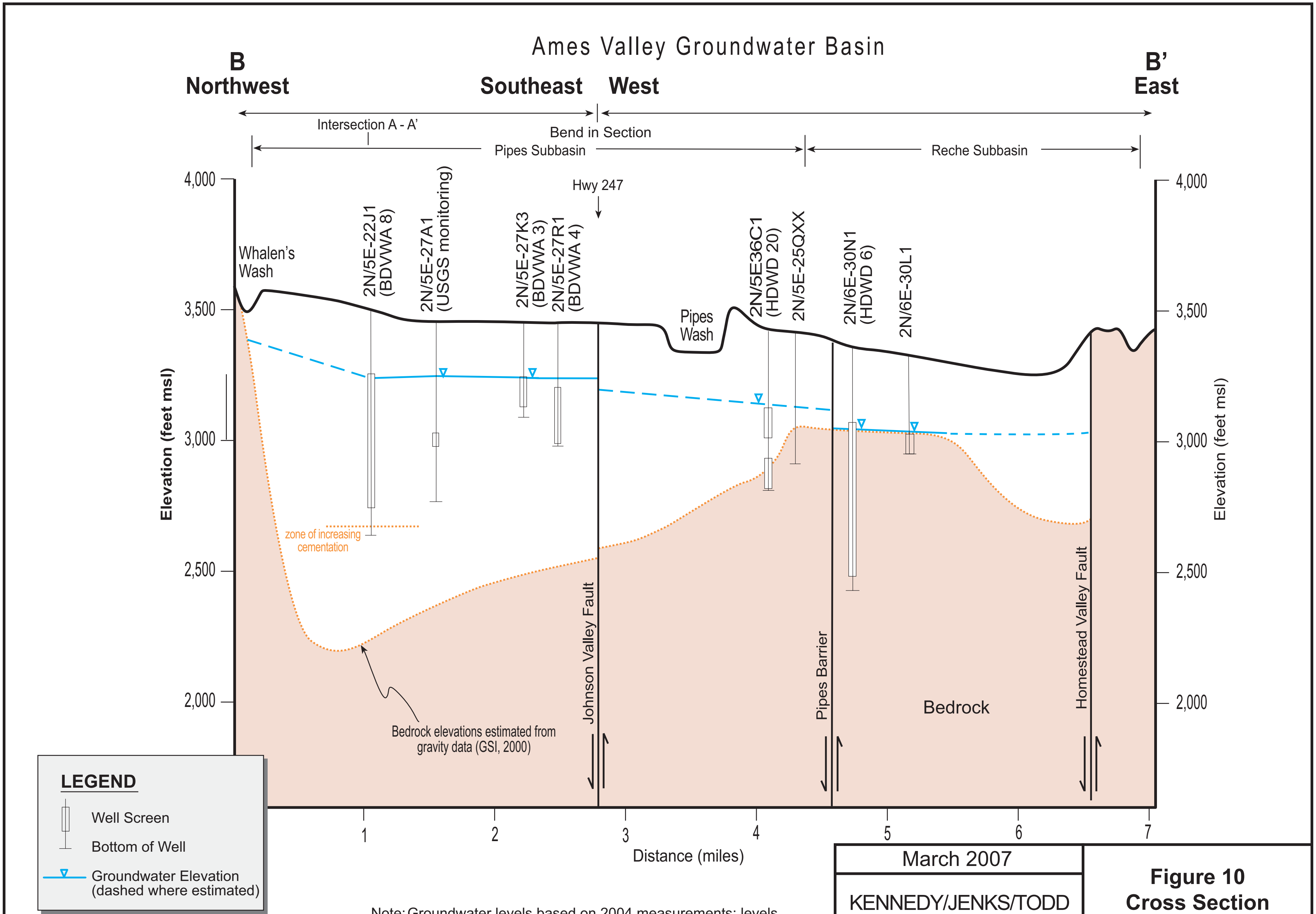
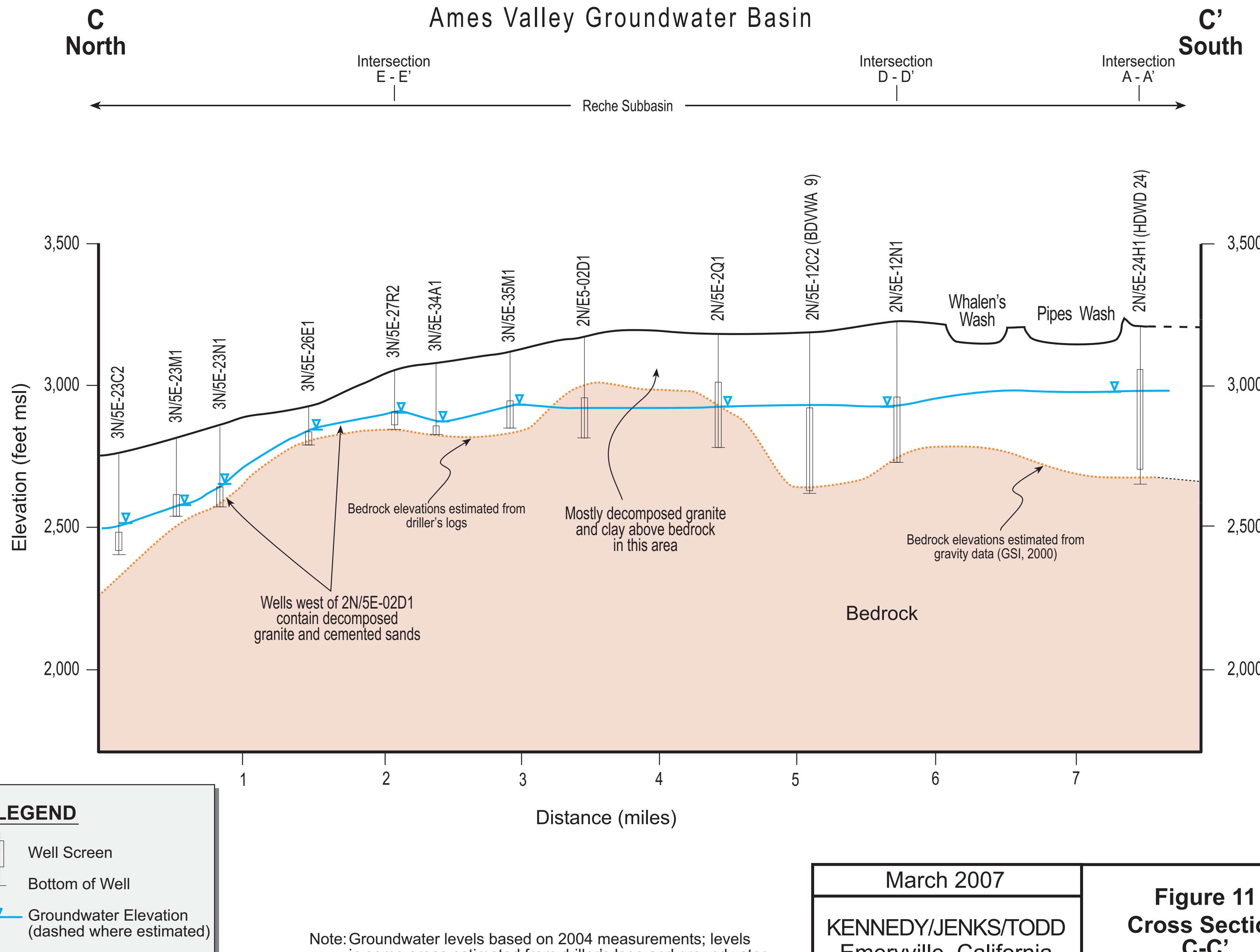
Emeryville, California



Vertical displacement along faults is unknown.

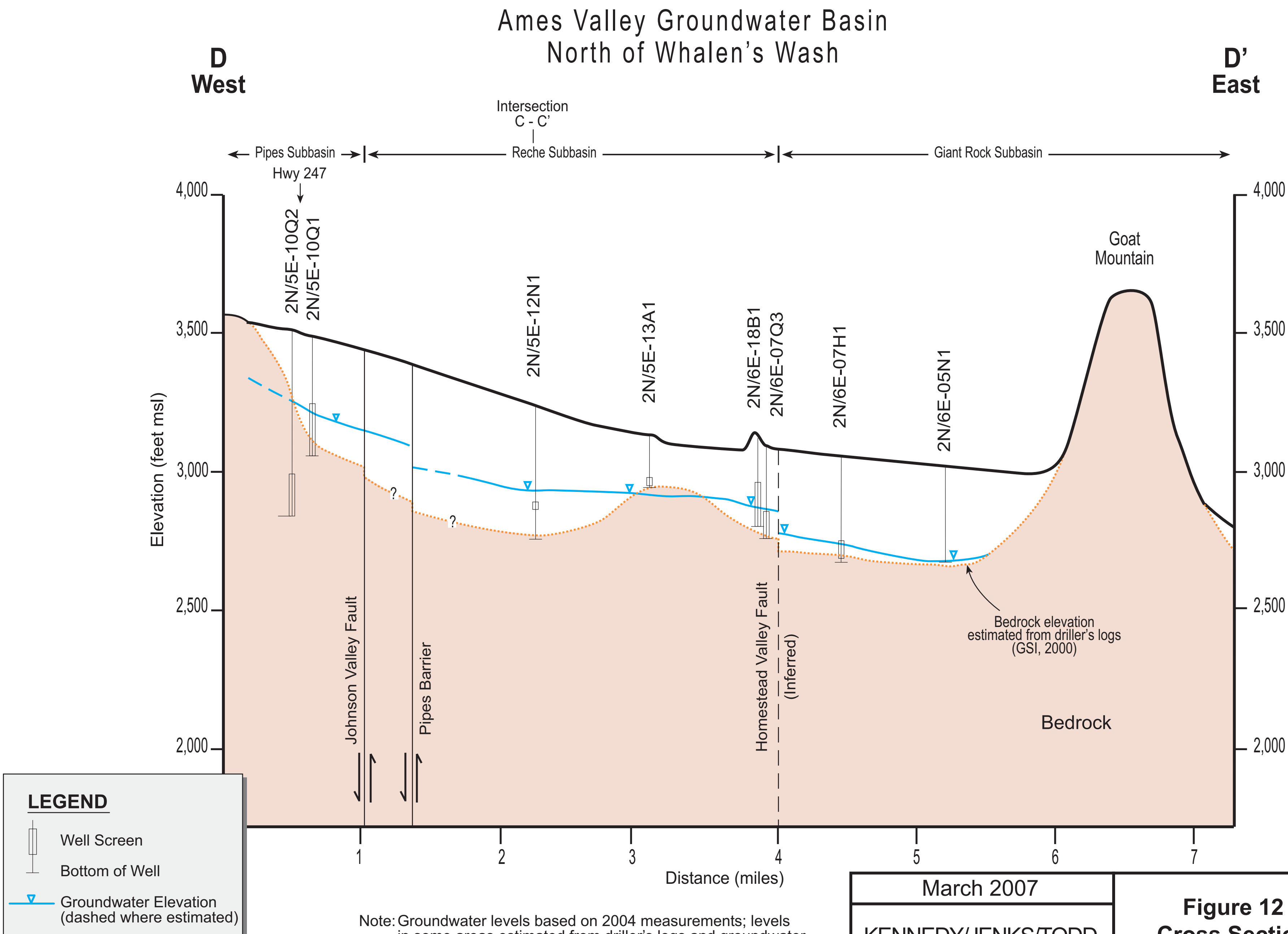
Note: Groundwater levels based on 2004 measurements; levels in some areas estimated from driller's logs and groundwater level trends.

March 2007	Figure 10 Cross Section B-B'
KENNEDY/JENKS/TODD Emeryville, California	



Note: Groundwater levels based on 2004 measurements; levels in some areas estimated from driller's logs and groundwater level trends.

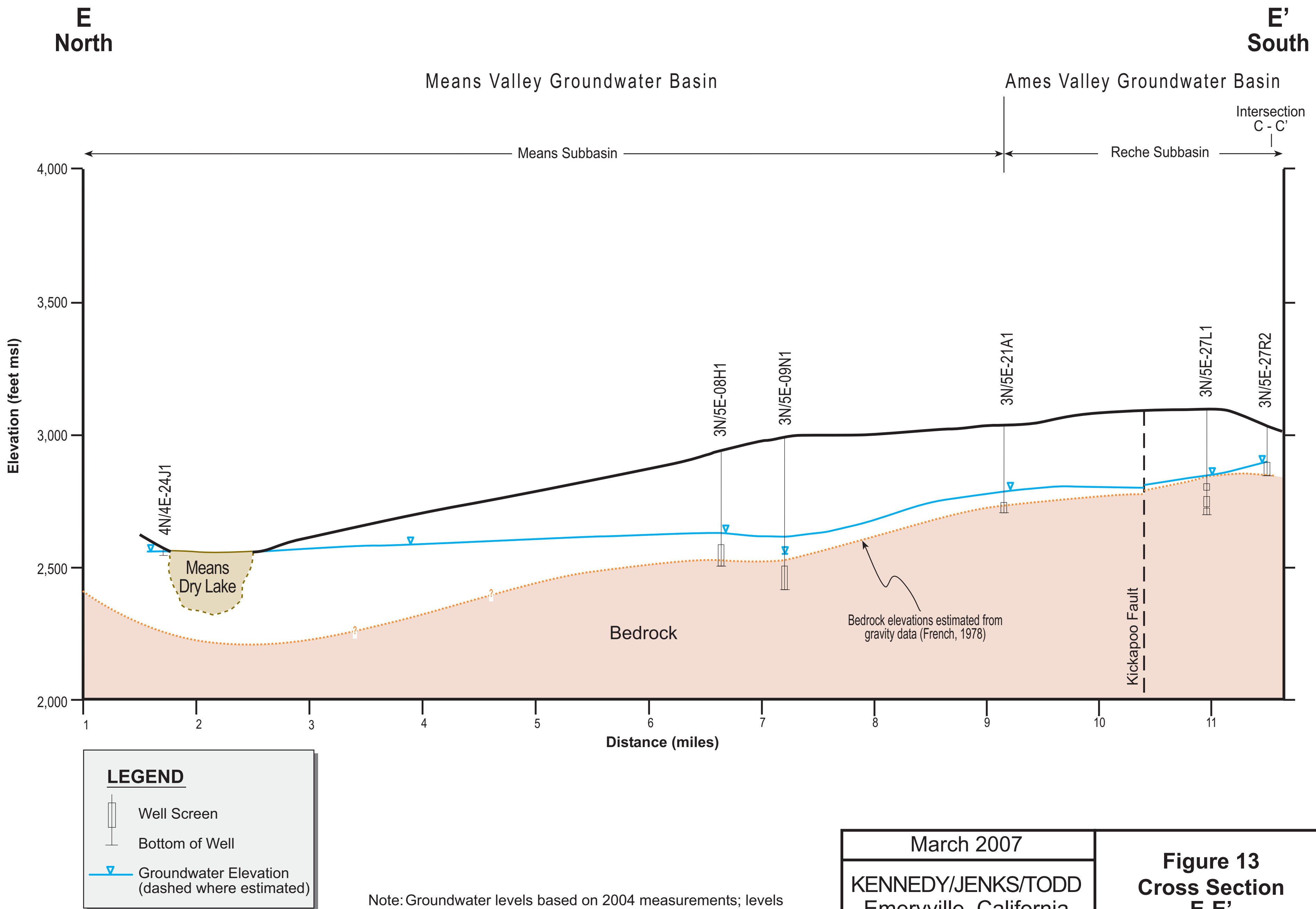
March 2007	**Figure 11**
KENNEDY/JENKS/TODD Emeryville, California	**Cross Section C-C'**



Note: Groundwater levels based on 2004 measurements; levels in some areas estimated from driller's logs and groundwater level trends.

Vertical displacement along faults is unknown.
Relative movement along Johnson Valley Fault changes north of Whalen's Wash (Riley and Worts, Jr., 1953)

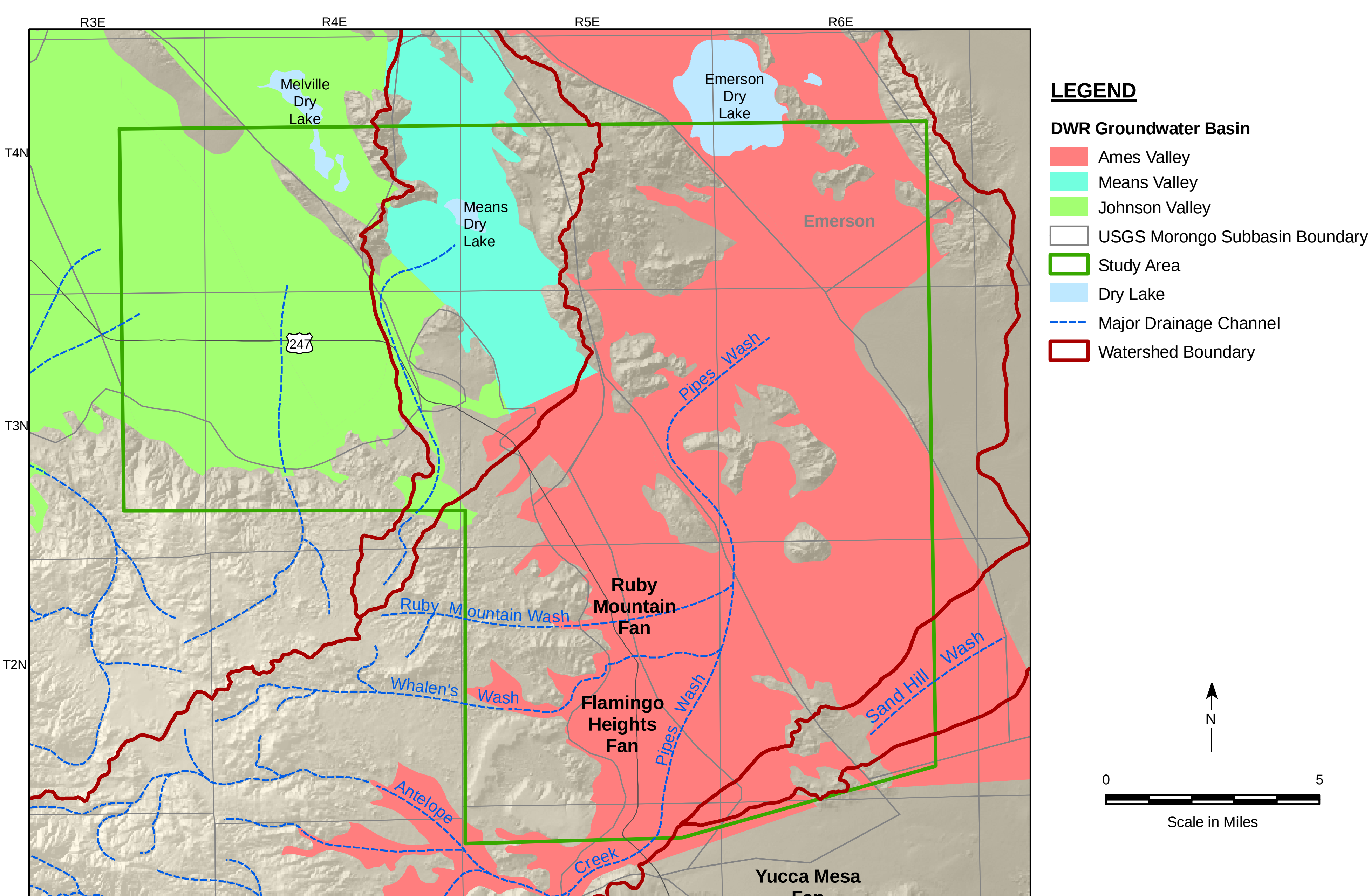
March 2007	**Figure 12**
KENNEDY/JENKS/TODD Emeryville, California	**Cross Section D-D'**



Vertical displacement along faults is unknown.

Note: Groundwater levels based on 2004 measurements; levels in some areas estimated from driller's logs and groundwater level trends.

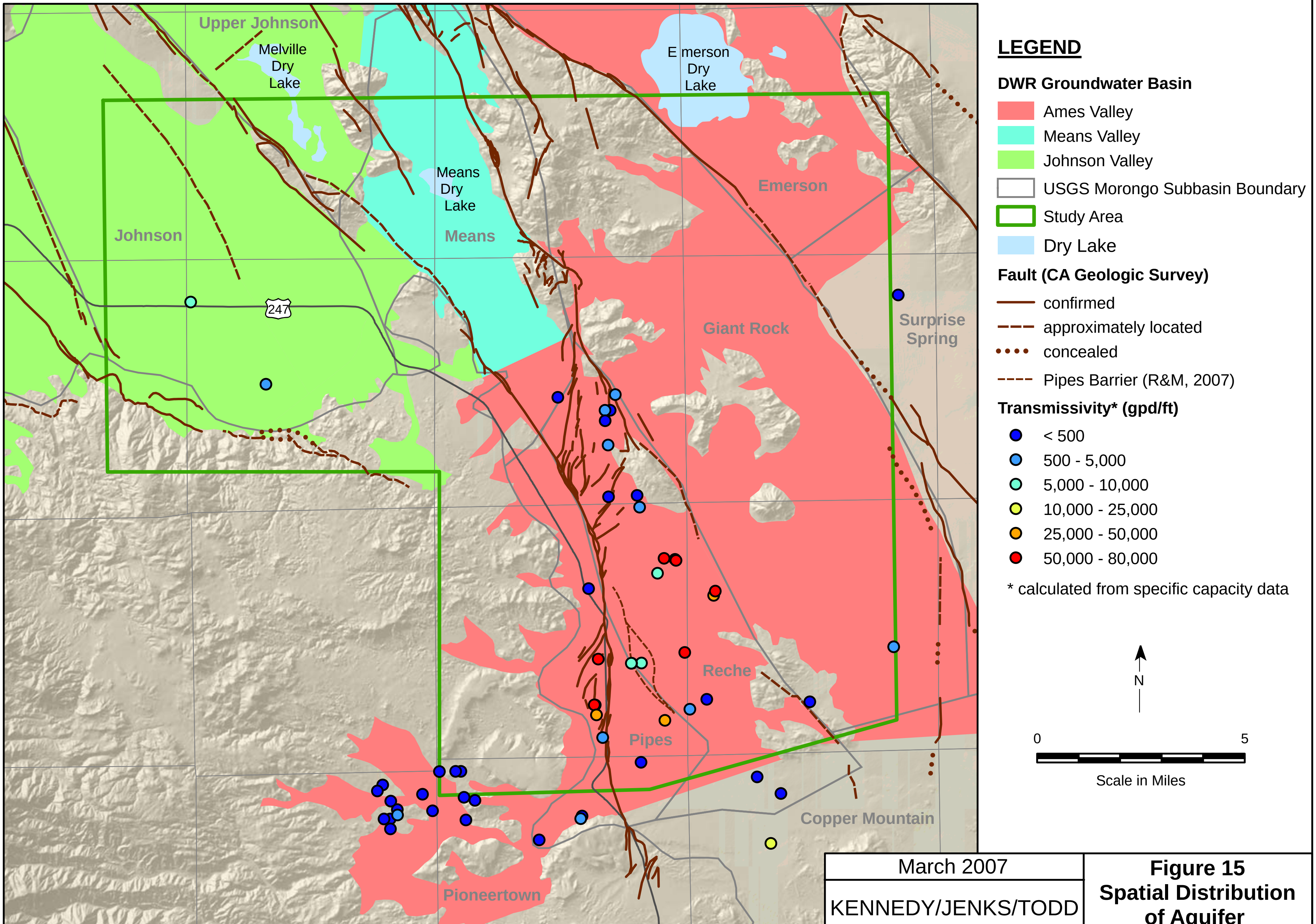
March 2007	**Figure 13**
KENNEDY/JENKS/TODD Emeryville, California	**Cross Section E-E'**



March 2007

KENNEDY/JENKS/TODD
Emeryville, California

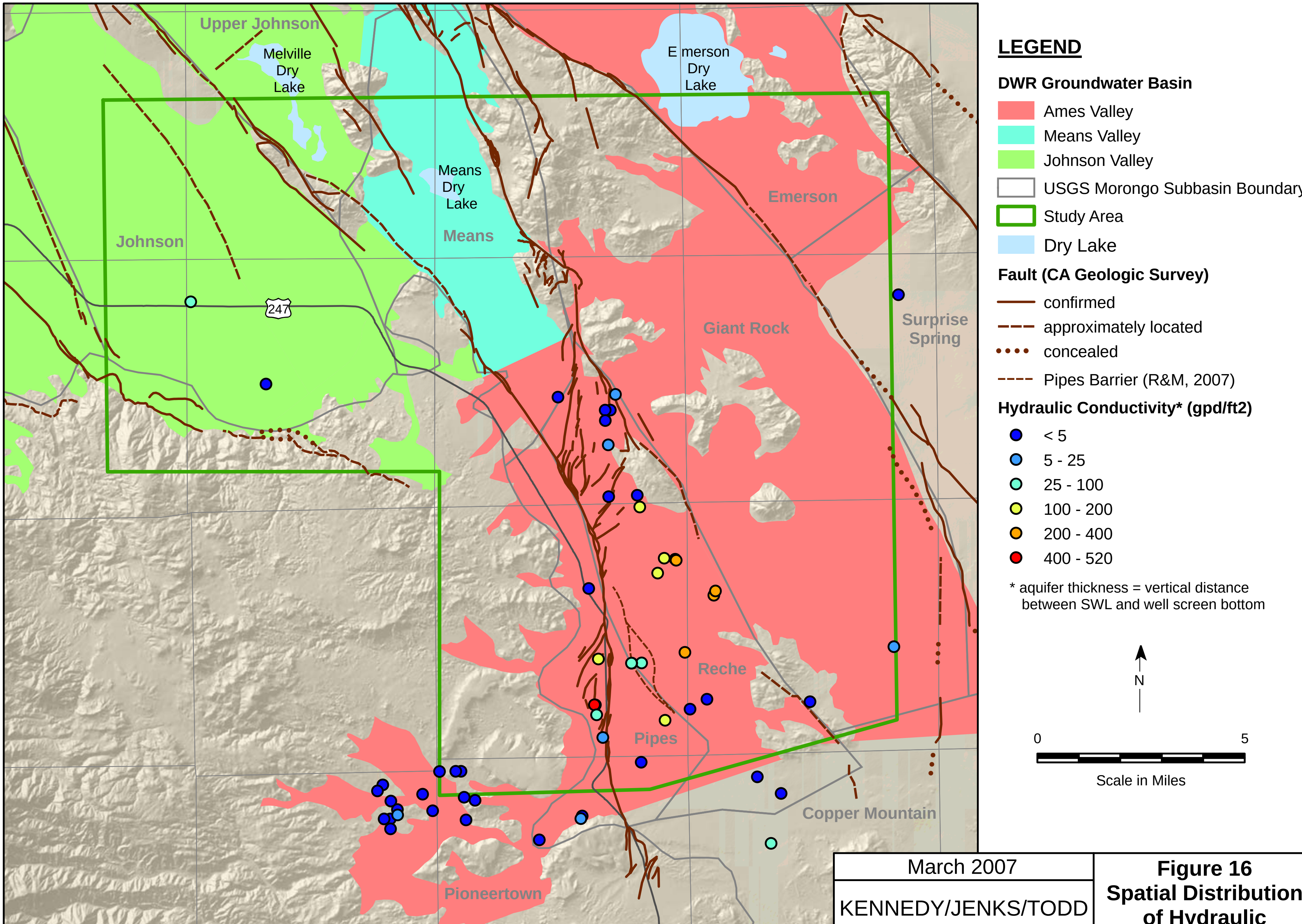
Figure 14
Geomorphic Features
Ames Valley
Groundwater Basin



March 2007

KENNEDY/JENKS/TODD
Emeryville, California

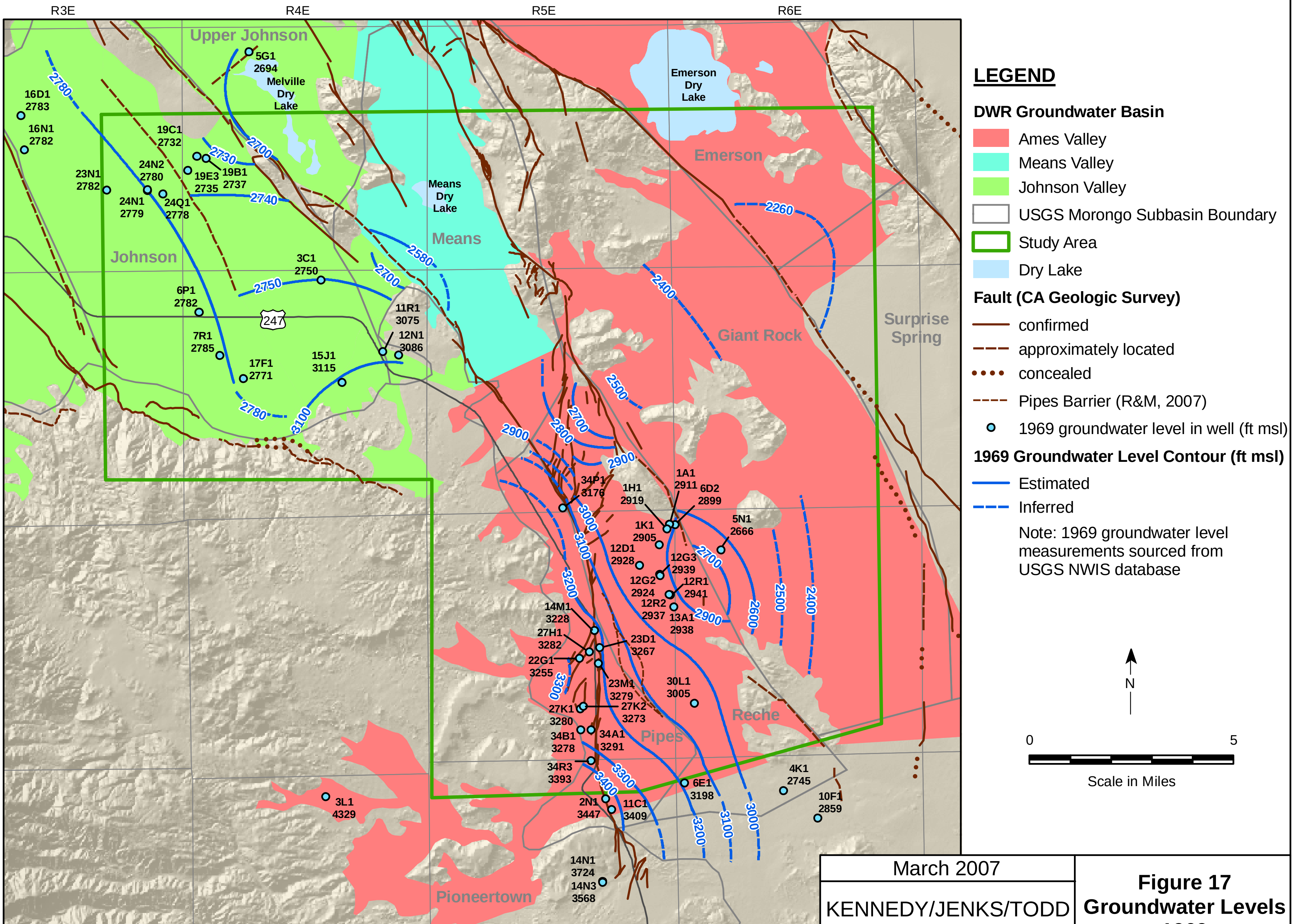
Figure 15
Spatial Distribution of Aquifer Transmissivity Values



March 2007

KENNEDY/JENKS/TODD
Emeryville, California

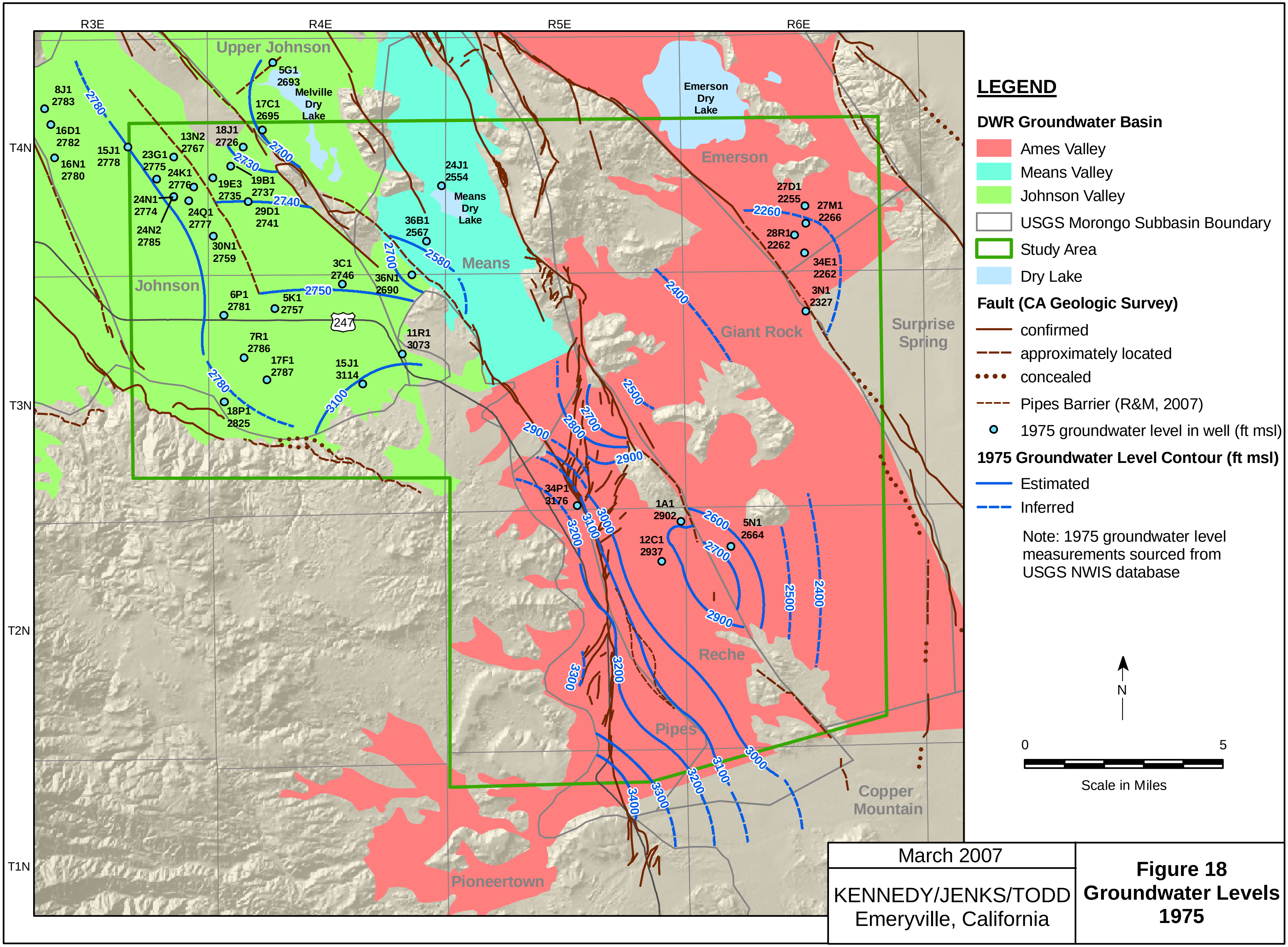
Figure 16
Spatial Distribution of Hydraulic Conductivity Values



March 2007

KENNEDY/JENKS/TODD
Emeryville, California

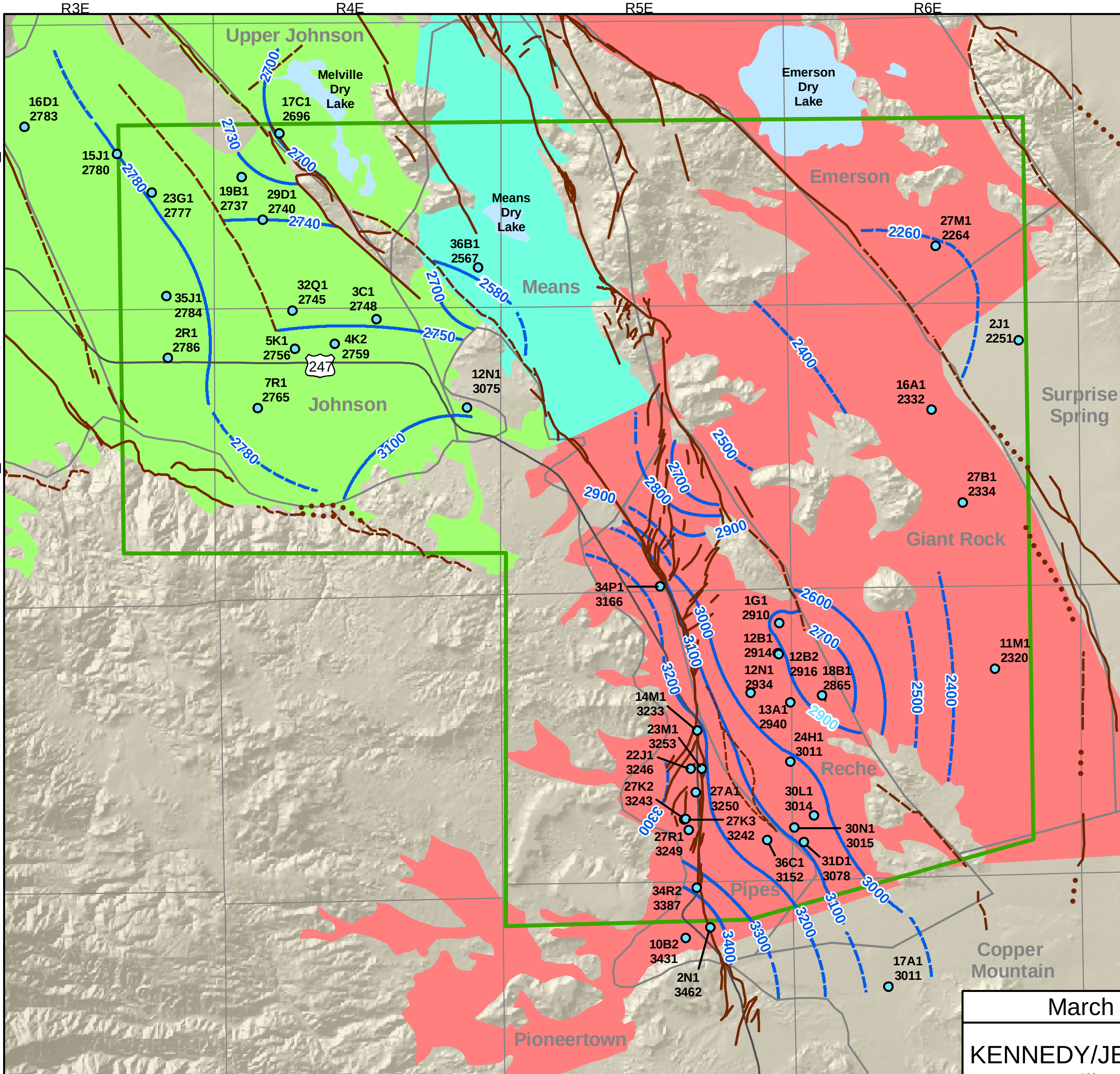
Figure 17
Groundwater Levels
1969



March 2007

KENNEDY/JENKS/TODD
Emeryville, California

Figure 18
Groundwater Levels 1975



LEGEND

DWR Groundwater Basin

- Ames Valley
- Means Valley
- Johnson Valley
- USGS Morongo Subbasin Boundary
- Study Area
- Dry Lake

Fault (CA Geologic Survey)

- confirmed
- approximately located
- concealed
- Pipes Barrier (R&M, 2007)
- 1994 groundwater level in well (ft msl)

1994 Groundwater Level Contour (ft msl)

- Estimated
- Inferred

Note: 1994 groundwater level measurements sourced from USGS NWIS database and Ames Valley Basin Monitoring Program

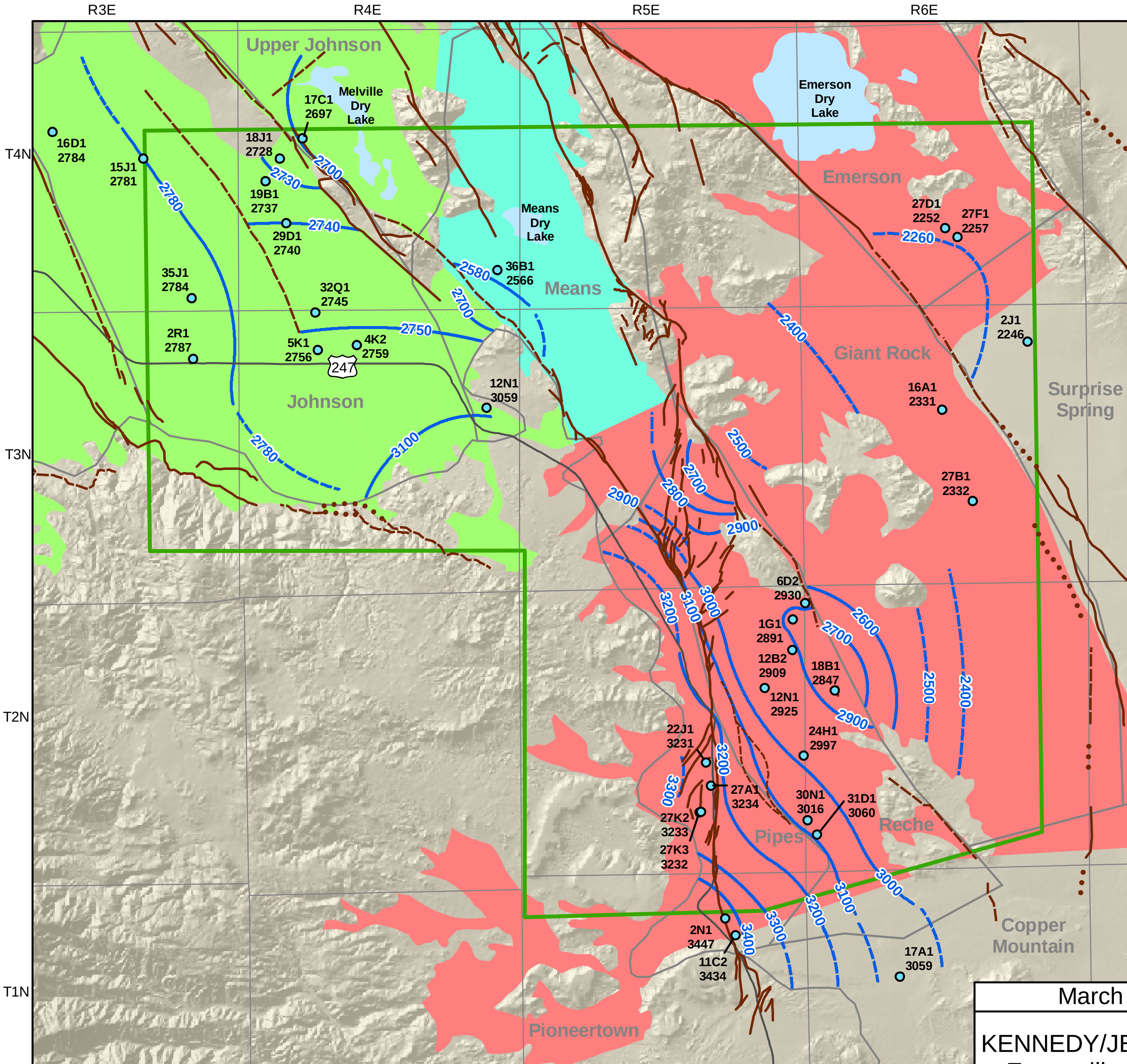
N

0 5
Scale in Miles

March 2007

KENNEDY/JENKS/TODD
Emeryville, California

Figure 19
Groundwater Levels 1994



LEGEND

DWR Groundwater Basin

- Ames Valley
- Means Valley
- Johnson Valley
- USGS Morongo Subbasin Boundary
- Study Area
- Dry Lake

Fault (CA Geologic Survey)

- confirmed
- approximately located
- concealed
- Pipes Barrier (R&M, 2007)
- 2004 groundwater level in well (ft msl)

2004 Groundwater Level Contour (ft msl)

- Estimated
- Inferred

Note: 2004 groundwater level measurements sourced from USGS NWIS database and Ames Valley Basin Monitoring Program

N

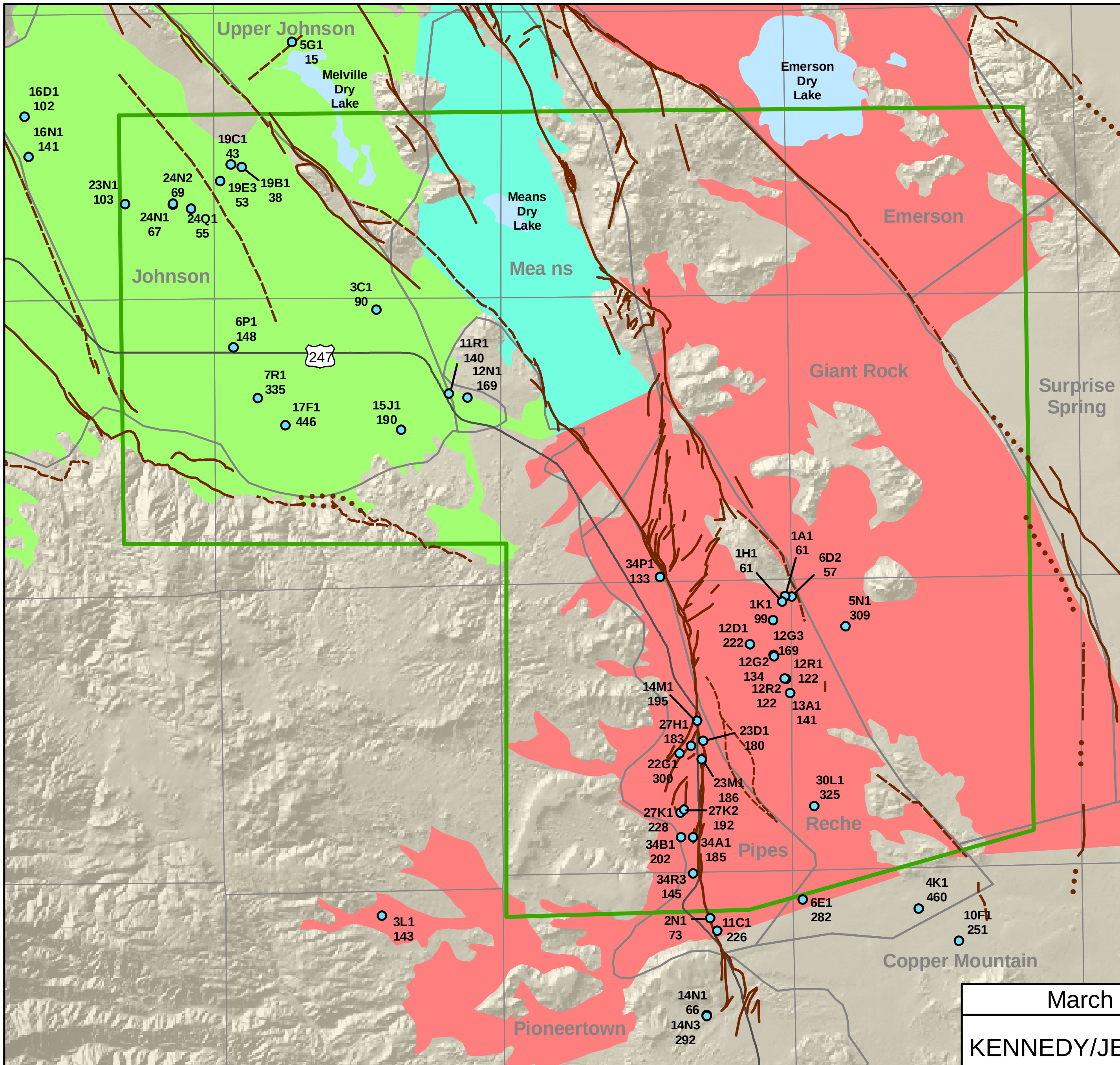
0 5

Scale in Miles

March 2007

KENNEDY/JENKS/TODD
Emeryville, California

Figure 20
Groundwater Levels 2004



LEGEND

DWR Groundwater Basin

- Ames Valley
- Means Valley
- Johnson Valley
- USGS Morongo Subbasin Boundary
- Study Area
- Dry Lake

Fault (CA Geologic Survey)

- Fault
- approximately located
- concealed
- Pipes Barrier (R&M, 2007)
- 1969 groundwater level in well (ft bgs)

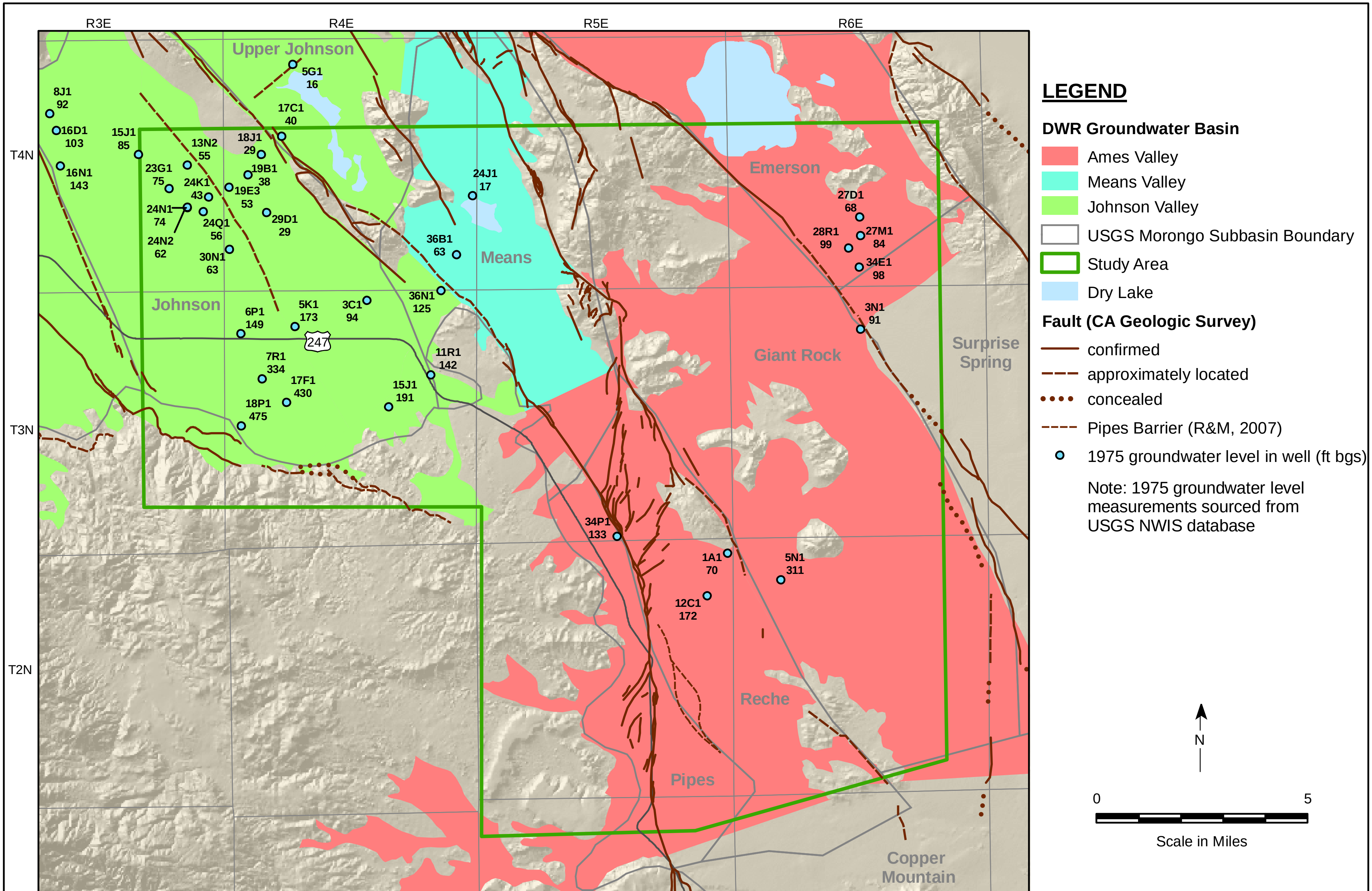
Note: 1969 groundwater level measurements sourced from USGS NWIS database

N

0 5

Scale in Miles

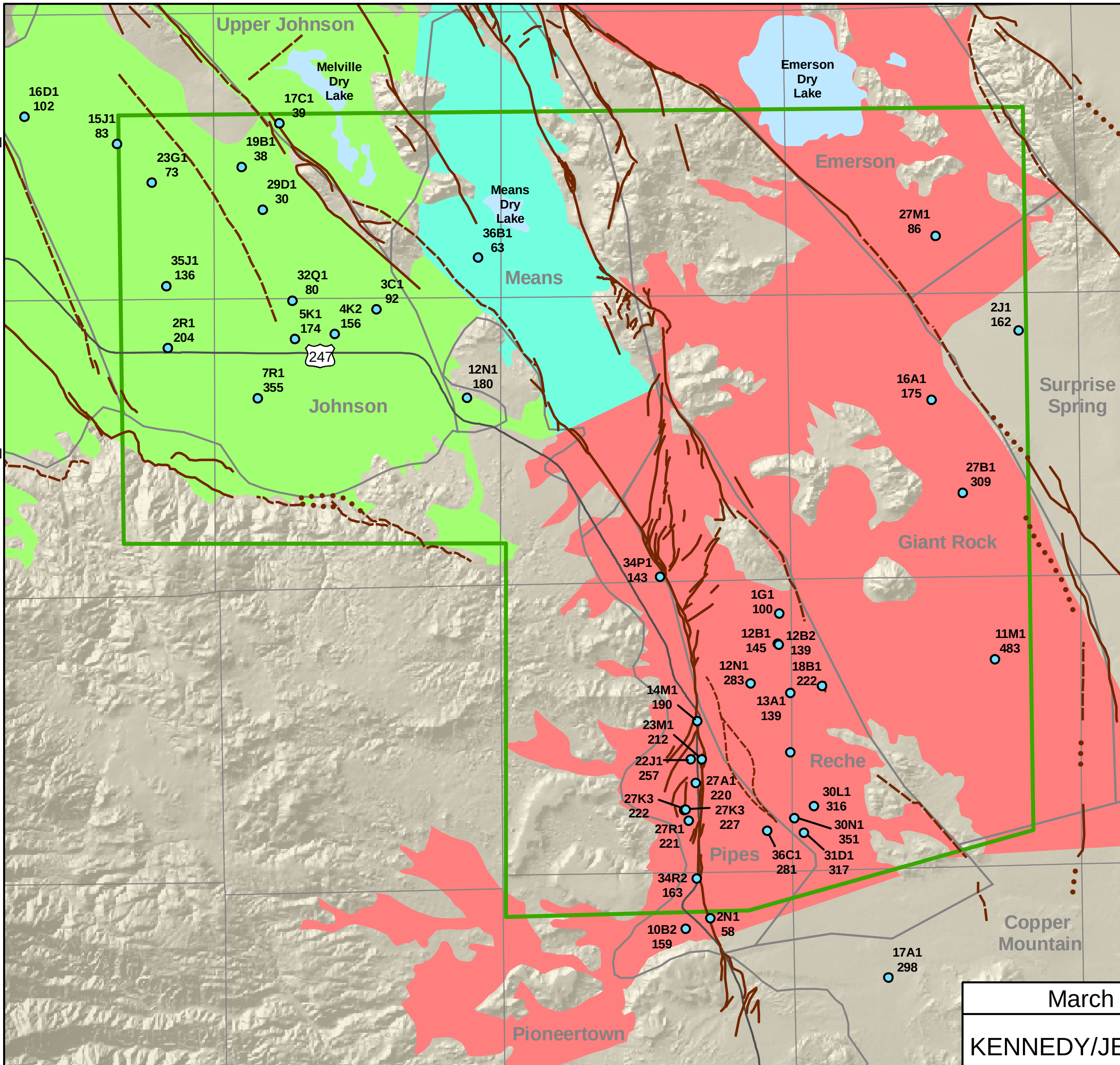
March 2007	**Figure 21**
KENNEDY/JENKS/TODD Emeryville, California	**Depth to Water 1969**



March 2007

KENNEDY/JENKS/TODD
Emeryville, California

Figure 22
Depth to Water
1975



LEGEND

DWR Groundwater Basin

- Ames Valley
- Means Valley
- Johnson Valley
- USGS Morongo Subbasin Boundary
- Study Area
- Dry Lake

Fault (CA Geologic Survey)

- confirmed
- approximately located
- concealed
- Pipes Barrier (R&M, 2007)
- 1994 groundwater level in well (ft bgs)

Note: 1994 groundwater level measurements sourced from USGS NWIS database and Ames Valley Basin Monitoring Program

N

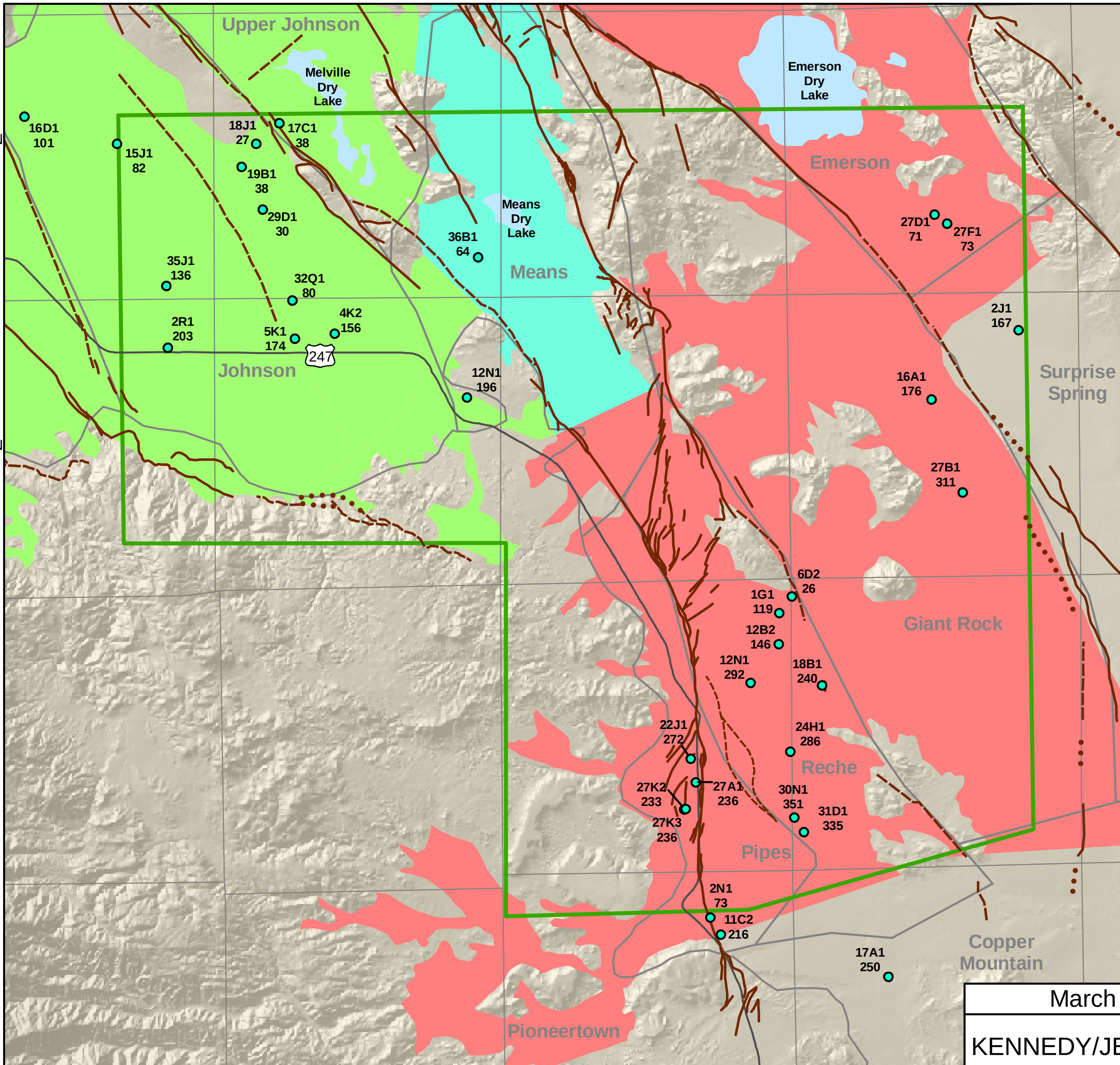
0 5

Scale in Miles

March 2007

KENNEDY/JENKS/TODD
Emeryville, California

Figure 23
Depth to Water
1994



March 2007

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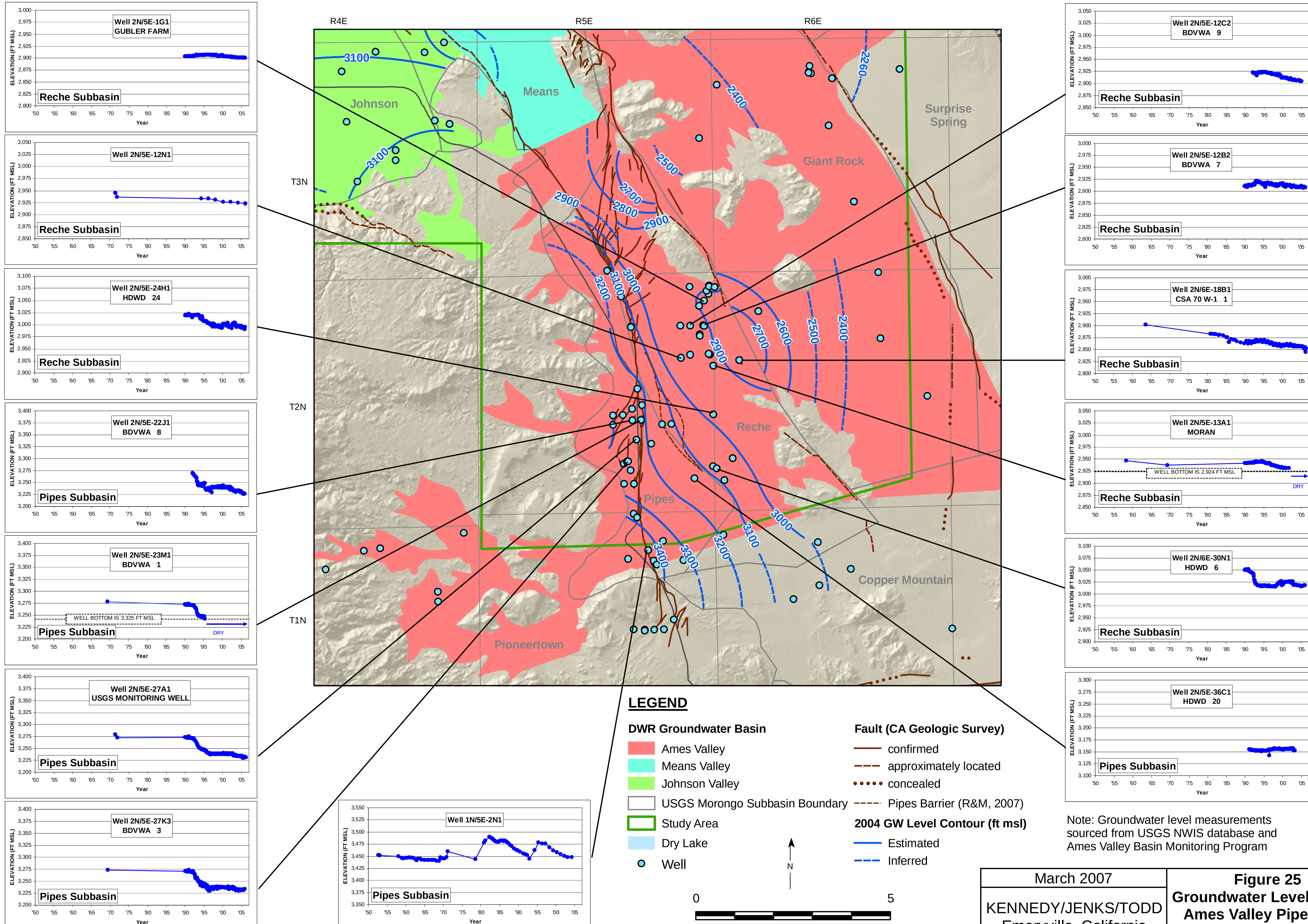
Emeryville, California

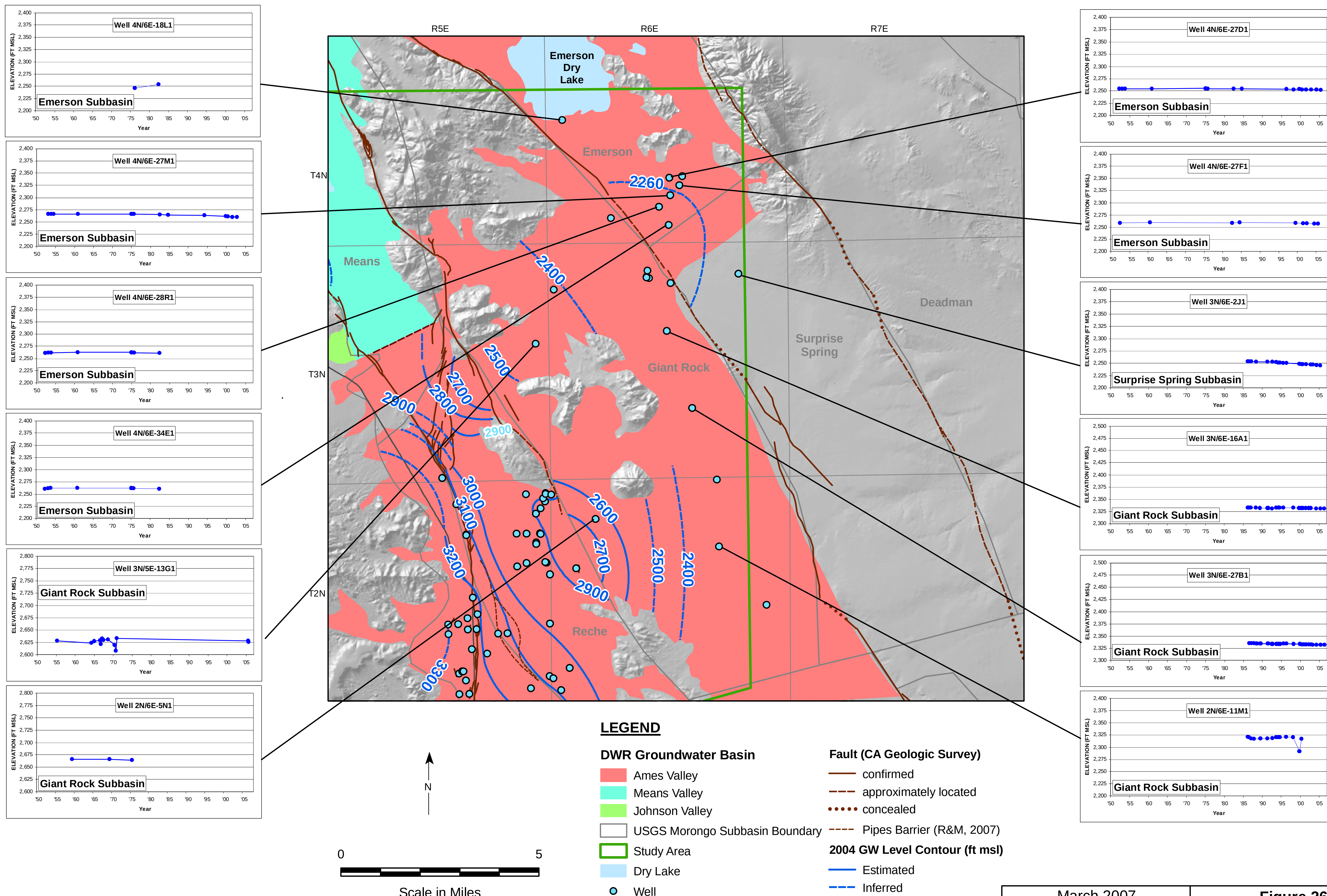
Figure 24
Depth to Water
2004



March 2007

KENNEDY/JENKS/TODD
Emeryville, California

Figure 25
Groundwater Level Trends Ames Valley Pipes and Reche Subbasins

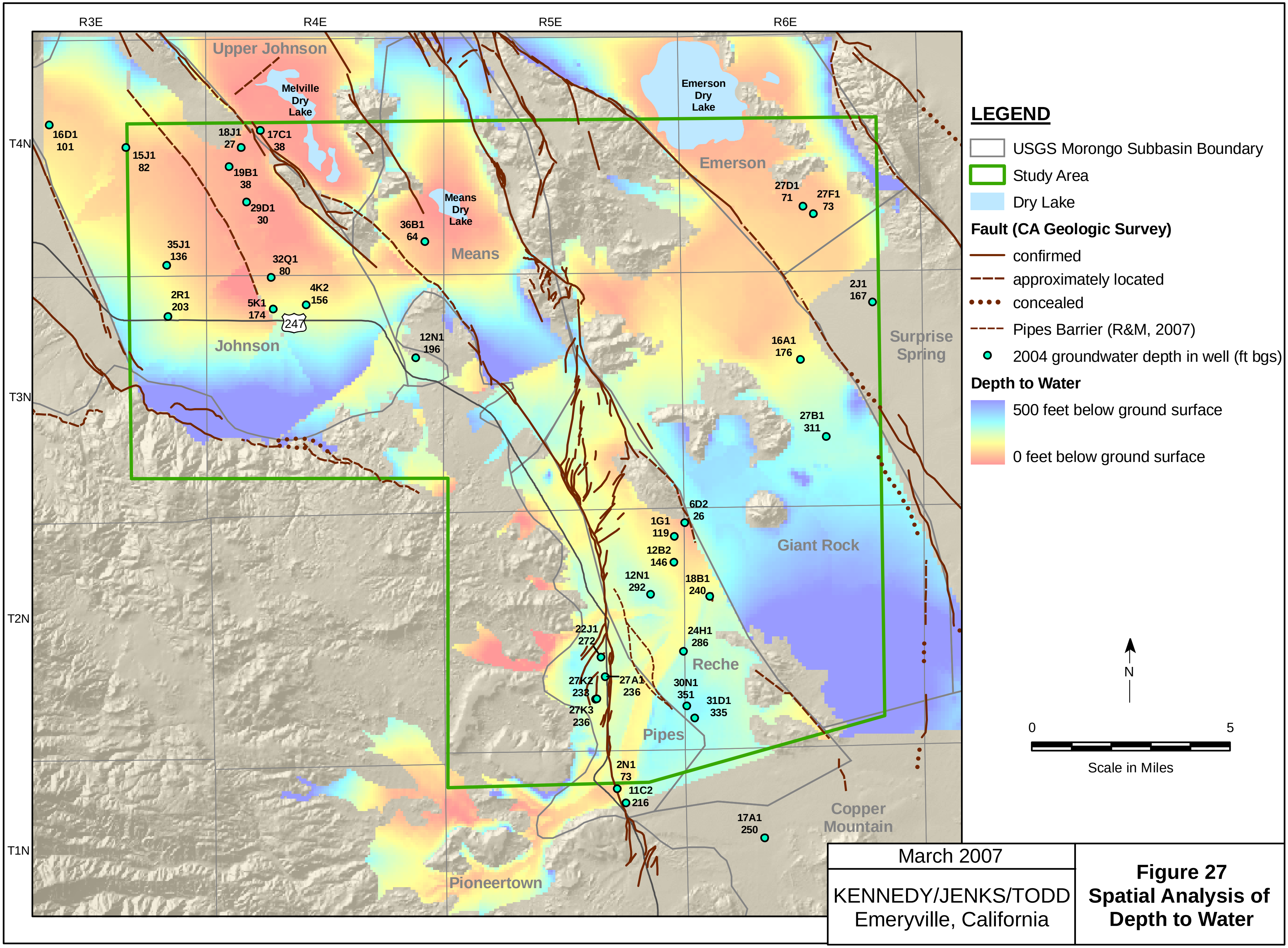


Note: Groundwater level measurements sourced from USGS NWIS database and Ames Valley Basin Monitoring Program

March 2007

KENNEDY/JENKS/TODD
Emeryville, California

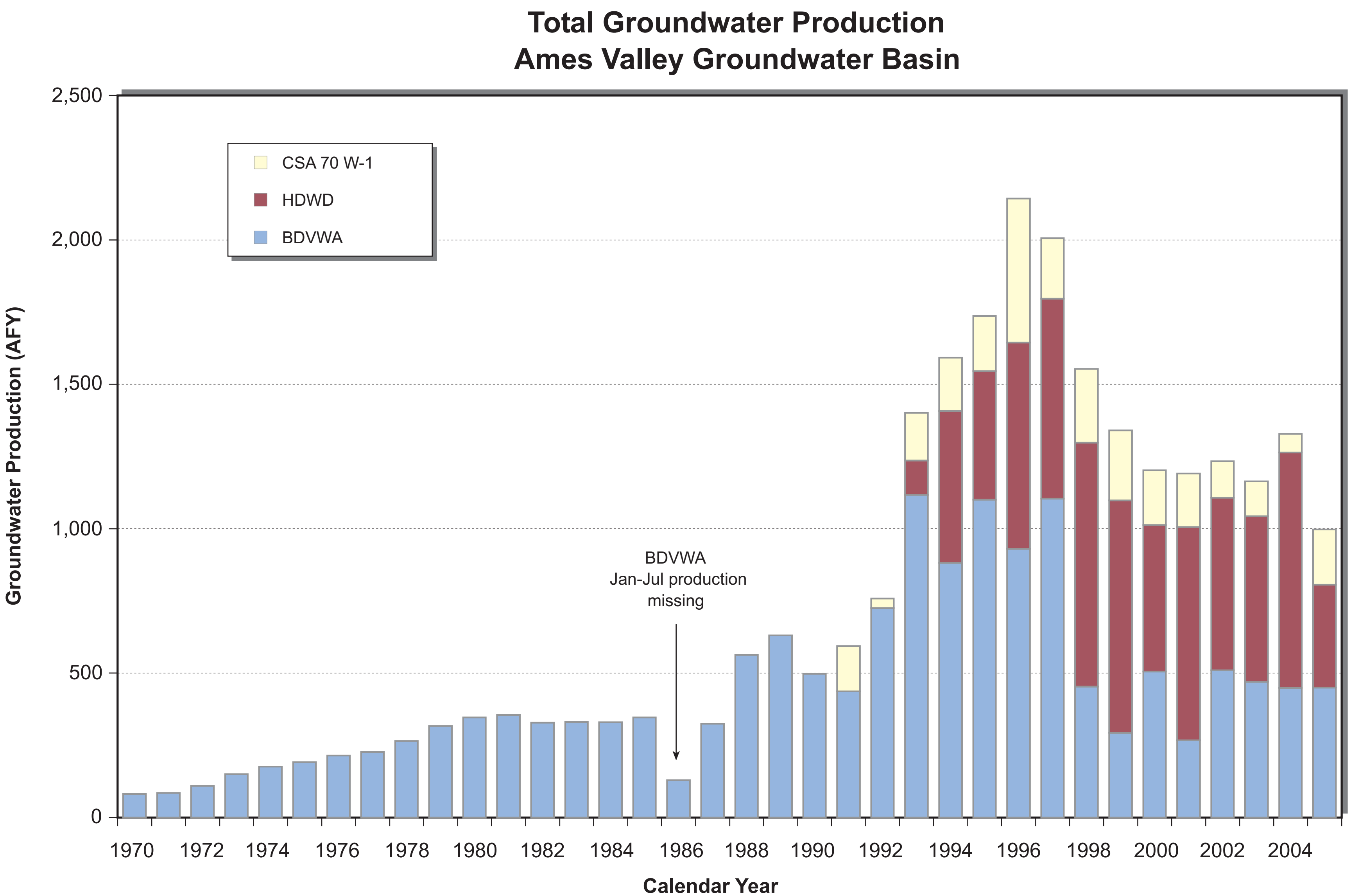
Figure 26
Groundwater Level Trends
Ames Valley Giant Rock
and Emerson Subbasins



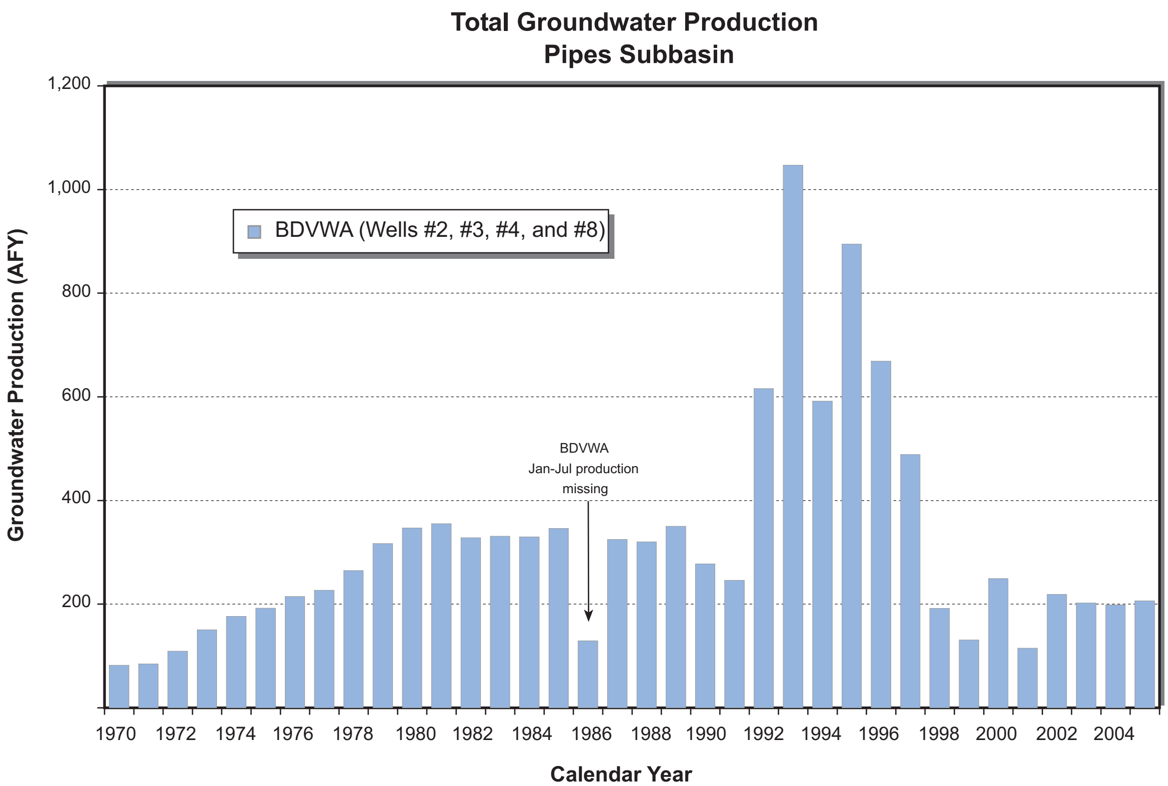
March 2007

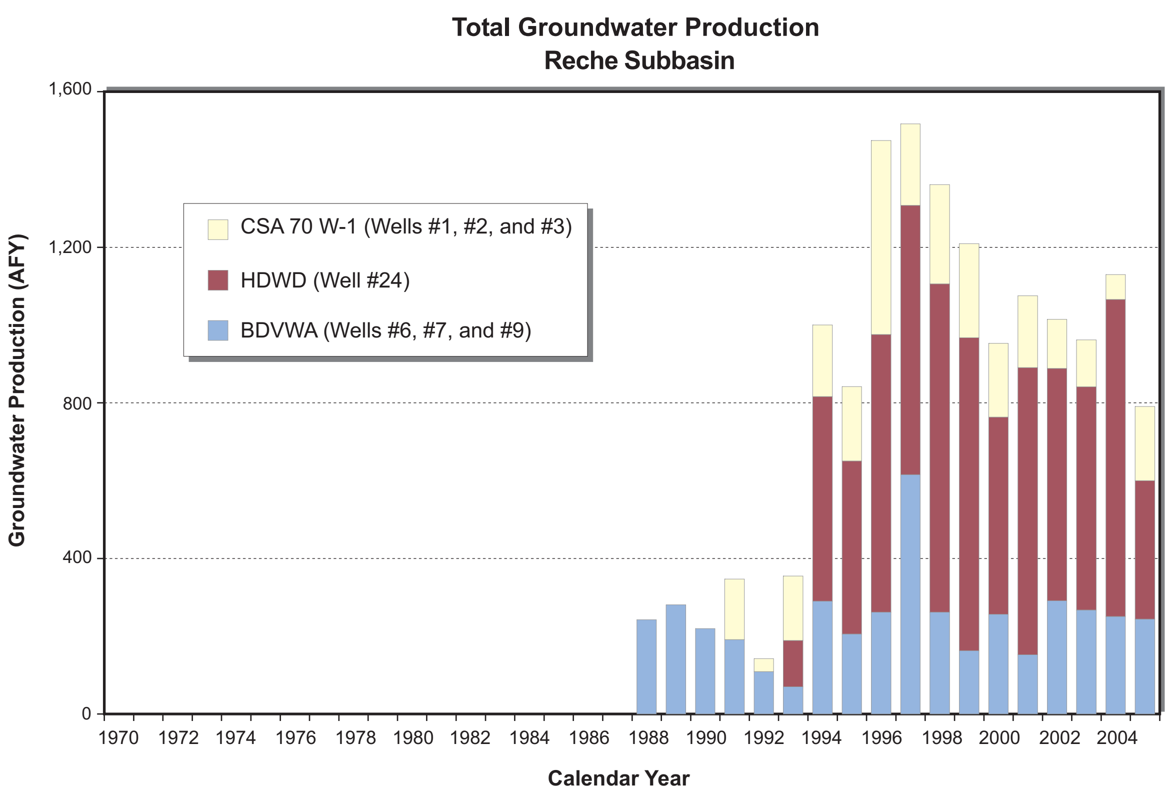
KENNEDY/JENKS/TODD
Emeryville, California

Figure 27
Spatial Analysis of Depth to Water



March 2007	**Figure 28**
KENNEDY/JENKS/TODD Emeryville, California	**Total Groundwater Production Ames Valley Groundwater Basin**

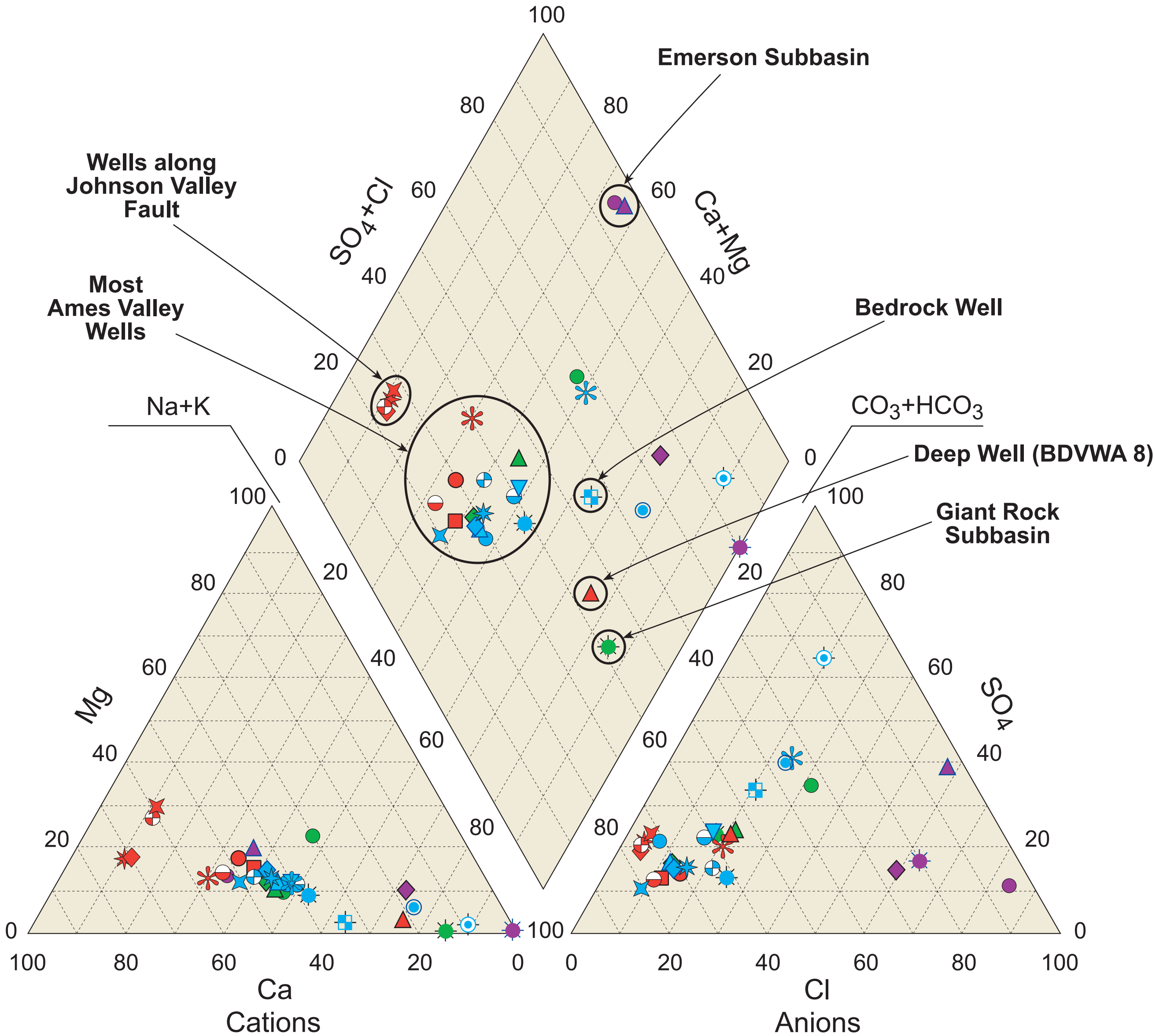




March 2007

KENNEDY/JENKS/TODD
Emeryville, California

Figure 29
Groundwater Production in Pipes and Reche Subbasins



LEGEND

Pipes Subbasin
- HDWD 21
- BDVWA 2
- BDVWA 3
- BDVWA 4
- BDVWA 8
- 2N/5E-27H1
- 2N/5E-27J1
- 2N/5E-10A1
- 2N/5E-03G1

Giant Rock Subbasin
- 2N/6E-24C1
- 3N/6E-04P2
- 3N/6E-16A1
- 3N/6E-27B1

Reche Subbasin
- BDVWA 6
- BDVWA 7
- BDVWA 9
- CSA W-1 3
- CSA W-1 2
- CSA W-1 1
- Moran
- HDWD 24
- HDWD 6
- 2N/5E-12N1
- 2N/6E-30L1
- 3N/5E-13G1
- 3N/5E-23D2

Emerson Subbasin
- 4N/6E-18L1
- 4N/6E-27D1
- 4N/6E-34E1
- 4N/6E-28R1

February 2007

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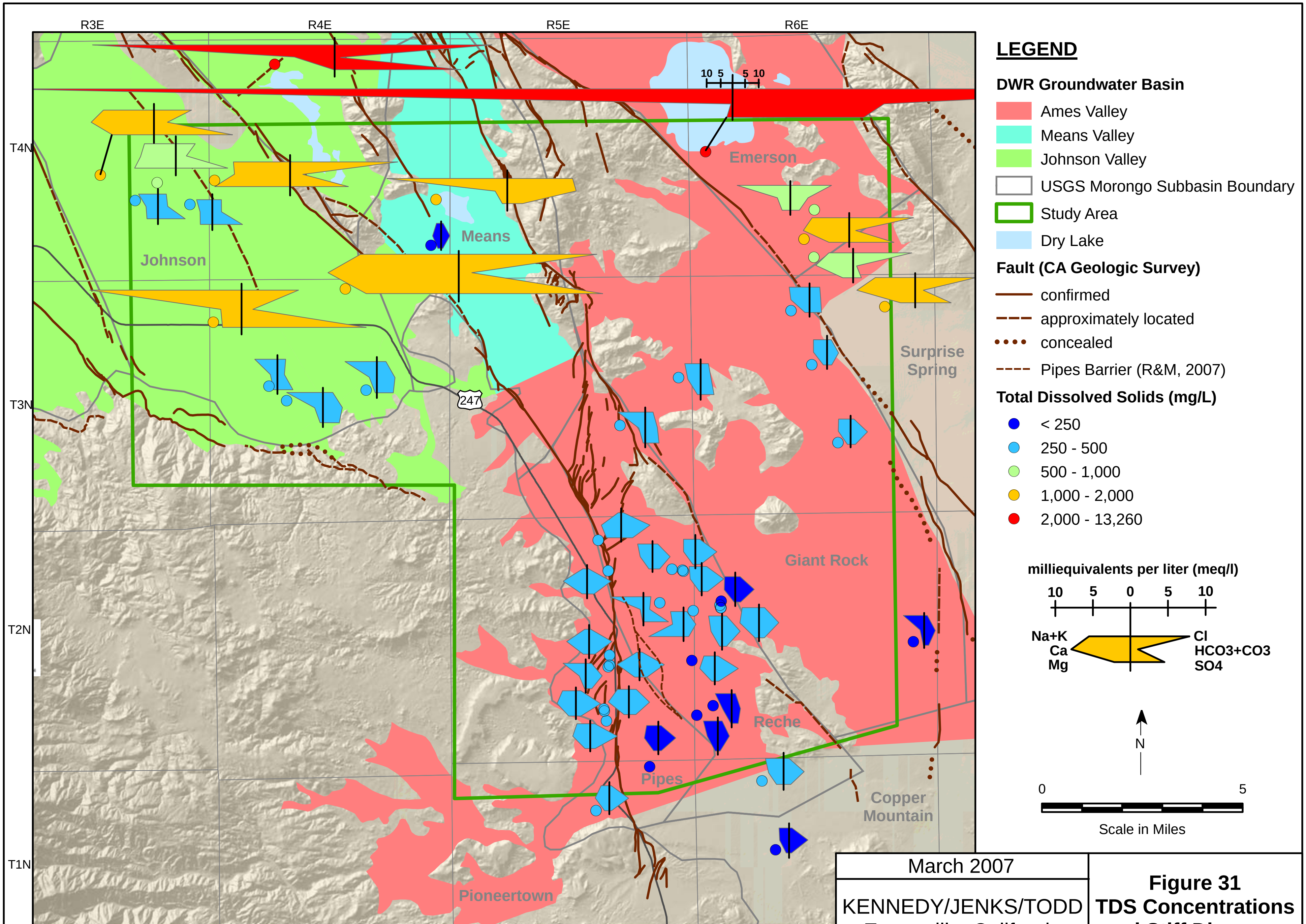
Emeryville, California

Figure 30
Trilinear Diagram for Wells in Ames Velley Groundwater Basin



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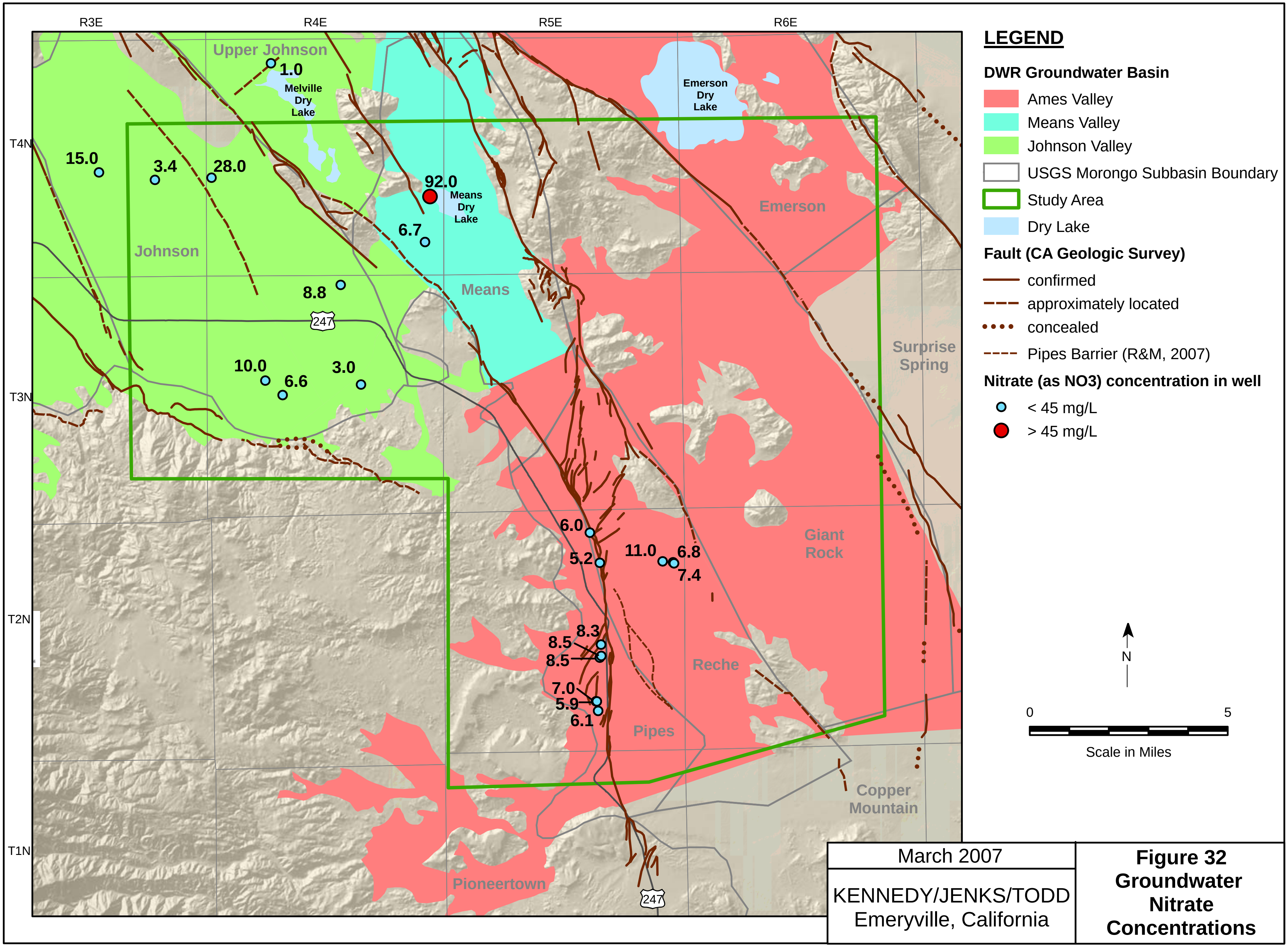
Emeryville, California

Figure 31
TDS Concentrations and Stiff Diagrams



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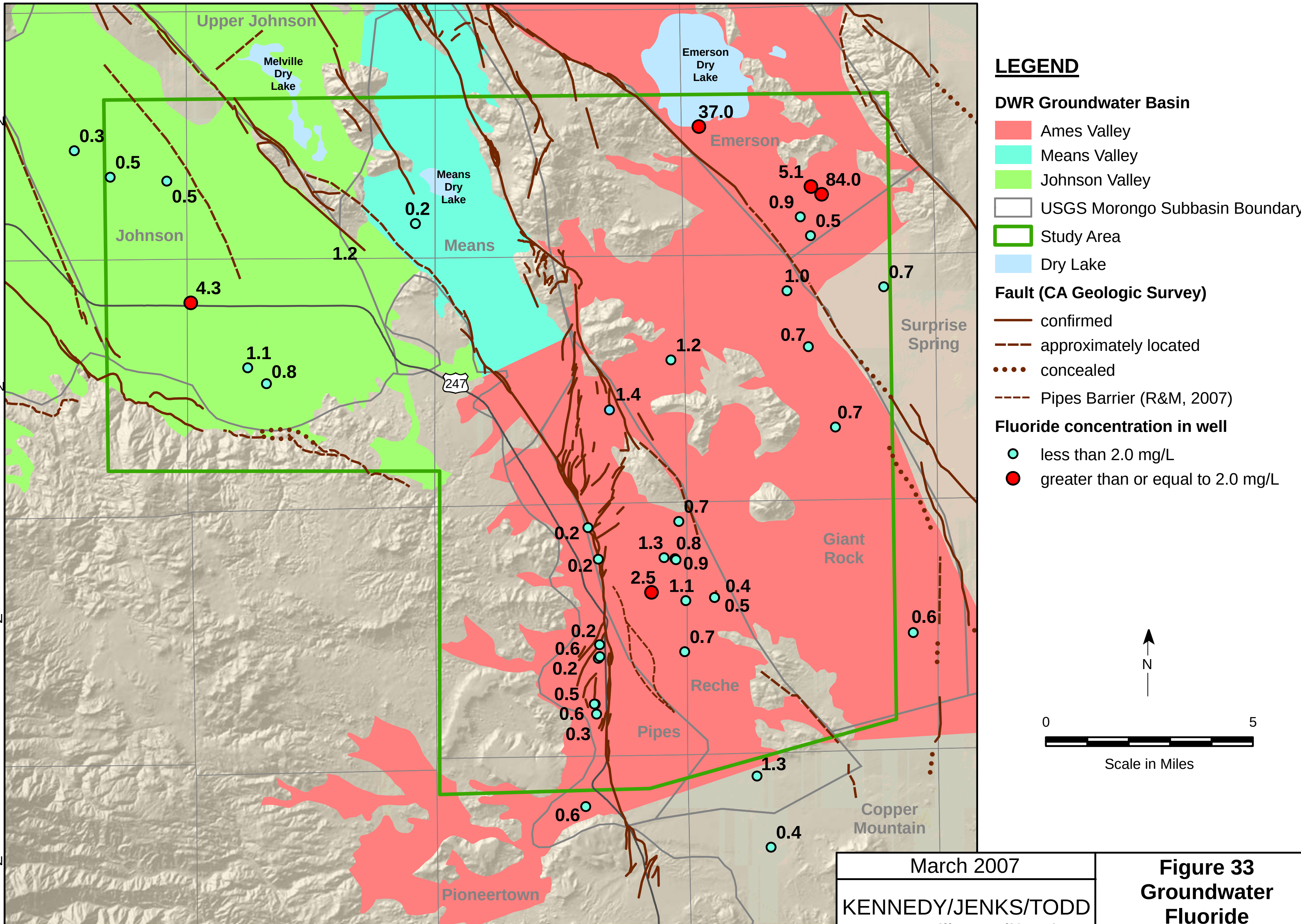
Emeryville, California

Figure 32
Groundwater Nitrate Concentrations



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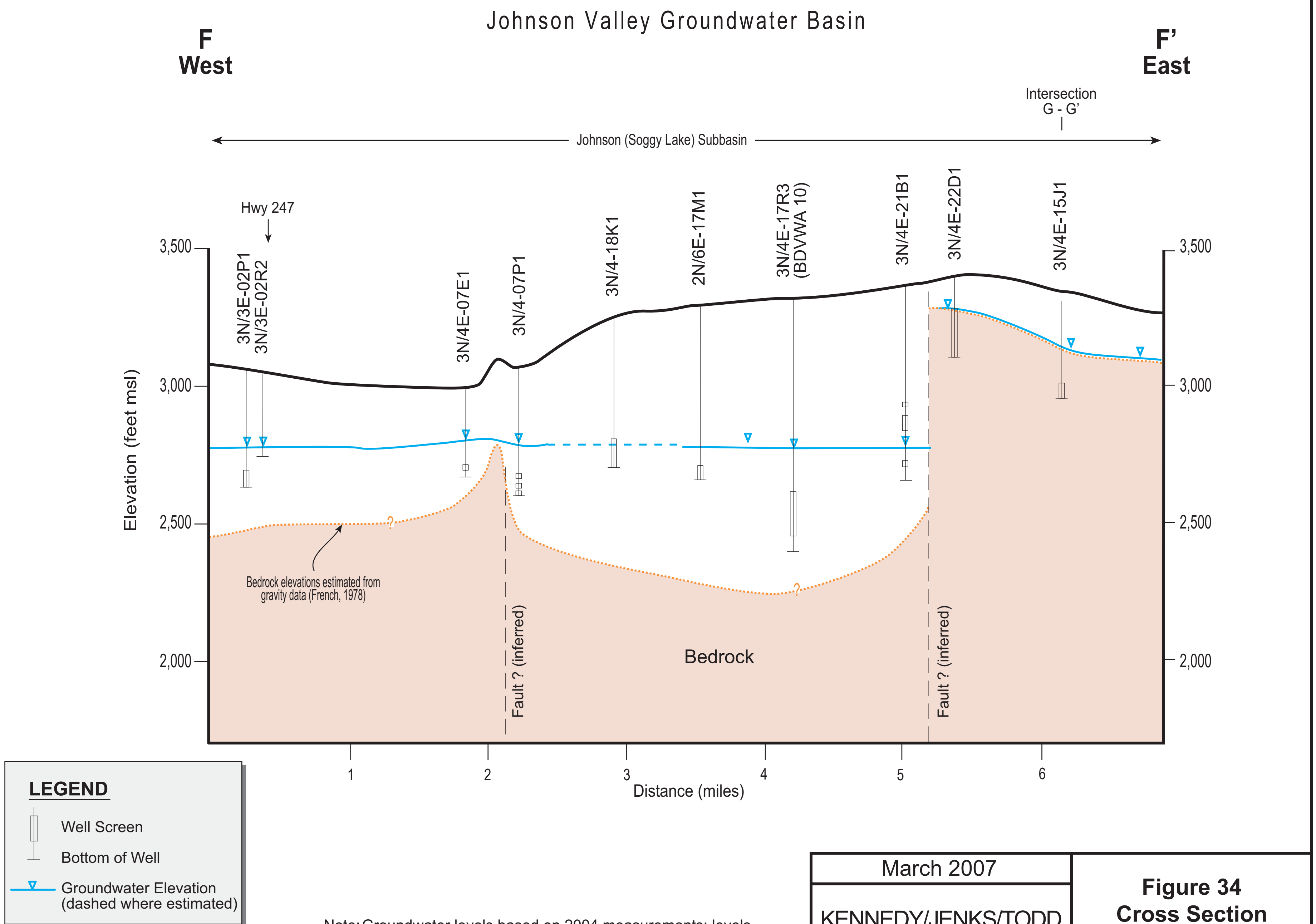
Emeryville, California

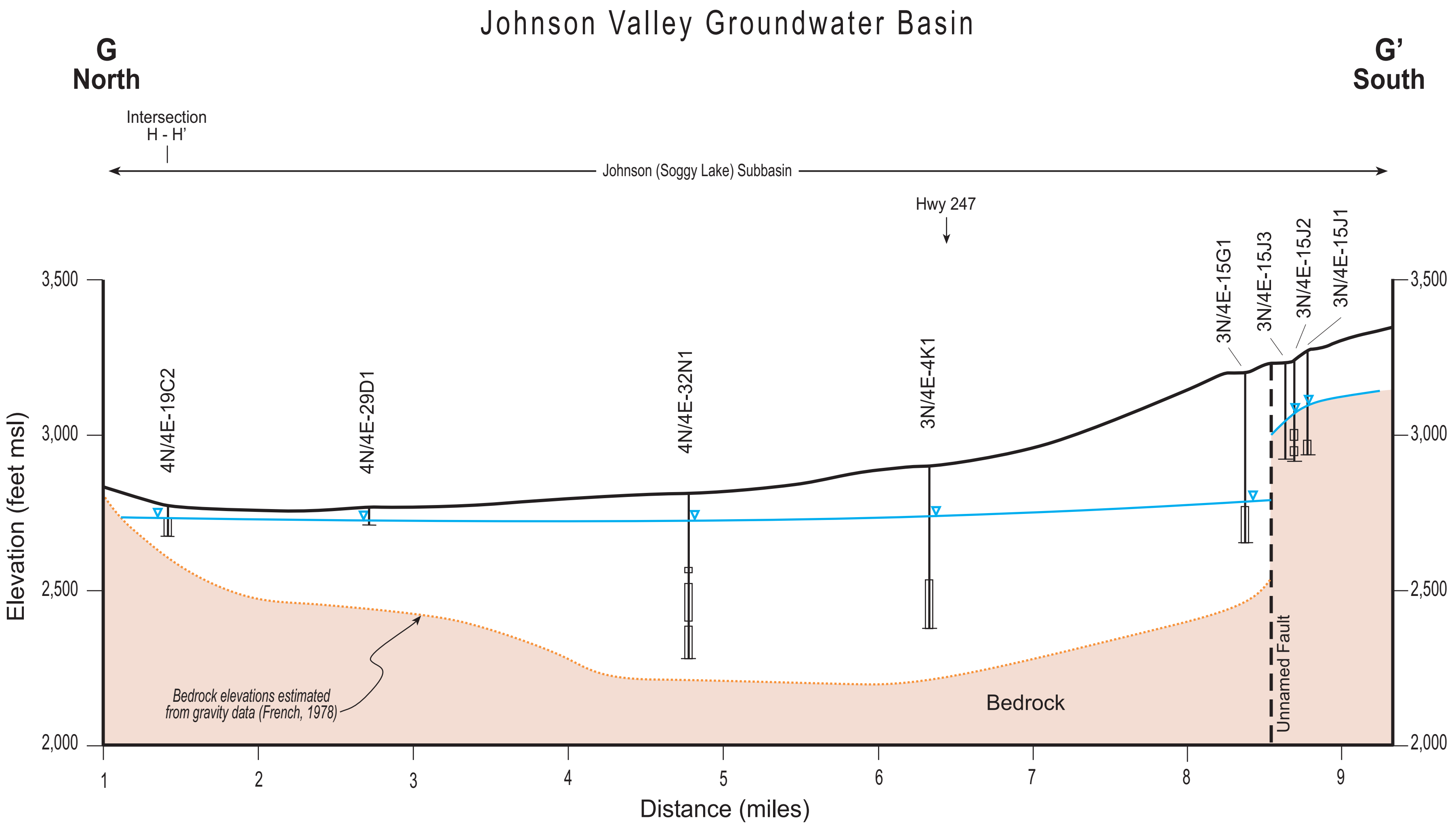
Figure 33
Groundwater Fluoride Concentrations



Vertical displacement along faults is unknown.

Note: Groundwater levels based on 2004 measurements; levels in some areas estimated from driller's logs and groundwater level trends.

March 2007	**Figure 34**
KENNEDY/JENKS/TODD Emeryville, California	**Cross Section F-F'**



LEGEND

Well Screen

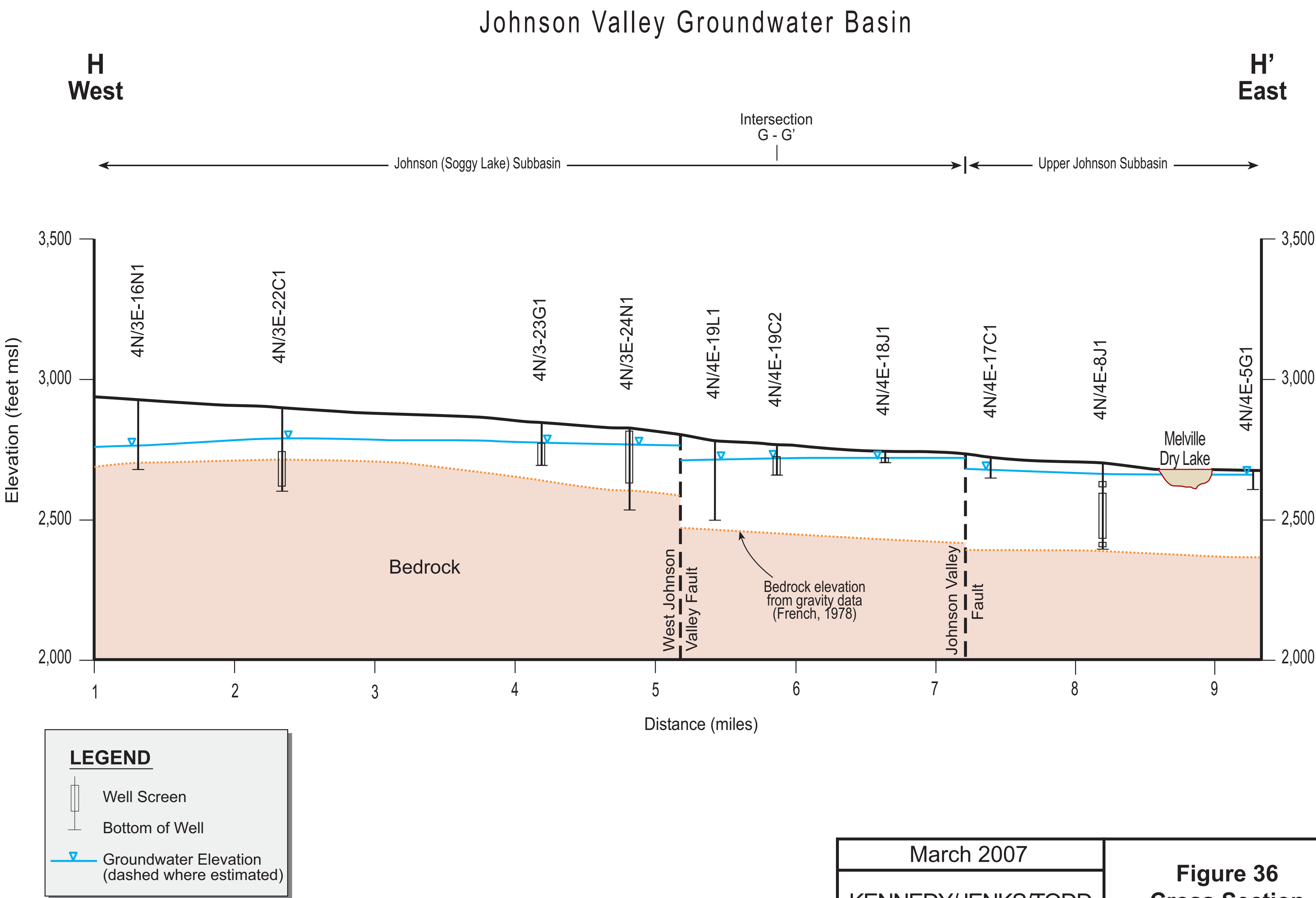
Bottom of Well

Groundwater Elevation (dashed where estimated)

Vertical displacement along faults is unknown.

Note: Groundwater levels based on 2004 measurements; levels in some areas estimated from driller's logs and groundwater level trends.

March 2007	**Figure 35**
KENNEDY/JENKS/TODD Emeryville, California	**Cross Section G-G'**



Vertical displacement along faults is unknown.

Note: Groundwater levels based on 2004 measurements; levels in some areas estimated from driller's logs and groundwater level trends.

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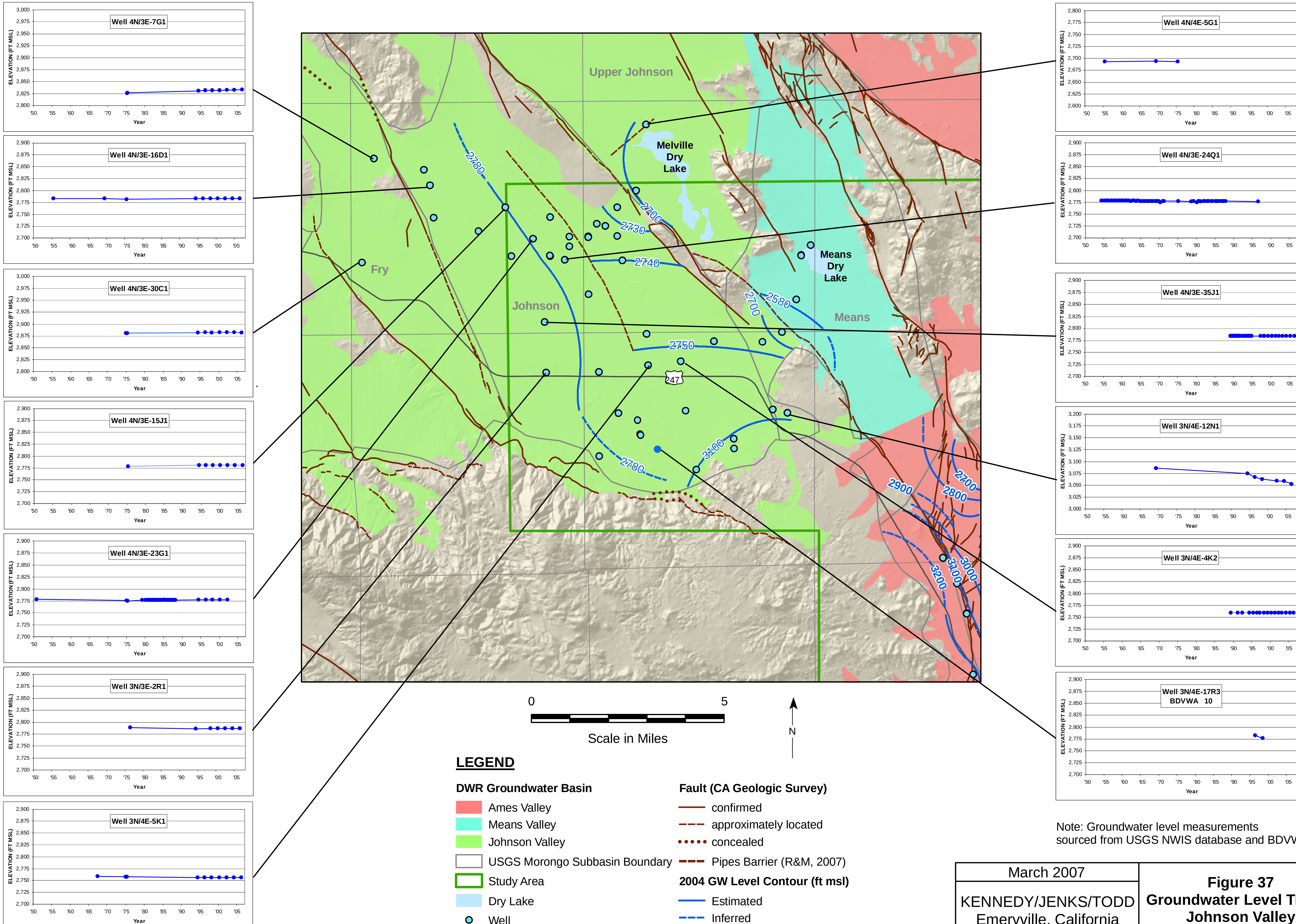
KENNEDY/JENKS/TODD
Emeryville, California

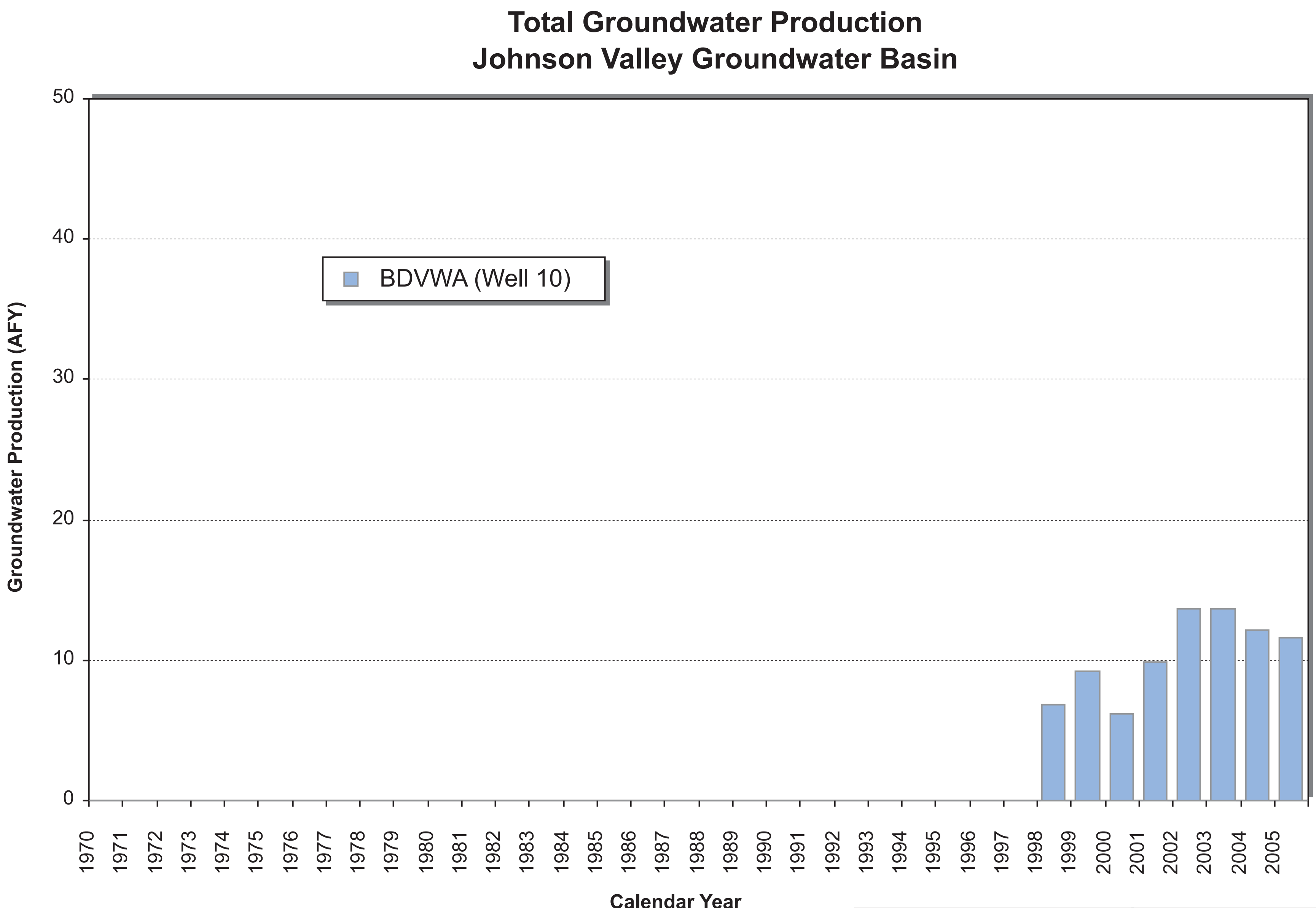
Figure 36
Cross Section
H-H'



March 2007

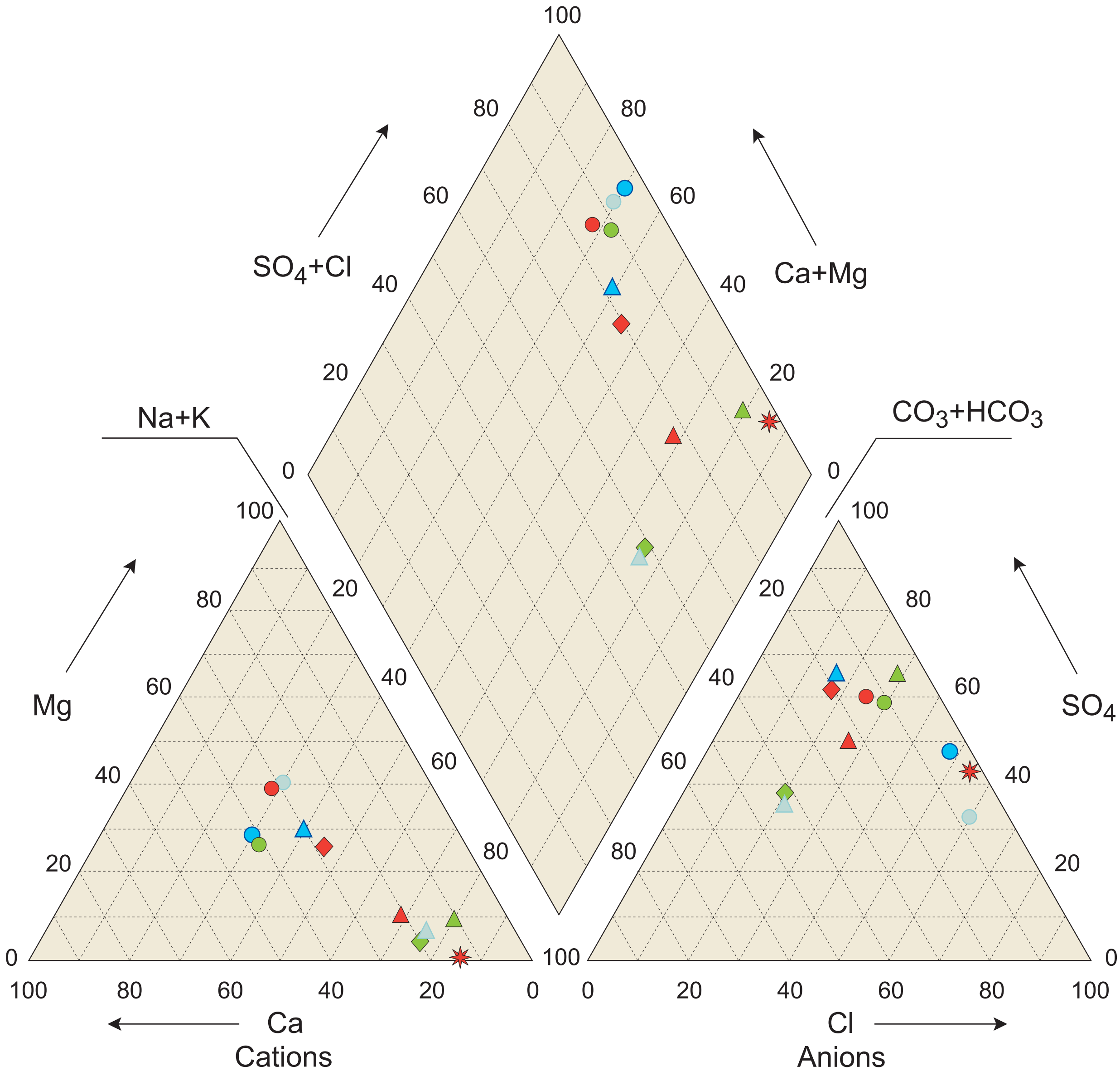
KENNEDY/JENKS/TODD
Emeryville, California

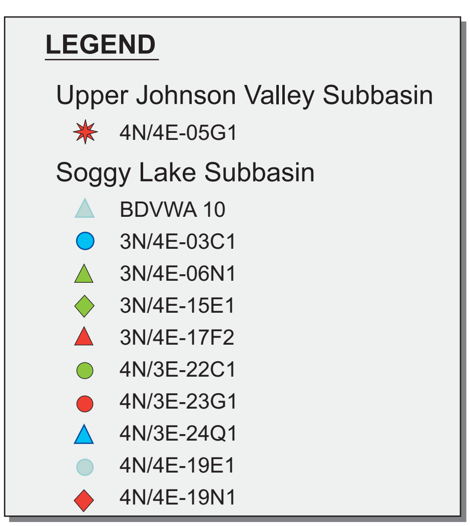
Figure 37
Groundwater Level Trends
Johnson Valley



Data include documented municipal production only.
Population data indicate reliance on additional water sources including private wells, but the amount of additional groundwater use is unknown.

March 2007	**Figure 38**
KENNEDY/JENKS/TODD Emeryville, California	**Total Groundwater Production Johnson Valley Basin**

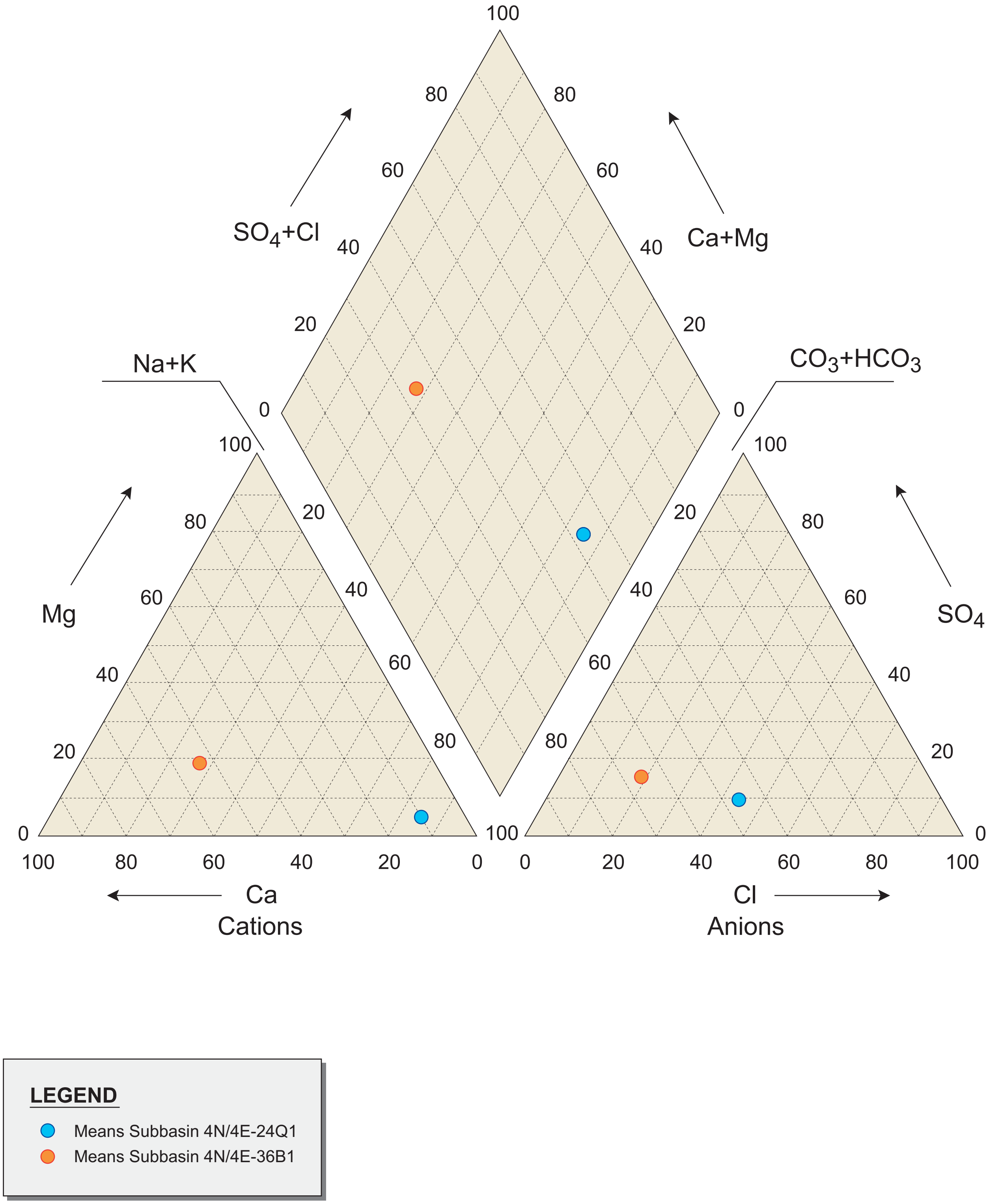




February 2007

KENNEDY/JENKS/TODD
Emeryville, California

Figure 39
Trilinear Diagram for Wells in Johnson Valley Groundwater Basin



February 2007	**Figure 40**
KENNEDY/JENKS/TODD Emeryville, California	**Trilinear Diagram for Wells in Means Valley Groundwater Basin**

Aquifer Science & Technology

Your Ground Water Resource

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REPORT ON THE GEOPHYSICAL INVESTIGATIONS FOR THE AMES, MEANS, AND JOHNSON VALLEYS, NEAR YUCCA VALLEY CALIFORNIA

MOJAVE WATER AGENCY
VICTORVILLE, CALIFORNIA

MARCH/2007

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Waukesha, WI 53188-1020
(262) 542-5733
(262) 542-5631 Fax

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INTRODUCTION

The Mojave Water Agency (MWA), working cooperatively with the Bighorn-Desert View Water Agency (BDVWA) and the Hi-Desert Water District (HDWD), are conducting extensive investigations into the feasibility of storing water in the unconsolidated material in the Ames, Means, and Johnson Valley Groundwater Basins near Yucca Valley, California. These studies have been designed to determine if the unconsolidated materials in the basins are appropriate for artificial recharge and to determine how the stored water can be efficiently recovered. **Figure 1** shows the location of the groundwater basins.

Test drilling, basin analysis, water quality studies, and geophysical studies have been conducted by the USGS and a variety of private consultants in this area for over 20 years. These studies have indicated that the basins are cut by faults that are believed to act as partial barriers to groundwater flow (**Figure 1**). The location and hydraulic function of these barriers are critical in understanding the flow within and between the basins and the fate of any recharged water.

The grain size and permeability of valley fill sediments can vary significantly, both laterally and vertically, over relatively short distances. The cost of drilling through these sediments is significant due to the depth of penetration required and the nature of the sediments. Faults present narrow drilling targets that can be difficult to accurately locate beneath unconsolidated valley fill deposits that cover the faults and mask their surface expressions. The number of borings that can be drilled in practical terms is considerably lower than the number that would be needed to characterize the grain size distribution and faulting of the study area. As a result, less expensive means of gathering subsurface information are needed.

Geophysical surveys are an exploration tool that can provide information on the lateral and vertical distribution of grain size for lower costs and with more complete coverage than is possible by test drilling. The results of the geophysical surveys are typically used to site borings in critical areas or to interpolate between borings to provide more accurate predictions of the location of facies changes in the subsurface.

Previous geophysical work conducted in the area has been limited to a few regional gravity surveys, some limited electrical resistivity and seismic refraction surveys, and some aerial magnetic data that covers portions of the area. These studies provide background data into the general nature of the subsurface, but more site specific and detailed investigations were needed to evaluate the feasibility of artificial recharge in the study area.

The MWA prepared a Request for Proposal (RFP), dated April 3, 2006, for the purpose of securing a qualified consultant to complete geophysical investigations in the area. The purpose of the investigations was to define the subsurface characteristics and hydraulic properties of the aquifer system and map the location of the major faults in the area. AST was awarded the contract in June of 2006. MWA awarded a parallel contract to Kennedy/Jenks/Todd, LLC (KJT) to construct a conceptual hydrogeologic model of the basins to assist MWA in evaluating the water resources of the study area. Our geophysical investigations were planned in conjunction with MWA and KJT to provide additional subsurface information to support the hydrogeologic conceptual model.

Based on experience with similar projects, Aquifer Science & Technology (AST) recommended to the MWA in our May 18, 2006 proposal, that the objectives of this study would be best accomplished through the use of two electrical methods; a high resolution electrical resistivity survey to map the lateral and vertical grain size distribution of the upper 300 to 400 feet, and a Time Domain Electromagnetic Induction (TEM) survey to determine the grain size distribution to depths of up to approximately 1,000 feet.

The resistivity survey was designed to provide the greatest resolution of the distribution of coarse grained and fine grained sediments above the water table, which will most significantly affect the ability of water to quickly reach the water table in the area, and map the shallow portions of the fault zones, which separate the major groundwater basins in the study area. The TEM survey was designed to determine the grain size distribution of the lower unsaturated zone and the saturated aquifer material above bedrock. A modification of the TEM method that measures three components of the magnetic field was proposed to map the location and orientation of deeper portions of the fault planes. However, the results of the resistivity survey made the three component TEM survey unnecessary.

The geophysical methods used in this survey measure the subsurface electrical properties in different ways. Each method has a different optimal range of depth and resistivity values and loses accuracy when working out of the optimal range. As a result, the measurements made by each method in a given area will show similar trends but will not match exactly in terms of layer depth and resistivity.

Figure 2 shows the locations of the TEM soundings and resistivity line locations. The major survey effort was concentrated in and around the BDVWA well field in and around Pipes Wash and Whalen's Wash, which runs east-west and intersects Pipes Wash near its northern terminus. Additional TEM soundings were conducted near BDVWA Well 10, located approximately 10 miles to the northwest in Johnson Valley (**Figure 3**).

GEOLOGIC SETTING

The survey areas lie above deep valleys surrounded by mountains. The valley fill deposits consist of a complex mixture of coarse sand and gravel deposits, fine silty sand, and clay rich deposits. The permeability of the valley fill deposits varies significantly according to the grain size of the material. Areas with predominantly fine grained valley fill deposits have limited capacity for infiltration of water.

Beneath the valley fill deposits lies crystalline basement rock, which is assumed to have very low permeability. The depth to crystalline basement rock varies significantly within the valley. Several faults cut the crystalline basement rock and valley fill sediment. The location of many of these faults are generally known, but the exact location is not precisely known due to the smooth surface of the valley fill sediments. One hydraulic barrier, the Inferred Pipes Barrier, is known from water level data. This feature is assumed to be a fault, but its presence and location has not been confirmed by direct field observation. The faults are believed to produce significant vertical displacement across the valley fill sediments and on the surface of the basement rock. The faults are also believed to truncate permeable units in the valley fill or create low permeability zones of fault gouge that inhibit lateral flow of groundwater and form partial hydraulic barriers.

ELECTRICAL PROPERTIES OF SEDIMENTS AND ROCK

The resistivity and TEM methods are all broadly classified as electrical methods because they measure the electrical properties of the subsurface. The specific electrical property measured by these methods is electrical resistivity. Electrical resistivity is measured in units of ohm-meters (ohmm), and is the mathematical inverse of the more familiar property of electrical conductivity.

Resistivity is a material property that can be used to determine the characteristics of the subsurface. The resistivity of sediment or rock horizon is determined by the moisture content and by the particular mineralogical composition of the material. Materials saturated with fresh water generally have lower resistivity values than unsaturated materials. Unsaturated sand and gravel typically has very high resistivity values (300 to 1,000 ohmm). Clay rich materials, such as lacustrine clays, generally exhibit very low resistivity (less than 30 ohmm). Materials containing little clay, such as unweathered granite or competent carbonate formations and clean sand and gravel, generally exhibit very high resistivity values (greater than a few hundred ohmm). Porous materials saturated with fresh water, such as various sand and gravel mixtures, have intermediate resistivity values (between approximately 100 and 300 ohmm). Porous units saturated with brackish or saline water have lower resistivity values (10 to less than 1 ohmm). The more fine grain material present in a formation the lower the electrical resistivity of the material. Very silty sand and sand/silt/clay mixtures will exhibit resistivity values of between 30 to about 100 ohm-meters. Using these general relationships, resistivity measurements can be used to distinguish subsurface sediment types. Typical resistivity values for various types of unconsolidated geologic materials are shown on **Table 1.**

RESISTIVITY SURVEY

Description of the Resistivity Method

The method of electrical resistivity incorporates the introduction of an electrical current into the ground through a pair of electrodes (current electrodes) while measuring the resultant voltage field in the ground at an offset pair of electrodes (potential electrodes). The purpose of the resistivity survey is to delineate variations with depth in the subsurface material. This is based on the fact that the subsurface penetration of the electrical current is a function of the electrode separation. The change in electrical properties with depth is determined by taking measurements at increased electrode spacings and modeling the change in apparent resistivity with electrode spacing. This type of survey is referred to as a resistivity sounding. By making a series of soundings along a profile line, the lateral changes in layer resistivity can also be determined.

High resolution multi-node resistivity systems use a cable system with multiple conductors to connect many electrodes to a switching box. The switching box selects pairs of current and potential electrodes to make resistivity measurements. The spacing between current and potential electrodes, the spacing between the electrode pairs, and the position of the center of the electrode arrays are changed from one measurement to the next in a systematic way to provide resistivity measurements to different depths and different positions along a profile line. These systems can make hundreds of measurements in a matter of a few hours. The data can be interpreted to produce a relatively high resolution two dimensional section that shows the lateral and vertical changes in resistivity along the profile line.

The resistivity values recorded in the field are called apparent resistivity values because they are a composite measure of the resistivity of all layers that the current traveled through. The field data must be modeled to distinguish the effects of each electrical layer penetrated in order to determine the thickness and resistivity of each layer. Multi-node resistivity data is typically modeled to produce a two dimensional resistivity section that shows the modeled resistivity of the subsurface beneath the profile line.

Substantial lateral changes in electrical properties in close proximity to either side of the resistivity profile line can introduce three dimensional effects into the data, which will in-turn introduce errors into a two dimensional survey and the resultant interpretation. In particular, the resistivity sections will show the position and orientation of major faults that are perpendicular to the line with a high degree of accuracy, but the modeled resistivity values may not be accurate.

Of particular significance is a phenomenon known as the paradox of anisotropy (Keller and Frischknecht, 1966), which causes conductive dikes to appear as high resistivity features due to the distortion of the current field created by the dike. The paradox of anisotropy makes faults with conductive clay rich fault gouge, or conductive fluids filling fractures and voids associated with the fault, appear as resistors when the fault plane is nearly vertical and cuts the resistivity line at an orientation close to perpendicular. As the orientation of the fault plane becomes more oblique to the survey line, the signature of the fault becomes more like a wide conductor. The limitations of imaging a three dimensional structure with a two dimensional survey method must be kept in mind when interpreting the field data and processed sections. These effects can be eliminated or reduced by using three dimensional resistivity methods. However, the cost and complexity of three dimensional survey methods are generally not justified for most surveys. For this survey, knowing the position and approximate orientation of the faults was adequate and three dimensional survey methods were not required.

The high resolution multi-node resistivity method provides a higher level of vertical and lateral resolution and shallower depths than the TEM method. The resistivity method is also more sensitive to changes in high resistivity material than the TEM method. As a result, the resistivity method is ideally suited to define the stratigraphy of the coarse grained sediments above the water table in this area. At depths below about 400 feet, the resistivity method loses resolution due to the long current path lines required to obtain the depth of penetration, which results in a large volume of the subsurface sampled to make each measurement. This reduces the sensitivity of the method to changes at depth.

Description of Resistivity Field Procedures

A geophysical survey consisting of 15 high-resolution resistivity profiles was conducted between October 17 and October 23, 2006. **Figure 2** shows the location of the survey lines. The resistivity data were collected using a SuperSting™ model R1 IP, with a Swift™, multi-node resistivity imaging system, manufactured by Advanced Geosciences, Inc., (AGI) of Austin, Texas. Survey profile locations were chosen on the basis of site availability, adequate open area free of cultural interference, and previous discussions with MWA and KJT personnel. Line locations were modified in the field as necessary in consultation with MWA personnel to improve data quality and provide data in more advantageous locations.

The Sting system consisted of a transmitter/receiver, switch box, four 450-foot long electrode cables, each with 14-takeouts (electrode connection points) spaced 10 meters (approximately 32.8 feet) apart, 56 metal stakes (electrodes), and a 12-volt deep cycle marine battery to power the transmitter. The system was laid out with the transmitter/receiver, switch box, and battery in the middle of the four cables. Using four cables and 56 electrodes, the total line length was approximately 1,800 feet. For each sounding, steel electrodes were pounded into the ground and attached to the cable at each 10-meter takeout. The electrode spacing was controlled by the transmitter's internal switching system. The switching system selects various electrodes to form dipole pairs of current electrodes and potential electrodes with different dipole spacings, dipole offsets, and array centers. Hundreds of measurements were made along each profile line to measure the lateral and vertical changes in subsurface resistivity.

The modeling package Earth Imager was used to model the field data. This program models the field data to image the lateral and vertical changes in subsurface resistivity. Available subsurface geologic data was used to provide estimates of the depth to bedrock and sediment types in order to improve the accuracy of the resistivity models.

RESISTIVITY SURVEY RESULTS AND DISCUSSION

Data quality was very good on all 15 lines. Each of the resistivity profiles achieved a depth of penetration of about 300 to 450 feet. Each of the modeled profile lines are plotted with a uniform resistivity scale of 30 ohm-meters as the lower limit and 500 ohmm as the upper limit to allow the lines to be easily compared. The resistivity value of a given sediment type depends on the grain size, degree of saturation, and conductivity of the formation fluid. Assuming low TDS formation fluid, the color scale and corresponding lithology typical for those resistivity ranges are represented as follows: clay is shown in dark blue; clay and silt mixtures are shown as light blue; silty fine sand is shown in bluish-green, sand with variable silt is shown in green; sand and gravel with minor silt or saturated sand and gravel is shown in yellow and orange; and, clean unsaturated sand and gravel or very coarse gravel is shown in red. **Table 2** presents an estimated lithology key for the color scale used on **Figures 4 to 11**. This key is based on past experience on similar sites. Local variations in the mineralogy of the sediments and formation water quality can cause deviations from the lithologies presented on **Table 2**.

Using a uniform resistivity scale reduces the level of detail that can be seen on some of the lines. Plots of each line with a scale selected to enhance the more subtle resistivity variations on each line are included in **Appendix A.** The processed resistivity lines are presented on **Figures 4 through 11**. **Figure 12** shows the resistivity plots to approximate scale superimposed on the base map with the interpreted location of the major faults. A brief discussion of the results obtained along each of the resistivity profiles follows.

Resistivity Profile 1

Line 1 (**Figure 4**) shows high resistivity material on the west half of the line down to a depth of approximately 400 feet, grading into intermediate resistivity material on the east half of the line. This pattern appears to indicate coarse grained unsaturated sand and gravel on the west half of the line grading into finer sand and silty sand eastward heading away from Whalen's Wash, located immediately west of Line 1. This is consistent with the normal gradation from coarse grained to finer grained sediment moving from a wash into a basin. KJT indicated that the depth to water is approximately 350 feet in this area. Based on this information, it does not appear that the water table is readily discernable from the resistivity data at this location.

Resistivity Profile 2

Line 2 (**Figure 4**) lies a short distance south of the eastern edge of Line 1. The line shows almost entirely intermediate resistivity material. The resistivity values measured on Line 2 are in same range as the values measured on the eastern end of Line 1. This suggests that the sediment beneath Line 2 down to a depth of about 400 feet predominantly consist of fine sand or silty sand. KJT indicated that the depth to water is approximately 350 feet in this area. Based on this information, it does not appear that the water table is readily discernable from the resistivity data at this location.

Resistivity Profile 3

Line 3 (**Figure 5**) is located in Whalen's Wash and is oriented oblique to the axis of the wash. This modeled profile shows a high resistivity unit at the surface, overlying an intermediate resistivity unit at a depth of about 120 to 140 feet on the southwest end of the line to very near the surface on the northeast end. KJT indicated that the depth to water is approximately 160 feet in this area, which corresponds closely to the transition from high resistivity to intermediate resistivity material on the southwestern half of the line. The resistivity plot suggests a coarse grained unsaturated sand and gravel layer over a saturated sand unit that extends to over 400 feet. The resistivity of the sediments on the northeast end of the line are much lower, suggesting the presence of clay in this area.

The plot of Line 3 in **Appendix A** shows more detail within the intermediate resistivity unit. The sediments beneath the upper high resistivity unit appear to consist of lower-intermediate resistivity material with a zone of intermediate to higher-intermediate material between stations 313 and 396. This anomalous area may represent a former channel within the banks of the underlying wash area or a fault.

Resistivity Profile 4

Line 4 (**Figure 5**) is located directly in Whalen's Wash approximately 3,000 feet east of Line 3. This modeled profile shows a high resistivity unit at the surface, overlying a low resistivity unit at a depth. The high resistivity layer is less than 50 feet thick on the west end of the line and thickens to approximately 100 feet on the east end of the line. The resistivity plot suggests a coarse grained unsaturated sand and gravel layer over a clay unit that extends to over 400 feet.

A notable zone of higher resistivity material is present near station 591. This feature is approximately 60 feet wide and dips steeply to the west. This feature is located at the predicted location of the Inferred Pipes Barrier (**Figure 12**), and appears to represent a fault. The anomaly shows a higher resistivity, but it is likely that the fault is actually a conductive feature due to clay-rich fault gouge and or fluid filled fractures. The higher resistivity response is assumed to be due to the paradox of anisotropy.

The width of the fault and associated zone of alteration is probably thinner than the resistivity anomaly. The dip of the fault is probably consistent with the trend of the resistivity anomaly, though the dip of the resistivity anomaly is probably an apparent dip because it is unlikely that the fault cuts the resistivity line in a perpendicular orientation. The low resistivity unit appears to be offset about 50 feet downward to the east of the fault, suggesting that there is vertical offset on the fault.

The depth to water in this area is uncertain, because the nearest available well data is more than a mile away. KJT estimates that the depth to water in this area is about 150 feet on the west, or upthrown side of the fault, to approximately 190 feet on the downthrown (east) side. It appears that the water table is coincident with the top of the low resistivity unit.

The plot of Line 4 in **Appendix A** shows more detail within the low resistivity unit. There appears to be a layer with a resisitivity of about 30 Ohmm over a much lower resistivity unit (2 to 10 Ohmm) on the east side of the line. The very low resistivity unit is interpreted to represent fine grained sediment, such as clay. Conversely, the low resistivity unit could represent sand saturated with brackish to saline water. The intermediate resistivity unit could represent a siltier unit above the apparent clay unit.

Resistivity Profile 5

Line 5 (**Figure 6**) is located east of Pipes Wash near HDWD Well 6. This modeled profile shows a thin layer of intermediate resistivity sediment at the surface, overlying a layer of high to intermediate resistivity between about 50 to 100 feet beneath the surface. Beneath this layer lies a thick unit of lower resistivity material that extends to over 400 feet. The data suggests about 50 feet of fine grained sediment over a layer of silty sand that is about 50 feet thick and coarser grained on the west side of the line. Beneath the silty sand lies a finer grained unit, possibly with more clay, to a depth of over 400 feet. The depth to water was reported at approximately 350 feet in HDWD Well 6 in September 2005. The water table appears to lie within the low resistivity layer.

A zone of higher resistivity in the lower unit is present at the west end of the line. This feature is located at the predicted location of the Inferred Pipes Barrier (**Figure 12**). The anomaly is not a sharp planar feature like the anomaly on Line 4, and appears to represent a change in material type across a broad zone. It is possible that this feature represents a fault, though the signature is not as clear as on several other lines.

Resistivity Profile 6

Line 6 (**Figure 6**) is located southwest of Line 5 near HDWD Well 20. The eastern 200 feet of Line 6 partially overlaps the western end of line 5 about 200 feet north of Line 5. The modeled profile shows a layer of high resistivity sediments at the surface, thickening to over 100 feet on the west side of the line. Beneath this layer lies a thick unit of lower resistivity material that extends to over 400 feet. The data suggests up to 100 feet of unsaturated coarse grained sediments over a layer of silty sand or clay that extends to below 400 feet. The upper unit thins to less than about 30 feet on the eastern end of the line. KJT estimated the depth to water at 320 to 325 feet, indicating that the water table is well below the top of the low resistivity unit.

The plot of Line 6 in **Appendix A** shows more detail within the low resistivity unit. A zone of higher resistivity in the lower unit is present at the east end of the line. This feature is located near the predicted location of the Inferred Pipes Barrier (**Figure 12**). The anomaly is not a sharp planar feature like the anomaly on Line 4, and appears to represent a change in material type across a broad zone. It is possible that this feature represents a fault, though the signature is not a clear as on several other lines.

<u>Resistivity Profile 7</u>

Line 7 (**Figure 7**) is located directly in Pipes Wash. This modeled profile shows a high resistivity unit at the surface, overlying a low resistivity unit at a depth of between about 100 to 120 feet thick. The underlying unit has a resistivity of about 2 to 50 Ohmm and extends to below 400 feet. The resistivity plot suggests a coarse grained unsaturated sand and gravel layer over a layer of fine silty sand and clay that extends to over 400 feet.

A notable zone of higher resistivity is present beneath station 591. This feature is approximately 100 to 150 feet wide and dips steeply to the west. This feature is located at the predicted location of the Inferred Pipes Barrier (**Figure 12**), and appears to represent a fault. The anomaly shows a higher resistivity, but it is likely that the fault is actually a conductive feature due to clay-rich fault gouge and or fluid filled fractures. The higher resistivity response is assumed to be due to the paradox of anisotropy.

The width of the fault and associated zone of alteration is probably thinner than the resistivity anomaly. The dip of the fault is probably consistent with the trend of the resistivity anomaly, though the dip of the resistivity anomaly is probably an apparent dip because it is unlikely that fault cuts the resistivity line in a perpendicular orientation. The low resistivity unit appears to be offset about 50 feet downward to the east, suggesting that there is vertical offset on the fault. The depth to the water table is unknown in this area, but it is likely to be within the fine grained unit.

The plot of Line 7 in **Appendix A** shows more detail within the low resistivity unit. There appears to be a layer with a resisitivity of about 50 Ohmm over a much lower resistivity unit (2 to 10 Ohmm). The low resistivity unit probably represents a clay unit. The clay unit appears to be offset by about 50 feet. The intermediate resistivity unit shows less offset across the fault. This unit could represent a siltier unit above a clay unit or could represent a saturated silty unit. If the intermediate layer does represent a saturated zone, it could indicate higher water levels on the west side of the fault. This is consistent with the estimated depth to water provided by KJT of 150 feet on the west half of the line and 185 feet to the east. Based on these estimates, the water table appears to coincide with the top of the intermediate resistivity unit.

<u>Resistivity Profile 8</u>

Line 8 (**Figure 7**) is located directly in Pipes Wash directly west of Line 7. The eastern 800 feet of Line 8 partially overlaps the western end of line 7. This modeled profile shows a high resistivity unit at the surface, overlying a low resistivity unit at depth. The high resistivity layer is about 100 to 150 feet thick. The underlying unit has a resistivity of about 2 to 50 Ohmm and extends to below 400 feet. The resistivity plot suggests a coarse grained unsaturated sand and

gravel layer over a layer of fine silty sand and clay that extends to over 400 feet. KJT estimated the depth to water to be 147 feet on the west half of the line and 154 feet to the east. Based on these estimates, the water table appears to coincide with the top of the intermediate to low resistivity unit.

A notable zone of higher resistivity is present near stations 591 to 787. This feature is approximately 300 feet wide and may consist of two separate vertical features. The strongest part of the anomaly is about 50 feet wide and dips steeply to the west near station 560. No known faults are located near this anomaly. Based on the distinct signature, it is likely that this feature represents a previously unknown fault. The anomaly shows a higher resistivity, but it is likely that the fault is actually a conductive feature due to clay-rich fault gouge and or fluid filled fractures. The higher resistivity response is assumed to be due to the paradox of anisotropy. Another high resistivity feature is present at the extreme east end of the line that appears to correlate to the anomaly observed on Line 7.

The width of the fault and associated zone of alteration is probably thinner than the resistivity anomaly. The dip of the fault is probably consistent with the trend of the resistivity anomaly, though the dip of the resistivity anomaly is probably an apparent dip because it is unlikely that the fault cuts the resistivity line in a perpendicular orientation. The low resistivity unit appears to be offset about 60 feet downward to the east, suggesting that there is vertical offset on the fault. The depth to the water table is unknown in this area, but it is likely to be within the fine grained unit.

The plot of Line 8 in **Appendix A** shows more detail within the low resistivity unit. Much of this layer has a resisitivity of about 20 to 50 Ohmm, with a smaller body with a much lower resistivity unit (2 to 10 Ohmm) between about 250 to 400 feet on the east side of the line. The low resistivity unit probably represents a clay unit. The intermediate resistivity unit could represent a siltier unit above a clay unit or could represent a saturated silty unit. If the intermediate layer does represent a saturated zone, it could indicate higher water levels (about 50 feet) on the west side of the fault.

<u>Resistivity Profile 9</u>

Line 9 (**Figure 8**) is located along the wall of Pipes Wash about 1,200 feet northwest of Line 14. Line 9 was positioned cross the Inferred Pipes Barrier and several inferred deep bedrock faults. This modeled profile shows a layer of high resistivity sediments at the surface, thickening to over 200 feet on the east side of the line. Beneath this layer lies a thick unit of intermediate resistivity material that extends to over 400 feet. The data suggests about 200 feet of unsaturated coarse grained sediments over a layer of silty sand that extends to below 400 feet. The modeled data do not show a strong resistivity anomaly that would suggest the presence of a fault beneath the line. However, on the east end of the line the modeled data do indicate a thicker section of high resistivity material that may indicate a faulted zone in this area.

The nearest well data to Line 9 is from BDVWA Well 8 approximately 4,000 feet to the west and HDWD Well 24 approximately 1 mile to the east. KJT estimated the depth to water to be 210 feet on the west half of the line and 188 feet to the east. This puts the top of the saturated zone at the top of the intermediate resistivity layer, suggesting that this layer may represent saturated material. A very thin layer of finer grained sediment is present at the surface on the eastern half of the line.

Resistivity Profile 10

Line 10 (**Figure 8**) is located just north of Hondo Street east of Highway 247 near BDVWA Well 1 and BDVWA Well 8. This modeled profile shows a high to intermediate resistivity unit at the surface, which overlies a low resistivity unit. The upper layer is about 100 feet thick on the west end of the line and about 150 feet thick on the east end. The underlying unit has a resistivity of about 10 to 100 Ohmm and extends to below 400 feet. The resistivity plot suggests a coarse grained unsaturated sand and gravel layer on the west half of the line that grades into a layer of fine silty sand on the east half. The lower layer appears to consist of fine silty sand and clay that extends to over 400 feet. The depth to water in BDVWA Well 1 was reported at 217 feet in 1994. In 2004 and 2005 BDVWA Well 1 was dry. The depth to water in BDVWA Well 8 was reported at 278 feet in 2005. KJT estimated the depth to water to be 230 feet on the west half of the line and 260 feet on the east. This places the top of the water table approximately 50 to 100 feet within the low resistivity material.

A notable zone of higher resistivity is present near stations 394 to 900. This feature is approximately 500 feet wide and may consist of two separate vertical features. The strongest part of the anomaly is about 150 feet wide and dips at about 45 degrees to the west near station 650. This feature is located near the predicted location of the Johnson Valley Fault (**Figures 1 and 12**), and appears to represent a fault. The anomaly shows a higher resistivity, but it is likely that the fault is actually a conductive feature due to clay-rich fault gouge and or fluid filled fractures. The higher resistivity response is assumed to be due to the paradox of anisotropy.

The width of the fault and associated zone of alteration is probably thinner than the resistivity anomaly. The dip of the fault is probably consistent with the trend of the resistivity anomaly, though the dip of the resistivity anomaly is probably an apparent dip because it is unlikely that the fault cuts the resistivity line in a perpendicular orientation. The low resistivity unit appears to be offset about 80 feet downward to the east, suggesting that there is vertical offset on the fault.

Resistivity Profile 11

Line 11 (**Figure 9**) is located just north of Starlite Mesa and east of Highway 247. This modeled profile shows a thin layer of intermediate resistivity sediment at the surface, overlying a layer of high to intermediate resistivity to a depth of about 100 to 150 feet beneath the surface. Beneath this layer lies a thick unit of lower resistivity material that extends to over 400 feet. The data suggests about 30 feet of fine grained sediment over a layer of coarse to silty unsaturated sand that is about 50 to 100 feet thick and coarser grained on the east side of the line. Beneath the sand unit lies a finer grained unit, possibly silty sand with some clay, to a depth of over 400 feet. KJT estimated the depth to water to be 195 feet on the west half of the line and 230 feet on the east. These estimates indicate that the water table is coincident with the top of the low resistivity unit and suggest this unit consists of saturated fine silty sand with some clay.

A zone of higher resistivity material in the lower unit is present at the east end of the line. This feature is located at the predicted location of the Johnson Valley Fault (**Figure 12**). The anomaly occurs at the end of the line and no data is available to determine its width, apparent dip, or offset. It is possible that this feature represents a fault, though the signature is not a clear as on several other lines due to its position on the line.

Resistivity Profile 12

Line 12 (**Figure 9**) is located just north of Lone Tree Street and crosses George Street. This modeled profile shows a layer of high resistivity sediment at the surface, overlying a layer of intermediate to low resistivity at a depth of about 100 to 200 feet beneath the surface. The intermediate to low resistivity material extends to over 400 feet. The data suggests about 100 to 200 feet of coarse grained unsaturated sediments over a layer of silty sand and clay to a depth of over 400 feet.

A zone of low resistivity material in the lower unit is present at the west end of the line. This feature is located at the predicted location of the Homestead Valley Fault (**Figure 1** and **12**). The anomaly occurs at the end of the line and no data is available to determine its width, apparent dip, or offset. It is possible that this feature represents an abrupt change in stratigraphy that may be associated with a fault, though the signature is not a clear as on several other lines due to its position on the resistivity line. KJT estimated the depth to water to be 122 feet on the up thrown side of the fault (west) and 305 feet on the downthrown (east) side. These estimates indicate that the water table is coincident with the top of the intermediate resistivity unit on the west side and within the intermediate resistivity unit on the east side of the line.

Resistivity Profile 13

Line 13 (**Figure 10**) is located just north of Lone Tree Street immediately west of Line 12. This modeled profile shows a high resistivity unit at the surface, overlying a low resistivity unit at a depth of approximately 140 feet on the west end of the line and 120 feet on the east end. The underlying unit has a resistivity of about 30 to 120 Ohmm and extends to below 400 feet. This layer appears to be a continuation of a similar unit seen on the far west end of Line 12. The resistivity plot suggests a coarse grained unsaturated sand and gravel layer above a layer of fine silty sand that extends to over 400 feet. The depth to the water table in BDVWA Well 7 was reported at 149 feet in 2005. KJT estimated the depth to water to be 115 feet on the west half of the line and 130 feet on the east. This places the water table very close to the top of the low resistivity zone, suggesting that this layer may represent saturated material.

A notable zone of higher resistivity is present near stations 591 to 787. This feature is approximately 200 feet wide and dips steeply to the west. This feature is located near the predicted location of the Homestead Valley Fault (**Figure 12**), and appears to represent a fault. The anomaly shows a higher resistivity, but it is likely that the fault is actually a conductive feature due to clay-rich fault gouge and or fluid filled fractures. The higher resistivity response is assumed to be due to the paradox of anisotropy.

The width of the fault and associated zone of alteration is probably thinner than the resistivity anomaly. The dip of the fault is probably consistent with the trend of the resistivity anomaly, though the dip of the resistivity anomaly is probably an apparent dip because it is unlikely that the fault cuts the resistivity line in a perpendicular orientation. The low resistivity unit appears to be offset about 100 feet downward to the east, suggesting that there is vertical offset on the fault.

Resistivity Profile 14

Line 14 (**Figure 10**) is located directly in Pipes Wash about 1,200 feet southeast of Line 9. This modeled profile shows a high resistivity unit at the surface, overlying a low resistivity unit at a depth of between about 100 to 150 feet. The underlying unit has a resistivity of about 2 to 50 Ohmm and extends to below 400 feet. The resistivity plot suggests a coarse grained unsaturated sand and gravel layer over a layer of fine silty sand, with some clay on the western end, that extends to over 400 feet. HDWD Well 24 is the nearest well to Line 14 (approximately 4,000 feet northeast) for which recent water level data is available. The depth to water in HDWD Well 24 was reported at 278 feet in 2005.

A zone of higher resistivity material is present in the low resistivity unit between stations 591 to 984. This anomalous feature is approximately 400 feet wide and may consist of two separate vertical features. This feature is located near the predicted location of the Pipes Inferred Barrier (**Figure 12**), and appears to represent a fault. The anomaly shows a higher resistivity, but it is likely that the fault is actually a conductive feature due to clay-rich fault gouge and or fluid filled fractures. The higher resistivity response is assumed to be due to the paradox of anisotropy.

The width of the fault and associated zone of alteration is probably thinner than the resistivity anomaly. The low resistivity unit appears to be offset about 60 feet downward to the east, suggesting that there is vertical offset on the fault. If this layer represents a saturated zone, it could indicate higher water levels (about 60 feet) on the west side of the fault.

Resistivity Profile 15

Line 15 (**Figure 11**) is located directly in Pipes Wash about 2,000 feet west of Line 6. This modeled profile shows a high resistivity unit at the surface, overlying a low resistivity unit at a depth of approximately 150 to 180 feet. The underlying unit has a resistivity of about 5 to 70 Ohmm and extends to below 400 feet. The resistivity plot suggests a coarse grained unsaturated sand and gravel layer over a layer of fine silty sand and clay that extends to over 400 feet. The resistivity drops significantly at a depth of about 350 feet.

The depth to the water table in HDWD Well 20 was reported at 281 feet in 2002. Line 14 is approximately 130 feet lower in elevation than HDWD Well 20, suggesting the depth to water may be about 180 feet. KJT estimated the depth to water to be 155 feet on the west half of the line and 173 feet on the east. This estimate places the water table at the top of the low resistivity unit, suggesting that the unit consists of saturated material.

A notable zone of higher resistivity is present near stations 420 to 530. This feature is approximately 200 feet wide. No known faults are located near this anomaly. Based on the distinct signature, it is likely that this feature represents a previously unknown fault. The anomaly shows a higher resistivity, but it is likely that the fault is actually a conductive feature due to clay-rich fault gouge and or fluid filled fractures. The higher resistivity response is assumed to be due to the paradox of anisotropy.

The width of the fault and associated zone of alteration is probably thinner than the resistivity anomaly. The anomaly occurs near the end of the line and no data is available from the west side of the feature to determine its width, apparent dip, or offset.

TEM SURVEY RESULTS AND DISCUSSION

Description of TEM Method

The Time Domain Electromagnetic Induction (TEM) method uses a heavy gauge wire laid out as a square or rectangle to form a transmitter loop. A current of several amps is passed through the transmitter loop. The current is cut off with a steep ramp function creating a broad band EM pulse as the electric field of the transmitter loop collapses. The EM pulse propagates vertically into the subsurface and induces eddy currents in horizontal conductors. The intensity of the magnetic field created by the eddy currents is measured as a function of time by a receiver coil positioned in the center of the transmitter loop. The field data is then modeled to produce a horizontally layered resistivity model of the subsurface. Standard acquisition and modeling technology does not account for three-dimensional structures so significant errors can occur near abrupt lateral resistivity contrasts such as faults.

The depth of maximum sensitivity of TEM surveys is determined by the design of the survey equipment and the field conditions. The parameters of the survey were selected based on site conditions and the desired target depth. The layout of the soundings was optimized to measure the electrical resistivity of the unconsolidated material to depths of between approximately 500 to 1,000 feet. The sensitivity of the survey to shallow material was unavoidably sacrificed by the choice of instrument and layout of the transmitter loop. As a result, the shallow portions of the TEM models may not correlate exactly to the resistivity models, which focus on the upper 300 to 400 feet and measure later variations in resistivity.

Based on the results of the TEM surveys completed for the MWA in 2005 at the Oro Grande Wash field site, in conjunction with forward modeling completed prior to the 2005 field work, an adequate depth of penetration could be achieved by the TEM surveys using a 50-meter by 50-meter transmitter loop. Therefore, a 50-meter by 50-meter transmitter loop was used as the primary transmitter loop size for the surveys. As with the 2005 surveys, at a few locations the loop size was increased to 100 meters by 100 meters to see if data quality was improved and/or consistent with the 50-meter by 50-meter loop. For most sites, the smaller loops produced essentially equivalent data quality.

In addition to the 50-meter transmitter loops, smaller transmitter loops were utilized at several survey locations in the Ames Valley area due to limited open space and where cultural interference was a concern due to the presence of structures, buried utilities, overhead power lines, and other extraneous "noise" sources. At these sites, a multi-turn loop consisting of a 15-meter by 15-meter square loop with three turns of wire was used to collect the field data. A 15-meter three-turn transmitter loop is roughly equivalent to a 45-meter by 45-meter single turn loop, though the magnetic moment of the transmitter is not as strong. The advantage of the 15-meter multi turn loop is it's smaller "foot print" while collecting the data, This provides a more focused EM pulse into the subsurface than a larger transmitter loop and is subject to less interference from adjacent objects. Multiple turn loops obtain similar data to the equivalent larger single turn loops, although with a less effective depth of penetration due to the weaker magnetic moment.

Description of TEM Field Procedures

A geophysical survey consisting of 35 TEM soundings was conducted between October 17 and October 23, 2006. Thirty-two of the soundings were completed in the Ames Valley area and three of the soundings were completed in Johnson Valley. The Ames and Johnson Valley TEM locations are shown on **Figure 2** and **Figure 3**, respectively.

The TEM data were collected using a Geonics TEM 57 transmitter and a PROTEM 58D receiver. A Coleman Powermate Plus 1,850 Watt portable generator was utilized to provide power to the transmitter. Survey sounding locations were chosen on the basis of the availability of adequate open areas as free of cultural interference as could be managed. Consideration was also given to the sites position relative to known fault traces, the inferred Pipes Barrier, existing deep monitoring wells, and high resolution resistivity profiles. Preliminary survey locations were identified by MWA in conjunction with KJT prior to beginning the field work. Several of the sounding locations were moved as field conditions dictated so that as clear a signal as possible could be attained.

The TEM sounding data was modeled using TEMIX, a one-dimensional modeling software distributed by Interpex, Ltd. The modeled data provides an estimate of the geo-electrical section beneath a sounding location. The resistivity values and modeled unit thickness are bulk average values that are the result of recording measurements over a large surface area and depth section. The actual geology at a particular sounding location will often contain many thin interlayered units of variable composition and permeability, occasionally with gradational contacts. The modeled geo-electrical layers often represent a bulk average resistivity value of several layers that are too thin to image separately.

TEM SURVEY RESULTS AND DISCUSSION

The location of the survey sites, including the general locations of the 35 soundings conducted as part of this study, are shown on **Figure 2** and **Figure 3**. While the majority of the soundings produced useable data, several soundings were impacted by either noise from cultural sources, such as overhead power lines and buried utilities, or from buried structural features such as the Johnson Valley Fault System or the Inferred Pipes Barrier, which made the data more difficult to interpret. In most soundings, the full 20 gates of the high frequency data set were useable for the interpretation process. In the soundings that were effected by cultural interference or structural features, between 25 to 75 percent of the data was typically unusable due to a low signal to noise ratio. Soundings 5, 6, 7, 10, 16, and 19 suffered from severe interference from cultural features and the resulting modeled sections are of questionable validity. Soundings 8, 14, 24, 29, and 31 suffered minor to moderate interference but produced modeled sections that appear to be more valid. The other soundings produced good to excellent data quality and produced models that closely match the field data. The modeled TEM data including a summary table for all soundings are included in **Appendix B**.

Ames Valley Area

The modeled TEM data obtained from the soundings completed in the Ames Valley area indicates the presence of a complex structural environment in the subsurface basin and valley fill. Based on the interpretation of the modeled TEM resistivity data, it is apparent that the lateral and vertical stratagaphic sequence of the basin varies widely from sounding location to sounding location. The thickness of the interpreted units varies significantly across the survey area. For the most part, the units do not appear to be uniform or continuous across the survey area.

Beneath the majority of soundings, the upper material appears to consist of intermediate resistivity material characteristic of sand and gravel with varying amounts of silt. The thickness of the upper sand and gravel unit varies considerably across the study area, with modeled thicknesses ranging from less than 100 feet to greater than 400 feet. Most soundings detected a low resistivity unit beneath the upper layer. This layer is believed to consist of varying mixtures of silty sand and clay units that varies from less than 50 feet to greater than 600 feet thick. The deeper portion of this layer is below the regional water table and some of the lower resistivity of this unit can be attributed to the fact that it is saturated, particularly if the formation water is locally brackish or if evaporitic minerals are present in the sediment. Several soundings detected a second low resistivity unit beneath a layer of intermediate resistivity. The low resistivity unit appear to be thicker near the middle of the basin. The unit thins near the sides of the basin and in several locations appear to pinch out.

High to very high resistivity material characteristic of granitic bedrock was observed near the basin edges at several sounding locations. Additionally, high to very high resistivity material was modeled in several of the soundings toward the middle of the basin. This material is inferred to be the result of three dimensional effects from structural features, such as faulting and abrupt lateral changes in resistivity beneath a sounding location. Standard acquisition and modeling methods cannot resolve three dimensional structures and erroneous one dimensional models are produced. This phenomenon can actually add to the interpretation of faults and dipping planar features as long as this response is recognized as an indication of structure and not interpreted simplistically as a layered system.

Five geo-electrical cross sections were constructed from the modeled TEM sounding data to assist in the interpretation of the subsurface geology at the site. The locations of the geo-electrical cross sections are shown on **Figure 13**. The cross sections are oriented in a west to east direction in an attempt to cross perpendicular to the generally north-south trending structural features. Cross sections A-A', B-B', C-C', and D-D' cross the Johnson Valley Fault zone to the west and the inferred Pipes Barrier to the east. Cross section D-D' is constructed parallel to the axis of the Whalen's Wash. Cross section E-E' transects Pipes Wash approximately one mile northeast of cross section D-D' and appears to intersect the Homestead Valley Fault, which has been mapped to the north. A discussion of the TEM geo-electrical data and interpretation along each of the cross sections follows.

Cross Section A-A'

Geo-electrical cross section A-A' (**Figure 14**) is the southern most transect across the valley. Review of the resistivity data utilized to construct A-A' indicates the presence of an upper zone of intermediate resistivity material characteristic of sand and gravel with varying amounts of silt, across the entire length of the cross section. The interpreted thickness of the sandy material ranges from about 100 feet in the higher elevations on the west side of the section, to approximately 400 feet at TEM soundings 18 and 9.

Beneath the intermediate resistivity material there appears to be a continuous layer of low resistivity material. The thickness of the layer varies from less than 100 feet at TEM 19 to the west, to approximately 200 feet thick at TEM 1 and 2 on the east end of the line. The resistivity of this layer increases from west to east. This layer is interpreted to consist of clay on the western end of the line and fine silty sand to sandy clay on the east half of the line. A unit of intermediate resistivity material is present within the lower resistivity unit at soundings TEM 1 and 2 on the west end of the line. This unit is not present at TEM 3.

The interpretation of the TEM data is reasonably consistent with geologic logs on the west half of the line. TEM19 was impacted by cultural interference and the additional noise limited the resolution of the modeling process. Soundings TEM 1, 2, and 3 produced estimated depths to bedrock that are significantly greater than the well control in the area. These soundings were conducted adjacent to the faults of the inferred Pipes Barrier. The discrepancy between the TEM modeling and the well control in this area may be due to three-dimensional effects from the inferred Pipes Barrier that interfere with the modeling process, which assumes laterally continuous layers.

Cross Section B-B'

Geo-electrical cross section B-B' (**Figure 15**) runs parallel to cross section A-A' approximately one mile to the north. Review of the modeled TEM resistivity data indicates a complex structural and depositional environment. There appear to be no laterally continuous units of similar resistivity material across the transect. Large differences in the resistivity with depth occur between adjacent TEM soundings. The complex pattern may be indicative of the complex depositional pattern typical of an alluvial fan.

The predominantly north-south trending Johnson Valley Fault and associated fault splays appear to bisect the cross section between TEM soundings 16 and 15, 15 and 17, and 17 and 10. The inferred Pipes Barrier is expressed in the electrical data at TEM 35 in the form of a deep zone of very high resistivity material and a shallower zone of low to intermediate resistivity material between approximately 75 and 300 feet deep.

Consistent with west end of cross section A-A', a very high resistivity unit thought to represent granitic bedrock was detected at a depth of approximately 350 feet at TEM 14. TEM 16 appears to contain predominantly intermediate resistivity material consistent with sandy sediment. The contact between the high resistivity unit at TEM14 and the intermediate resistivity material at TEM 16 is relatively steep, which may suggest a fault. The steep slope of this contact is consistent with the data from resistivity lines 1 and 2.

Cross sections C-C'

Geo-electrical cross section C-C' (**Figure 16**) is located parallel to cross section B-B' approximately 1/2 mile to the north. The profile shows a similar complexity to section B-B'. An upper zone of intermediate resistivity material characteristic of sand and gravel is present across the entire length of the cross section with the exception of TEM 23 on the east end of the transect. The interpreted thickness of the sandy material ranges from a little over 100 feet in the eastern portion of the section at TEM 33 and 34, and generally thickens to the west to between approximately 300 and 400 feet. This unit appears to be over 1,000 feet thick at TEM 24, but this interpretation is questionable due to poor data quality at this sounding. Resistivity Line 1 indicates that the upper 300 to 400 feet is likely to consist of high to intermediate resistivity sediments. It is likely that high resistivity granitic bedrock is present within several hundred feet of ground surface on the west end of the cross section.

Beneath the upper layer lies an apparently continuous layer of low resistivity material across the transect (not including TEM 24). The thickness of the layer varies from approximately 50 feet at TEM 31, to greater than 600 feet thick at TEM 29 and 30. Some of the variations in the thickness of this unit may be due to three dimensional effects on the data from the several faults that cut the profile. Based on the observed resistivity values, this layer is interpreted to consist of fine silty sand to clay. A deeper unit of intermediate to higher intermediate resistivity material is evident between TEM soundings 31 and 34. Based on the modeled resistivity values, this unit is interpreted to primarily consist of sand and gravel.

The inferred Pipes Barrier is expressed in the geo-electrical data between TEM soundings 31, 32, and 33. The modeled section for sounding TEM 32 indicated a high resistivity unit to within about 350 feet of the surface. This result is anomalous to the surrounding soundings and well control. We believe that this unit is an artifact of the modeling process caused by three-dimensional effects from the faulting of the inferred Pipes Barrier adjacent to this sounding. Resistivity line R9 found intermediate resistivity material to a depth of over 400 feet adjacent to TEM 32.

On the east end of the cross section, TEM 23 exhibits very high resistivity material at a depth of approximately 240 feet. The TEM data was unable to detect a deeper geo-electric unit beneath the very high resistivity unit. The high resistivity unit is likely coarse sand and gravel, the thickness of which is unknown. Available well logs in the area indicate bedrock is approximately 500 feet deep near this sounding.

Cross Section D-D'

Geo-electrical cross section D-D' (**Figure 17**) is located in Whalen's Wash approximately 1 mile north of cross section C-C'. An upper zone of intermediate resistivity material characteristic of sand and gravel is present across the entire transect. The interpreted thickness of the sandy material ranges from approximately 150 feet in the eastern portion of the section at TEM 21 and 22, and thickens to the west to about 230 feet at TEM 20. Resistivity Lines 3 and 4 also suggest that the layer of intermediate resistivity material is thicker on the western end of the line.

An apparently continuous layer of low resistivity material lies beneath the intermediate resistivity material at all three sounding soundings. The thickness of the low resistivity layer varies from approximately 70 feet at TEM 20 to the west, to approximately 275 feet thick at TEM 22. Based on the observed resistivity values, this layer is interpreted to consist of fine silty sand on the west end of the line to clay on the east end. Resistivity Lines 3 and 4 also suggest that this layer has higher resistivity more indicative of silty sand on the western end of the line and lower resistivity more indicative of a higher clay content on the eastern end of the line.

Intermediate resistivity material is present beneath the low resistivity unit at all three soundings. At TEM 20 and TEM 22 the resistivity of this unit is indicative of sand and gravel. The resistivity of this layer is lower at TEM 21. This could indicate finer grained material or three-dimensional effects from the faulting on either side of the sounding. A low resistivity unit, consistent with silty sand, was detected at a depth of greater than 700 feet at TEM 20.

The inferred locations of the Johnson Fault and Pipes Barrier are shown on **Figure 17**. The faults appear to offset the layers downward to the east.

Cross Section E-E'

Geo-electrical cross section E-E' (**Figure 18**) is located approximately 2 miles northeast of cross section D-D'. The two soundings on the east side of the line (TEM26 and TEM27) detected a thick sequence of lower to intermediate resistivity material from the surface to over 1,000 feet. Based on the modeled resistivity values, this layer is interpreted to consist of fine sand with varying degrees of silt. Sounding TEM25 detected a low resistivity layer at a depth of about 340 feet and a high resistivity layer at about 840 feet. These layers are interpreted to consist of silty sand and clay over granitic bedrock. A low resistivity layer may be present at depth at TEM27. The presence of this layer is questionable due to higher noise levels in the deeper portion of this sounding. Resistivity Lines 12 and 13 also indicate a thicker sequence of intermediate grained material on the east portion of the line and a thick layer of low resistivity material closer to the surface on the west part of the line.

The transition between the geo-electric layers at TEM 25 and TEM 26 is likely an expression of the Homestead Valley Fault zone. The inferred location of the Homestead Valley Fault zone is shown on **Figure 18**. Resistivity Lines 12 and 13 also detected indications of the fault zone.

Johnson Valley

One geo-electrical cross section was constructed using the modeled electrical resistivity data obtained from the three TEM soundings completed in Johnson Valley. The location of the cross section is shown on **(Figure 19)**. Geo-electrical Cross Section F-F' is illustrated in **Figure 20**. Review of the geo-electric data indicates that the stratum consists of three types of material. The upper layer consists of intermediate to higher-intermediate resistivity material consistent with sand and gravel at TEM soundings 12 and 13 and grades to lower-intermediate resistivity material (possibly siltier sand) at TEM 11 to the south. The difference in resistivity of this layer are generally small, suggesting that the differences in grain size may be minor. The interpreted thickness of the upper unit ranges from approximately 200 feet at TEM 13 to the north, to greater than 400 feet at TEM 11 to the south.

The middle layer consists of low resistivity material consistent with silty sand and clay that ranges in thickness from approximately 150 feet at TEM soundings 12 and 13 to 200 feet at TEM 11. The lowermost unit consists of high resistivity material that is characteristic of granitic bedrock. The interpreted depth to the lower unit ranges from approximately 725 feet at TEM 13 to 1,100 feet at TEM 11.

CONCLUSIONS

Review of the modeled geophysical data collected as part of this study indicates that the high resolution multimode electrical resistivity and time domain electromagnetic induction (TEM) geophysical survey methods provided an efficient means to collect high quality data of the subsurface material in the study area. The resistivity data appeared to be the most useful for mapping the composition of the upper 300 to 400 feet of the basin fill material and mapped the position and structure of the faults with the greatest detail. The TEM data was more useful at mapping the composition of the deeper basin fill deposits. Based on our interpretation of the geophysical data, the following conclusions can be drawn.

- The modeled TEM and resistivity data indicate the presence of a complex structural and dispositional basin in the study area.
- Both the resistivity and TEM data appear to be an effective tool for identifying fault locations in the subsurface.
- The resistivity survey was able to map the Johnson Valley Fault, the Homestead Valley Fault and some previously unknown faults.
- The resistivity data indicates that the Inferred Pipes Barrier is a fault system with several splays in the general location assumed prior to this survey.
- The resistivity data indicates that the shallow portion of the basin fill is generally coarse grained, but this unit is limited to about 100 to 200 feet thick in most of the survey area.
- The resistivity data was able to detect the water table as a decrease in resistivity in coarse grained units at several soundings.
- The resistivity and TEM data indicate that a finer grained unit is present beneath the upper coarse grained unit over most of the survey area. This unit varies in thickness and grain size. Some locations may have better potential for recharging the deeper portions of the basin than others.
- The TEM data indicates that coarse to intermediate grained units are present in the deeper basin fill deposits over portions of the survey area. These units are believed to form the aquifers for the public supply wells in the area.

- Based on the three TEM soundings completed in Johnson Valley, it appears that low resistivity material is continuous across the site and is overlain by predominantly intermediate to higher-intermediate resistivity sand and gravel. The low resistivity layer may represent silty sand with varying amounts of clay.

The interpretation provide in this report is based on remote sensing and is subject to multiple interpretations. The grain size of the subsurface material was based on typical ranges for earth materials but changes in saturation, formation fluid conductivity, and mineralogy can cause local deviation from typical ranges. MWA should confirm our interpretation with direct field investigations, such as borings or test pits. The results of these borings could be used to improve the correlation of resistivity to grain size for the area. Of particular interest would be several monitoring wells drilled on both sides of the Inferred Pipes Barrier and some test pits across the interpreted location of the associated faults interpreted by the resistivity data.

Table 1

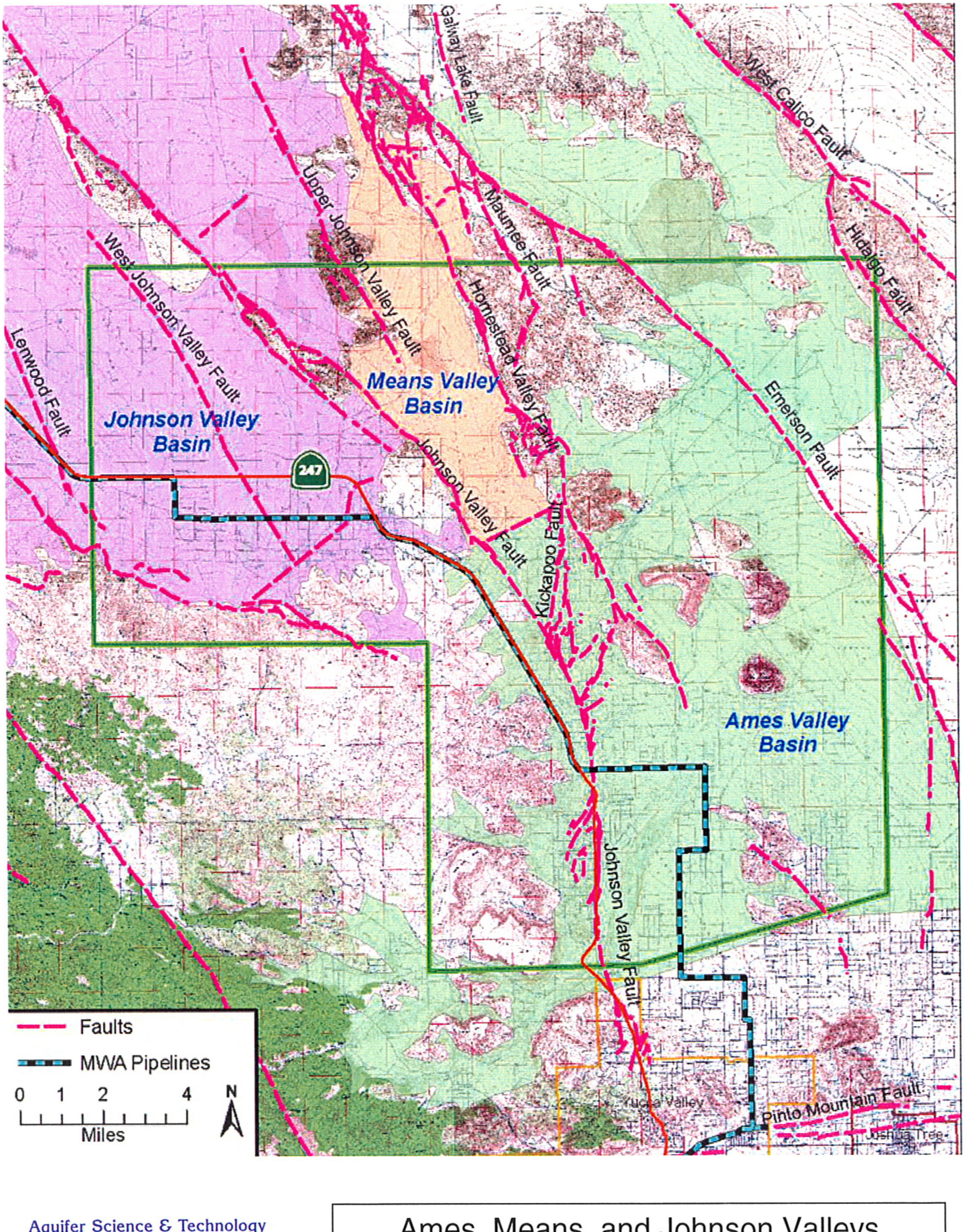
Typical Resistivity Values for Geologic Materials

Material	Approximate Resistivity Range (Ohmm)
Unsaturated sand and gravel	300 - 1000
Saturated sand and gravel (freshwater)	100 - 300
Silty sand (saturated)	30 - 100
Clay rich materials (saturated)	<30
Porous material saturated with brackish to saline water	<1 - 10
Granitic bedrock	400 - 1000

Table 2

Typical Lithology for Color Scale Used on Interpreted Resistivity Line Plots (Assumes Freshwater or Unsaturated Conditions)

Modeled Resistivity Color Scale	Resistivity Range (Ohmm)	Typical Lithologoy
Dark Blue	<30	Clay
Light Blue	30 - 100	Fine silty sand with some clay (saturated)
Green	100 - 150	Fine sand (saturated)
Yellow and Orange	150 - 300	Sand and gravel (saturated)
Red	>300	Coarse sand and gravel (unsaturated) or granitic bedrock



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Ames, Means, and Johnson Valleys
General Study Area
Figure 1

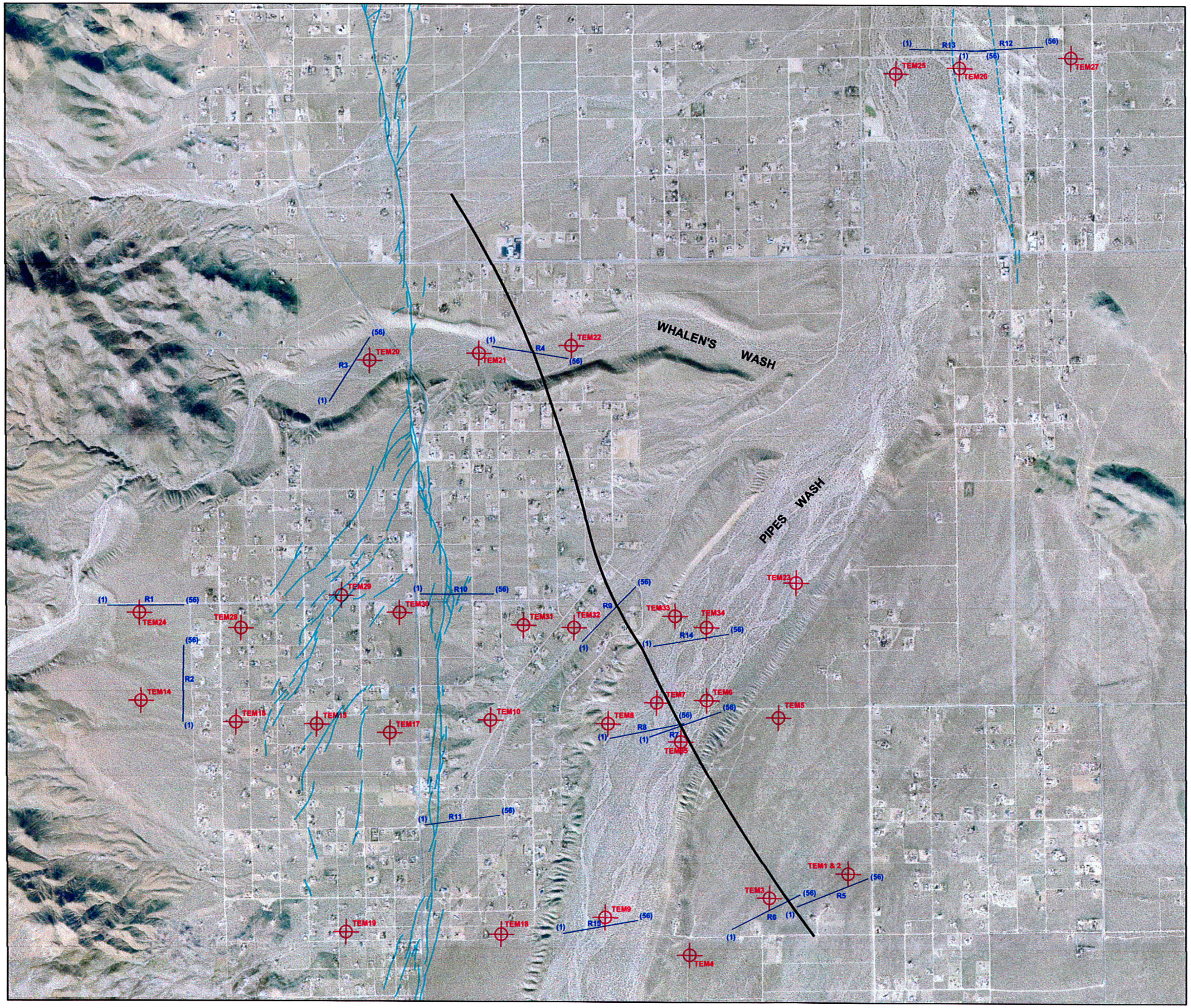

FIGURE 2

GEOPHYSICAL SURVEY LOCATIONS

PIPES WASH AREA

AMES VALLEY, CALIFORNIA

LEGEND

(1) R1 (56) RESISTIVITY LINE (ELECTRODE NO.)

TEM 1 TIME DOMAIN ELECTRO MAGNETIC INDUCTION (TEM) SOUNDING

FAULT TRACES

PREDICTED TREND OF THE INFERRED PIPES BARRIER

N
W E
S

0 1200 2400 4800
SCALE IN FEET

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XREFS:

RM811LB

FIGURE 3

TEM SURVEY LOCATIONS

JOHNSON VALLEY, CALIFORNIA

LEGEND

TEM 12 TEM SOUNDING

N
W E
S

0 750 1500 3000

SCALE IN FEET

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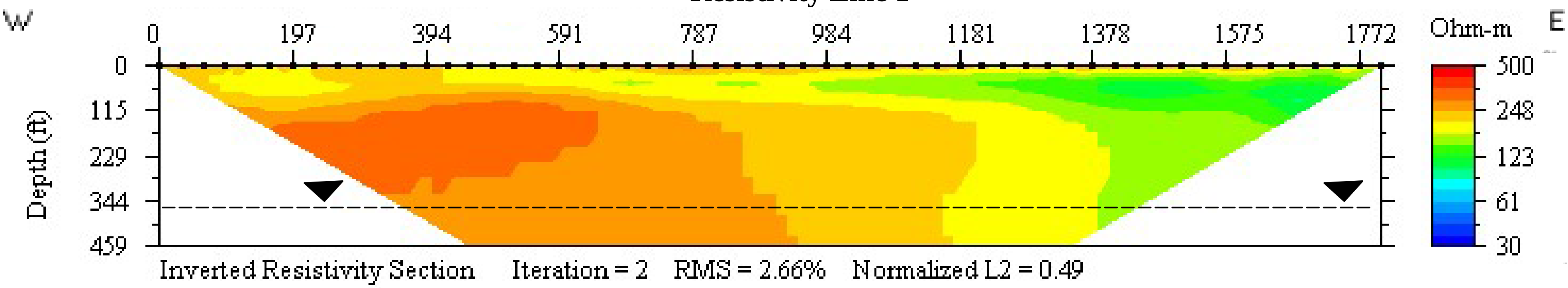
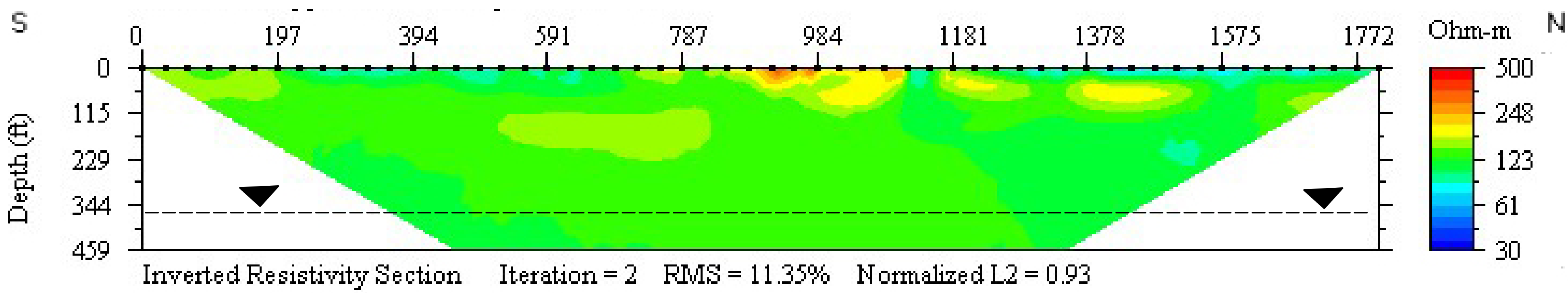
Figure 4

Resistivity Line 1



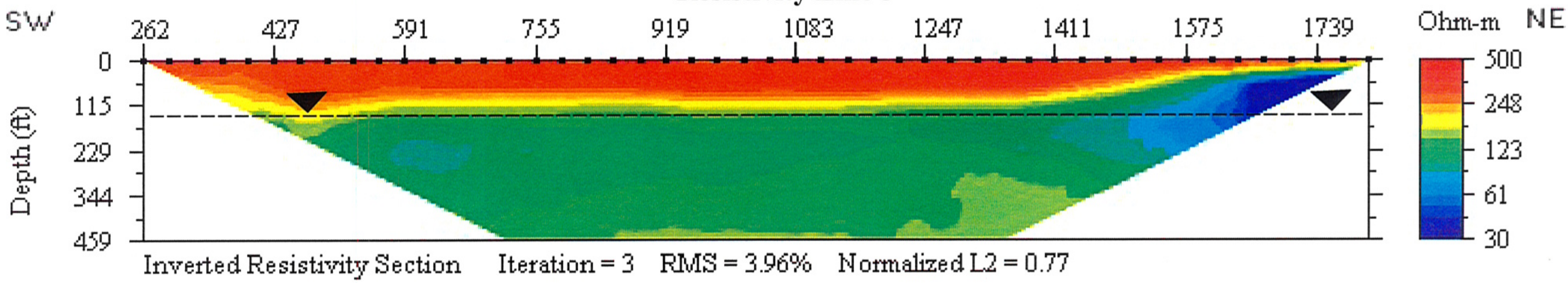
Resistivity Line 2



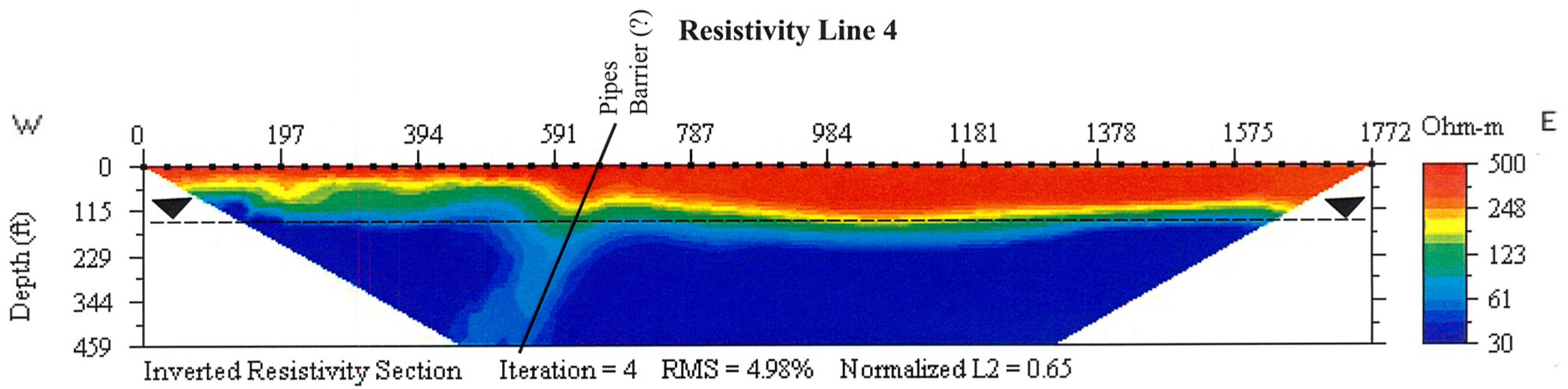
Approximate depth to water per KJT (ft bgs)

Figure 5

Resistivity Line 3



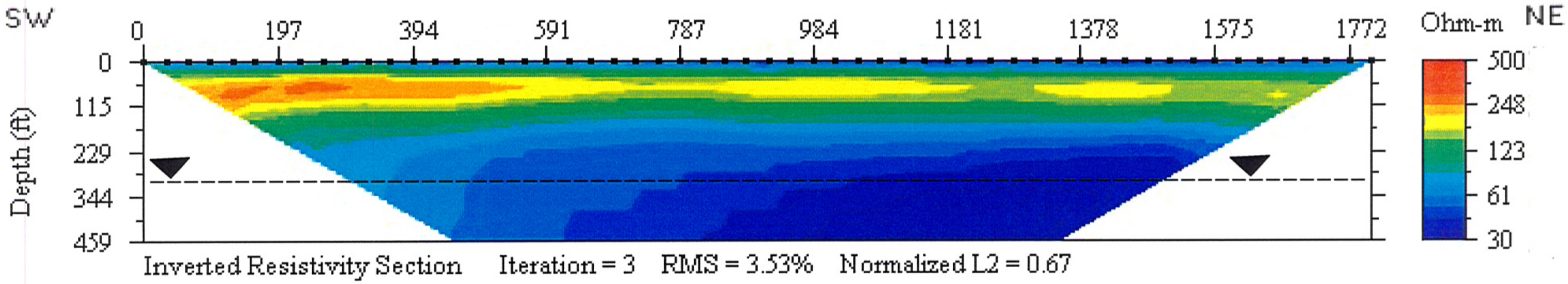
Resistivity Line 4



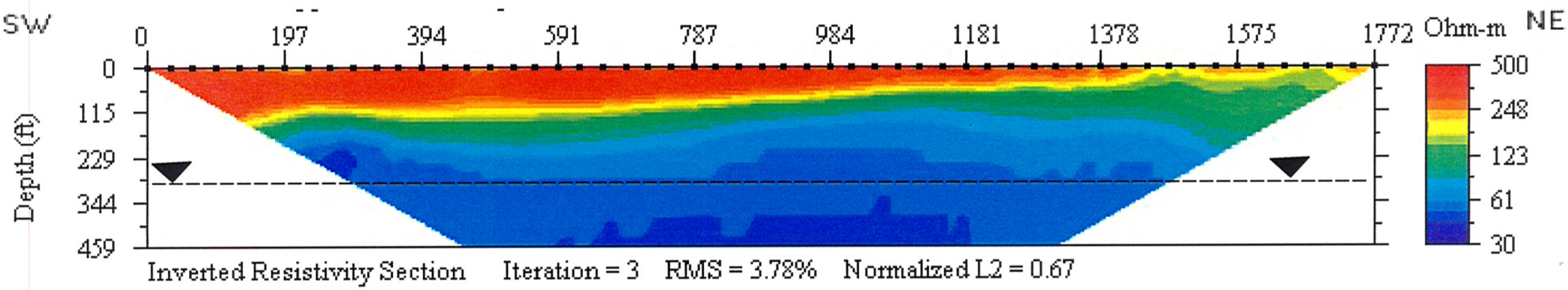
Approximate depth to water per KJT (ft bgs)

Figure 6

Resistivity Line 5

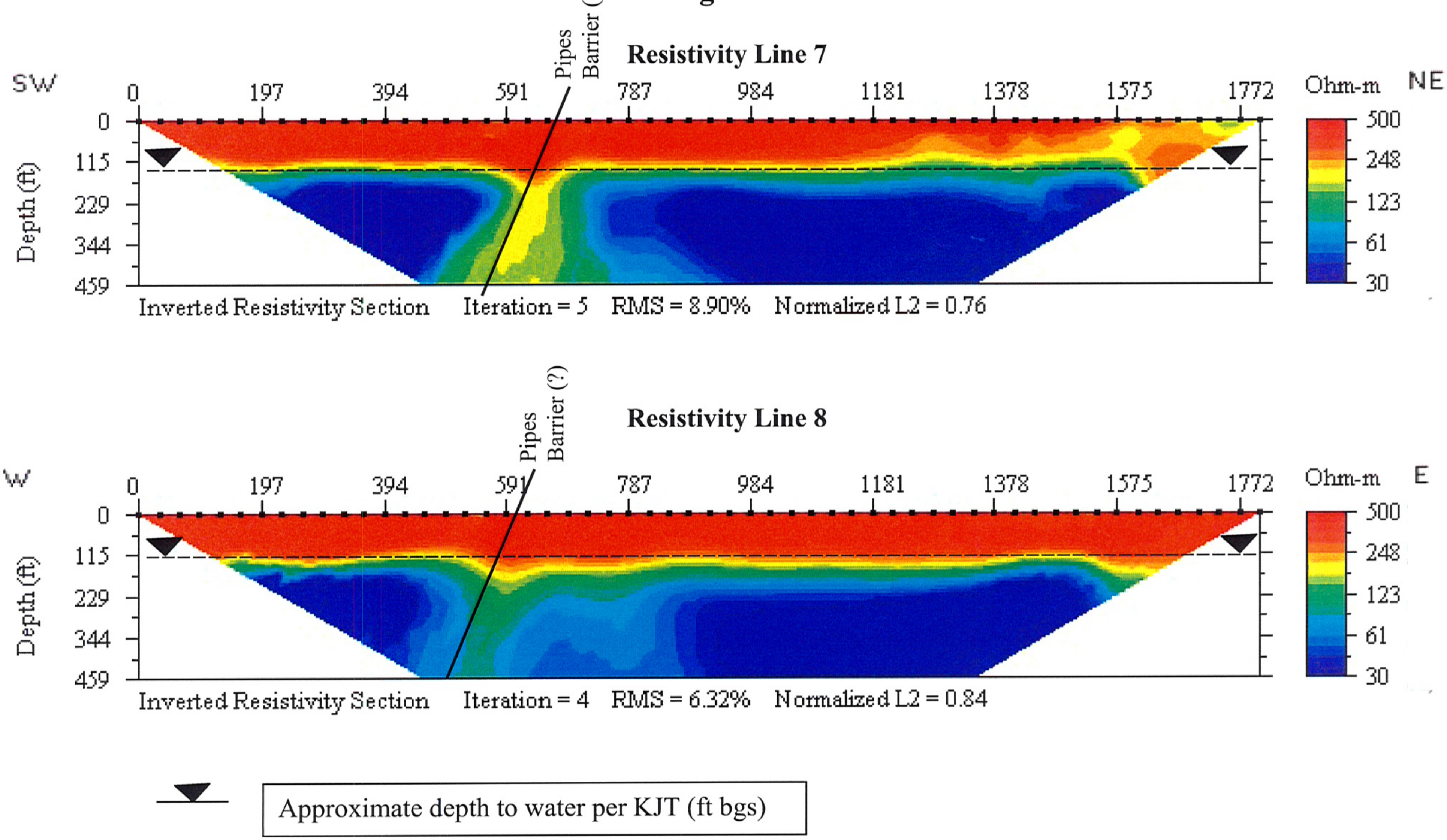


Resistivity Line 6



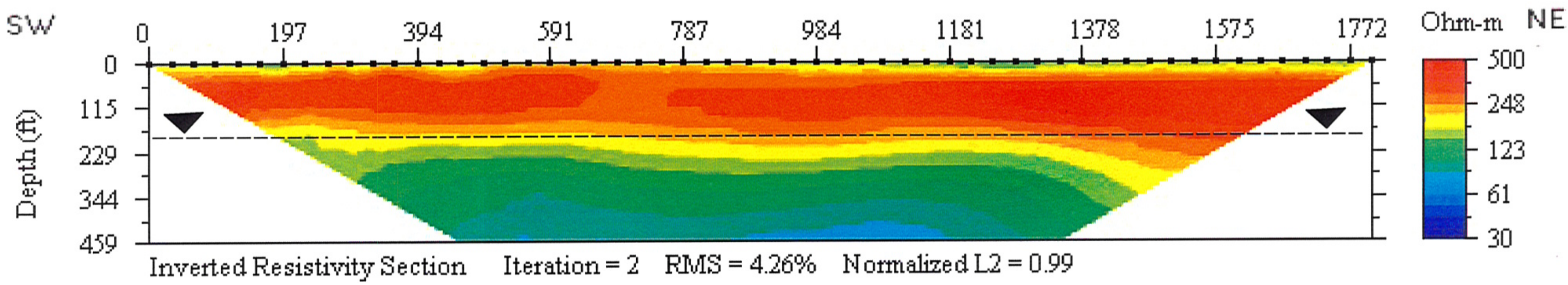
Approximate depth to water per KJT (ft bgs)

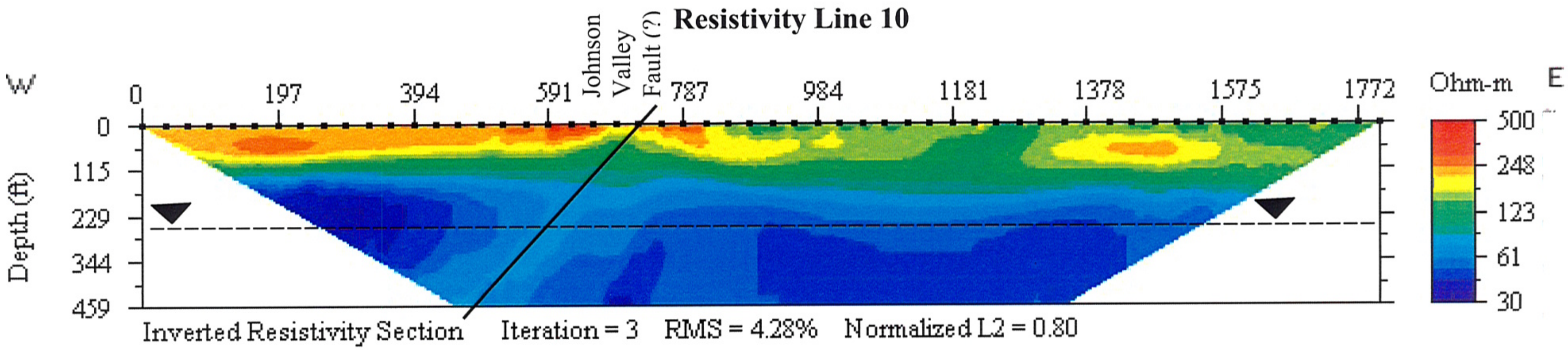
Figure 7



Resistivity Line 7
SW
NE
Pipes Barrier (?)
0
197
394
591
787
984
1181
1378
1575
1772
Depth (ft)
0
115
229
344
459
Ohm-m
500
248
123
61
30
Inverted Resistivity Section
Iteration = 5
RMS = 8.90%
Normalized L2 = 0.76
Resistivity Line 8
W
E
Pipes Barrier (?)
0
197
394
591
787
984
1181
1378
1575
1772
Depth (ft)
0
115
229
344
459
Ohm-m
500
248
123
61
30
Inverted Resistivity Section
Iteration = 4
RMS = 6.32%
Normalized L2 = 0.84
Approximate depth to water per KJT (ft bgs)

Figure 8

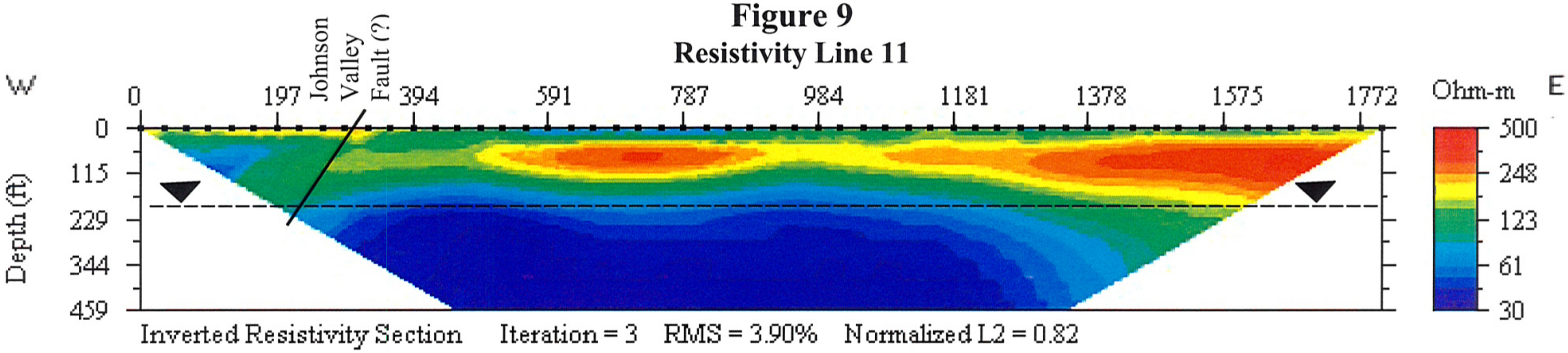




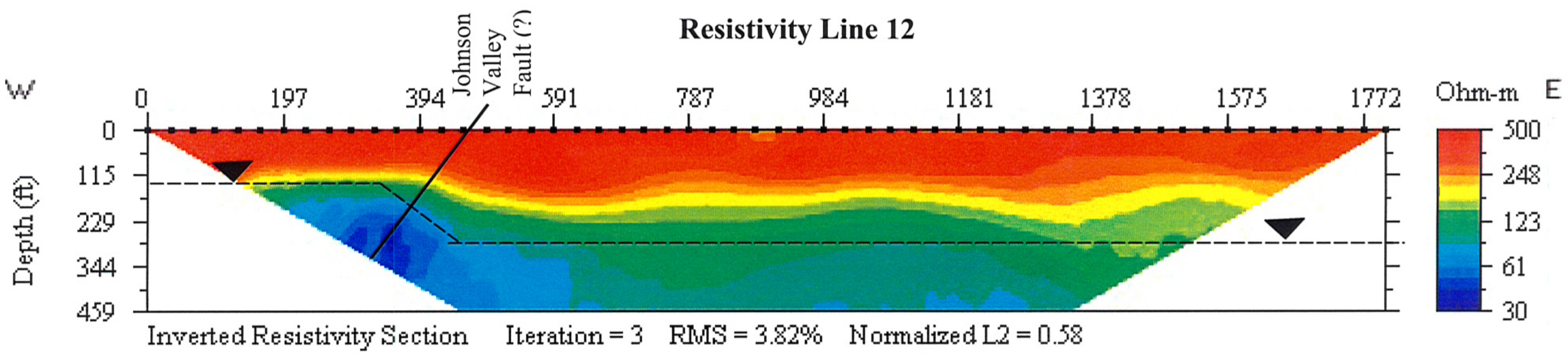
Approximate depth to water per KJT (ft bgs)

Figure 9

Resistivity Line 11



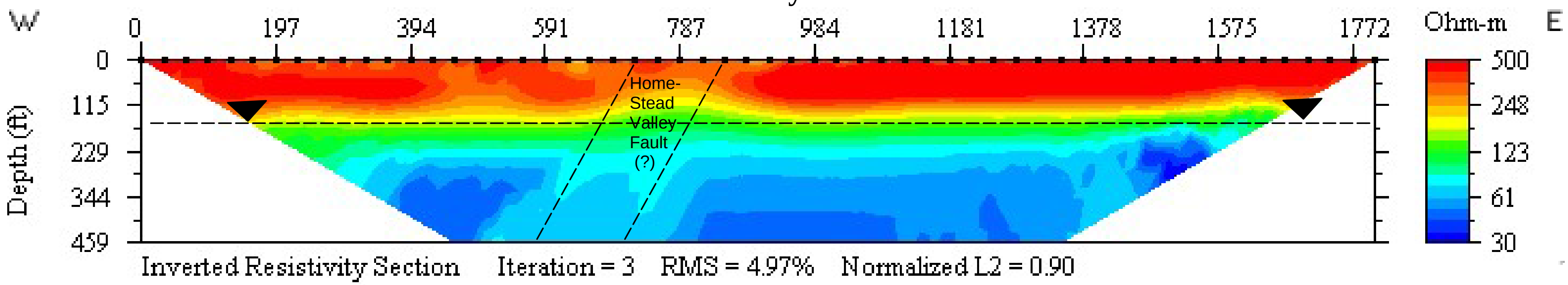
Resistivity Line 12



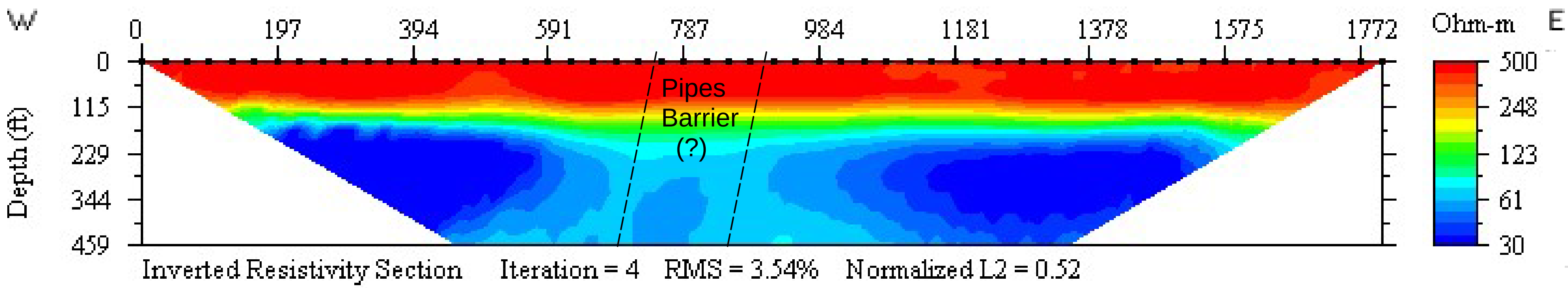
Approximate depth to water per KJT (ft bgs)

Figure 10

Resistivity Line 13

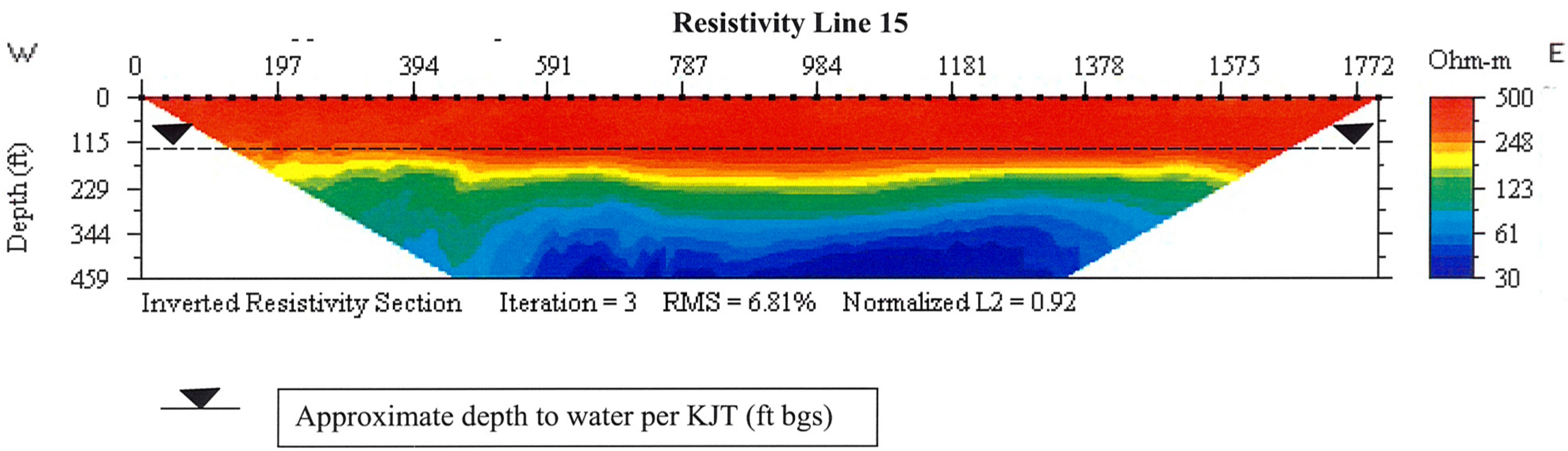


Resistivity Line 14



Approximate depth to water per KJT (ft bgs)

Figure 11



Resistivity Line 15
W
E
0
197
394
591
787
984
1181
1378
1575
1772
Depth (ft)
0
115
229
344
459
Ohm-m
500
248
123
61
30
Inverted Resistivity Section
Iteration = 3
RMS = 6.81%
Normalized L2 = 0.92
Approximate depth to water per KJT (ft bgs)

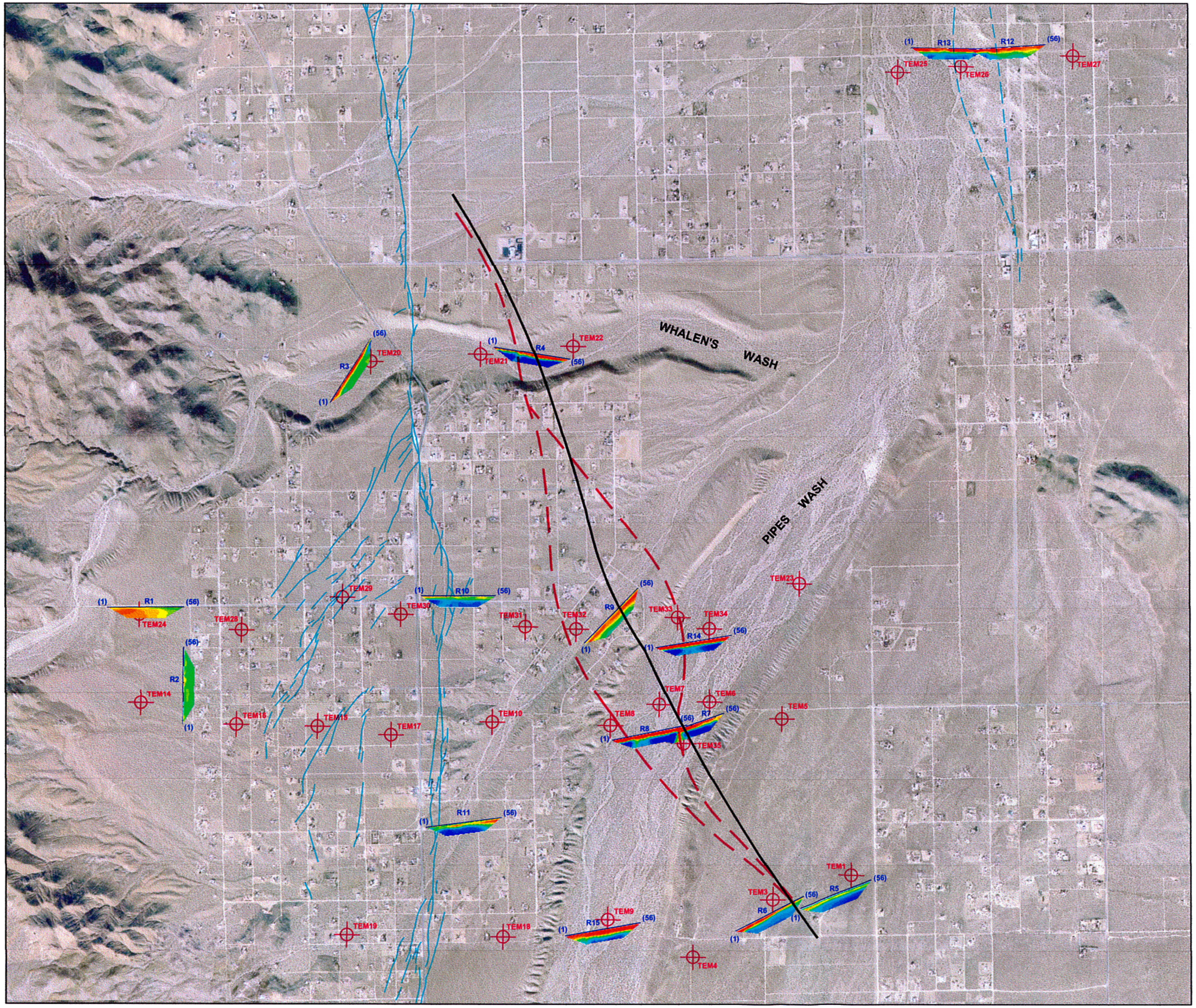


FIGURE 12

GEOPHYSICAL SURVEY LOCATIONS WITH MODELED RESISTIVITY PROFILES

PIPES WASH AREA

HOMESTEAD VALLEY, CALIFORNIA

LEGEND

(1) R1 (56) RESISTIVITY LINE (ELECTRODE NO.)

TEM 1 TEM SOUNDING

FAULT TRACES

PREDICTED TREND OF THE INFERRED PIPES BARRIER

PROJECTED TREND OF THE INFERRED PIPES BARRIER FROM GEOPHYSICAL DATA

N
W E
S

0 1200 2400 4800

SCALE IN FEET

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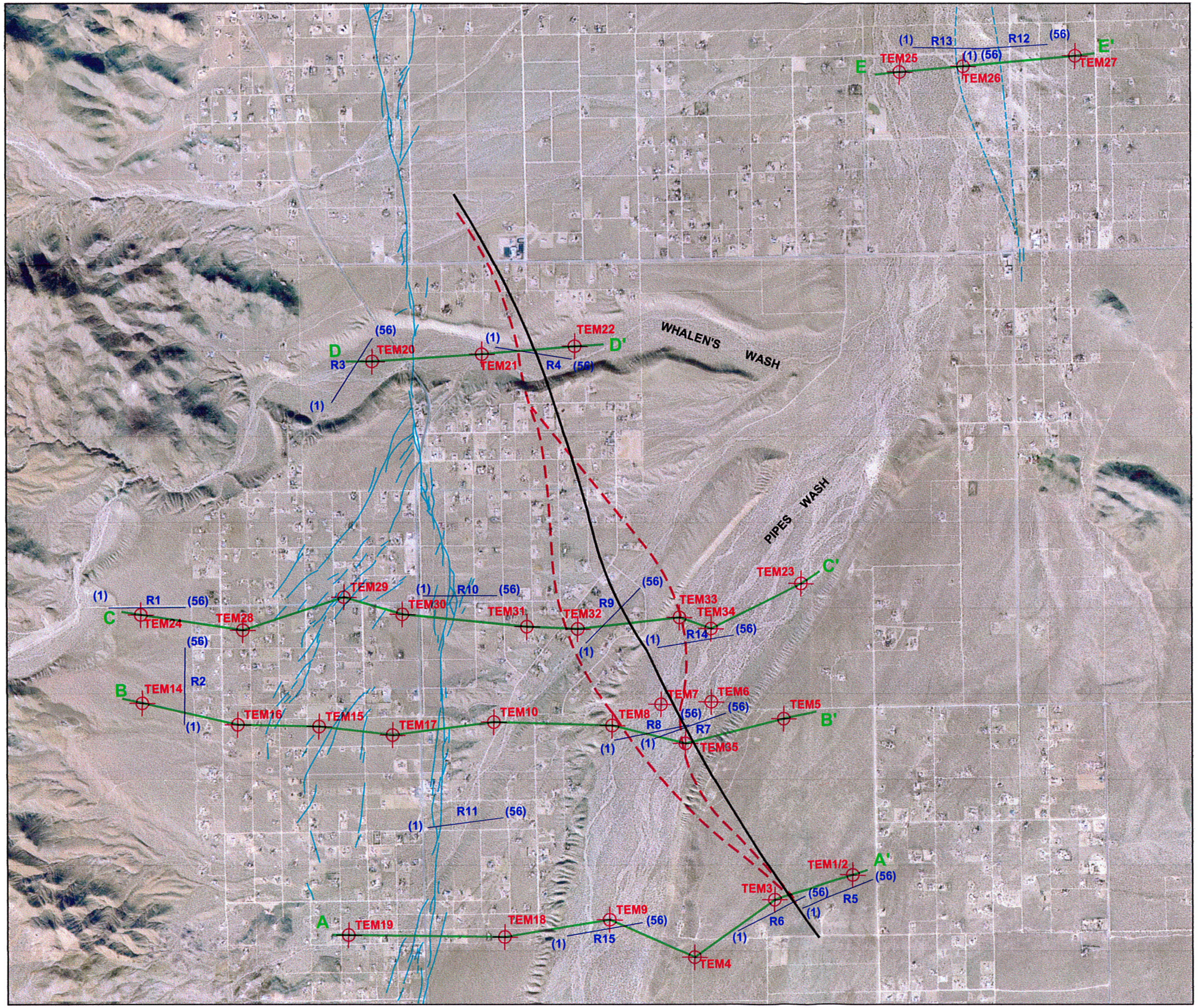
FIGURE 13

TEM GEO-ELECTRICAL CROSS SECTION LOCATIONS

PIPES WASH AREA

HOMESTEAD VALLEY, CALIFORNIA



LEGEND

(1) R1 (56) RESISTIVITY LINE (ELECTRODE NO.)

TEM 1 TEM SOUNDING

A A' CROSS SECTION

FAULT TRACES

PREDICTED TREND OF THE INFERRED PIPES BARRIER

PROJECTED TREND OF THE INFERRED PIPES BARRIER FROM GEOPHYSICAL DATA

N
W E
S

0 1200 2400 4800
SCALE IN FEET

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Jan 03, 2007 1:34pm
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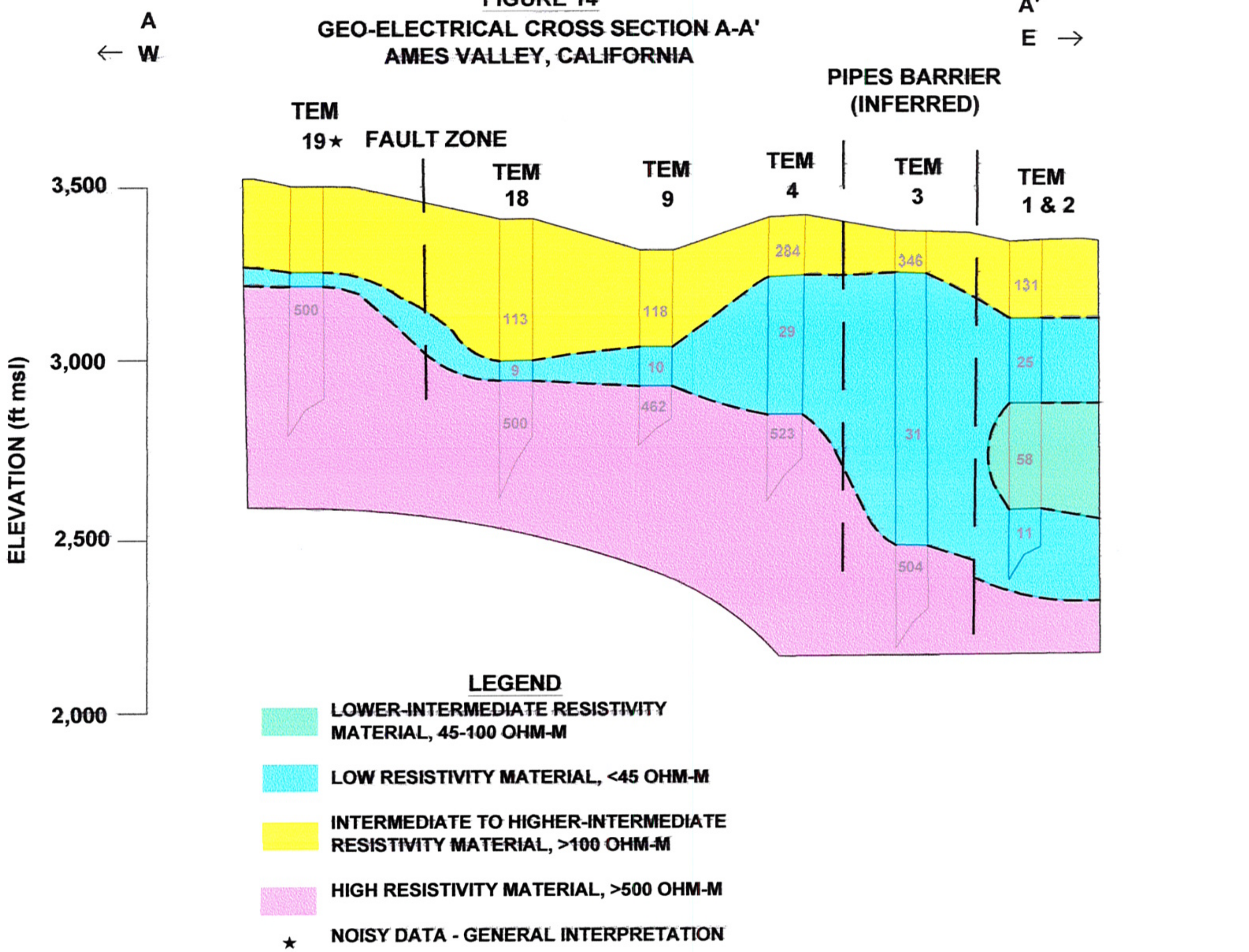
XREFS:

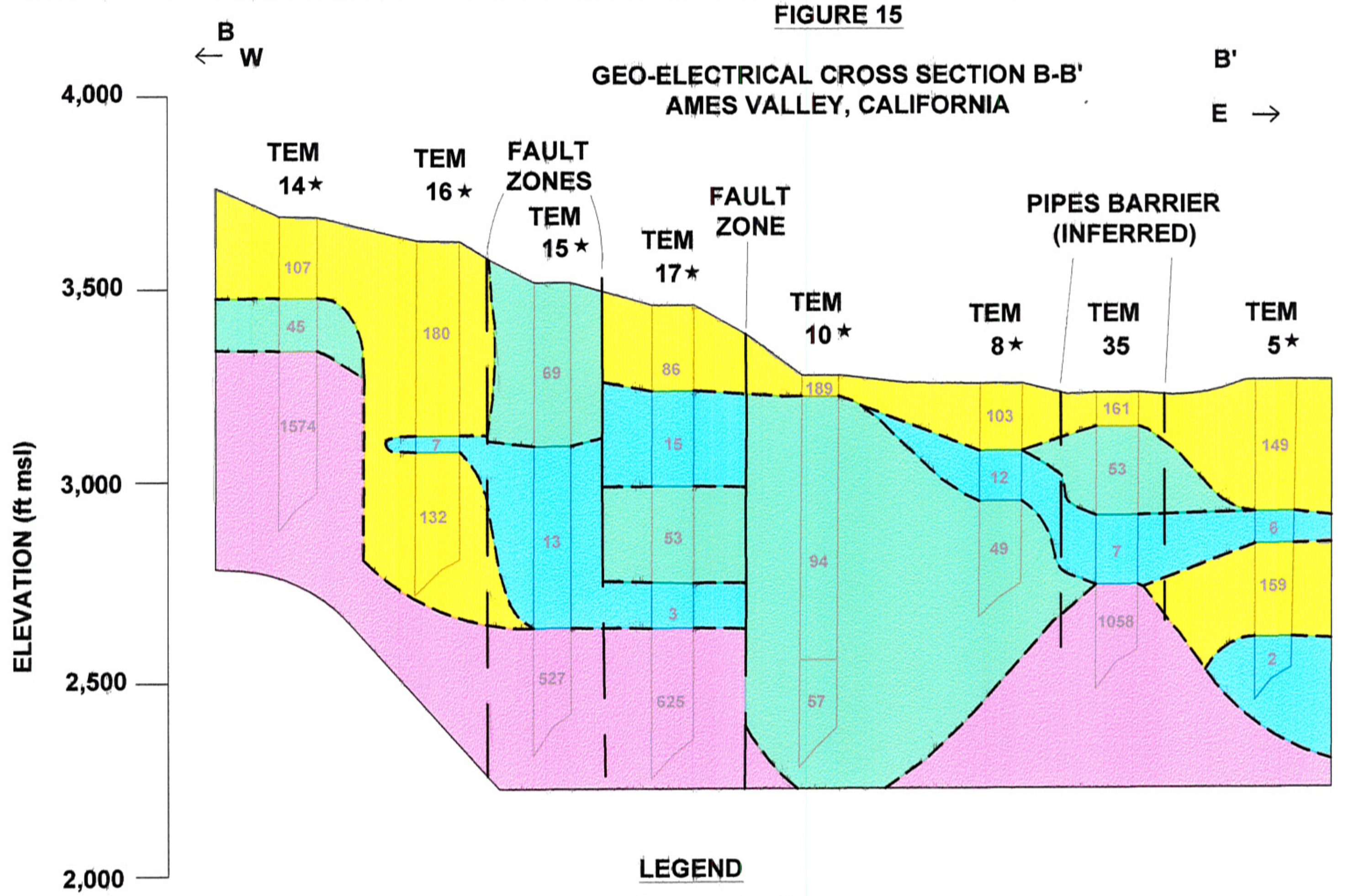
FIGURE 14
GEO-ELECTRICAL CROSS SECTION A-A'
AMES VALLEY, CALIFORNIA



HORIZONTAL NOT TO SCALE
RESISTIVITY IN OHM-METERS

FIGURE 15

GEO-ELECTRICAL CROSS SECTION B-B'
AMES VALLEY, CALIFORNIA



LEGEND

- LOWER-INTERMEDIATE RESISTIVITY MATERIAL, 45-100 OHM-M
- LOW RESISTIVITY MATERIAL, <45 OHM-M
- INTERMEDIATE TO HIGHER-INTERMEDIATE RESISTIVITY MATERIAL, >100 OHM-M
- HIGH RESISTIVITY MATERIAL, >500 OHM-M
- ★ NOISY DATA - GENERAL INTERPRETATION

HORIZONTAL NOT TO SCALE
RESISTIVITY IN OHM-METERS

FIGURE 16

GEO-ELECTRICAL CROSS SECTION C-C'
AMES VALLEY, CALIFORNIA

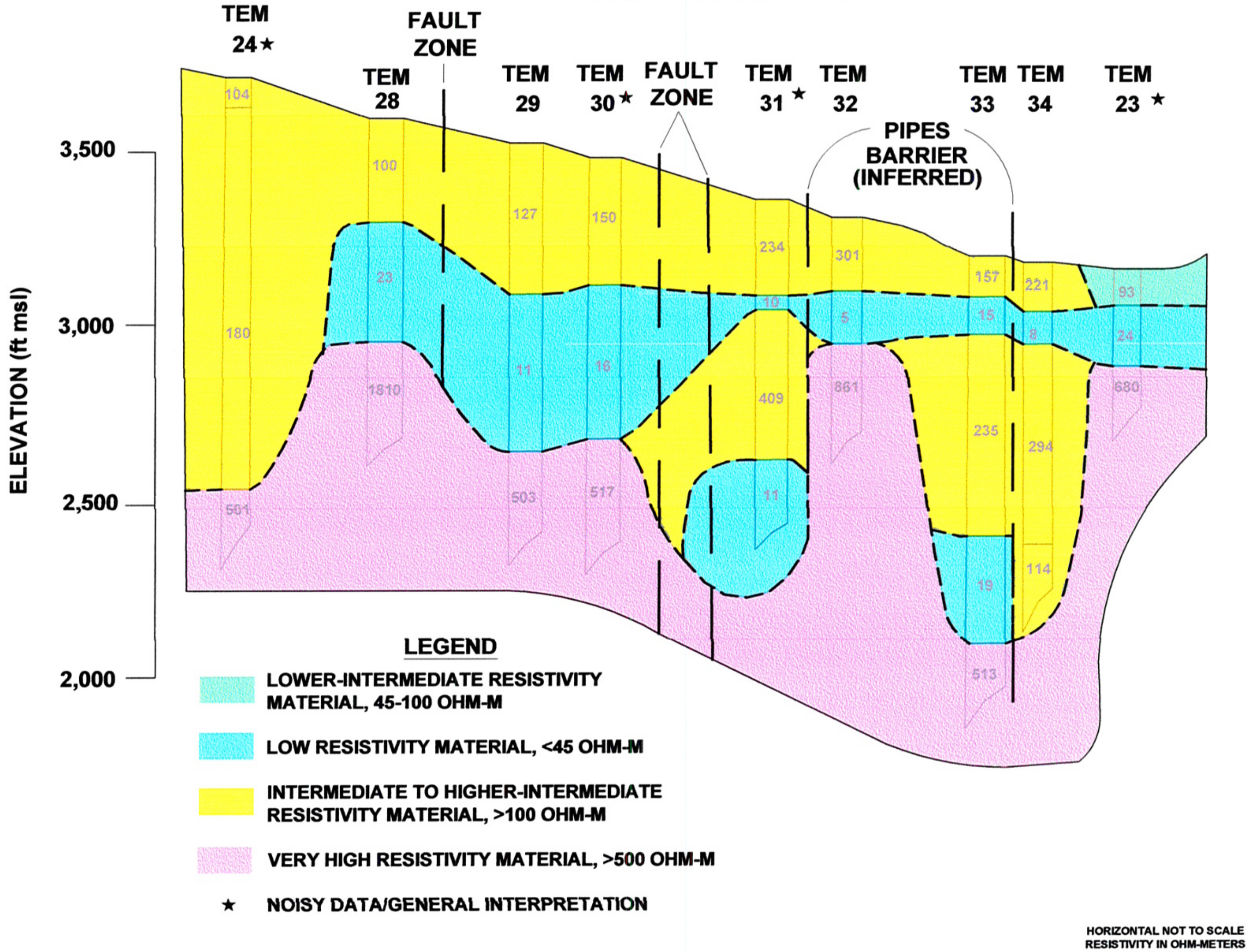


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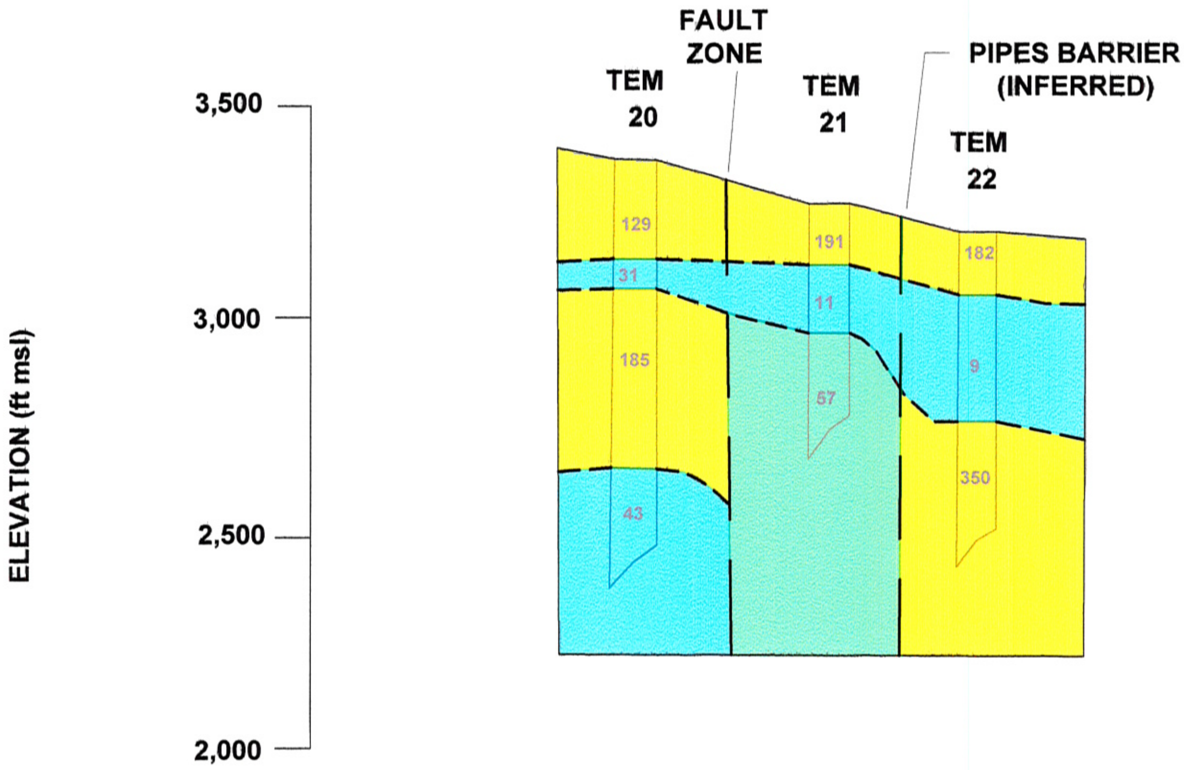
FIGURE 17

GEO-ELECTRICAL CROSS SECTION D-D'
AMES VALLEY, CALIFORNIA

D ← W

D' E →



LEGEND

- LOWER-INTERMEDIATE RESISTIVITY MATERIAL, 45-100 OHM-M
- LOW RESISTIVITY MATERIAL, <45 OHM-M
- INTERMEDIATE TO HIGHER-INTERMEDIATE RESISTIVITY MATERIAL, >100 OHM-M

HORIZONTAL NOT TO SCALE
RESISTIVITY IN OHM-METERS

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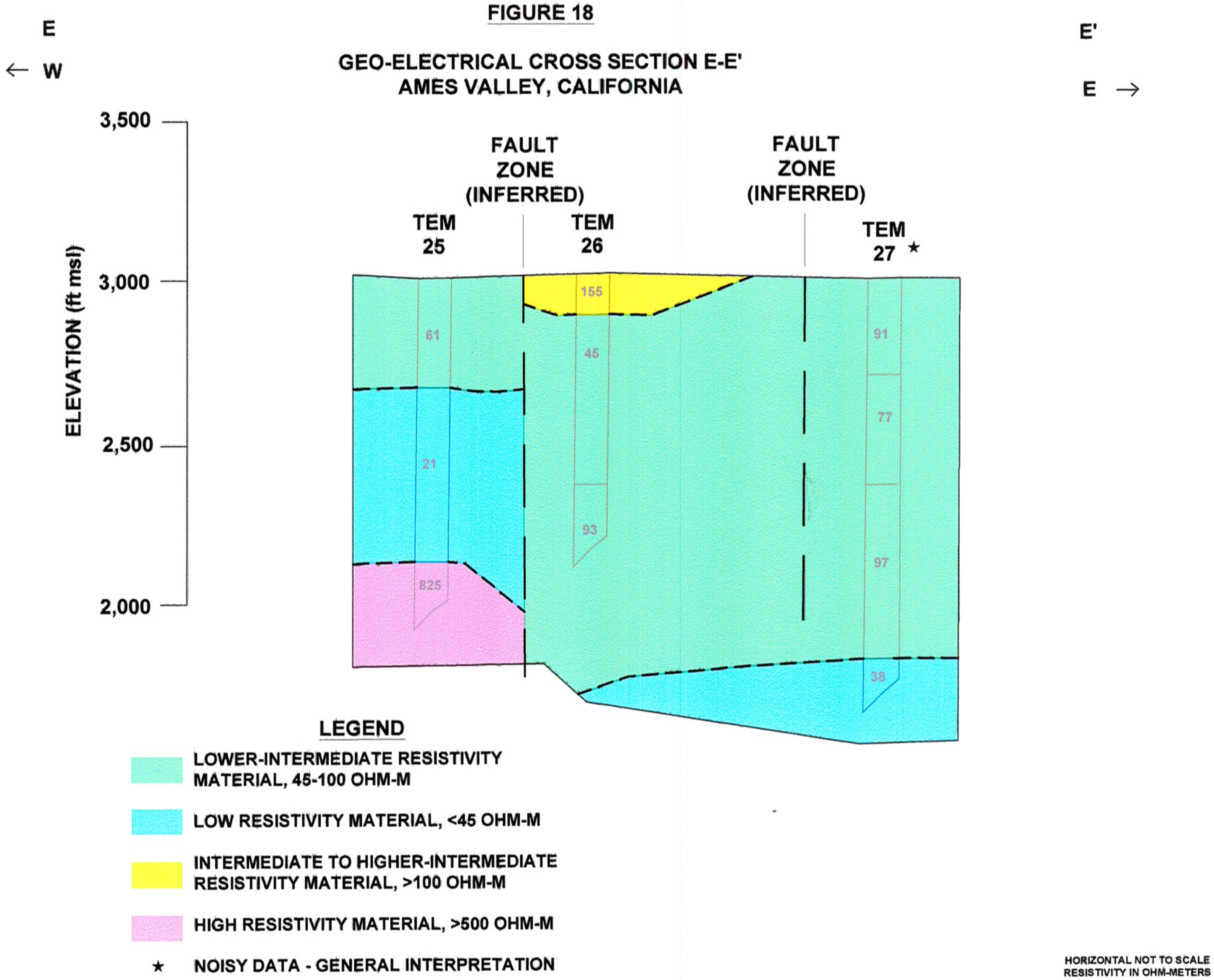
FIGURE 18

GEO-ELECTRICAL CROSS SECTION E-E'
AMES VALLEY, CALIFORNIA



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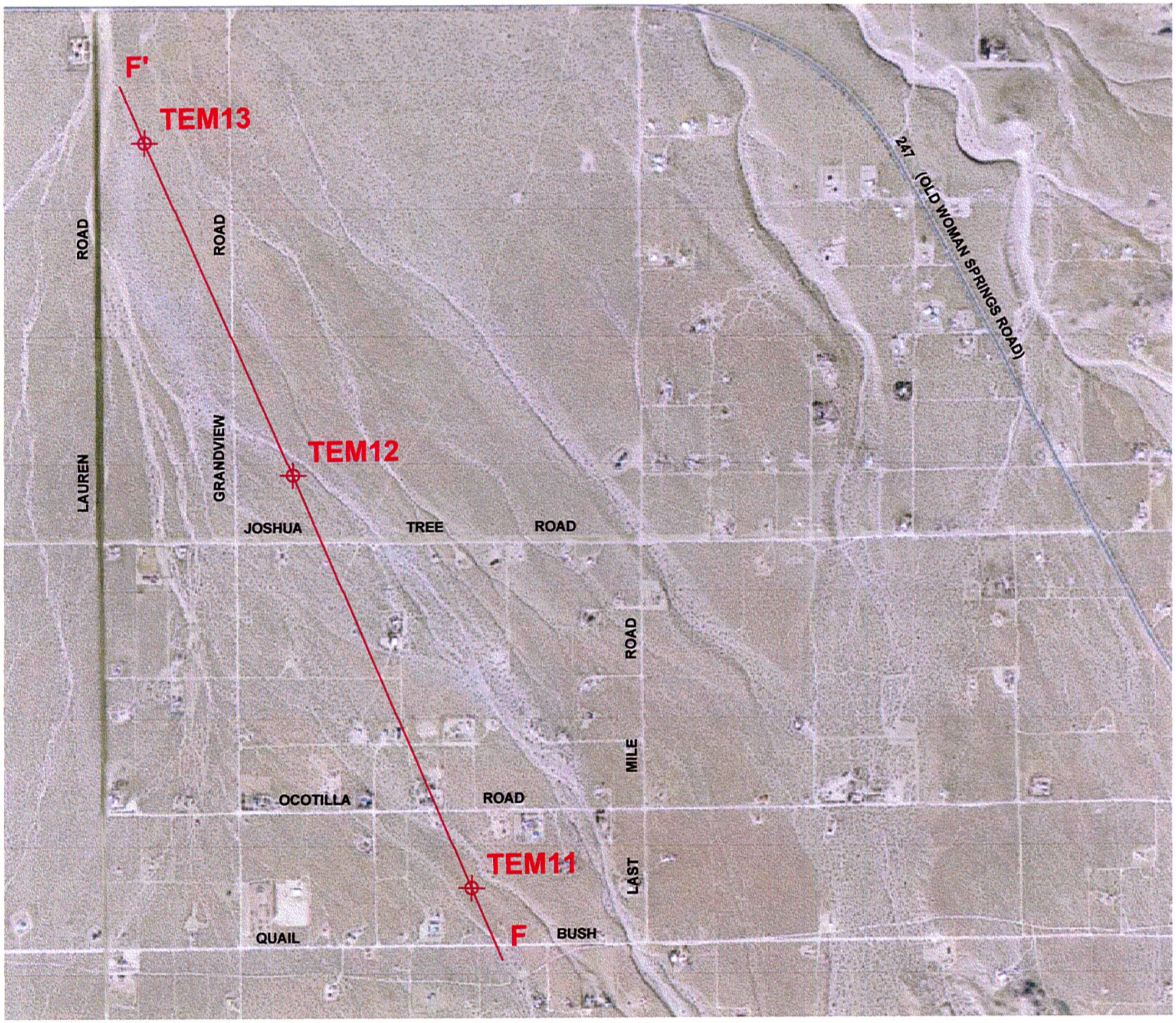


FIGURE 19

TEM SURVEY AND GEO-ELECTRIC CROSS SECTION LOCATIONS

JOHNSON VALLEY, CALIFORNIA

LEGEND

TEM 12 — TEM SOUNDING

F — F' CROSS SECTION

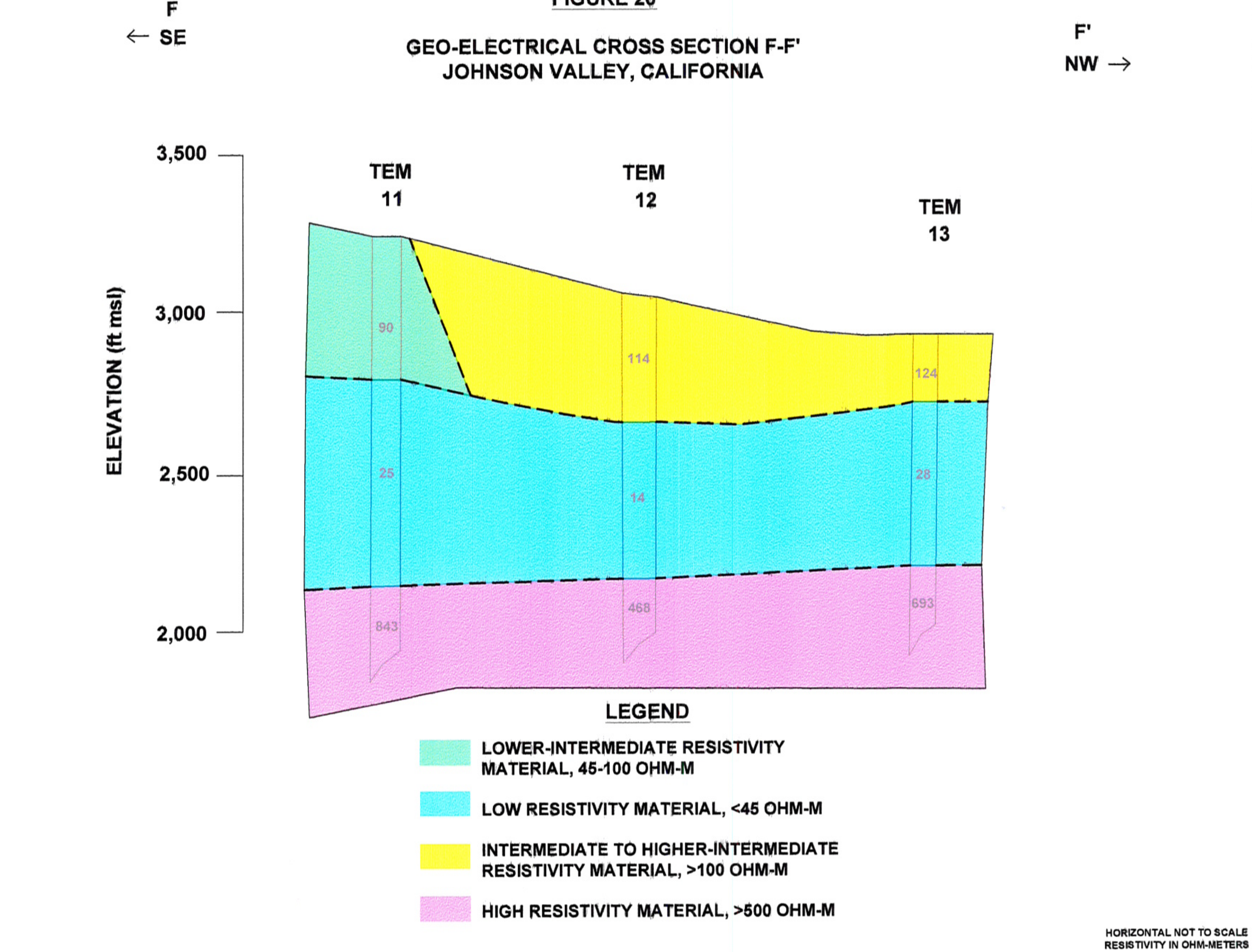
0 750 1500 3000

SCALE IN FEET

Aquifer Science & Technology

FIGURE 20

GEO-ELECTRICAL CROSS SECTION F-F'
JOHNSON VALLEY, CALIFORNIA

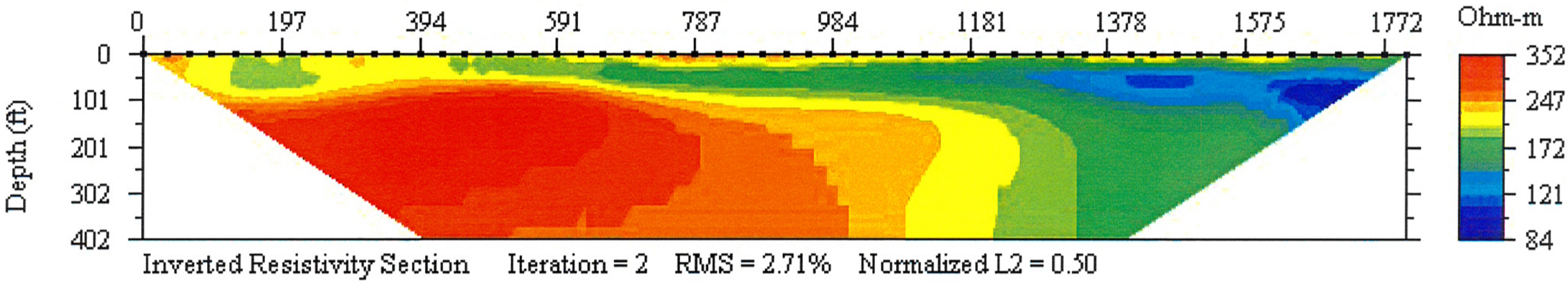


HORIZONTAL NOT TO SCALE
RESISTIVITY IN OHM-METERS

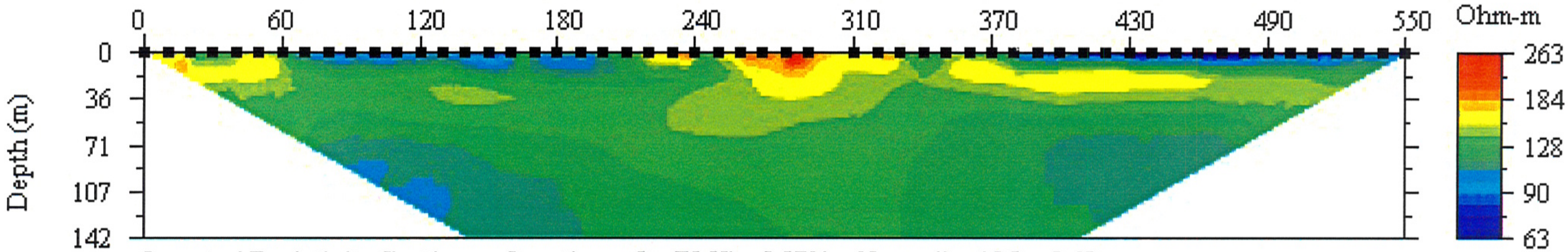
Appendix A

Resistivity Profiles

Resistivity Line 1

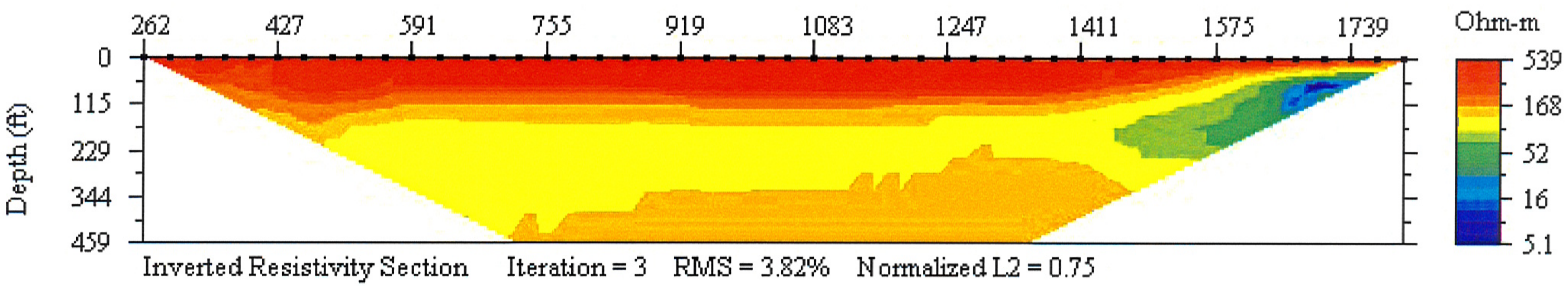


Resistivity Line 2

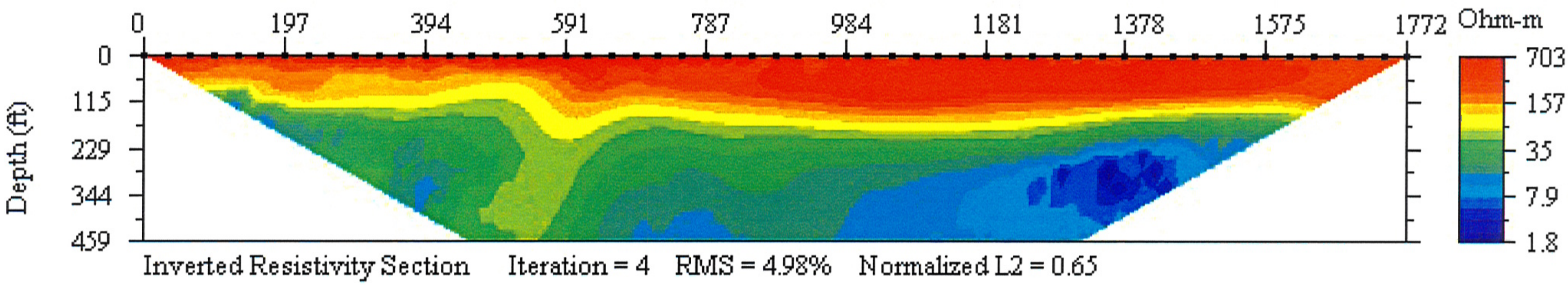


Inverted Resistivity Section Iteration = 2 RMS = 2.37% Normalized L2 = 0.62

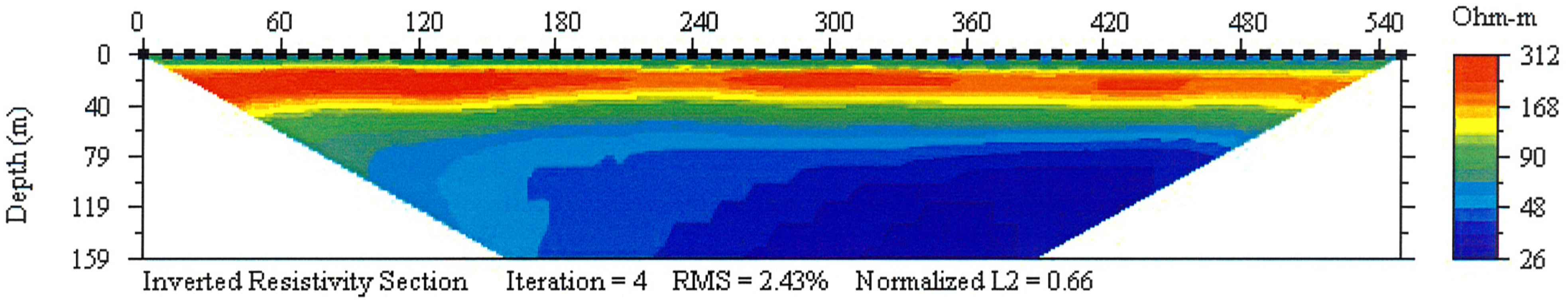
Resistivity Line 3



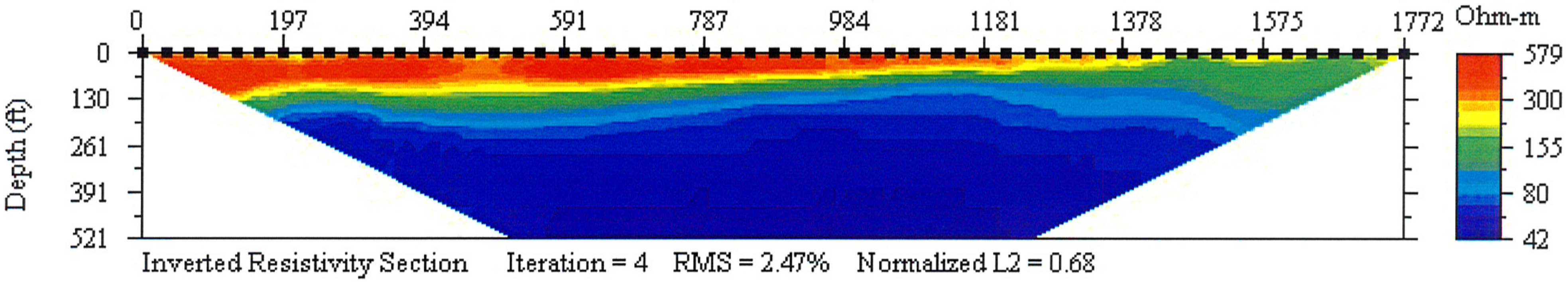
Resistivity Line 4



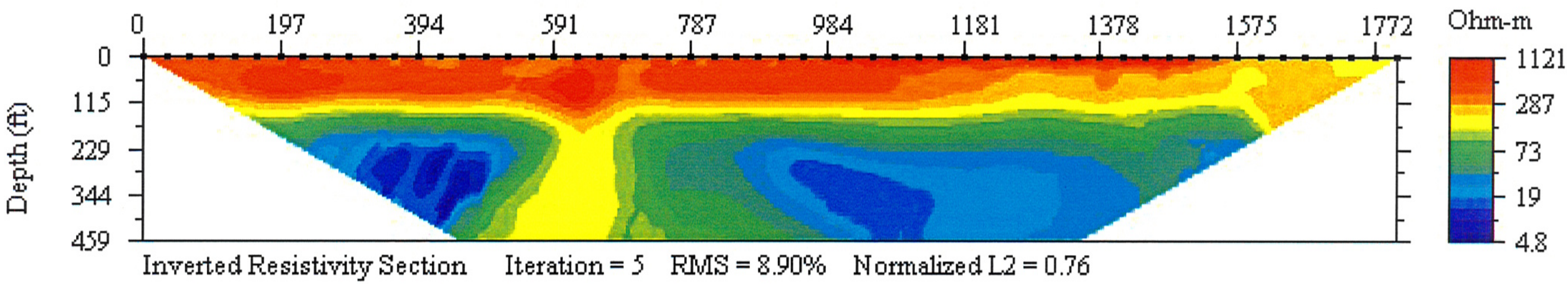
Resistivity Line 5



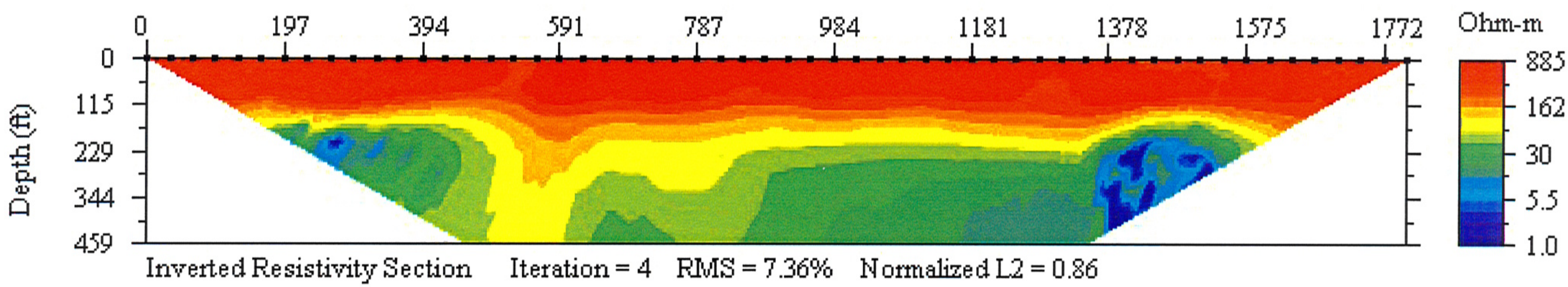
Resistivity Line 6



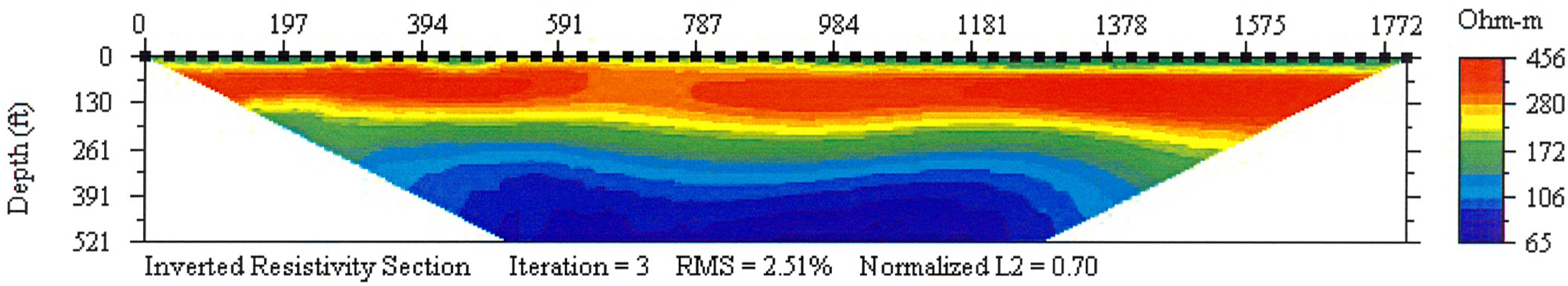
Resistivity Line 7



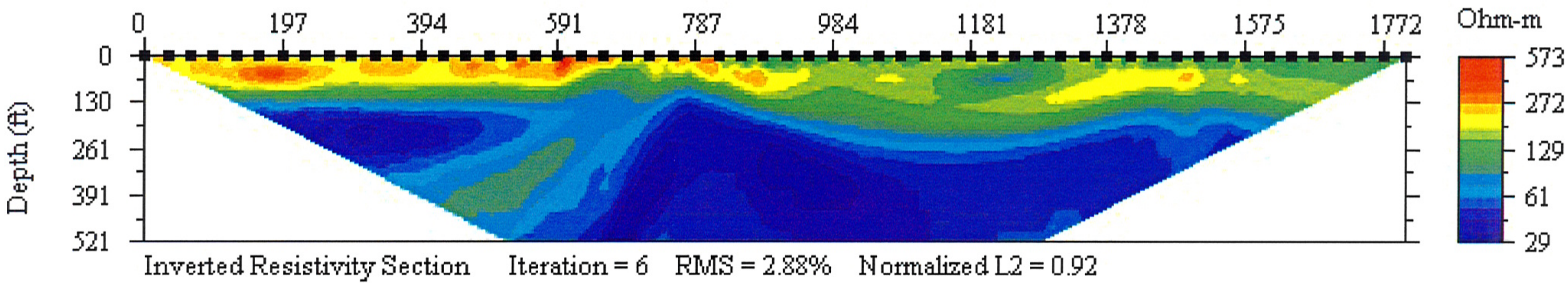
Resistivity Line 8



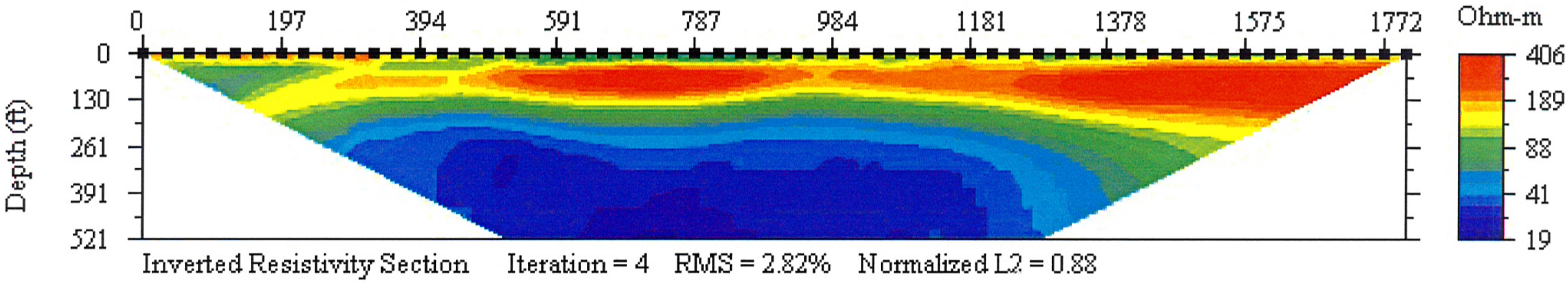
Resistivity Line 9



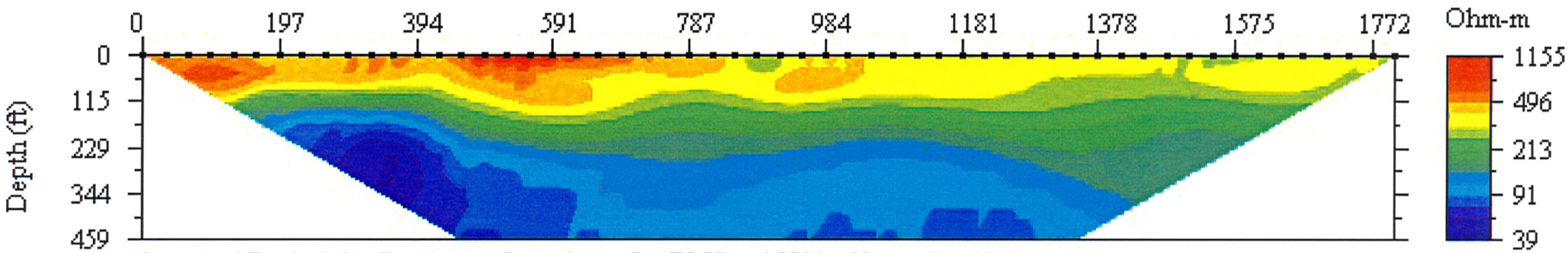
Resistivity Line 10



Resistivity Line 11

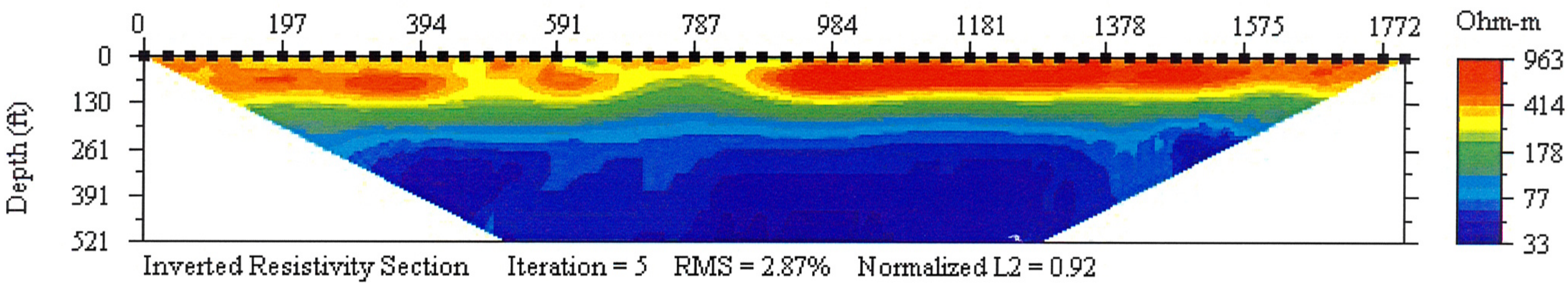


Resistivity Line 12

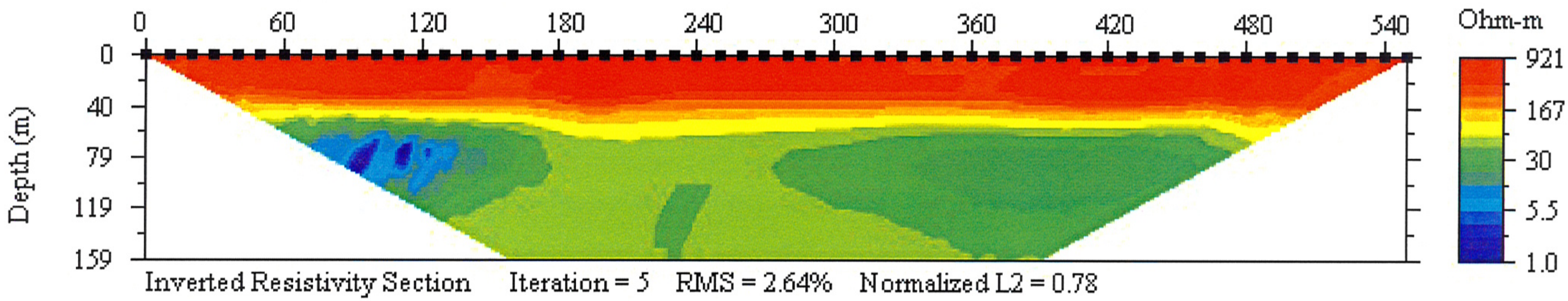


Inverted Resistivity Section Iteration = 3 RMS = 4.08% Normalized L2 = 0.60

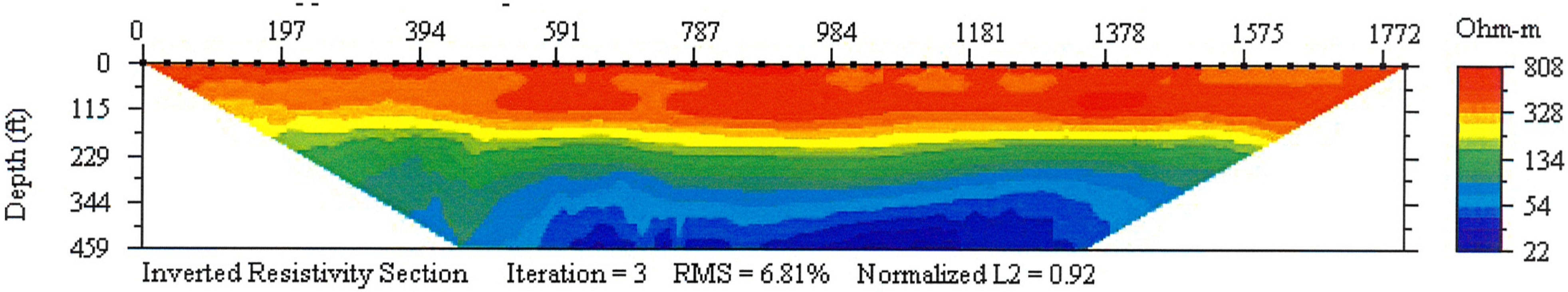
Resistivity Line 13



Resistivity Line 14



Resistivity Line 15



Appendix B

TEM Model Plots and Summary Table

Table B1
Mojave Water Agency, Homestead Valley 2006, Modeled TEM Results

TEM 1

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
79	67	219.8	220
18	73	239.4	459
58	93	305.0	764
11			

TEM 2

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
183	98	321.4	321
32	62	203.4	525
59	159	521.5	1046
11			

TEM 3

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
346	39	127.9	128
31	234	767.5	895
504			

TEM 4

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
284	53	173.8	174
29	119	390.3	564
523			

TEM 5

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
149	102	334.6	335
6	22	72.2	407
159	73	239.4	646
2			

TEM 6 noisy

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
122	59	193.5	194
16	88	288.6	482
232			

TEM 7 noisy late windows

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
63	74	242.7	243
10	63	206.6	449
355			

TEM 8 sl noisy late

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
103	50	164.0	164
12	36	118.1	282
49			

TEM 9

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
118	77	252.6	253
10	47	154.2	407
226			

TEM 10 noisy late windows

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
189	16	52.5	52
94	208	682.2	735
57			

TEM 11 Johnson Valley

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
90	134	439.5	440
25	201	659.3	1099
843			

TEM 12 Johnson Valley

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
114	121	396.9	397
14	148	485.4	882
468			

TEM 13 Johnson Valley

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
124	64	209.9	210
28	157	515.0	725
693			

TEM 14 some interference

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
107	62	203.4	203
45	43	141.0	344
1574			

TEM 15

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
69	125	410.0	410
13	145	475.6	886
470			

TEM 16 noisy

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
180	150	492.0	492
7	11	36.1	528
132			

TEM 17 noisy at depth

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
86	75	246.0	246
15	84	275.5	522
53	69	226.3	748
3	34	111.5	859
260			

TEM 18

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
113	125	410.0	410
9	19	62.3	472
213			

TEM 19 noisy-general trend

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
341	70	229.6	230
36	22	72.2	302
639			

TEM 20 some interference

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
129	70	229.6	230
31	22	72.2	302
185	128	419.8	722
43			

TEM 21

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
191	45	147.6	148
11	47	154.2	302
57			

TEM 22

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
182	46	150.9	151
9	84	275.5	426
350			

TEM 23

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
93	31	101.7	102
24	54	177.1	279
680			

TEM 24 some noise

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
104	28	91.8	92
180	332	1089.0	1181
501			

TEM 25 sm noise

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
61	104	341.1	341
21	164	537.9	879
825			

TEM 26

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
155	36	118.1	118
45	158	518.2	636
93			

TEM 27 int/noisy

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
91	89	291.9	292
77	105	344.4	636
97	165	541.2	1178
38			

TEM 28

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
100	91	298.5	298
23	101	331.3	630
1810			

TEM 29 some noise

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
127	132	433.0	433
11	140	459.2	892
503			

TEM 30 noisy at depth

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
150	109	357.5	358
16	140	459.2	817
517			

TEM 31 sm noise

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
234	81	265.7	266
10	11	36.1	302
409	131	429.7	731
11			

TEM 32

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
301	63	206.6	207
5	44	144.3	351
861			

TEM 33

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
149	35	114.8	115
15	32	105.0	220
236	176	577.3	797
19	95	311.6	1109
513			

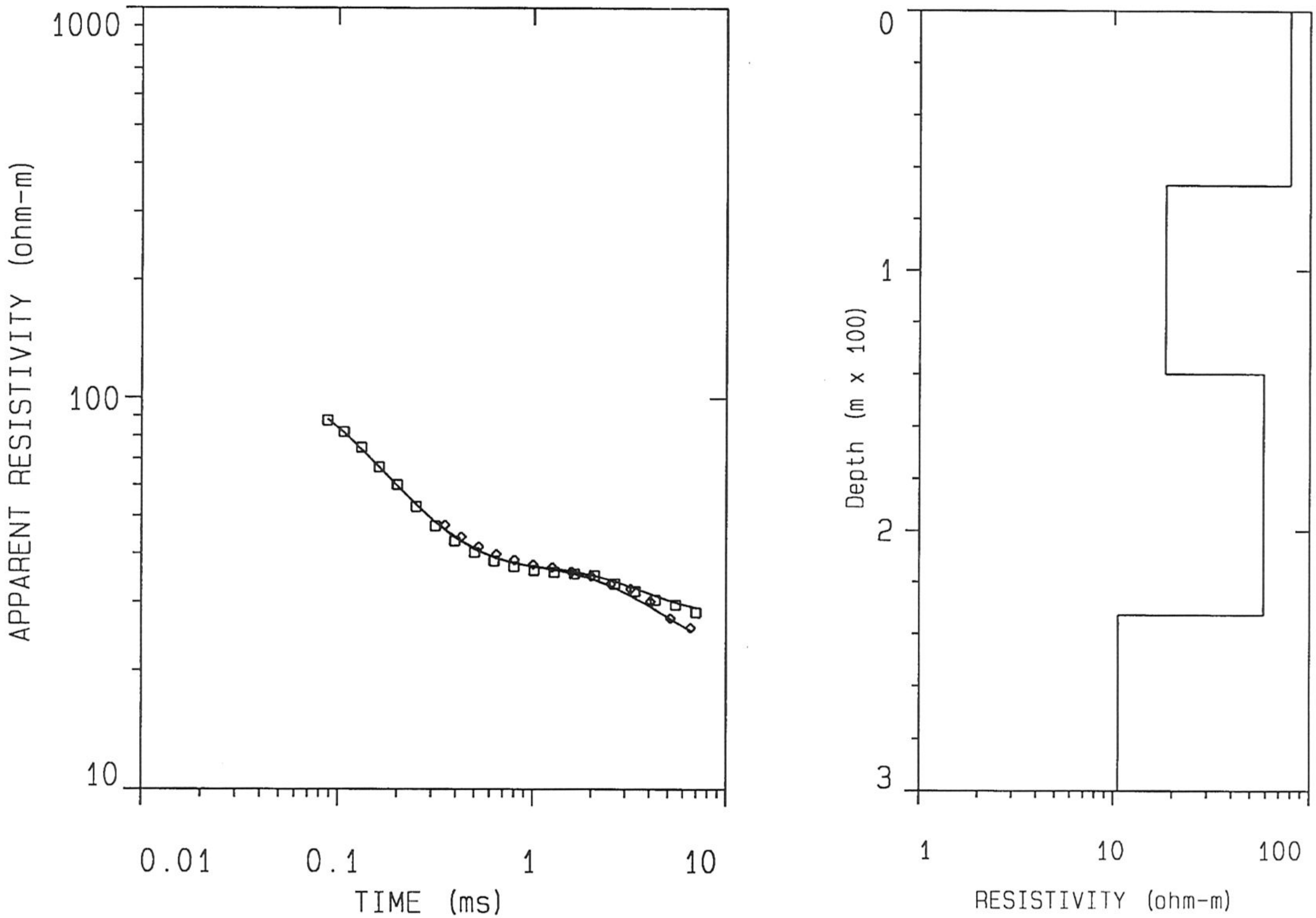
TEM 34

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
221	47	154.2	154
8	24	78.7	233
294	170	557.6	790
114			

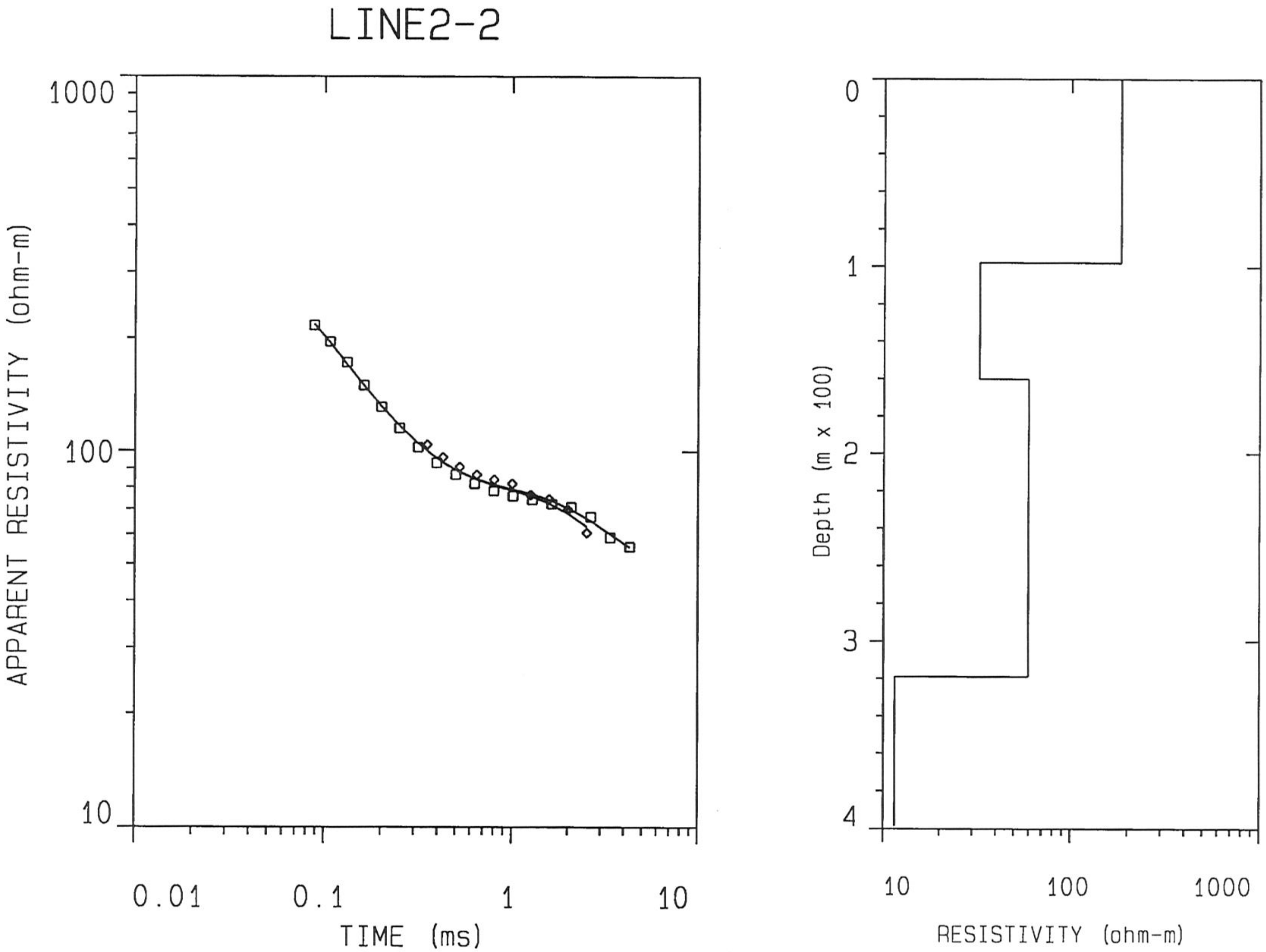
TEM 35

rho (ohm-m)	thickness (m)	thickness (ft)	depth (ft)
161	23	75.4	75
53	70	229.6	305
7	54	177.1	482
1058			

LINE1

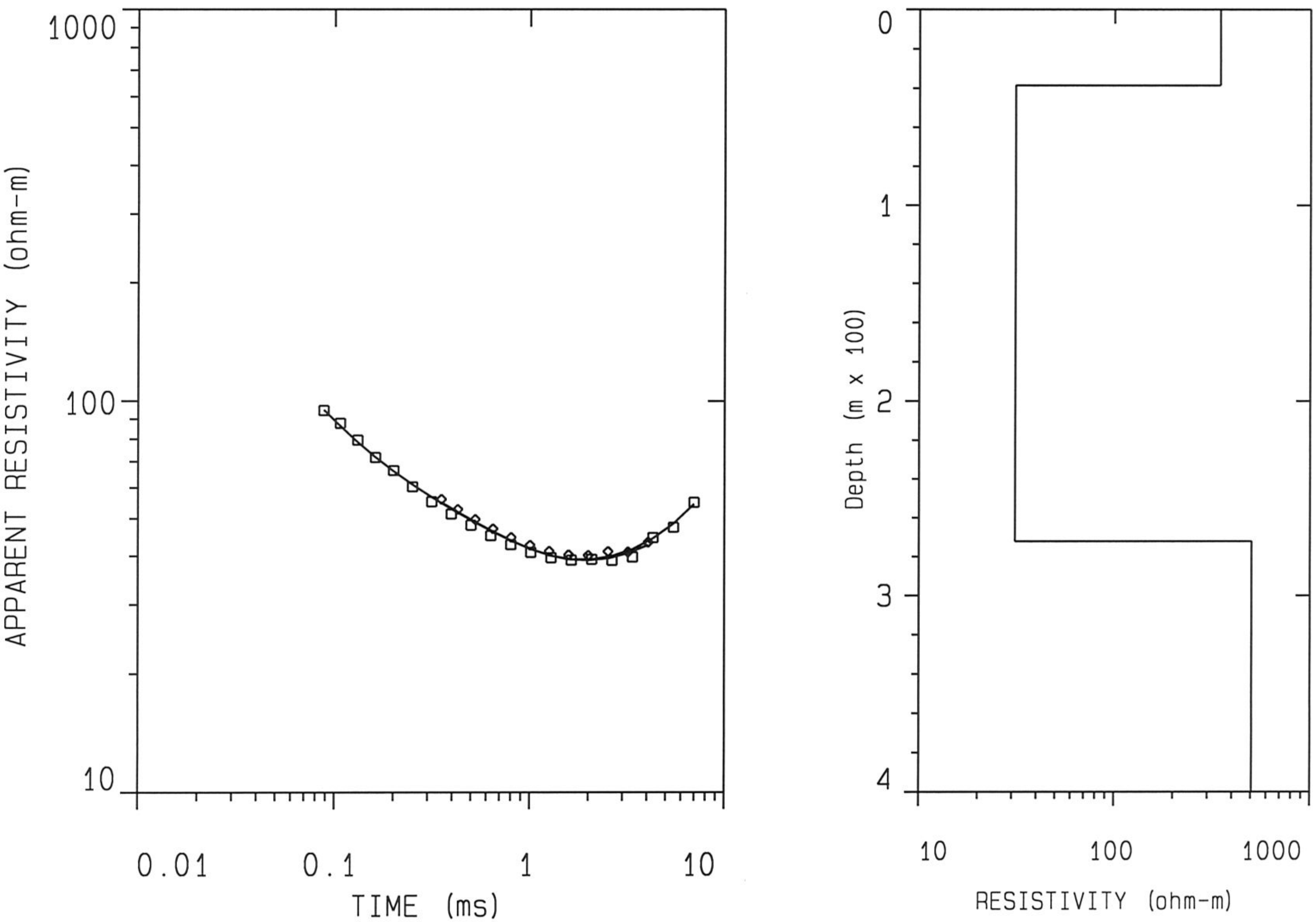


1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
3
Depth (m x 100)
1
10
100
RESISTIVITY (ohm-m)



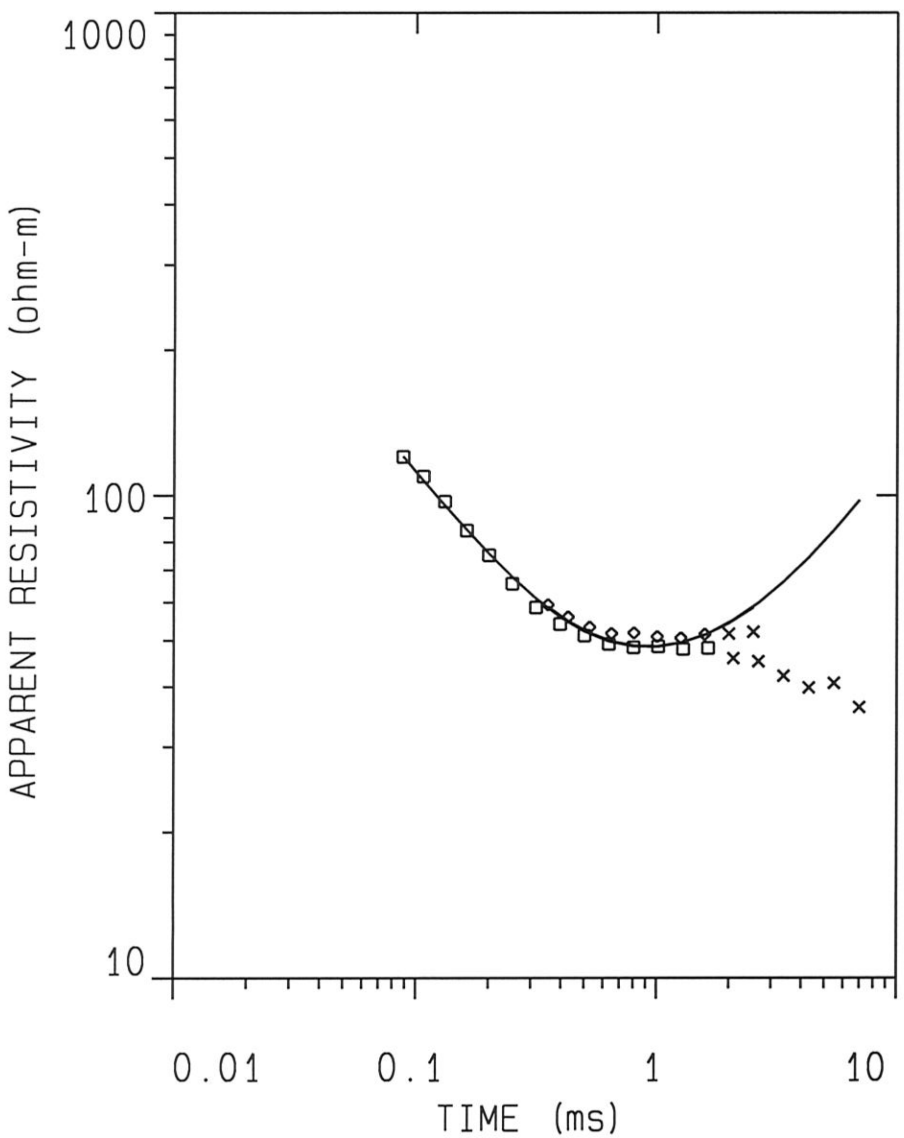
LINE2-2
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
3
4
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

LINE3-2

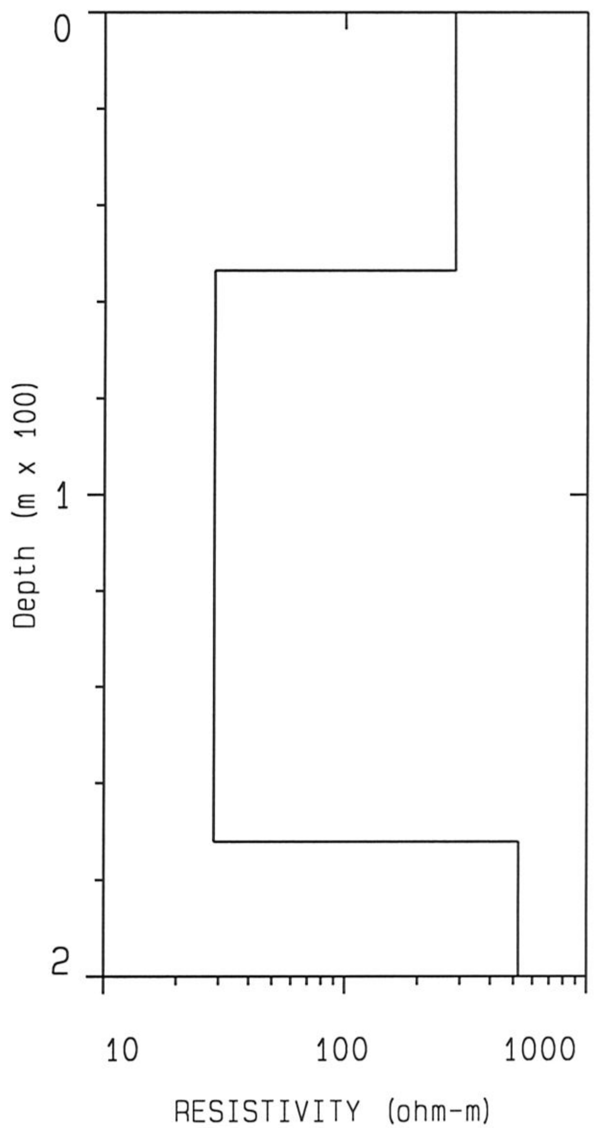


1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
3
4
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

LINE4-2

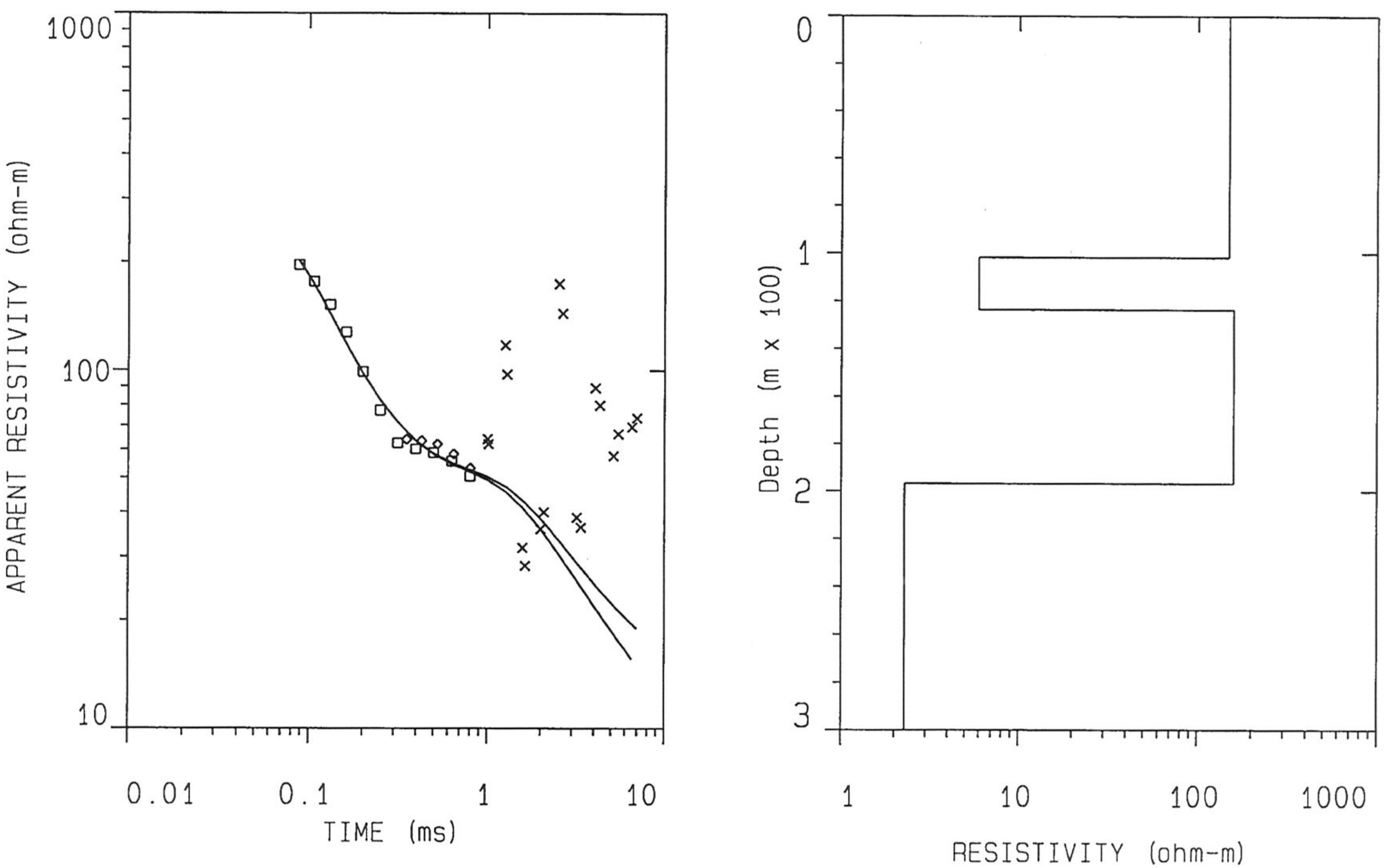


1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)

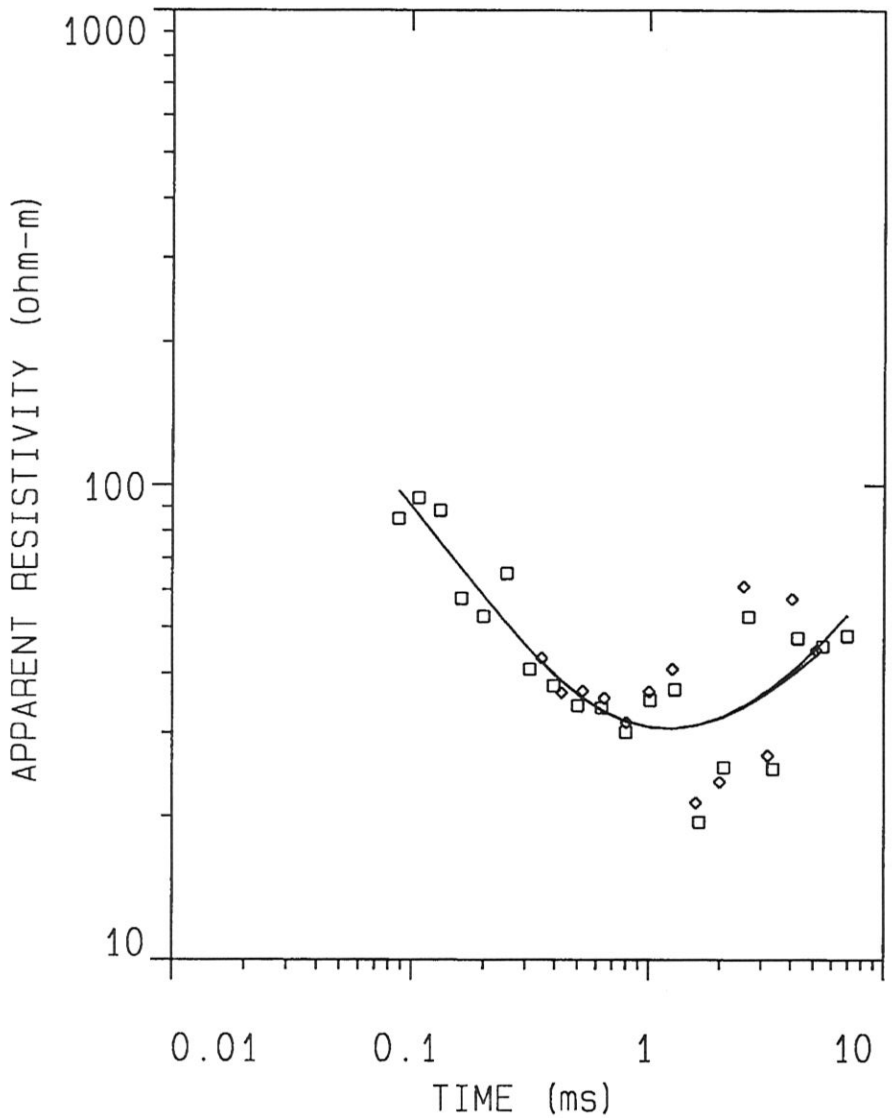


0
1
2
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

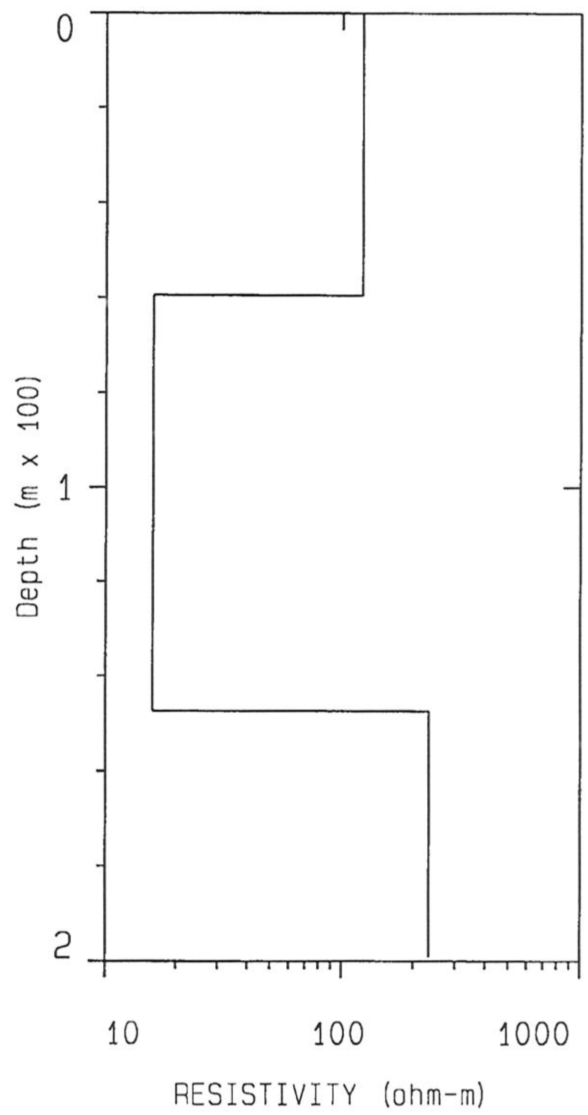
LINE5


1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
3
Depth (m x 100)
1
10
100
1000
RESISTIVITY (ohm-m)

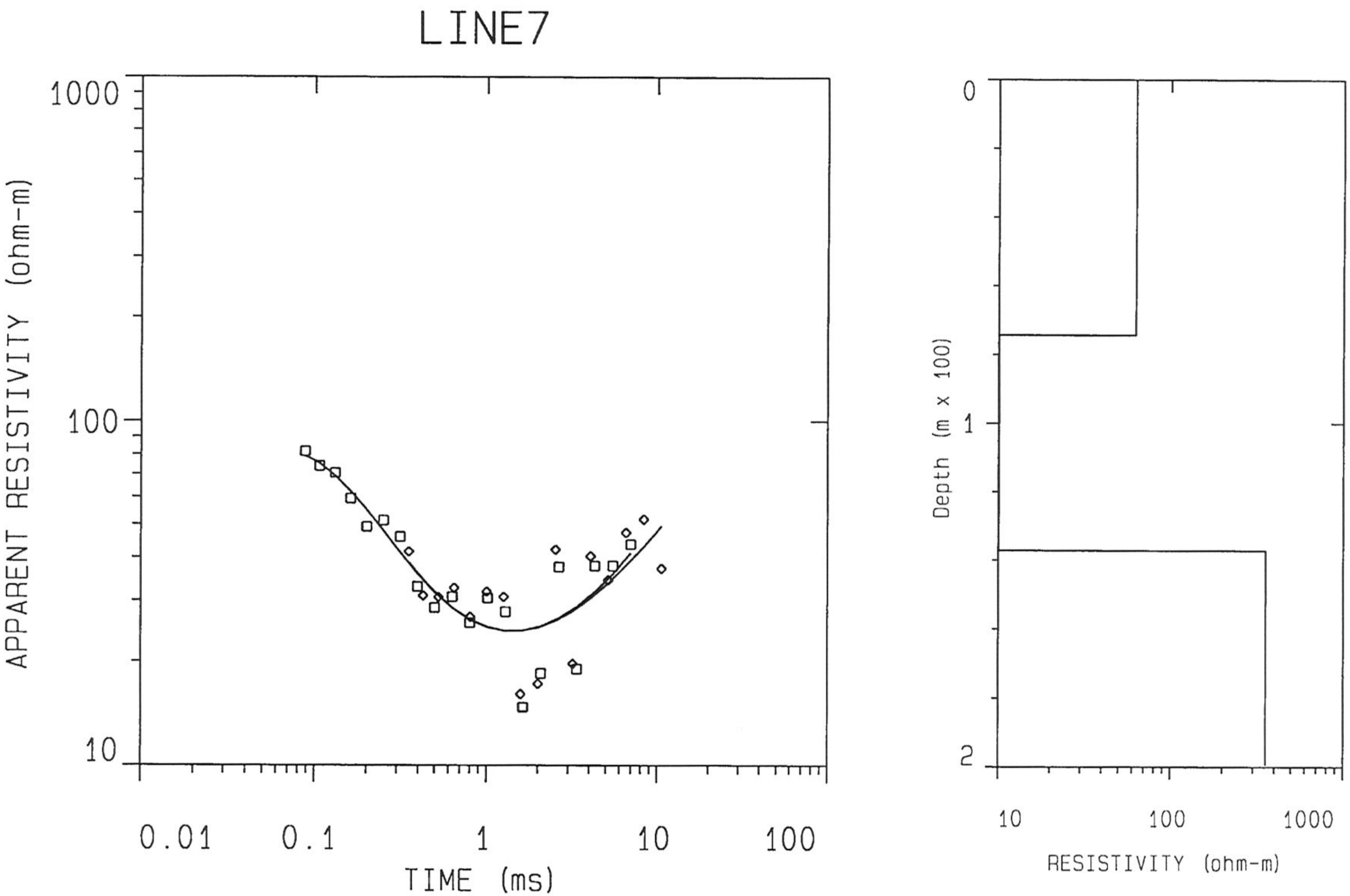
LINE6



1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)

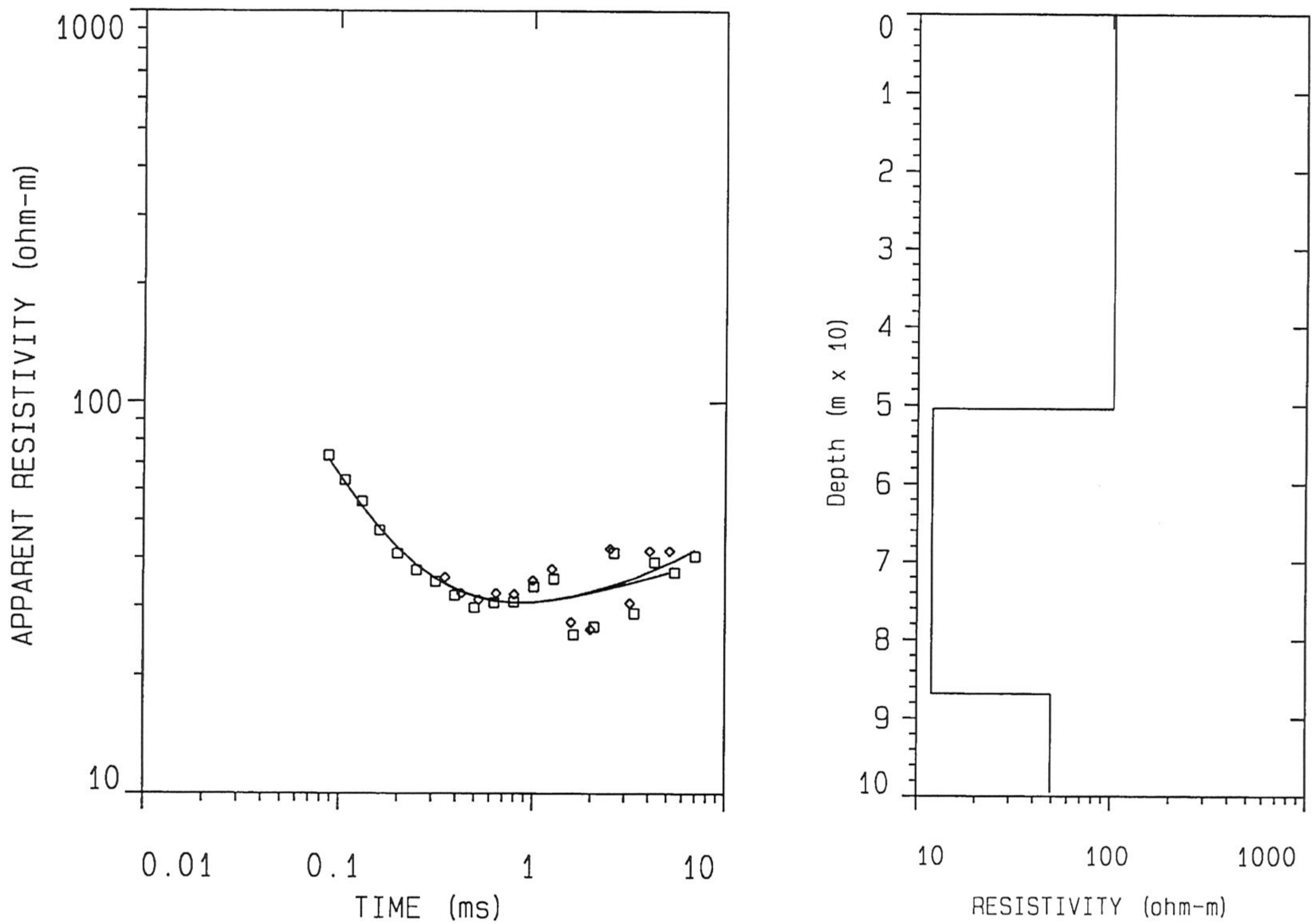


0
1
2
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)



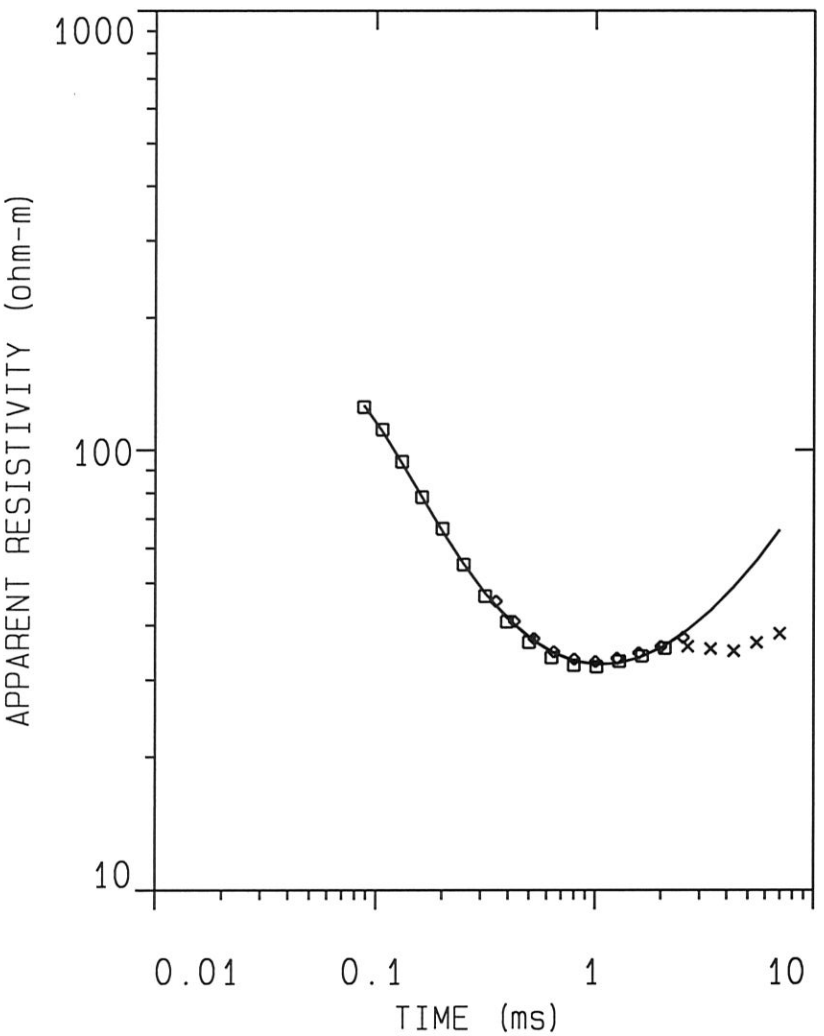
LINE7
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
100
TIME (ms)
0
1
2
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

LINE8

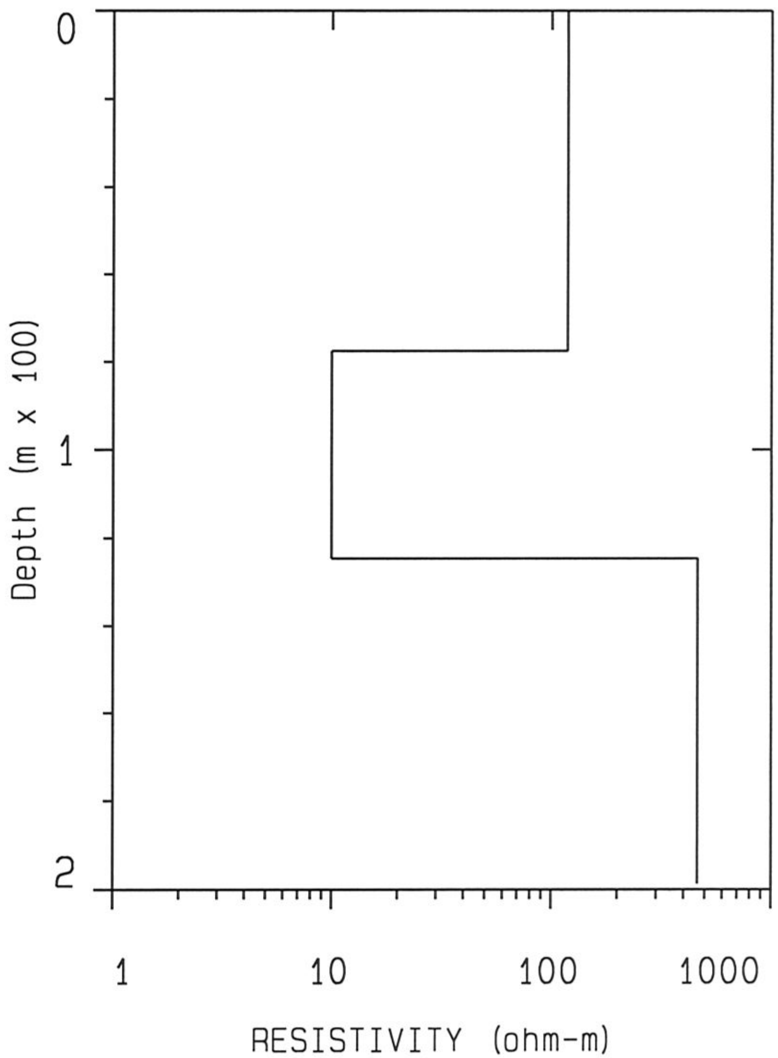


1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
3
4
5
6
7
8
9
10
Depth (m x 10)
10
100
1000
RESISTIVITY (ohm-m)

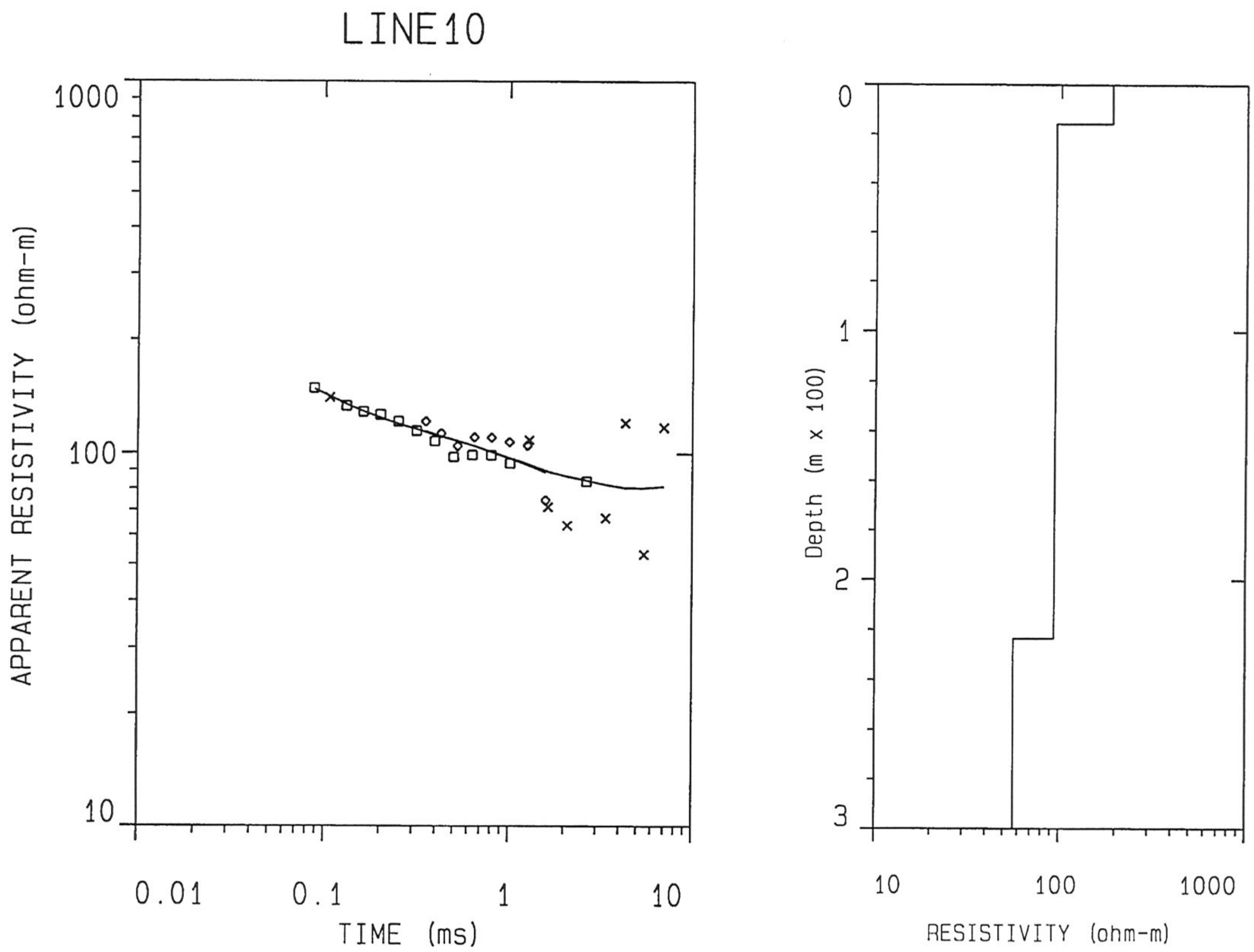
LINE9-2



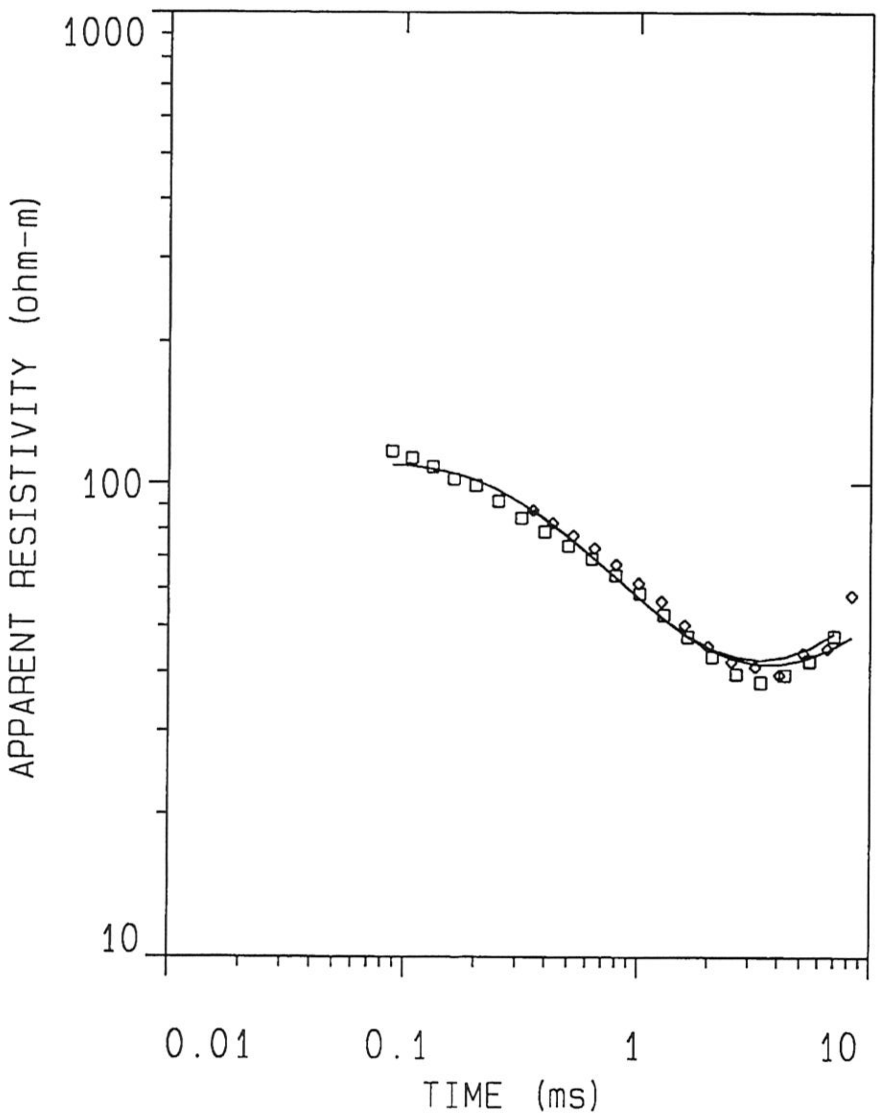
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)



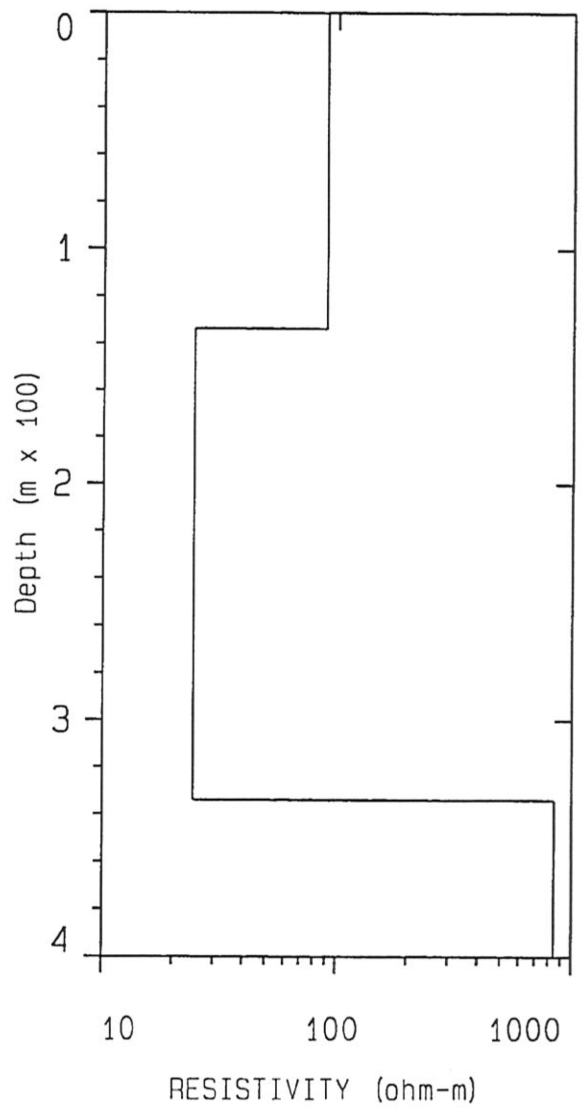
0
1
2
Depth (m x 100)
1
10
100
1000
RESISTIVITY (ohm-m)


LINE10
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
3
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

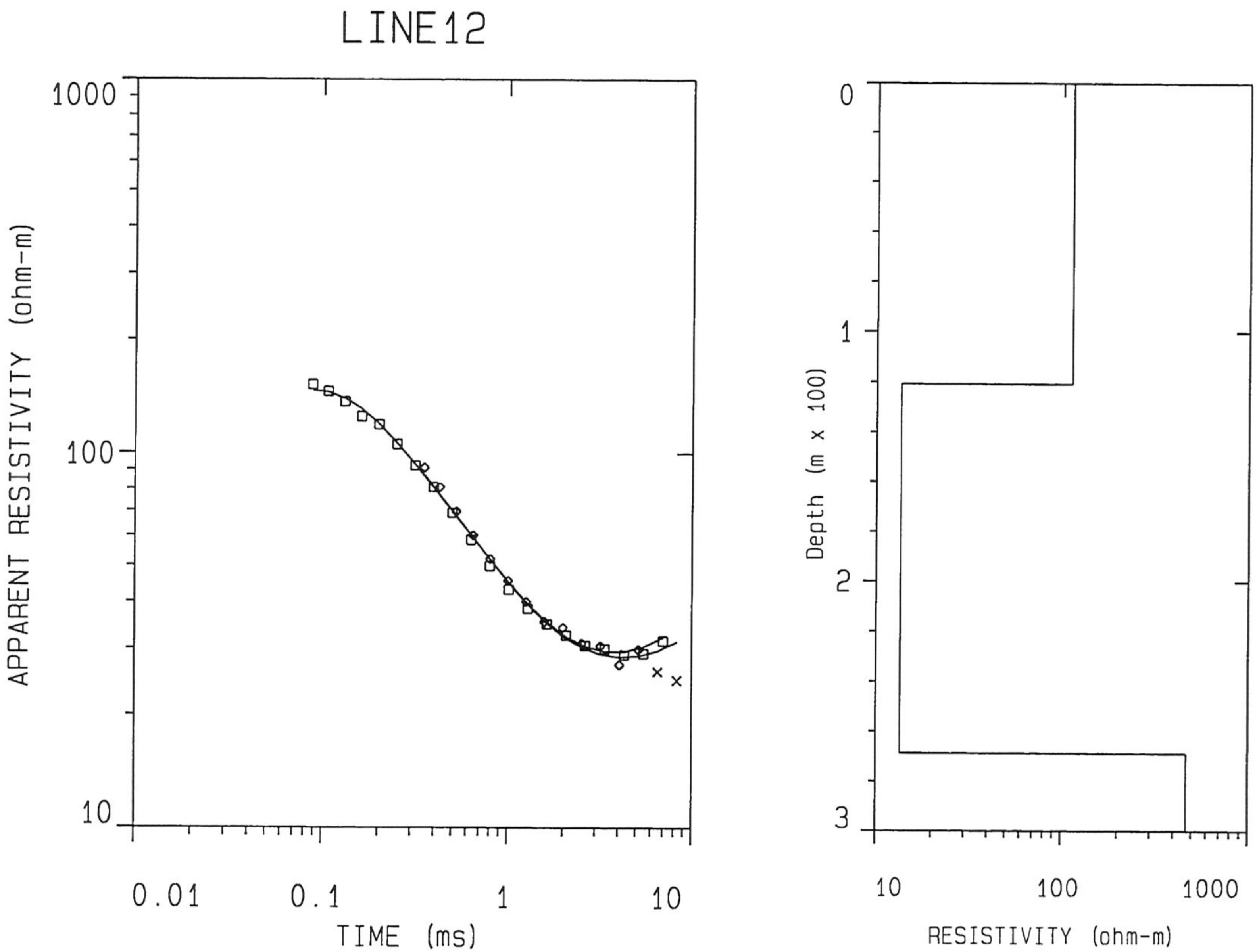
LINE11



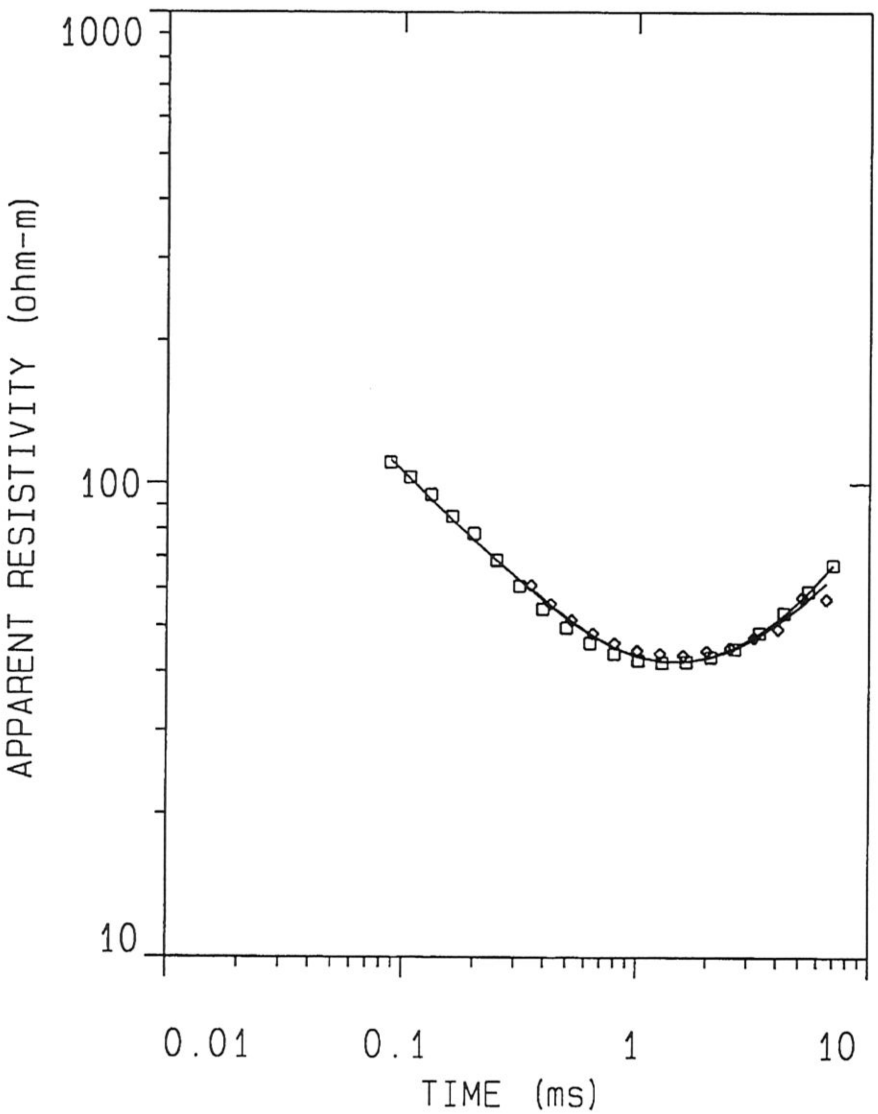
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)



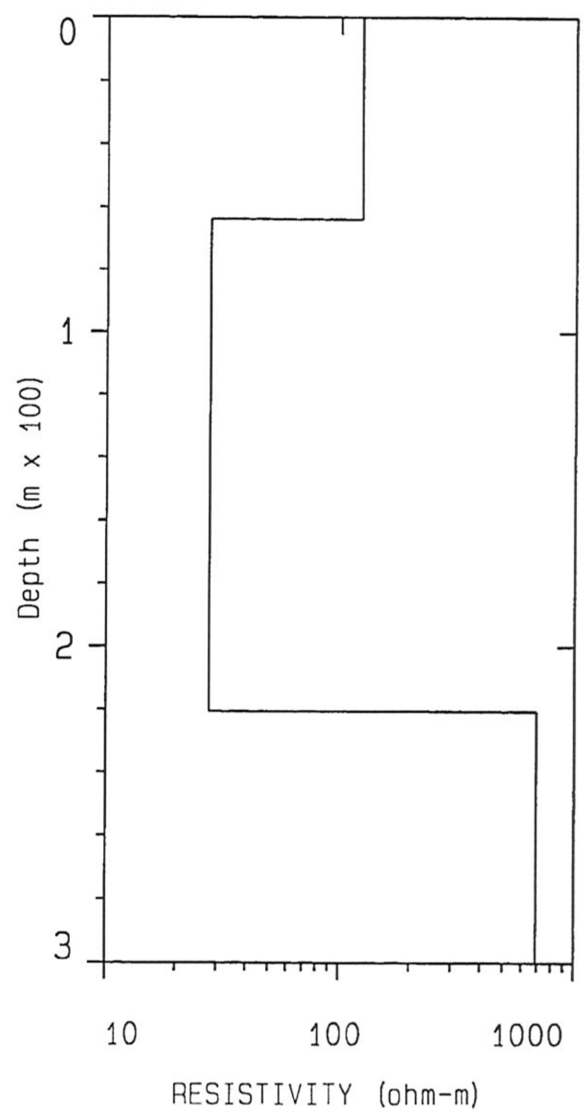
0
1
2
3
4
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)


LINE12
APPARENT RESISTIVITY (ohm-m)
1000
100
10
0.01
0.1
1
10
TIME (ms)
Depth (m x 100)
0
1
2
3
10
100
1000
RESISTIVITY (ohm-m)

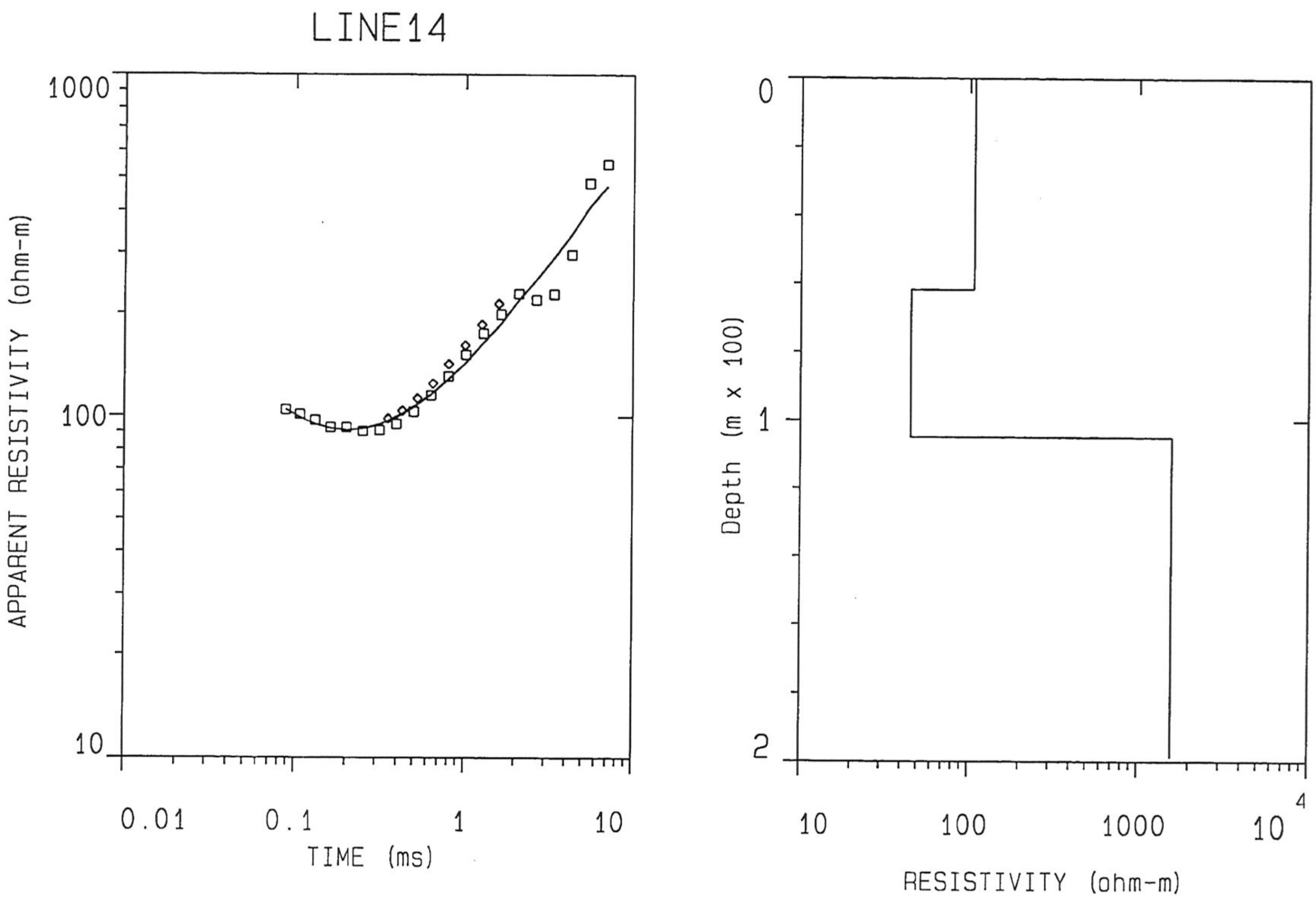
LINE13



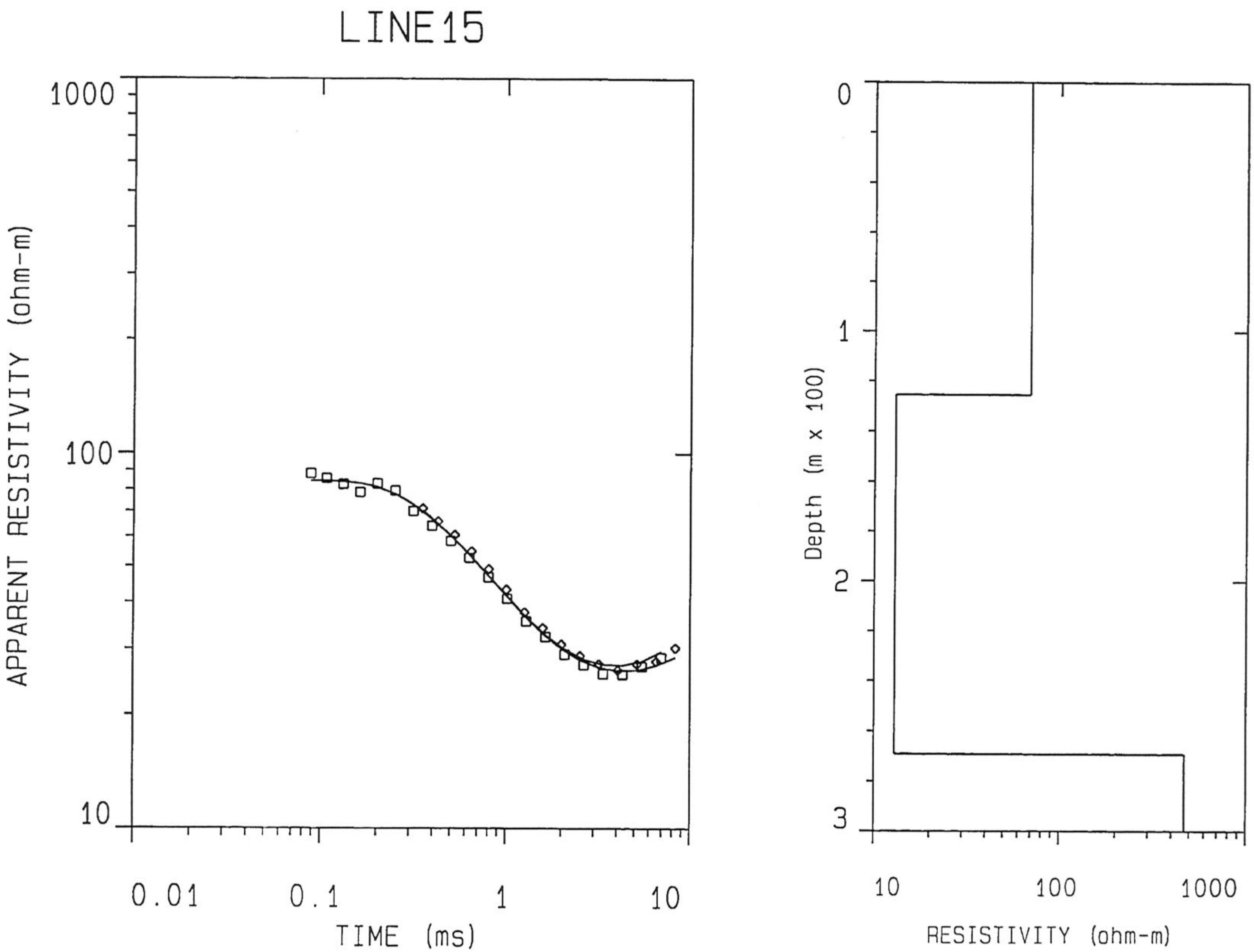
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)



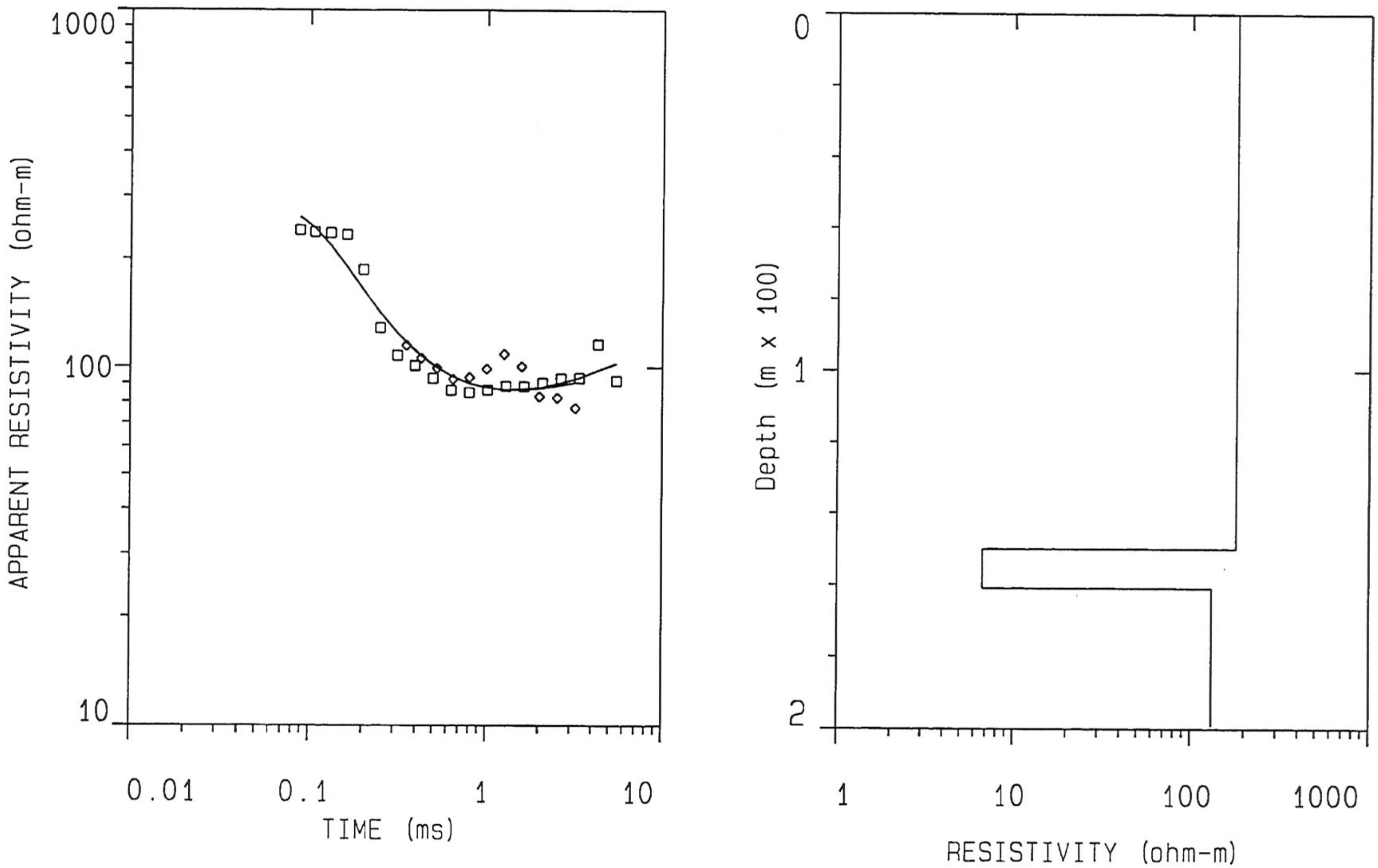
0
1
2
3
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)



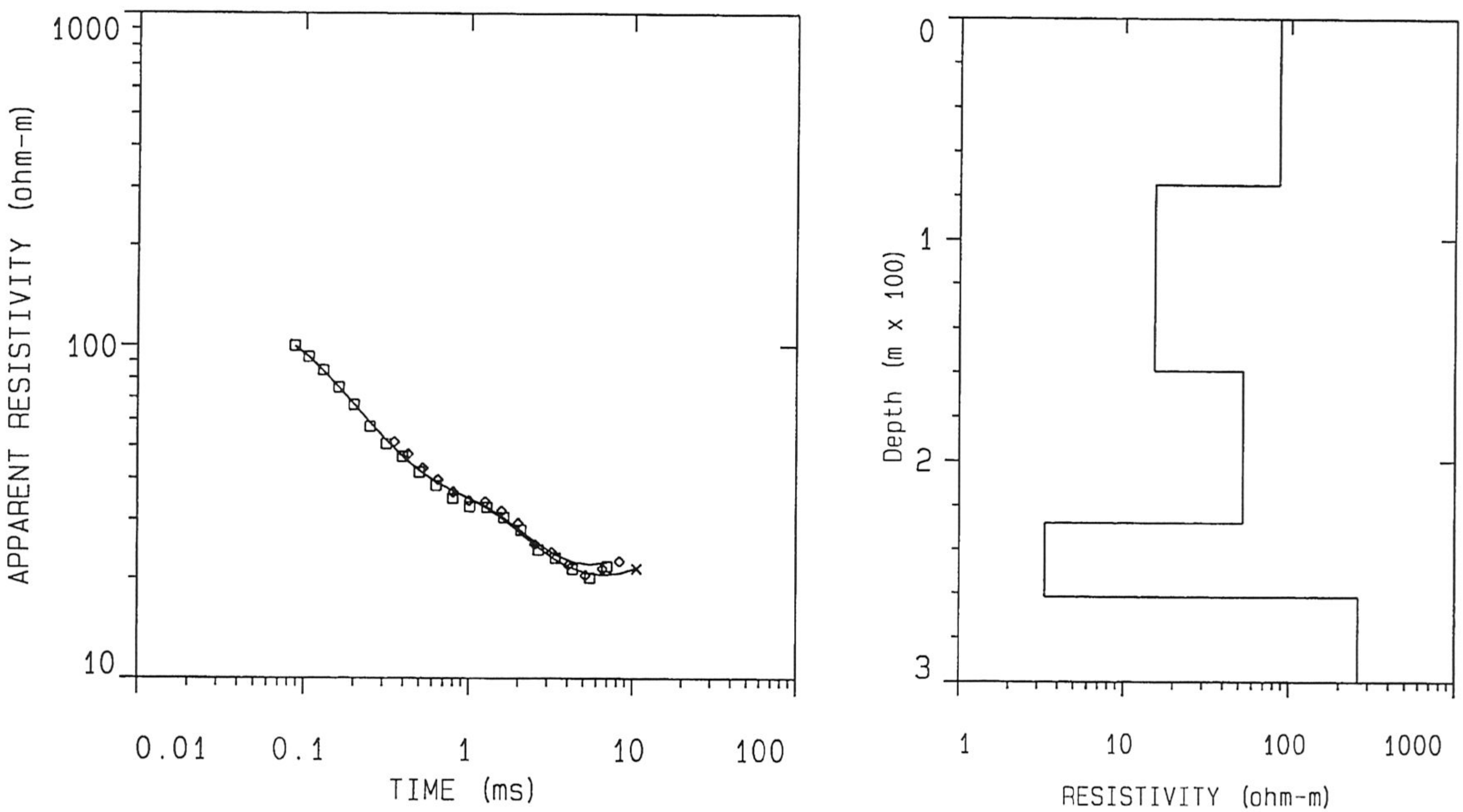
LINE14
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
Depth (m x 100)
10
100
1000
10^4
RESISTIVITY (ohm-m)


LINE15
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
3
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

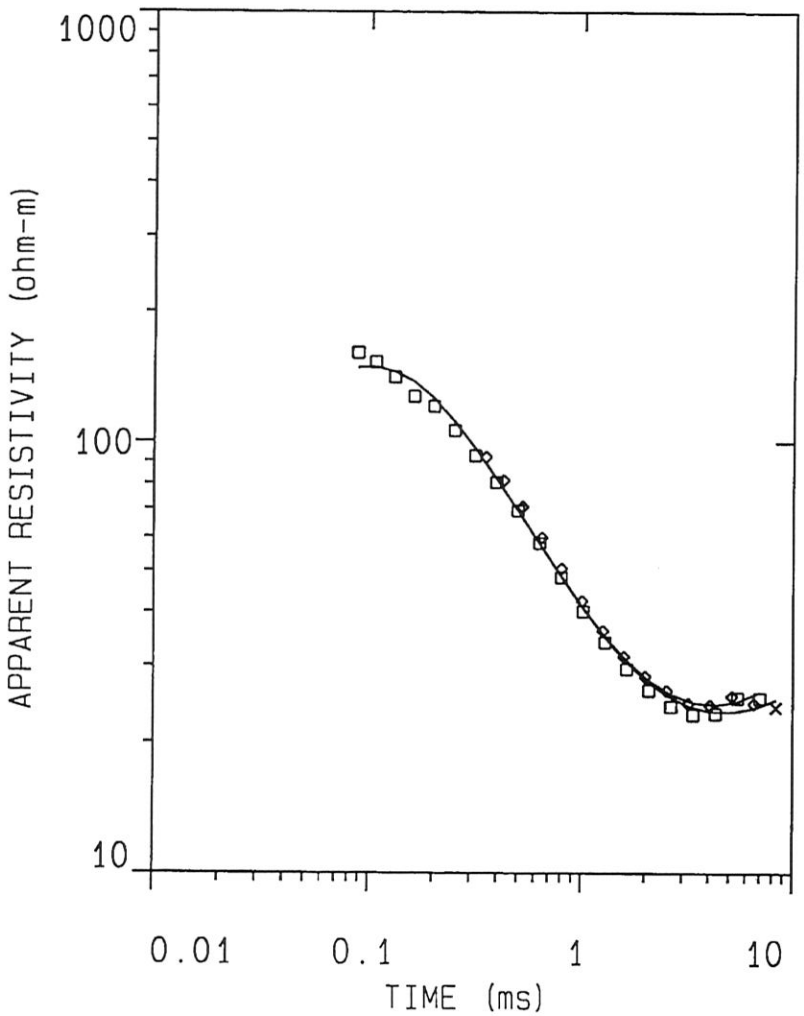
LINE16

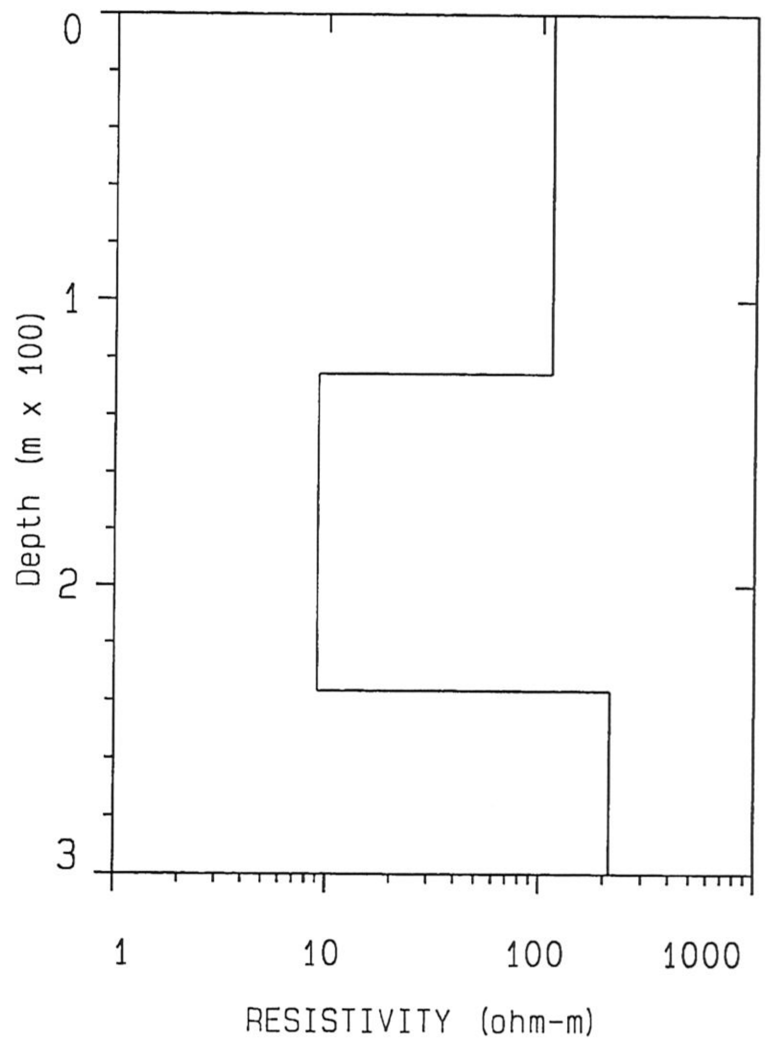

1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
Depth (m x 100)
1
10
100
1000
RESISTIVITY (ohm-m)

LINE17

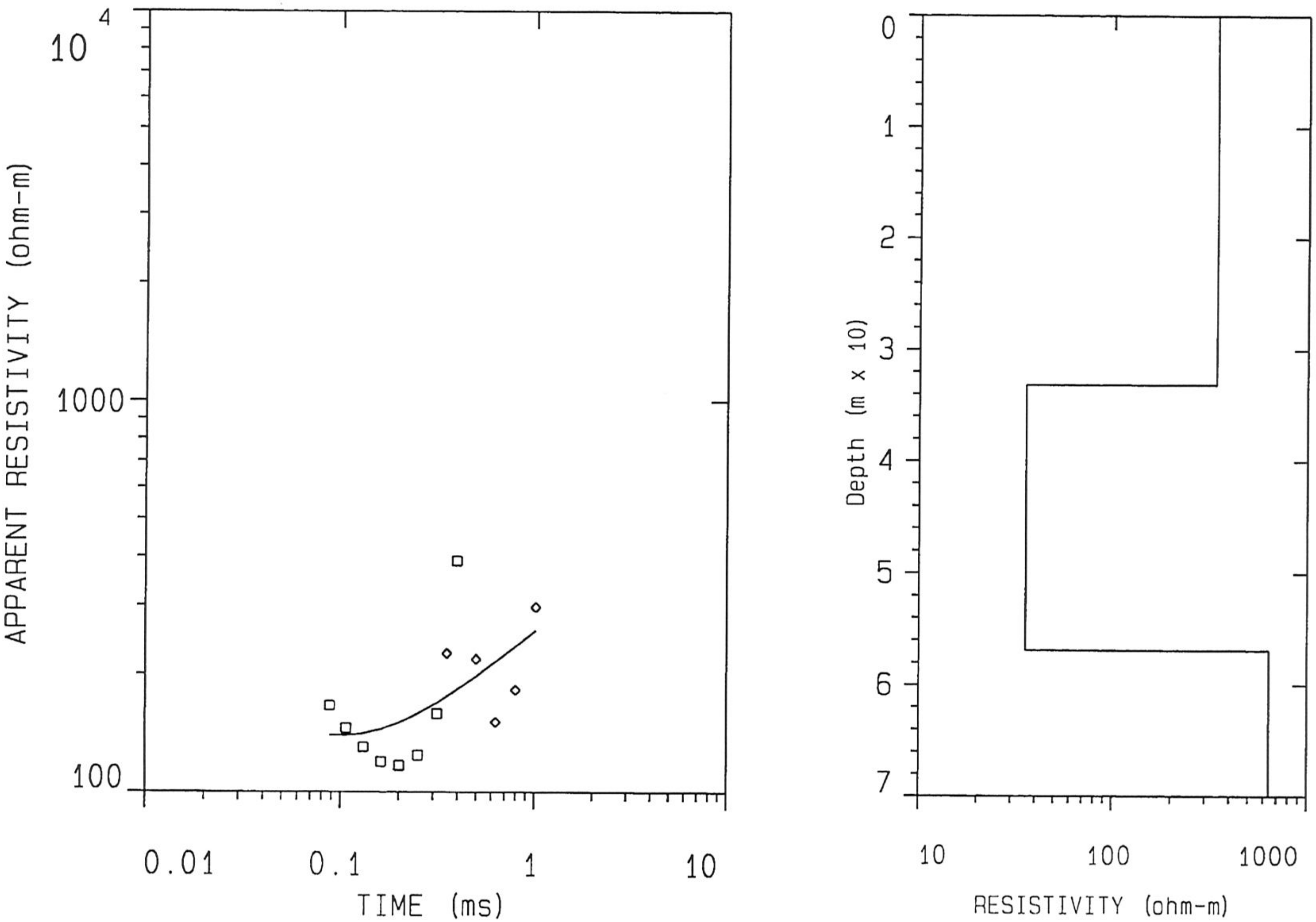

APPARENT RESISTIVITY (ohm-m)
1000
100
10
0.01
0.1
1
10
100
TIME (ms)
Depth (m x 100)
0
1
2
3
1
10
100
1000
RESISTIVITY (ohm-m)

LINE18


1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)

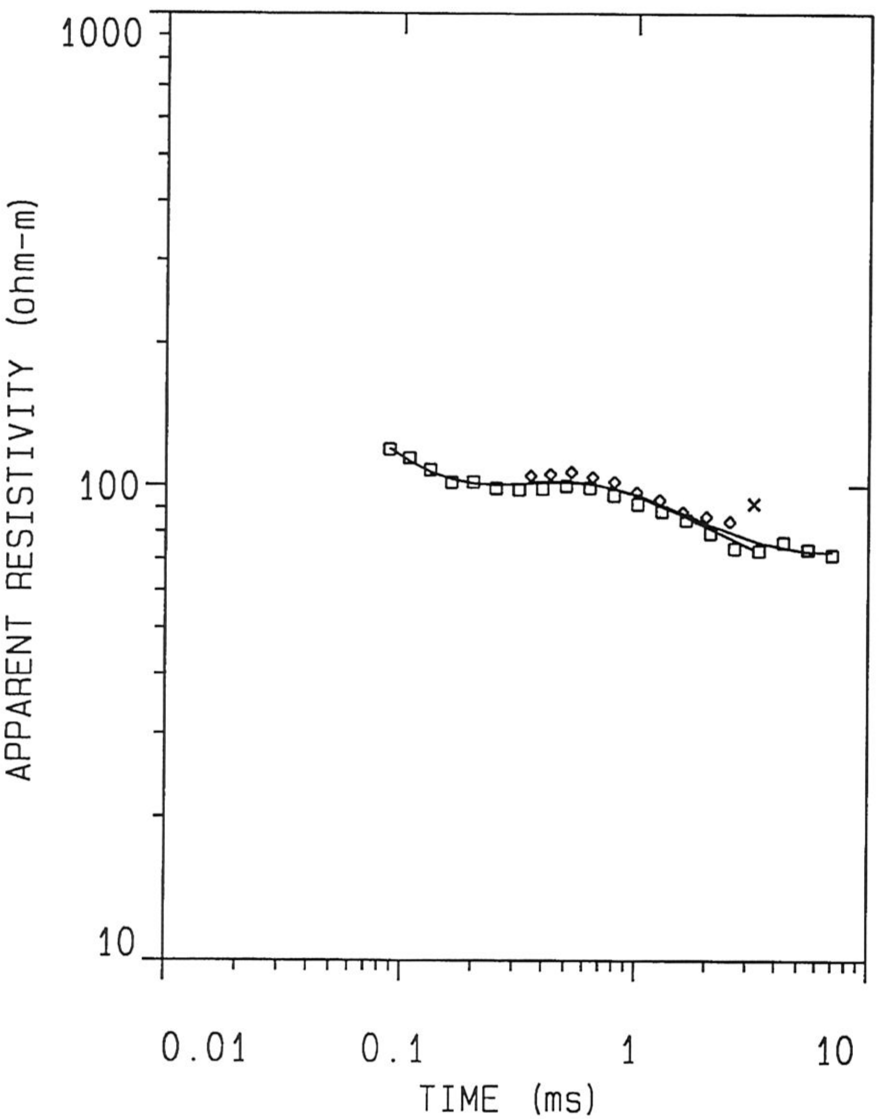

0
1
2
3
Depth (m x 100)
1
10
100
1000
RESISTIVITY (ohm-m)

LINE19

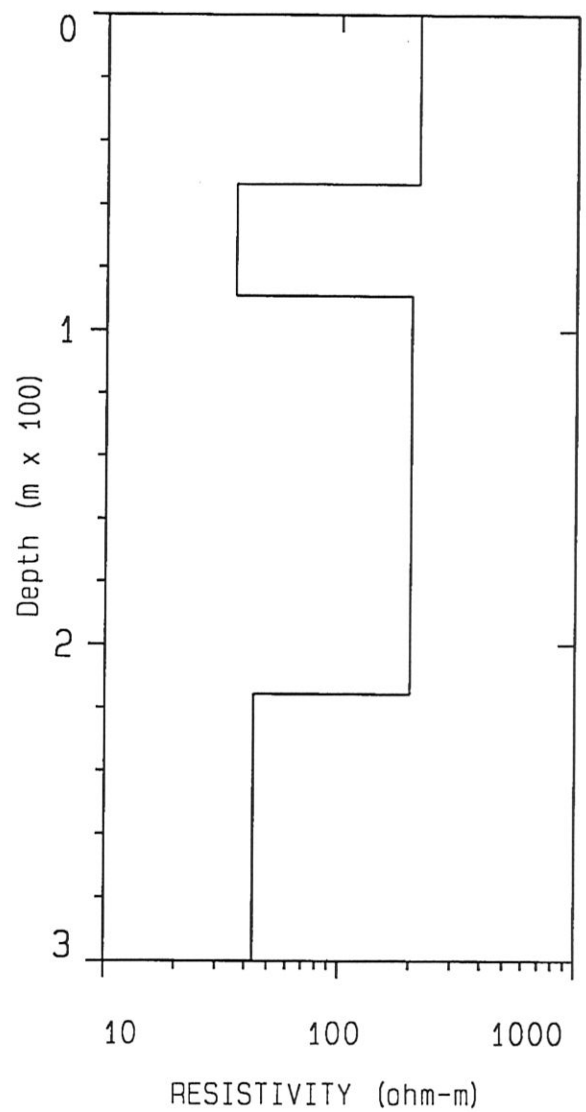


10^4
1000
100
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
3
4
5
6
7
Depth (m x 10)
10
100
1000
RESISTIVITY (ohm-m)

LINE20

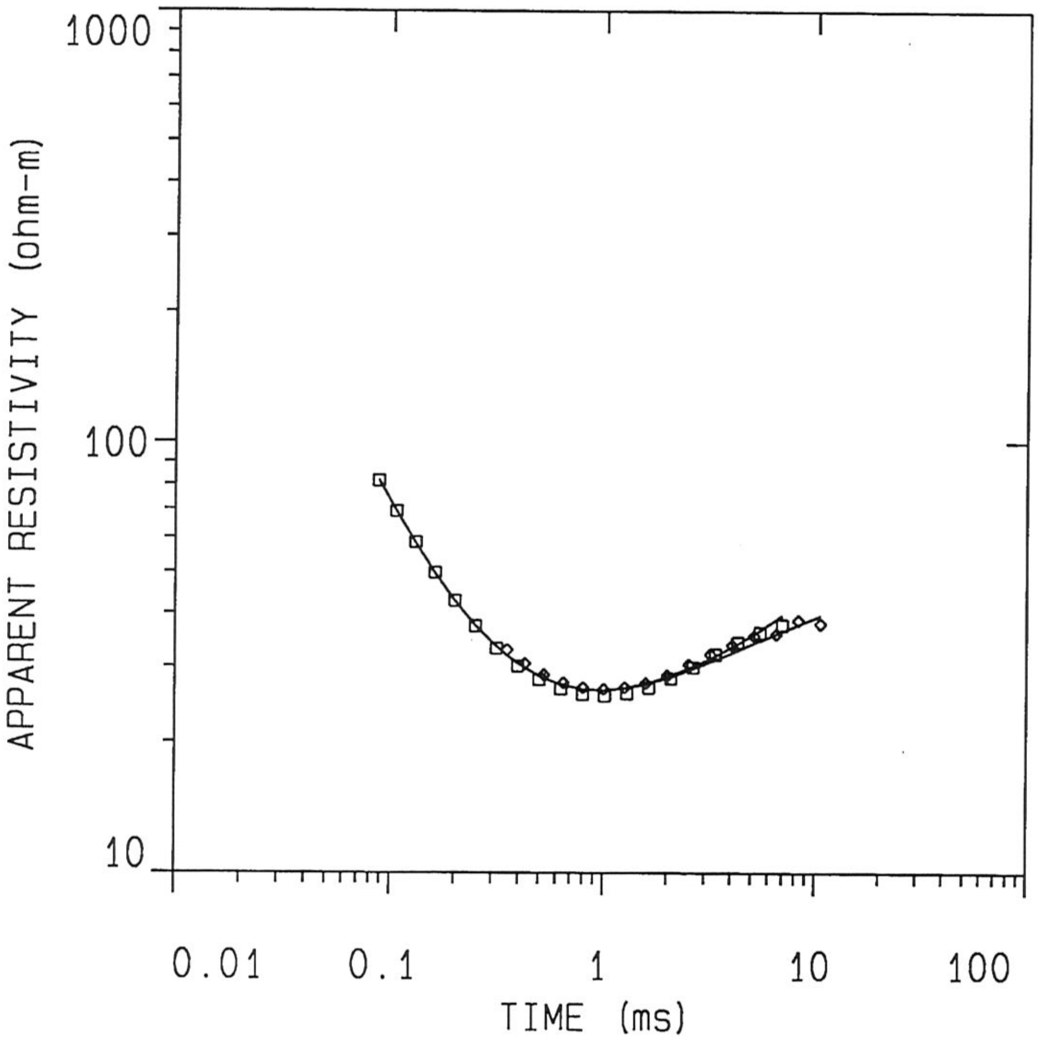


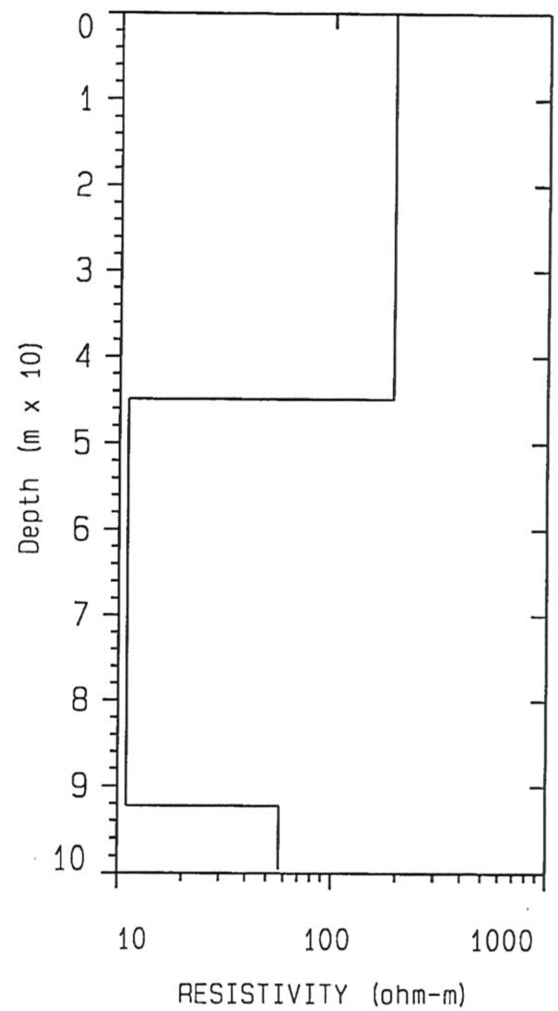
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)



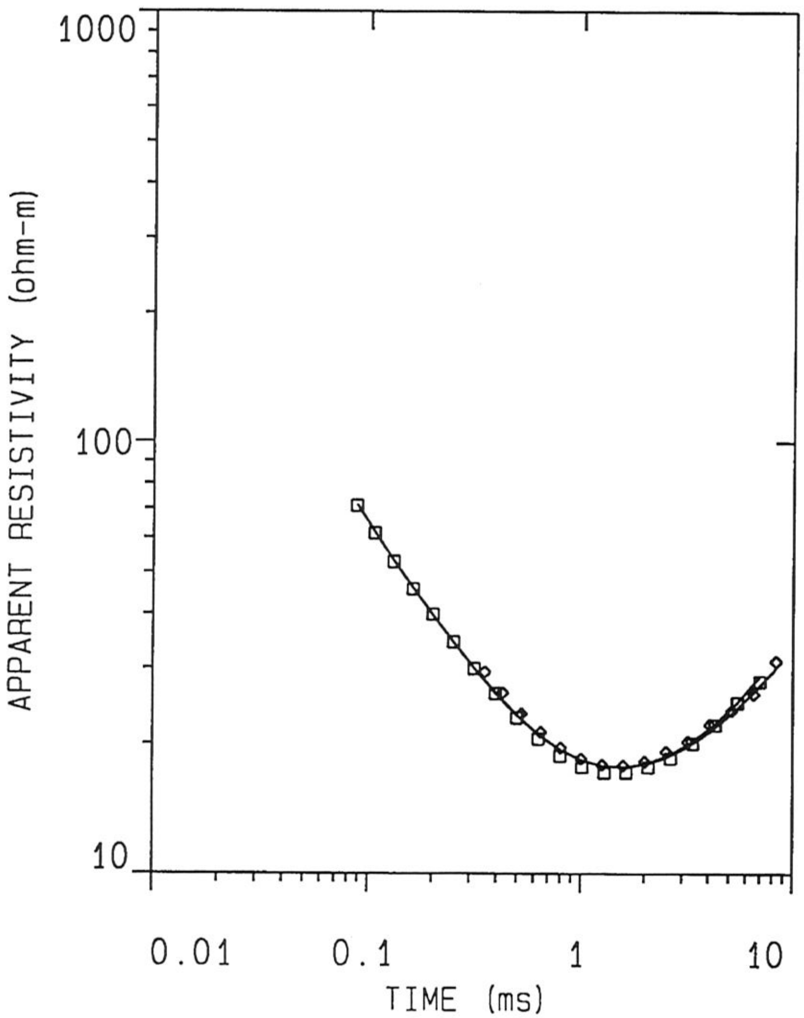
0
1
2
3
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

LINE21-2

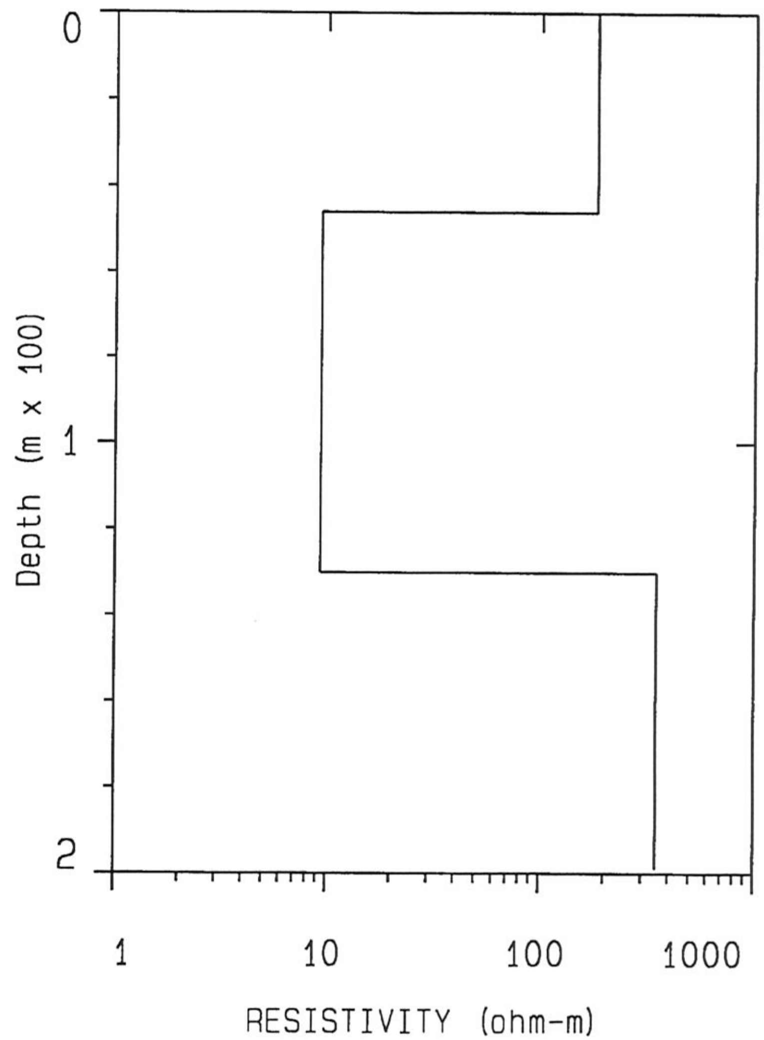

1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
100
TIME (ms)


0
1
2
3
4
5
6
7
8
9
10
Depth (m x 10)
10
100
1000
RESISTIVITY (ohm-m)

LINE22

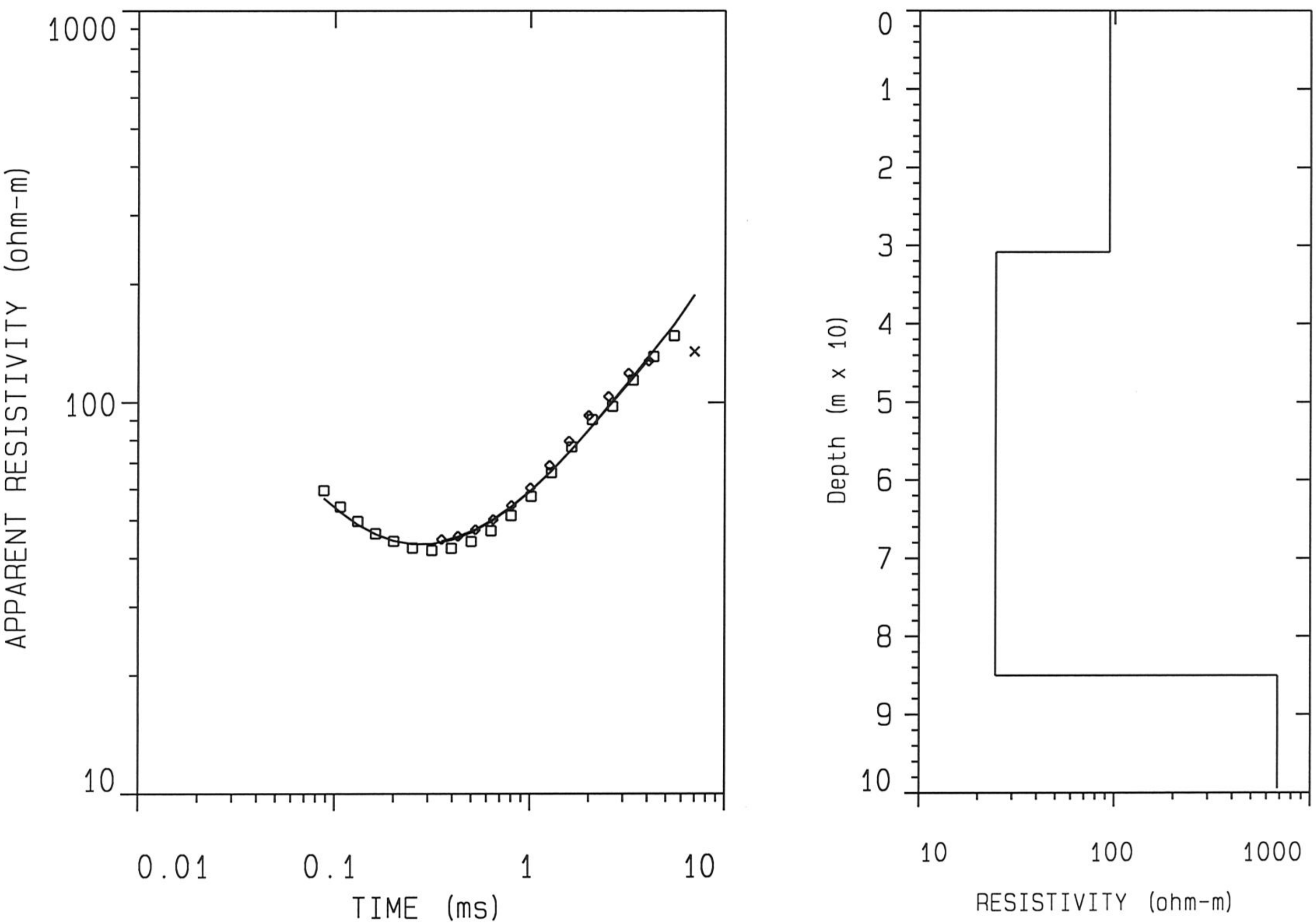


1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)



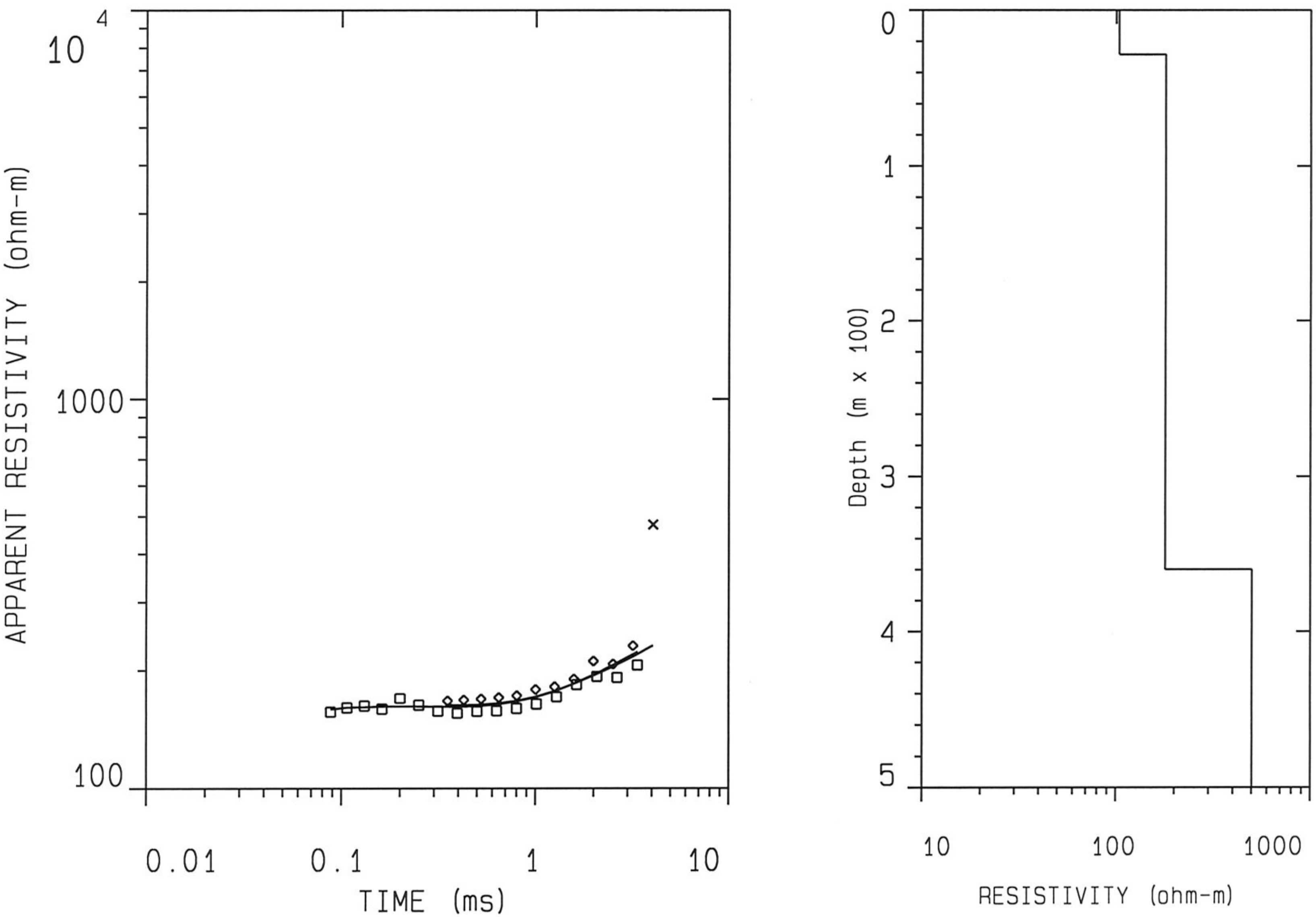
0
1
2
Depth (m x 100)
1
10
100
1000
RESISTIVITY (ohm-m)

LINE23-2

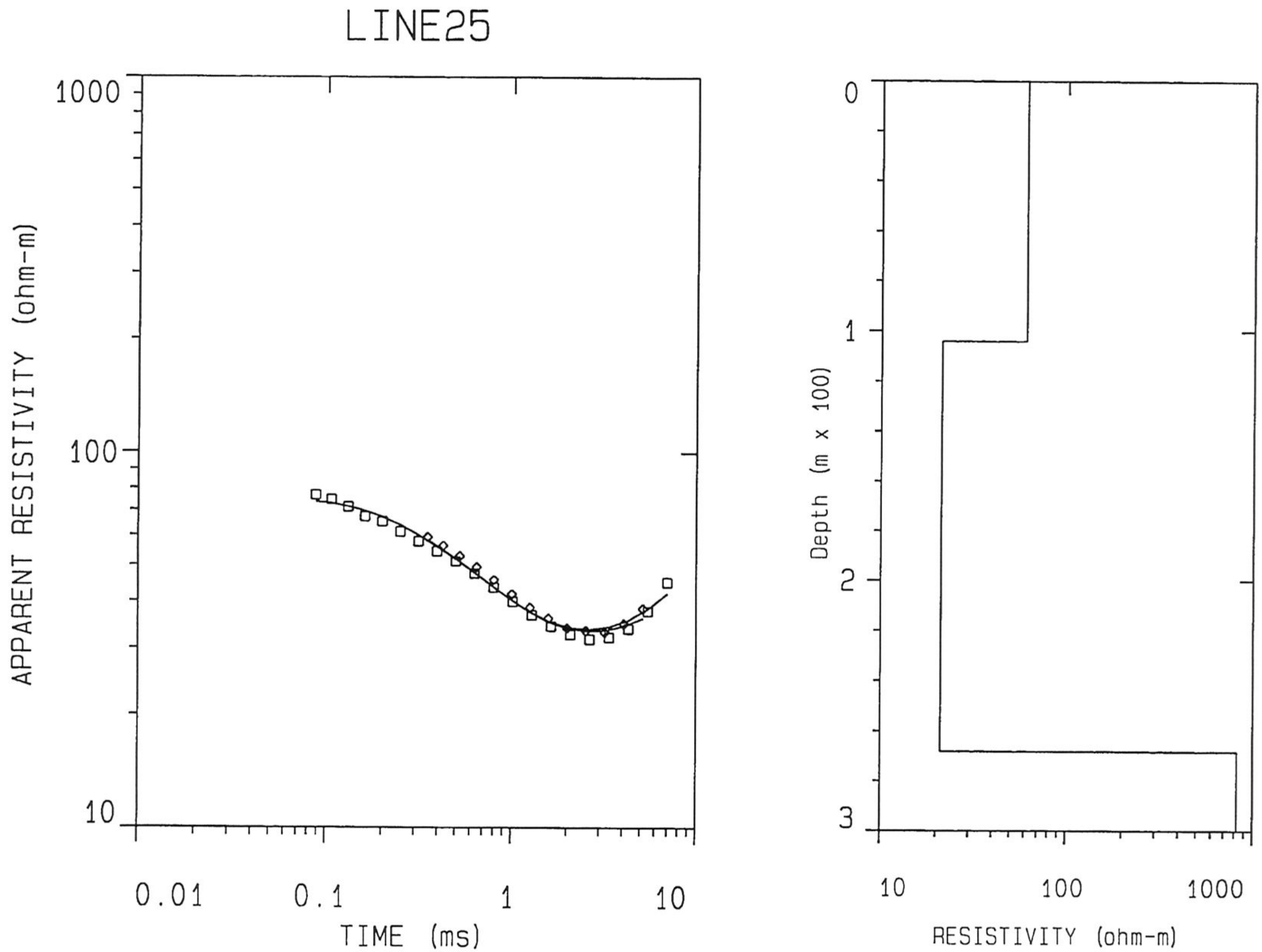


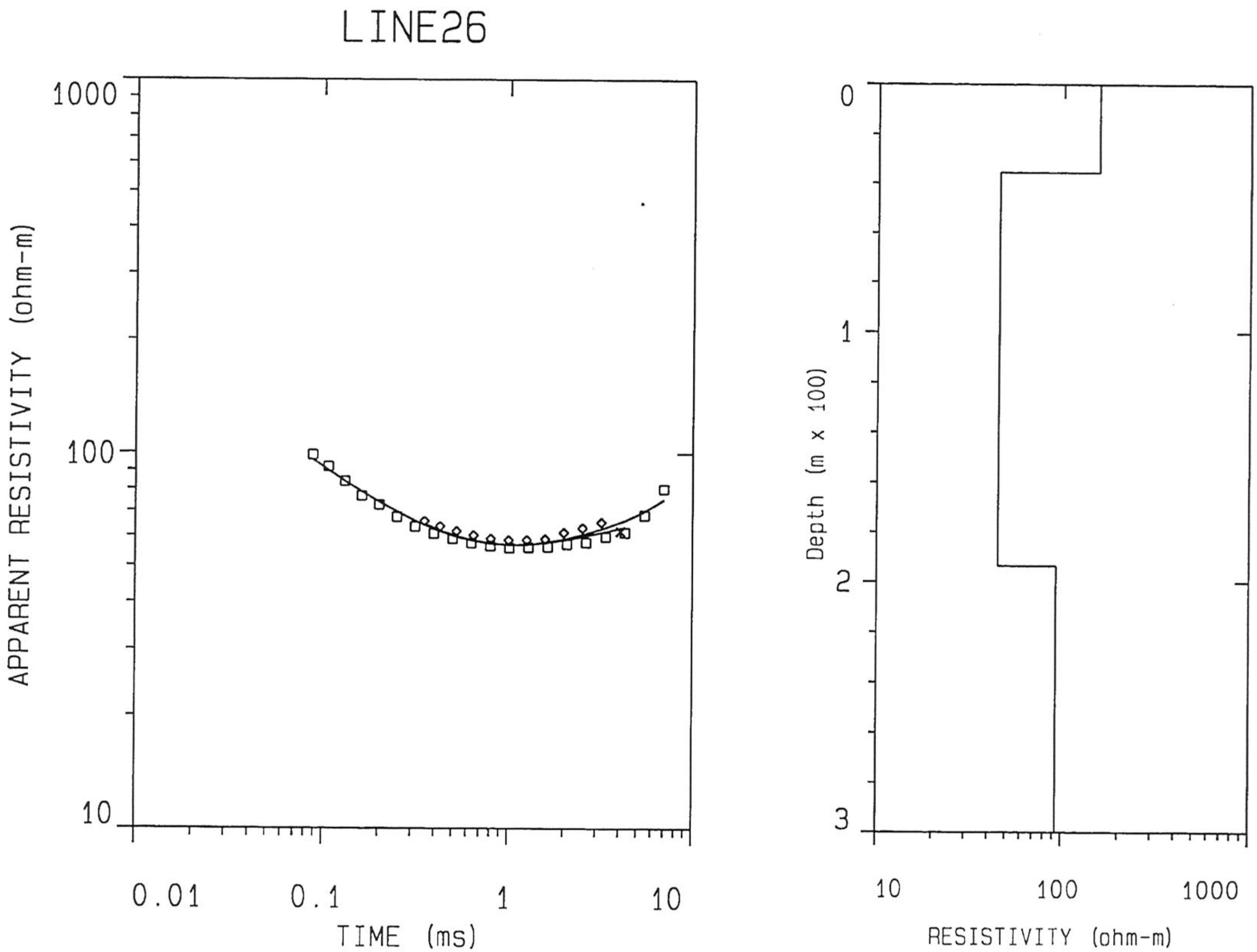
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
3
4
5
6
7
8
9
10
Depth (m x 10)
10
100
1000
RESISTIVITY (ohm-m)

LINE24-2

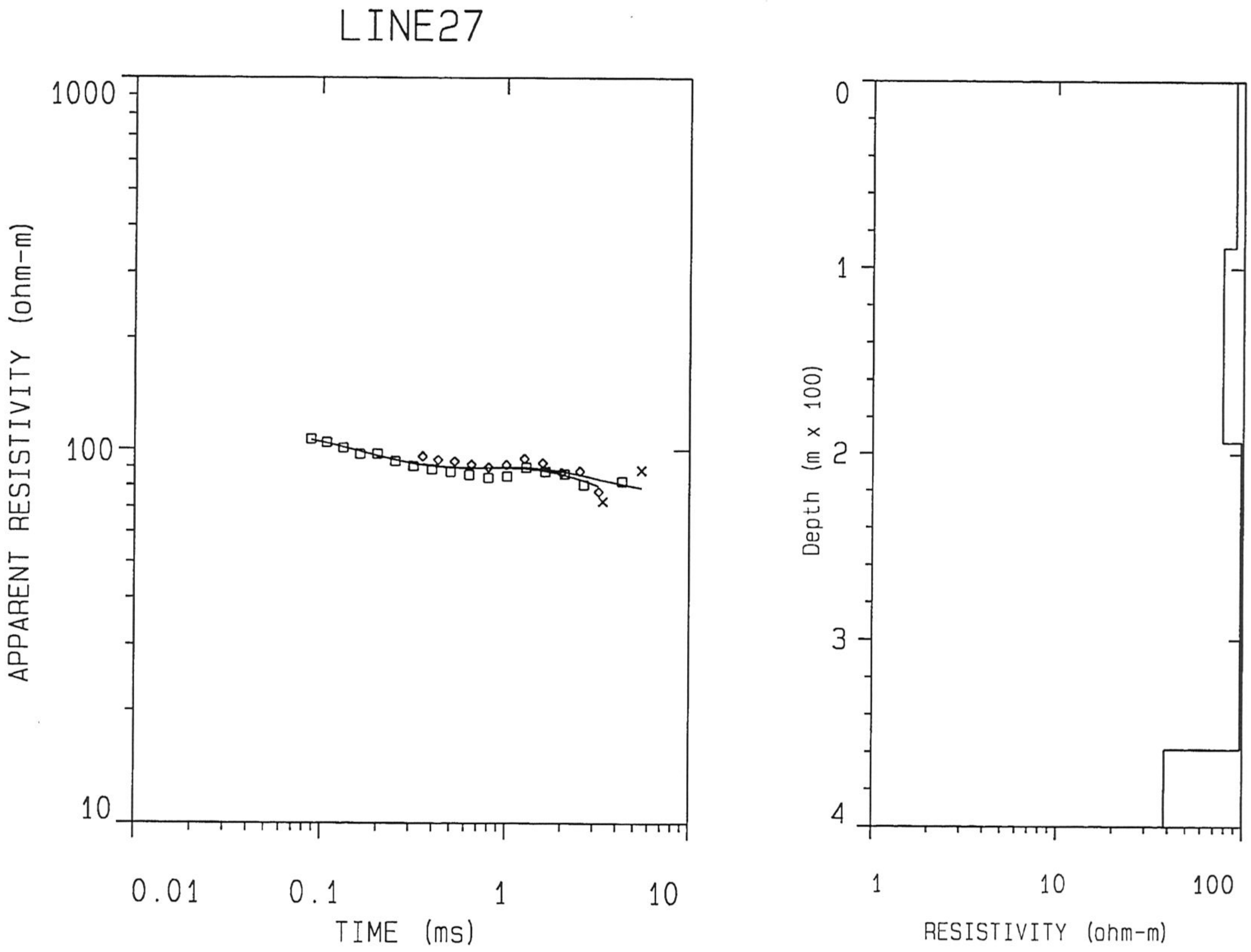


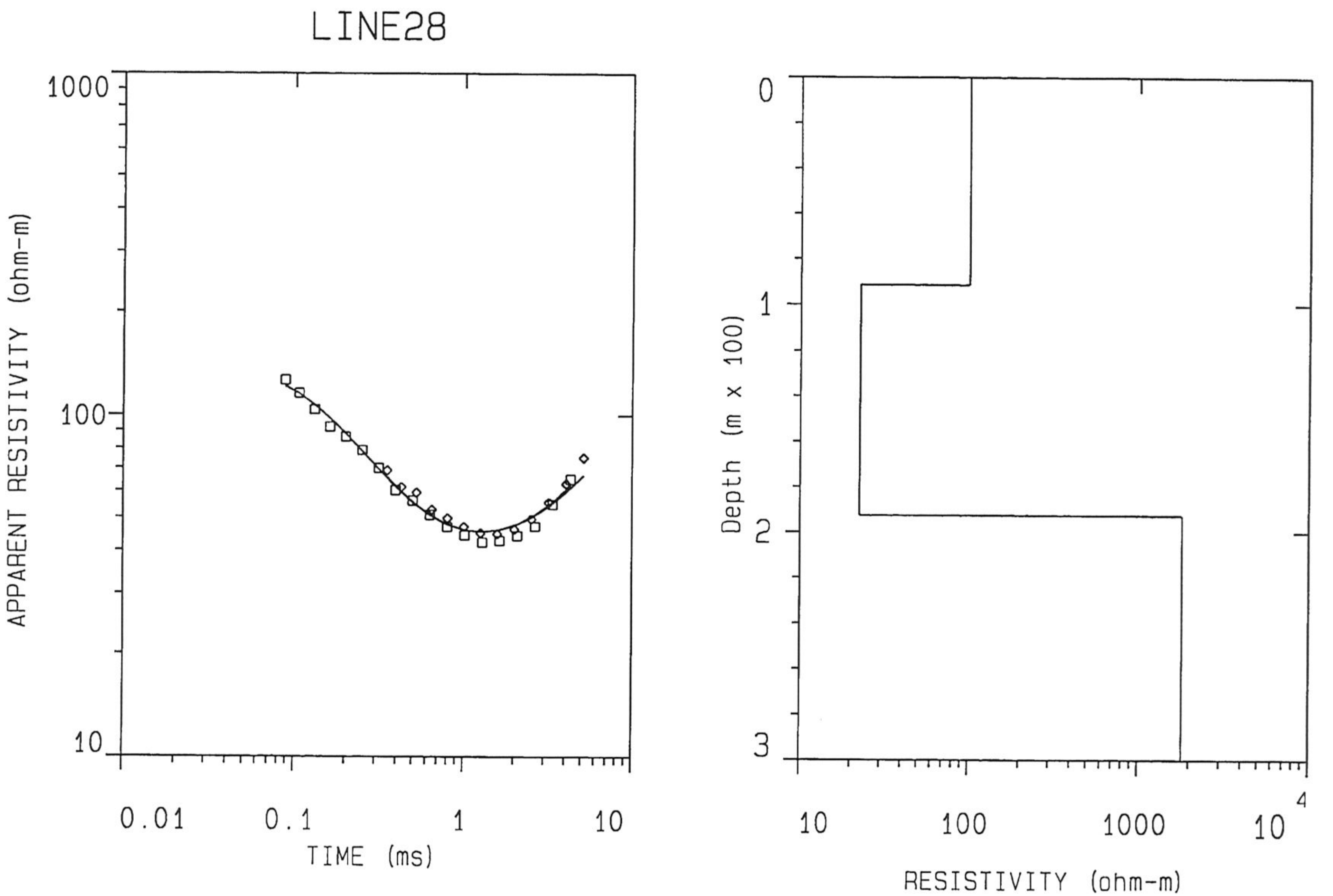
10^4
1000
100
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
3
4
5
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)


LINE25
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
3
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)



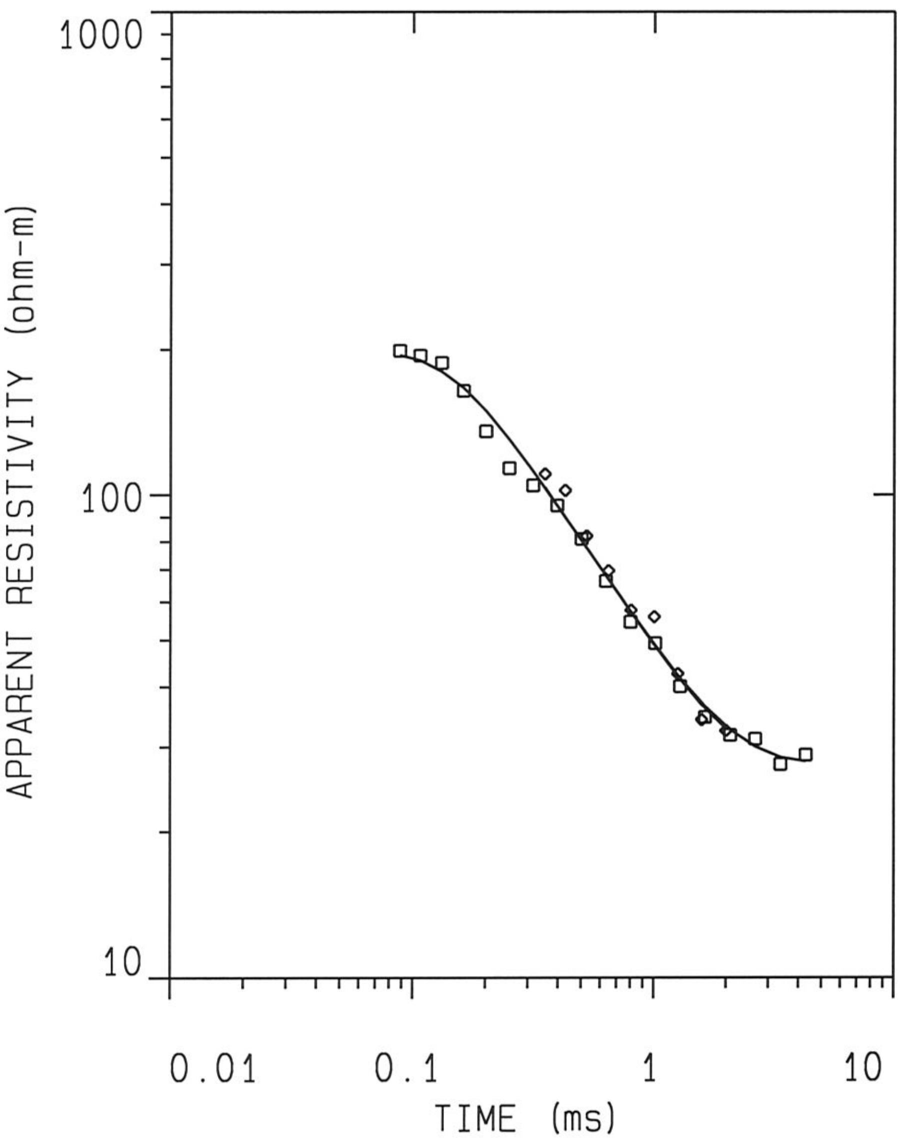
LINE26
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
3
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)


LINE27
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
3
4
Depth (m x 100)
1
10
100
RESISTIVITY (ohm-m)

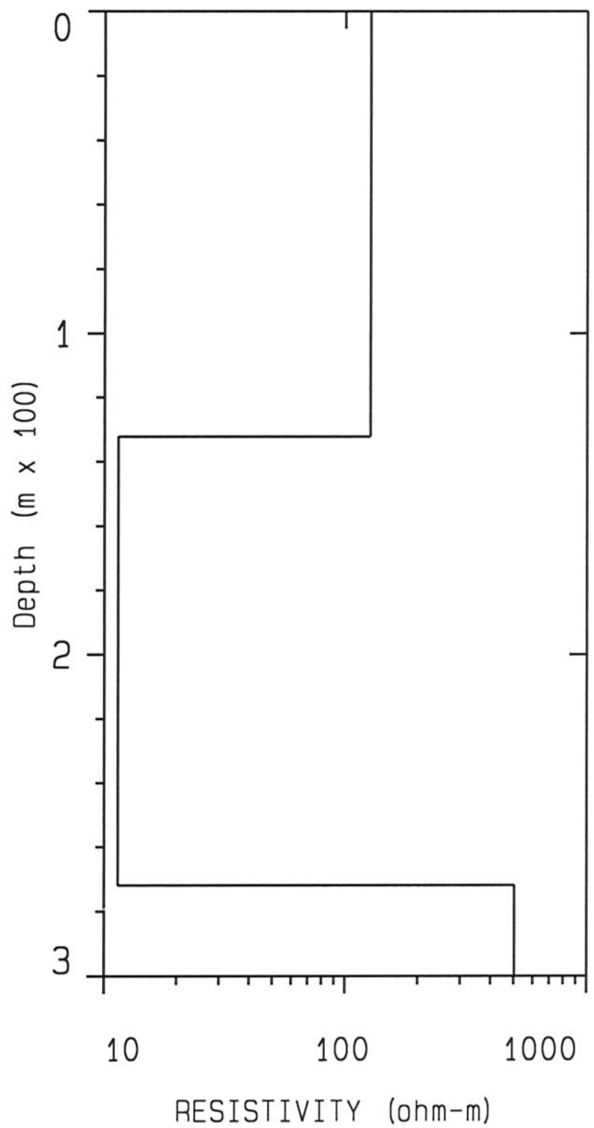


LINE28
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)
0
1
2
3
Depth (m x 100)
10
100
1000
10^4
RESISTIVITY (ohm-m)

LINE29-2

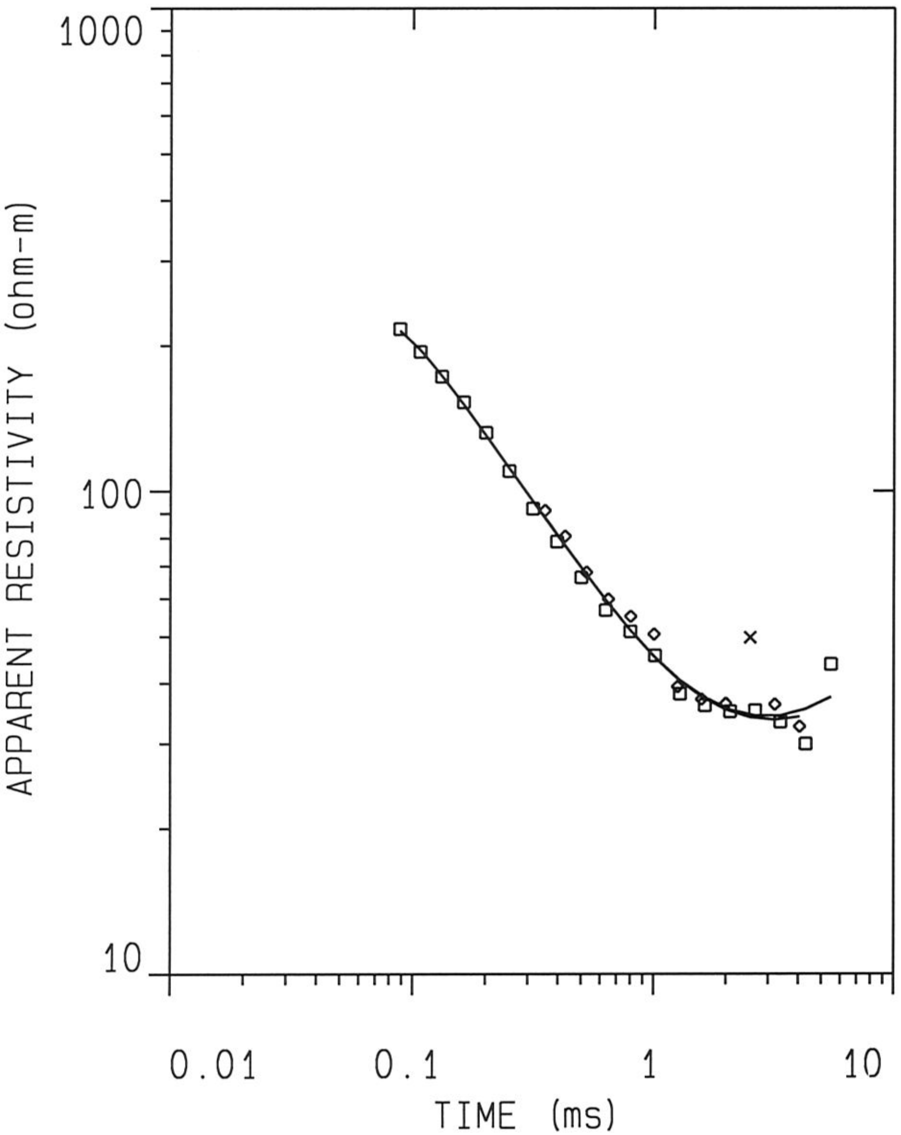


1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)

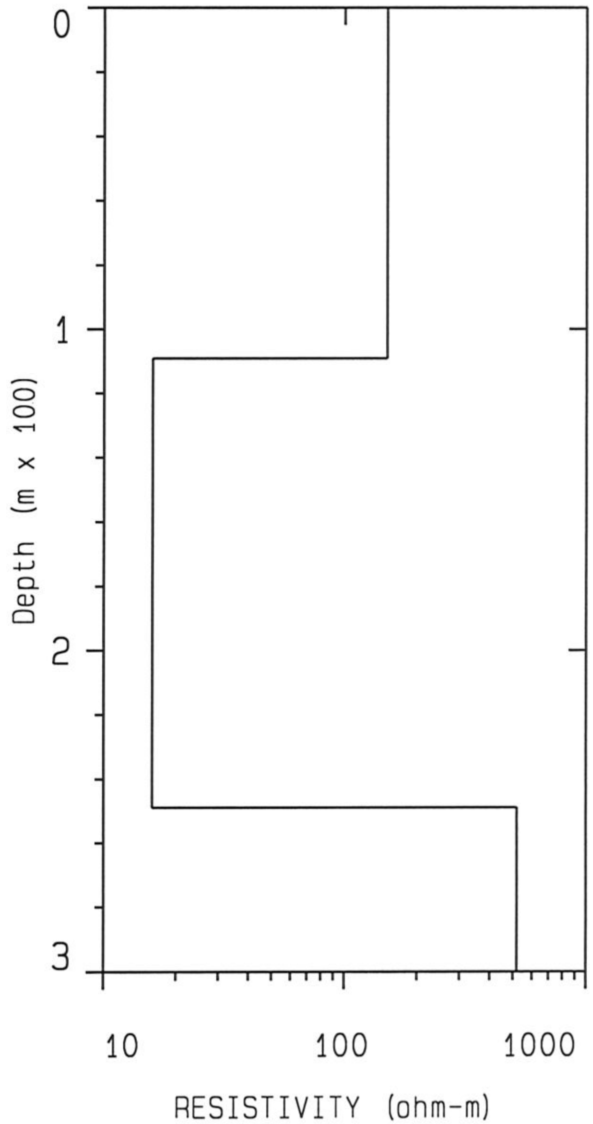


0
1
2
3
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

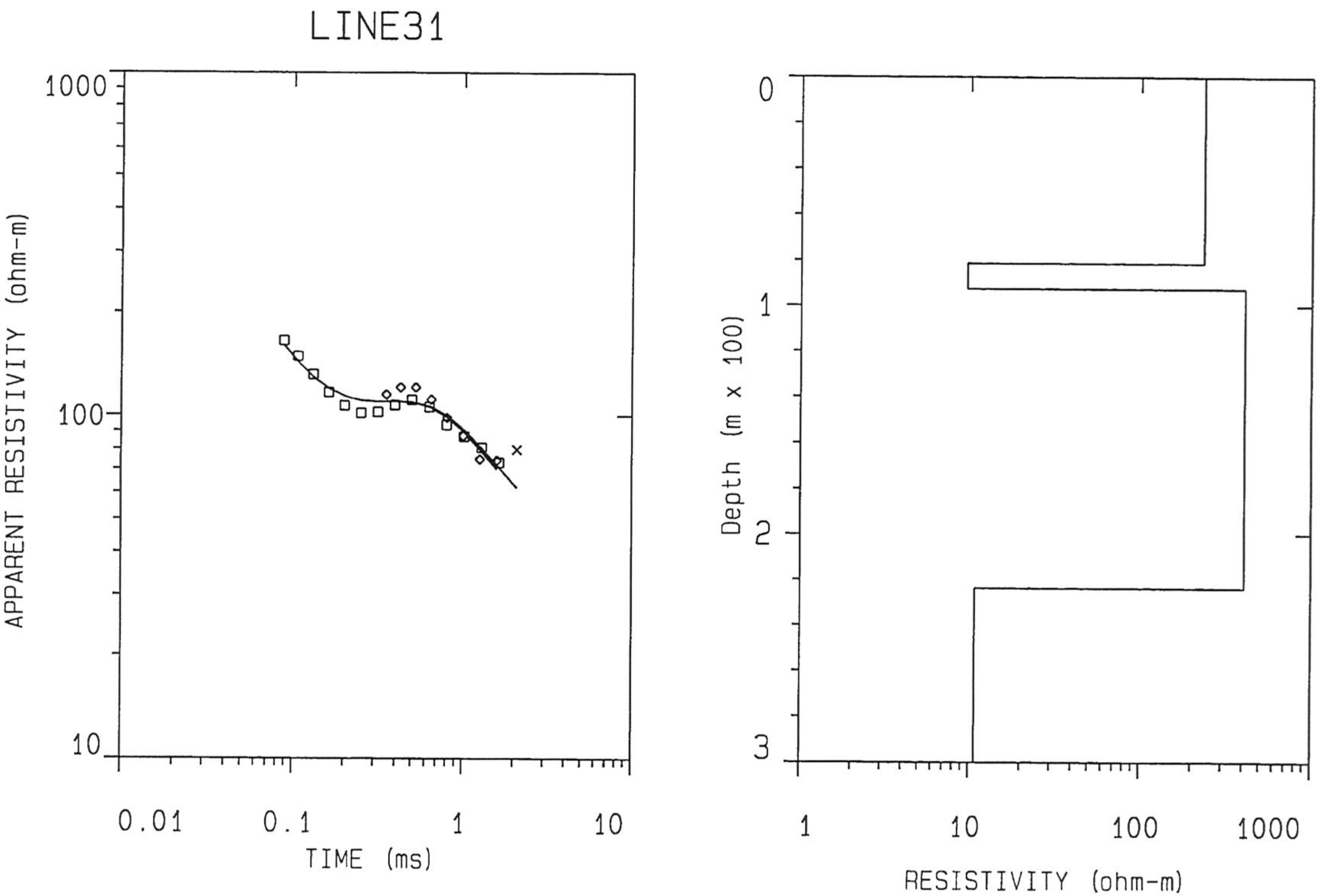
LINE30-2



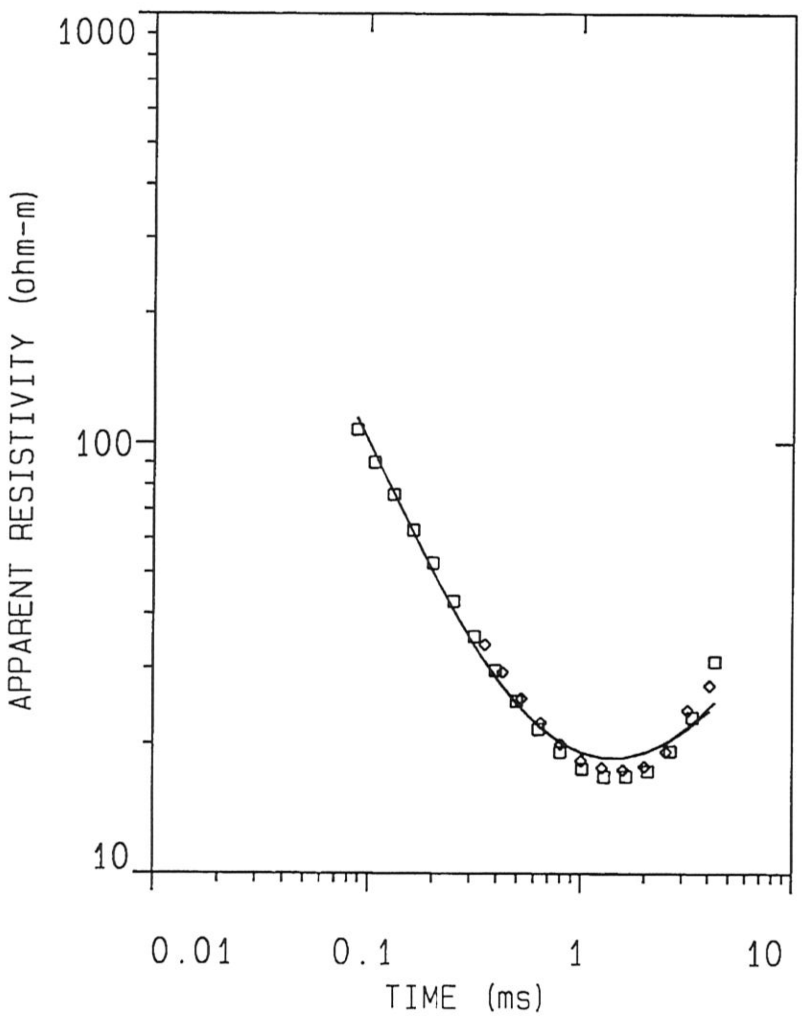
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)



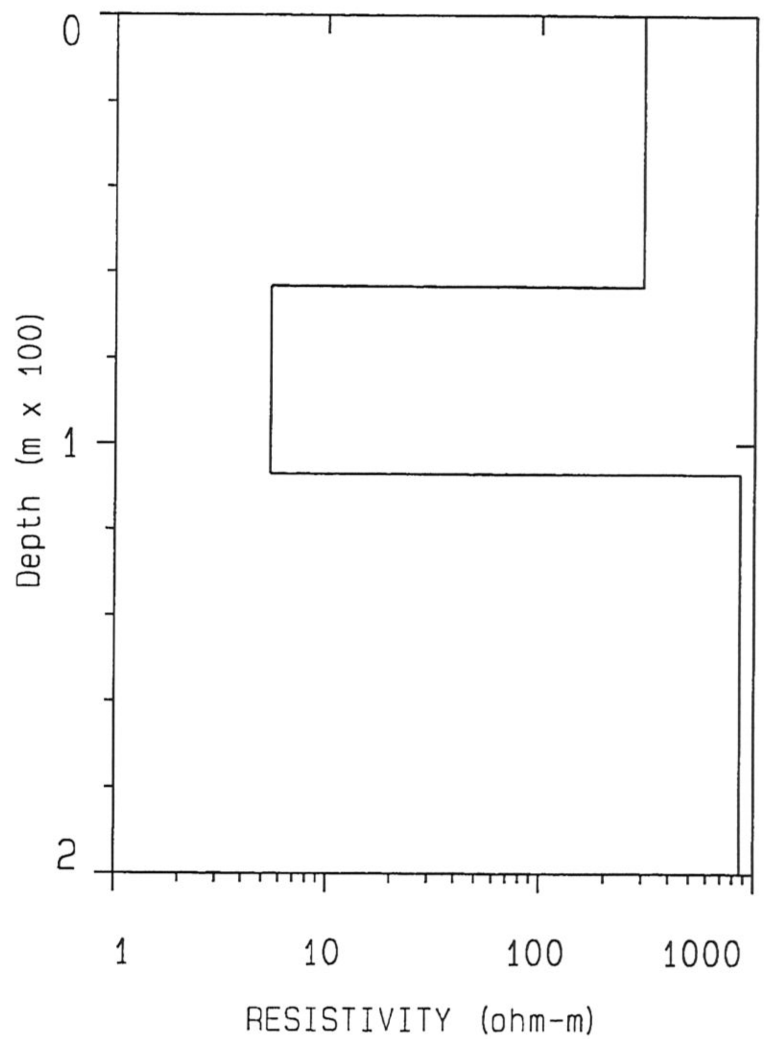
0
1
2
3
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)


LINE31
APPARENT RESISTIVITY (ohm-m)
1000
100
10
0.01
0.1
1
10
TIME (ms)
Depth (m x 100)
0
1
2
3
1
10
100
1000
RESISTIVITY (ohm-m)

LINE32

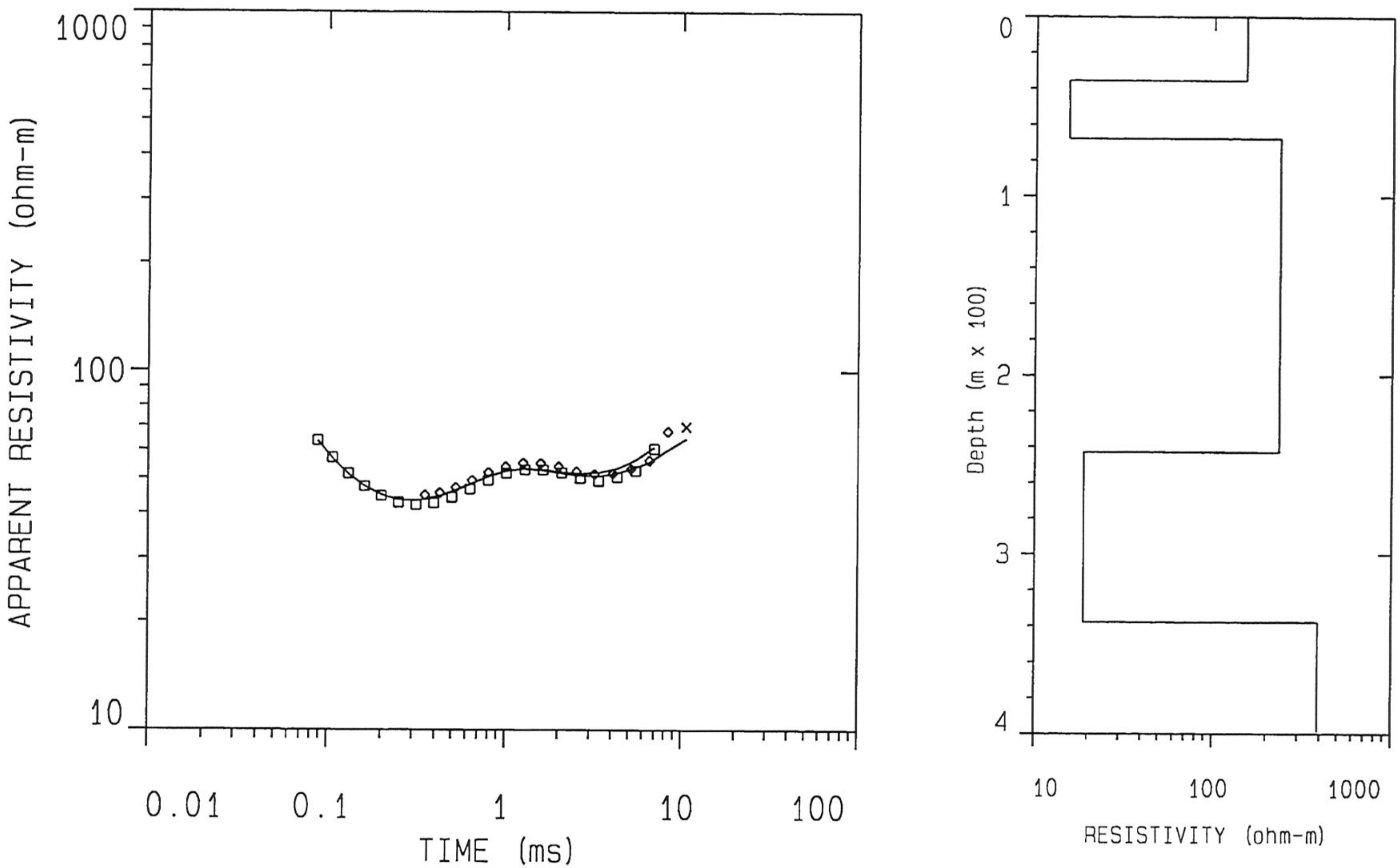


1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)



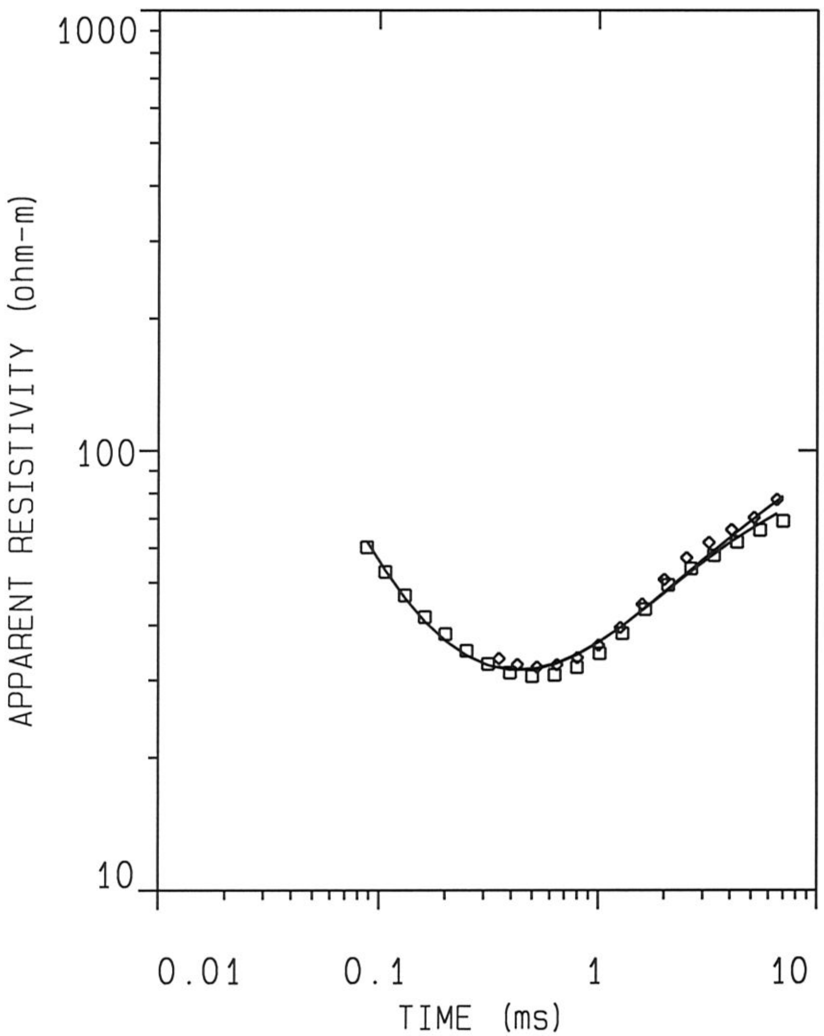
0
1
2
Depth (m x 100)
1
10
100
1000
RESISTIVITY (ohm-m)

LINE33

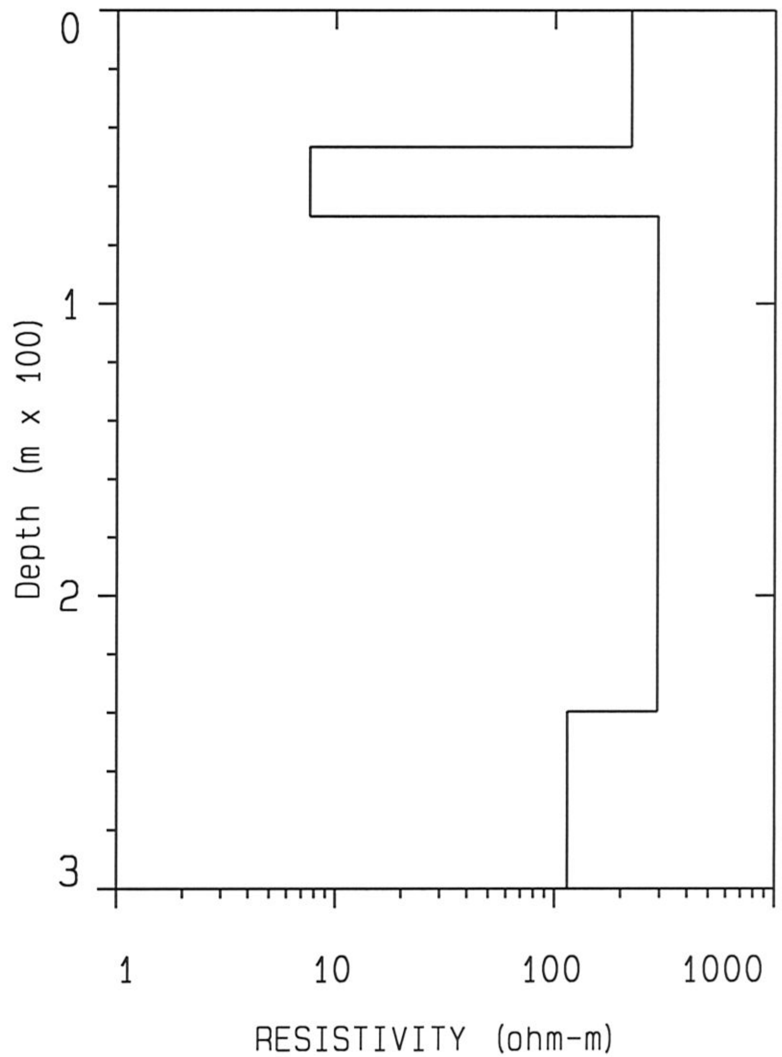


1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
100
TIME (ms)
0
1
2
3
4
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

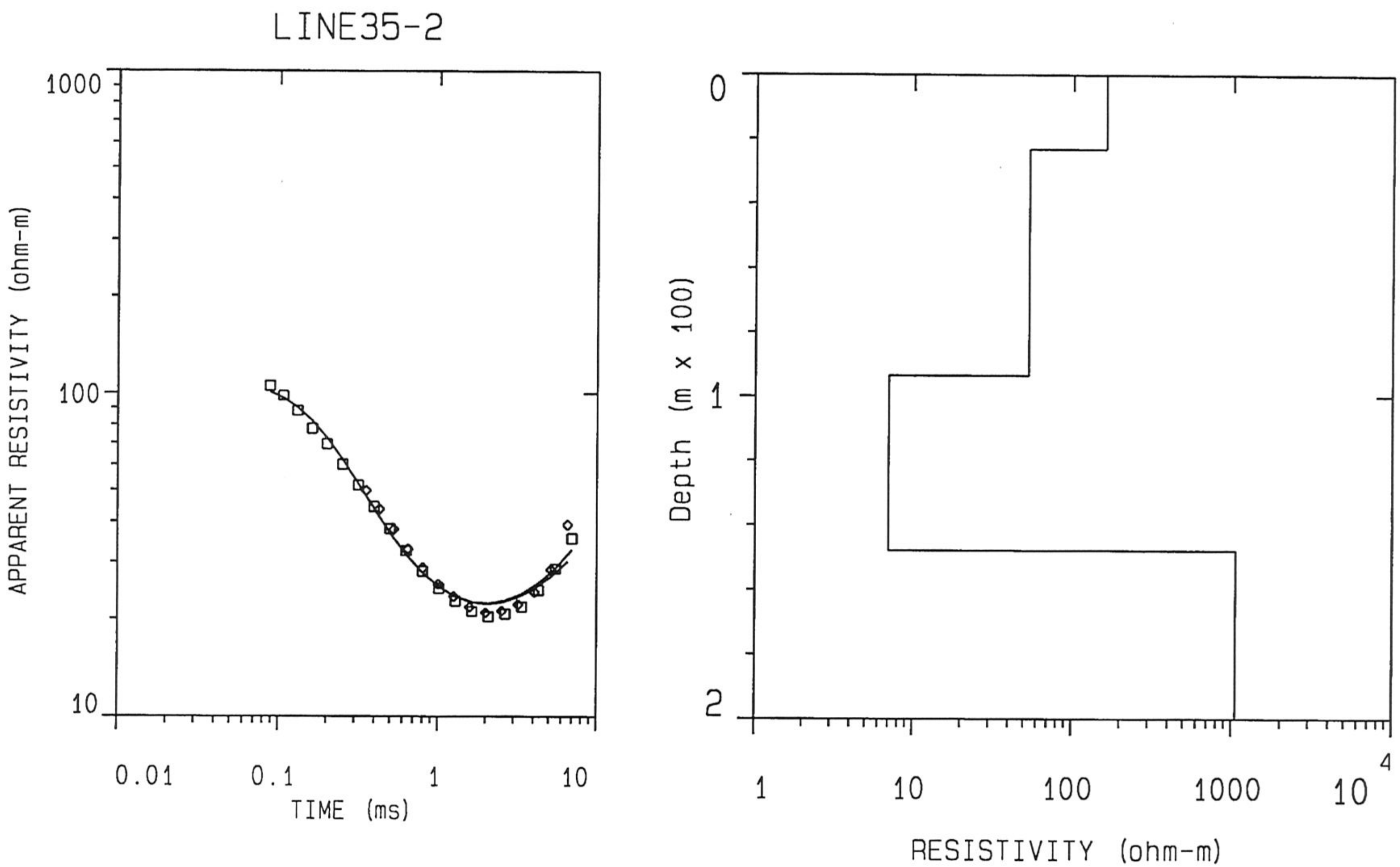
LINE34-3



1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
TIME (ms)



0
1
2
3
Depth (m x 100)
1
10
100
1000
RESISTIVITY (ohm-m)



LINE35-2
APPARENT RESISTIVITY (ohm-m)
1000
100
10
0.01
0.1
1
10
TIME (ms)
Depth (m x 100)
0
1
2
1
10
100
1000
10^4
RESISTIVITY (ohm-m)