# Groundwater Conditions at the Artesia Sewage Treatment Facility, Pahrump, Nevada

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## Introduction

The Artesia Sewage Treatment Facility is located in the southern part of the Town of Pahrump, Nevada. Figure 1 is a general topographic map of the central portion of Pahrump Valley showing the location of the facility and the area of investigation for this report. The facility is a package treatment works (PTW) that includes a rapid infiltration basin (RIB). Effluent from the PTW may be discharged into the RIB during operations. As such, it is necessary to evaluate the groundwater conditions in the area of the facility to determine if adverse impacts on water quality may result from the infiltration of treated effluent.

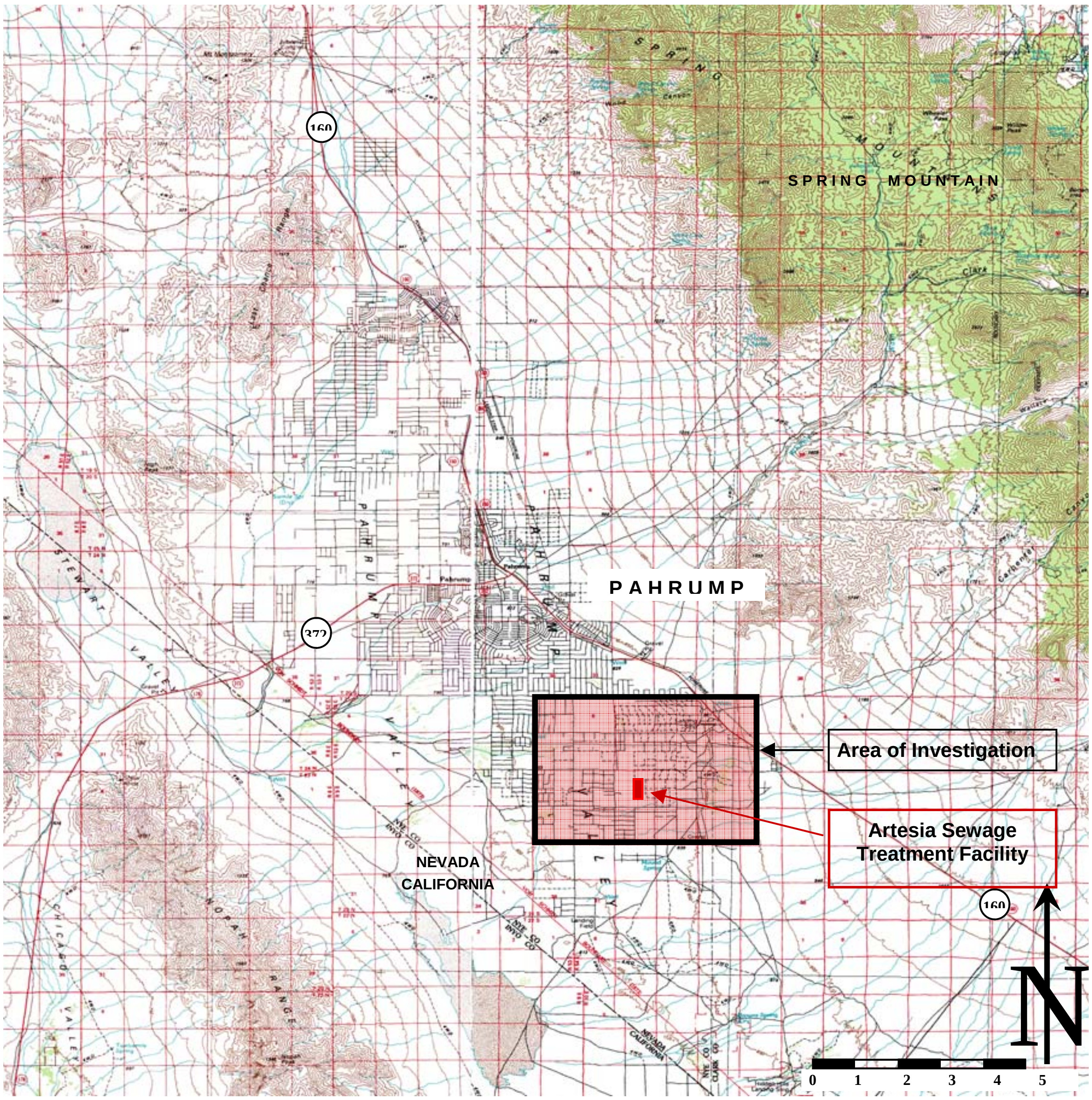



**Figure 1. Location of Artesia Sewage Treatment Facility and the Area Included in this Investigation.** Base map 1:100,000 scale Death Valley Junction and Las Vegas topographic quadrangles.

This investigation was conducted in the spring of 2005 and included the compilation of historic water quality analyses and water level data, the preparation of maps of key water quality constituents and the elevation of the water table, and research into the geologic history of the basin and naturally occurring reservoirs of nitrate and sulfate in desert soils.

Water chemistry analyses were compiled from three sources: 1) a set of historic water quality analyses by the Nevada Division of Health State Laboratory in Reno; 2) the results of analyses for samples collected in late 2004 by the Southern Nye County Conservation District; and 3) water quality monitoring results for Monitor Well #1 at the Artesia Sewage Treatment Facility. Figure 2 shows the locations of the sampled wells.

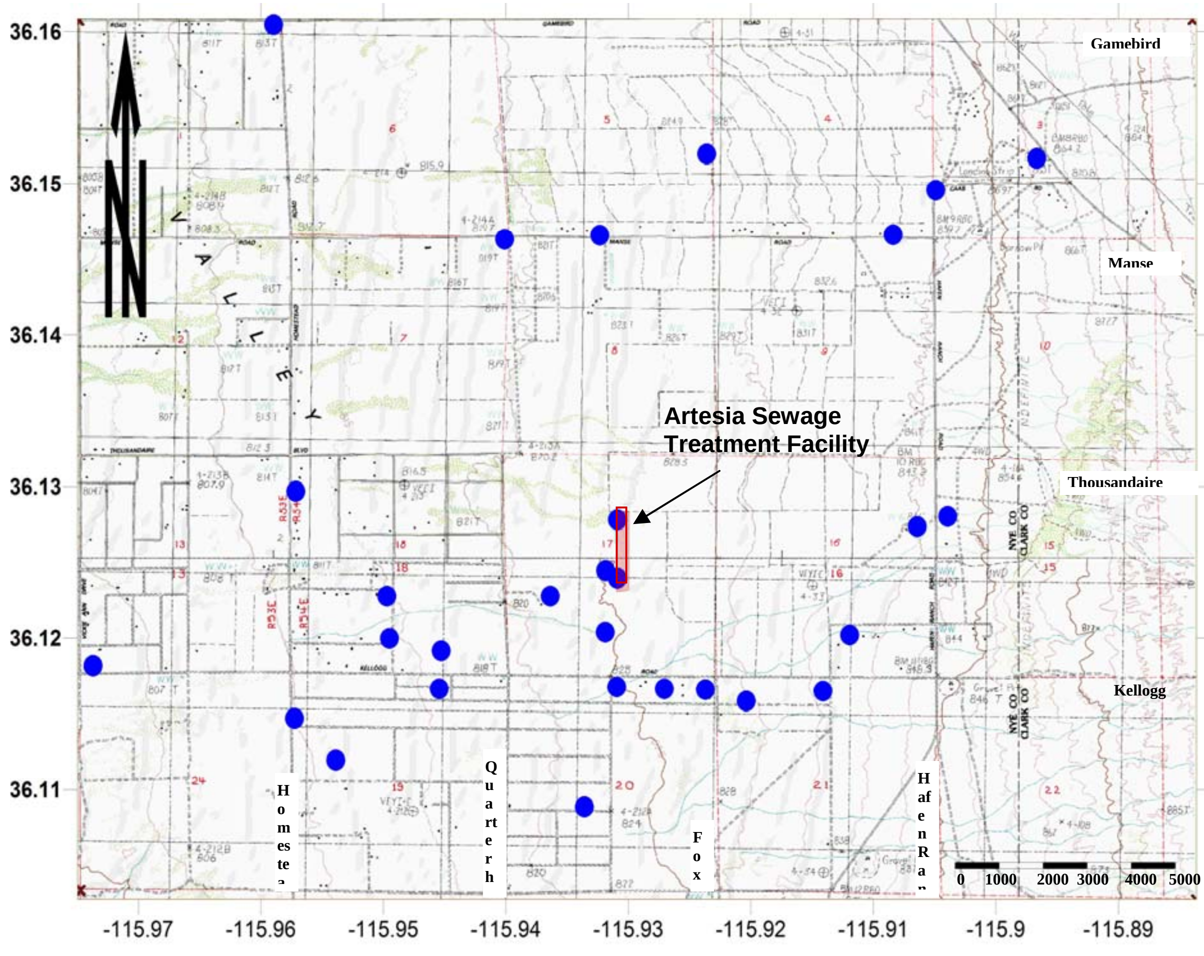



**Figure 2. Location of Wells with Water Quality Data**

The historic water quality analyses are summarized in Table 1. The analyses include standard cations and anions, selected metals, fluride, nitrate, pH, and total dissolved solids (TDS). The Conservation District analyses are summarized in Table 2 and include pH, conductivity, dissolved oxygen, biological oxygen demand, coliforms, nitrate, phenols, and TDS. The results of the analyses for Monitor Well #1 are listed in Table 3 and include TDS, nitrate, nitrite, total Kjeldahl nitrogen, total nitrogen, chloride, and pH.

**Table 1. Historic Water Quality Analyses for Southern Pahrump.**

| NDH TEST NO. | SAMPLE DATE | T/R | Sect | GENERAL LOCATION | TDS @103 deg C (ppm) | CA (ppm) | MG (ppm) | NA (ppm) | K (ppm) | SO4 (ppm) | CL (ppm) | NO3 (ppm) | HCO3 (ppm) | CO3 (ppm) | FL (ppm) | AS (ppm) | FE (ppm) | MN (ppm) | ZN (ppm) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46886 | 7/17/1986 | 21S / 54E | 19 | NE1/4 | 318 | 54 | | 12 | 1 | 46 | 34 | 16.8 | | 0 | 0.26 | 0.004 | 10.60 | 0.02 | | 7.58 |
| 55171 | 11/10/1980 | 21S / 54E | 17 | SE COR.- NE1/4 NE1/4 | 2264 | 259 | 127 | 175 | 2 | 1178 | 126 | 0.3 | 205 | 0 | 0.15 | 0.000 | 1.52 | 0.09 | 3.93 | 7.63 |
| 55172 | 11/10/1980 | 21S / 54E | 20 | NE COR.- NW1/4 NE1/4 | 2176 | 317 | 149 | 71 | 2 | 1043 | 178 | 42.5 | 232 | 0 | 0.14 | 0.000 | 0.07 | 0.00 | 1.83 | 7.50 |
| 55173 | 11/10/1980 | 21S / 54E | 19 | NE1/4 NW1/4 | 679 | 106 | 51 | 16 | 1 | 122 | 128 | 72.1 | 176 | 0 | 0.15 | 0.000 | 0.38 | 0.01 | 0.42 | 7.85 |
| 55174 | 11/10/1980 | 21S / 54E | 18 | SE COR.- NE1/4 SW1/4 | 1846 | 265 | 126 | 56 | 2 | 404 | 325 | 389.0 | 166 | 0 | 0.11 | 0.000 | 0.27 | 0.02 | 0.32 | 7.55 |
| 59145 | 4/15/1982 | 21S / 53E | 1 | NE1/4 | 502 | 53 | 56 | 12 | 3 | 109 | 66 | 8.2 | 200 | 6 | 0.54 | 0.005 | 0.05 | 0.01 | 0.02 | 8.20 |
| 68012 | 4/3/1985 | 21S / 54E | 18 | NE1/4 | 562 | | | 12 | 1 | 117 | 110 | 28.9 | | 0 | 0.15 | 0.001 | 0.01 | 0.00 | | 8.05 |
| 69894 | 10/24/1985 | 21S / 54E | 5 | SE1/4 NE1/4 | 431 | 71 | 49 | 18 | 2 | 84 | 2 | 10.9 | 376 | 0 | 0.16 | < 0.003 | 0.40 | 0.02 | 0.00 | 7.69 |
| 69895 | 10/24/1985 | 21S / 54E | 3 | NE1/4 SW1/4 | 235 | 49 | 23 | 5 | 1 | 32 | 1 | 2.3 | 234 | 0 | 0.13 | < 0.003 | 0.00 | 0.00 | 0.00 | 7.91 |
| 71327 | 4/3/1986 | 21S / 54E | 5 | | 1042 | 53 | | 184 | 3 | 503 | 12 | 13.2 | 342 | 0 | 0.15 | < 0.003 | 0.00 | 0.04 | 0.03 | 7.32 |
| 73371 | 9/11/1986 | 21S / 54E | 7 | | 2225 | 9 | | 739 | 1 | 1199 | 114 | 17.7 | | 0 | 0.22 | < 0.003 | 0.01 | 0.00 | | 7.66 |
| 73695 | 10/7/1986 | 21S / 54E | | | 2247 | | | 13.7 | | 1285 | | | | | | | | | | |
| 74496 | 1/6/1987 | 21S / 54E | 18 | SW COR. | 998 | 160 | | 19 | 1 | 286 | 213 | 64.0 | | 0 | 0.19 | < 0.003 | 0.16 | 0.01 | | 7.63 |
| 75498 | 4/7/1987 | 21S / 54E | 4 | | 320 | 64 | | 8 | 1 | 46 | 2 | 5.2 | | 0 | 0.26 | 0.003 | 0.01 | 0.00 | | 7.68 |
| 76763 | 8/13/1987 | 21S / 54E | 4 | SW1/4 SE1/4 | 522 | 86 | 42 | 31 | 1 | 91 | 36 | 16.9 | 381 | 0 | 0.16 | < 0.003 | 0.02 | 0.00 | 0.02 | 7.59 |
| 77638 | 11/5/1987 | 21S / 54E | 5 | SW1/4 SE1/4 | 1856 | 183 | | 155 | 3 | 880 | 41 | 21.9 | | 0 | 0.19 | < 0.003 | 0.22 | 0.01 | | 7.58 |
| 78112 | 1/7/1988 | 21S / 54E | 20 | NE1/4 NE1/4 | 955 | 141 | 71 | 24 | 2 | 346 | 68 | 121.8 | 217 | 0 | 0.17 | < 0.003 | 0.23 | 0.01 | 0.62 | 7.75 |
| 78113 | 1/7/1988 | 21S / 54E | 20 | NE1/4 NE1/4 | 1277 | 172 | 80 | 65 | 2 | 329 | 138 | 285.4 | 183 | 0 | 0.18 | < 0.003 | 0.12 | 0.00 | 0.07 | 7.80 |
| 78114 | 1/7/1983 | 21S / 54E | 17 | SW1/4 NE1/4 | 1974 | 205 | 132 | 161 | 2 | 997 | 82 | 44.1 | 300 | 0 | 0.15 | < 0.003 | 0.58 | 0.02 | 0.16 | 7.61 |
| 78115 | 1/7/1983 | 21S / 54E | 17 | SW1/4 SE1/4 | 2192 | 294 | 145 | 105 | 2 | 813 | 250 | 231.9 | 249 | 0 | 0.13 | < 0.003 | 0.18 | 0.02 | 2.00 | 7.59 |
| 78116 | 1/7/1983 | 21S / 54E | 16 | SE1/4 SW1/4 | 502 | 76 | 36 | 29 | 1 | 179 | 23 | 7.2 | 234 | 0 | 0.13 | < 0.003 | 0.19 | 0.00 | 0.02 | 7.91 |
| 85170 | 1/3/1990 | 21S / 54E | 21 | NW1/4 NE1/4 | 238 | 43 | 23 | 9 | 1 | 50 | 2 | 2.5 | 185 | 10 | 0.28 | < 0.003 | 0.09 | 0.00 | 0.15 | 8.22 |

| Table 2. Water Quality Analyses from the Southern Nye County Conservation District | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LATITUDE | LONGITUDE | DTGW | pH | Temp. | Cond. | DO | BOD | Coliforms | NO3 | Phenols | Lab TDS | Calc TDS |
| 36.217064 | -116.083583 | 60 | 7.6 | 20.8 | 334 | 7.1 | ND | 0 | 0.44 | ND | | 153 |
| 36.087489 | -115.912301 | 0 | 8.4 | 18.9 | 343 | 7.0 | ND | 0 | 0.26 | ND | | 162 |
| 36.140087 | -115.979945 | 75 | 8.2 | 18.6 | 345 | 6.5 | ND | 0 | 0.13 | ND | | 164 |
| 36.128046 | -115.903940 | 90 | 7.5 | 17.6 | 355 | 9.5 | ND | 0 | 0.35 | ND | | 174 |
| 36.127368 | -115.906421 | 76 | 8.3 | 20.8 | 359 | 7.3 | ND | 0 | 0.32 | ND | | 178 |
| 36.137929 | -115.987060 | | 8.0 | 18.3 | 372 | 6.1 | ND | 0 | 0.21 | ND | | 192 |
| 36.208525 | -116.089777 | 60 | 7.6 | 19.8 | 372 | 7.2 | ND | 0 | 0.24 | ND | | 192 |
| 36.282489 | -116.075694 | 54 | 6.9 | 22.1 | 379 | 5.9 | ND | 0 | ND | ND | | 199 |
| 36.349366 | -116.032175 | | 8.1 | 22.1 | 380 | 4.2 | ND | 0 | 1.00 | ND | 234 | |
| 36.115852 | -115.920373 | | 8.3 | 20.5 | 381 | 7.2 | ND | 0 | 1.30 | 0.08 | | 201 |
| 36.118192 | -115.973706 | | 8.1 | 19.1 | 397 | 8.0 | ND | 0 | 0.30 | ND | | 218 |
| 36.212426 | -116.059227 | 61 | 7.8 | 17.8 | 413 | 4.9 | ND | present | 0.16 | ND | | 223 |
| 36.259959 | -116.014903 | 58 | 7.7 | 24.9 | 410 | 2.8 | ND | no laboratory analyses were performed | | | | 231 |
| 36.302533 | -116.013515 | 104 | 7.1 | 21.3 | 411 | 7.5 | ND | 0 | 0.60 | ND | | 232 |
| 36.214900 | -116.062000 | 61 | 7.7 | 19.1 | 402 | 5.6 | ND | 0 | 0.23 | ND | | 234 |
| 36.201447 | -116.078711 | 56 | 7.1 | 20.9 | 422 | 6.0 | ND | 0 | 0.23 | ND | | 243 |
| 36.228300 | -116.037100 | | 7.7 | 19.6 | 460 | 5.7 | ND | 0 | 1.30 | ND | | 283 |
| 36.204039 | -116.068375 | 59 | 7.4 | 21.5 | 474 | 6.7 | ND | 0 | 0.23 | ND | | 297 |
| 36.209999 | -116.044528 | 64 | 7.1 | 21.5 | 484 | 6.8 | ND | 0 | 0.28 | ND | | 307 |
| 36.197700 | -116.071900 | 60 | 7.4 | 19.3 | 493 | 7.2 | ND | 0 | 1.10 | ND | 294 | |
| 36.129836 | -115.982033 | 78 | 8.1 | 18.3 | 516 | 7.0 | ND | 0 | 1.60 | ND | | 340 |
| 36.255656 | -116.044748 | 56 | 8.0 | 20.0 | 532 | 5.9 | ND | 0 | 1.40 | ND | | 357 |
| 36.219928 | -116.049591 | 65 | 8.0 | 17.8 | 630 | 8.0 | ND | 0 | 0.77 | ND | 494 | |
| 36.209700 | -116.024300 | | 7.4 | 21.4 | 656 | 6.9 | ND | 0 | 0.72 | ND | | 484 |
| 36.220000 | -116.024100 | | 6.3 | 20.0 | 1076 | 7.1 | ND | 0 | 19.00 | ND | 810 | |
| 36.108876 | -115.933592 | 74 | 8.0 | 19.0 | 1314 | 5.7 | ND | 0 | 52.00 | ND | | 1162 |
| 36.129690 | -115.957159 | | 7.7 | 18.8 | 1337 | 5.9 | ND | 0 | 3.70 | ND | | 1186 |
| 36.119986 | -115.949513 | 59 | 8.0 | 18.4 | 1395 | 6.5 | ND | 0 | 12.00 | ND | 1330 | |
| 36.216005 | -116.034002 | 55 | 7.0 | 19.6 | 1740 | 4.5 | ND | 0 | 2.80 | ND | | 1601 |
| 36.215600 | -116.023900 | | 7.1 | 20.1 | 1816 | 7.5 | ND | 0 | 3.20 | ND | 1620 | |
| 36.235300 | -116.016600 | | 6.9 | 19.6 | 2367 | 5.9 | ND | 0 | 4.90 | ND | 2280 | |

| Table 3. Water Chemistry Results for Monitor Well # 1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **SAMPLE DATE** | **TDS @103 deg C (mg/L)** | **NITRATE (mg/L)** | **NITRITE (mg/L)** | **TOTAL KJELDAHL NITROGEN (mg/L)** | **TOTAL NITROGEN** | **CHLORIDE (mg/L)** | **pH** | **COMMENTS** |
| 1/13/2003 | 1270 | 1.3 | | | | 33.4 | | Chemical quality **exceeds** Nv State standards (TDS) |
| 3/10/2003 | 1330 | < 0.50 | < 0.05 | < 1 | < 0.05 | 58 | 7.26 | Chemical quality **exceeds** Nv State standards (TDS) |
| 4/17/2003 | 1340 | 2.2 | < 0.05 | < 1 | 2.2 | 600 | 7.04 | Chemical quality **exceeds** Nv State standards (TDS) |
| 7/1/2003 | * | 0.91 | < 0.05 | * | 0.91 | * | * | |
| 1/14/2004 | 1308 | 1.8 | < 0.05 | < 1 | < 1.8 | 17 | 7.12 | Chemical quality **exceeds** Nv State standards (TDS) |
| 10/6/2004 | 1190 | 2.3 | < 0.05 | 2.6 | 4.9 | 20 | 7.05 | Chemical quality **exceeds** Nv State standards (TDS) |
| 1/12/2005 | 1180 | 2.5 | < 0.05 | 2.4 | 4.9 | 14 | 6.88 | Chemical quality **exceeds** Nv State standards (TDS) |

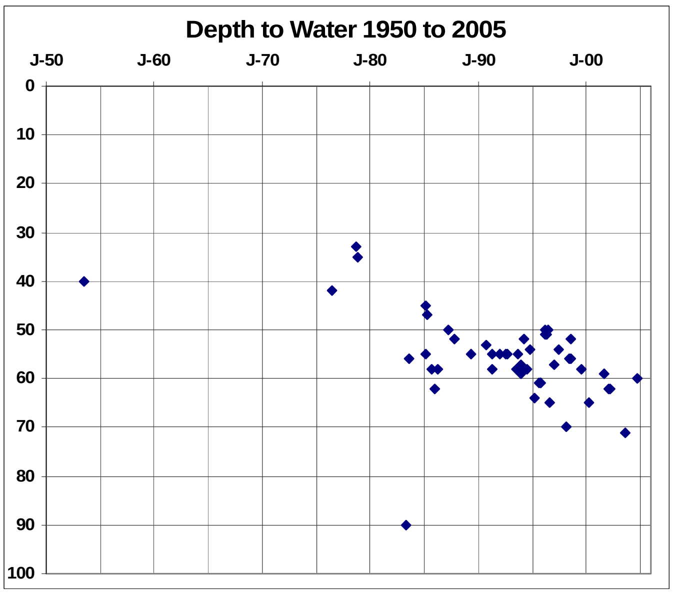
*** Indicates bad copy, not able to read lab report**

**State of Nevada Safe drinking water limits: TDS=1000, Nitrates=45**

Information on the groundwater conditions of Pahrump Valley was compiled from several sources including Malmberg (1967), Harrill (1986), Sweetkind et al (2003), Buqo (2004), geologic quadrangle maps published by the Nevada Bureau of Mines and Geology and the U.S. Geological Survey, and the records of the Nevada Division of Water Resources. In addition to these data sources, water-level information on file with the Nye County Department of Natural Resources and Federal Facilities was compiled. This Department conducts water-level monitoring throughout southern Nye County and adjacent areas in Clark and Inyo counties and is the most up-to-date source of water level data in Pahrump.

## General Groundwater Conditions

Groundwater under the area of investigation occurs at depths ranging from less than 25 ft to more than 70 ft below land surface. In general, the shallowest groundwater is just east of Highway 160 and the depth to water increases to the west. The depth to groundwater at the Artesia Sewage Treatment Facility is about 70 ft. Water levels in the area of interest have been declining since the 1980s. The hydrograph at left is a plot of the depth to water recorded on the Well Drillers Log for each of the wells drilled in the same section as the Artesia Sewage Treatment Facility (Township 21S, Range 54 E, Section 17). As shown on the hydrograph, water levels have declined almost 40 ft over the last 20 to 25 years. The results of routine water level monitoring by Nye County indicate that water levels continue to drop in the area at a rate of about one foot per year.




Groundwater flow under most of Pahrump Valley is generally to the southwest. Flow under the sewage facility is more to the west, reflecting the presence of a pumping center southeast of the facility. Figure 3 shows the configuration of the water table at both regional and local scales. The water table gradient under the sewage facility is slightly less than 0.01 (dimensionless) and is to the west-southwest.

The aquifers in Pahrump Valley have not been well defined because of a lack of deep wells. Thousands of shallow domestic wells have penetrated the upper basin-fill deposits to less than 200 ft. Few agricultural wells extend more than a few hundred ft in depth. In fact, only 19 wells in the valley have been drilled more than 500 ft below land surface. Well Drillers Logs were reviewed for selected wells on file with the Division of Water Resources (Appendix A).

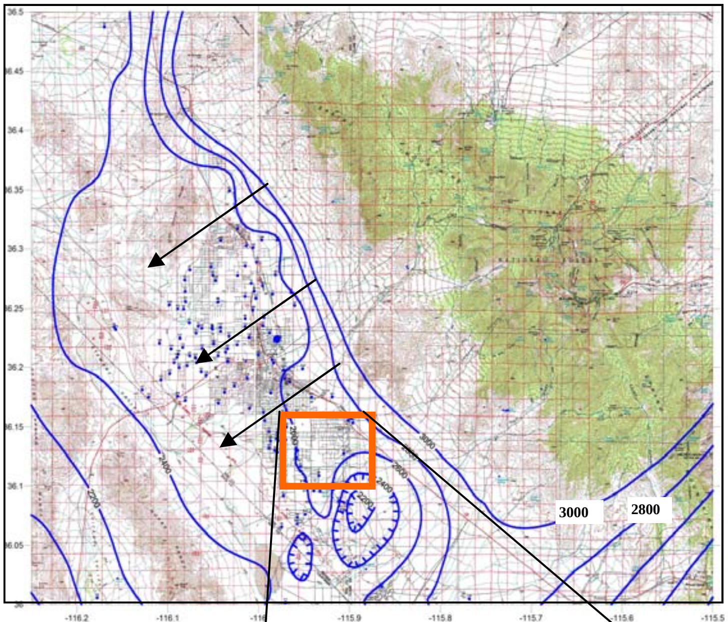
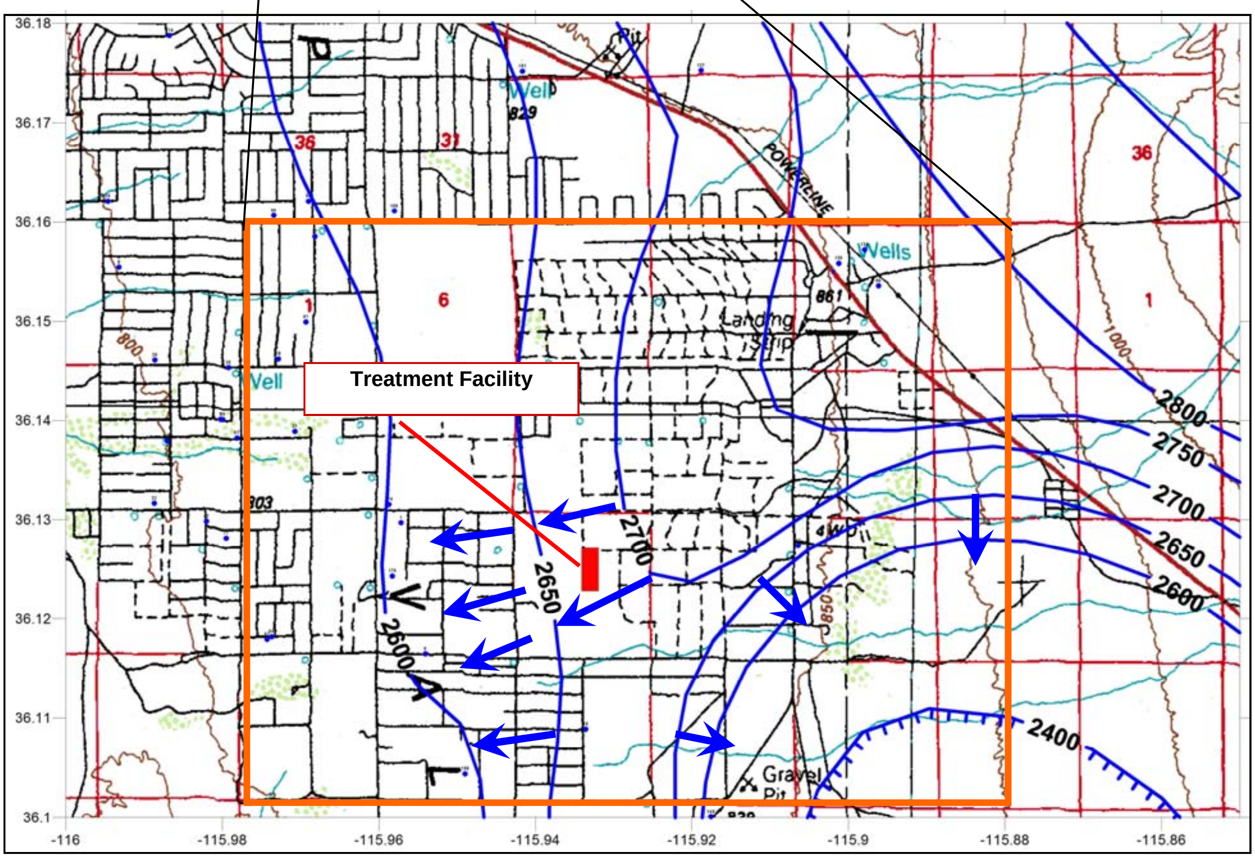



**Figure 3. Potentiometric Maps of Pahrump Valley and the Area of Investigation.**

General flow directions are shown by the arrows.

The blue contour lines are the elevation of the water table in feet above mean sea level.

**Source data:** Nye County Department of Natural Resources and Federal Facilities regional groundwater elevation database, spring 2004 baseline.



The Well Drillers Logs indicate that the water table aquifer under the treatment facility is a mixture of clay and "caliche." The geologic quadarangle map by DePaolo (1999), shows that the sewage facility and surrounding area are situated over a sequence of fine-grained basin deposits. These deposits consist of an upper unit of silt and mud that is typically 3 to 10 ft thick. Underlying this upper unit are massive to thick bedded mud deposits with interbeds of calcrete, calcite-cement, calcareous mud, and shell fragments. This lower unit is of lacustrine (lake) origin and the total thickness is not known. The deepest agricultural well in the vicinity, drilled to a depth of 500 ft in 1953, did not fully penetrate the unit. Thus it may be inferred that the water table under most of the area of interest is near the top of a thick sequence of ancient lakebeds.

Of note with respect to the performance of a RIB are the low permeability and high porosity of the mud deposits. The permeability of the lake beds likely ranges from about $1 \times 10^{-4}$ to $1 \times 10^{-8}$ cm/sec. The porosity also likely varies from about 10 percent to 40 percent with the lower value representative of the calcareous or cemented zones and the higher value representative of the clay rich zones. Infiltration from a RIB will be slow because of the high clay and silt content. Once the infiltration has reached the water table, the groundwater travel time through the saturated zone will be quite slow. Based upon an assumed permeability of $1 \times 10^{-4}$ cm/sec, a porosity of 25 percent, and a gradient of 0.01, the groundwater travel time will on the order of only four ft per year.

## Existing Water Quality

The results of the water chemistry analyses in Tables 1 and 2 were plotted to show the distribution of key water quality parameters (TDS, sulfate, nitrate, and chloride). The maps are shown in Figures 4 through 7. As shown, there is a considerable area with elevated levels of these chemical parameters. Concentrations of TDS occurs\ at levels in excess of the secondary drinking water standard of 500 ppm (parts per million) over an area of about nine square miles. Concentrations in excess of 1,000 ppm occur over an area of about 3-1/2 square miles. Within this area, in a generally north trending zone two miles long and one-third of a mile wide, the TDS is higher than 2,000 ppm. The TDS immediately adjacent to the sewage treatment facility ranges from 1,180 to 2,030 ppm.

The distribution of sulfate is very similar to that of TDS. There is no drinking water standard for sulfate but there is a recommended maximum concentration of 250 ppm on the basis of aesthetic values, namely odor and taste. The highest concentrations found to date exceed 1,000 ppm, which renders the water unpalatable without treatment. The sulfate concentration in the groundwater under and down gradient of the facility ranges from 1,000 to almost 1,200 ppm. The concentration of chloride is somewhat similar in distribution to both TDS and sulfate, and the differences can be attributed to the distribution of wells for which chloride analyses are available. The concentrations of chloride range from slight traces (one to two ppm) to more than 300 ppm in one well. The secondary maximum contaminant level for chloride is 250 ppm, based on taste. The chloride concentrations in the vicinity of the treatment facility range from 80 to 250 ppm.

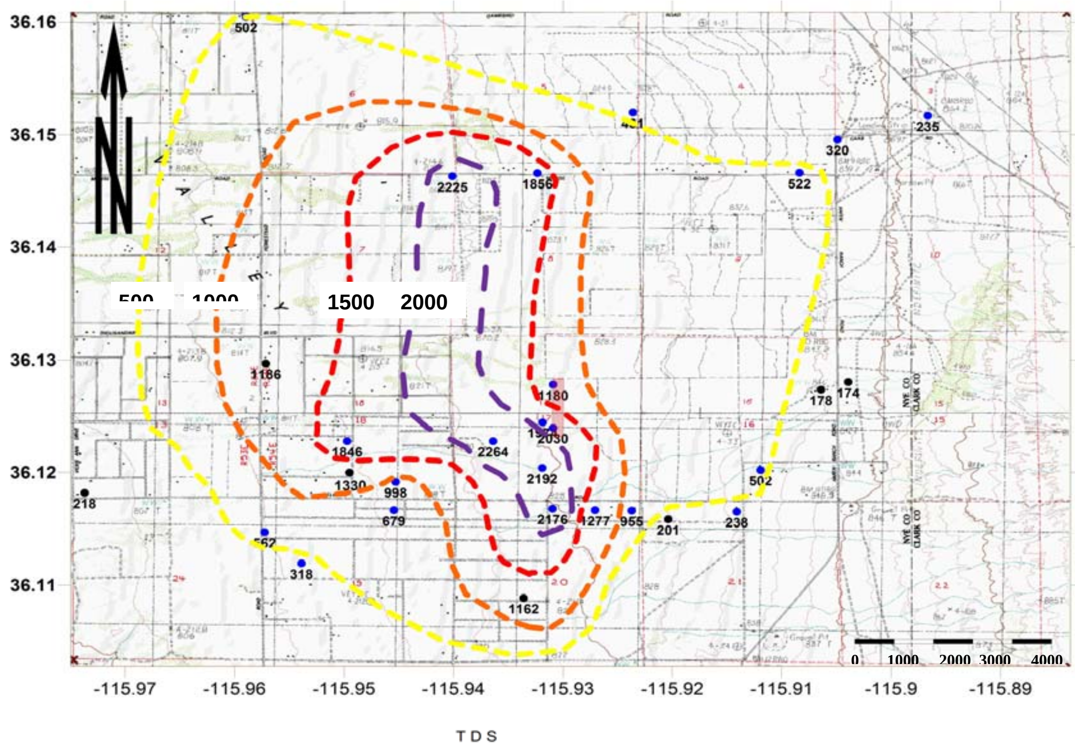



Figure 4. Distribution of Total Dissolved Solids in Groundwater Samples (ppm)

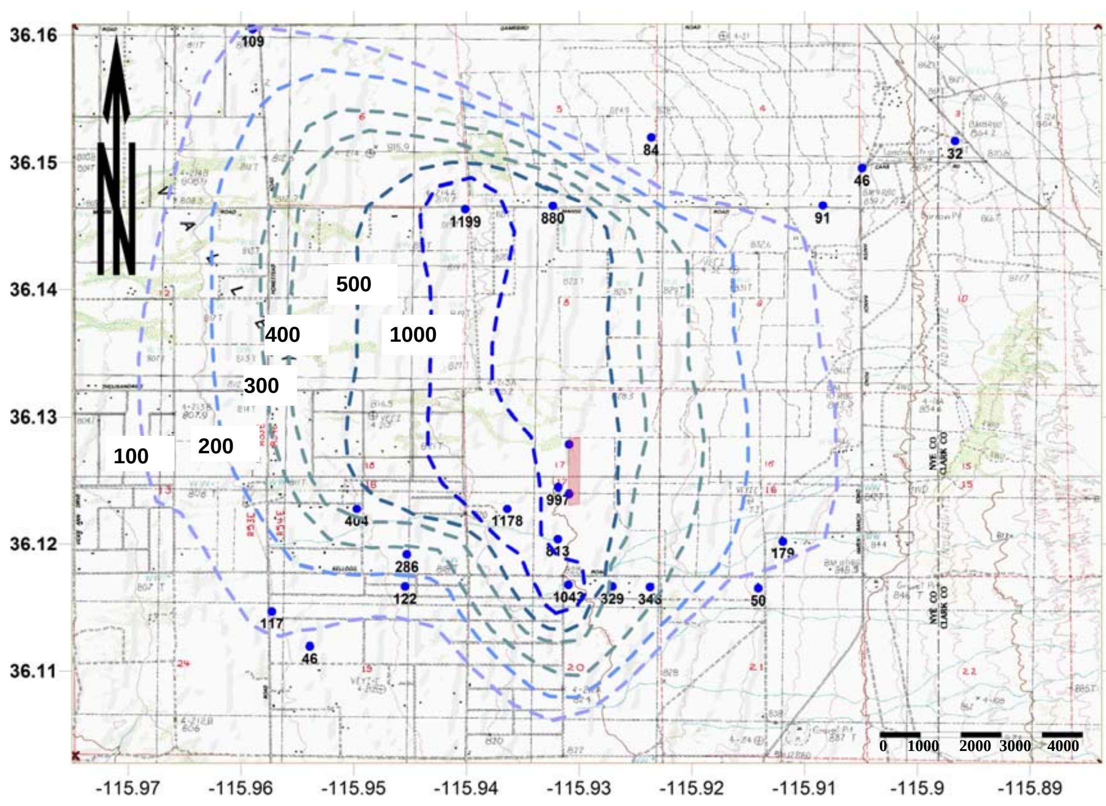



Figure 5. Distribution of Sulfate in Groundwater Samples (ppm)

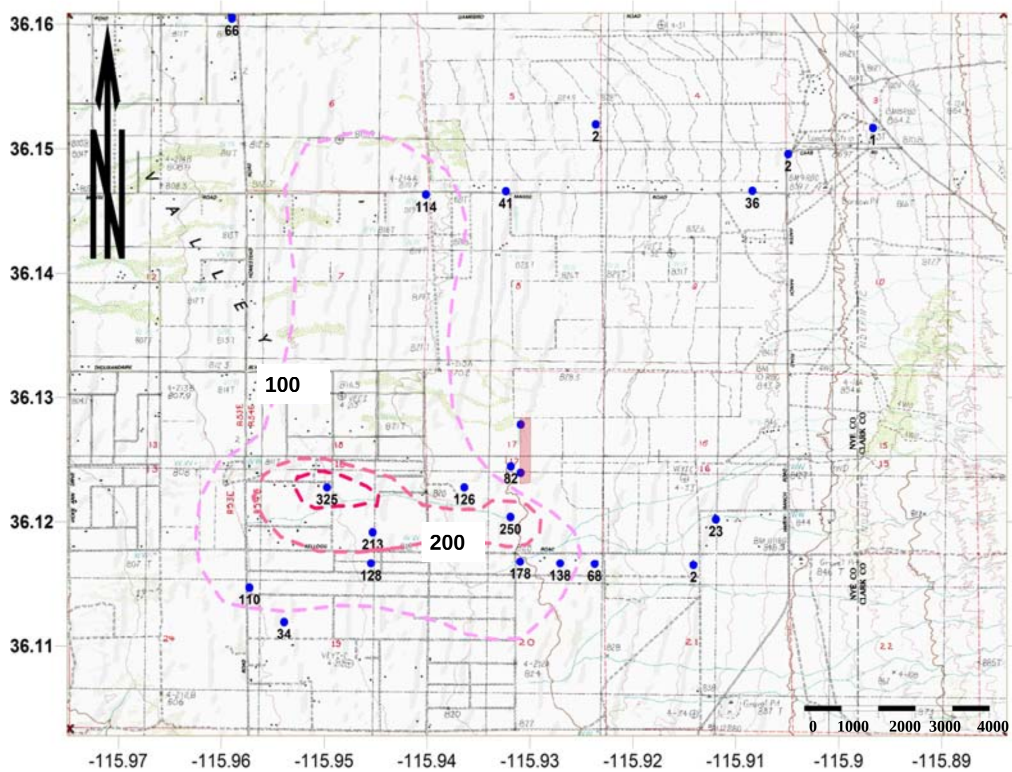



Figure 6. Distribution of Chloride in Groundwater Samples (ppm)

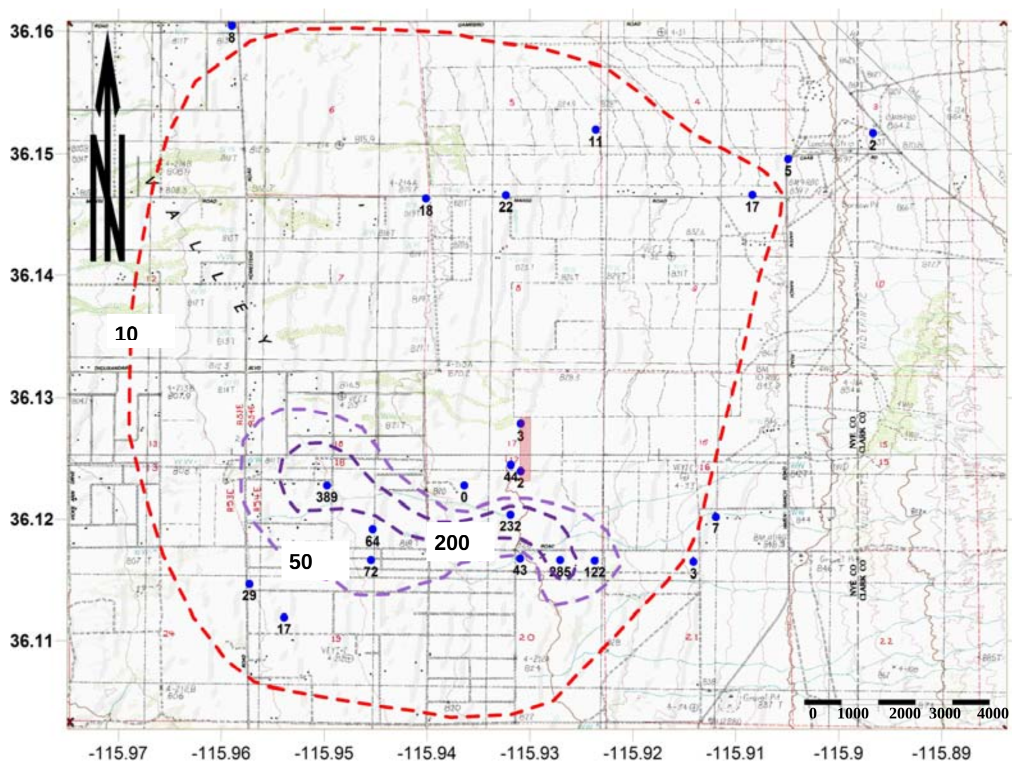



Figure 7. Distribution of Nitrate in Groundwater Samples (ppm)

Elevated concentrations of nitrate in the groundwater (greater than 10 ppm) are evident over an area of about ten square miles (See Figure 7). The primary drinking water standard for nitrate is 10 ppm. Nitrate concentrations of more than 10 ppm occur in a generally east-west zone that is almost two miles long and about one-quarter mile wide. The highest observed concentration of nitrate was 389 ppm, almost 40 times drinking water standard. Concentrations in the vicinity of the sewage treatment facility range from 2 to 232 ppm.

**Evaluation of the Effects of Effluent Infiltration**

The effects of the infiltration of effluent from the RIB will depend on the operation of the treatment works, seasonal variations in rainfall and evapotranspiration, and the chemistry of the effluent stream. Given the low vertical permeability of the lacustrine and caliche layers that underlie the site, infiltration rates will be very slow, about three inches per day (assuming a head of three feet in the RIB and a permeability of .000001 cm/sec) or about 90 ft per year. This calculation establishes that infiltration from an RIB has the potential to reach the water table if operated continuously. During the late spring, summer, and early fall, high evaporations rates will significantly reduce (or eliminate) the daily infiltration rate.

Attenuation of dissolved solids in the soil column under the RIB will effectively remove some of the chemical constituents in the effluent, especially any trace metals, chloride, and phosphates. Nitrates, sulfate, and other more mobile cations and anions may ultimately reach the groundwater, however, the groundwater down gradient of the RIB is brackish in quality with concentrations of nitrate, TDS, and sulfate well above their respective drinking water standards. Additionally, chloride has been documented at levels up to 30 percent above the maximum contaminant level. Given the severe limitations of the existing groundwater quality, the introduction of treated effluent into the RIB and its subsequent infiltration into the groundwater will likely have a beneficial effect on the groundwater quality, albeit probably negligible in magnitude.

**Source of Existing Groundwater Quality Limitations**

Historically, nitrate or sulfate contamination in groundwater has been attributed to actions by man such as agricultural use of fertilizers, munitions manufacturing, mining activities, ore smelters, coal-fired power plants, and sewage disposal. In recent years, a great deal of scientific research has established that naturally occurring geologic nitrogen and sulfate can be significant non-point sources of groundwater contamination. For example, gypsum deposits and sulfide mineral deposits can result in elevated concentrations of sulfate in both groundwater and surface water. Researchers have also found that reservoirs of ntitrates occur in the shallow subsurface of many arid areas. Based upon these more recent studies it now appears that elevated concentrations of these two parameters may be derived from natural subsurface reservoirs of nitrate and sulfate that are mobilized by flushing by recharge and fluctuating groundwater.

Naturally Occurring Sulfate

Hem (1989) reports that sulfur is widely distributed in sedimentary rocks as metallic sulfides, in gypsum deposits, and in volcanic rocks. In arid environments such as southern Nevada, there is not enough precipitation to leach all available sulfate from the unsaturated soils above the water table. As a consequence, a large reservoir of sulfate is available for transfer to the groundwater from the infiltration of irrigation water. Another likely source of elevated sulfate in the groundwater in southern Pahrump is naturally occurring gypsum deposits. Sulfate derived from gypsum can be attributed to two likely sources,: 1) natural deposition of gypsum as an evaporative layer on the bench platform of the Pleistocene lake that once covered the entire valley floor of the basin; and 2) the weathering of gypsum-rich dolomite in the upland areas (Hem, 1989).

According to information presented by Longwell, et al (1965), the closest metallic sulfide deposits are in the Mount Potosi area and the southern Spring Mountains in Sandy (Mesquite) Valley and Ivanpah Valley and are not considered a possible source for the elevated sulfate levels in the groundwater under Pahrump. Dolomite layers within the Bird Spring Formation in the Wheeler Wash and Carpenter Canyon watersheds and gypsums units in the Kaibab Limestone in the Trout Canyon watershed provide a large natural reservoir of sulfate for solution and transport to the lowland areas of the basin. However, if dolomite dissolution were the primary source of sulfate, then the concentration of sulfate should increase toward the source, i.e., to the east toward the Spring Mountains where the dolomite and limestone are present. As shown in Figure 5, this type of distribution is clearly not the case.

Therefore it is considered most likely that the elevated concentration of sulfate in the groundwater in southern Pahrump is derived from a subsurface reservoir of sulfate that originated in the delta deposits of the streams that once fed the Pleistocene lake. Papke (1976) lists ten sulfate authigenic minerals that are likely to occur in playa deposits, with gypsum being the most common. Over geologic time, the lake that once covered the lowlands rose and fell numerous times leaving a layered geologic record of evaporite deposits interbedded with clays. This sequence was repeated many times and resulted in the numerous clay and “caliche” layers reported on the Well Drillers Logs for the area. Sulfate reservoirs are probably present in each of the layers described as caliche.

The evaporite-rich layers above the water table probably only contribute sulfate to the groundwater under irrigated areas and in response to very wet years. The greatest contribution of sulfate probably comes from the flushing of the gypsum or other evaporties from the caliche layers in the zone of seasonal groundwater fluctuations. Seasonal fluctuations in the groundwater are typically a few feet but can vary depending on how much pumping is concentrated in a given area. As the static water table in the area is known to be declining at the rate of about one foot per year, an inexhaustible reservoir of sulfate is probably available for dissolution into the groundwater.

## Naturally Occurring Nitrate

Dahlgren and Holloway (2002) reported that the principal source of nitrogen in geologic media is from the deposition of organic matter in sediments. Increased deposition of bioavailable nitrogen (N) at the land surface has adversely affected water quality and habitat around the world. Understanding such impacts requires quantification of nitrogen sources, reservoirs, and nitrogen cycling rates. Historically, nitrogen loss from the soil zone by leaching was generally considered negligible in desert environments. Recent research by Walvoord et al (2003) has seriously challenged this assumption and has identified significant reservoirs of nitrate in the desert soils on the Nevada Test Site and the Amargosa Research Station. Further, the new research has documented large subsurface reservoirs of nitrate with concentrations as high as 2,000 ppm. These subsurface accumulations provide a ready source for groundwater contamination.

Like sulfate, the nitrate reservoir is probably related to the Pleistocene lake in Pahrump Valley, specifically the decay of vegetation in bog and marsh deposits adjacent to the shoreline. These deposits have since been reworked, resulting in the redistribution of some of the nitrate in the deltaic and lacustrine sediments. As the Pleistocene wet climate gave way to the arid Holocene, these units of the rich organic material were subsequently buried under more recent alluvium. Plant processes removed much of the nitrate out of the root zone but did not remove the nitrate from depths greater than about 3 meters (19 ft).

The layered evaporite rich valley-fill deposits provide a huge reservoir of nitrates in the area. As with sulfate, the primary methods for mobilization of the nitrate are from the infiltration of recharge (especially along natural drainages and irrigated land) and from seasonal flushing of nitrate rich horizons by the groundwater. Given the depth to groundwater (greater than 70 ft over most of the area), groundwater flushing is probably the predominant source of the very high nitrates in the groundwater in southern Pahrump.

## Conclusions

Based upon the results of the water chemistry analyses, review of published research and data, and the observations recorded above, a number of conclusions may be reached with respect to the operation of the RIB at the Artesia Sewage Treatment Facility:

1. Groundwater occurs at a depth of about 70 ft below the sewage treatment facility and there are seasonal fluctuations in the water table of about ten ft.

2. The water table gradient under the facility is about 0.01 to the west southwest.

3. The water table aquifer comprises alternating layers of evaporite deposits and clay, with each layer typically ranging between 10 and 50 ft in thickness.

4. The permeability of the valley-fill sediments is low, on the order of .000001 cm/sec.

5. Groundwater travel time under the facility is approximately 4 ft per year.

6. Under assumed worst-case conditions, infiltration of effluent from the Rapid Infiltration Basin could reach the water table in less than one year.

7. Extensive naturally occurring subsurface reservoirs of nitrate and sulfate were deposited in the near shore environments of a Pleistocene Lake that existed in Pahrump Valley before the Holocene climate change.

8. Flushing of nitrate and sulfate by seasonal fluctuations of the water table has resulted in elevated concentrations of these chemical constituents in the groundwater, particularly in the area northwest, west, and south of the sewage treatment facility.

9. The groundwater down gradient of the facility is brackish with total dissolved solids concentrations of more than 2,000 ppm, sulfate concentrations of more than 1,000 ppm, and nitrate concentrations of more than 200 ppm, all well above the respective drinking water standards for these parameters.

10. Because the groundwater down gradient of the facility is not of potable quality, the infiltration of treated effluent in the Rapid Infiltration Basin is not expected to result in the degradation of the groundwater under, or down gradient of the facility.

## Recommendations

Based upon the findings and conclusions stated, the following recommendations are made:

1. Monitoring of groundwater quality at the facility should continue throughout the use of the Rapid Infiltration Basin to confirm the results of this evaluation and to provide an early detection of any variances.

2. Resampling of the wells that were sampled historically should be considered for further research into the nitrate and sulfate reservoirs. Such sampling would be research-oriented however, with no bearing on the suitability or use of the treatment facility.

References Cited

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## APPENDIX A

## WELL DRILLER LOGS