Conceptual Flow and Transport Model Uranium Plume near the Homestake Millsite

Milan, NM

Prepared for: Bluewater Valley Downstream Alliance

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SUMMARY

The Homestake Mining Company's (HMC) millsite at Grants, New Mexico, has been the source of many contaminants to the groundwater around the mill since 1961. Federal and state agencies recognized that seepage from HMC's large tailings pile (LTP) had contaminated groundwater in subdivisions downgradient of the LTP with uranium (U) and selenium by the mid-1970s (EPA 2011). Groundwater transported U off of the millsite to subdivisions downgradient of the mill where concentrations reached many times current drinking water standards. This report presents a conceptual flow model (CFM) and conceptual transport model for groundwater flow and U transport in the groundwater basin near and upgradient of the LTP. The report tests the hypothesis that excess U found in groundwater beneath, southeast of, and northeast of the LTP are due simply to seepage from the LTP and that U entering the alluvium as discharge from the Middle San Mateo Creek basin has not reached the area around the LTP.

CFMs for three separate time periods are developed for this project. The first is the natural, or predevelopment state for groundwater flows existing prior to development. The second is the CFM as affected by mining, including the discharge of mine dewatering water and its subsequent secondary recharge in stream bottoms and the seepage of water from tailings impoundments. The third is the system as it evolves after the discharge of dewatering water stopped and the millsites began to be reclaimed and attempts made to stop the seepage and constrain the spread of contaminants.

The LTP lies near the confluence of the flowpaths from three watersheds, the Lower San Mateo, Lobo Creek, and Stanley and Card Range basin. San Mateo Creek carries the runoff from five drainages - the Martin Draw, Arroyo del Puerto, and the Upper, Middle, and Lower San Mateo Creek basins – ending near the LTP. The confluence of the Arroyo del Puerto and Middle San Mateo Creek occurs near a bedrock constriction about 3 ½ miles northeast of the LTP commonly known as Sand Curve. Surface streams are mostly ephemeral, flowing naturally only in response to precipitation or snowmelt runoff.

There are three aquifers near the Homestake Millsite and LTP. They are from the ground surface down the Quaternary alluvium, the Chinle shale and sandstone, and the San Andres formation. Alluvium covers the area although areas south of the LTP are thin enough to not be saturated. The Chinle formation has three layers permeable enough to be aquifers – the Upper, Middle, and Lower Chinle formation - which subcrop under the alluvium.

Groundwater flows from the northeast to the southwest in the alluvium. Total recharge to the basin upgradient of the LTP ranges from 200 to 950 acre-feet/year (af/y). Leakage from the alluvium into the Chinle subcrops provides most recharge to the Chinle. Groundwater flow

direction in the Chinle is variable, but naturally may have trended to the northeast along the dip of the formation. The San Andres outcrops to the southwest in the Zuni Mountains where it is likely recharged.

Groundwater flow through the Sand Curve area naturally ranges from about 144 to 724 af/y, depending on the assumptions used for the hydraulic properties. Downstream from Sand Curve, the flow velocity is about 0.5 ft/day, so it would take more than 80 years for groundwater to flow from Sand Curve to the LTP. Downgradient from the LTP, the gradient becomes steeper and the velocity increases to about 0.7 ft/d. Groundwater flow from Lobo Creek basin would range from about 40 to 200 af/y. Groundwater also flows southeast from the Bluewater Millsite area but converges with flow from the San Mateo Creek areas a couple miles downgradient of the LTP. High permeability alluvium on the west end of the LTP trends southwest connecting alluvium from the LTP with that from the Bluewater millsite.

Construction of the LTP at Homestake began in the late 1950s and tails water applied to the LTP began to seep into the alluvium. By the 1970s, there were saturated tailings perched on the ground surface and an up-to-30-ft mound had formed on top of the water table. Maximum U concentrations under the LTP exceeded 100 mg/l through the 1970s. Through the 1980s and 1990s, the concentration under the LTP decreased but a plume of U concentrations exceeding 0.1 mg/l expanded southwestward and southward under various subdivisions, as detailed in this report. HMC implemented various strategies to constrain or dilute the U concentrations, including injection to create hydraulic barriers, capturing seepage, and pumping and disposing U-laden water by irrigation.

Substantial U mining and milling in the basins upstream of Sand Curve also began in the late 1950s. These facilities discharged mine dewatering water directly to ephemeral arroyos and developed tailings impoundments that leaked like Homestake's LTP. Most of that discharge, which totaled about 275,000 af, seeped to groundwater beneath the arroyos. The mine dewatering water often had U concentrations ranging from 2 to 19 mg/l, levels far above today's drinking water standard of 0.03 mg/l.

This U seepage into the groundwater beneath San Mateo Creek has likely not affected groundwater under the Homestake LTP for three reasons. First, as noted above, the groundwater flow rate was about 0.5 ft/d and water seeping into the groundwater downstream of Sand Curve would require more than 80 years to advect to the LTP. Advection is the process of a substance moving with the bulk flow.

The second reason is that U is heavily retarded as it flows with the groundwater. Homestake had completed retardation tests in the alluvium near the LTP that showed the U transport would take about five times longer than advection, so U transport would require as much as

400 years to reach the LTP. Finally, most of the U may not have reached the groundwater as it seeps from the arroyos due to attenuation. Homestake tested the unsaturated alluvium beneath its irrigation disposal sites and demonstrated that most of the applied U became bound to the soil and did not reach the groundwater. This is likely to apply to much of the water seeping through the arroyo bottom.

These processes also apply to seepage beneath the LTP, but the seepage rate from the LTP is much more concentrated in a local area with probably much higher U concentrations so a significant amount of U reaches the groundwater. Soil beneath the LTP would likely be highly laden with U. U initially exceeded 100 mg/l in the mound beneath the LTP but the concentrations later decreased as U advected to the south and southwest due to the increased gradient caused by the mound under the LTP. The U concentrations under the subdivisions are high but much less than the concentrations closer to the LTP because of attenuation. Hydraulic barriers and groundwater pumping for remediation may have limited the extent of the plume.

Wells north and northeast of the LTP, mostly within half a mile of the LTP, have experienced intermittent U concentration increases. Groundwater table maps show that the mound under the LTP reversed the gradient and caused U advection to the northeast. Additionally, dispersion and diffusion would have pushed U in that direction over the distance between the LTP and the near-upgradient wells; a 100 mg/l U plume under the mound would establish a steep concentration gradient such that diffusion to the northeast could drive some contaminant movement at least a short distance from the LTP.

In conclusion, the conceptual flow and transport model for the Lower San Mateo basin supports the hypothesis that U seeping from the LTP exclusively causes the U plume at, downgradient of, and to the near upgradient of the LTP. Uranium from upstream of Sand Curve has reached the basin but likely has been retained upstream of the LTP. General groundwater flow from the Bluewater millsite has prevented U from reaching the Homestake LTP plume.

INTRODUCTION

The Homestake Mining Company's (HMC) millsite at Grants, New Mexico, has been the source of many contaminants, initially considered to be selenium (Se) and radium, to the nearby groundwater since 1961 (EPA 2011, Chavez 1961). Contaminants later identified included uranium (U) (EPA 2011, 1975), which is the primary subject of this analysis. Uranium has been transported off of the millsite to the subdivisions downgradient of the mill, with concentrations reaching many times current drinking water standards. The area south and southwest of the LTP had the worst contamination resulting from U mining in the Grants area (Kaufman et al 1975, 1976).

This project involves a preliminary site evaluation for the Homestake Site near Grants, NM with the objective of determining where U contamination originated and how it has moved around the site. This report includes an assessment of the source of contamination at the site and whether it is background. This involves development of a conceptual flow and transport model (CFTM) for the site, based on interpretation of existing data and studies.

The study area is the watershed and groundwater basins that affect flow to, under, and through the HMC millsite in Grants (Figure 1). It includes the millsite and subdivisions south and southwest of the site, the San Miguel and Ambrosia Lake basins north of the site, and the approximately three miles of alluvium between the confluence of Arroyo del Puerto and San Mateo Creek at Sand Curve and the HMC Millsite (Figure 2, Figure 20 below shows details of the confluence).

The analysis completed for this report relied on existing data, primarily as reported in various monitoring reports and site assessments. Although the raw data has been obtained, the report uses snapshots from many reports, rather than recreating those figures, because of budgetary constraints. This also means that the contours and other decisions that went into drawing contours or flow paths have been accepted as accurate for the purpose of this report.

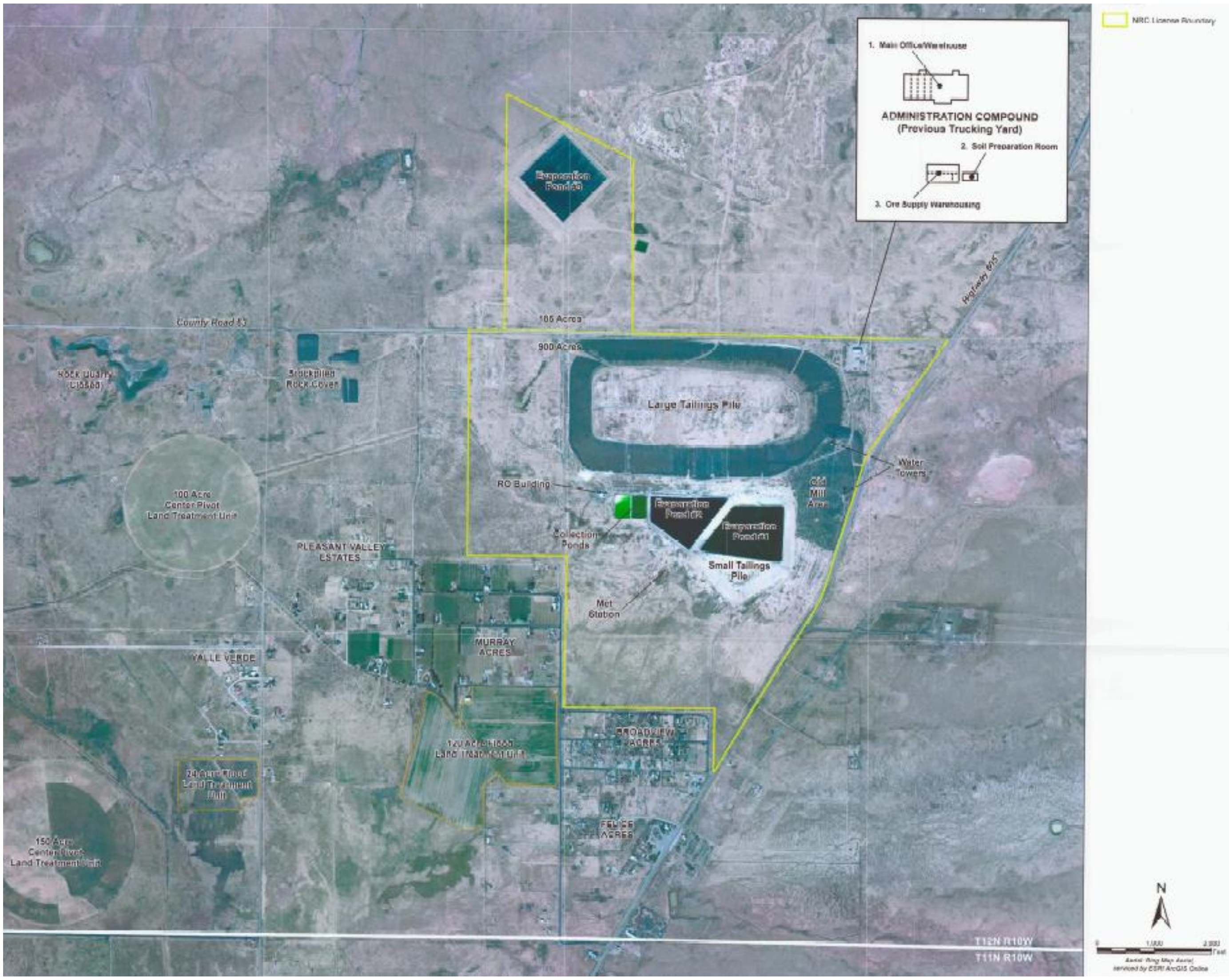

Figure 1: Snapshot of Figure 5-3.1, Grants Reclamation Project (HMC 2012), showing the general site layout.

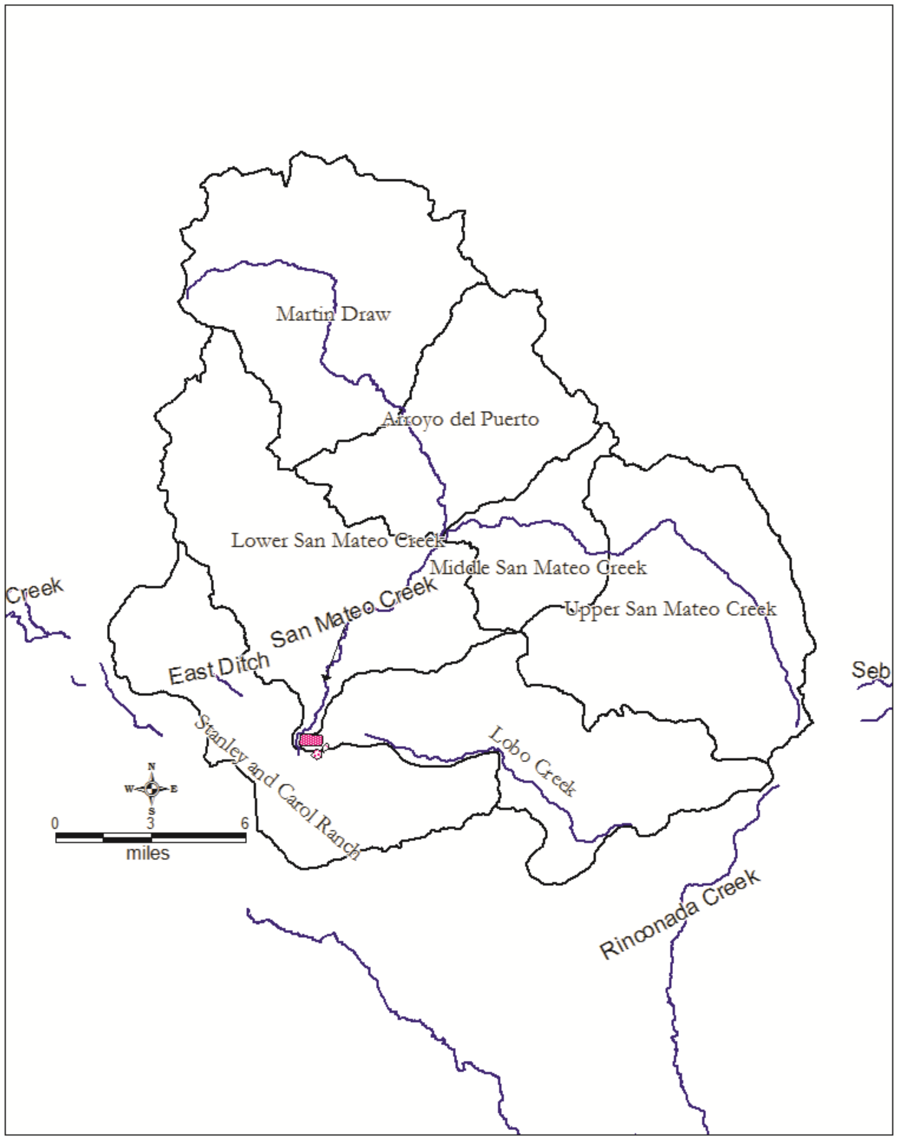

Figure 2: General watersheds at the HU12 scale, and named streams. The purple areas are the Homestake tailings and millsite area.

CONCEPTUAL FLOW MODEL

The CFM describes primarily groundwater flow, due to the lack of surface flow in the study area, from recharge of precipitation through discharge, the five geologic formations through which the groundwater flows and from which runoff commences, the soils and other surface conditions. Flow paths are controlled by hydraulic conductivity contrasts, geologic formations and topography. Groundwater flows downhill, or downgradient, following a path of least resistance, so the largest flux, or groundwater flow, is through areas with the highest transmissivity, which means the thickest and most conductive. Flux rate, or the rate that groundwater flows along a pathway, is the product of conductivity and gradient. Total groundwater flow is the product of flux rate and cross-sectional area, and is estimated for flow through constrictions where the parameters are known; this is also known as the Darcian flow rate after the originator of the original groundwater flow equation.

For the CFM, the following are developed herein or obtained from other documents:

- Regional and local geology maps and cross-section plots
- Hydrogeology of the geologic formations, including estimates of conductivity (K), porosity (n), and storage coefficient (S or Sy for specific yield for unconfined aquifers)
- Groundwater water level contours, both regional and for the local millsite area, for differing time periods and hydrogeologic formations.
- Time series plots of groundwater levels for monitoring wells within the study area
- Estimates of recharge and groundwater flow through various sections of the study site at different points in time
- A good site history of activities that affect groundwater flow and contamination

CFMs for three separate time periods are developed for this project. The first is the natural, or predevelopment state. This attempts to define the groundwater flows existing prior to development. The second is the CFM as affected by mining, including the discharge of mine dewatering water and its subsequent secondary recharge in stream bottoms or the seepage of water from tailings impoundments. The third is the system as it evolves after the discharge of dewatering water ceased and millsites are reclaimed and attempts made to stop the seepage and constrain the spread of contaminants. There are overlaps between the second and third period because attempts to contain contaminant plumes began in the 1970s although the HMC millsite continued to operate until 1992.

A CFTM describes the sources of contaminants, their movement to and through aquifers, and estimates the amounts of contaminant loads or concentration. The description includes maps and time series of contaminant concentrations and an interpretation of what caused the concentrations to change. The CFTM also describes the ability of aquifers to attenuate or retain contaminants. The following additional items are developed herein or obtained from other documents:

- Contour maps of contaminant concentration
- Time series graphs of contaminant concentrations at various wells
- Estimates of the transport time for U to reach from the San Mateo watershed to the HMC millsite
- Estimate of attenuation of U along transport pathways

The millsite, the ultimate source of most contaminants discussed herein, lies near the confluence of the flowpaths from three watersheds, defined at the HU12 scale (Figure 2). The primary stream, which essentially ends at the millsite, is San Mateo Creek which carries runoff from five drainages, the Martin Draw, Arroyo del Puerto, and the Upper, Middle, and Lower San Mateo Creek basins; the millsite may be in the floodplain of San Mateo Creek. All basins other than the Lower San Mateo join above and both surface and groundwater flow would enter through the constriction near Sand Curve. On Figure 2, that is just below the confluence of Arroyo del Puerto Creek and San Mateo Creek. Lobo Creek joins San Mateo Creek from the east, with the dividing line between basins literally splitting the LTP. Downgradient (in the alluvium, see below) is the Stanley and Card Farm basin (Figure 2). With a small exception, all streams are ephemeral and flow naturally only in response to precipitation or snowmelt runoff; the exception are upper reaches of San Mateo Creek which have some spring flow.

The Lower San Mateo Creek basin controls the flow northeast of the LTP. The upstream four basins (Figure 2) just described provide flow to the Lower San Mateo Creek through the constriction at Sand Curve. The flow, including surface and groundwater, entering Lower San Mateo Creek basin near Sand Curve changes with time due to mining in the upper basins.

Hydrogeology

Three formations are considered aquifers or are sufficiently permeable to allow groundwater flow relevant to the conceptual flow model near the Homestake Millsite – the Quaternary alluvium, the Chinle shale and sandstone, and the deeper San Andres formation. Figures 3 and 4 show the general surface geology around the study area as clipped from an EPA study of the area. Most of the Lower San Mateo Creek and Lobo Creek basins surrounding the millsite consist of alluvium or Tertiary-aged basalt flows. There are sandstone outcrops through the area. The northwest-southeast trending outcrop north of the millsite and bounding the Lower San Mateo Creek and Lobo Creek basins are mostly Dakota sandstone or various Jurassic-aged sandstones. The obvious gap through the sandstone northeast of the millsite, consisting of alluvium, is the Sand Curve bedrock constriction through which surface or groundwater from the upper four basins must flow.

A more detailed map of the immediate area near the LTP shows the outcrops of the three Chinle aquifers and the San Andres aquifer (Figure 5). From southwest to northeast, there is the San Andres, and the Lower, Middle and Upper Chinle. The upper and middle Chinle outcrop under the LTP, according to Figure 5.

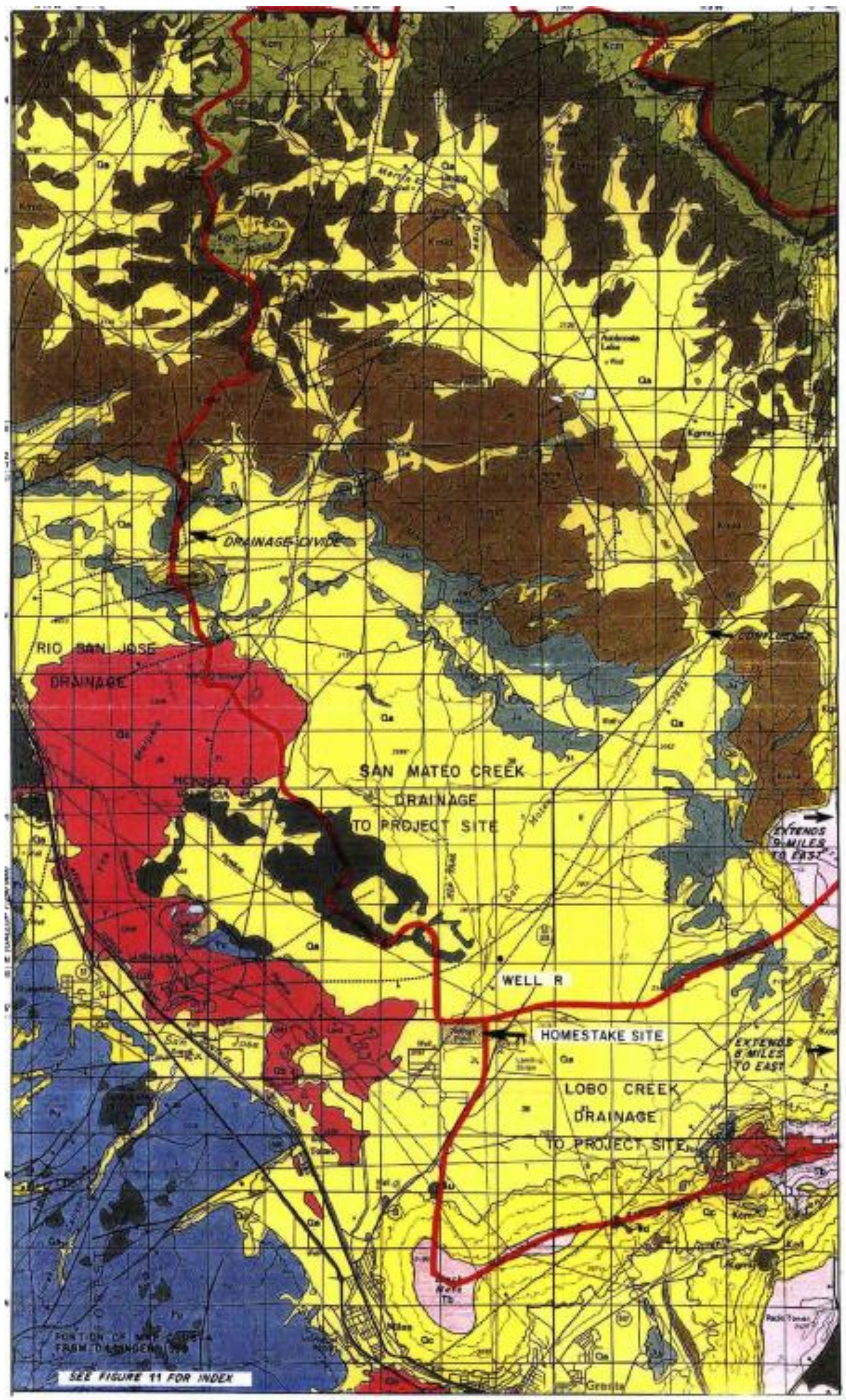

Figure 3: Snapshot of Exhibit 3a (EPA 2011) showing the surface geology for the study area. See Figure 4 for the key.

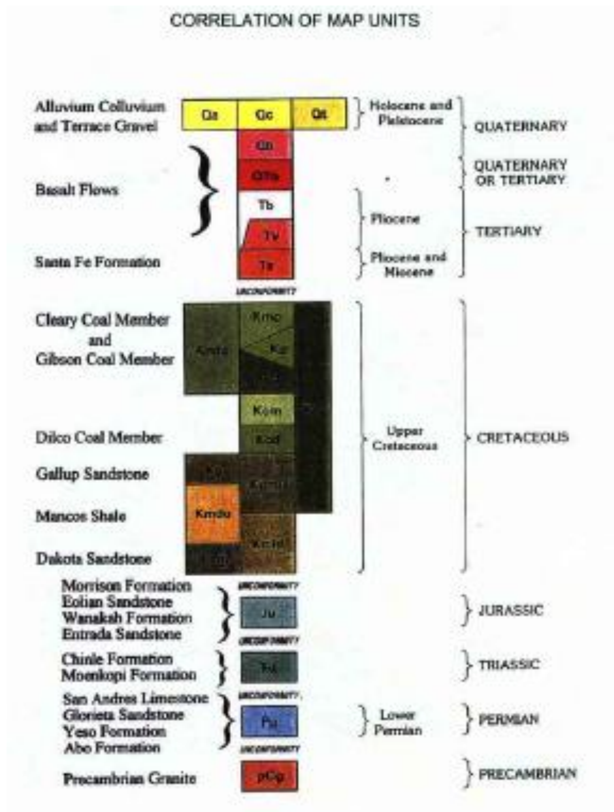

Figure 4: Snapshot of Exhibit 3b (EPA 2011) showing the key for the surface geology map in Figure 3.

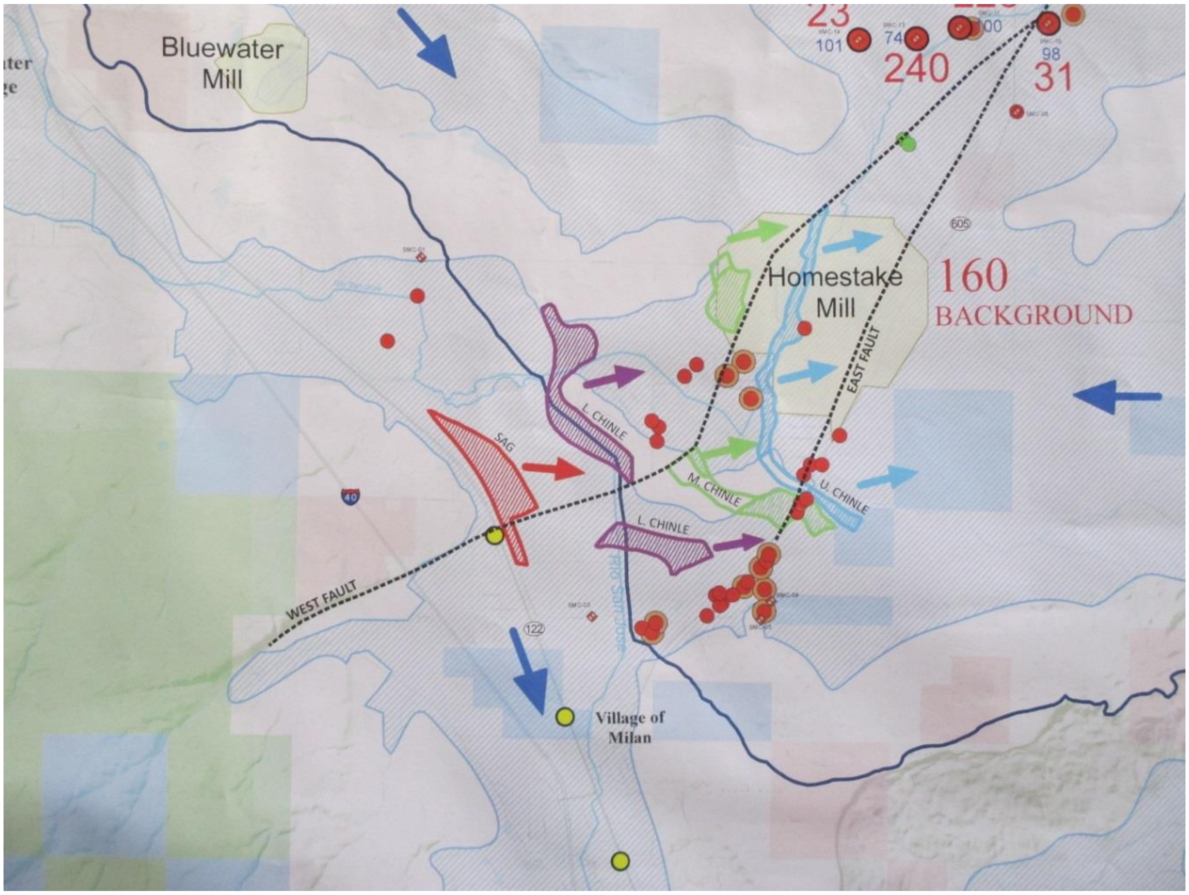

Figure 5: Photograph of large-scale geology map provided by the EPA to Mr. Milton Head. This map shows details of the bedrock geology near the Homestake Mill with outcrops of the Chinle layers and the projected path of the West and East Faults. The lighter blue cross-hatching is the Upper Chinle aquifer.

Alluvium

Quaternary alluvial deposits form generally small aquifers within the study area, with some areas being unsaturated through their entire thickness. Contours of the base of the alluvium, the top of underlying bedrock, resemble a confluence of three converging stream channels (Figure 6 and 7). The San Mateo alluvium extends northeast from the LTP to the Sand Curve area. The Lobo alluvium extends to the east although the bedrock channel is less-well mapped because there is a lack of wells extending to the bedrock (Figure 6). The Rio San Jose alluvium south of the LTP is in a bedrock channel with a well-defined canyon wall, especially on the south, that has more than 100 feet (ft) of relief (Figure 6). Because the base of the Rio San Jose alluvium is 50 or more ft below that of the San Mateo where they meet, there is a significant drop for the bottom of the San Mateo alluvium channel which substantially increases the transmissivity. There are alluvial channels formed by bedrock south of Felice Acres and due west of Pleasant Valley estates (Figure 6). Based simply on cross-section and conservation of mass, there should be either high conductivity alluvium or a high gradient water table driving flow through these narrow sections because the flow through the constrictions must equal the flow from the San Mateo alluvium to the northeast.

An old drainage ditch under west end of the LTP may be a high-permeability preferential flow path (EPA 2011, p 14)Figure 6). It could divert flow from the LTP area toward Pleasant Valley and Murray Acres. Groundwater flowing through it would be diverted either east or west, depending on the aquifer properties in those directions. The saturated thickness on the west side of the LTP is about 50 ft (Figure 7). Northeast of the LTP about ½ mile, the saturated alluvium is about a mile wide with a maximum depth of about 50 ft.

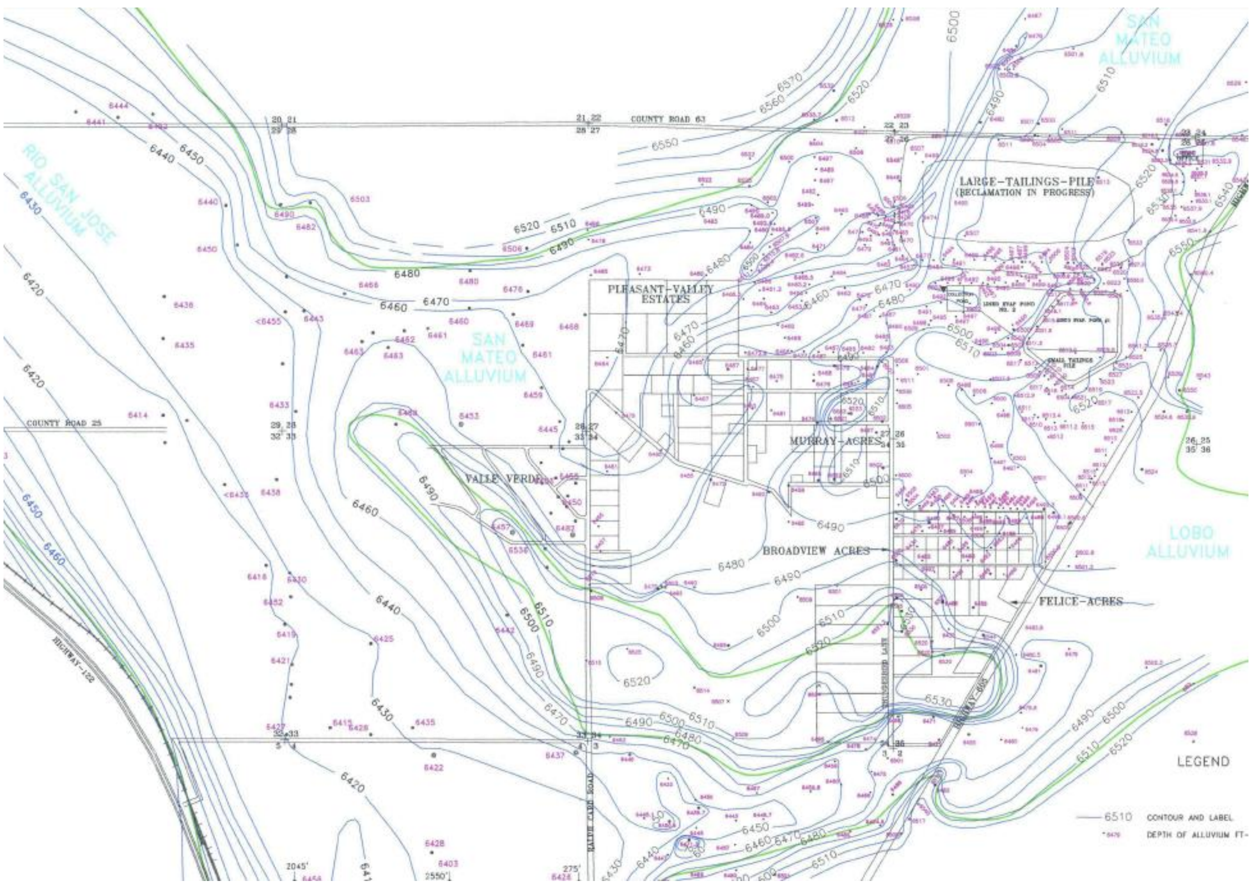

Figure 6: Snapshot of Figure 2-2, Elevation of the Base of the Alluvium (Homestake and Hydro-Engineering 2010). The contours are the interpreted base. The green line is the boundary of the alluvial aquifer and represents a bedrock outcrop.

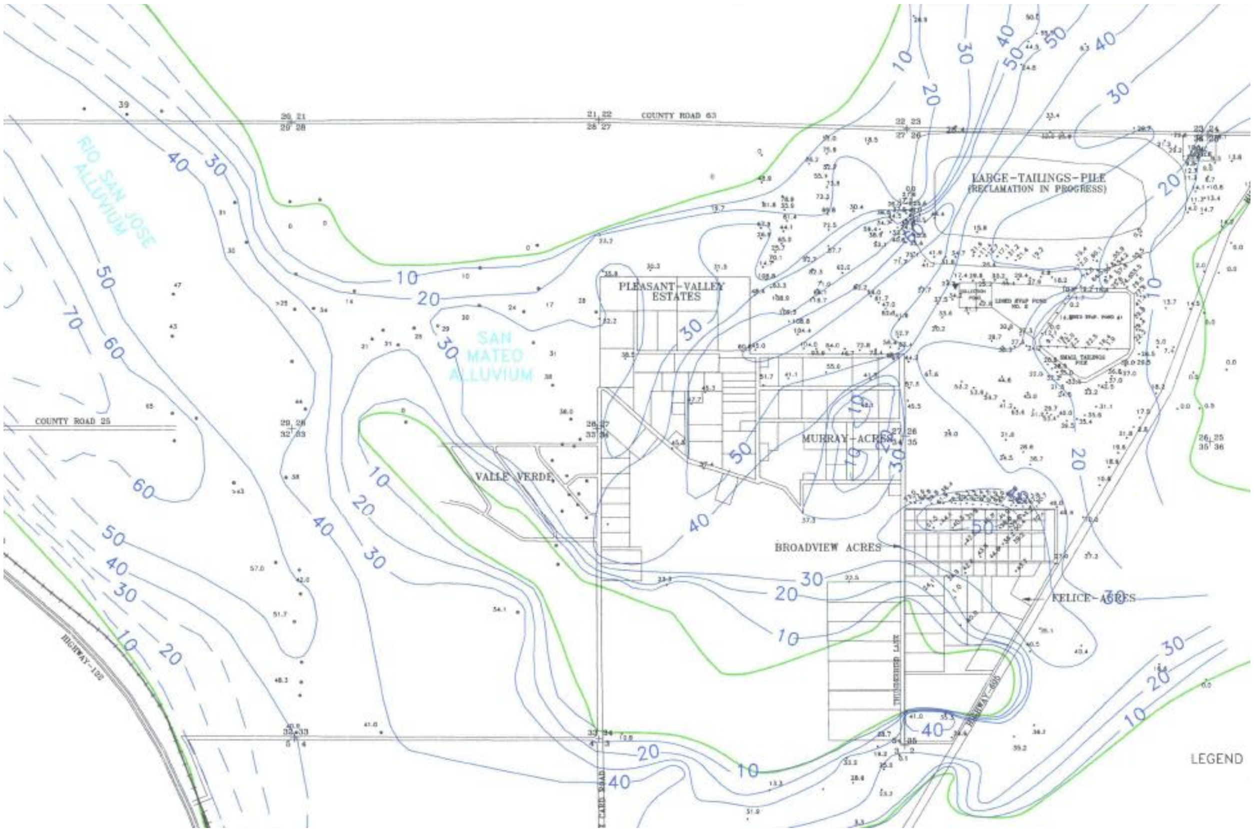

Figure 7: Snapshot of Figure 2-7 (Homestake and Hydro-Engineering 2010) showing the saturated thickness of the alluvial aquifer.

The alluvium conductivity varies from less than 10 to over 200 ft/d (Figure 8). Well yields are as high as 1110 gpm but average near 5 to 10 gpm (Baldwin and Rankin 1995). Under and northeast of the LTP conductivity is mostly less than 20 ft/d (Figure 8); the well directly north is labeled 26 ft/d and the well east of the 10 ft/d contour is 2.3 ft/d. Conductivity of the Lobo alluvium is generally less than 20 ft/d. Conductivity exceeds 50 ft/d under Felice Acres and ranges from 50 to 200 ft/d under Pleasant Valley Estates. The 200 ft/d contour under the subdivision defines the area of high conductivity in the Rio San Jose alluvium. Transmissivity, the product of thickness and conductivity, shows where most groundwater would flow through this system (Figure 9). The channel west from the LTP is the most likely pathway for flow to naturally exit the area because of the high transmissivity, as compared to the transmissivity of the channel heading south from the Lobo alluvium.

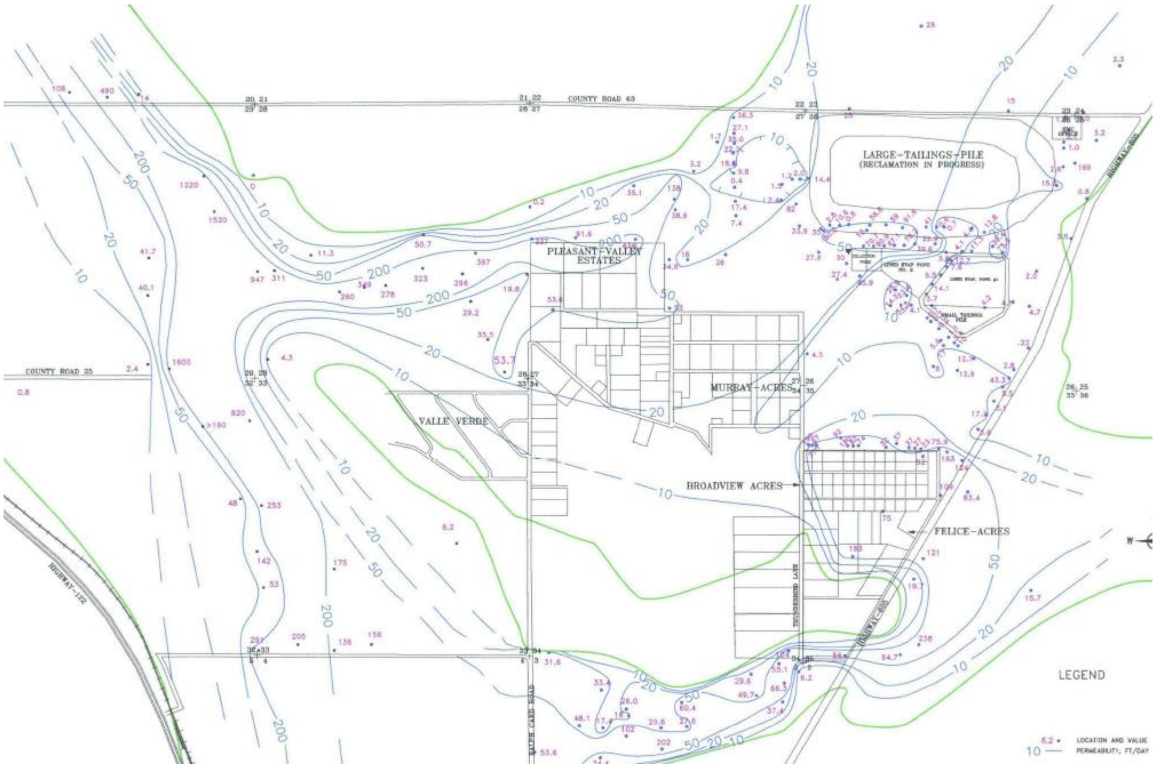

Figure 8: Snapshot Figure 2-8 (Homestake and Hydro-Engineering 2010) showing the hydraulic conductivity (ft/d) of the alluvial aquifer, based on contouring pump tests that had been documented in previous studies.

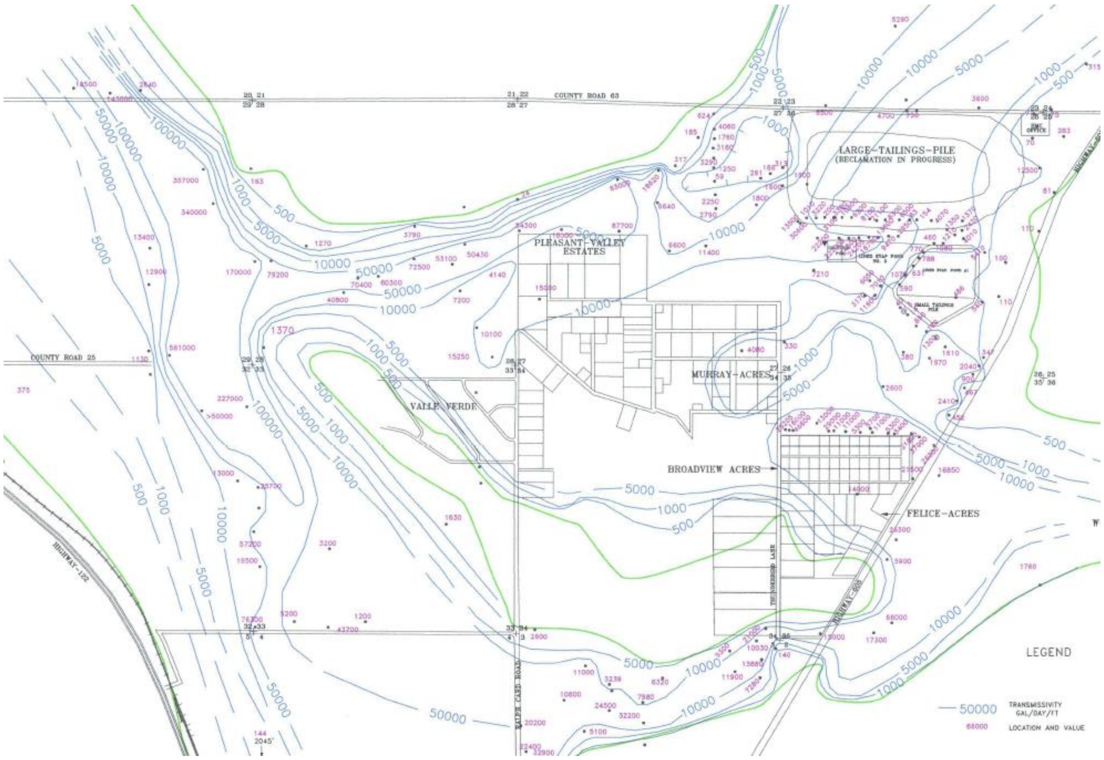

Figure 9: Snapshot of Figure 2-9 (Homestake and Hydro-Engineering 2010) showing transmissivity (gal/day/ft) for the alluvial aquifer.

Bedrock Formations

The bedrock beneath the alluvium is the Chinle formation, a combination of shale and sandstone layers. Sandstone layers form the Upper and Middle Chinle aquifers and fractured shale forms the Lower Chinle (HMC 2012). Underlying the Chinle is the San Andres limestone layer. Figure 5 shows the location of outcrops near the LTP and Figures 10 through 14 provide a three-dimensional depiction. The Chinle sandstone layers subcrop under the alluvium south of the LTP and generally slope downward to the northeast (along section A-A’, Figure 11) until they become more horizontal. Under the LTP, only the upper Chinle dips slightly to the north. The east-west cross-sections show a general dip to the southeast as well (Figures 11 through 14), so in three dimensions the formations dip to north of east. The upper, middle and lower Chinle formations are slightly less than 50, about 50, and more than 50 ft thick, respectively, and are separated by from 100 to more than 250 ft of relatively unfractured Chinle shale.

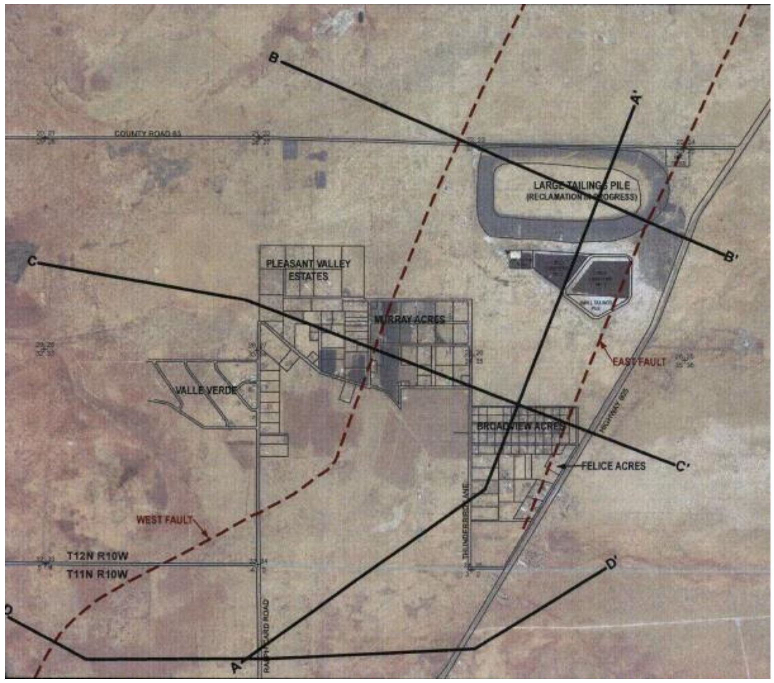

Figure 10: Snapshot of Figure 3.1-4 (HMC 2012) showing the location of geologic cross-sections shown in Figures 11 through 14.

Faults also can be both barriers and conduits to flow due to offsets in permeable layers and rock fracturing (Caine et al 1996). Conceivably, the East and West faults could be preferential flow pathways in the northeast-southwest direction (Figures 5 and 10). There could also be flow barriers in the northwest-southeast direction due to the sandstone layers abutting shale across the faults. This likely segmenting groundwater flow in the aquifers among sections - west of the West fault, between the faults, and east of the East fault (Figures 12 and 13) (Baldwin and Rankin 1995). Pump tests in the Middle Chinle between the faults showed a significant bounding effect (HMC 2012).

The transmissivity of the upper Chinle just west and east of the East Fault is 10,000 and 2000 gpd/ft, respectively, while the formation away from the fault has transmissivity between 100 and 2000 gpd/ft (HMC 2012). Conversely, transmissivity in the middle Chinle was much lower near the faults than between them (HMC 2012). There is no data on the degree of fracturing in the shale near the faults between the aquifer layers. The faults could, in addition to preferential flow along their path, provide vertical pathways among the layers which would cause groundwater types and contaminants to mix among layers.

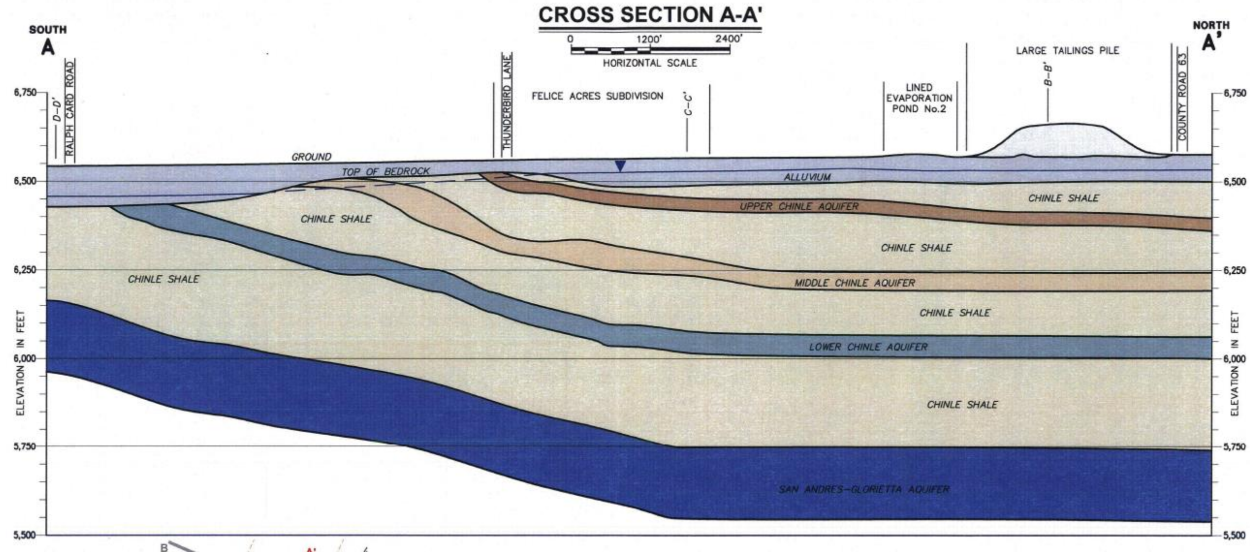

Figure 11: Snapshot of Figure 3.1-5 (HMC 2012) showing cross-section A-A'. See Figure 10 for location.

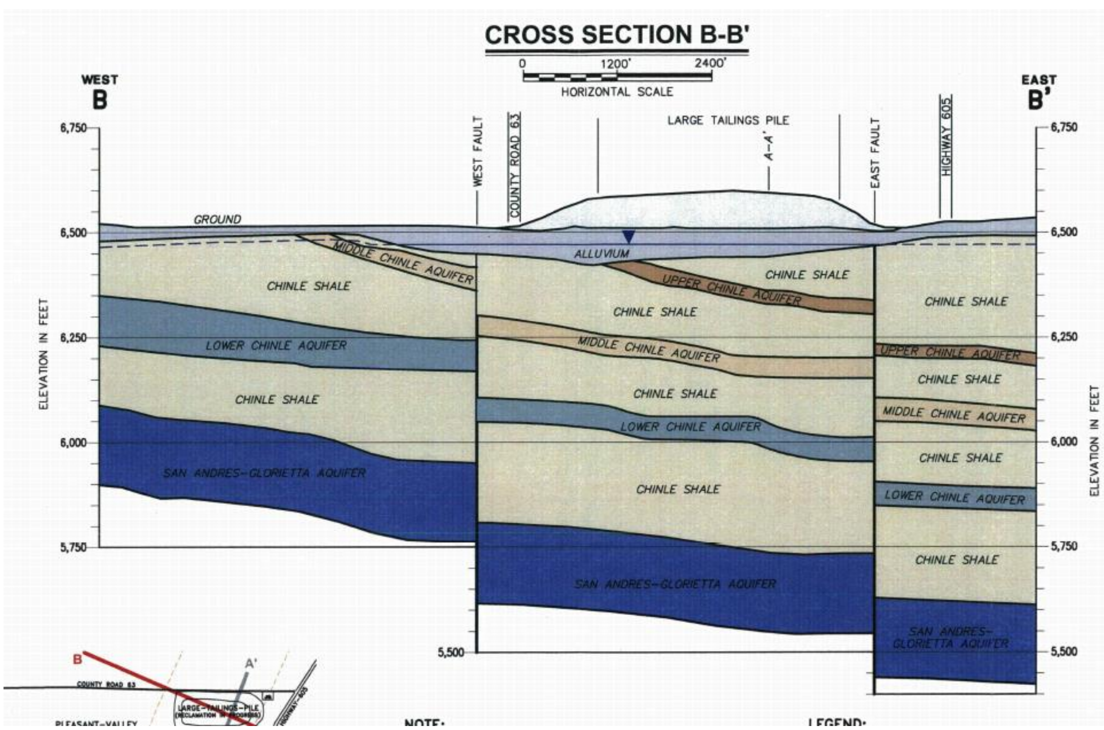

Figure 12: Snapshot of Figure 3.1-6 (HMC 2012) showing cross section B-B'. See Figure 10 for location.

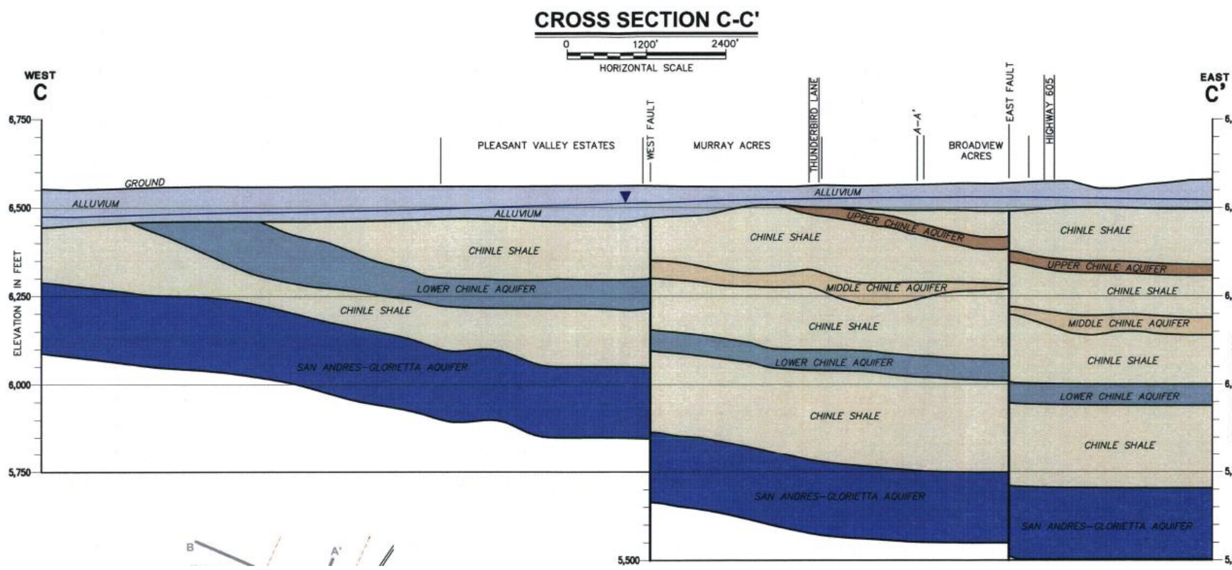

Figure 13: Snapshot of Figure 3.1-7 (HMC 2012) showing cross section C - C'. See Figure 10 for location.

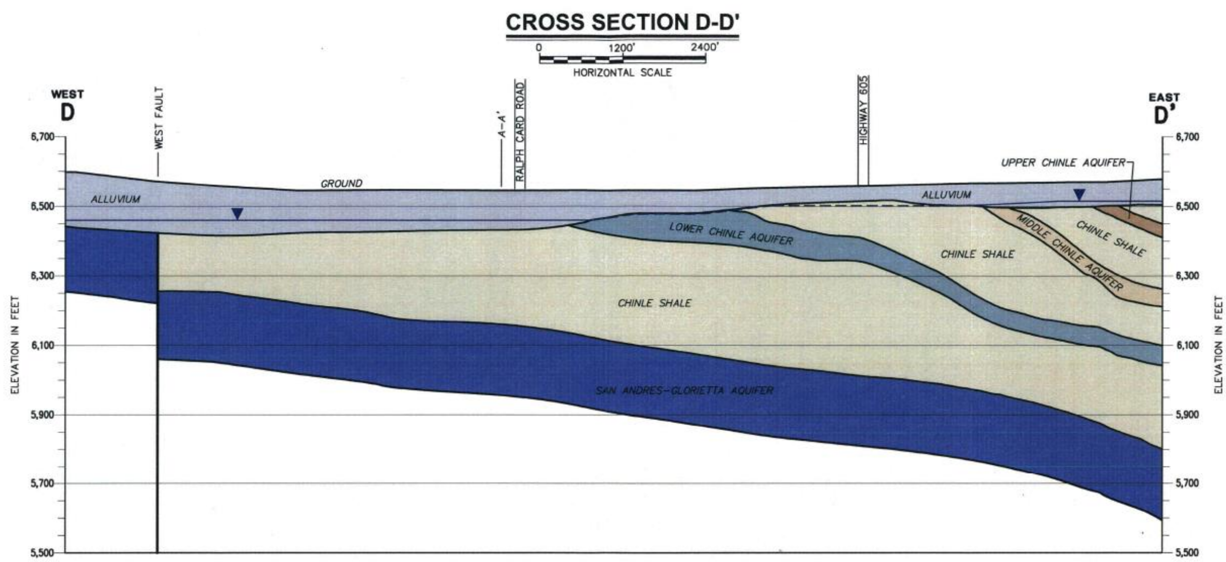

Figure 14: Snapshot of Figure 3.1-8 (HMC 2012) showing cross-section D-D'. See Figure 10 for location.

The Chinle sandstone is likely recharged primarily where it outcrops or subcrops, due to substantial impermeable shale layers separating the alluvium from the sandstone (Baldwin and Rankin 1995). Chinle water is generally sodium bicarbonate or sodium bicarbonate sulfate with low calcium and chloride concentrations; a high sodium percentage has been considered indicative of the Chinle formation in wells where other information was incomplete (Baldwin and Rankin 1995). Calcium concentrations that exceed nominal levels indicate mixing with San Andres water. High TDS, up to 18,000 mg/l (Id.), distinguishes Chinle water in the Grants-

Bluewater region. The variability is due to the "complex and highly varied nature of flow systems in the Chinle strata and of the strata themselves" (Id. p 42).

San Andres Formation

This formation is limestone ranging from 80 to 150 ft thick in the Grants-Bluewater area (Baldwin and Rankin 1995). There may be three different units, including "a lower massive limestone that may contain interbedded sandstone and limestone, a middle medium-grained sandstone, and an upper massive fossiliferous limestone (Id., p 16). Hydrogeologically, this means the formation probably has properties that vary depending on level in the vertical sequence. The limestone may also have formed karst topography with up to 100 ft relief filled with overlying Chinle formation (West 1972). This means simply that the thickness of both the San Andres and Chinle formations may change rapidly and that there may be intermittent significant hydraulic connection. The formation outcrops extensively to the southwest in the Zuni Mountains, which may be a source of recharge (Figure 3) (Milton Head, personal communication, November 2014).

The San Andres water is mostly a calcium sulfate bicarbonate type, with limestone being the source of calcium. This is in contrast to the sodium bicarbonate sulfate type in the San Andres.

Two possible natural discharge points for the San Andres aquifer are the Ojo del Gallo spring and Horace Springs (Baldwin and Rankin 1995). Prior to extensive agricultural development, the first discharged about 7 cfs and the second about 4.9 cfs. By 1984, the discharge from the Ojo del Gallo spring dropped to 1.2 cfs. Discharge from Horace Springs may be water that moves upward through a fault at Grants and moves eastward through alluvium to discharge at the springs (Id.). Their water type indicates the springs are in the San Andres formation.

In the Grants-Bluewater area, several well tests found transmissivity varying from 55,000 to 450,000 ft^2/d, a very large and transmissive range. West (1972, Table 1) noted the San Andres limestone (and Glorieta sandstone) "yields adequate quantities of water for irrigation and for industrial and municipal supplies". He describes it as "thick-bedded to massive light-gray limestone, sandy limestone, and limy sandstone; locally cavernous, 95-170 ft thick." Storage coefficients ranged from 0.00047 to 0.00097. Both properties indicate the aquifer provided large quantities of water to the area. One well yielded as much as 2830 gpm.

Figure 15 shows the hydraulic properties for the various aquifers as determined from the calibration of a numerical groundwater flow model (Hydro-Engineering 2006).

TABLE 1-1. SUMMARY OF MODFLOW MODEL HYDRAULIC PROPERTIES.

Property	Range of Values
Alluvium Thickness	0 to Approx. 140 feet in active area
Alluvial Aquifer Specific Yield	0.12 to 0.20 - Typically 0.2
Alluvial Aquifer Hydraulic Conductivity	10 to 800 ft/day - Typically 30 to 60 ft/day
Alluvial Vertical Conductance	0 to 0.00175 day^{-1}
Alluvial/Upper Chinle Aquitard Storage Coefficient	0.0001
Alluvial/Upper Chinle Aquitard Transmissivity	0.0001 ft^2/day
Alluvial/Upper Chinle Aquitard Vertical Conductance	0 to 0.001 day^{-1}
Upper Chinle Aquifer Storage Coefficient	0.0001
Upper Chinle Aquifer Transmissivity	4 to 1337 ft^2/day - Typically 40 to 100 ft^2/day
Upper Chinle Aquifer Vertical Conductance	0.0000001 to 0.001 day^{-1}
Upper/Middle Chinle Aquitard Storage Coefficient	0.0001
Upper/Middle Chinle Aquitard Transmissivity	0.0001 ft^2/day
Upper/Middle Chinle Aquitard Vertical Conductance	0.0000001 to 0.001 day^{-1}
Middle Chinle Aquifer Storage Coefficient	0.0001
Middle Chinle Aquifer Transmissivity	7 to 2674 ft^2/day - Typically 30 to 300 ft^2/day
Middle Chinle Aquifer Vertical Conductance	0.0000001 to 0.001 day^{-1}
Lower Chinle Aquifer Storage Coefficient	0.0001
Lower Chinle Aquifer Transmissivity	1 ft^2/day
Lower Chinle Aquifer Vertical Conductance	0.0000001 to 0.0001 day^{-1}
San Andres Aquifer Storage Coefficient	0.0001
San Andres Aquifer Transmissivity	60000 ft^2/day

Figure 15: Snapshot from Hydro-Engineering (2006) showing hydraulic properties of various formations as calibrated from a groundwater flow model.

Historic Water Balance

Total groundwater inflow to the Lower San Mateo Creek basin is the flux entering through the constriction at Sand Curve, flux entering from Lobo Canyon, flux flowing northward through the San Andres formation, and local natural recharge, likely infiltration of runoff from the mountains, or mountain-front recharge (Wilson and Guan 2004).

There have been no detailed recharge studies completed for the area or for the state, as there have been for other southwestern states, such as Flint and Flint (2007) and Maxey and Eakin (1949) for Nevada and Anderson et al. (1992) for Arizona. Hydro-Engineering (2006) models natural recharge as a distributed inflow to their model but does not state the rate they used; they imply it is very low. HMC (2012) cites a Hydro-Engineering report as stating it is 0.5 in/y.

The US Geological Survey published a series of papers collected as Professional Paper 1703 – *Ground-water Recharge in the Arid and Semiarid Southwestern United States* (Stonestrom et al. 2007). Flint and Flint (2008) used a basin characterization method (BCM) to estimate recharge for the entire Southwest, including the study area. The BCM essentially is a water balance of the surface layers that use precipitation, evapotranspiration (ET), and the rates that water can flow through and be stored in the layers to estimate recharge. Areas in which ET substantially exceeds precipitation will have recharge only in the rare times when the precipitation rate exceeds the ET rate and the soil is sufficiently transmissive to allow infiltration to pass beyond the reach of ET. Maps in Flint and Flint (2008) show that the basins receive less than about 12 cm/yr precipitation and that the Zuni Mountains receive up to 30 cm/yr[1]. Figures 16 through 18 summarize their recharge estimates. Most low elevations of the study area, mostly with alluvial geology, are in the 0 to 0.1 mm/y recharge zone. A small amount of runoff would discharge from the mountains and recharge the groundwater beneath the channels or at the top of valley-bounding alluvial fans.

[1] Figure 2 in Flint and Flint (2008) shows the annual precipitation but it appears to have an error in it because it ranges from 0 to 4,500 mm/year. That is the equivalent of 4.5 meters per year, which is far too high. For this study, the following zero has been dropped so that 2,700 mm/y is 270 mm/y, or 27 cm/y.

Figure 16: Snapshot of portion of recharge map, Figure 11 in Flint and Flint (2008). The map shows the northwest corner of New Mexico. The gray areas represent recharge of 0 to 0.1 mm/y (Figure 17). The northwest to southeast trending colored zones are the Zuni Mountains. Notice the very small colored area north of the Zuni Mountains, shown in blow-up on Figure 18.

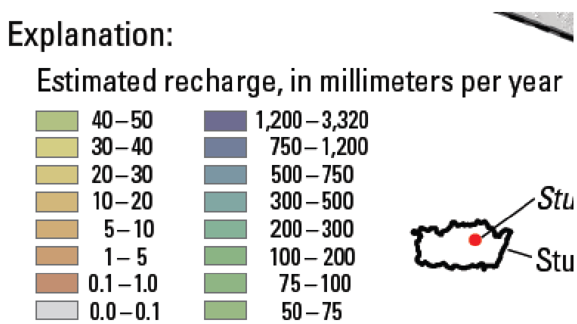

Figure 17: Snapshot of the legend portion of recharge map, Figure 11 in Flint and Flint (2008). This figure supports Figures 16 and 18.

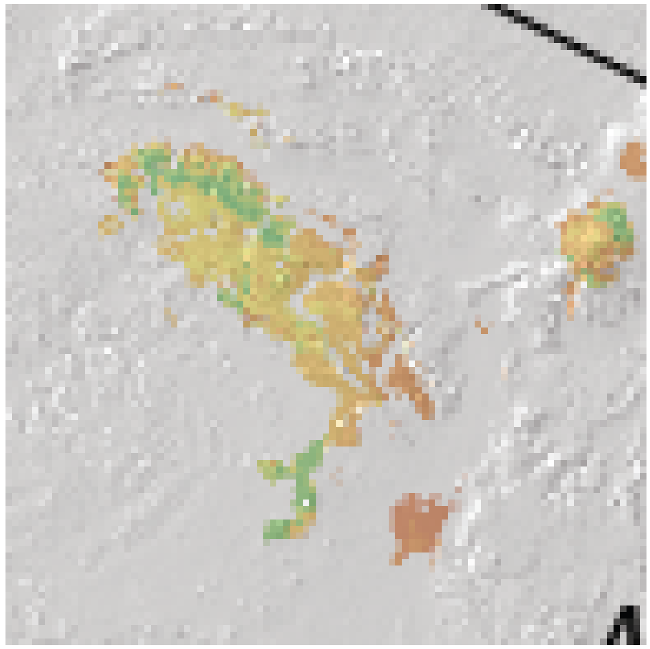

Figure 18: Snapshot of portion of recharge map, Figure 11 in Flint and Flint (2008), showing detail around the Zuni Mountains, the northwest to southeast trending colored zones. Figure 17 is a snapshot of the color code and estimated run-off.

Much more recharge occurs in the mountains (Figure 18). Estimating from Figures 1 and 18, the Zuni Mountains southwest and the compact circular area around Mt Taylor northeast of the project area are apparent as higher recharge zones. Zuni Mountains' recharge appears as high as 200 mm/y, with most occurring in the limestone outcrops (Figures 3 and 18) which recharges the San Andres aquifer. The recharge near Mt Taylor appears as high as 75 mm/y and likely supports springs in the Upper San Mateo Creek and Lobo Creek basins. The very small band of 0.1 to 1 mm recharge along the Mesa Montanosa, the sandstone outcrop that separates the Martin Draw and Arroyo del Puerto basins from the Lower San Mateo Creek basin (Figure 2), probably recharges the Chinle sandstone. Notably, the more extensive mesas that form the north boundary of those two basins do not have recharge in excess of 0.1 mm, probably because they are shale from which most precipitation would run off. There is probably more runoff recharge in these basins at the base of the mesas than the method accurately accounts for (because it does not route the runoff to downstream recharge locations).

Recharge in the upper basins above Sand Curve is approximately 364 af/y and the total for the study area is about 480 af/y (Table 1) based on mid-range values from Figure 18 and estimates of the proportion of a basin within the various recharge zones. Spring flow in the Upper San Mateo Creek basin is about 0.5 cfs or 360 af/y (HMC 2012), which confirms the recharge estimates are of the correct order of magnitude.

Table 1: Recharge by groundwater basin (acre-feet/year or af/y) based on Flint and Flint (2007).

		Recharge Zone (mm/y)							
Basin	**Area (mi2)**	**0.1**	**0.55**	**2.5**	**7.5**	**15**	**25**	**35**	**Recharge (af/y)**
Martin Draw	58.7	0.84	0.08	0.06	0.02				52.7
Arroyo del Puerto	38.3	0.85	0.08	0.05	0.02				32.5
Upper San Mateo	57.7	0.69	0.1	0.08	0.06	0.04	0.02	0.01	269.6
Middle San Mateo	18.8	0.93	0.04	0.02	0.01				9.5
TOTAL above Sand Curve	173.5								364.3
Lower San Mateo	59.2	0.93	0.05	0.02					21.2
Lobo Creek	46.3	0.78	0.1	0.06	0.04	0.02			85.9
Stanley and Card Farm	42.3	1							8.9
Total for Study Area	321.3								480.3

Groundwater flow in the Chinle aquifer apparently originates locally by recharge from the alluvium above and quite likely naturally from upward flow from the San Andres formation, which follows a typical Tothian circulation (Toth 1963) of mountain recharge and valley discharge. Groundwater discharge is to downstream groundwater along the Rio San Jose and to ET, which is likely to be small because there few natural phreatophytes or springs in the near area. Scattered salt cedar along the confluence at Sand Curve may also represent a small ET flux from groundwater, although these may have originated with the mine dewatering discharge.

Natural groundwater flow under the LTP is from the northeast, based on groundwater contours from 1961, (Figure 19, NMED 2010)[2]. Groundwater flow from the west near the Bluewater millsite is clearly further west toward a low point or point of convergence of flow from the Bluewater and Homestake sites.

[2] NMED (2010) was released in "draft" form only. References to that report herein are to data or factual statements, not to conclusions. Analysis herein drawn from NMED (2010) is original to this study, even if the concept first appeared in that report.

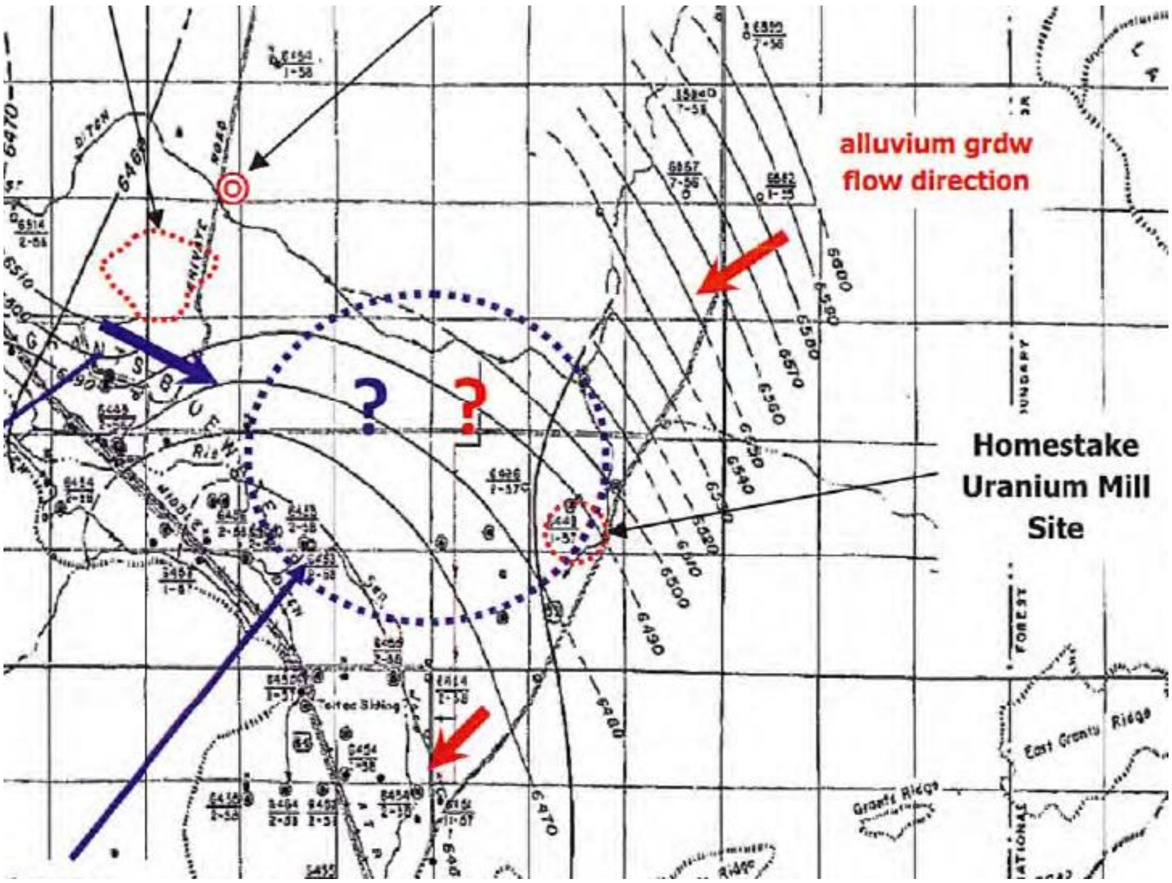

Figure 19: Snapshot from Figure 4 of NMED (2010) showing alluvial groundwater contours "after Grant (1961)". The encircled area to the west is the Anaconda Bluewater Millsite and the double circle is a deep injection well for mill waste.

The bedrock constriction near Sand Curve is a good place to estimate interbasin flow from the Arroyo del Puerto and Middle San Mateo basins to Lower San Mateo basin (Figure 20). Section A-A' is just 0.48 miles long with relatively steep bounds. Saturated thickness very roughly could range from about 40 to 100 ft. Based on Figure 19, the gradient is about 0.0057 ft/ft or a 30 ft in a mile. The only study with estimates for conductivity in the alluvium suggest a range from 30 to 60 ft/d, although it could be more variable (Hydro-Engineering 2006, Baldwin and Rankin 1995). Using the range for saturated thickness and K, the natural flow rate through the constriction varies from 144 to 724 af/y (17,280 to 86,400 ft^3/d).

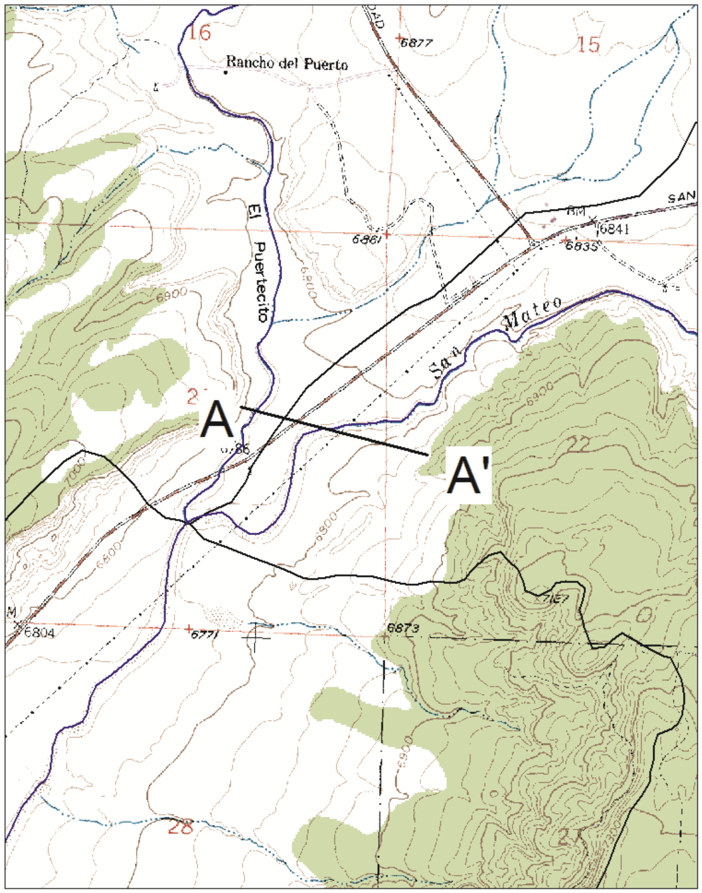

Figure 20: Topographic detail and section A-A' near the confluence of Arroyo el Puerto and San Mateo Creek.

Downstream of the constriction, the cross-section widens and the gradient drops. Groundwater flows from the northeast to the LTP at about 0.5 ft/day based on a gradient of 0.0033 ft/ft, conductivity of 30 ft/d and effective porosity of 0.2 (HMC 2012, p 3-7, Hydro-Engineering 1992). Southwest of Murray Acres injection system groundwater flow is about 0.7 ft/day based on gradient equal to 0.006, conductivity equal to 20 ft/d, and n equal to 0.2 (Hydro-Engineering 1992).

The Lobo Creek drainage, which joins from the east, area is 46 mi^2 or just 27% of the area above Sand Curve and there is no more high recharge area there than above Sand Curve. There is no well- defined thickness or width for this area, so a Darcy's Law estimate is not possible. Based on proportional area, the estimate for flow from the Lobo Creek basin would be from 40 to 200 af/y. Together, the estimates for flow through Sand Curve and from the Lobo Creek basin suggest a range of 200 to 950 af/y natural flow through the alluvium through Homestake Mill area.

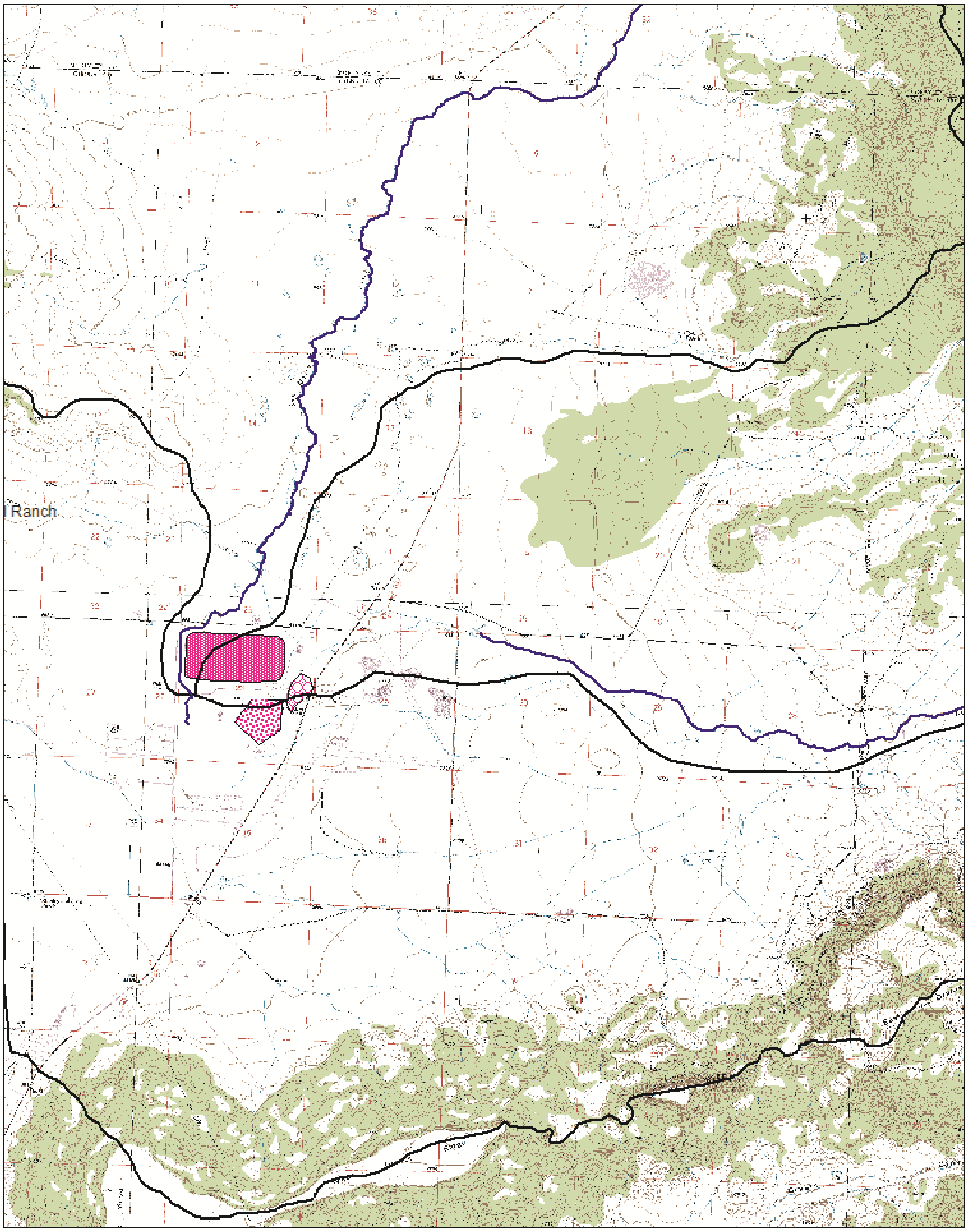

Figure 21: West portion of Lobo Creek basin showing the general plan view of the area through which groundwater would flow.

Mine Dewatering and Mill Development Period (1958-1990)

A couple dozen underground uranium mines and at least two major millsites were developed in the Martin Creek and Arroyo del Puerto basins between 1958 and 1990. These mines and millsites discharged mine dewatering water and leaked tailings water. Most of the dewatering water flowed down the arroyos and eventually sank into the sandy soil but added to the natural flow at Sand Curve. The water table in some wells in the area of Sand Curve may have increased as much as 70 feet[3].

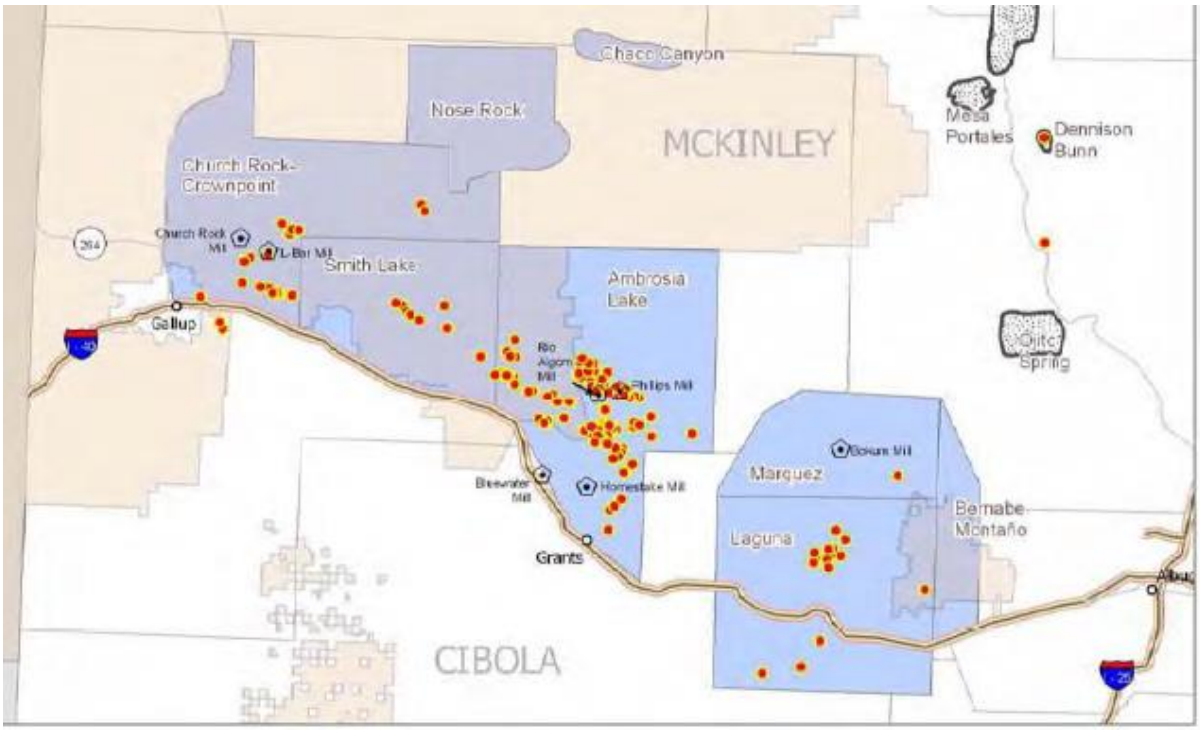

Figure 22: Snapshot from Figure 1 (NMED 2010) showing the general uranium mining districts between Albuquerque and Gallup, along with individual mines as orange dots.

The Arroyo del Puerto, which flows from the northwest, has sandstone canyon walls and sandy alluvium in the bottom. Flow that sinks into the sand would likely discharge back into the stream wherever the sandstone constricts the flow, such as Sand Curve (Figure 23). Most surface water through the constriction would have percolated in a broad sandy area downstream from the San Mateo Creek bridge (Figure 24), although there are no recent signs of discharge. Phreatophytes both up- and downstream of the culvert (Figure 24) suggest there is a shallow groundwater table, although it cannot be said with certainty that discharges from above the constriction caused the vegetation to take root.

[3] EPA, personal communication, March 5, 2015. This information was part of a presentation at the NMDEP offices in Grants NM.

Figure 23: Photograph of Arroyo del Puerto showing the constriction through which surface water would flow.

Figure 24: Photograph looking downstream from Hwy at the San Mateo Creek culvert. The channel is poorly defined and the area south beyond the vegetation is sandy.

EPA (1975) and Kaufman et al. (1976, 1975) provide the most complete source of early water quality data for flow from the upper basin. Tailings pond seepage at the Kerr-McGee mill at Ambrosia Lake was reported to be 491,000,000 l/y, or 130,000,000 g/y (Id.). The overall reported discharge from various sources totals over 10,500 af/y (Table 2), with most of the discharge being in the Arroyo del Puerto basin. If this all percolated and became groundwater the average groundwater flow downgradient of Sand Curve would increase by more than ten times to almost 11,000 af/y; this would have caused the saturated thickness to increase substantially[4]. Assuming operations from 1958 through 1982, although not all facilities started or ended discharge at the same time, about 275,000 af of water entered the Lower San Mateo Creek basin as groundwater.

The water quality of this discharge was very poor, with uranium concentrations far exceeding today's drinking water standard of 0.03 mg/l. Discharge standards at the time were as high as 2 mg/l (EPA 1975), and many discharges far exceeded that amount (Table 2). Reported U concentrations ranged from 0.26 to 19 mg/l for mine discharges; the higher values are for low volume seepage flows or decant water. If the U concentration for the entire 275,000 af estimated to be discharged to the Lower San Mateo basin averaged 0.26, 2, 10, or 20 mg/l, the total amount of U would have been 194,000, 1,496,000, 7,478,000, and 14,209,000 pounds, respectively.

The Bluewater Millsite was also reported to discharge at 183,000,000 liters/year, or 48,300,000 gallon/year (EPA 1975). This is in addition the water injected into deep aquifers near the site (West 1972).

[4] Id.

Table 2: Reported flow and uranium/selenium concentrations for various discharge points. From EPA (1975) and Kaufman et al (1975)

		Uranium (mg/l)			Selenium (mg/l)		
Discharge Point	**Avg flow (mgd)**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**
K-M Tailings Bypass	0.64	4.2	1.3	2.5	0.07	0.03	0.05
K-M Sec 30W Mine Q	1.36	6.7	5.9	6.2	0.04	0.03	0.03
K-M Sec 19 Mine Q	0.15			0.26			
K-M Sec 35 Mine Q	3.77	26	14	19	0.08	0.04	0.07
K-M Sect 36 West Mine Q	2.07	3.4	2.6	3	0.01		
K-M Sect 36 East Mine Q	0.14	2.5	2.3	2.4	0.03		
K-M Seepage below tailings				160			0.7
Ranchers Johnny M Mine Q	0.46			0.12			
UN Ion-exchange Q	0.08	11	5.9	7.8	0.12	0.02	0.08
UN Homestake Ion-exchange	0.6	5.8	2.3	3.7	0.33	0.3	0.32
UN Homestake Partners Tailings Pile Decant				150			0.92
Anaconda Co. Injection	0.16			130			0.03
Total	9.43						
Total in af/y	10,562.						

Leakage from HMC Millsite

Leakage from the LTP would have consisted primarily of the water used to slurry the ground tailings onto the pile. The tailings consisted of 40% solids which were added to the impoundments, at least early in their development, by truck (Skiff and Turner 1981). The maximum tailings disposal capacity was 3400 tons per day, but from 1986 through 1990 the average throughput was 2000 tpd (Kuhn and Jenkins undated). About 1,220,000 tons of tails were placed in the small tailings pile and 21,000,000 tons were placed in the LTP between 1958 and 1990, which is an average of about 1900 tpd (HMC 2012). The total water placed, at 60% of the tails, would have been about 6500 af. Tailings solution and precipitation on top of the tails was recovered with two centrally located decant towers and returned to the mill for processing in an ion exchange circuit.

Tails water would also seep through the LTP to the ground surface as the tails consolidated by squeezing water from the pores. Chavez (1961) presented the earliest data regarding groundwater levels and quality near the millsite (Figure 25). He noted that contaminants in his wells 5 and 9, upgradient from the millsite, are due to "radial seepage", implying that water entering the alluvium from LTP seepage is moving against the gradient. Water surface elevation for six wells near the millsite increased up to ten ft between 1960 and 1972 and more by 1982[5].

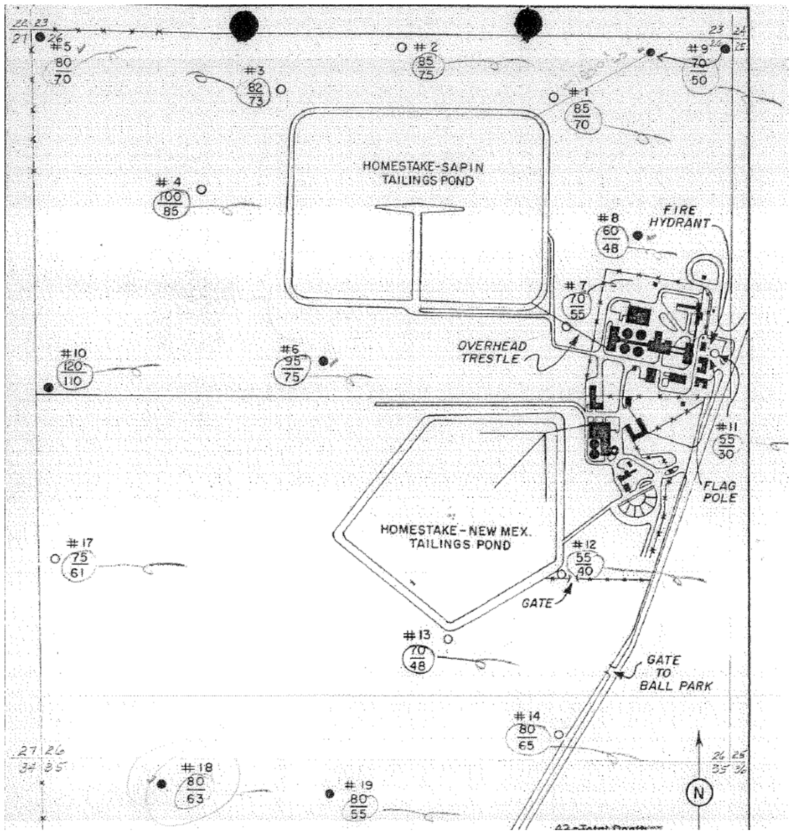

Figure 25: Snapshot from Chavez (1961) showing location of monitoring wells around the millsite. The two rectangles are half sections, for perspective. Note that the tailings pond is much smaller in this picture than it became by 1992. File 43490-1.pdf.

During operations, a saturated zone formed within the LTP above the ground surface due to the lower conductivity of the soil beneath the tails which prevented seepage from saturating the soil between the ground surface and water table (Figure 26). The phreatic surface within the tails slopes downward to the edge of the LTP where it causes a wetted surface on the side of the LTP.

Unsaturated seepage through the ground surface beneath the LTP formed a mound on top of the groundwater table. Even in 1976, it was apparent that the mound under the LTP was

[5] Chavez (1961) lists wells 5, 6, 9, 10, 18, and 20 as having water level altitude equal to 6527, 6519, 6532, 6514, 6501, and 6503 ft, respectively. The copy of this report as received (file 43490-1) has handwritten data for 1972 that shows water surface elevation equal to 6532, 6525, 6540, 6518, 6514, and 6513. Additional data for 1982 is not readable for three wells, but for the three that are readable the water surface elevation continued to increase.

evidence of seepage from the LTP (Science and Engineering Resources 1976). The water table mound under the crest of the embankment was generally about 20 ft higher than the phreatic surface near the toe of the LTP (D'Appolonia 1980) (Figure 26).

Tails seepage flowed both laterally to the toe and vertically to the groundwater at rates depending on the properties of the alluvium and the tails (Figure 27). Under the embankment, the tails conductivity was about 1×10^{-4} cm/s (2.8 ft/d) and in the middle of the tails it was closer to 1×10^{-6} cm/s (0.3 ft/d). The alluvium under the LTP had K equal to about 5×10^{-5} cm/s (1.4 ft/d)[6]. The estimated conductivity values are an average of falling head permeability tests in many piezometers completed in the tails and soils (D'Appolonia 1980).

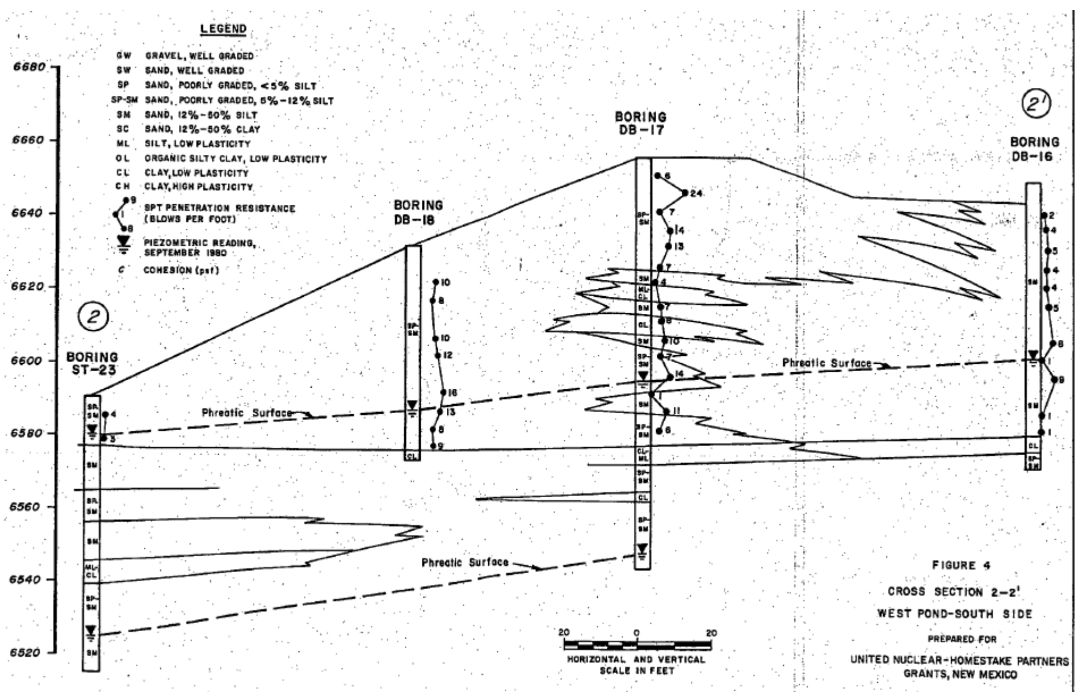

Figure 26: Snapshot of Figure 4, D'appolonia (1980) showing a cross-section through the south side of the west pond of the large tailings pile

[6] HMC (2012) Figure 3.2.2-4 shows that conductivity under the pile is 20 ft/d. If this were correct, it is unlikely that there would be a 20 foot mound because flow estimates described subsequent to this point would yield estimates that are unrealistically high. HMC (2012) cites HMC and Hydro-Engineering (2010) for this information.

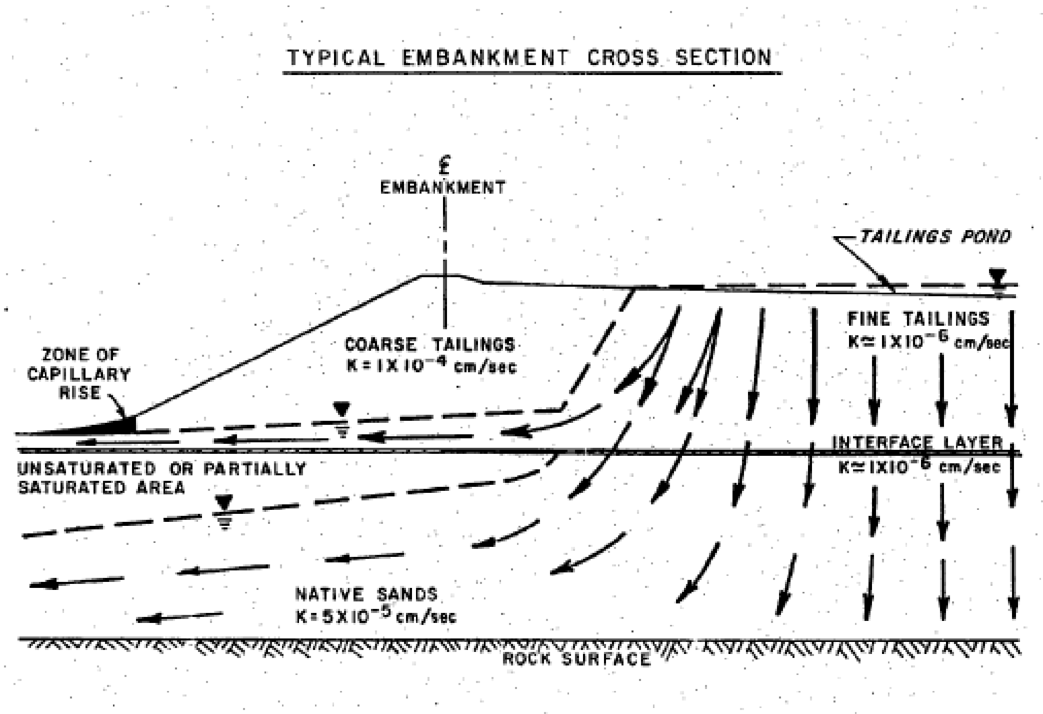

Figure 27: Snapshot of Figure 28 D'Appolonia (1980) showing schematic of cross-section through the large tailings pile embankment.

Seepage to the water table from 1958 through 1977 would likely have achieved quasi-steady state with the 20-foot mound. The vertical seepage reaching the top of the mound would equal the sum of net seepage away from the mound in all directions. The mound would change the gradient as discussed above and decrease the flow from upgradient while increasing the gradient, and flow, downgradient. Net seepage reflects how the seepage from the LTP would change the seepage through a section under the LTP by both adding water and decreasing the flow from upgradient under the LTP. The Dupuit equation, assuming all assumptions hold, would accurately represent the flow under the LTP. The Dupuit equation (Fetter 2001) is:

$$q' = \frac{1}{2}K\left(\frac{h_1^2 - h_2^2}{L}\right)$$

In this equation, h1 and h2 is the saturated thickness from the phreatic surface to the impervious base, assumed to be the base of the alluvial aquifer. Here, h1 is under the embankment and h2 is at the toe of the LTP. An important assumption is that flow at this point is essentially horizontal. Because the mound would have formed under the entire LTP, the vertical component of the flow near the edge would be slight so the horizontal flow assumption is acceptable. The head values h1 and h2 represent the head through the entire cross-section. Flow downgradient from the LTP would be a combination of flow from upgradient of the LTP and seepage through the LTP and h1 and h2 would reflect that combination. The saturated thickness of the alluvium varies from about 60 ft on the west side to about 10 ft on the east, with a broad section of 40 ft thickness along the north and south side (Figure 7). The equation as just described is most accurate along a downgradient section where the section is 60 ft thick. The effective length of the section would be about 4800 ft, from NW to SE corner of the LTP assuming the flow is perpendicular to a section formed by the corners of the LTP.

The length from the embankment to edge of the tailings, L, is about 140 ft. The mound is assumed to be 20 ft so that h1 is 20 ft higher than h2, and the total value is the thickness from Figure 7 plus 20 ft. The total net flow through a 4800 ft section is about 560 af/y. All of the parameters have substantial uncertainty, so this estimate could be 50% too high or low. For comparison, a 20-foot mound over 234 acres and 0.2 porosity would contain 936 af of water, which supports the assumption of steady state seepage. Another comparison that supports the calculations is that 80,000 kg of U remained in the mound in 2001. Mixed through the 936 af, the concentration would equal 61 mg/l. Actual concentrations under the mound exceed 10 mg/l which suggests that U has built over about 30 years (HMC 2012, Figures 4.2.3-1 to 4.2.3-4) but has also flowed downgradient creating the plume southwest of the site and that some U has bound to soil particles becoming attenuated.

Flow from upgradient under the LTP can be estimated with Darcy's law by adjusting the estimate for flow through Sand Curve (assuming the flow from Lobo Creek basin enters downgradient). Based on the 2009 contours (Figure 42, below) and assumming a cross-section from the northwest to southeast corner of the LTP, the gradient is 0.0017 ft/ft, K=20 ft/d (HMC 2012, Figure 3.2.2-4), and thickness equals 40 ft (HMC 2012, Figure 3.2.2-3). Scaling on both gradient and K, the Darcys flow would range from about 29 to 144 af/y under the LTP. This decreased rate is a fraction of the 144 to 724 af/y calculated above for natural flow from northeast of the LTP for two reasons. First, conductivity under the LTP is lower, 20 ft/d, and second, the slope is about a third as much because of the mound which would cause groundwater to backup, upgradient of the LTP. The mound under the LTP is evidence of how the tailings seepage changes flow patterns near the LTP. The lower conductivity under the LTP and the thicker saturated zone west of the LTP also suggests that some natural flow could be diverted west of the LTP.

The calculations above provide an order of magnitude estimate of seepage from the LTP into the groundwater beneath the LTP. The difference between the Dupuit estimate for flow through the section downgradient of the LTP, 560 af/y, and the mid-range Darcy's Law estimate for flow from upgradient, about 87 af/y, is 473 af/y, or 293 gpm, which is higher than but a similar order of magnitude to the 153 gpm seepage estimated by HMC (1982) based on there being 3400 tons/day of tails being deposited. These estimates are also consistent with the 6500 af estimate of tails water placed during impoundment construction. Because LTP seepage adds so much flow to the general flow through the alluvial aquifer beneath the LTP, LTP seepage dominated flow downstream during LTP operations.

Mine Closure and Remediation Period (1977 to present)

HMC commenced remediation activities in 1977 but added tails to the LTP until 1992, so the mine closure and remediation period overlaps with the millsite operations' period. However, HMC commenced in 1977 other actions that changed the flow direction under and downgradient from the tailings in an attempt to contain the contaminants. A general summary of actions near the LTP (HMC 2012) to contain and remediate the contaminant plume follows:

- 1977 – A hydraulic barrier was created between the LTP and the subdivisions to the southwest by injecting clean water on the north side of Broadview Acres
- 1978 – Active tailings seepage collection started
- 1980 – Alluvial groundwater collection begins in Murray Acres
- 1990 – EP-1 was constructed and operations commence
- 1992 – Toe drains were installed arund the perimeter of the LTP
- 1995 – Dewatering of the LTP was started and EP-2 constructed
- 1996 – Groundwater collected from the Upper Chinle aquifer for reinjection into the alluvial aquifers where COC concentrations were elevated
- 1999 – RO plant constructed and used to treat water for injection into the alluvial aquifer, capacity is 300 gallons per minute (GPM).
- 2000 – flushing of the tailings for the source control program and the land treatment program begun. Land treatment is irrigation
- 2002 – second RO unit increases capacity to 600 gpm
- 2010 – EP-3 constructed

As noted, HMC began to collect tailings seepage in 1978, alluvial groundwater in 1980, installed toe drains to collect seepage from the LTP beginning in 1992 and began dewatering the LTP in 1995. Injection well hydraulic barriers may have blocked regional flow to the southwest. The total amount of water collected from the tails, toe and groundwater from 1978 to 2009 was 15,230 af, with the majority being from the groundwater (Figure 28). The amount collected from groundwater had decreased from the mid 1980s through the late 1990s, but then increased to rates similar to those in the 1980s for a part of the 2000s. It is beyond the scope of this report to discuss in detail the pumping, but the increase likely coincides with the flushing of the tails which would have pushed more water through the LTP. It also caused groundwater divides and troughs observed in many of the contour maps, as discussed below. Both the amount drawn from the toe and tails increased coincident with flushing.

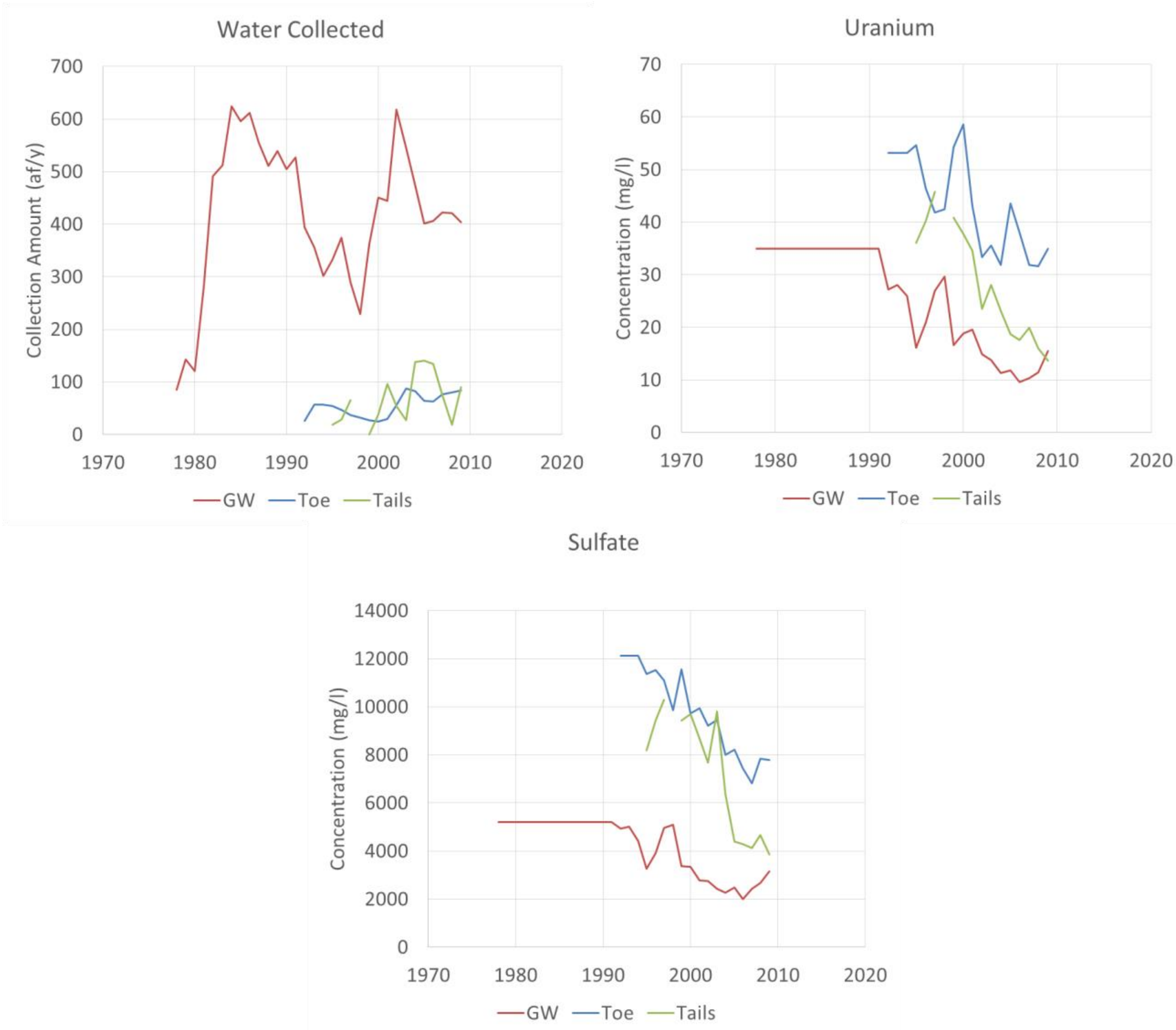

Figure 28: Amount of water collected, uranium and sulfate concentrations from the HMC tailings pile. Data from EPA (2011 Table, 4).

The earliest groundwater contour map developed for the site during operations was from 1976 (Figure 29). Flow is from the northeast to southwest and there is a mound of at least 15 ft under the LTP. A 6540 ft amsl contour occurs uphill (northeast) from the LTP as well as around the south side of the LTP. The 6525 ft contour bends sharply around the southwest corner. The 6540, 6535, 6530, and 6525 contours parallel each other closely on the south of the LTP and essentially outline the mound. By 1983, collection wells established on the south side and southwest corner of the LTP formed troughs in the groundwater table (Figure 30). Also, a 6520 ridge west of the small tailings impoundment (STP) dropped to a trough lower than 6510. By 1986, the troughs are a couple of feet deeper (Figure 31). Injection wells further southwest created a ten-ft mound under the northern parts of Murray Acres and Pleasant Valley (Figure 31) that would act as a groundwater divide if the contour represents head through the entire saturated zone. By 2000, the troughs are still apparent but the flow apparently is from the east and northeast under the LTP to the west and southwest to Pleasant Valley Acres, Murray Acres, and Valle Verde (Figure 32). The large ridge that had been apparent in 1986 is mostly gone. Contours west of the LTP in 2000 and 2009 (Figures 32 and 33) show a water table sloping due west to a trough trending northwest to southeast from the Bluewater Millsite. It is not clear whether the trough corresponds with a significant pumping well. No apparent ridges due to injection wells remained in the groundwater table (CH2MHill 2001). Groundwater mounds had either formed or been identified southeast of the small tailings pile and number 1 evaporation pond on the east of the flow paths near Highway 605 (Figures 32 and 33). The mound is higher and more distinct in 2009.

The groundwater mound beneath and north of the LTP increased significantly between 2000 and 2009. In 2000, a 6535 contour roughly trended under the LTP from south to north, with the 6540 contour under the east end and then extending north (Figure 32). The 6540 contour was well north of this area in 1986 and before (Figures 29 through 31). By 2009, the 6540 contour is through the middle of the LTP and the 6545 extends under the east end of the LTP and under the STP. The overall effect of the mound has been to divert flow to the west and prevent flow from the northeast from reaching the Millsite area.

Figure 29: Snapshot of Water Level Elevation, dated 1976 as drawn. UNHP Mill and Vicinity. United Nuclear Homestake Partnership, Milan, New Mexico. (Science and Engineering Resources, Inc. 1976) Socorro, New Mexico.

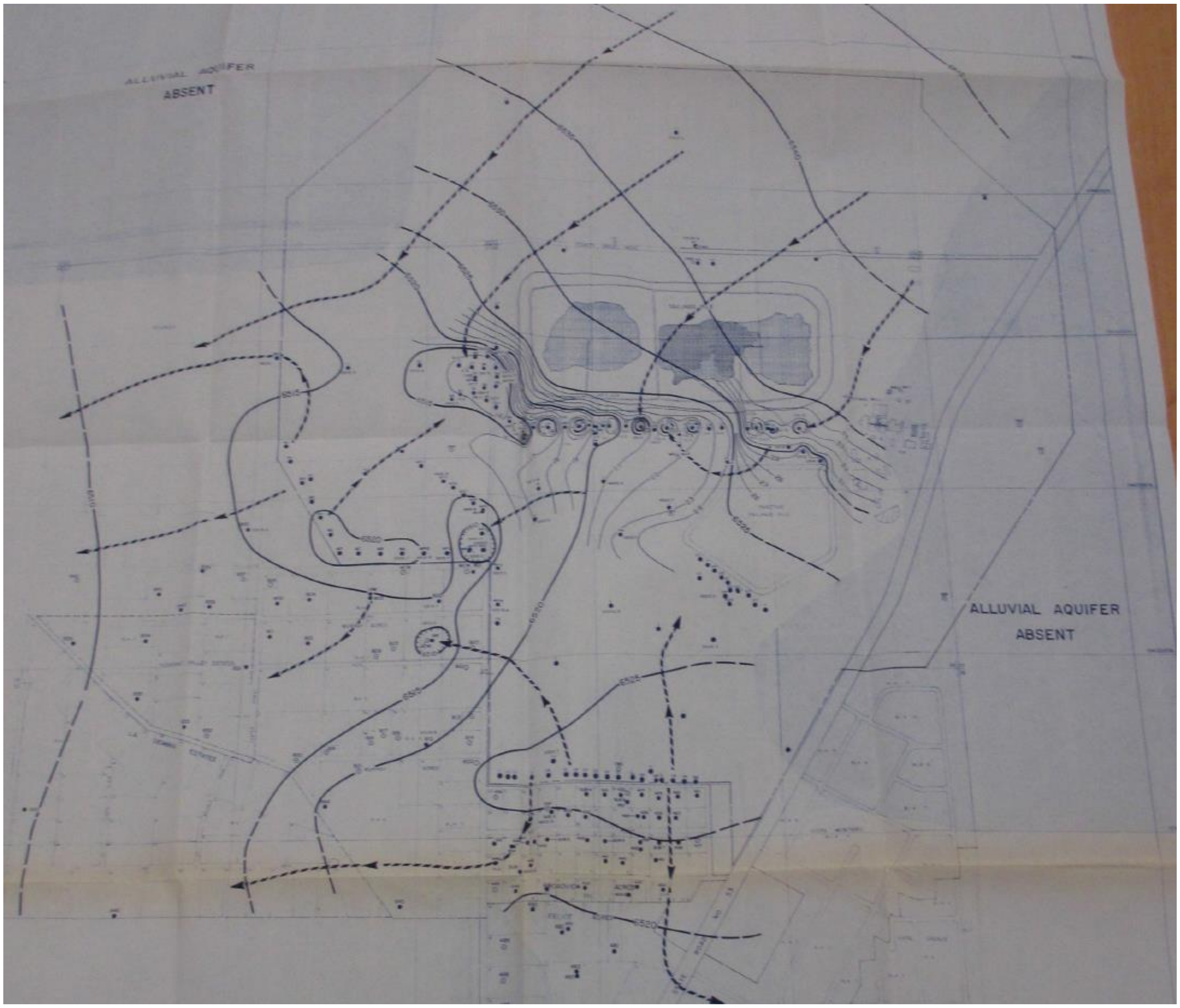

Figure 30: Snapshot of 1983 water level map: Water Level Elevations of the Alluvial Aquifer, December 1983, in Ft. - MSL. Homestake Mill Property and Adjacent Properties.

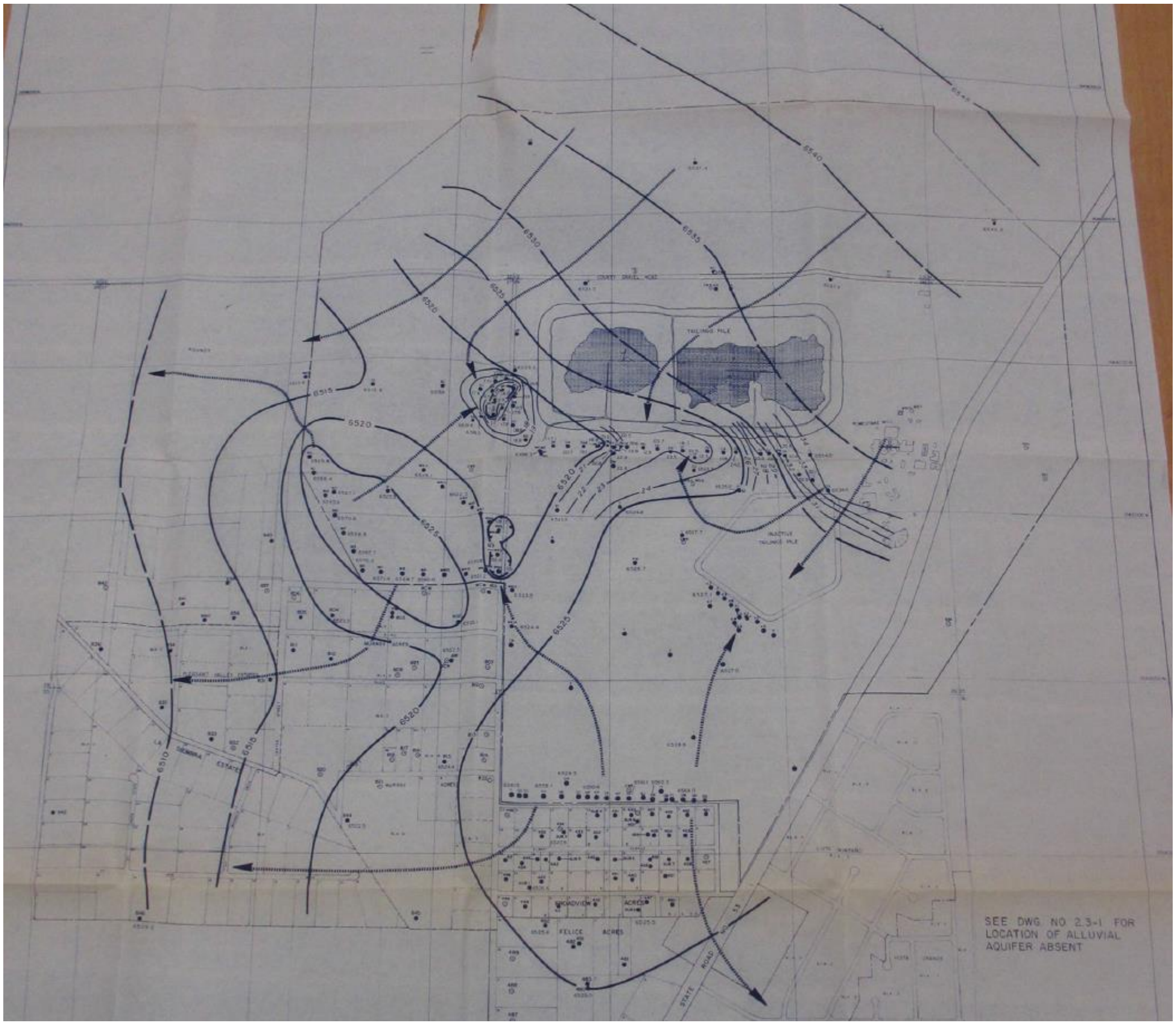

Figure 31: Snapshot HMC map. Water Level Elevation of the Alluvial Aquifer near the Homestake Mill, June 1986, in Ft. - MSL. Map file 43489-1 Maps.

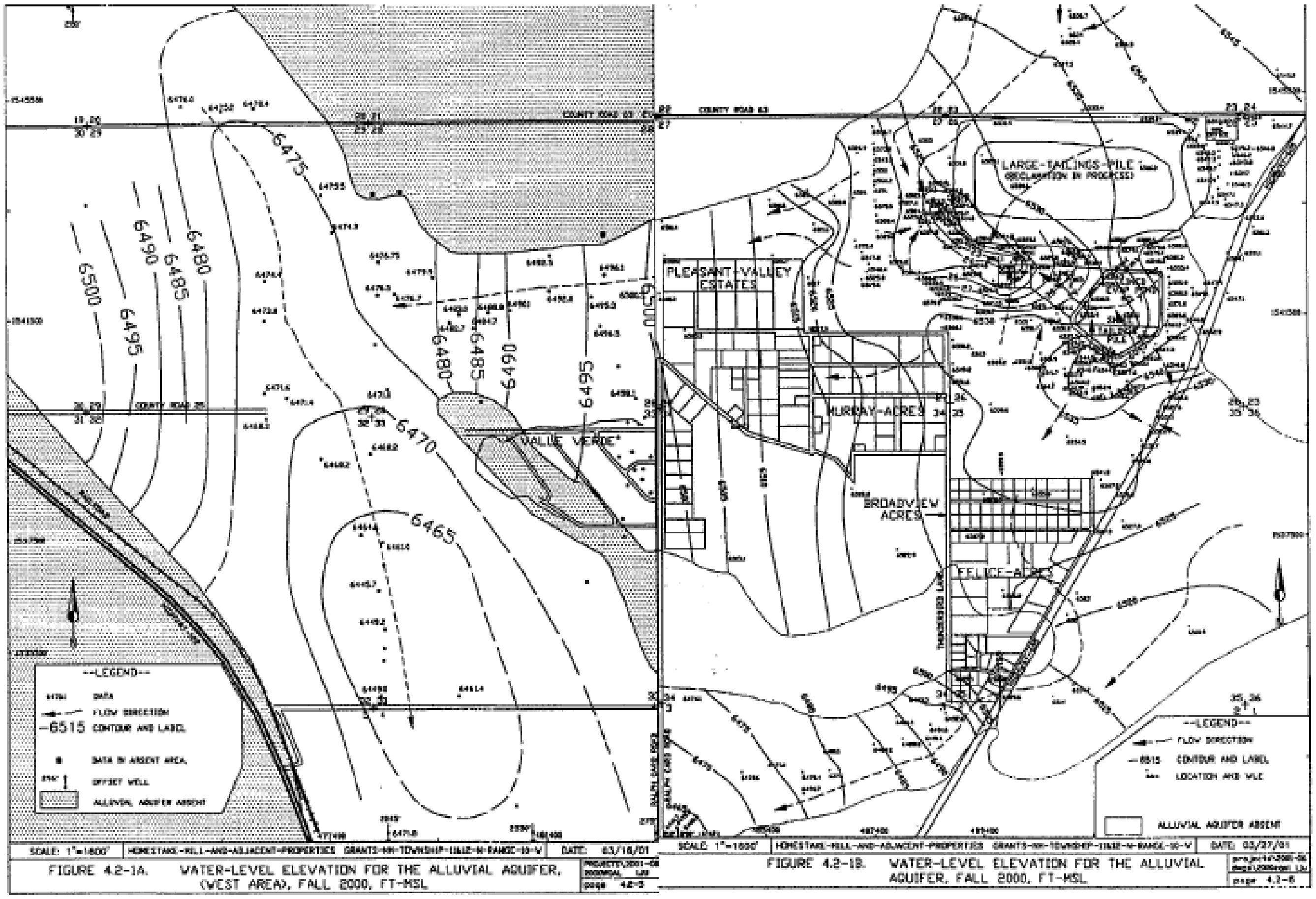

Figure 32: Snapshot Figure 17 (CH2M Hill 2001) showing potentiometric surface for alluvial layer in 2000.

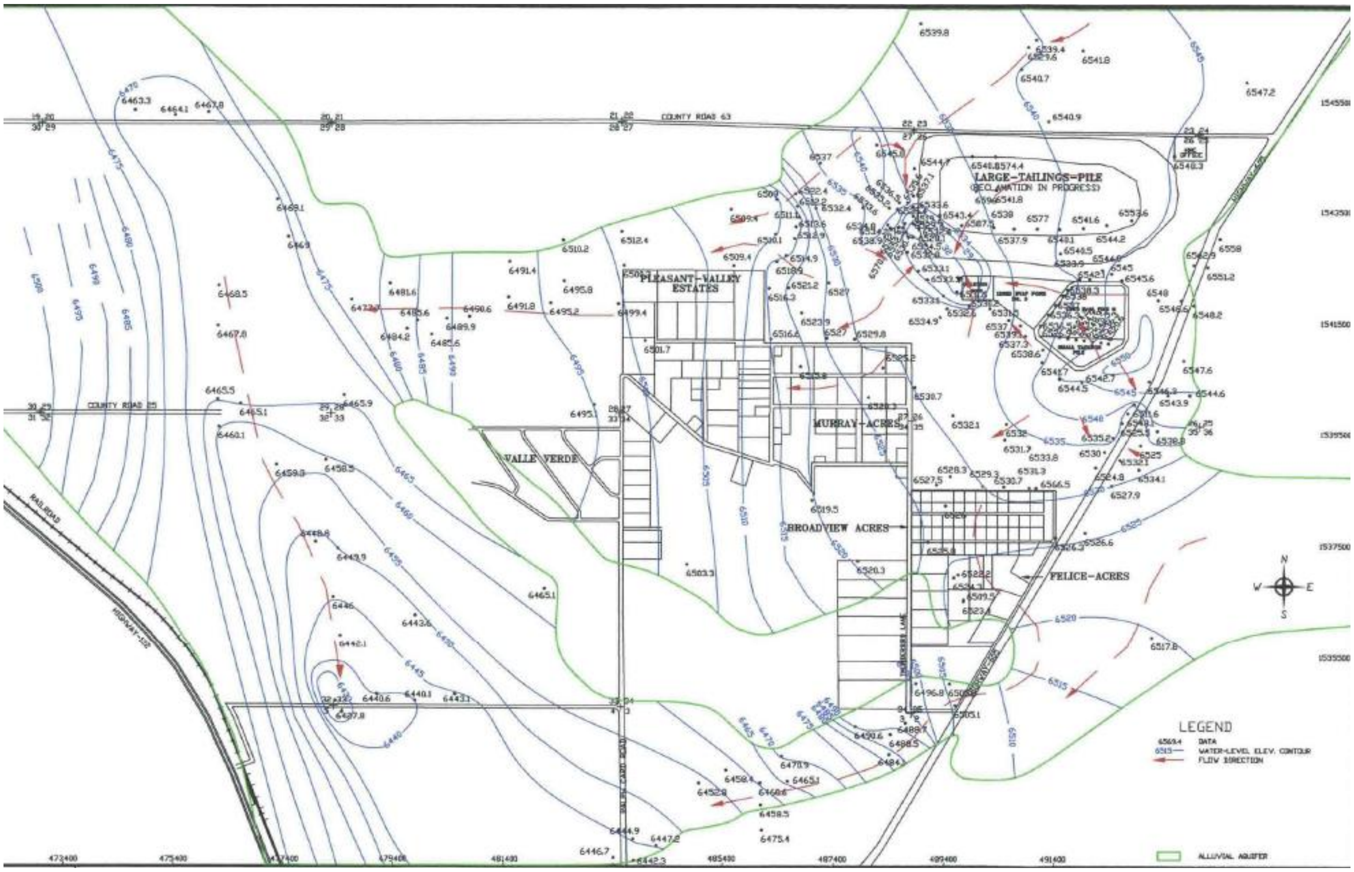

Figure 33: Snapshot of Exhibit 10 (EPA 2011) showing potentiometric surface in the alluvium in 2009. The green line is the outline of the alluvial aquifer.

Chinle aquifer groundwater levels also varied with time, but there is a paucity of observation data. In the Upper Chinle, year 2000 groundwater levels west of the East Fault undulate around 6520 to 6530 and flow is to the north or south depending on location (Figure 34). Groundwater levels increase 30 ft across the East Fault to the east. Upper Chinle groundwater elevations under the LTP, including the point where the Upper Chinle subcrops, are 10 feet lower than in the alluvium (Figure 32). This indicates there is likely a downward gradient for recharge and contaminants to reach the Chinle aquifer.

Groundwater flows northward through the Middle Chinle under the LTP, but the groundwater is about 50 ft lower than in the alluvium (Figure 35). Groundwater contours west of West Fault are 30 to 40 feet higher than east of the West fault, and the groundwater flows to the south. East of the East Fault, flow is to the east (Figure 35).

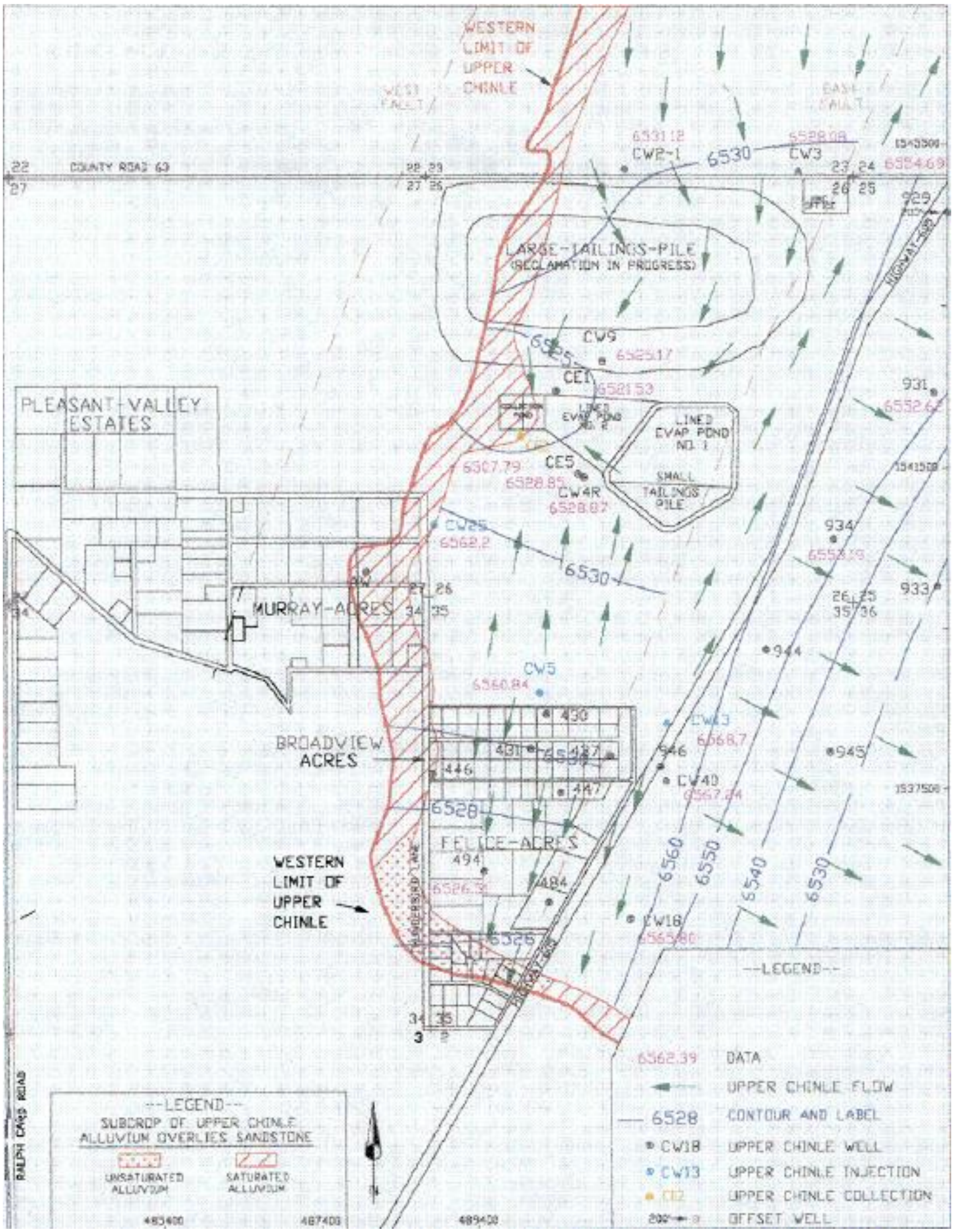

Figure 34: Snapshot of Figure 18 (CH2M Hill 2001) showing potentiometric surface and flow direction interpretations for the Upper Chinle aquifer in 2000.

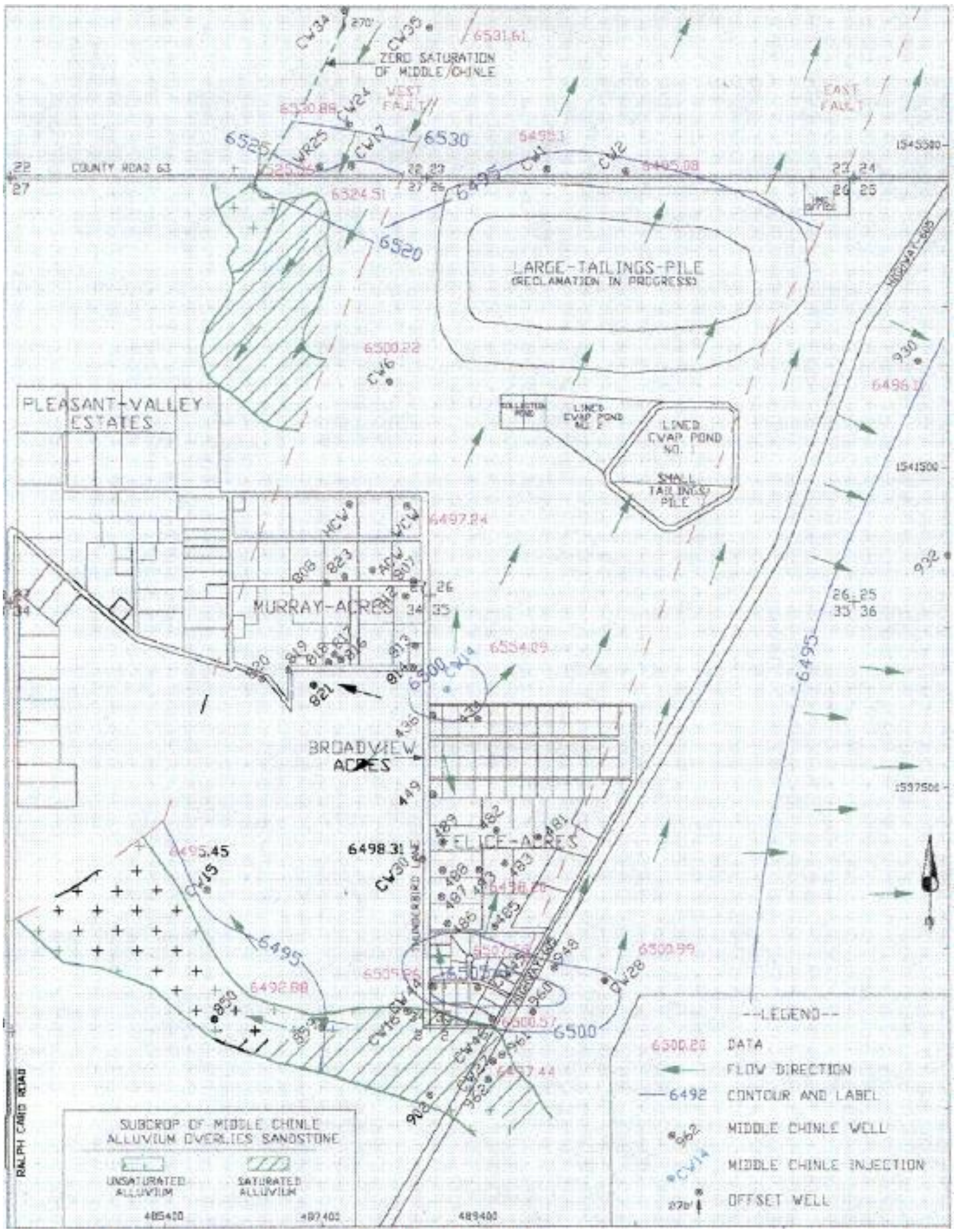

Figure 35: Snapshot of Figure 19 (CH2M Hill 2001) showing potentiometric surface and flow direction interpretations for the Middle Chinle aquifer.

CONTAMINANT TRANSPORT WITH TIME

Alluvial Aquifer

Both uranium and sulfate concentrations in the water collected from the tails have been very high (Figure 28). The system collected over a million pounds of U. Water with these concentrations seeps from the tails water to form mounds beneath the LTP and U plumes downgradient of the site. Flushing the LTP decreased the concentration in all three collection points, but even by 2009 all still exceeded 10 mg/l (Figure 28). Concentrations in excess of 1 mg/l do not extend far from the bounds of the LTP because soils and aquifers attenuate U, although sufficient U reaches the subdivision's wells to make the concentrations hazardous. Sulfate concentrations parallel U concentrations over much of the time period.

In 1976, U concentration exceeded 100 mg/l under the west end of the LTP and under the STP (Figure 36). The smallest contour, 0.5 mg/l, surrounds the impoundments. The position of the 0.5 mg/l contour on the north side of the LTP may not be justified due to too little data. U concentration exceeded 0.5 mg/l near the Murray Acres subdivision and was as high as 10 mg/l two miles south of the LTP. By 1981, the area within the 100 mg/l contracted slightly, but the 50 mg/l contour surrounded most of the LTP (Figure 37). Concentrations southeast of the LTP increased from less than 10 mg/l to over 100 mg/l. The concentration under Murray Acres increased to greater than 10 mg/l. Further south, however, the area within 10 mg/l contours contracted. Figure 37 does not have a 0.5 mg/l contour, but the 0.1 and 1.0 mg/l contours suggest the plume had not expanded much even as the concentrations within the plume increased significantly.

The 100 and 50 mg/l contours under the LTP shifted but did not expand very much from 1981 to 1983 (Figure 38). The largest change was the area of the 10 mg/l contour expanded to include all of the STP and the northeast corner of Murray Acres. The area with low concentration northeast of Murray Acres disappeared. The southwest trend "tongue" of 0.05, 0.1 and 1.0 mg/l contours extended further into Murray Acres. A substantial area in Broadview and Felice Acres had U greater than 1 mg/l.

The 100 mg/l contour almost disappeared and the 50 mg/l contour contracted significantly by 1986 (Figure 39). The tongue into the northeast part of Murray Acres receded. The largest contour in Broadview and Felice Acres dropped from 1.0 to 0.1 mg/l by 1986 and the area within it continued to contract by 1994 (Figure 40). The lower concentrations between the LTP and the northeast corner of Murray Acres were restored, but still exceeded 0.1 mg/l in the subdivision. The 50 mg/l contour under the LTP remained similar to its 1986 configuration. The plume west of the LTP remained about a mile from the LTP but the contours increased from 1983 to 1994 so that there was a substantial area ranging from 0.1 to 1.0 mg/l.

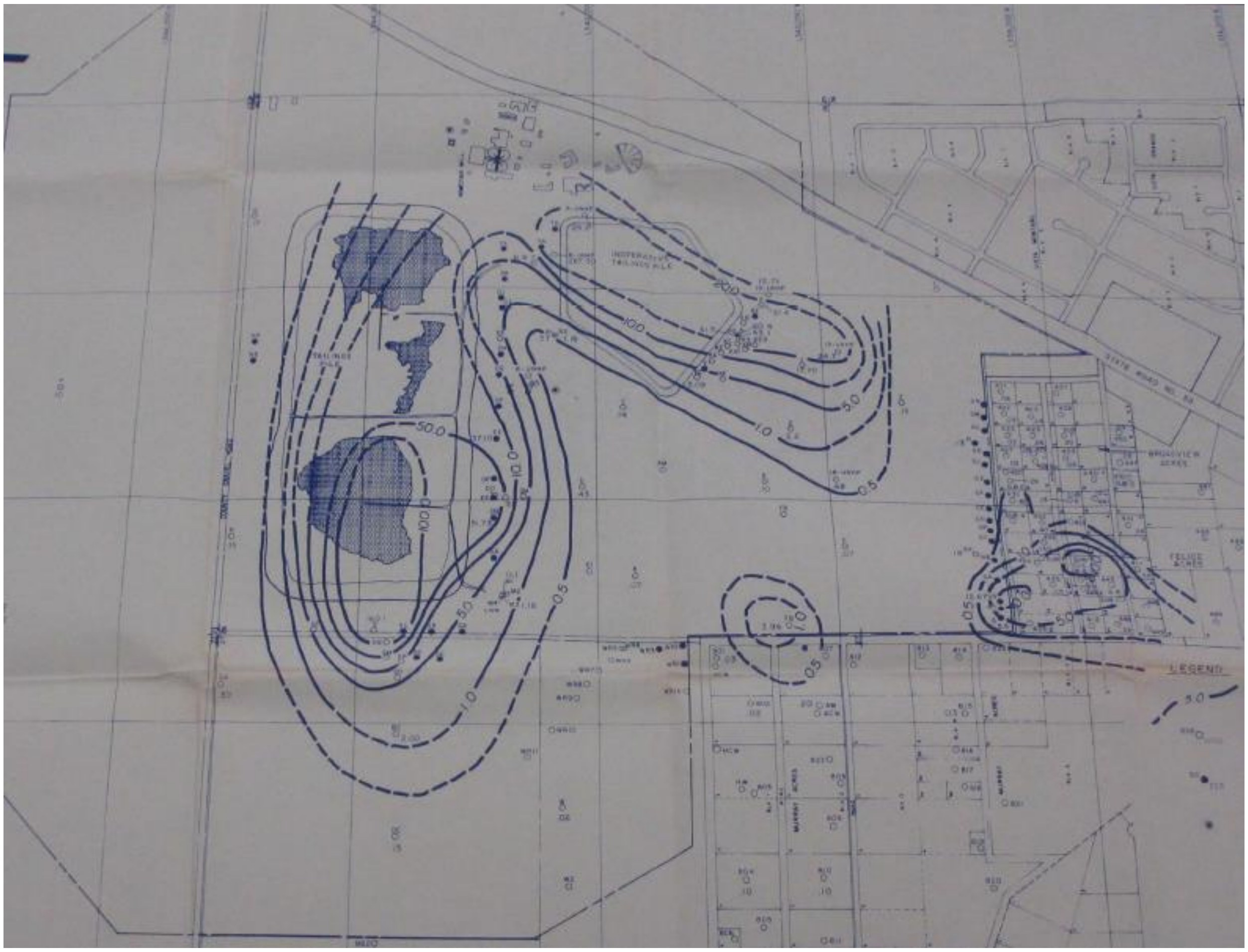

Figure 36: Snapshot of 1976 uranium concentration map. Uranium Concentrations in Groundwater from the Alluvial Aquifer, August 1976. Prepared for Homestake Mining Company, Grants, New Mexico, D'appolonia. Note that north is to the left in this figure.

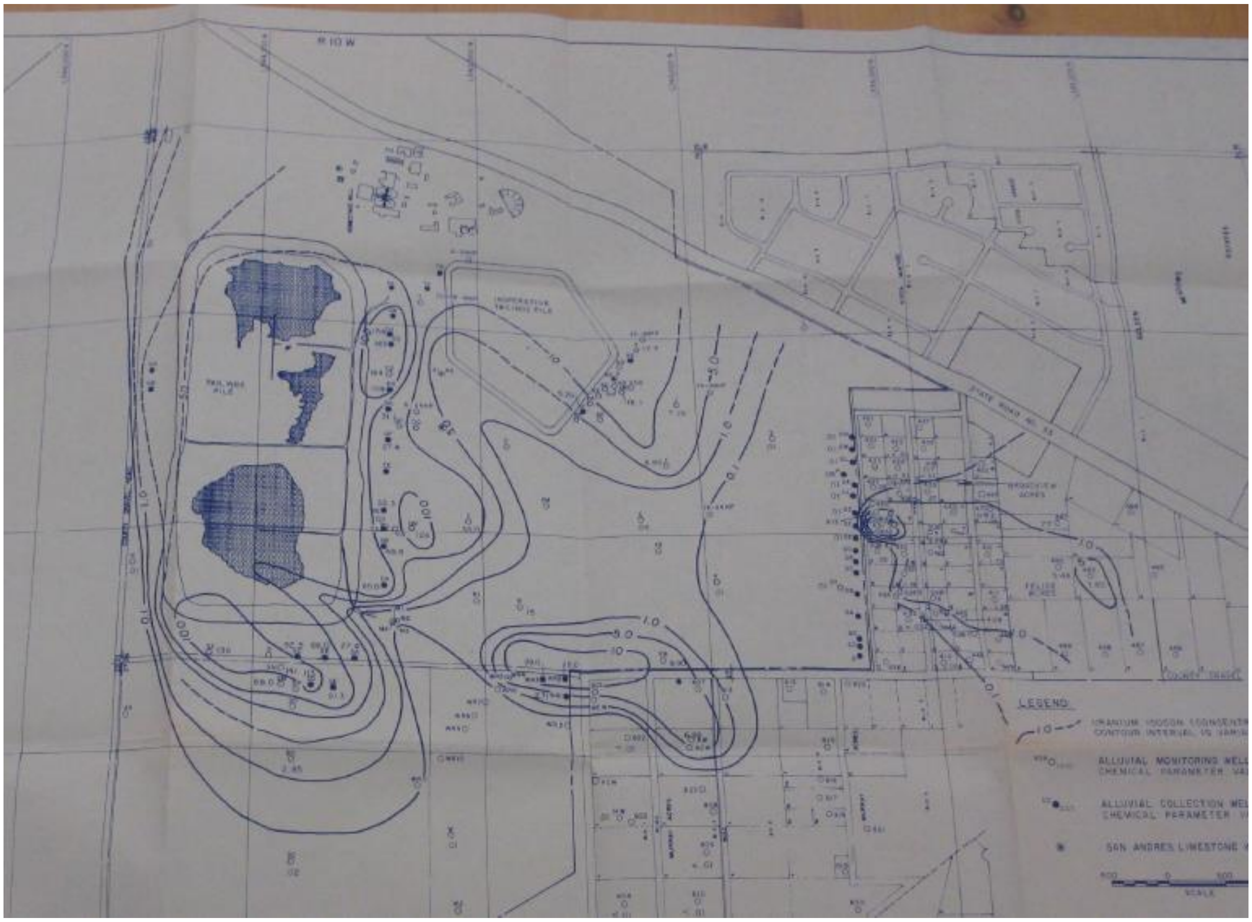

Figure 37: Snapshot of 1981 uranium concentration map. Uranium Concentrations in Groundwater from the Alluvial Aquifer, Fall 1981. Prepared for Homestake Mining Company, Grants, New Mexico, D'appolonia.

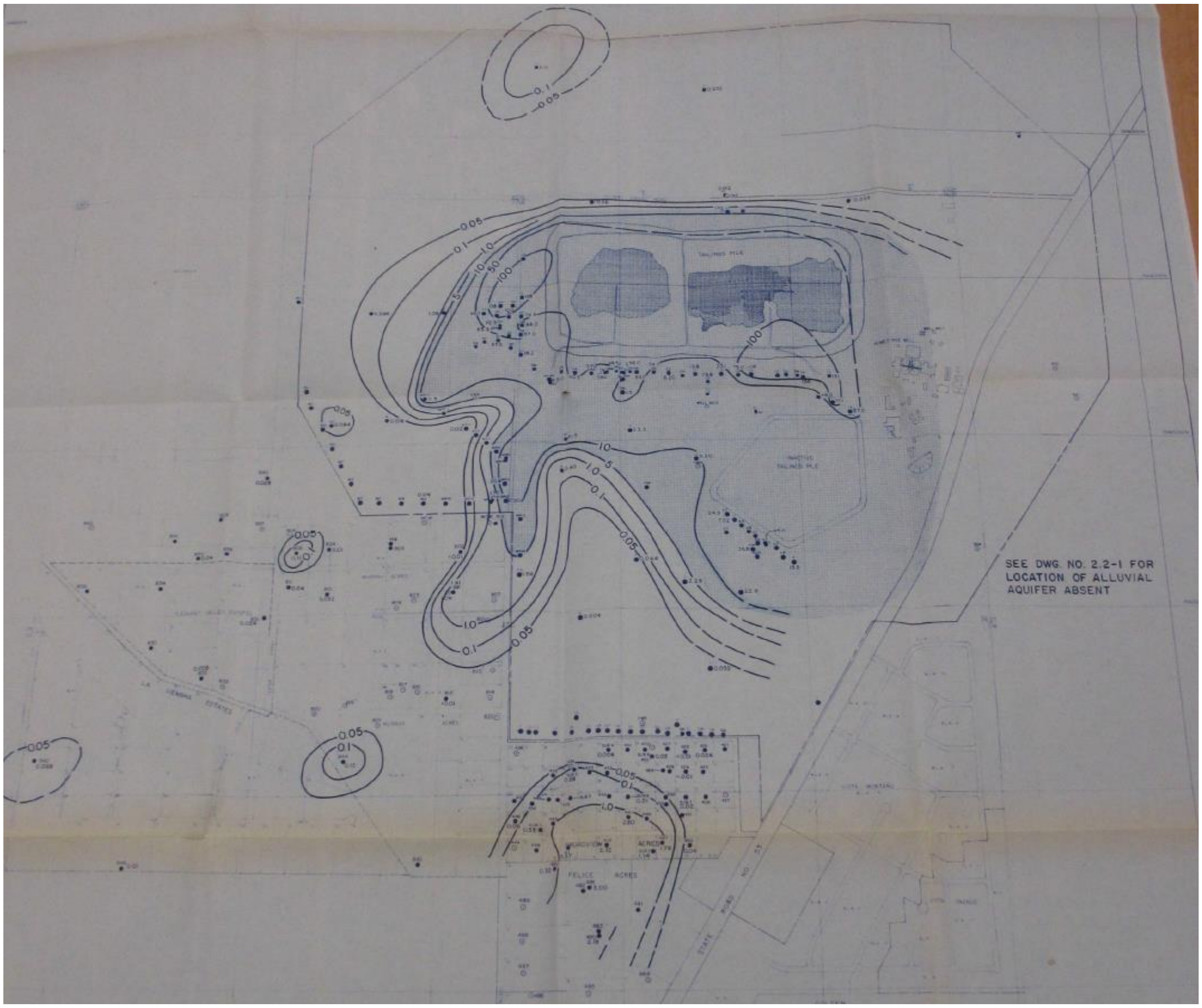

Figure 38: Snapshot of uranium concentration map, 1983. Uranium Concentrations for the Alluvial Aquifer, November 1983, in mg/l. Homestake Mill Property and Adjacent Properties. File 43491-4 Maps.pdf.

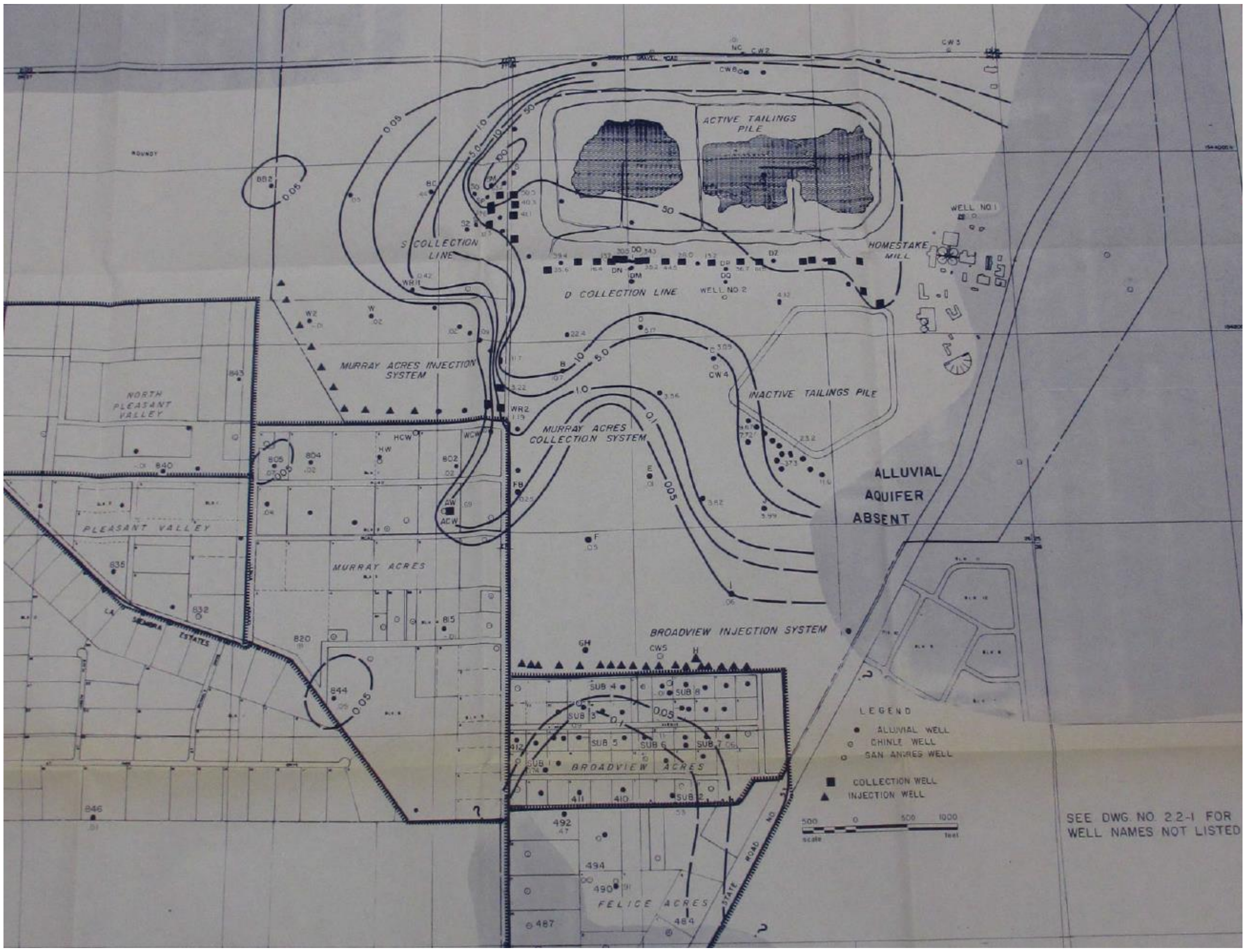

Figure 39: Snapshot of uranium concentration map: Uranium Concentrations for the Alluvial Aquifer, June, 1986, in mg/l. Homestake Mill Property and Adjacent Properties. Map file 43489-1 Maps.pdf. Note the 100 mg/l contour west of the large tailings pile.

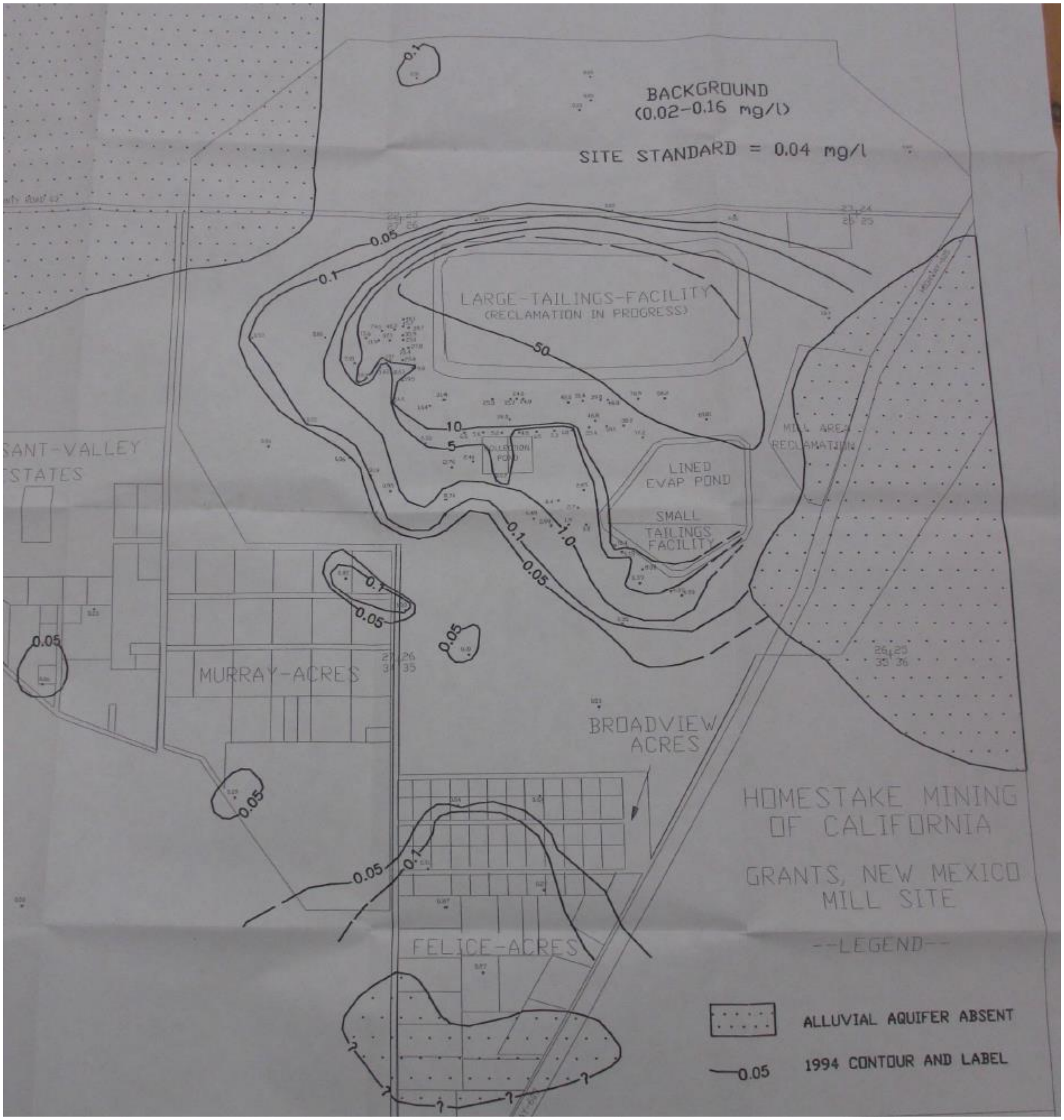

Figure 40: Snapshot of HMC uranium concentration map for 1994. Map title: Uranium Concentrations for the Alluvial Aquifer, Fall 1994, in MG/L. Homestake Mill and Adjacent Properties, Grants NM Township 12 N Range 10 W

The contours expanded further west between 1994 and 2005 (Figure 41). The area with 50 mg/l U concentration significantly decreased so that much of the LTP was within a 10 to 50 mg/l range and most was within the 5 mg/l contour. Concentrations under Murray and Broadview Acres had not apparently changed much except that a larger area used for the mapping extended the smaller contours further south. By 2005 a significant area south of Felice Acres with concentrations exceeding 0.1 mg/l and a plume of concentrations exceeding 1 mg/l formed south along Hwy 605. A very large plume with U exceeding 0.1 mg/l extended west and northwest toward the Bluewater Millsite. The plume essentially abutted against the bedrock on the north (green line in Figures 41 and 42). U contours contracted slightly from 2005 (Figure 41) to 2009 (Figure 42). The plume along Highway 605 dropped below 1 mg/l. Concentrations remained high between the plumes under the subdivisions, with concentrations exceeding 0.1 mg/l.

Figures 41 and 42 show U movement north of the LTP. The highest concentrations occurred north of the west end with a contour of 0.05 extending north. Considering the location next to the bedrock, the movement here is not clear.

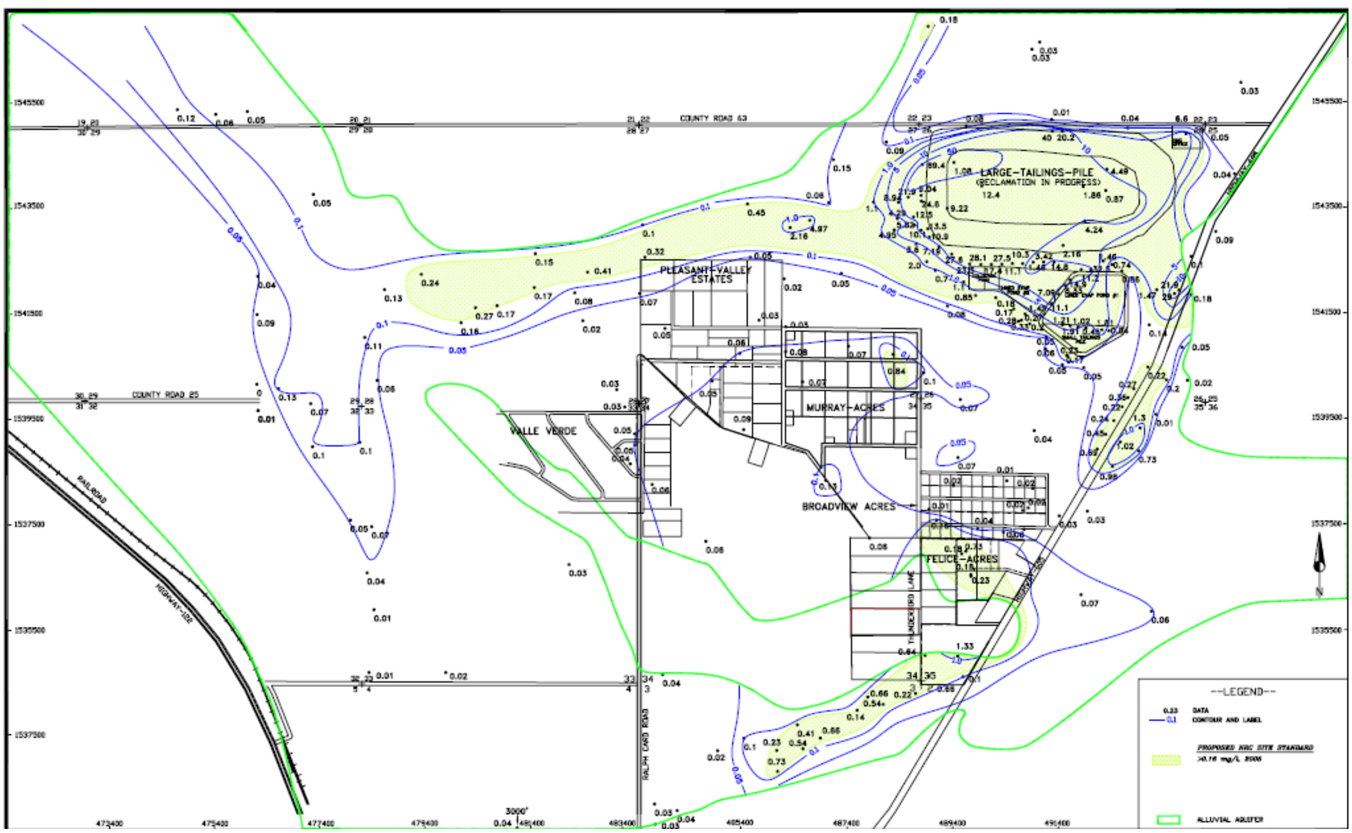

Figure 41: Snapshot of Exhibit 9b (EPA 2011) showing U concentrations in 2005.

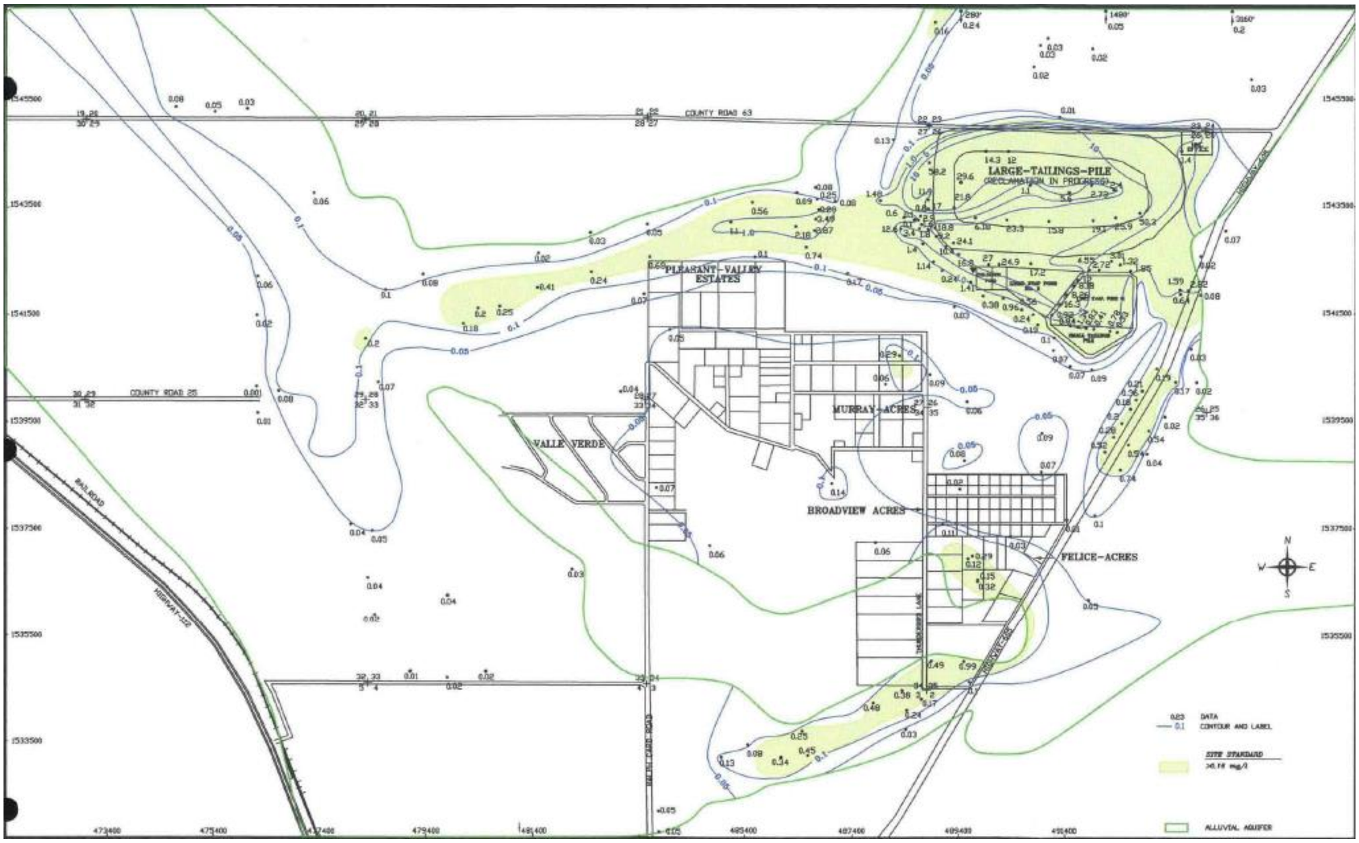

Figure 42: Snapshot of Exhibit 9a (EPA 2011) showing U concentrations in 2009.

All of the maps (Figures 36 through 42) show a steep concentration gradient on the north edge of the LTP, but the mapping does not appear to have been intended to consider the three miles between Sand Curve and the LTP. The monitoring reports (EPA 2011, HCM 2010) did not consider U concentrations in this area. Data for that area (ERG 2003) is discussed below.

Time-series graphs of well U concentrations (attached as Exhibits in Appendix A) also demonstrate the trends. Wells S2, S3, S4 and S11 show the U concentrations west of the LTP (Exhibit 1) are high but trend very slowly downward from the late 1980s through the 90s (Exhibit 2). U in the area between the LTP and Murray Acres had highs and lows in the 1980s and a general downward trend through the 1990s, but because periods differ among wells it is difficult to obtain a clear picture (Exhibit 3). The lack of data in early years may have caused the lack of high U concentration contours in the 1980s, rather than a lack of U.

Wells near the STP reflect an initial high concentration in well K2 that decreases but well Y increased and well X was steady (Exhibit 4). Well K5 had by far the highest U concentration in 1995 but it had no prior data. The U graphs suggest that the concentration under the STP was higher than shown on the contour maps (Figures 40 through 42).

Concentrations in well SUB3 in the Broadview Acres (Exhibit 5) reflect the spike in the high concentrations in the 1970s and early 1980s (Figure 37). Concentrations remained high through the 1980s but trended downward through the 1990s, with SUB3 decreasing the most. U remained high (Exhibit 5), but the graph for wells in Felice Acres shows that U remained high by 2000, but not as high as previous levels of 3 and 4 mg/l. Unfortunately there is data for wells 496 and 497 only since 1996 and they had high concentrations, which may explain why the plume appears to have expanded substantially since the late 1990s (Figures 41 and 42).

U concentrations at wells in the subdivisions southwest of the site were less than 0.4 mg/l in the 1980s and 0.2 mg/l in the 1990s, but well 802 increased to exceed 1.5 mg/l in the late 1990s and well F9 increased to higher than 10 mg/l in the early 1980s and late 1970s. Both exceptions are in the northeast portion closest to the LTP. Both wells had been sampled through the entire time period so reasons for the extremely different trends are not clear.

Chinle Aquifer

The only available U contours for the Chinle aquifer are for 1994 and 2000 (Figures 43 through 46) because of the paucity of data and questions regarding the stratigraphy of the Chinle aquifer (EPA 2011, p ES9 and p 13). U concentrations increased significantly between 1994 and 2000 in both aquifer layers. The largest increase in the Upper Chinle occurred in the area between the LTP and the subdivisions (Figure 44) and under Felice Acres in the Middle Chinle aquifer (Figure 46). It is not clear whether the increase is due to improved monitoring or is an actual increase in U load in the aquifers.

The graphs for wells in the Upper Chinle show that the concentrations are decreasing but are also highly variable (Exhibit 8). Well CE2 had the highest U concentrations but observations did not begin until 1999, so there is no way to know how the concentration contours would have looked had it been sampled earlier. Beginning around 1997, the concentration trend has become level, ignoring the small peak on well 494.

The upper Chinle aquifer subcrops under the LTP (Figure 5) and its top is more than 100 ft below ground surface at Felice Acres. It dips toward the north, but not steeply (Figure 11) and the groundwater flows to the north. The Middle Chinle subcrops west of the LTP, and west of the West Fault so there is an offset in the formation that could have prevented flow from either side of the fault from mixing.

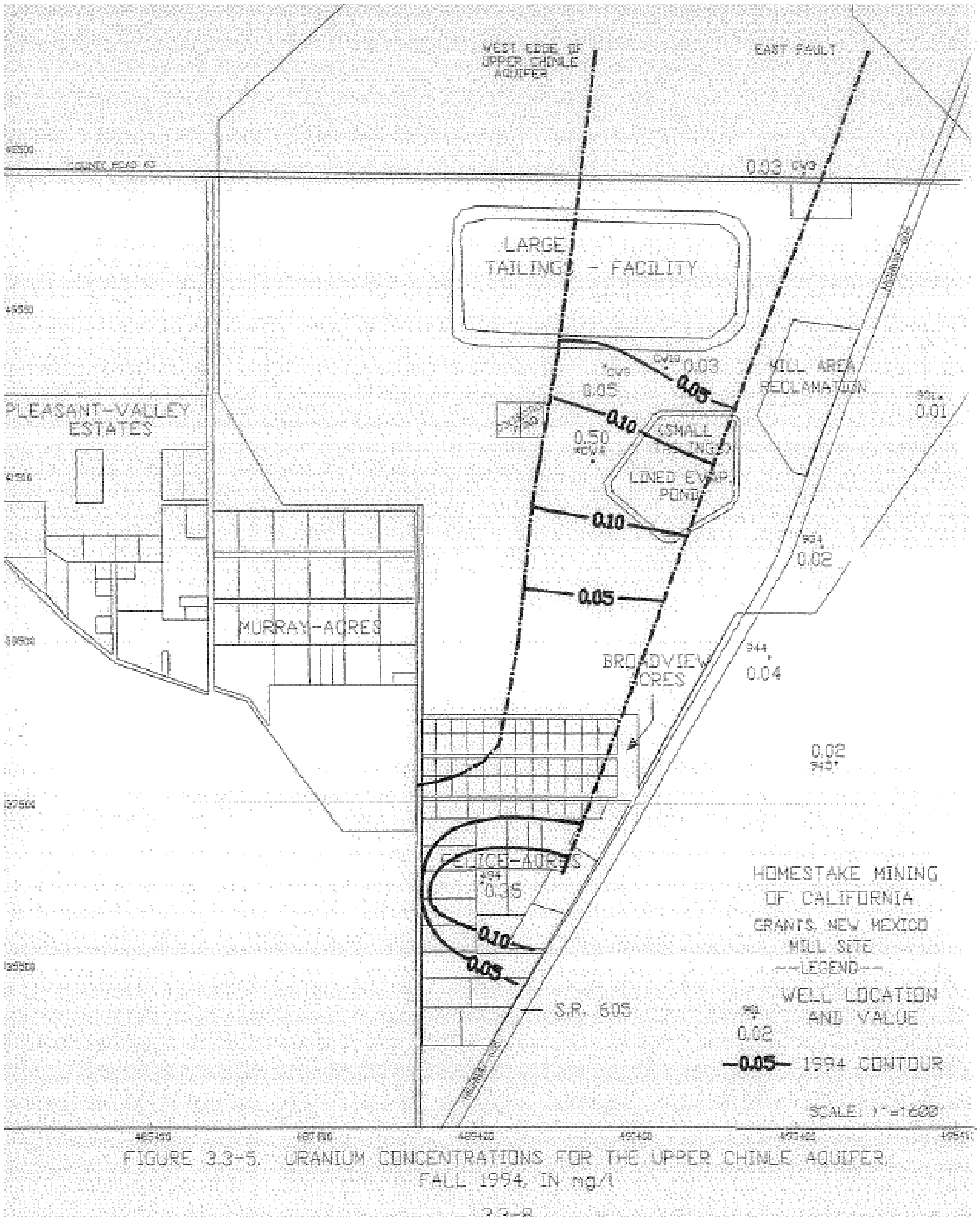

Figure 43: Uranium concentration in the Upper Chinle aquifer, 1994. File 43488-2.pdf

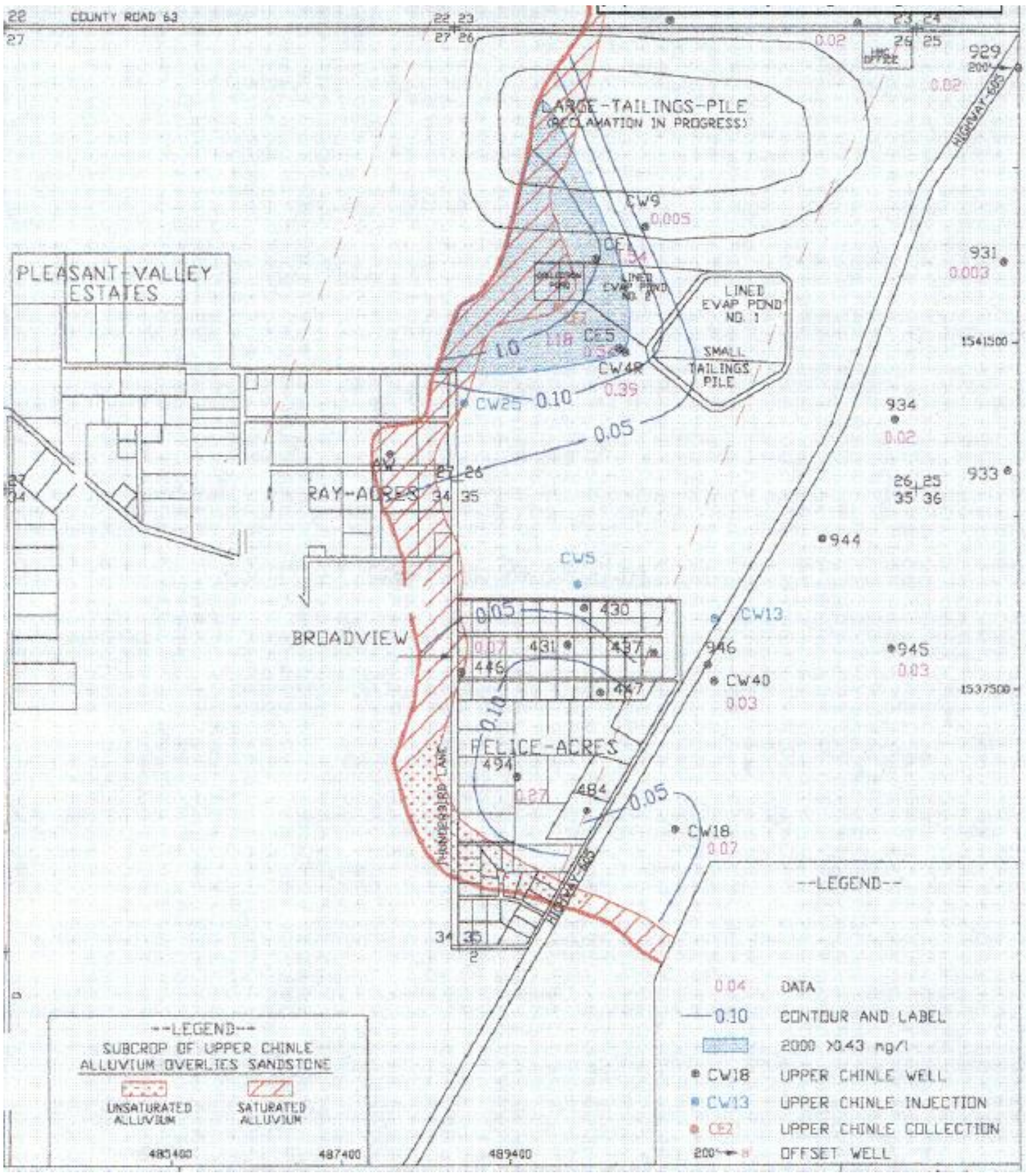

Figure 44: Snapshot of Figure 13 (CH2M Hill 2001) showing U concentration in upper Chinle aquifer in 2000.

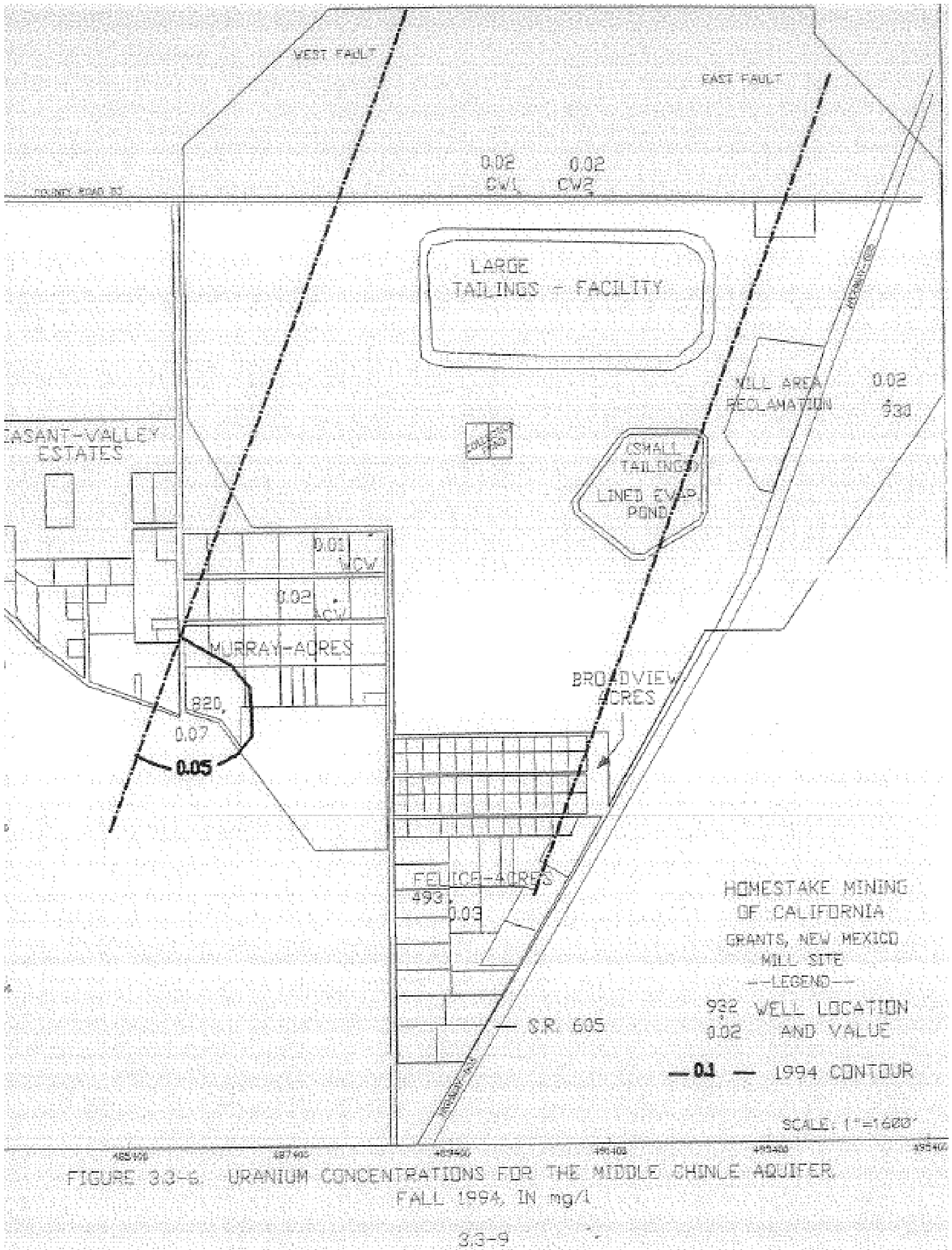

Figure 45: Uranium concentration Middle Chinle aquifer, 1994. File 43488-2.pdf.

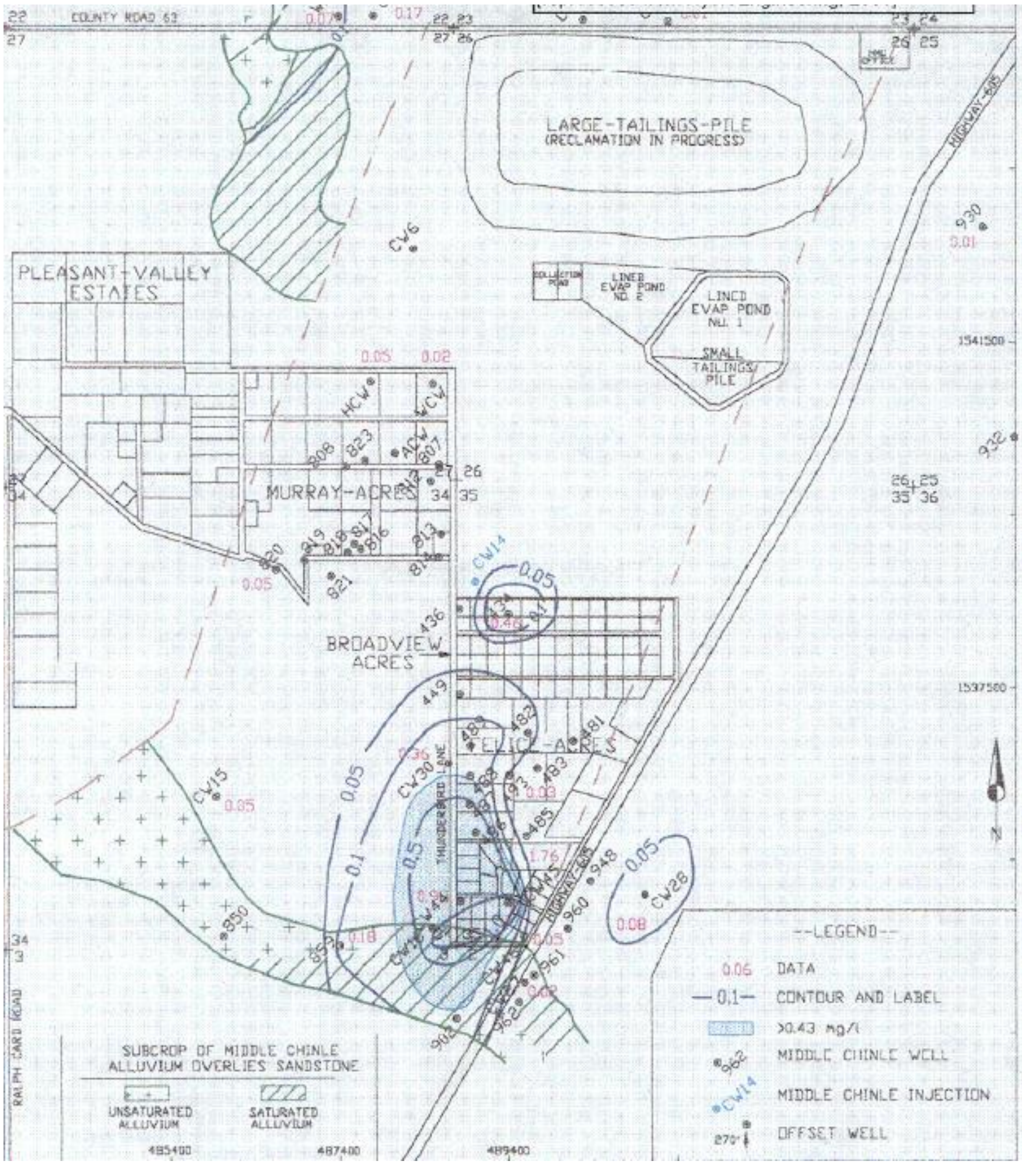

Figure 46: Snapshot of Figure 15 (CH2M Hill 2001) sowing U concentrations in 2000 for Middle Chinle Aquifer.

Bluewater Millsite

The Bluewater Millsite (NMED 2010, Figure 17) is not affecting HMC for two reasons. First, most of the wells there are in the San Andres, not the alluvium; the highest concentrations are south of Bluewater. Second, the samples east of Bluewater, mostly between Bluewater and HMC, are below detect, suggesting there is no pathway between the mills. The explanation of changes in TDS and anions along a transect between Bluewater and HMC (NMED 2010, Figure 2) does not indicate there is a flow path between sites; the description of change along that flow path demonstrates that TDS increases and decreases; the decreases are probably due to freshwater dilution due to flow from the south (NMED 2010, p 26-27).

U Transport between Ambrosia Basin and the LTP

Groundwater flows under the LTP from the northeast, but there are not many monitoring wells in that area, so it is difficult to assess trends in or sources of U. ERG (2001) performs a statistical analysis of wells in this area with the goal of defining groundwater protection standards for the project area. This review does not evaluate the statistical method or the final statistics completed in ERG (2001) but uses the raw data presented in that report to assess the U trends as part of the conceptual transport model. The wells shown on Figure 47 may be divided into far-upgradient (wells 922, 921, 920, 916, 914, and 950) and near-upgradient wells (wells P, P1, P2, P3, P4, CD, ND, and R). The near-upgradient wells are completed in alluvium but the completion of the far-upgradient wells is unknown because there were no completion diagrams available (ERG 2001, p 2).

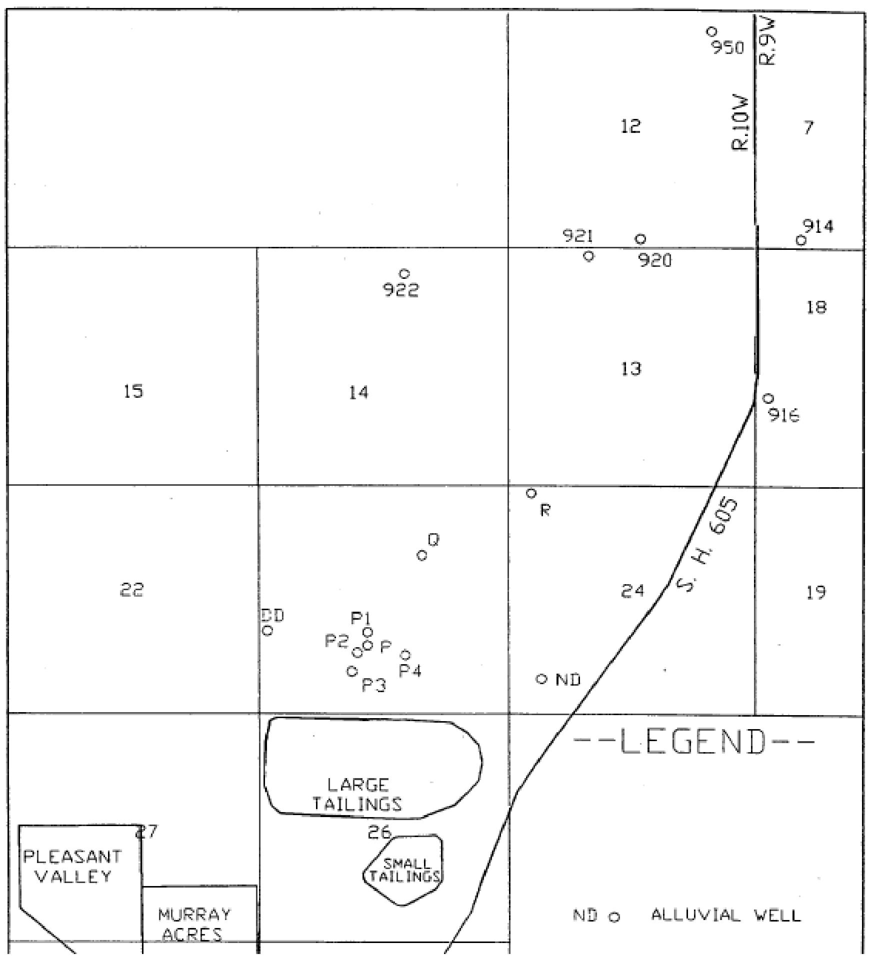

Figure 47: Snapshot of Figure 1 from ERG (2001) showing a sketch of the alluvial wells NE of the large tailings pile.

The U concentration at the near upgradient wells was predominantly flat between 0.01 and 0.1 mg/l since 1976 (Figure 48). Well CD trended upward slightly, achieving its highest concentrations in the late 1990s. Well CD lies north of the highest U concentrations under the LTP (Figures 36 through 42). Well P had several high U values prior to the early 1990s, but no apparent trend. Other wells had substantial fluctuations, but no obvious trends.

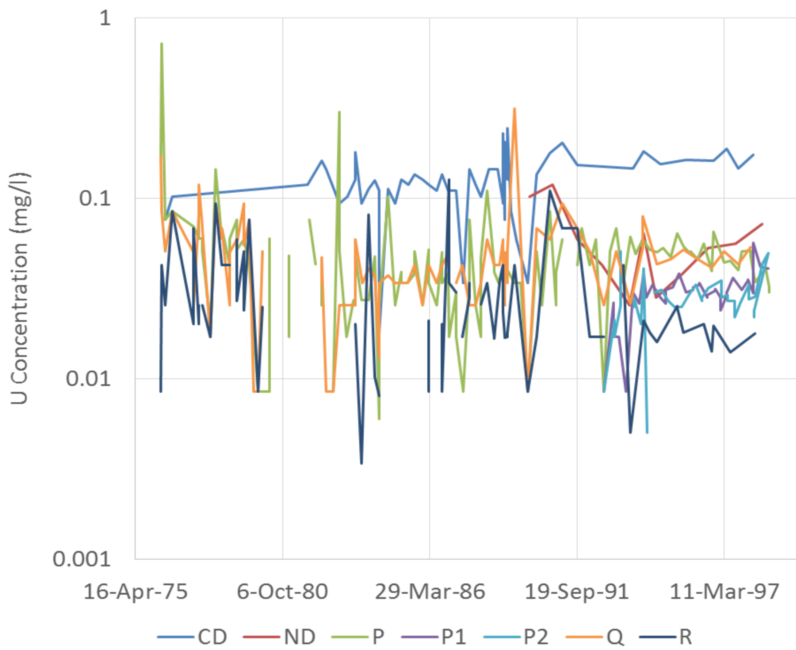

Figure 48: Time series plots of U concentration for near-upgradient wells between the LTP and Sand Curve. See Figure 47 the location of the wells. Data from ERG (2001).

The far-upgradient wells are from two to three miles northeast of the LTP (Figure 47). The U concentration at the far-upgradient wells also fluctuated but generally around lower values (Figure 49). Concentrations at wells 921 and 950 however varied between about 0.145 and 0.180 mg/l, but the period of record is too short to detect trends. Well 920 trended upward with concentrations reaching just less than those for well 921 by the late 1990s. These wells are in the middle of the flow path along the San Mateo alluvium, but as noted it is not clear whether their completion is alluvial. Wells 914 and 916 are east of and well 922 is west of the flow path and all have low, non-trending U values. Well R could be further downstream on the flow path and generally had U values much lower than wells 920, 921, and 950; two exceptions are spikes to greater than 0.1 mg/l (Figure 48).

The observed U concentrations are high near Sand Curve and near the LTP, but much lower in between. This trend is consistent with a hypothesis that U is slowly moving southward along the San Mateo flow path from Sand Curve. The values at well R are much lower than at wells 921 and 920. It is apparent that any U that has emerged from the Ambrosia Basin has moved less than a mile toward the LTP. U values at well R are generally less than at wells CD, P, P1 and P2 which are closer to the LTP. Because there is a low U value area in the northeast quarter of section 23 and most of section 13, it appears that U in the far northeastern portion of the San Mateo alluvium has not reached to within from 1 to 2 miles of the LTP. The increasing values at well CD and ND and the generally higher values in the cluster from P to P4 suggest that U emanating from the LTP affected wells just upgradient from the LTP.

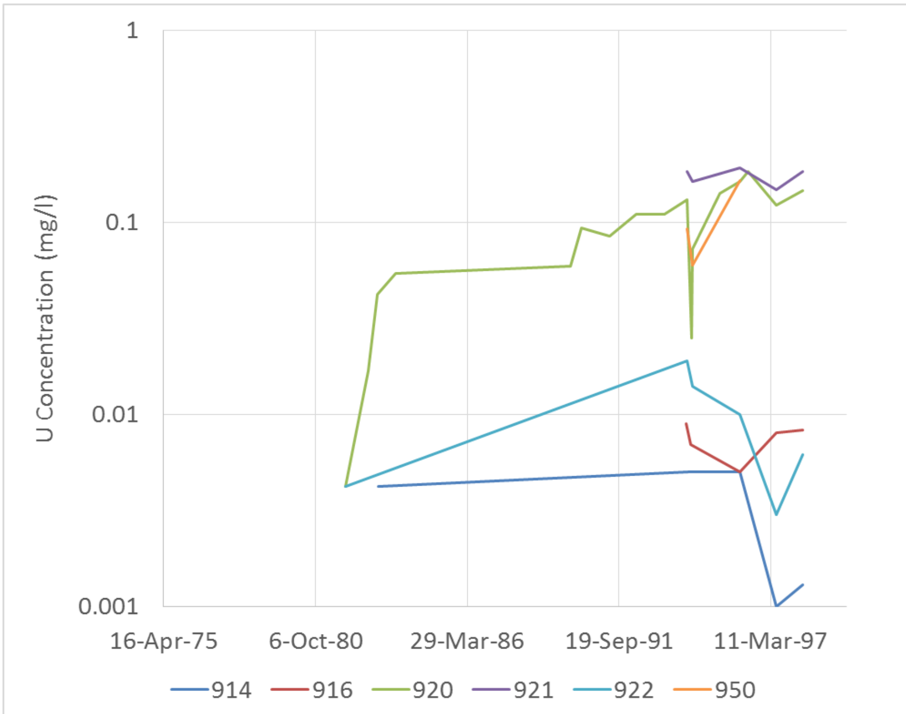

Figure 49: Time series plots of U concentration for far upgradient wells between the LTP and Sand Curve. See Figure 47 for the location of the wells. Data from ERG (2001).

The trends in U concentrations at wells between Sand Curve and the LTP suggest a hypothesis that U from Ambrosia Basin and other mine sites northeast of the LTP have not affected groundwater beneath the LTP. The trends also suggest that tails water under the LTP has affected the groundwater just upgradient from the site. The hydrogeology of the site and the physics of contaminant transport both support these hypotheses.

Three factors control the rate that a conservative contaminant moves through an aquifer – advection, dispersion, and diffusion (Fetter 1999). Advection is the movement of contaminants with the bulk flow of water. Dispersion is the spreading of the bulk of the contaminants due to fluid moving through pores of different sizes at different rates with pathways having substantially different lengths. Dispersion spreads a contaminant in all three directions – along the flow path, and horizontally and vertically from the flow path. Dispersivity is a function of length of the flow path from source to sink (Fetter 2001, Xu and Eckstein 1995). Diffusion is the movement of a contaminant from a high concentration to a low concentration, and occurs regardless of the movement, or lack thereof, of the groundwater. Diffusion is usually treated as part of dispersion, but in a very slow moving water body it may be the primary factor.

Uranium is not a conservative contaminant – it can be affected by both sorption processes and reactions as it transports through soils or an aquifer (Fetter 1999). Sorption includes adsorption, chemisorption, absorption, and ion exchange. Adsorption is the process by which a solute clings to a solid. Ion exchange occurs when a positively charged particle is attracted to the negative charge on a clay particle. Chemisorption is when a solute becomes chemically attached to a solid particle. Finally, absorption is when a solute diffuses into a particle, or is absorbed. There are many classifications of chemical reactions, some of which are reversible as water properties change. Detailed discussion of these processes is beyond the scope of this report, other than that all of these factors combined create a retardation coefficient (Fetter 1999), which has been estimated by Hydro-Engineering (2006) for the alluvium near the LTP using injection tests. Additionally, HMC (2012) presented the results of soil tests, which show that the amount of U retained in the soil as water percolates through the unsaturated soil increases with time due to some of the processes just mentioned.

Groundwater flows from the northeast to the LTP and primarily funnels through the flow path of higher transmissivity (Figure 9). As noted above, the average effective groundwater flow rate through this section is 0.5 ft/d, which is the advective rate that a molecule of water flows between points[7]. It would take contaminants about 88 years to move from Sand Curve to the LTP. Dispersion would cause U to breakthrough to, or reach, the LTP sooner, but it is not conceivable dispersion would move a significant amount of U three miles in significantly shorter time than advection.

As noted, U transport near the LTP has been shown to be significantly retarded in the alluvium. The retardation coefficient is the ratio of the rate that the constituent moves through the groundwater to the rate that it would if only advection and dispersion applied. Typically, retardation is a shift to longer travel times and lowered concentrations on a graph of concentration with time. Retardation reaches a steady state after the aquifer has retained all

[7] Because a cross section consists of mostly solids, either bedrock or particles, the actual groundwater flow occurs through connected pore spaces, so the rate a small parcel of water actually flows is much faster than Darcian flow. Effective porosity is the proportion of an aquifer that consists of connected pore spaces, and actual groundwater flow rate equal the Darcian flow divided by the effective porosity; for example, if the effective porosity is 0.2 (20% of the volume is pore space) groundwater will flow 1/0.2 or 5 times as fast as the Darcian velocity. Contaminants move at the rate of groundwater parcels not at the Darcian flow rate.

that it can hold, after which transport becomes more conservative, being affected mostly by advection and dispersion.

Hydro-Engineering (2006) injected U-laden water into wells completed in alluvium and sampled the water at nearby observation wells at different distances to estimate retardation coefficients. The water included chloride and sulfate to estimate advective rates for conservative constituents. The retardation coefficient increased as the transport distance increased. The estimated coefficients were 1.4, 2.4, 5.0, and unestimable because the test was not long enough. The distance between injection and observation wells were 7.2, 23.2, 50 and 76 ft, respectively. The travel time between wells based on the conservative chloride was .8, 6.5, 11, and 73 days, respectively[8]. The increasing retardation coefficient with time suggests that more factors slow and retard the flow over longer distances.

Applying these retardation coefficients to the San Mateo alluvium northeast of the LTP, the transport time would be much longer than predicted for advection. The most representative retardation coefficient, due to the length between test wells, is 5.0, thus retardation would increase the travel time over the advective rate by 5 times, so U transport from Sand Curve to the LTP could require more than 400 years. This is consistent with the observed increases in U in several far-upgradient wells (Figure 49) and the trends near the LTP. However, that assumes the U that was flowing in the waters in the wash actually reaches the aquifer during percolation.

HMC (2012) reported on the land application treatment used to remove U from relatively low U concentration groundwater collected downgradient from the LTP. As the water percolates, the soil column immobilizes U flowing through it by precipitation, uptake by plants, biological reduction to a less soluble species and subsequent precipitation, and sorption to mineral surfaces or organic matter (HMC 2012). HMC land-applied, through irrigation, groundwater with a maximum U concentration of 0.44 mg/l to four separate facilities. The amount of water applied ranged from 1 to about 6.5 ft/y, but mostly from 2 to 3.5 ft/y over irrigated areas of about 100, 24, 150, and 120 acres, respectively (HMC et al. 2011). The U concentration in the soils of the treated areas increased to as much as 5 mg/kg, although from 2 to 3 mg/kg was more common (Figures 50 to 52). The concentration reduced with depth to a background level of about 0.5 mg/kg at from 4 to 7 ft bgs, although spikes of U occurred at deeper levels. In general, most of the U applied to the land over a ten-year period had been retained in the soil before it reached the groundwater.

[8] These travel times are much faster than estimated for San Mateo alluvium. This is probably because the injection well creates a much higher gradient and drives the flow from the well to the observation point.

This retention would also occur to water percolating from washes through the soil to the groundwater. The concentrations, as reported above, of the water entering the washes was much higher than 0.44 mg/l, so it cannot be assumed that all of the U was retained without reaching the groundwater. However, it is likely that the amount of U retained was substantial, possibly as high as 5 mg/kg over most of the soil profile above the groundwater table. This would be consistent with the observations of U concentrations in the far-upgradient wells (Figure 49) being much less than discharged from the mines (Table 2).

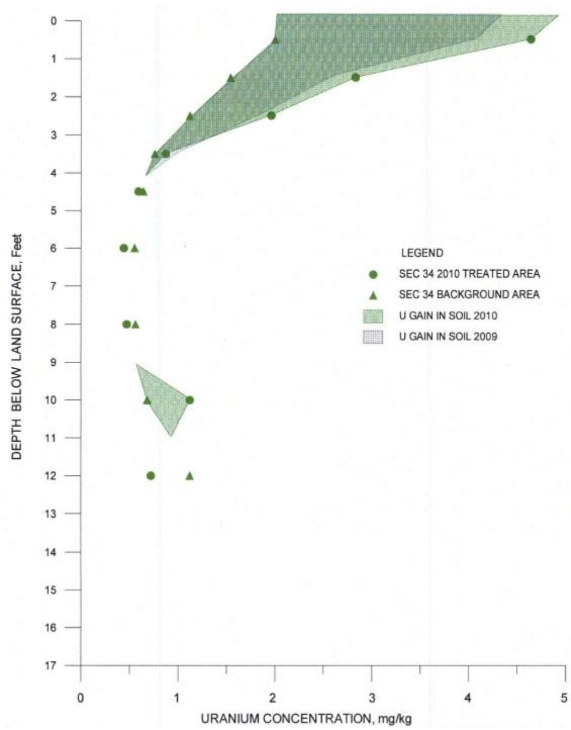

Figure 50: Snapshot of Figure 5.3.5-1 of HMC (2012) showing the trend of U concentration in soils with depth at the section 34 irrigation site.

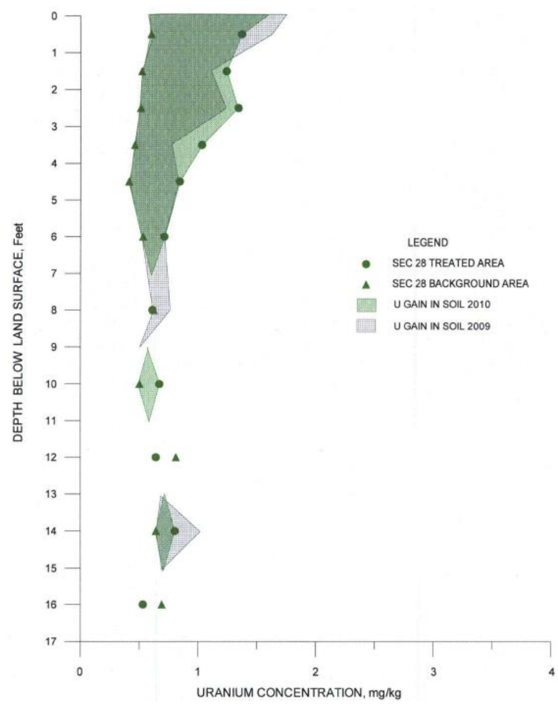

Figure 51: Snapshot of Figure 5.3.5-3 of HMC (2012) showing the trend of U concentration in soils with depth at the section 28 irrigation site.

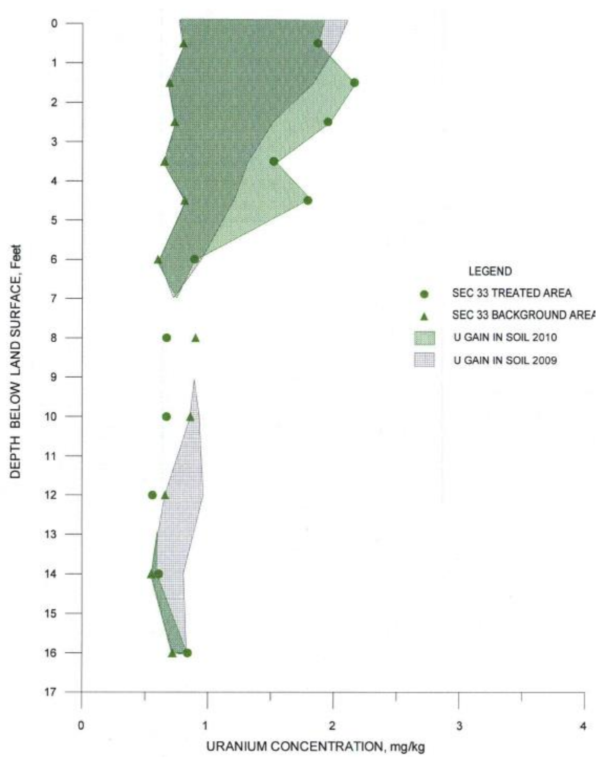

Figure 52: Snapshot of Figure 5.3.5-5 of HMC (2012) showing the trend of U concentration in soils with depth at the section 33 irrigation site.

In summary for the San Mateo alluvium upstream from the LTP, there are three reasons why mine dewatering discharge and tailing seepage from the Ambrosia Basin has not affected the background U concentrations at the LTP, as suggested by U data (ERG 2003). First, simple groundwater flow would take more than 85 years to advect U over the three miles from Sand Curve to the LTP; dispersion may speed the transport of a small amount of U toward the LTP, but certainly not enough to significantly affect concentrations or speed breakthrough of U at the LTP. Second, there would be significant retardation of any U that reaches the groundwater. This would slow the transport; at the third longest distance tested by HMC, 50 ft, the retardation slowed the transport by more than five times which would increase travel time from Sand Curve to LTP to more than 400 years. Third, because most of the U would have reached the alluvial groundwater by percolation from the wash, HMC also showed that much of the U would be retained by the unsaturated soils above the water table. This explains the observed U values upgradient of the LTP, except for the higher U values near the LTP, which the next section explains.

Transport near the LTP

U has percolated from the LTP and contaminated aquifers down and even cross-gradient from the LTP into the downgradient areas. This contamination commenced in the early 1960s and HMC began to take steps that they, and respective agencies, decided would contain and remediate the aquifers. Percolation from the LTP both caused a 20 to 30 ft mound on the water table and contaminated the groundwater directly beneath the LTP with U up to 100 mg/l. The processes described above for the San Mateo alluvium apply at the LTP, as discussed in the next paragraphs.

The LTP was an almost constant source of seepage to the groundwater without any attempt to prevent it for over 20 years from the late 1950s to the early 1980s, when some groundwater collection, drainage ditch collection, and injection wells altered the hydrology near the site. Contour maps of U concentration show that U concentration drops rapidly moving away from the LTP. The furthest that a 10 mg/l concentration reaches is to the northeast corner of Murray Acres, about 1/3rd mile from the LTP, in 1981 (Figure 37). It drops to 1 mg/l in another 600 ft or so. Higher concentrations also occur sporadically in Felice and Broadview Acres south of the LTP.

Advection explains many of the observed U values. K is higher between the LTP and Murray Acres (Figure 6) and the LTP mound increased the gradient. Having the bulk of the contaminant move with the groundwater flow 1/3rd mile towards Murray Acres in as much as 23 years (1958-81) driven by higher gradient than between the LTP and Sand Curve is feasible. The plume with U concentration exceeding 1 mg/l remained relatively constant in the northeastern portion of Murray Acres until mostly dissipating by 1994 (Figure 40). U concentrations of 0.5

and 0.1 mg/l extended another 1/3rd and half mile, respectively, with some observations further away. High bedrock and unsaturated zones of alluvium (Figure 6) diverted the advection to the south along Hwy 605 to and beyond Felice Acres and to the west beyond Pleasant Acres.

Dispersion likely explains the additional movement south and west from the LTP, especially along the pathways caused by the constriction of high bedrock and by high transmissivity. Diffusion could be a significant part of dispersion due to the extremely high concentration gradient, driving U from the 100 mg/l zone under the LTP; in zones with high gradients, calculations using Fick's Law (diffusion is a product of a diffusion coefficient and concentration gradient) show that a couple kilograms per year of U could diffuse through a 1000 ft wide section of aquifer. The actual rate would vary significantly over the domain.

The high concentration gradient also may reflect retardation. Much of the high U loads build up under the LTP rather than moving downgradient. There are probably substantial amounts of U sorbed to the unsaturated soil between the tails and the water table as well in the groundwater mound beneath the LTP.

Rising or elevated U concentrations northeast of the LTP may have been caused by U percolating from the LTP. The 20 to 30 ft groundwater mound under the LTP would have reversed the gradient, causing advection to the northeast from the LTP for a short distance. Dispersion and diffusion would also have pushed U in that direction over the distance between the LTP and the upgradient wells, which is similar to the distance between the LTP and Murray Acres.

In summary, the U concentrations around the LTP can be explained by simple advection, dispersion, and retardation of U percolating into the ground beneath the LTP. The general direction was southwest along the paths of higher conductivity following the general advective flow direction. Areas of unsaturated alluvium and high bedrock affected the paths. The mound and high concentration under the LTP caused U to move upgradient from the LTP.

CONCLUSION

The conceptual flow and transport model for the Lower San Mateo basin supports the hypothesis that U seeping from the LTP exclusively causes the U plume at, downgradient of, and to the near upgradient of the LTP. Uranium from upstream of Sand Curve has reached the Lower San Mateo basin but likely has been retained upstream of the LTP. General groundwater flow from the Bluewater millsite has prevented U from reaching the Homestake LTP plume.

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Appendix A: Figures from Groundwater Review

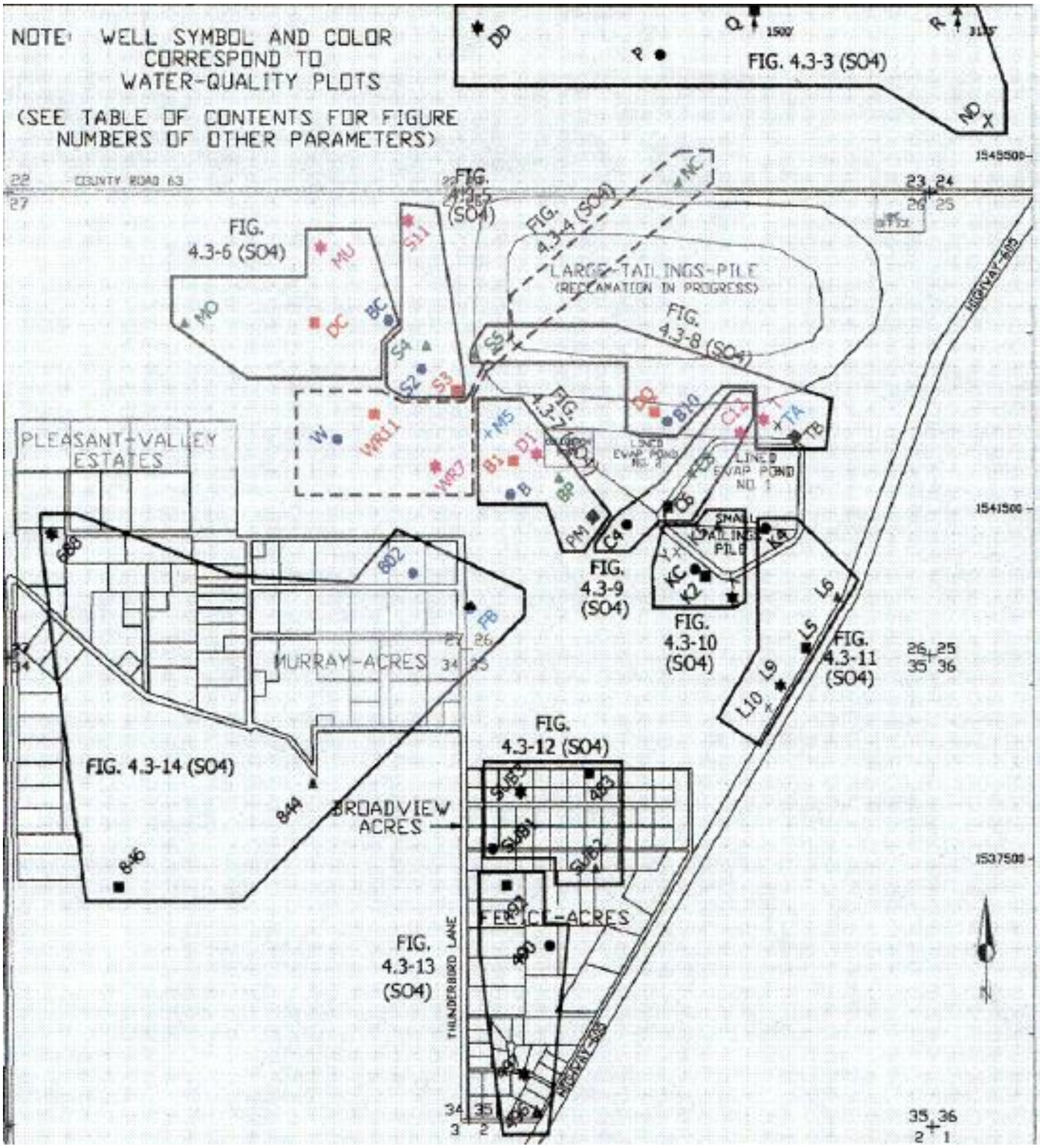

Exhibit 1: Snapshot from Figure 4 (CH2M Hill 2001) showing site map for wells with U concentration data.

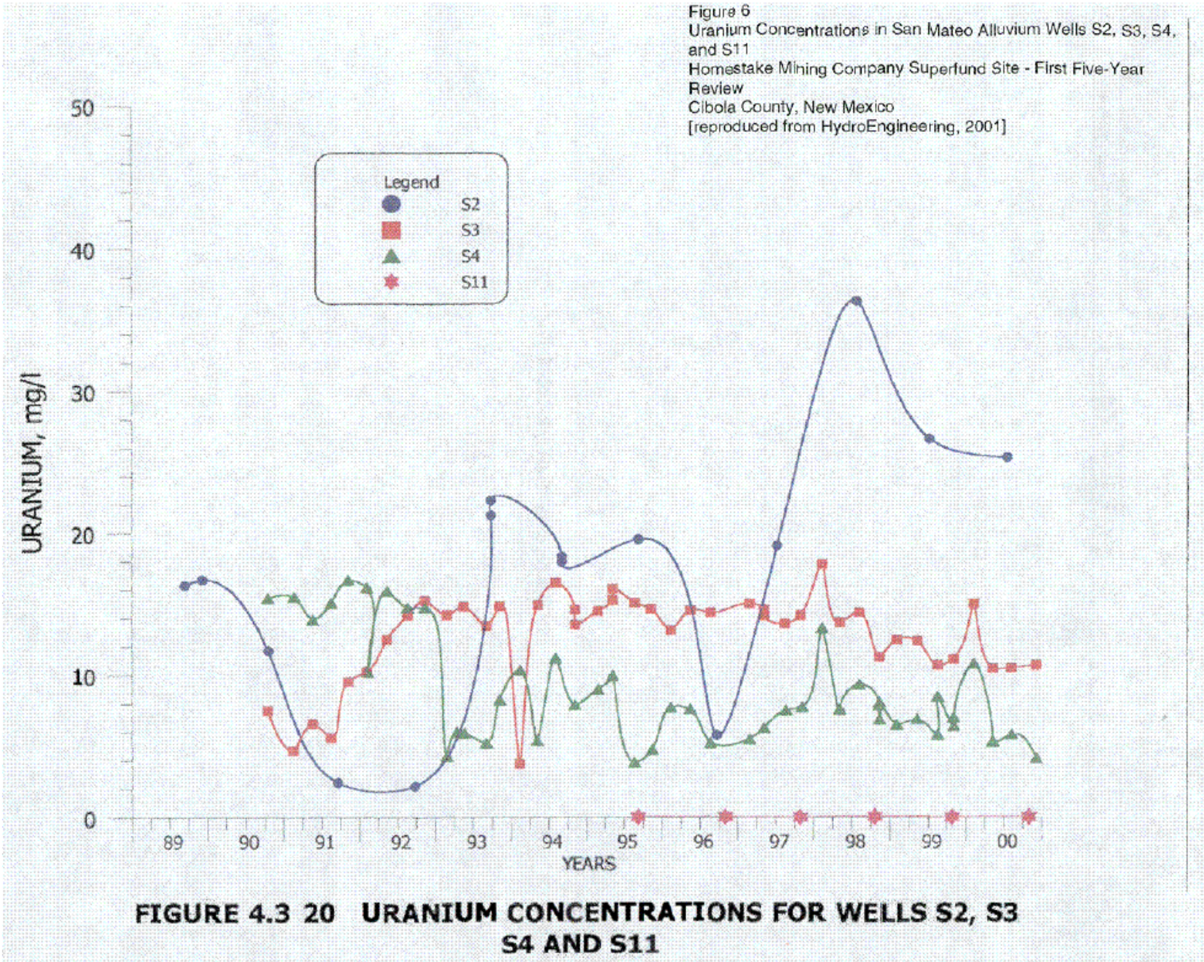

Exhibit 2: Snapshot from Figure 6 (CH2M Hill 2001) showing U trends with time for wells S2, S3, S4, and S11. These wells are just west of the tails impoundment. See Exhibit 1 for a map of the wells.

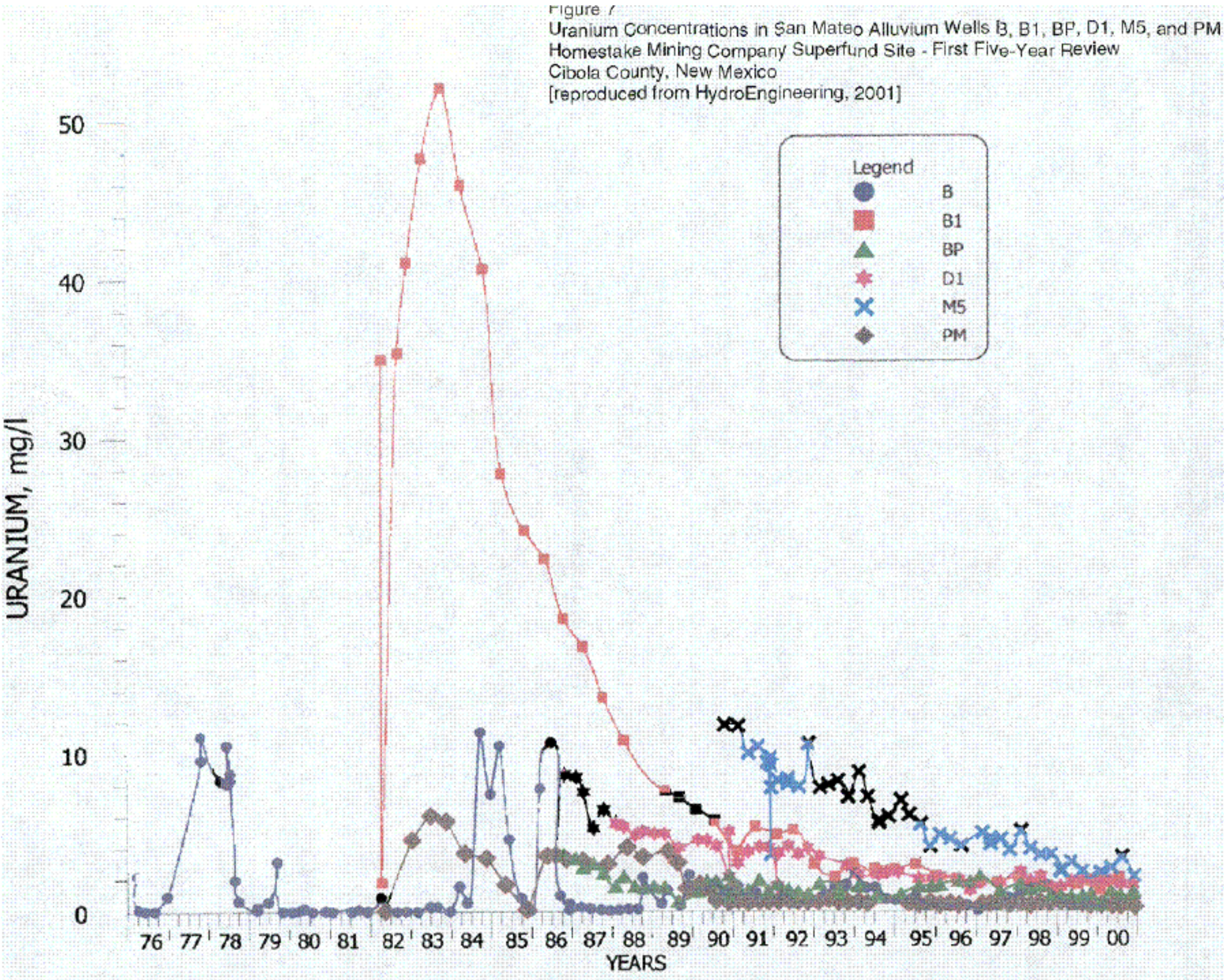

FIGURE 4.3-22. URANIUM CONCENTRATIONS FOR WELLS B, B1, BP, D1, M5 AND PM.

Exhibit 3: Snapshot from Figure 7 (CH2M Hill 2001) showing U trends with time for various wells. See Exhibit 1 for a map of the wells.

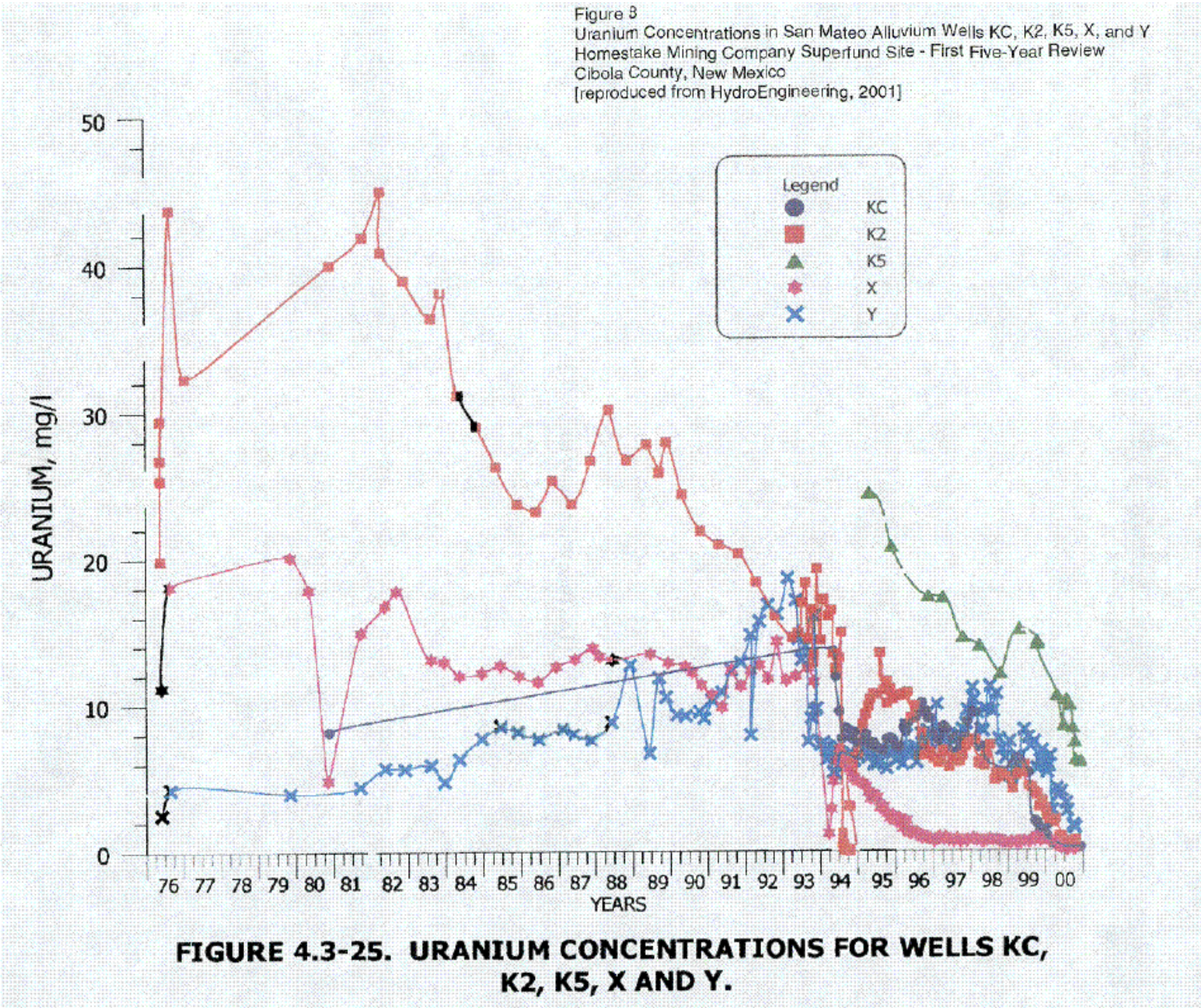

Exhibit 4: Snapshot from Figure 8 (CH2M Hill 2001) showing U trends with time for various wells. See Exhibit 1 for a map of the wells.

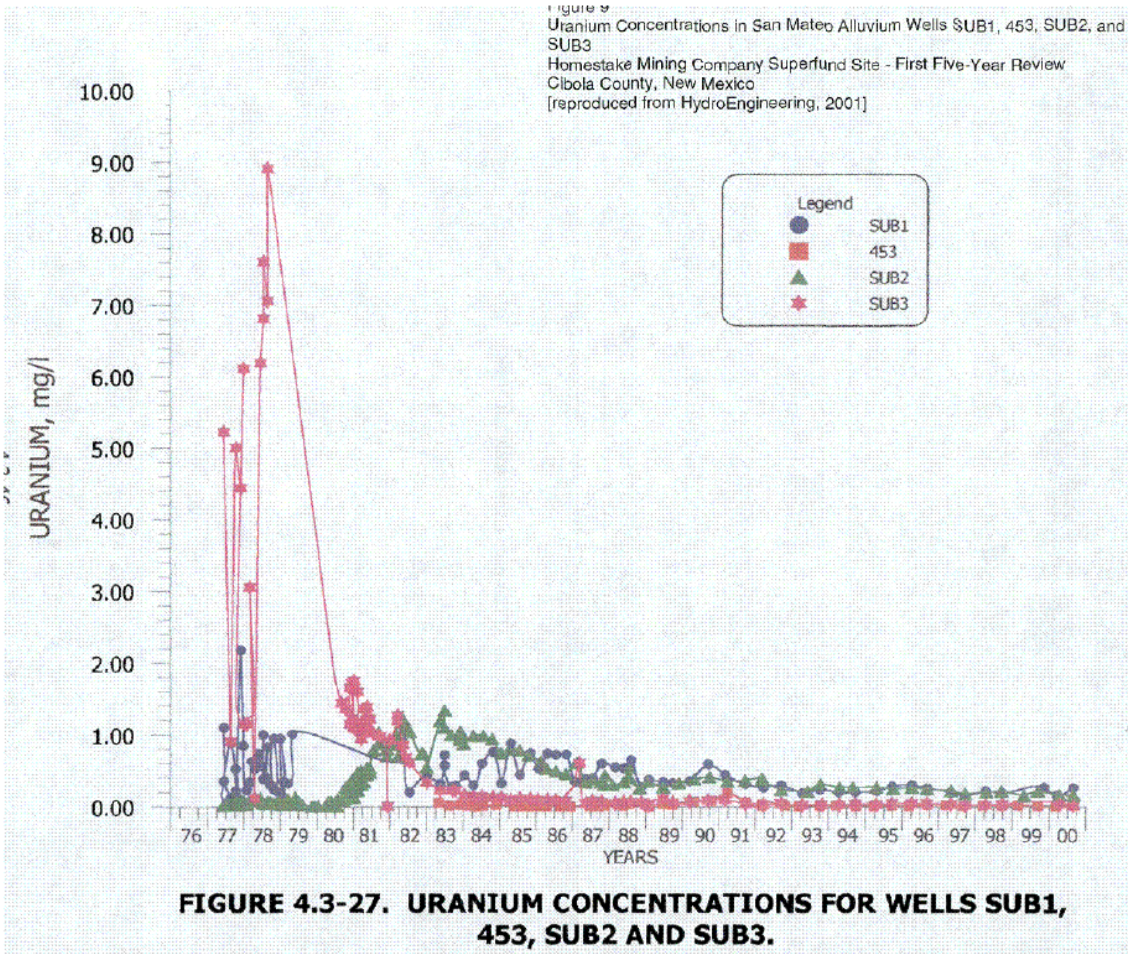

Exhibit 5: Snapshot from Figure 9 (CH2M Hill 2001) showing U trends with time for various wells. See Exhibit 1 for a map of the wells.

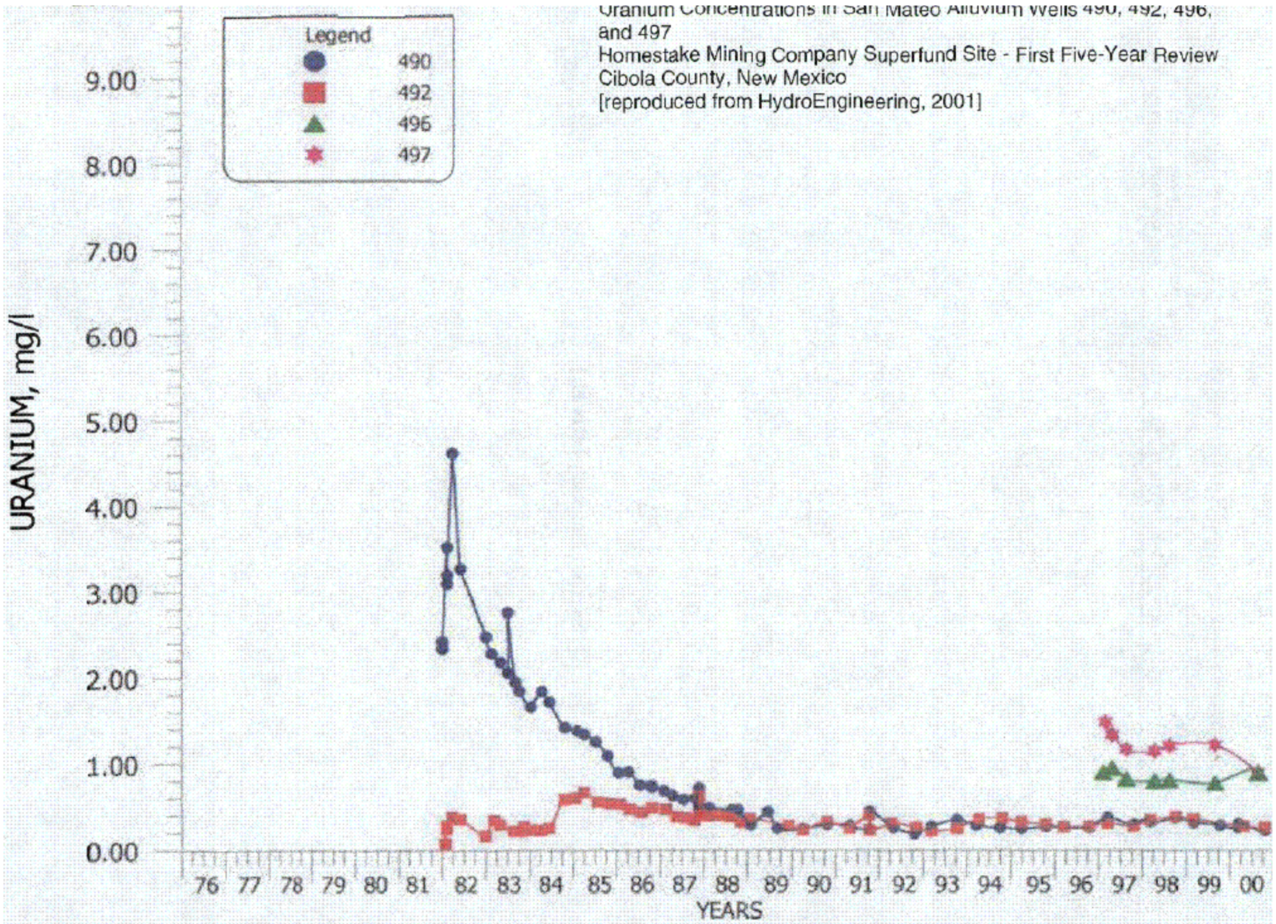

FIGURE 4.3-28. URANIUM CONCENTRATIONS FOR WELLS 490, 492, 496 AND 497.

Exhibit 6: Snapshot from Figure 10 (CH2M Hill 2001) showing U trends with time for various wells. See Exhibit 1 for a map of the wells.

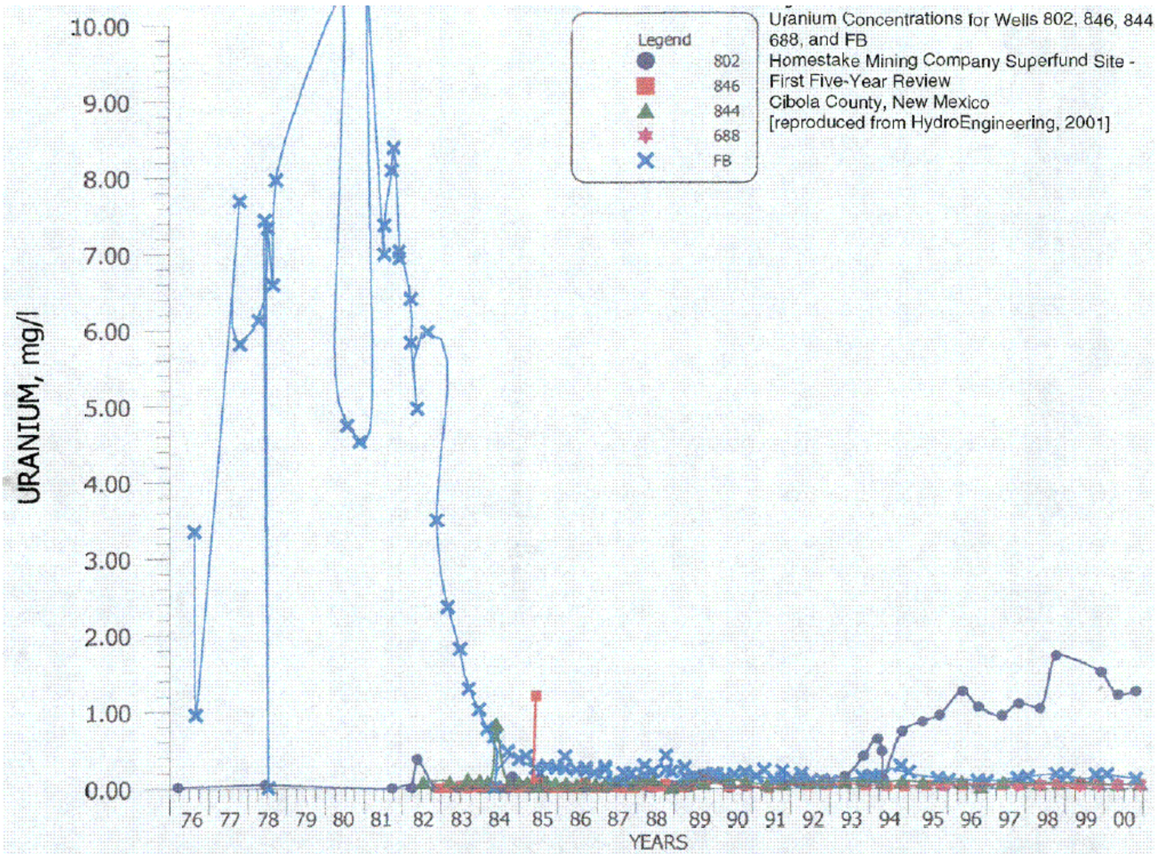

FIGURE 4.3-29. URANIUM CONCENTRATIONS FOR WELLS 802, 846, 844, 688 AND FB.

Exhibit 7: Snapshot from Figure 11 (CH2M Hill 2001) showing U trends with time for various wells. See Exhibit 1 for a map of the wells.

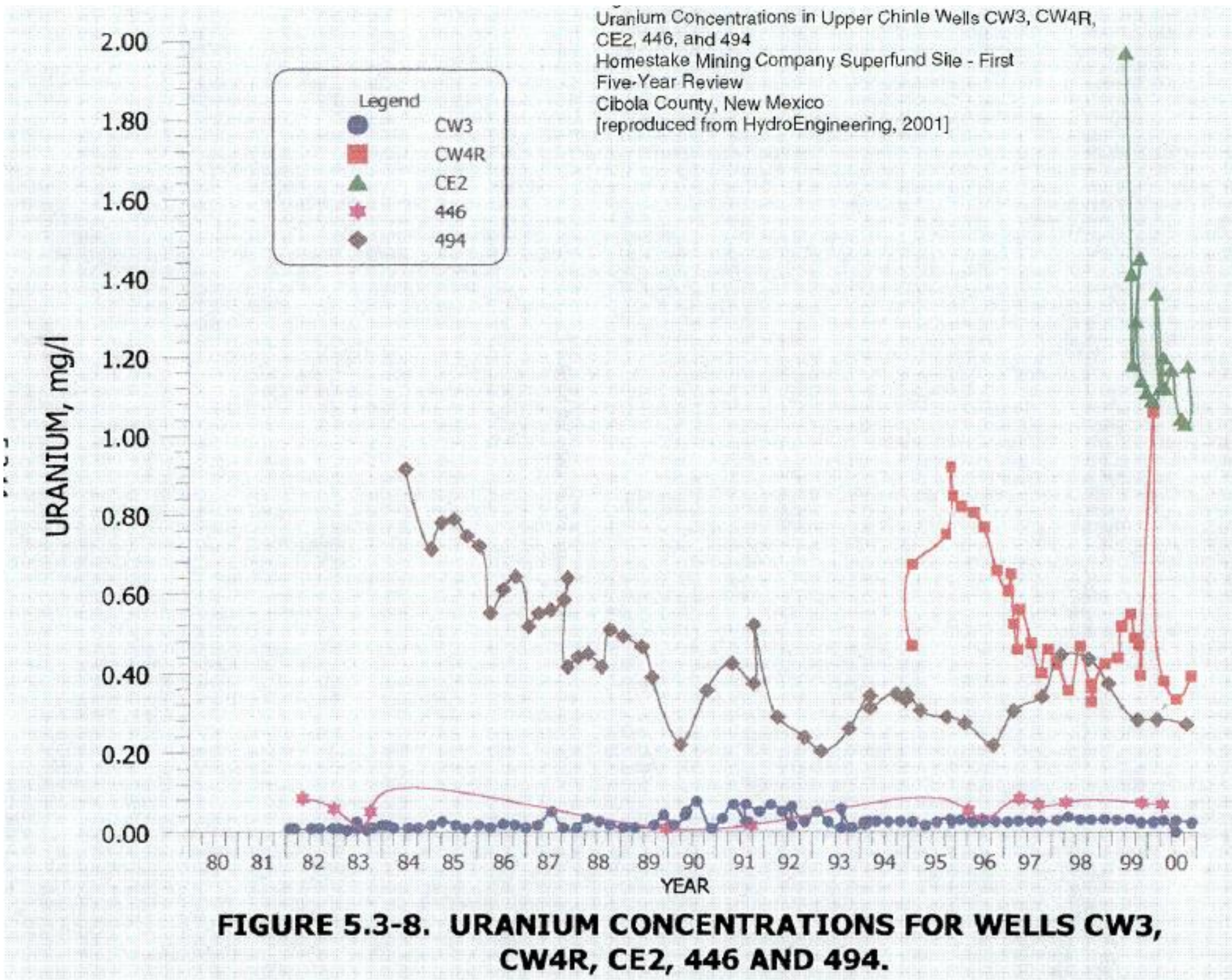

Exhibit 8: Snapshot of Figure 14 (CH2M Hill 2001) showing trend of monitoring wells in the Upper Chinle aquifer. See Exhibit 1 for a map of the wells.