SITE HYDROGEOLOGY AND ESTIMATION OF GROUNDWATER TRAVEL TIMES IN THE PERCHED ZONE WHITE MESA URANIUM MILL SITE NEAR BLANDING, UTAH

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Environmental Science & Technology

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1. INTRODUCTION

This report provides a brief description of the hydrogeology of the White Mesa Uranium Mill Site, located south of Blanding, Utah, and focuses on the occurrence and flow of groundwater within the relatively shallow perched groundwater zone at the site. Based on available existing hydrogeologic information from the site, estimates of hydraulic gradients and intergranular rates of groundwater movement (interstitial velocities) are provided. These estimates are then used to calculate average travel times for a hypothetical conservative solute (assuming no hydrodynamic dispersion) from tailings cell #3 at the site to a downgradient discharge point.

2. SITE HYDROGEOLOGY

Titan, 1994 provides a detailed description of site hydrogeology based on information available at that time. A brief summary of site hydrogeology that is based primarily on Titan, 1994, but includes the results of more recent site investigations, is provided below.

2.1 Geologic Setting

The White Mesa Uranium Mill site (the "Mill" or the "site") is located within the Blanding Basin of the Colorado Plateau physiographic province. Typical of large portions of the Colorado Plateau province, the rocks underlying the site are relatively undeformed. The average elevation of the site is approximately 5,600 feet above mean sea level (ft amsl).

The site is underlain by unconsolidated alluvium and indurated sedimentary rocks consisting primarily of sandstone and shale. The indurated rocks are relatively flat lying with dips generally less than 3°. The alluvial materials consist mostly of aeolian silts and fine-grained aeolian sands with a thickness varying from a few feet to as much as 25 to 30 feet across the site. The alluvium is underlain by the Dakota Sandstone and Burro Canyon Formation, which are sandstones having a total thickness ranging from approximately 100 to 140 feet. Beneath the Burro Canyon Formation lies the Morrison Formation, consisting, in descending order, of the Brushy Basin Member, the Westwater Canyon Member, the Recapture Member, and the Salt Wash Member. The Brushy Basin and Recapture Members of the Morrison Formation, classified as shales, are very fine-grained and have a very low permeability. The Brushy Basin

Member is primarily composed of bentonitic mudstones, siltstones, and claystones. The Westwater Canyon and Salt Wash Members also have a low average vertical permeability due to the presence of interbedded shales.

Beneath the Morrison Formation lie the Summerville Formation, an argillaceous sandstone with interbedded shales, and the Entrada Sandstone. Beneath the Entrada lies the Navajo Sandstone. The Navajo and Entrada Sandstones constitute the primary aquifer in the area of the site. The Entrada and Navajo Sandstones are separated from the Burro Canyon Formation by approximately 1,000 to 1,100 feet of materials having a low average vertical permeability. Groundwater within this system is under artesian pressure in the vicinity of the site, is of generally good quality, and is used as a secondary source of water at the site.

2.2 Hydrogeologic Setting

The site is located within a region that has a dry to arid continental climate, with average annual precipitation of less than 11.8 inches, and average annual evapotranspiration of approximately 61.5 inches. Recharge to aquifers occurs primarily along the mountain fronts (for example, the Henry, Abajo, and La Sal Mountains), and along the flanks of folds such as Comb Ridge Monocline.

Although the water quality and productivity of the Navajo/Entrada aquifer are generally good, the depth of the aquifer (approximately 1,200 feet below land surface [ft bls]) makes access difficult. The Navajo/Entrada aquifer is capable of yielding significant quantities of water to wells (hundreds of gallons per minute [gpm]). Water in wells completed across these units at the site rises approximately 800 feet above the base of the overlying Summerville Formation.

Perched groundwater in the Dakota Sandstone and Burro Canyon Formation is used on a limited basis to the north (upgradient) of the site because it is more easily accessible. Water quality of the Dakota Sandstone and Burro Canyon Formation is generally poor due to high total dissolved solids (TDS) and is used primarily for stock watering and irrigation. The saturated thickness of the perched water zone generally increases to the north of the site, increasing the yield of the perched zone to wells installed north of the site.

2.3 Perched Zone Hydrogeology

Perched groundwater beneath the site occurs primarily within the Burro Canyon Formation. Perched groundwater at the site has a generally low quality due to high total dissolved solids (TDS) in the range of approximately 1,200 to 5,000 milligrams per liter (mg/L), and is used primarily for stock watering and irrigation in the areas upgradient (north) of the site. Perched water is supported within the Burro Canyon Formation by the underlying, fine-grained Brushy Basin Member. Figure 1 is a contour map showing the approximate elevation of the contact of the Burro Canyon Formation with the Brushy Basin Member, which essentially forms the base of the perched water zone at the site. Wells and piezometers shown in Figure 1 consist of surveyed perched zone monitoring wells and piezometers that include temporary perched zone monitoring wells (TW4-series wells) associated with an area of elevated perched zone chloroform concentrations located east and northeast (cross-gradient to upgradient) of the tailings cells. Contact elevations are based on perched monitoring well drilling and geophysical logs and surveyed land surface elevations. As indicated, the contact generally dips to the south/southwest beneath the site.

Figures 2 through 5 are perched groundwater elevation contour maps for the years 1990, 1994, 2002, and 2009, respectively. Based on the contoured water levels, groundwater within the perched zone flows generally south to southwest beneath the site. Beneath the tailings cells, perched groundwater flow is generally southwest to south-southwest. Perched groundwater flow will be discussed in more detail in Section 2.3.2.

2.3.1 Lithologic and Hydraulic Properties

Although the Dakota Sandstone and Burro Canyon Formations are often described as a single unit due to their similarity, previous investigators at the site have distinguished between them. The Dakota Sandstone is a relatively-hard to hard, generally fine-to-medium grained sandstone cemented by kaolinite clays. The Dakota Sandstone locally contains discontinuous interbeds of siltstone, shale, and conglomeratic materials. Porosity is primarily intergranular. The underlying Burro Canyon Formation hosts most of the perched groundwater at the site. The Burro Canyon Formation is similar to the Dakota Sandstone but is generally more poorly sorted, contains more conglomeratic materials, and becomes argillaceous near its contact with the underlying Brushy Basin Member. The permeabilities of the Dakota Sandstone and Burro Canyon Formation at the site are generally low.

No significant joints or fractures within the Dakota Sandstone or Burro Canyon Formation have been documented in any wells or borings installed across the site (Knight Piésold, 1998). Any fractures observed in cores collected from site borings are typically cemented, showing no open space.

2.3.1.1 Dakota

Based on samples collected during installation of wells MW-16 (no longer used) and MW-17, located immediately downgradient of the tailings cells at the site, porosities of the Dakota Sandstone range from 13.4% to 26%, averaging 20%, and water saturations range from 3.7% to 27.2%, averaging 13.5%. The average volumetric water content is approximately 3%. The permeability of the Dakota Sandstone based on packer tests in borings installed at the site ranges from 2.71 x 10^{-6} centimeters per second (cm/s) to 9.12 x 10^{-4} cm/s, with a geometric average of 3.89 x 10^{-5} cm/s.

2.3.1.2 Burro Canyon

The average porosity of the Burro Canyon Formation is similar to that of the Dakota Sandstone. Based on samples collected from the Burro Canyon Formation at MW-16 (no longer used), located immediately downgradient of tailings cell #3, porosity ranges from 2% to 29.1%, averaging 18.3%, and water saturations of unsaturated materials range from 0.6% to 77.2%, averaging 23.4%. Titan, 1994, reported that the hydraulic conductivity of the Burro Canyon Formation ranges from 1.9 x 10^{-7} to 1.6 x 10^{-3} cm/s, with a geometric mean of 1.1 x 10^{-5} cm/s, based on the results of 12 pumping/recovery tests performed in monitoring wells and 30 packer tests performed in borings prior to 1994.

Hydraulic testing of wells MW-01, MW-03, MW-05, MW-17, MW-18, MW-19, MW-20, and MW-22 during July, 2002, newly installed wells MW-23, MW-25, MW-27, MW-28, MW-29, MW-30, MW-31, MW-32, TW4-20, TW4-21, and TW4-22 during June, 2005, and newly installed wells TW4-23, TW4-24, and TW4-25 during November, 2007 (Figure 5), yielded average perched zone permeabilities ranging from approximately 2 x 10^{-7} cm/s to 5 x 10^{-4} cm/s, similar to the range reported by previous investigators at the site (Hydro Geo Chem, Inc [HGC], 2002; HGC, 2005; HGC, 2007). Downgradient (south to southwest) of the tailings cells, average perched zone permeabilities based on tests at MW-3, MW-5, MW-17, MW-20, MW-22, and MW-25 ranged from approximately 4 x 10^{-7} to 1 x 10^{-4} cm/s Permeability estimates from these tests were based on pumping/recovery and slug tests analyzed using several different methodologies.

25 temporary perched zone monitoring wells (Figure 5) have been installed at the site to investigate elevated concentrations of chloroform initially discovered at well MW-4 in 1999. Some of the coarser-grained and conglomeratic zones encountered within the perched zone during installation of these wells are believed to be partly continuous or at least associated with a relatively thin, relatively continuous zone of higher permeability (International Uranium [USA] Corporation [IUSA] and HGC, 2001). The higher permeability zone defined by these wells is generally located east to northeast of the tailings cells at the site, and is hydraulically cross-gradient to upgradient of the tailings cells with respect to perched groundwater flow.

Based on analyses of pumping tests at MW-4 and drilling logs from nearby temporary wells, the permeability of this relatively thin coarser-grained zone was estimated to be as high as 2.5×10^{-3} cm/s. Relatively high permeabilities measured at MW-11, located on the southeastern margin of the downgradient edge of tailings cell #3, and at MW-14, located on the downgradient edge of tailings cell #4, of 1.4×10^{-3} cm/s and 7.5×10^{-4} cm/s, respectively (UMETCO, 1993), may indicate that this zone extends beneath the southeastern margin of the cells. However, this zone of higher permeability within the perched water zone does not appear to exist downgradient (south-southwest) of the tailings cells. At depths beneath the perched water table, the zone is not evident in lithologic logs of temporary wells TW4-4 and TW4-6 (located east [cross-gradient] of cell #3, as shown in Figure 5), nor is it evident in wells MW-3, MW-5, MW-12, MW-15, MW-16, MW-17, MW-20, MW-21, or MW-22, located south to southwest (downgradient) of the tailings cells, based on the lithologic logs or hydraulic testing of the wells. The apparent absence of the zone south of TW4-4 and south-southwest of the tailings cells indicates that it "pinches out" (HGC, 2005).

Because of the generally low permeability of the perched zone beneath the site, well yields are typically low (less than 0.5 gpm), although sustainable yields of as much as 4 gpm are possible in wells intercepting larger saturated thicknesses and higher permeability zones on the east side of the site (for example, at TW4-19, shown in Figure 5). Sufficient productivity can generally be obtained only in areas where the saturated thickness is greater, which is the primary reason that the perched zone has been used on a limited basis as a water supply to the north (upgradient) of the site.

2.3.2 Perched Groundwater Flow

Perched groundwater flow at the site has historically been to the south/southwest. As presented in Section 2.3, Figures 2 through 5 are perched groundwater elevation contour maps for the years 1990, 1994, 2002, and 2009, respectively. The 1990, 1994, and 2002 maps were hand contoured because of sparse data. As groundwater elevations indicate, the perched groundwater gradient changes from generally southwesterly in the western portion of the site, to generally southerly in the eastern portion of the site. The most significant changes between the 2002 and 2009 water levels result from pumping of wells MW-4, TW4-19, TW4-20, and MW-26. These wells are pumped to reduce chloroform mass in the perched zone east and northeast of the tailings cells.

In general, perched groundwater elevations have not changed significantly at most of the site monitoring wells since installation, except in the vicinity of the wildlife ponds and the pumping wells. For example, relatively large increases in water levels occurred between 1994 and 2002 at MW-4 and MW-19, located in the east and northeast portions of the site, as shown by comparing Figures 3 and 4. These water level increases in the northeastern and eastern portions of the site are likely the result of seepage from wildlife ponds located near the piezometers shown in Figure 4, which were installed in 2001 for the purpose of investigating these changes. The increase in water levels in the northeastern portion of the site has resulted in a local steepening of groundwater gradients over portions of the site. Conversely, pumping of wells MW-4, TW4-19, TW4-20, and MW-26 has depressed the perched water table locally and reduced average hydraulic gradients to the south and southwest of these wells.

Perched water discharges in springs and seeps along Westwater Creek Canyon and Cottonwood Canyon to the west-southwest of the site, and along Corral Canyon to the east of the site, where the Burro Canyon Formation outcrops. The discharge point located most directly downgradient of the tailings cells is Ruin Spring. This feature is located approximately 10,000 feet south-southwest of the tailings cells at the site and is depicted on the USGS 7.5-minute quad sheet for Black Mesa (Figure 6).

3. PERCHED ZONE HYDROGEOLOGY BENEATH AND DOWNGRADIENT OF THE TAILINGS CELLS

Perched water as of the 1st Quarter, 2009 was encountered at depths of approximately 52 to 115 ft bls in the vicinity of the tailings cells at the site (Figure 7). Beneath tailings cell #3, depths to water ranged from approximately 70 feet below top of casing (ft btoc) in the eastern portion of the cell (at MW-31), to approximately 114 ft btoc at the southwest margin of the cell (at MW-23). Assuming an average depth of the base of tailings cell #3 of 25 feet below grade, this corresponds to perched water depths of approximately 45 to 89 feet below the base of the cell, and an average depth of approximately 67 feet beneath the base of the cell.

3.1 Saturated Thickness

The saturated thickness of the perched zone as of the 4th Quarter, 2006 ranges from approximately 93 feet in the northeast portion of the site to approximately 6 feet in the southwest portion of the site (Figure 8). Beneath tailings cell #3, the saturated thickness varies from approximately 57 feet in the eastern portion of the cell to approximately 7 feet in the western portion of the cell. South-southwest of the tailings cells, the saturated thickness ranges from less than 1 foot at MW-21 to approximately 28 feet at MW-17. The average saturated thickness south-southwest of the tailings cells, based on measurements at MW-3, MW-5, MW-12, MW-14, MW-15, MW17, MW-20 and MW-23, is approximately 14 feet. The average saturated thickness based on measurements at MW-5, MW-15, MW-3, and MW-20, which lay close to a line between the center of tailings cell #3 and Ruin Spring, is approximately 12 feet. By projecting conditions at these wells, the average saturated thickness is estimated to be approximately 10 to 15 feet between MW-20 and Ruin Spring.

3.2 Perched Water Flow

Perched groundwater flow beneath the tailings cells has historically been southwest, with the gradient steepening since about 1994 and becoming more westerly as perched water levels near the wildlife ponds in the northeastern portion of the site have risen. Perched water flowing beneath the tailings cells eventually discharges in springs and seeps located in Westwater Canyon, to the south-southwest of the cells. The primary discharge point for perched water flowing beneath the tailings cells is believed to be Ruin Spring, located approximately 10,000 feet south-southwest of the cells.

Perched zone hydraulic gradients currently range from a maximum of approximately 0.05 feet per foot (ft/ft) east of tailings cell #2 to approximately 0.01 ft/ft downgradient of cell #3, between cell #3 and MW-20. The average hydraulic gradient between the downgradient edge of tailings cell #3 and Ruin Spring can be approximated assuming the following:

1. The elevation of Ruin Spring, based on the USGS topographic map for Black Mesa, is approximately 5,390 ft amsl.
2. The distance between the downgradient edge of tailings cell #3 and Ruin Spring is approximately 10,000 feet.
3. The average groundwater elevation at the downgradient edge of tailings cell #3 is approximately 5,511 ft amsl.

Using these assumptions, the average perched zone hydraulic gradient between tailings cell #3 and Ruin Spring is approximately:

$$\frac{5511-5390}{10{,}000}=0.012\,ft\,/\,ft$$

A hypothetical worst case average perched zone hydraulic gradient can also be estimated assuming the perched water elevation to be coincident with the base of tailings cell #3. The elevation of the base of tailings cell #3, which is also the approximate pre-existing land surface elevation near the center of the cell, is approximately 5,580 ft amsl. Under these conditions, for an unconfined perched zone, the maximum possible average perched zone hydraulic gradient between tailings cell #3 and Ruin Spring would be approximately:

$$\frac{5580-5390}{10{,}000}=0.019\,ft\,/\,ft$$

3.3 Permeability

The average permeability of the perched zone downgradient of tailings cell #3 can be approximated based on the pumping/recovery test and slug test data obtained from perched zone wells located along the downgradient edge of and south of cell #3. Peel conducted hydraulic tests at perched zone wells MW-11, MW-12, MW-14, and MW-15 in 1992 (UMETCO, 1993). Results of these tests are provided in Table 1. HGC conducted slug tests at perched zone wells MW-3, MW-5, MW-17, MW-20, and MW-22 in July 2002 (HGC, 2002), and MW-25 in June, 2005 (HGC, 2005).

The HGC slug test results were analyzed using different solution methods including KGS (Hyder, 1994), and Bouwer-Rice (Bouwer and Rice, 1976). Each method yielded slightly different results as shown in Table 2, which is based on Table 1 of HGC, 2002, and Table 1 of HGC, 2005. A range of average permeabilities for the portion of the site south of the tailings cells can be obtained by taking the geometric mean of the Peel test results and the results obtained by the various solution methods used to analyze the HGC data. Averaging the Peel test results for wells MW-11, MW-12, MW-14, and MW-15 with the HGC KGS results for wells MW-3, MW-5, MW-17, MW-20, MW-22, and MW-25 yields a geometric average of 2.3×10^{-5} cm/s, and similarly averaging the Peel test results with the HGC Bouwer-Rice results yields a geometric average of 4.3×10^{-5} cm/s, as shown in Table 2. The "early time" results at MW-5 using the Bouwer-Rice solution (from Table 1 of HGC, 2002) were used in the computations to yield a conservatively high estimate of permeability.

4. EVALUATION OF POTENTIAL FLOW PATHS AND TRAVEL TIMES FOR HYPOTHETICAL SEEPAGE ORIGINATING FROM CELL #3

Although more than 25 years of groundwater monitoring at the site has shown no impact to perched water from the tailings cells, an evaluation of hypothetical transport of a conservative solute in seepage from cell #3 is presented assuming a flow path from the base of the cell to the perched water, and thence to Ruin Spring. Average travel times for a conservative constituent moving from the base of tailings cell #3 to the perched water, and then moving with the perched water to Ruin Spring, are computed assuming no hydrodynamic dispersion.

The porosities and water saturations used in the calculations were based on measurements reported in Titan, 1994, for samples collected from the Dakota Sandstone during drilling of MW-16 and MW-17, and from the Burro Canyon Formation during drilling of MW-16 (no longer used).

4.1 Estimated Travel Time From the Base of Cell #3 to the Perched Zone

Knight-Piésold estimated a maximum volumetric seepage rate for tailings cell #3 based on cell construction and liner characteristics, of approximately 80 cubic feet per day (ft/day) or 0.42 gpm over the entire cell (Knight-Piésold, 1998). Most of this seepage was estimated to be via diffusion through the liner. This rate was estimated to decrease over time as the cell desaturates once the final cover is emplaced. Assuming a cell footprint of $3.38 \times 10^6 ft^2$, this rate is equivalent to 2.37×10^{-5} (ft/day) or 0.0086 ft/year.

The average rate of downward movement of a conservative solute dissolved in the seepage, assuming 1) no hydrodynamic dispersion, 2) an average water saturation of 0.20, 3) an average porosity of 0.18, and assuming that this rate of seepage would not significantly raise the average saturation of the underlying materials, can be approximated as:

$$\frac{0.0086 ft/yr}{(.20)(.18)} = 0.24 ft/yr$$

The average time to travel 70 feet to the perched water zone would then be approximately 290 years. This is a conservative estimate because the average water saturations would be likely to increase, thereby reducing the downward rate of travel, and increasing the travel time.

4.2 Estimated Travel Time From Tailings Cell #3 to Ruin Spring

Under current conditions, the average hydraulic gradient between the downgradient edge of tailings cell #3 to Ruin Spring is estimated to be 0.012, as discussed in Section 3.2. Assuming the following:

Average porosity	= 0.18
Average hydraulic gradient	= 0.012
Flow path length	= 10,000 ft
Average permeability range	= 2.3 x 10^{-5} to 4.3 x 10^{-5} cm/s (0.064 ft/day to 0.120 ft/day)

The average rate of intergranular movement of perched groundwater (interstitial or pore velocity) can be approximated to range from 0.0043 ft/day to 0.0080 ft/day (or 1.6 feet per year (ft/yr) to

2.9 ft/yr). The estimated average travel time for a conservative solute, assuming no hydrodynamic dispersion, from tailings cell #3 to Ruin Spring would then be approximately 6,250 to 3,450 years over this range of permeabilities. Under conditions of the maximum possible average perched groundwater gradient of 0.019 ft/ft, as estimated in Section 3.2, and assuming the same permeabilities, porosity, and path length as above, the estimated average travel times would range from approximately 4,055 to 2,160 years.

4.3 Estimated Total Travel Time from the Base of Tailings Cell #3 to Ruin Spring

The total average travel time for a conservative solute from the base of tailings cell #3 to Ruin Spring under current conditions would be the sum of 1) the travel time from the base of cell #3 to the perched water table, and 2) the time to travel within the perched zone to Ruin Spring. Based on the estimates provided in Sections 4.1 and 4.2, the total average travel time of a conservative solute (assuming no hydrodynamic dispersion) over the range of average permeability estimates would be between 6,540 and 3,740 years, assuming an average hydraulic gradient of 0.012 ft/ft.

Conditions may hypothetically develop under which travel times may be reduced, such as an increase in average perched zone groundwater gradients between tailings cell #3 and Ruin Spring (as discussed in Section 3.2) or as a result of reduced vadose zone travel times due to development of a relatively large leak in cell #3. Under hypothetical conditions in which a relatively large leak were to develop in tailings cell #3, potentially reducing vadose zone travel times to only a few years, the vadose zone travel time could be ignored, and the total average travel time (assuming no hydrodynamic dispersion) would range from approximately 6,250 to 3,450 years, assuming an average hydraulic gradient of 0.012 ft/ft. Under hypothetical conditions in which the average perched zone hydraulic gradient between tailings cell #3 and Ruin Spring reached 0.019 ft/ft, which also implies a negligible vadose zone travel time, the total average travel time (assuming no hydrodynamic dispersion) over the estimated range in permeability would be between approximately 4,055 and 2,160 years.

Estimates based on hypothetical assumptions of a relatively large leak in tailings cell #3 or an average hydraulic gradient as high as 0.019 ft/ft between cell #3 and Ruin Spring are considered very conservative because they assume conditions that are unlikely ever to develop.

5. REFERENCES

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6. LIMITATIONS STATEMENT

The opinions and recommendations presented in this report are based upon the scope of services and information obtained through the performance of the services, as agreed upon by HGC and the party for whom this report was originally prepared. Results of any investigations, tests, or findings presented in this report apply solely to conditions existing at the time HGC's investigative work was performed and are inherently based on and limited to the available data and the extent of the investigation activities. No representation, warranty, or guarantee, express or implied, is intended or given. HGC makes no representation as to the accuracy or completeness of any information provided by other parties not under contract to HGC to the extent that HGC relied upon that information. This report is expressly for the sole and exclusive use of the party for whom this report was originally prepared and for the particular purpose that it was intended. Reuse of this report, or any portion thereof, for other than its intended purpose, or if modified, or if used by third parties, shall be at the sole risk of the user.

TABLES

TABLE 1
Peel Hydraulic Test Results[1]

Well	Hydraulic Conductivity (cm/s)
MW-11	1.4×10^{-3}
MW-12	2.2×10^{-5}
MW-14	7.5×10^{-4}
MW-15	1.9×10^{-5}

Notes:
cm/s = centimeters per second
[1] From UMETCO, 1993

TABLE 2

Results of July 2002 and June 2005 Hydraulic Tests[2]

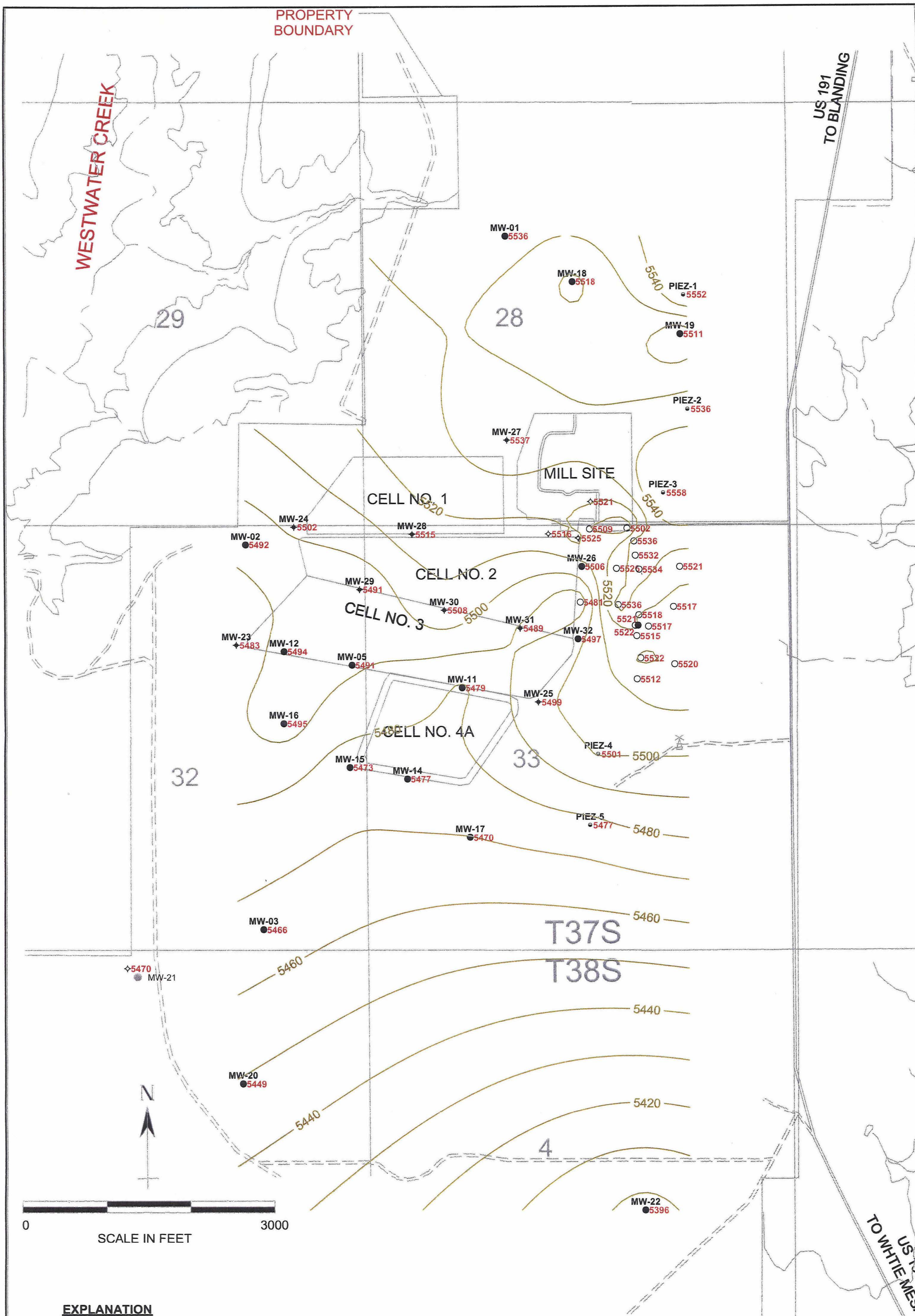
	Permeability in Centimeters Per Second	
Well	KGS	Bouwer-Rice
MW-3	4.0×10^{-7}	1.5×10^{-5}
MW-5	3.5×10^{-6}	2.4×10^{-5}
MW-17	2.6×10^{-5}	2.7×10^{-5}
MW-20	--	9.3×10^{-6}
MW-22	1.0×10^{-6}	7.9×10^{-6}
MW-25	1.1×10^{-4}	7.4×10^{-5}

Geometric Average of above test results with Peel[3] test results for MW-11, MW-12, MW-14, and MW-15.

2.3×10^{-5}	4.3×10^{-5}

[2]From HGC, 2002; HGC, 2005
[3]From UMETCO, 1993

FIGURES



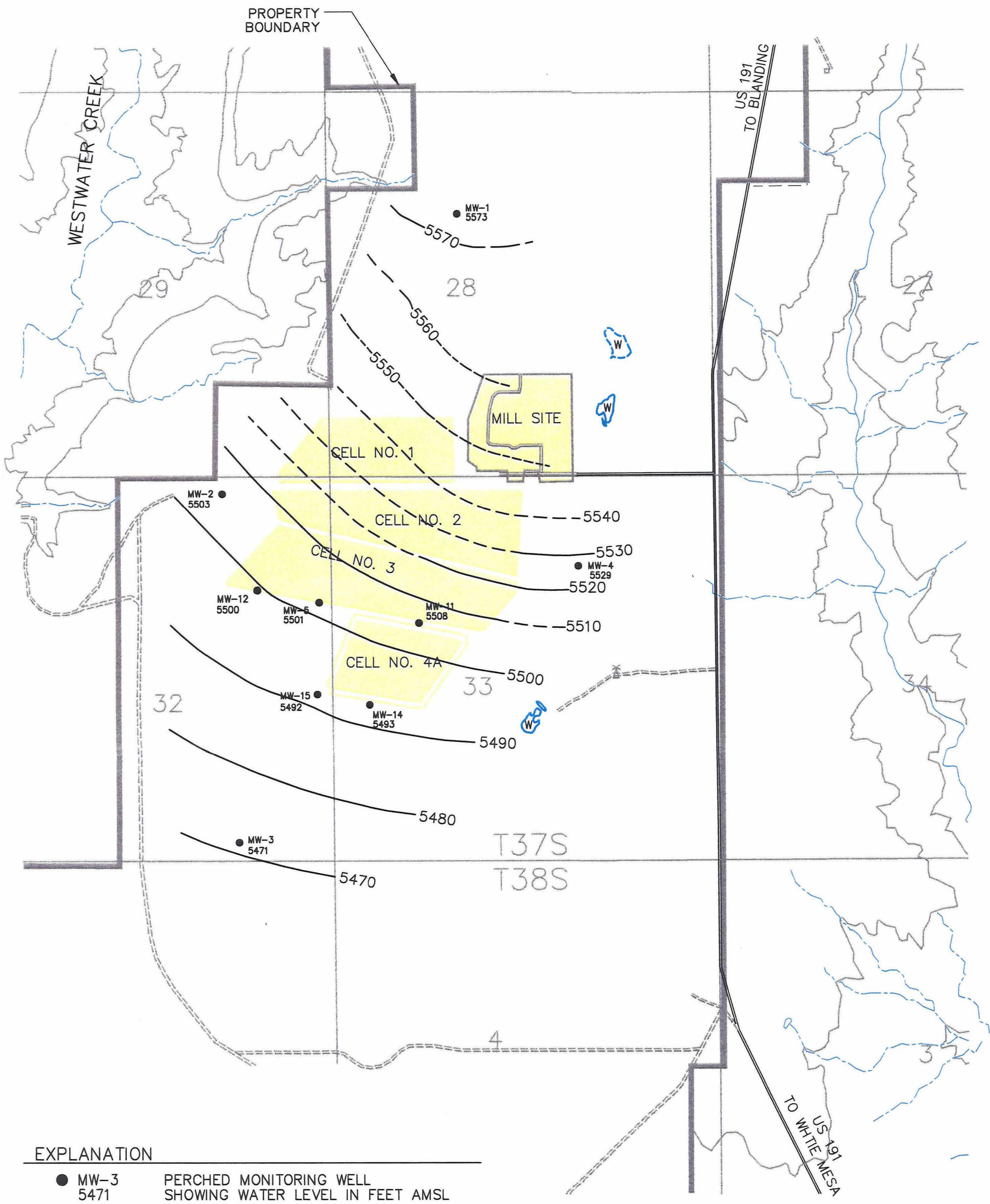
EXPLANATION

MW-20 ● 5449	perched monitoring well showing elevation in feet amsl
○ 5512	temporary perched monitoring well showing elevation in feet amsl
PIEZ-1 ● 5552	perched piezometer showing elevation in feet amsl
MW-31 ✦ 5489	perched monitoring well installed in 2005 showing elevation in feet amsl
✧ 5525	temporary perched monitoring well installed in 2005 showing elevation in feet amsl

HYDRO GEO CHEM, INC.

APPROXIMATE ELEVATION OF TOP OF BRUSHY BASIN (Contours Generated by Kriging)

APPROVED	DATE	REFERENCE	FIGURE
SJS	8/27/09	H:/718000/hydrpt09/bbel05rev.srf	1



EXPLANATION

● MW-3 5471	PERCHED MONITORING WELL SHOWING WATER LEVEL IN FEET AMSL
W	WILDLIFE POND
5580 ——— – – –	WATER LEVEL CONTOUR LINE, DASHED WHERE UNCERTAIN

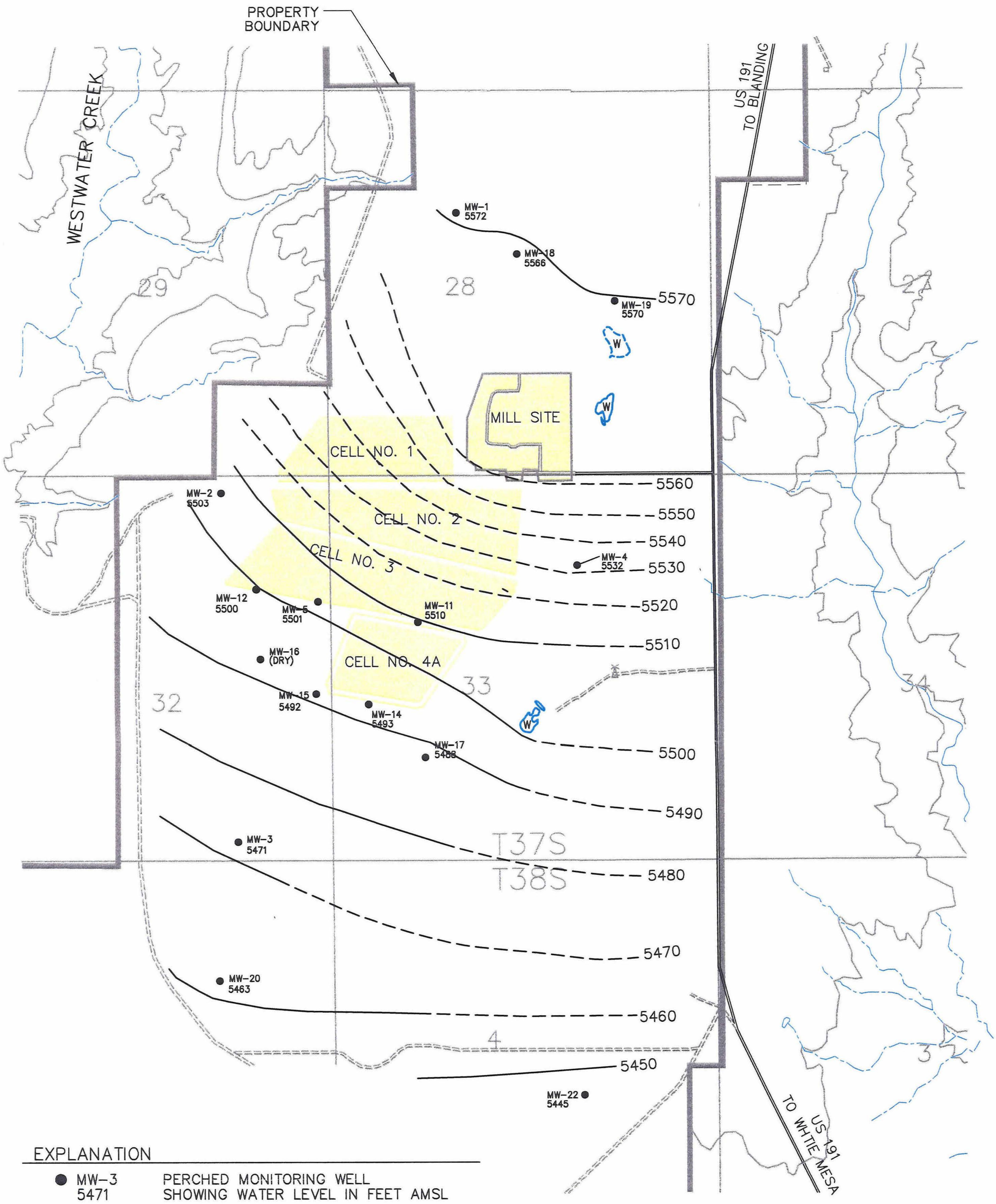
N

0 SCALE IN FEET 3000

HYDRO GEO CHEM, INC.

PERCHED WATER LEVELS
AUGUST 1990

Approved	Date	Revised	Date	Reference:	FIG:
SS	01/30/03			71800071	2



EXPLANATION

● MW-3 5471	PERCHED MONITORING WELL SHOWING WATER LEVEL IN FEET AMSL
W	WILDLIFE POND
5580 ——— — —	WATER LEVEL CONTOUR LINE, DASHED WHERE UNCERTAIN

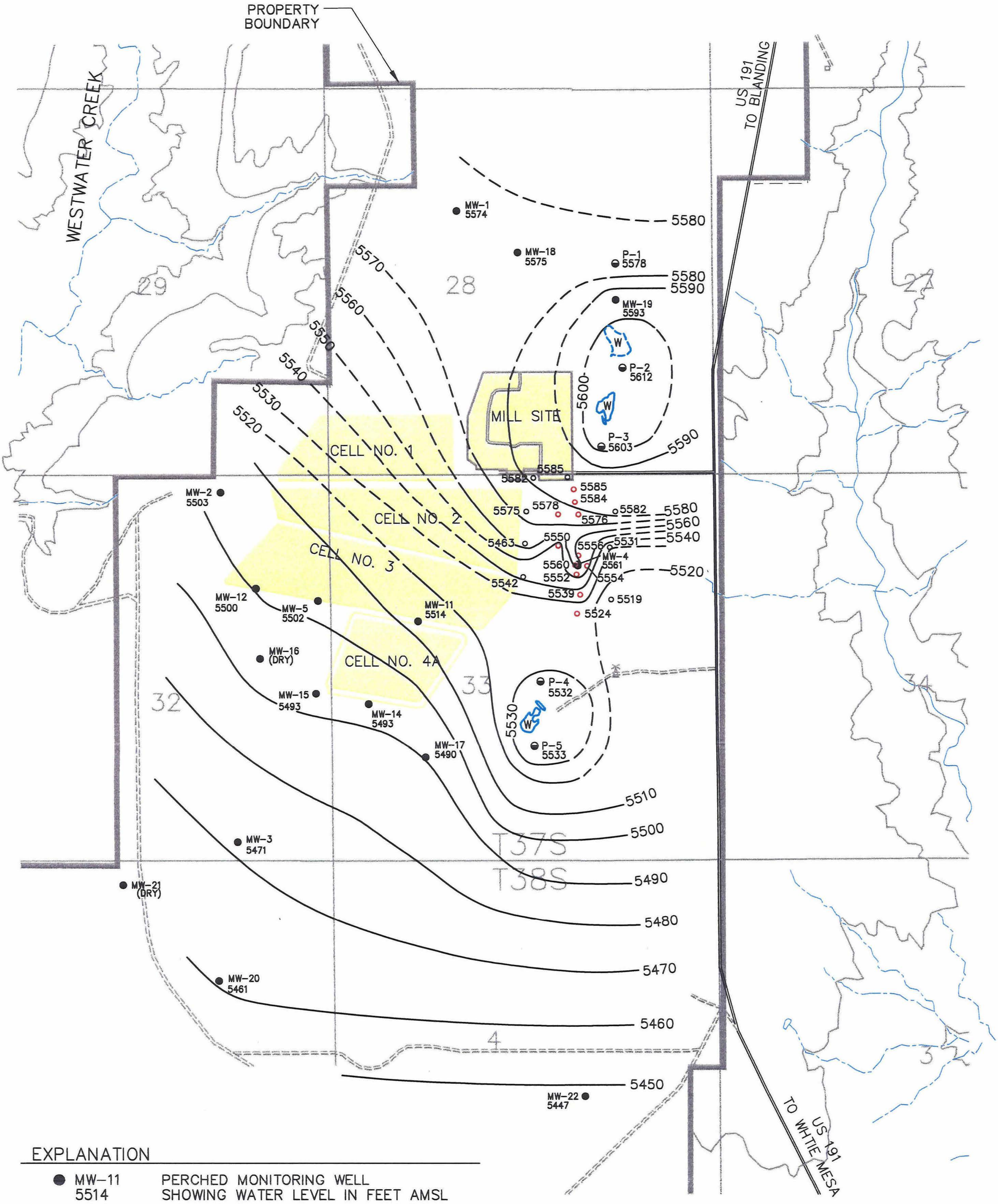
N

0 3000
SCALE IN FEET

HYDRO GEO CHEM, INC.

PERCHED WATER LEVELS
AUGUST 1994

Approved	Date	Revised	Date	Reference:	FIG:
SS	01/30/03			71800070	3



EXPLANATION

● MW-11 5514	PERCHED MONITORING WELL SHOWING WATER LEVEL IN FEET AMSL
○ 5524	TEMPORARY PERCHED MONITORING WELL SHOWING WATER LEVEL IN FEET AMSL
◒ P-5 5533	PIEZOMETER SHOWING WATER LEVEL IN FEET AMSL
5580 ——— – – –	WATER LEVEL CONTOUR LINE, DASHED WHERE UNCERTAIN
W	WILDLIFE POND

NOTE: WATER LEVELS FOR PIEZOMETERS ARE FROM AUGUST, 2002

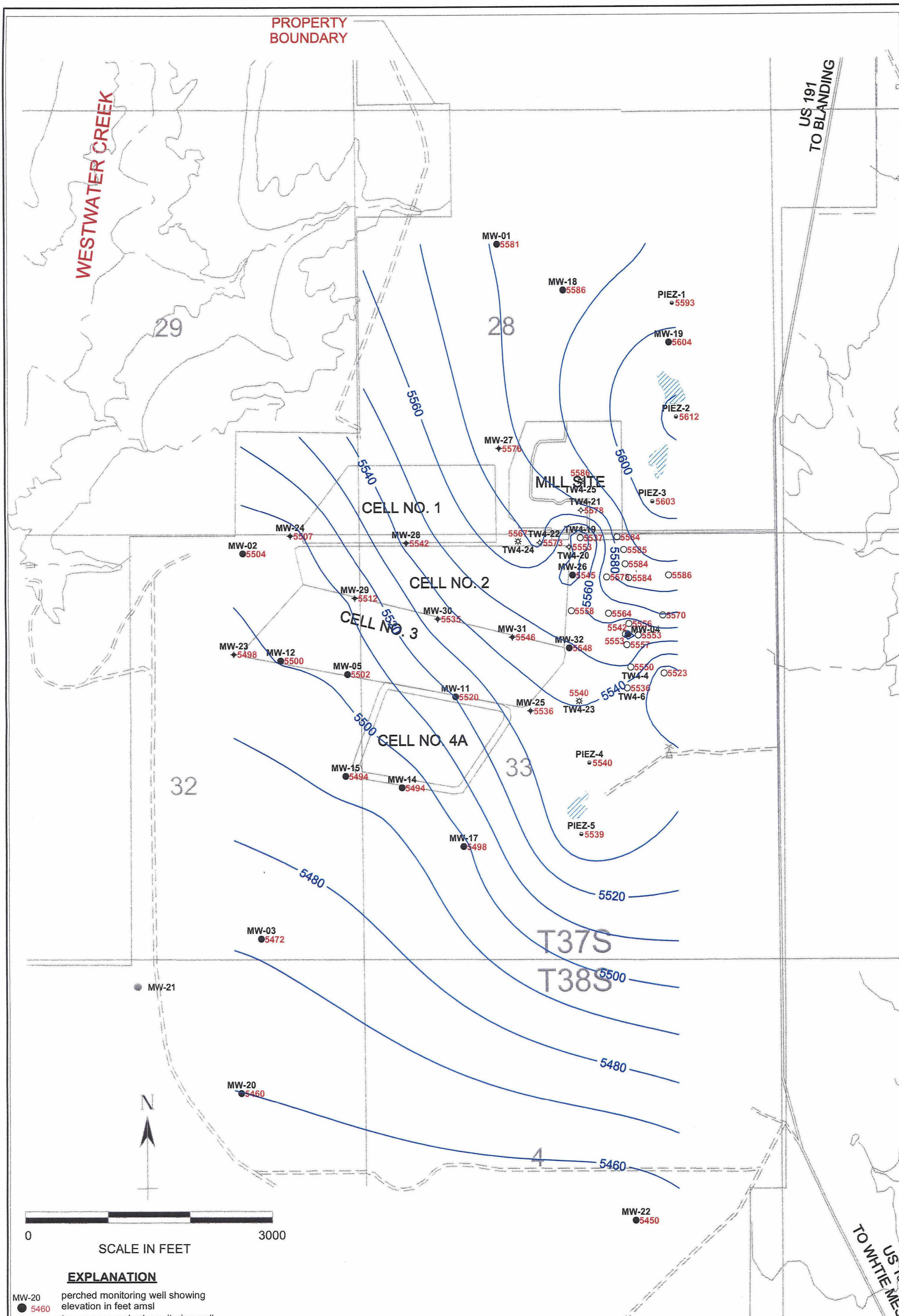
N

0 — 3000
SCALE IN FEET

HYDRO GEO CHEM, INC.

PERCHED WATER LEVELS
SEPTEMBER 2002

Approved	Date	Revised	Date	Reference:	FIG:
SS	01/30/03			71800074	4



NOTES: Locations and elevations for TW4-23, TW4-24, and TW4-25 are approximate

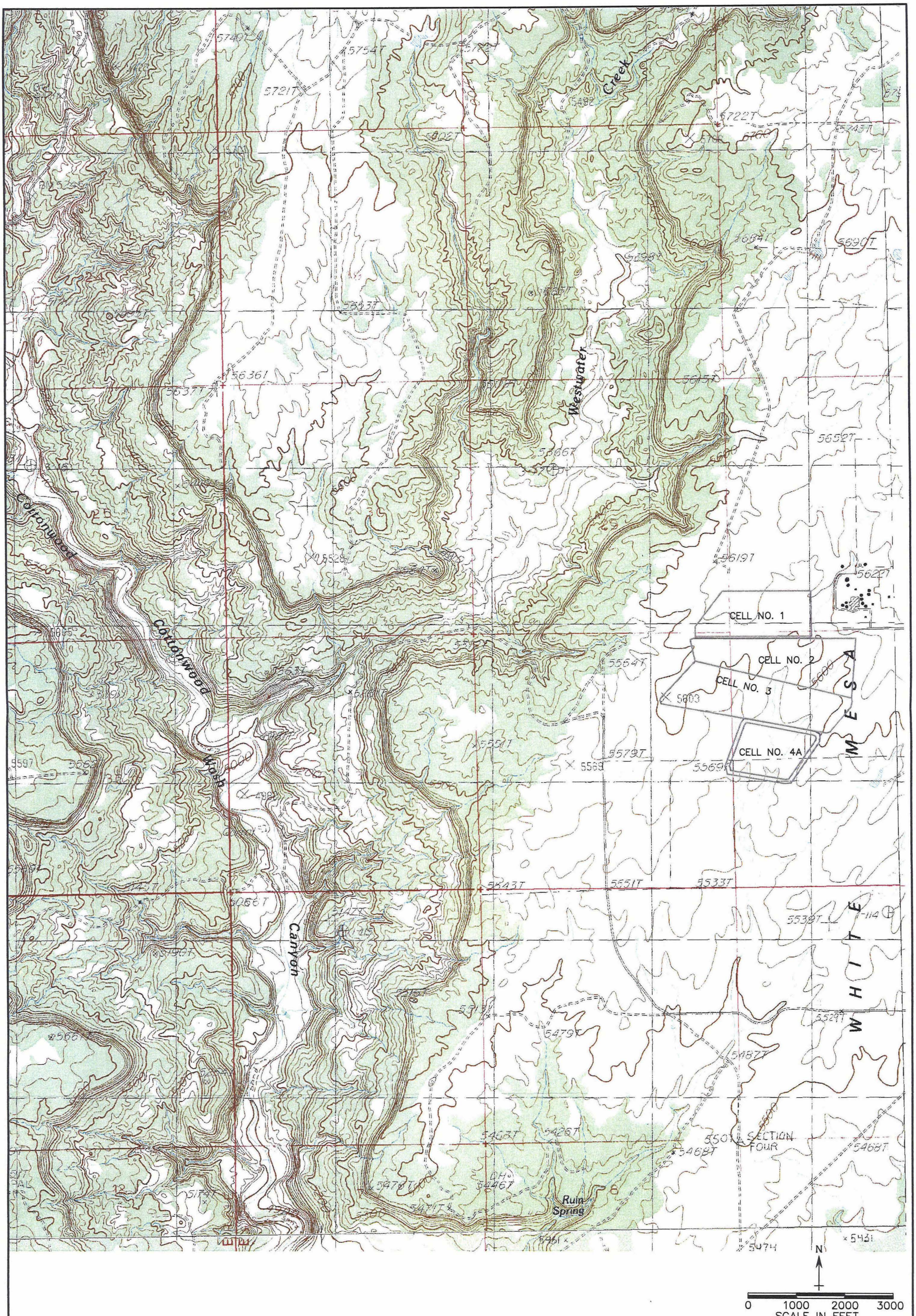
EXPLANATION

- MW-20 ● 5460 — perched monitoring well showing elevation in feet amsl
- ○ 5556 — temporary perched monitoring well showing elevation in feet amsl
- PIEZ-1 • 5593 — perched piezometer showing elevation in feet amsl
- MW-31 ✦ 5546 — perched monitoring well installed April, 2005 showing elevation in feet amsl
- ✧ 5573 — temporary perched monitoring well installed April, 2005 showing elevation in feet amsl
- ☼ 5540 — temporary perched monitoring well installed May, 2007 showing approximate elevation in feet amsl

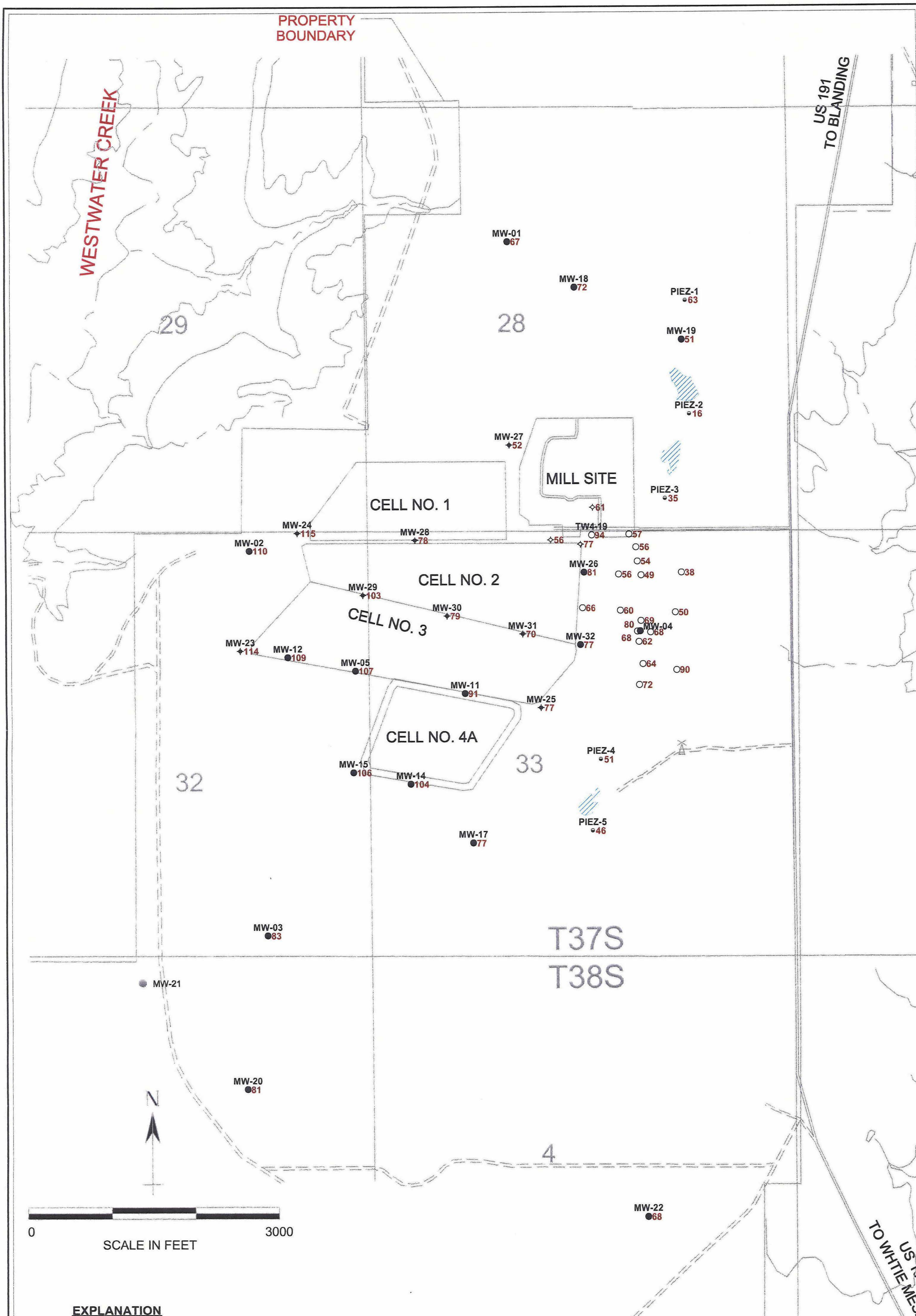
HYDRO GEO CHEM, INC.

KRIGED PERCHED WATER LEVELS 1st QUARTER, 2009

APPROVED	DATE	REFERENCE	FIGURE
SJS	8/27/09	H:/718000/hydrpt09/wl0309rev.srf	5



HYDRO GEO CHEM, INC.	PORTION OF USGS BLACK MESA 7.5' SHEET SHOWING APPROXIMATE LOCATION OF TAILING CELLS IN RELATION TO NEARBY CANYONS AND RUIN SPRING					
Approved SS	Date 1/30/03	Revised	Date	Reference: 71800076	FIG: 6	



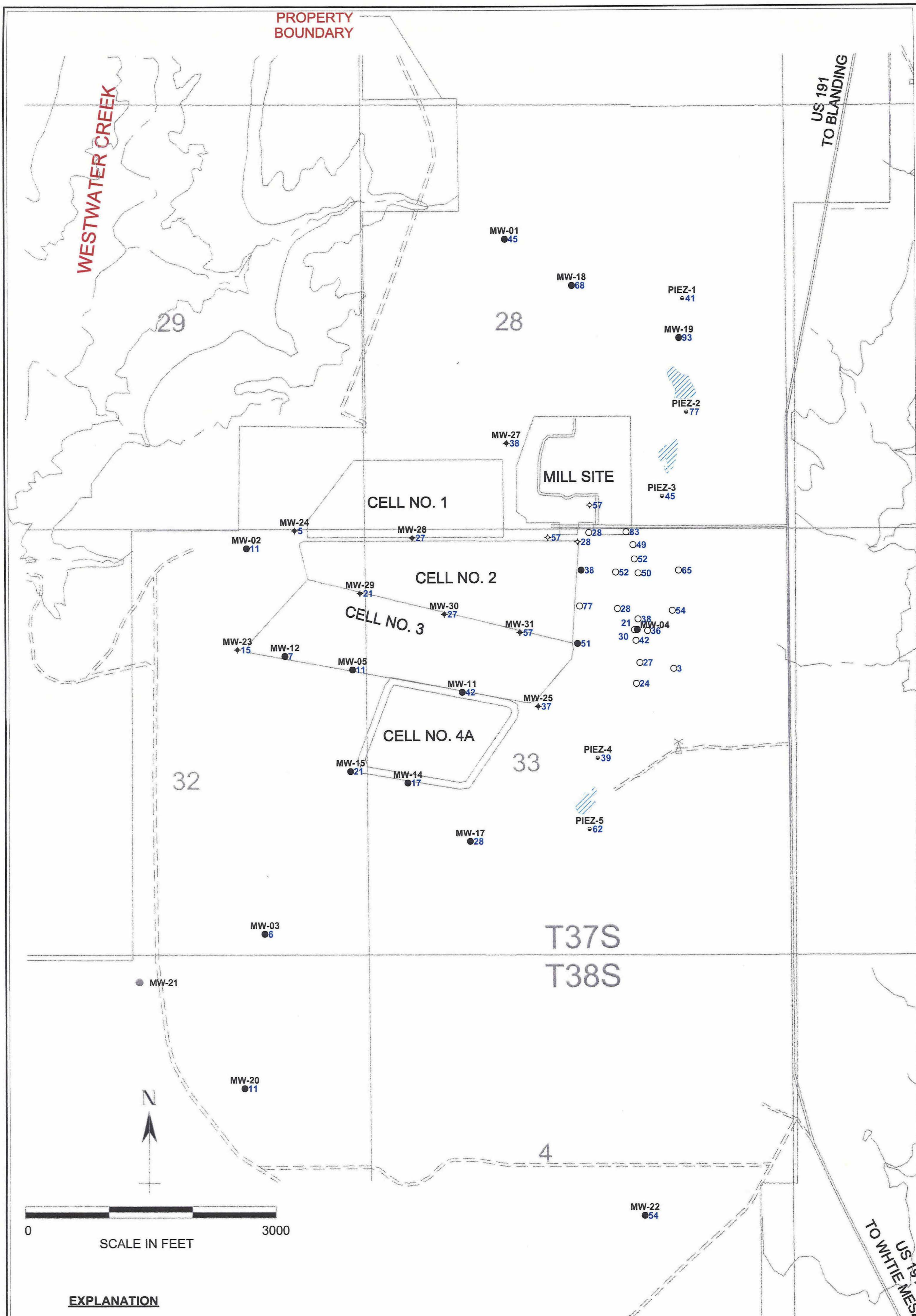
EXPLANATION

MW-20 ● 81	perched monitoring well showing depth to water in feet
○ 69	temporary perched monitoring well showing depth to water in feet
PIEZ-1 ● 63	perched piezometer showing depth to water in feet
MW-31 ✦ 70	perched monitoring well installed April, 2005 showing depth to water in feet
✧ 56	temporary perched monitoring well installed April, 2005 showing depth to water in feet

HYDRO GEO CHEM, INC.

DEPTH TO PERCHED WATER
1st QUARTER, 2009

APPROVED	DATE	REFERENCE	FIGURE
SJS	8/27/09	H:/718000/hydrpt09/dtw0309.srf	7



EXPLANATION

MW-20 ● 11	perched monitoring well showing saturated thickness in feet
○ 38	temporary perched monitoring well showing saturated thickness in feet
PIEZ-1 ● 41	perched piezometer showing saturated thickness in feet
MW-31 ✦ 57	perched monitoring well installed April, 2005 showing saturated thickness in feet
✧ 57	temporary perched monitoring well installed April, 2005 saturated thickness in feet

HYDRO GEO CHEM, INC.

PERCHED ZONE SATURATED THICKNESS
1st QUARTER, 2009

APPROVED	DATE	REFERENCE	FIGURE
SJS	8/27/09	H:/718000/hydrpt09/satdthck.srf	8