Groundwater Modeling and Proposed Monitoring Wells for the Shootaring Canyon Mill Tailings Disposal Facility

Prepared For:
Uranium One.
3801 Automation Way
Suite 100
Fort Collins, CO 80525

Prepared By:
GARD Water Consultants, Inc.
8701 Sunflower Road
Loveland, Colorado 80537

July 11, 2008

Table of Contents

FIGURES

1.0 INTRODUCTION

The Shootaring Canyon Mill Site (Site) located 48 miles south of Hanksville, Utah, and just north of Ticaboo, Utah was the last conventional uranium mill to be built in the United States. The mill was commissioned and operated for four months in 1982 before being mothballed due to declining uranium prices. It has been on care and maintenance since that time. The site location is displayed in Figures 1 through 3.

Permitting is currently underway to restart the mill. As part of that process, a new tailings impoundment is proposed. The new proposed tailings disposal cell will be located directly west of the Shootaring Canyon Mill as shown on Figure 4. The new tailings disposal cell and has been designed and will be constructed and operated according to approved best management practices. A detail of the disposal liner is provided in Figure 5. The tailings disposal cell liner consists of three major components, a) a leachate collection system that limits tailings fluid head on the primary liner, b) a leak detection system that underlies the leachate collection system which allows prompt detection of potential leakage and removal of the leachate to maintain minimal head on the secondary liner and c) a third liner of compacted clay that underlies the leak detection system which has low permeability and self healing characteristics to supplement the primary and secondary liners. This system of multiple liners, with the associated operation and monitoring programs (reference) and the different engineered geotechnical, hydrologic and hydraulic characteristics of each liner, encompasses the primary ground water protection system for operation of the tailings disposal cell.

The principal purpose of this report is to support the development of a groundwater monitoring network that will serve as the secondary groundwater protection system. The objective of the monitoring system is to provide prompt detection of potential changes in ground water quality which could be indicative of a failure of the primary ground water protection system. The results of this secondary ground water protection monitoring system will be used to evaluate compliance with State ground water protection requirements as stated in the Ground Water Quality Discharge Permit UGW170003 and to ensure that the uppermost aquifer is protected to the maximum extent feasible, as stipulated in UAC R317-6-4.

The design of the secondary monitoring system has relied on data collected from previous investigations, primarily the Ground-water Monitoring of Shootaring Canyon Tailings, Hydro-Engineering, 2006 and Ground-water Hydrology of Shootaring Canyon Tailings, Hydro-Engineering, 1998. The data analysis included evaluation of monitoring wells at the site.

Driller’s logs were insufficient to make detailed geologic picks; therefore only wells with geophysical neutron logs were used in the interpretation. Neutron logs respond primarily to the amount of hydrogen in the formation. Hydrogen is contained in oil, natural gas, and water, and is used to identify zones of porosity. In sediment of the same relative age and depositional environment, the interpreted porosity can be used to infer grain size. Coarse grained deposits typically contain more pore space whereas finer grained deposits have less porosity. The interpreted logs were used to develop a three-dimensional geologic model that could be used with confidence to evaluate the groundwater flow at the facility.

This report describes the site hydrogeologic conceptual model based on interpretation of existing site data. Using these data and the site conceptual model, a numerical ground water flow and transport model has been developed. This model is used to evaluate the flow and transport of potential tailings fluids as a basis for the design of the ground water monitoring network.

2.0 SITE HYDROGEOLOGIC CONCEPTUAL MODEL

Conceptual models form the basis for investigation of field observations and laboratory data. The characteristics of the site hydrogeologic conceptual model are described in Sections 2.1 through 2.3.

2.1 Hydrogeology

The hydrogeologic conceptual model is based upon geologic and geophysical logs collected during previous site investigations (Hydro Engineering, 1998, 2006). Seventeen groundwater monitoring wells with accompanying geophysical logs from the following wells were used to develop the conceptual geologic model. These wells include RM16, RM11, RM4, RM5, RM15, RM6, RM13, RM-3, RM-14, RM-19, RM7, RM18, RM12, RM9, RM20, RM1 and RM12. Table 2-1 summarized the interpreted bottom elevations of each hydrogeologic unit or subunit. Figures 5, 6 and 7 present geologic cross sections originally presented in Hydro-Engineering, 2006, and include well and geophysical log details.

The proposed Shootaring Canyon Mill tailings disposal cell is underlain by a thin veneer of loose fluvial and aeolian sediments. The sediments are comprised of sands derived from weathered Entrada sandstone and unconsolidated to poorly consolidated windblown sediments. These sediments are situated well above the first encountered groundwater.

These loose sediments are underlain by the Entrada Sandstone. The Entrada Sandstone, which underlies all of the mill facilities and the tailings disposal cell, is a member of the San Rafael Group and contains the first occurrence of ground water and is the uppermost aquifer at the site. The Entrada Sandstone consists primarily of uniform fine-grained sandstone with occasional interbeds of shale and siltstone. In the vicinity of the mill and tailings disposal cell, the Entrada Sandstone exhibits two lower permeability sandstone subunits of the Entrada (Hydro Engineering, 1998). These subunits are discontinuous across the site domain and are important because the lower permeability may influence the local ground water flow beneath the site. These discontinuous subunits of the Entrada Sandstone appear to have lower permeability relative to the bulk of the Entrada Sandstone based on the interpretation of the neutron logs (Hydro Engineering 2006). Although these subunits have a slightly different character than the bulk of the Entrada Sandstone, they have been produced by small variations in depositional environment and are considered as part of the Entrada Sandstone.

The presence of these finer grained sandstone subunits have been interpreted principally from the character of the geophysical neutron logs and the results of single well pumping tests. The hydrogeologic character of the finer grained unit is apparently variable within the subunit. This variation encompasses the higher hydraulic conductivity of the bulk Entrada Sandstone, 0.2 feet per day, to 0.06 feet per day, as measured from the single well pumping tests (Hydro Engineering, 2006). Single well pumping tests are less reliable than multiple well pumping tests to determine hydraulic conductivity. The data from RM9 represent the best available estimation of the hydraulic conductivity for the upper subunit, 0.06 feet per day, because the well is screened only in the upper low permeability sandstone subunit. No pump test data isolating only the lower sandstone subunit is available.

Figure 4 defines the locations for three cross-sections developed by Hydro Engineering (Hydro Engineering, 1998, 2006). Figure 6 represents the geologic cross-section 1-1. The cross-section is located south of the proposed tailings dam and is oriented in an east-west direction. The cross-section illustrates the presence of both the upper and lower low permeability sandstone subunits in this area. Although present, the upper sandstone subunit is not saturated and is limited in extent to two wells, RM4 and RM5. The lower low permeability sandstone subunit is present in RM11, RM4, RM5 and RM15 but is absent in RM6 and RM13. This subunit is saturated or nearly saturated in the four wells it was encountered.

Figure 7 depicts the cross-section 2-2'. The cross-section extends along the western side of the tailings ponds until RM14. The cross-section then is extended eastward to the east side of the tailings impoundment. No low permeability sandstone subunits were identified on this cross-section.

Figure 8 presents the geologic cross-section 3-3' (see Figure 4 for location of this cross section) which runs from the Shootaring Dam through the cross valley berm to the two upgradient wells, RM1 and RM12. This cross-section is also presented in Figure 14 as a fence diagram through the conceptual model. Interpretation of the site geophysical logs indicates a localized lower permeability subunit or zone of the Entrada Sandstone with limited lateral extent in the area of the Shootaring Canyon Dam. These geophysical logs and cross sections demonstrate that the low permeability zone forms a localized perched water condition identified in wells RM8 and RM9.

Well and geophysical data show this low permeability zone and perched water condition does not have significant lateral extent. Specifically, the shallow low permeability zone and perched water condition identified in locations RM8/RM20, RM4, RM5 and RM9 is not present in the following locations.

- On the Western margins of the tailings impoundment area:
  Locations RM3 and RM14 as shown in Figure 7.
  Location RM11 as shown in Figure 6.

- To the North along the Cross Valley Berm:
  Locations RM14, RM19, RM7, RM18 and RM2 as shown on Figure 7

- On the Eastern margins of the tailings impoundment area:
  Location RM13 as shown in Figure 5
  Location RM2 as shown in Figure 7

- At or below the Shootaring Dam:
  Locations RM11, RM15, RM6 as shown on Figure 6

Figures 10 and 16 illustrate the limited location and extent of this low permeability sandstone subunit. Where the subunit is identified in locations RM4 and RM5 near the Shootaring Dam, it is not saturated. The dip of the localized subunit is to the north with the top elevation approximately 4380 feet above mean sea level (MSL) near the embankment (locations RM4 and RM5 in Figure 3-1) and approximately 4290 feet MSL in locations RM8 and RM9 (Figure 3-3). It should also be noted that the extension of the low permeability zone identified in locations RM4 and RM5 near the Shootaring Dam is very near the pre-embankment ground surface while the Entrada aquifer water table surface is more than 100 feet below the ground surface, therefore, data from locations RM8 and RM9 and the geophysical log of RM20 represent a distinct and localized condition, both hydrogeologically and geochemically from that of the main Entrada aquifer.

The Carmel Formation is present beneath the Entrada and consists of clays, shales, and interbedded sandstones. The Carmel is approximately 160 feet thick beneath the Shootaring Canyon Mill site and acts as an aquitard. The top of the Carmel Formation is considered the base of the uppermost aquifer system at the Site. Although the Navajo Sandstone underlies the Carmel Formation, it is considered isolated form site activities by the Carmel because of the great difference (200 feet) between water levels in the Entrada and Navajo sandstones and the very low hydraulic permeability of the Carmel (Hydro-Engineering, 1998).

As mentioned previously, 17 wells were used to generate the conceptual geologic model. Data from these wells were interpreted and entered into the three-dimensional modeling software called EVS (C-Tech, 2008). EVS allows the data to be interpreted between the monitoring wells and presented in a block three-dimensional model. The model can be viewed in section and the conceptual model data checked to ensure agreement with geologic concepts. The resulting conceptual model as rendered by EVS is illustrated in Figures 9 through 14. These figures show the resulting hydrogeologic unit surfaces at the Mill site. Figure 9 illustrates the entire three-dimensional conceptual model. Each subsequent figure has a geologic layer removed, beginning with removal of the uppermost layer. Figure 14 is a cross-sectional cut through the middle of the model from north to south along cross-section 1-1, illustrating the location of the low permeability sandstone subunits.

Table 2-1. Data Used for EVS Conceptual Model – Elevations are for the Bottom of the Surface

Well Name	Easting	Northing	Surface Elevation	Entrada1	Upper Low K	Entrada 2	Lower Low K	Entrada 3
RM4	61099	56472	4395.5	4365.5	4343.5	4235.5	4155.5	3995.5
RM9	61363	56767	4369.31	4288.31	4284.31	4248.31	4189.31	3969.31
RM20	61592	57208	4380.83	4290.83	4286.83	4220.83	pinched out	3980.83
RM2	63040	57731	4519.76	4399.76	4369.76	4311.76	4219.76	4119.76
RM1	61827	59307	4449.2	4303.2	4285.2	4257.2	4225.2	4049.2
RM11	60769	56594	4436.14	4356.14	pinched out	4256.14	4206.14	4036.14
RM13	61996	56648	4434.81	4334.81	pinched out	4234.81	pinched out	4034.81
RM14	61368	58419	4450.84	4400.84	pinched out	4260.84	pinched out	4050.84
RM15	61354	56311	4343.75	4283.75	pinched out	4235.75	4059.75	3943.75
RM19	61524	58077	4409.5	4379.5	pinched out	4261.5	pinched out	4009.5
RM3	60647	57193	4461.32	4361.32	pinched out	4245.32	pinched out	4061.32
RM5	61286	56416	4379.12	4359.12	pinched out	4273.12	4189.12	3979.12
RM6	61481	56348	4374.57	4339.57	pinched out	4234.57	4174.57	3974.57
RM7	61645	57904	4395.86	4379.86	pinched out	4255.86	pinched out	3995.86
RM18	61851	57833	4421.56	4381.56	pinched out	4261.56	pinched out	4021.56

2.2 Groundwater Flow

The groundwater flow at Shootaring Mill was evaluated using phreatic surface data collected during March 2003 because this period contained the most complete groundwater elevation data set. Many wells that were geophysically logged and had recorded water levels were abandoned soon after March 2003. However, groundwater elevations have remained relatively stable over the past 10 years and the March 2003 data are considered as reasonably representative of current conditions. Table 2-2 summarizes the

2003 groundwater data and provides available 2008 data for comparison. Figure 4 shows the monitoring well locations.

The groundwater elevation data in Table 2-2 have been contoured and the results shown in Figure 15. The groundwater flow system in the main Entrada aquifer at the Shootaring Canyon Mill is relatively simple. Groundwater flow in the Entrada is generally from north to south, following the footprint of the canyon floor. The notable exception to this flow regime is the southeast component of flow in the eastern portion of the mill area. Evaluation of multi-well permeability tests indicates a flow barrier east of the tailings pond and south of the mill (Hydro Engineering, 2006). This “flow barrier” is likely a low permeability zone at that location.

The localized low permeability subunit of the Entrada Sandstone that creates the perched water zone observed in wells RM8 and RM9 in the southern portion of the site at a depth of approximately 75 feet below grade (fbg). Figure 16 depicts the extent of the low permeability sandstone subunit as well as the elevation and location of the perched water. Infiltration of meteoric waters from direct precipitation and infrequent surface flows down the drainage below the original tailings disposal cell migrates vertically through the vadose zone or unsaturated alluvial sediments and unsaturated Entrada Sandstone until it encounters the localized low permeability sandstone subunit.

This low permeability zone is interpreted to be lower in elevation at the limits of its northern extent, south of wells RM7, RM14, RM 18, and RM19, than in its southern extent, Wells RM4 and RM5. The northern dip of this subunit allows the perched groundwater to drain to the north from perched groundwater and subsequently vertically to the main Entrada aquifer. Some ground water flow is also expected to move vertically through the siltstone at a low rate until it also reaches the main Entrada aquifer directly below this localized low permeability zone.

Table 2-2 2003. Groundwater Elevations

Well	Easting	Northing	2003 Groundwater Elevation	2008 Groundwater Elevation	Difference
OW1A	63730	57140	4243.33		
OW2	63667	57094	4247.8		
RM1	61827	59307	4273.4		
RM10	61272	56286	4248.47		
RM12	61791	59477	4273.45		
RM15	61354	56311	4238.65	4237.37	-1.28
RM16	60772	56615	4241.2		
RM17	61993	56636	4246.18		
RM18	61851	57833	4257.15		
RM19	61524	58077	4256.9		
RM2	63040	57731	4261.51	4261.94	0.43
RM20	61592	57208	4251.63		
RM2R	63142	57924	4265.16		
RM3	60647	57193	4246.66	4246.2	-0.46
RM4	61099	56472	4240.1	4239.78	-0.32
RM4R	61086	56358	4240.32		
RM5	61286	56416	4239.72	4239.72	0
RM6	61481	56348	4239.17	4237.96	-1.21
RM7	61645	57904	4255.96	4255.25	-0.71

The main Entrada aquifer is the uppermost aquifer beneath the mill and tailings disposal cell. Within the Entrada Sandstone Aquifer is a low permeability sandstone subunit located toward the southern portion of the site a depth of 125 feet below ground level (Figure 10 and Figure 12). Although the subunit is described in the geologic logs and is confirmed in the geophysical logs as a silty sandstone or siltstone, the lower permeability of the subunit does not appear to significantly affect groundwater elevations. There is, however, a slight increase in the groundwater gradient in the vicinity (Figure 14, between Well RM9 and RM15). The average gradient of the Entrada Sandstone in the mill area is 0.011 foot per foot. This gradient does not appear to be related to changes in groundwater elevation as doesn’t change significantly from one sampling event to another.

2.3 Hydrogeologic Parameters

Hydrogeologic parameters were estimated from pumping test collected during the Ground-water Hydrology of Shootaring Canyon Tailings report data collection (Hydro-Engineering, 1989). Table 2.3 is a summary of the pumping test results collected during the project. The permeability values determined from the pumping tests ranged from a low of 0.08 feet per day to a high of 0.21 feet per day with an average of 0.17 feet per day. Permeability was estimated to be 0.2 feet per day for the bulk of the Entrada Sandstone.

Data from the area east of the tailings area indicate a slightly different flow direction. The change in flow direction is consistent with a change in the permeability. Permeability in this region of the model was lowered to 0.02 feet per day to obtain a good fit with the data. This value is consistent with the estimates of permeability obtained from single well pumping tests conducted on wells RM2 and OW1.

Effective porosity was estimated from literature values to be 0.1 (Freeze & Cherry, 1976). Using Darcy's law for a unit area, $v = KiA/n_e$ or $Ki/n_e = 0.2*0.011/0.1 = 0.022$ feet per day or about 8 feet per year. This slow advective flow rate indicates a lower frequency of groundwater monitoring will be required in the unlikely event that the multiple tailings disposal cell liner systems fail to perform as designed.

Approximately 6.4 inches of precipitation per year fall at Ticaboo, Utah (http://climate.fizber.com/utah-city-hanksville-climate.html). Experience has shown that about 20 percent of the rainfall or about 0.0002 feet per day is a good approximation of recharge to the aquifer in southern Utah.

The upper low permeability sandstone subunit (the perched zone) has an estimated area of about 980,000 square feet. The resulting recharge to the perched groundwater is about 170 cubic feet per day average using the recharge estimate of 0.0002 feet per day. The perched groundwater zone is interpreted to be radial flowing from the highest measured elevation at RM20 (Figure15). The permeability has been measured at the site in two single well pumping tests. The permeability in well RM8 was measured at 0.02 feet per day and at RM9 at 0.6 feet per day. The ground water phreatic surface elevation in the northern portion of the perched water zone exceeds the elevation of the interpreted surface of the localized low permeability subunit of the Entrada Sandstone where it pinches out. This indicates groundwater likely spills over and moves in a vertical direction through unsaturated sediments until it reaches the uppermost aquifer water table of the Entrada Sandstone. It is estimated that as much as 18 cubic feet per day is discharged from the perched groundwater system in this way (see Appendix I).

The perched groundwater also discharges vertically through the localized low permeability subunit as downward seepage. It is estimated that approximately 180 cubic feet per day discharges via this mechanism and is the dominant flow path from the perched groundwater to the regional aquifer (Appendix I).

Table 2.3. Aquifer Test Results From RM15 Multi-Well Pump Test and Single Well Pump Tests

		Transmissivity								Distance
	Drawdown	Straight	Theis		Recovery	Hydraulic		Storage Coefficient		From
	@end	Line	Early Time	Late Time	Method	Permeability		Theis Early Time	Jacobs' Method	Well RM15
Well No.	(ft)	(GPD/ft)	(GPD/ft)	(GPD/ft)	(GPD/ft)	(ft/day)	(DARCY)	Dimensionless	Dimensionless	(ft)
RM 15 Multi-Well Test Entrada Sandstone										
RM15	79.2	360	--	--	--	0.14	0.04	--	--	--
RM1	0.6	--	--	420	--	0.16	0.05	6.0E-04	--	3032
RM2	0.9	--	--	420	--	0.16	0.05	8.0E-04	--	2204
RM3	3.4	--	560	560	--	0.21	0.06	4.6E-04	--	1130
RM4	11.5	560	440	520	--	0.20	0.06	3.7E-04	--	302
RM5	12.2	600	650	560	--	0.21	0.06	9.6E-04	--	125
RM6	17.5	480	470	490	--	0.19	0.06	3.3E-04	--	125
RM7	0.2	--	--	--	--	--	--	--	--	1619
OW1A	0.9	--	--	210	--	0.08	0.02	4.9E-04	--	2461
Single Well Tests Entrada Sandstone										
RM1	14.9	63	--	--	--	0.14	0.04	--	--	--
RM4	--	--	--	--	230	0.08	0.02	--	--	--
RM7	57.7	13	--	--	--	0.02	0.01	--	--	--
RM12	--	130	--	--	--	0.05	0.02	--	8E-05	--
WW1	--	130	--	--	--	0.05	0.02	--	8E-05	--
Single Well Tests Perched Entrada										
RM8	14.1	5	--	--	--	0.02	0.01	--	--	--
RM9	14.1	11	--	--	--	0.06	0.02	--	--	--
	Multi-Well Test Navajo Sandstone									
WW1	--	15800	15700	--	17000	5.28	1.60	--	--	--
OW1B	--	22600	21300	--	19800	7.55	2.29	5.6E-03	4.2E-03	53
OW3	--	18800	--	--	19800	6.28	1.91	--	5.0E-03	98.8

3.0 GROUNDWATER MONITORING WELL NETWORK

This section describes the basis for design of the proposed ground water monitoring network of wells for the Shootaring Canyon Mill. The monitoring plan is based upon the results of a stochastic groundwater model developed form site specific data and based upon the current hydrogeologic conceptual model. The modeling effort was used to support location, well spacing and depth of the groundwater monitoring well network required to detect potential releases from the tailing pond.

3.1 Groundwater Model

Groundwater Vistas (Rumbaugh, 2004), a graphical user interface (GUI) used to create MODFLOW (Harbaugh, 1994) and MT3DMS (Zheng, 1999) model input files, was used to design the groundwater monitoring network, a simple three-dimensional groundwater flow and transport model. The groundwater model consists of 169 row and 129 columns spaced 25 feet apart. The model contains 10 layers each 50 feet thick.

Although the model simulates the conditions from surface to the base of the Entrada, MODFLOW is incapable of simulating unsaturated flow (MacDonald, Harbaugh, 1994) and therefore the perched zone could not be included in the analytical model. Groundwater exiting the perched zone that exists under the footprint of the proposed impoundment will move vertically until it encounters the main Entrada aquifer. While the perched groundwater was not explicitly included in the model, all groundwater from the perched zone ultimately flows to the main Entrada under the footprint of the impoundment.

The deeper, low permeability sandstone subunit was simulated as saturated. Boundary conditions were set as constant head cells along the boundaries of the model. The constant heads were set to achieve the approximate groundwater elevations and gradients in the observed data.

This model is used to develop a basis for designing the groundwater monitoring lateral well spacing and vertical screen depths to ensure prompt detection of changes in ground water quality in the unlikely event that the multiple liner systems fail to perform as designed. The area east of the tailings pond, beneath the mill was modeled using a hydraulic conductivity range and standard deviation similar to the low permeability sandstone subunit. No further attempts were made to adjust the hydrogeologic parameters to obtain a better fit to observed data than the adjustment to the constant heads.

Stochiometric methods were used in lieu of more rigorous calibration efforts to obtain the most likely spread of potential plumes. The stochastic model used Monte Carlo techniques to vary the hydrogeologic parameters over the range of expected values. The parameters and ranges are provided in Table 3.2. These values were obtained from Table 2-3. The mean piezometric head distribution resulting from the stochastic modeling is illustrated in Figure 18. A comparison of the measured heads and the modeled heads is illustrated in Figure 19.

Permeability values were varied one order of magnitude above and below the mean value for each hydrostratigraphic unit. The range of dispersion used in the model was derived from the Gelhar field-scale evaluation. This relationship between the model scale and longitudinal dispersivity is summarized in Figure 17 and shows the variation of dispersion with the scale of the plume. Porosity values were obtained from a literature review (Freeze and Cherry, 1979). The values used for porosity were varied over a large range of values in the stochastic model to account for the wide variation in reported values.

Two constant source terms were used to simulate the effects of a release from the tailings impoundment. The source terms were placed in the model at 1500 and 500 feet north of the proposed monitoring well network to simulate the potential releases. The source terms were placed at the top of the groundwater surface at simulated concentrations of 100,000 ppm.

Table 3.2. Parameters Used in the Stochastic Flow and Transport Model

Parameter	Distribution	Parameter Value	Standard Deviation	Minimum Parameter Value	Maximum Parameter Value
Entrada Permeability	LogNormal	0.2	2	0.02	2
Sandstone Subunit Permeability	LogNormal	0.02	2	0.002	0.2
East Entrada Permeability	LogNormal	0.02	2	0.002	0.2
Porosity	Normal	0.1	2	.01	0.25
Dispersivity	Normal	10	2	1	1000

3.2 Groundwater Modeling Results

The stochastic groundwater flow and transport modeling results confirm that the groundwater flow velocity is very low. Model simulation times were 36,500 days or 100 years. At the conclusion of the stochastic simulations, the mean plume extents were calculated using Groundwater Vistas. Figure 20 summarizes the results of the modeling effort. The figure shows the footprints of both plumes. The resulting plume emanating from the 1500 foot source had developed sufficient width to be detected by monitoring wells spaced of 400 feet apart (Figure 20). Although the plume extended to a depth 250 feet (150 feet below groundwater surface) at the proposed monitoring well network, the highest concentrations and greatest mass was located between the water table and 100 feet below the water table (Figure 21). Groundwater is encountered at depths of approximately 120 feet to 150 feet below ground level and the base of the planned tailings pond. To ensure detection of this modeled plume, monitoring wells will require 300 feet spacing between wells that are screened to a depth of 50 to 100 feet below the groundwater surface (approximately 170 to 220 feet deep).

The plume from the source term placed 500 feet from the monitoring network that passes through the siltstone in the uppermost aquifer barely had sufficient time to reach the monitoring well network in the 100 year simulation. This source was placed at the southern extent of the tailings pond and represents the nearest a release could occur. The plume was approximately 200 feet in width and the highest concentrations and greatest mass was located at depths between the groundwater surface and 50 feet (Figure 22) To ensure detection of this simulated plume, monitoring wells will need to be spaced 175 feet apart and be screened from the water table to a depth of 50 feet below the water table of 120 to 170 feet below ground surface.

To be certain of detecting any possible contamination released from the tailings pond, the more restrictive well design of the two release points should be implemented. Maximum monitor well spacing should be 175 feet to detect potential releases from the nearest point within the tailings pond. The wells should be screened from the groundwater surface to 100 feet below the groundwater surface (120 to 220 feet below ground surface). Figure 23 summarized the preferred locations for the groundwater monitoring wells.

3.3 Particle Tracking Model

In addition to the stochastic modeling, MODPATH was also used to evaluate the transport of potential releases from the tailings pond. The advantage of the MODPATH model is that it takes relatively less time to compute the particle pathlines. The model is incapable of computing actual concentrations but is useful in determining potential monitoring well locations.

MODPATH particles were placed around the perimeter of the tailings pond, at the top of the water table. The particles were allowed to run until they exited the model at the southern end of the model.

As stated previously, the eastern portion of the model (Eastern Entrada) was modeled using 0.02 feet per day. Three pump test results are available for this area. Monitoring wells RM2 and OW1A have multi-well results ranging from 0.08 to 0.16 feet per day. The model was executed in separate simulation using these values of permeability for the Eastern Entrada. Variation of the permeability in this area significantly affects the flow direction in the southern portion of the model.

The results of this modeling effort using permeability of 0.08 and 0.16 feet per day are summarized in Figures 24 and 25, respectively. Figure 24 indicates that the particles substantially remain within the foot print of the valley floor. There is some excursion to the west of the impoundment. The proposed well on the southwest corner the proposed facility will monitor any seepage in the area.

Figure 25 depicts the modeling results using the higher permeability, 0.16 feet per day. The modeling results indicate potential seepage to the east. The four monitoring wells to the east will be able to detect any seepage from the eastern portion of the tailings impoundment if it were to occur.

Finally, because the permeability of the eastern portion of the model appears to have a significant effect on the flow field beneath the site, a stochastic transport model was conducted using horizontally isotropic permeability for the whole model. The mode was executed using
$K_x = K_y = 0.2$ feet per day and $K_z = 0.01$ feet per day. An additional simulated source was placed at the extreme northeastern corner of the tailings pond. Figure 26 summarizes the results. The simulated source in the northeast portion of the tailings pond moves south to southwest through the mill area. The original two sources in the center of the pond do not display the budging effect of the low permeability sandstone subunit that was apparent in previous model simulations. Dispersion is a function of groundwater velocity. A stagnant groundwater flow regime will have very little dispersion and contaminant spreading is caused primarily by diffusion. The increased groundwater velocity in the vicinity of the tailing dam allows the closest source to spread to a greater degree than observed in previous simulations and the plume is detected in two of the proposed groundwater monitoring wells.

3.4 Recommendations

The results of the modeling indicate that a total of 14 down-gradient wells will provide leak detection monitoring for any potential leak from the proposed impoundment. The 14 monitoring wells should be placed at the approximate locations shown on Figure 23. Well spacing should be on the order of 175 feet to ensure detection of potential releases close to the monitoring well network. The wells should be screened from five feet above the groundwater surface to a depth of 100 feet into the saturated aquifer.

The new monitoring wells should be logged and the geologic information obtained from the drill program compared to the conceptual site model. Any differences should be evaluated to determine if the number and location of monitoring wells should be modified.

The long-term sampling interval for the monitoring well system should be at least one year. As presented earlier, the expected groundwater velocity is approximately 8 feet per year. Potential releases from anywhere in the tailing pond footprint will require almost 100 years to reach a monitoring well, without considering the effect of retardation on solute transport. Quarterly monitoring to develop information for intra-well background values is appropriate.

4.0 REFERENCES

ASTM D6771. Standard Practice for Low Flow Purging and Sampling for Wells and Devices Used for Ground-Water Quality Investigations. ASTM International.

Gelhar, L. 1974. A Critical Review of Field-Scale Dispersion in Aquifers. Water Resources Research.

C Tech Development Corporation, 2008. EVS Software

Freeze, R. and J. Cherry, 1979, Groundwater, Prentice-Hall

Harbaugh, A.and M. McDonald, 1994. User's Documentation for MODFLOW-96, an update to the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model, Open-File Report 96-485

Hydro-Engineering. 2006. Ground-water Monitoring of Shootaring Canyon Tailings

Hydro-Engineering. 1998. Ground-water Hydrology of Shootaring Canyon Tailings.

Pollock, D. 1994. User's Guide for MODPATH/MODPATH-PLOT, Version 3: A particle tracking post-processing package for MODFLOW, the U. S. Geological Survey finite-difference ground-water flow model. U.S. Geological Survey.

Rumbaugh, J. and D. Rumbaugh. 2004. A Guide to Using Groundwater Vistas. Environmental Simulations, Inc.

State of Utah. 2006. Ground Water Monitoring Plan Guidance, Solid Waste Management Program.

U.S. EPA. 1996. Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures EPA/540/S-95/504. Office of Solid Waste and Emergency Response, Washington, D.C.

Zheng, C., and P. Wang, 1999. MT3DMS: A Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide.

5.0 APPENDIX I FLOW CALCULATIONS

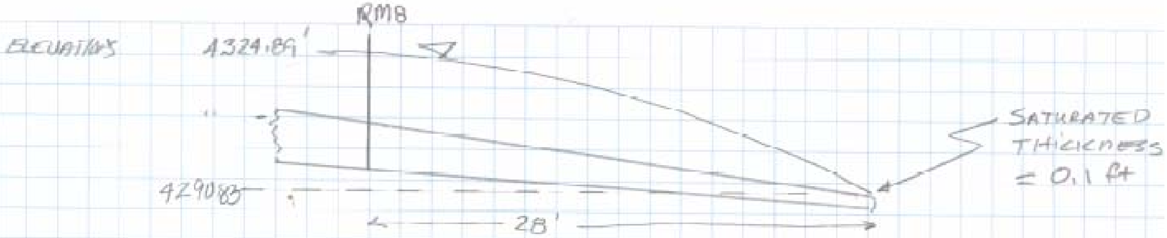
Gard water consultants, inc.

Project Shootaring

Date 4/23/08

Subject Calculation of Flow over North side of Perched zone

Page 1 of 1



1. Calculate gradient

$L = 28$ feet (roughly 1/2 distance from RM8 and RM-7

$H = 4324.89 - 4290.83 = 34.06$

$i = \frac{H}{L} = \frac{34.06}{28} = 1.22$ ft/ft

2. Calculate area of flow along North side of perched groundw

$L = 730$ ft Saturated thickness – assume 0.1 ft

$A = 730 * 0.1 = 73$ ft2

3 $K = 0.2$ ft/d

4 $Q = KiA = 0.2 * 1.22 * 73 = 17.8$ ft^3/d

Project Shootaring Canyon Mill

Date 4/23/08

Subject Calculate Flux through perching layer

Page 1 of 1

Gard water consultants, inc.

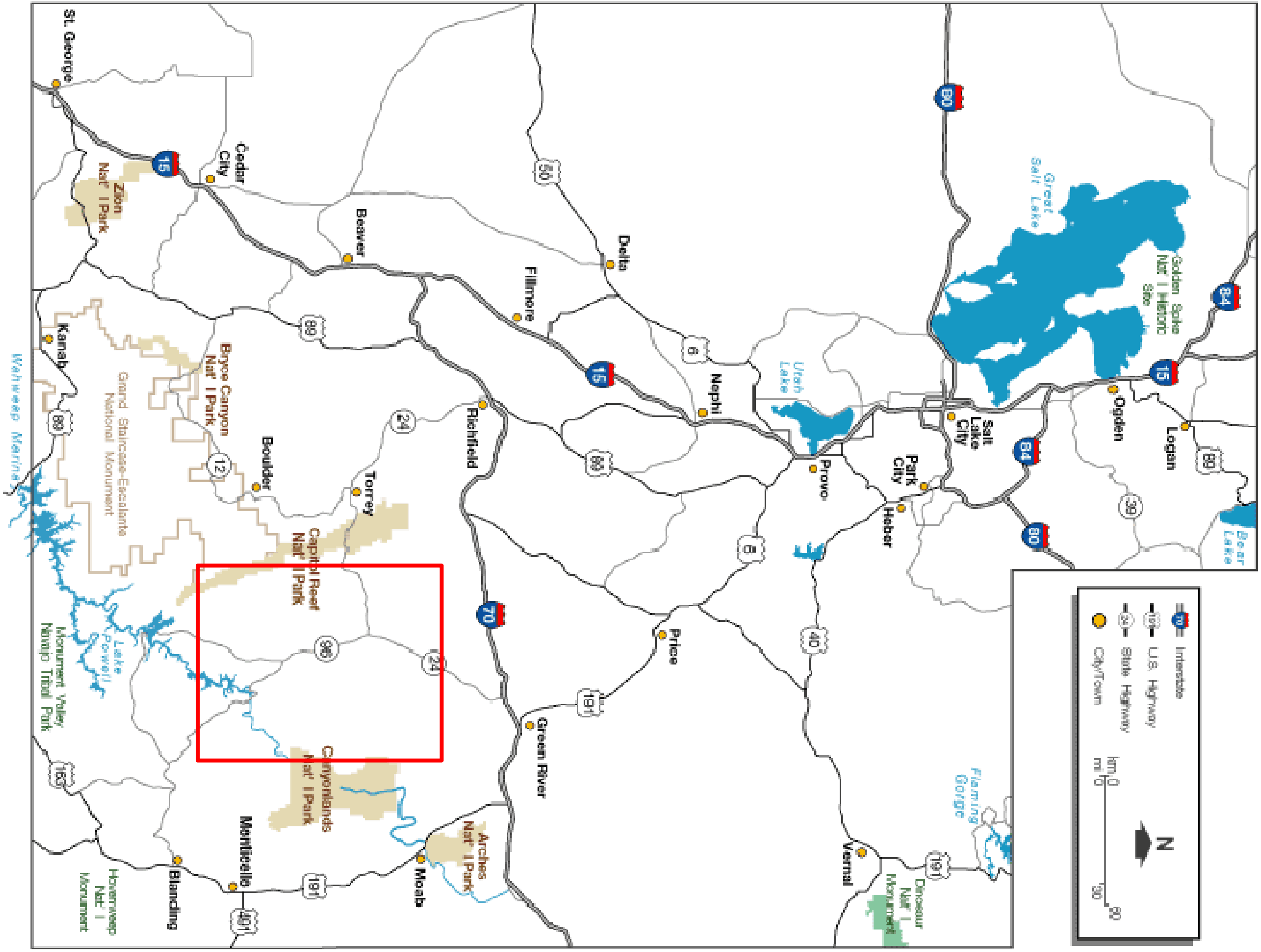
1. Assume aerial recharge $= 0.0002$ ft/d

2 AREA OF PERCHING SEDIMENTS 970,088 ft^2

$Q_r = (0.0002)(980,088) = 196\ ft^3/d$

if $18\ ft^3/d$ flow over north side then the remainder flows through sediments $= 178\ ft^3/d$

FIGURES



Gard water consultants, inc.

Figure 1
General Site Location Map

Date: Feb 2008

Project: Shootaring

File:C:\projects\shootaring\shootaring.ppt

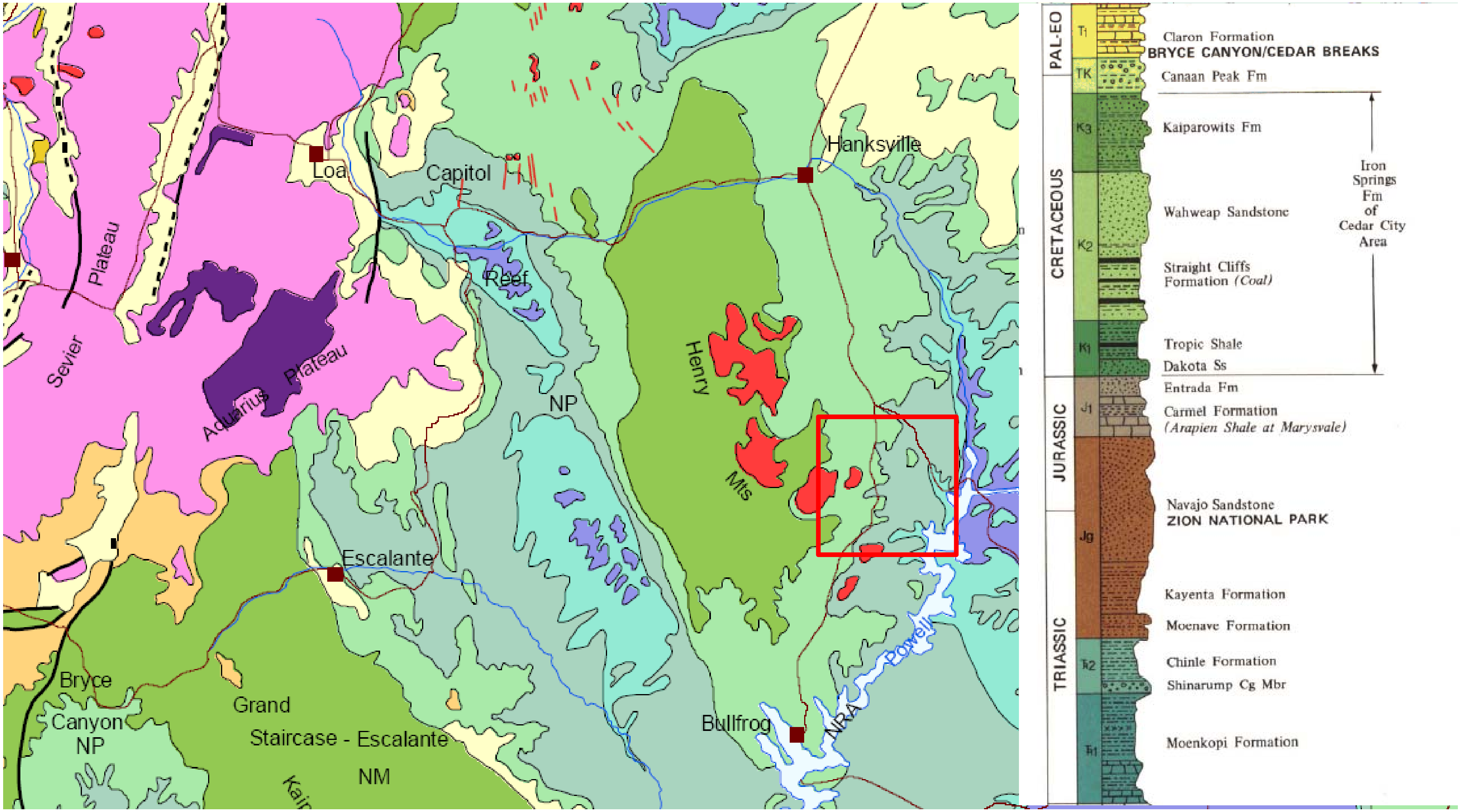
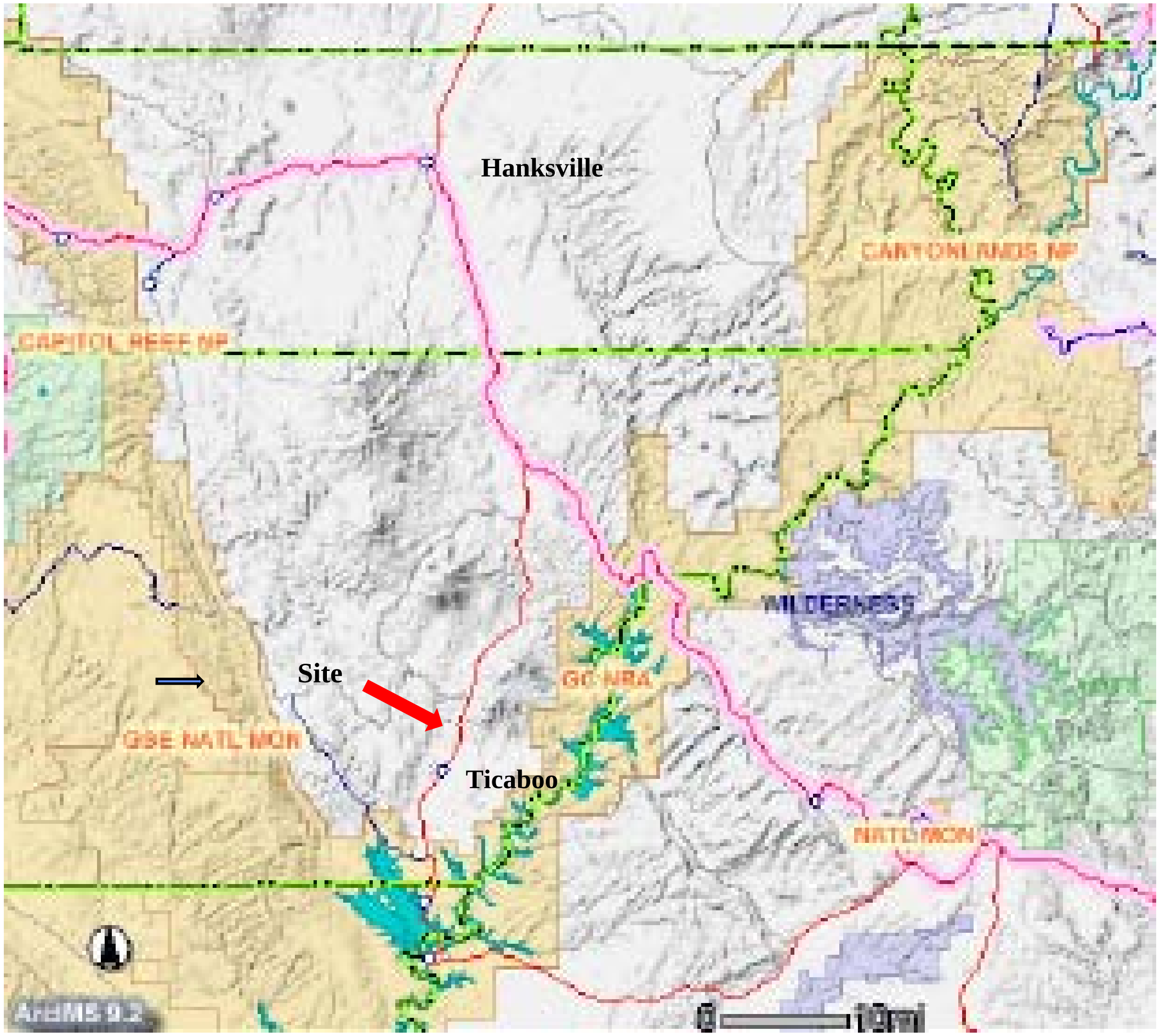


Figure 2
Local Site Location Geologic Map

Date: Feb 2008

Project: Shootaring

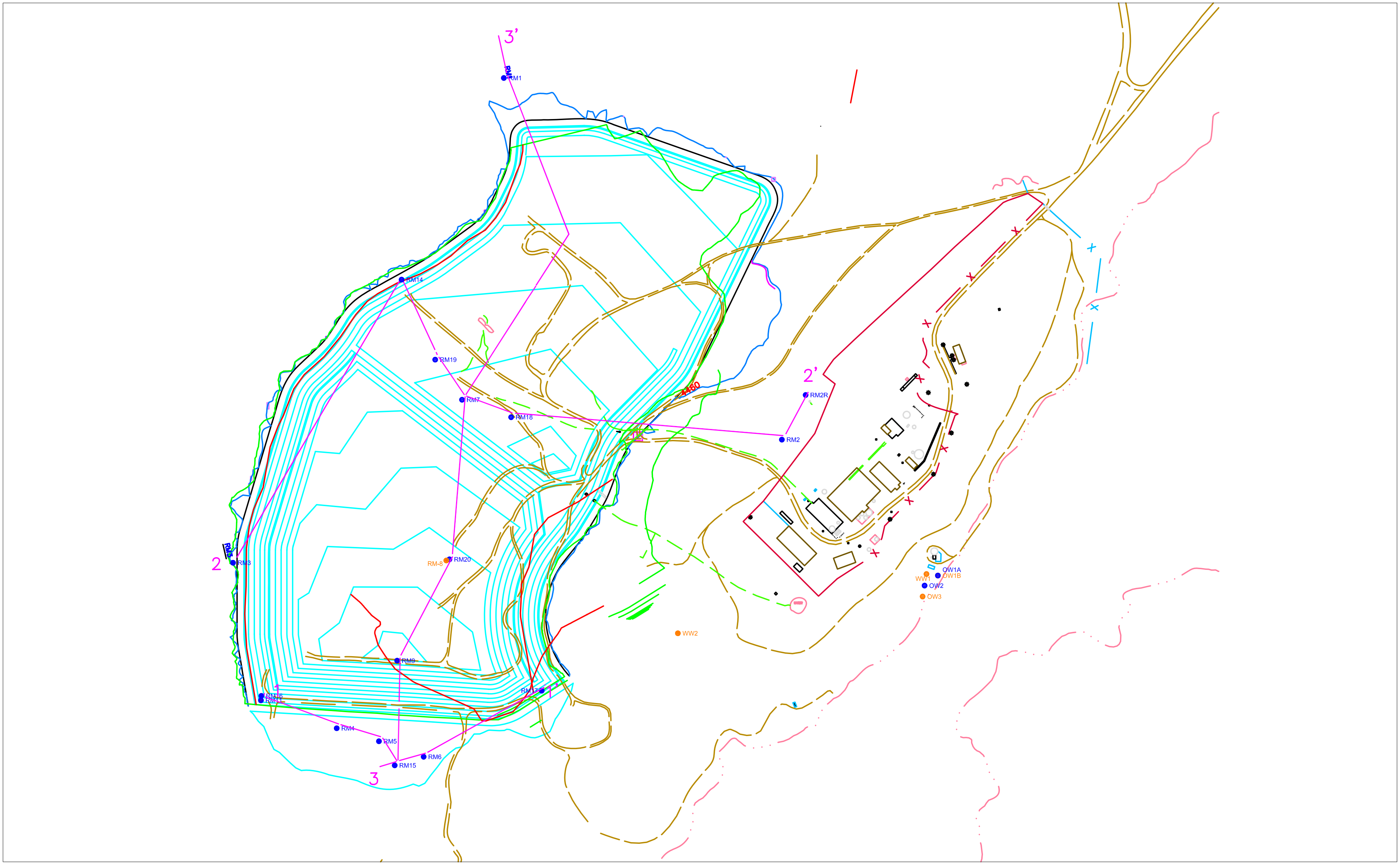
File: C:\projects\shootaring\shootaring.ppt



Gard water consultants, inc.

Figure 3
Site Location Map

Date:	Feb 2008
Project:	Shootaring
File:	C:\projects\shootaring\shootaring.ppt



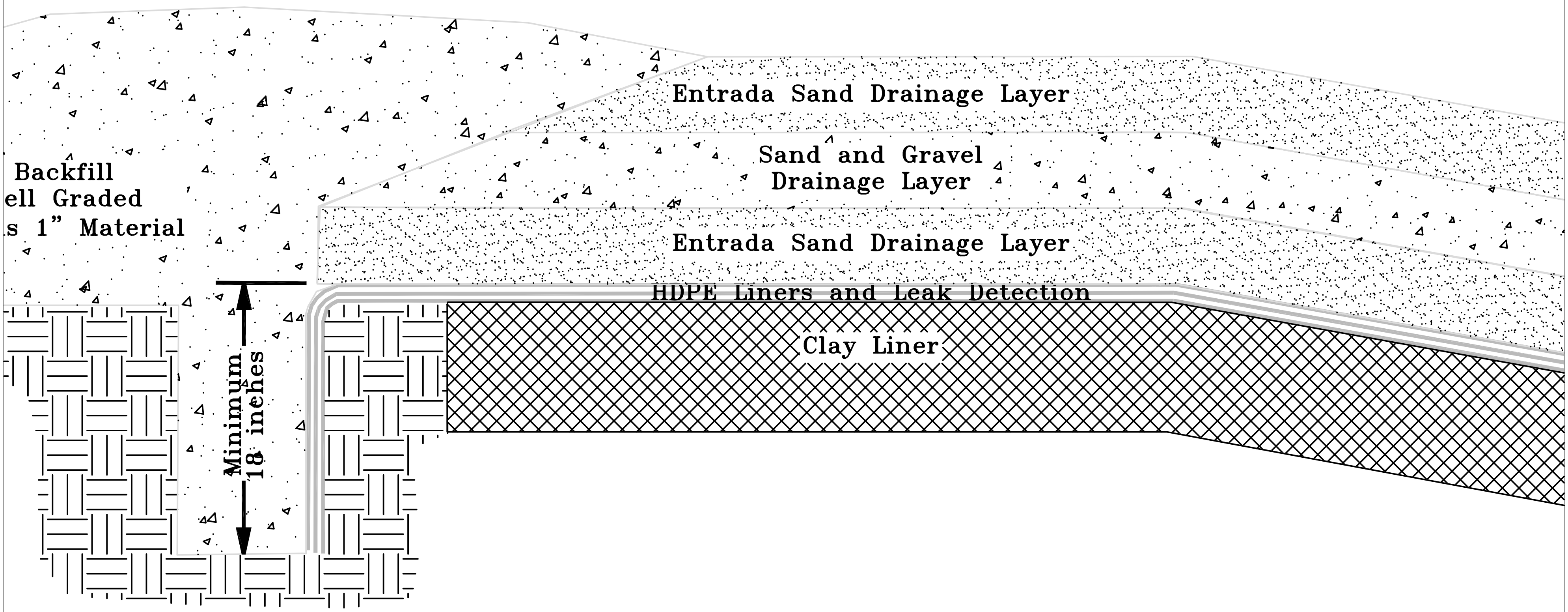
Gard water consultants, inc.

Figure 4
Monitoring Well and Cross-Section Location Map

Date April 2008

Project Shootaring Mill

FIle C:\Projects\Shootaring\Acad\new_site.dwg



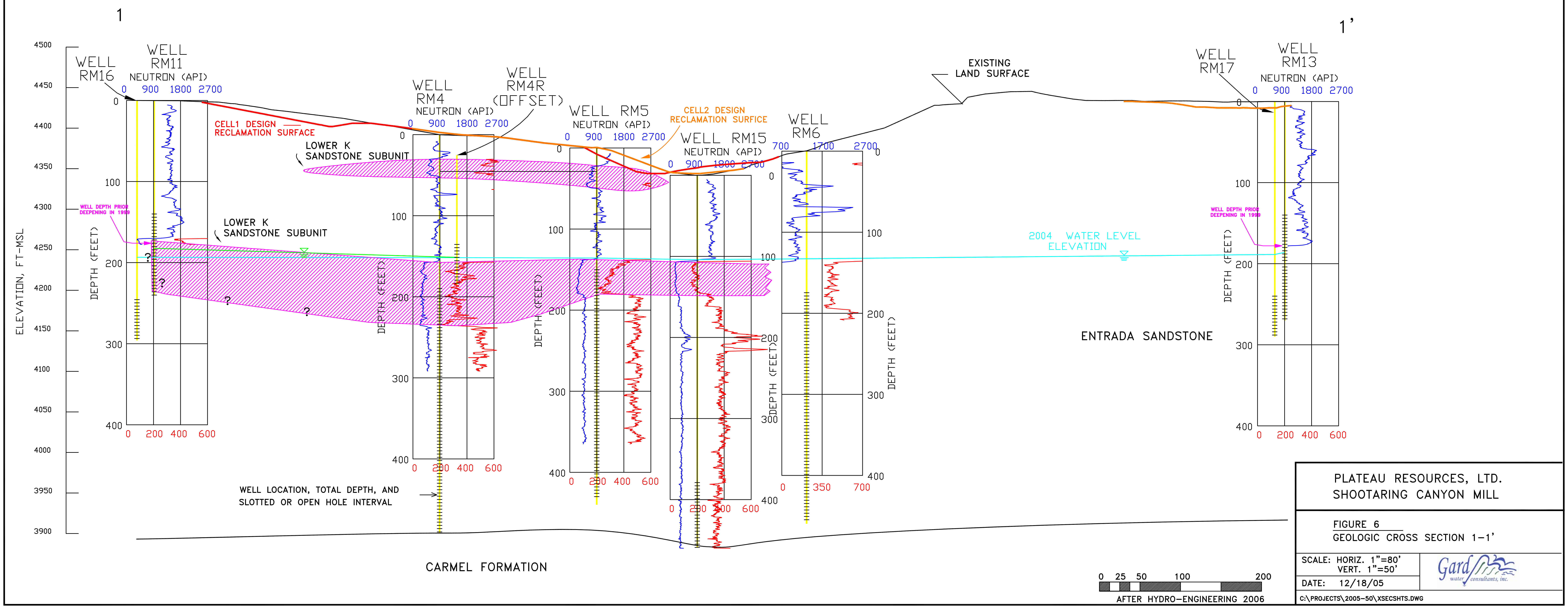
Gard water consultants, inc.

FIGURE 5
TAILINGS POND LINER DETAIL

Date
April 2008

Project
Shootaring Mill

FIle:C:\projects\shootaring\acad
\pond_liner.dwg



PLATEAU RESOURCES, LTD.
SHOOTARING CANYON MILL

FIGURE 6
GEOLOGIC CROSS SECTION 1-1'

SCALE: HORIZ. 1"=80'
VERT. 1"=50'

DATE: 12/18/05

Gard water consultants, inc.

C:\PROJECTS\2005-50\XSECSHTS.DWG

PLATEAU RESOURCES, LTD.
SHOOTARING CANYON MILL

FIGURE 7
GEOLOGIC CROSS SECTION 2-2'

SCALE: HORIZ. 1"=160'
VERT. 1"=80'
DATE: 12/18/05

Gard water consultants, inc.

C:\PROJECTS\2005-50\XSECSHTS.DWG

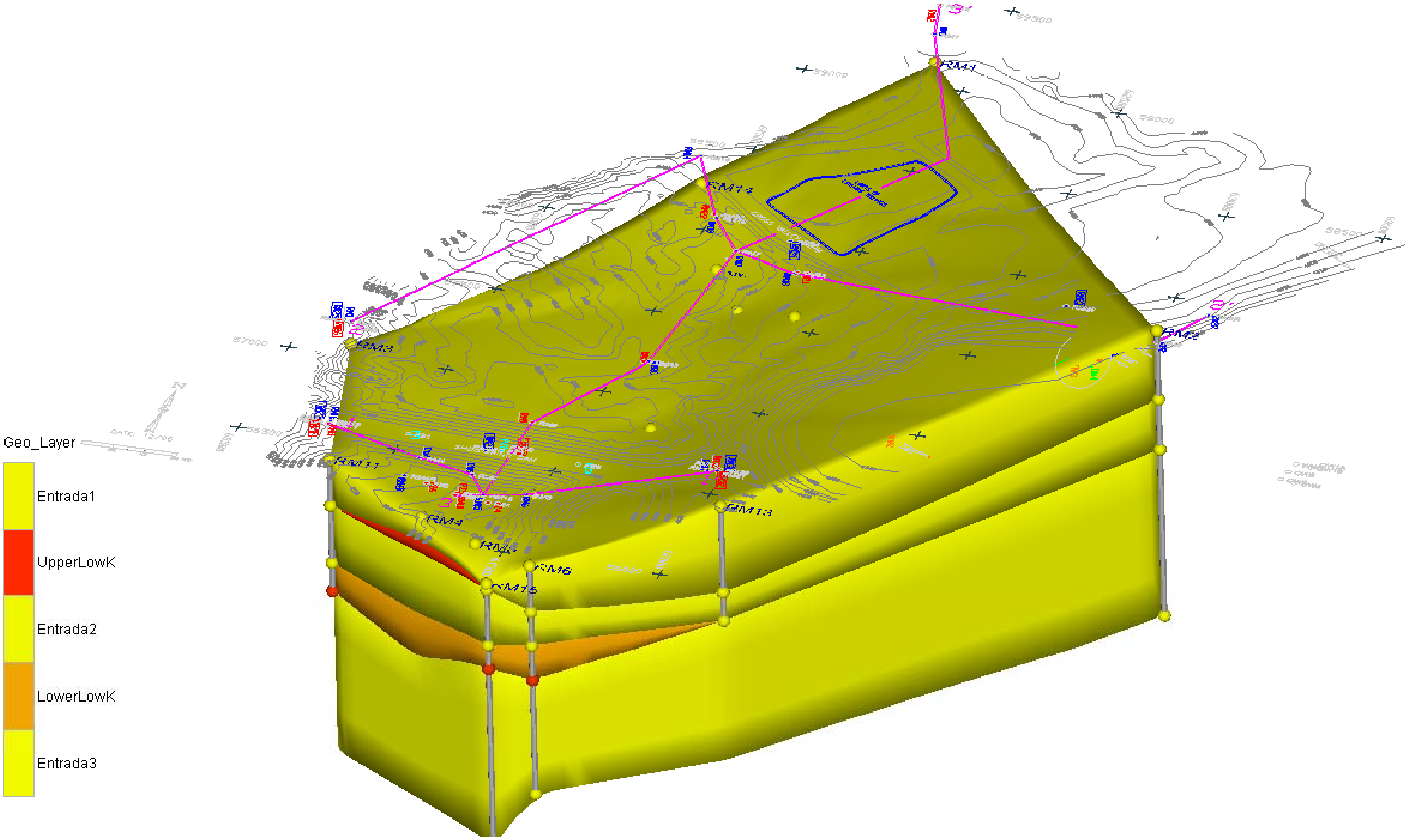
PLATEAU RESOURCES, LTD.
SHOOTARING CANYON MILL

FIGURE 8.
GEOLOGIC CROSS SECTION 3-3'

SCALE: HORIZ. 1"=160'
VERT. 1"=80'
DATE: 12/18/05

Gard water consultants, inc.

C:\PROJECTS\2005-50\XSECSHTS.DWG



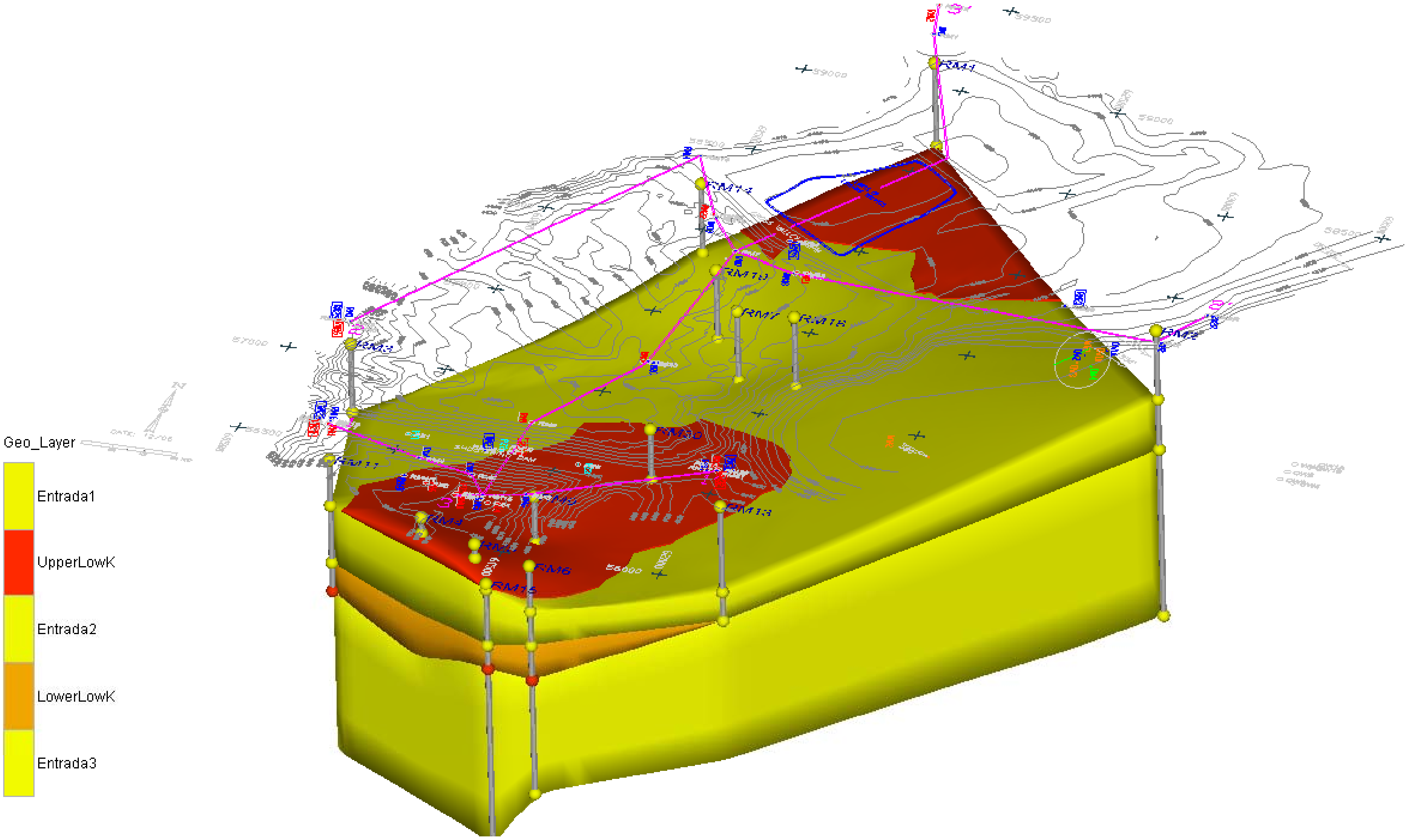
Gard water consultants, inc.

Figure 9
EVS Model Top of Model Showing Uppermost Entrada

Date: Feb 2008

Project: Shootaring

File:C:\projects\shootaring\shootaring.ppt



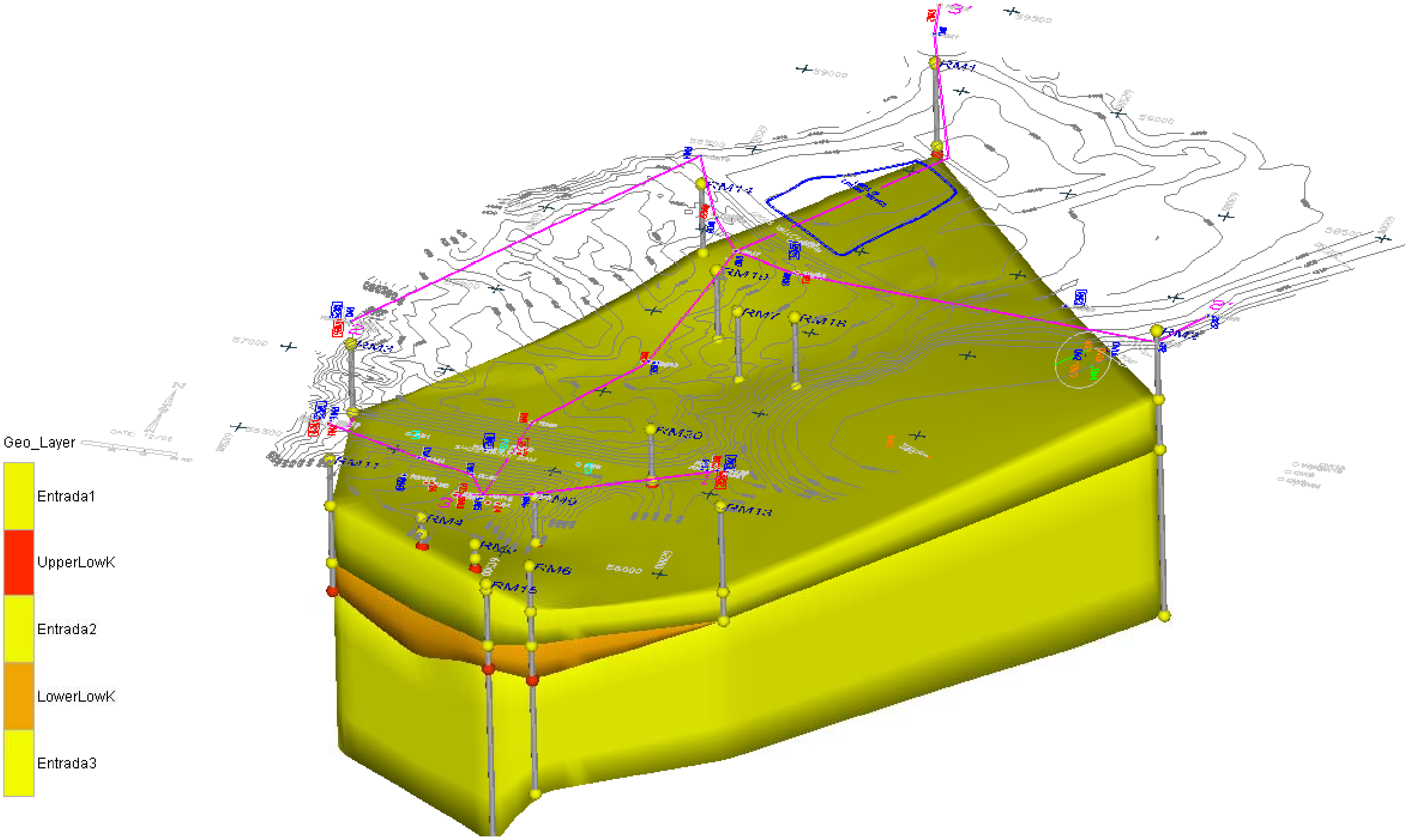
Gard water consultants, inc.

Figure 10
EVS Model - Uppermost Low Conductivity Zone

Date: Feb 2008

Project: Shootaring

File:C:\projects\shootaring\shootaring.ppt



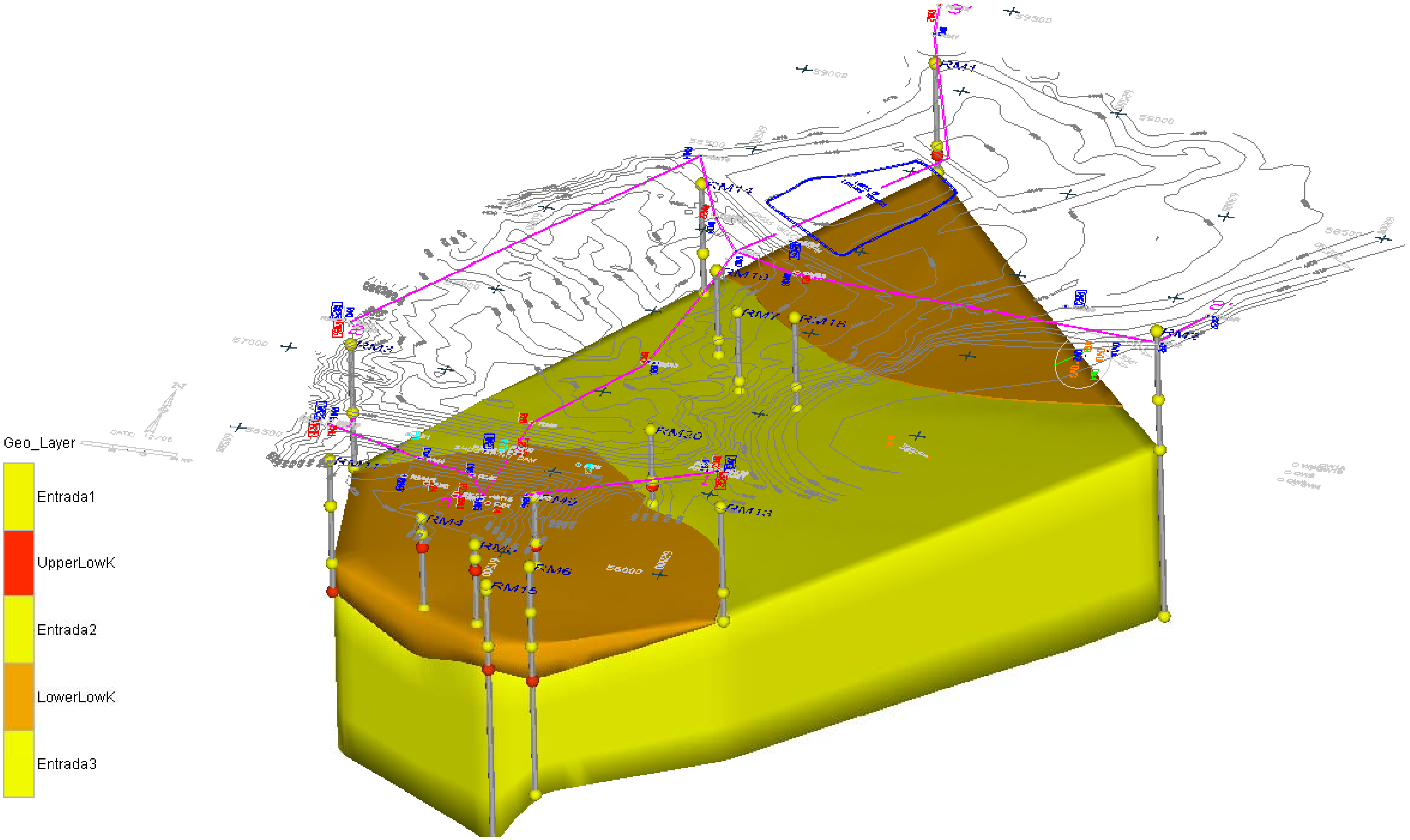
Gard water consultants, inc.

Figure11
EVS Model – Uppermost Low Conductivity Zone Removed

Date: Feb 2008

Project: Shootaring

File:C:\projects\shootaring\shootaring.ppt



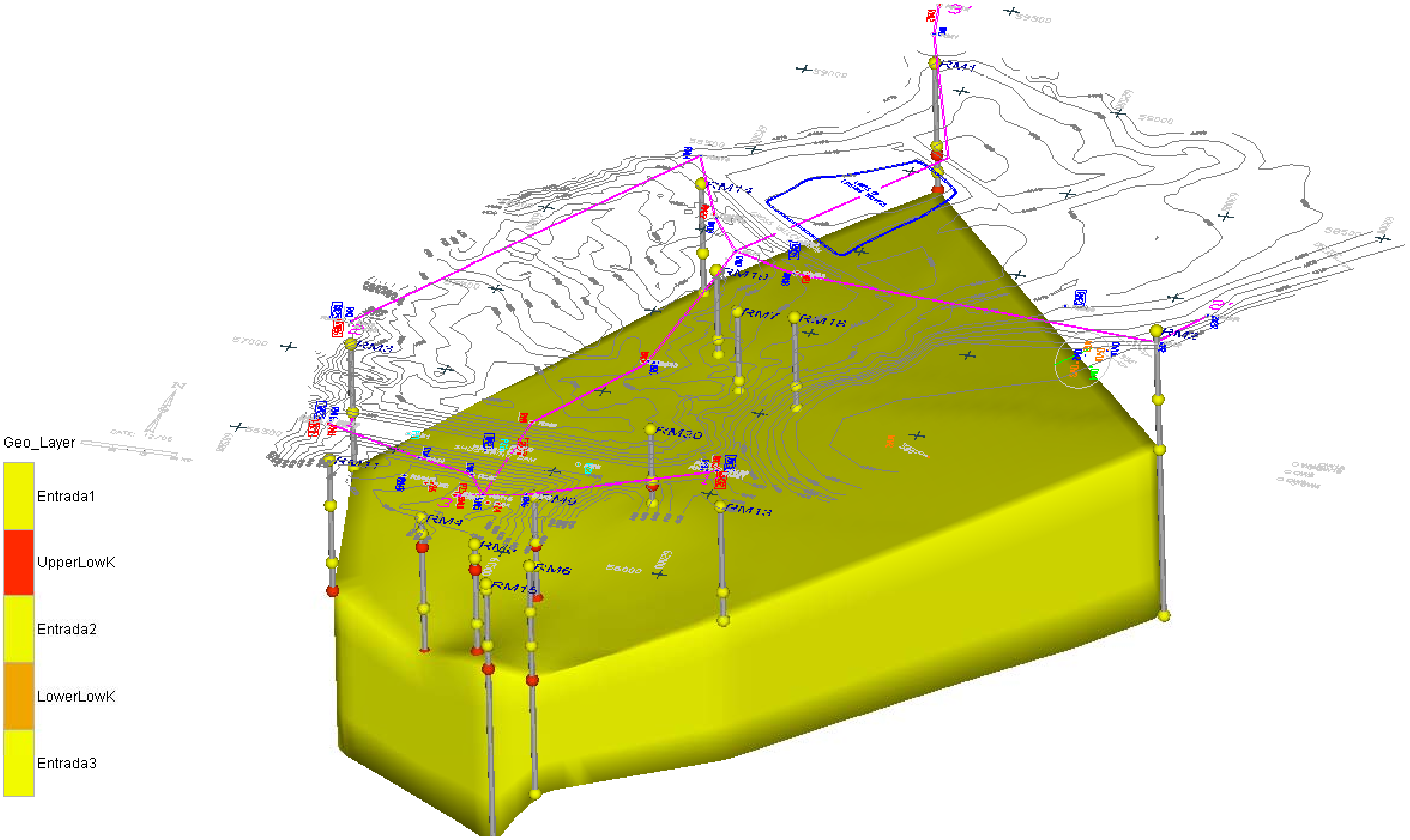
Gard water consultants, inc.

Figure 12
EVS Model – Deep Lower Conductivity Zone

Date: Feb 2008

Project: Shootaring

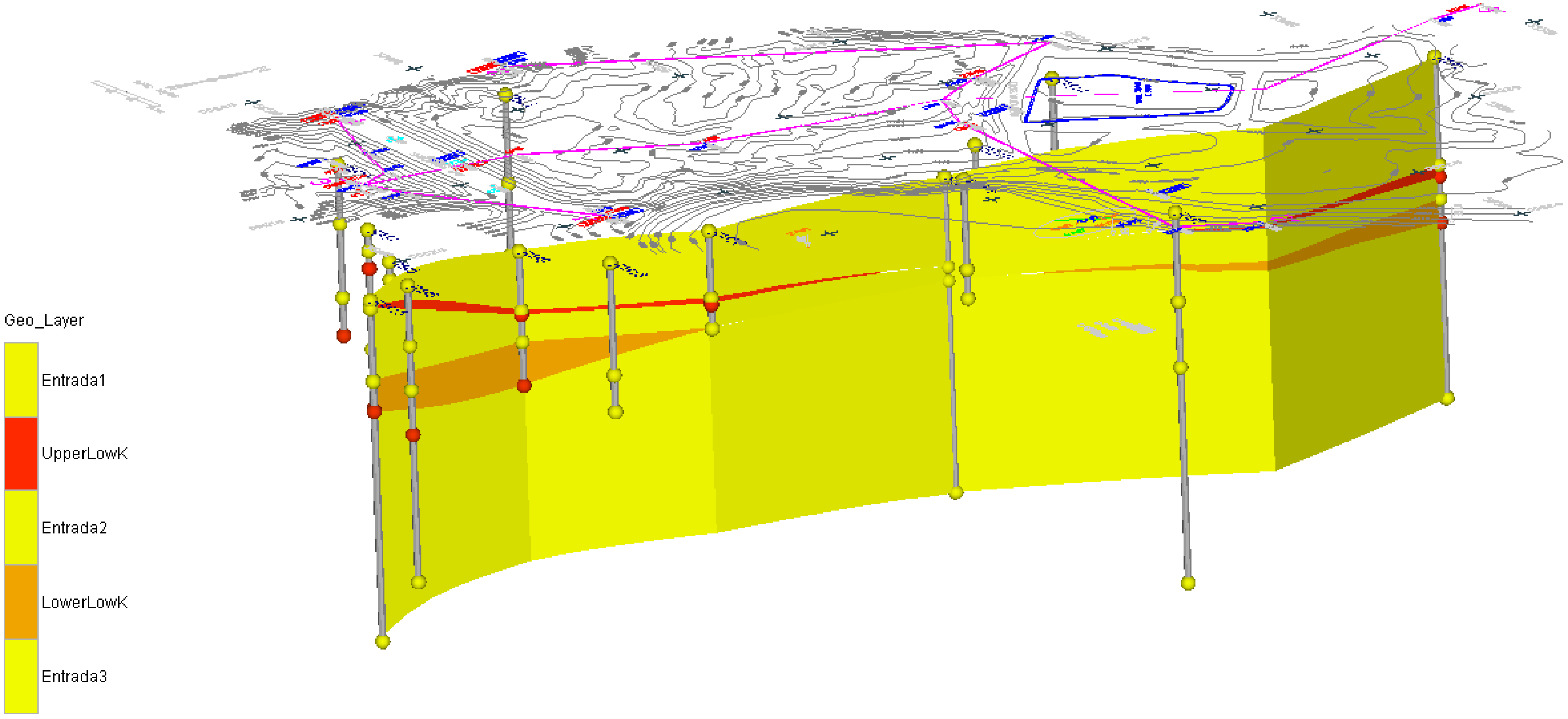
File:C:\projects\shootaring\shootaring.ppt



Gard water consultants, inc.

Figure 13
EVS Model- Deep Lower Conductivity Zone removed

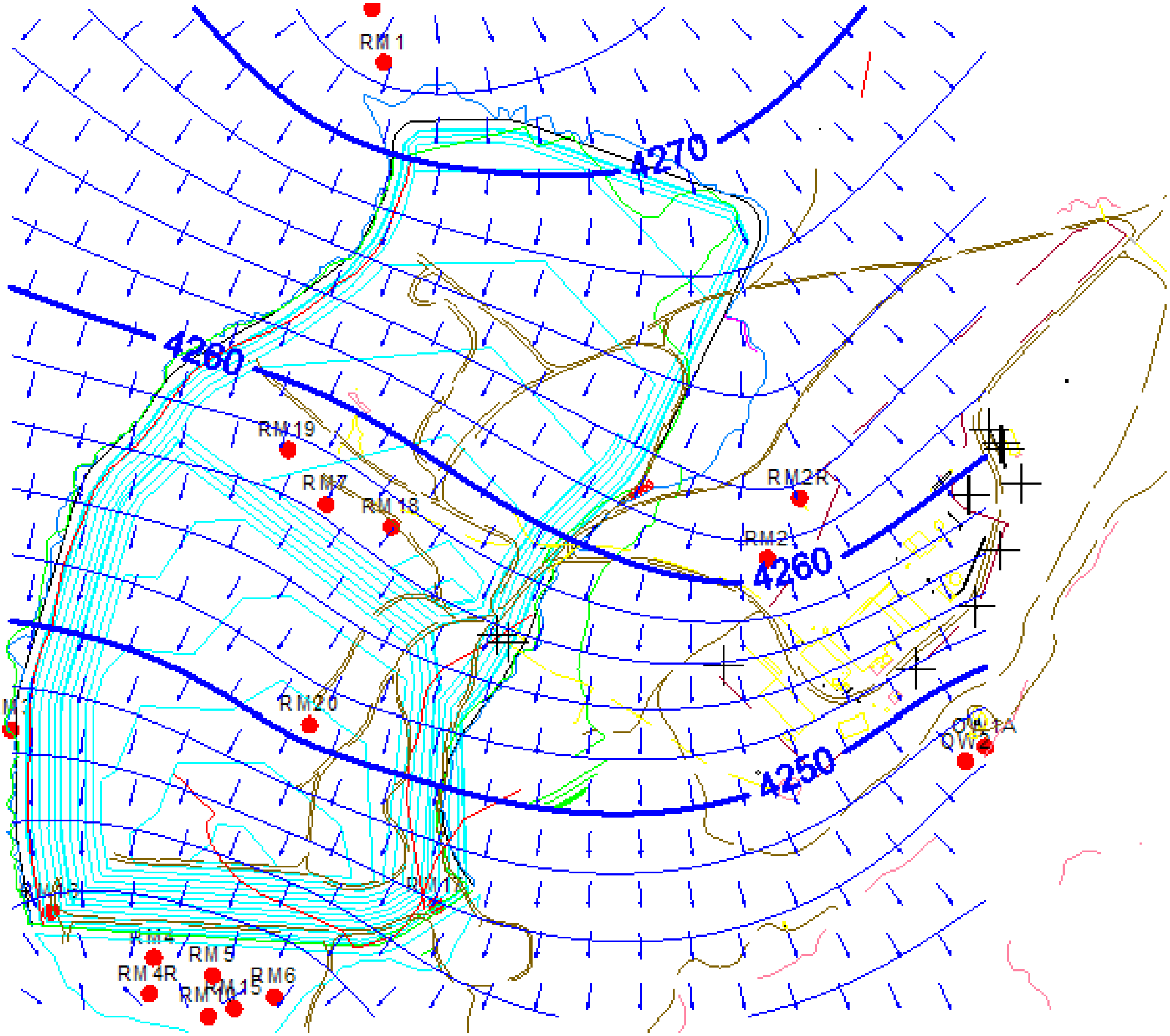
Date: Feb 2008
Project: Shootaring
File:C:\projects\shootaring\shootaring.ppt



Gard water consultants, inc.

Figure 14
North – South Cross Section of Conceptual Model

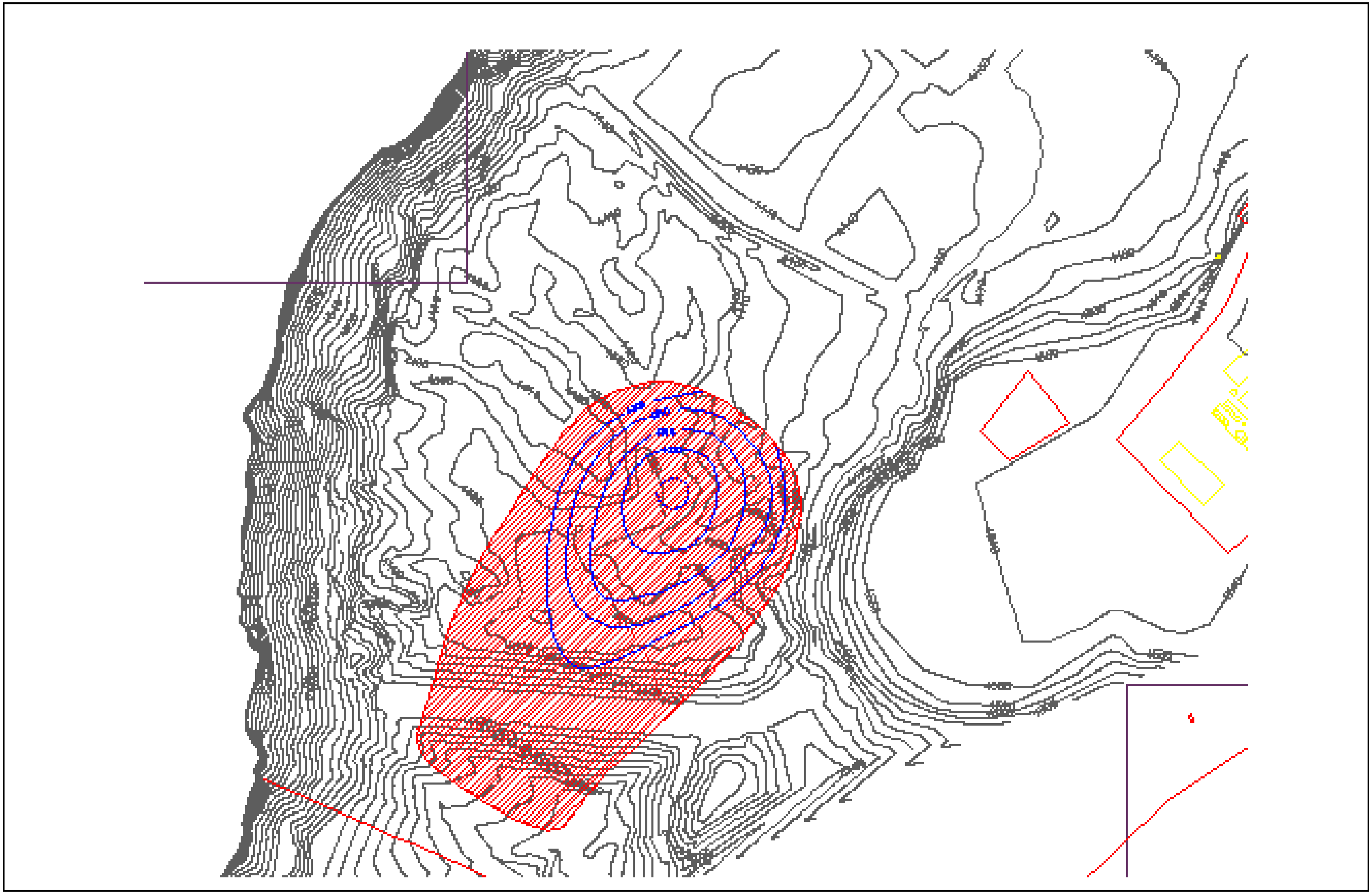
Date: Feb 2008
Project: Shootaring
File: C:\projects\shootaring\shootaring.ppt



Gard water consultants, inc.

Figure 15
Entrada 2003 Groundwater Elevations with Flow Arrows

Date:	Feb 2008
Project:	Shootaring
File:	C:\projects\shootaring\shootaring.ppt



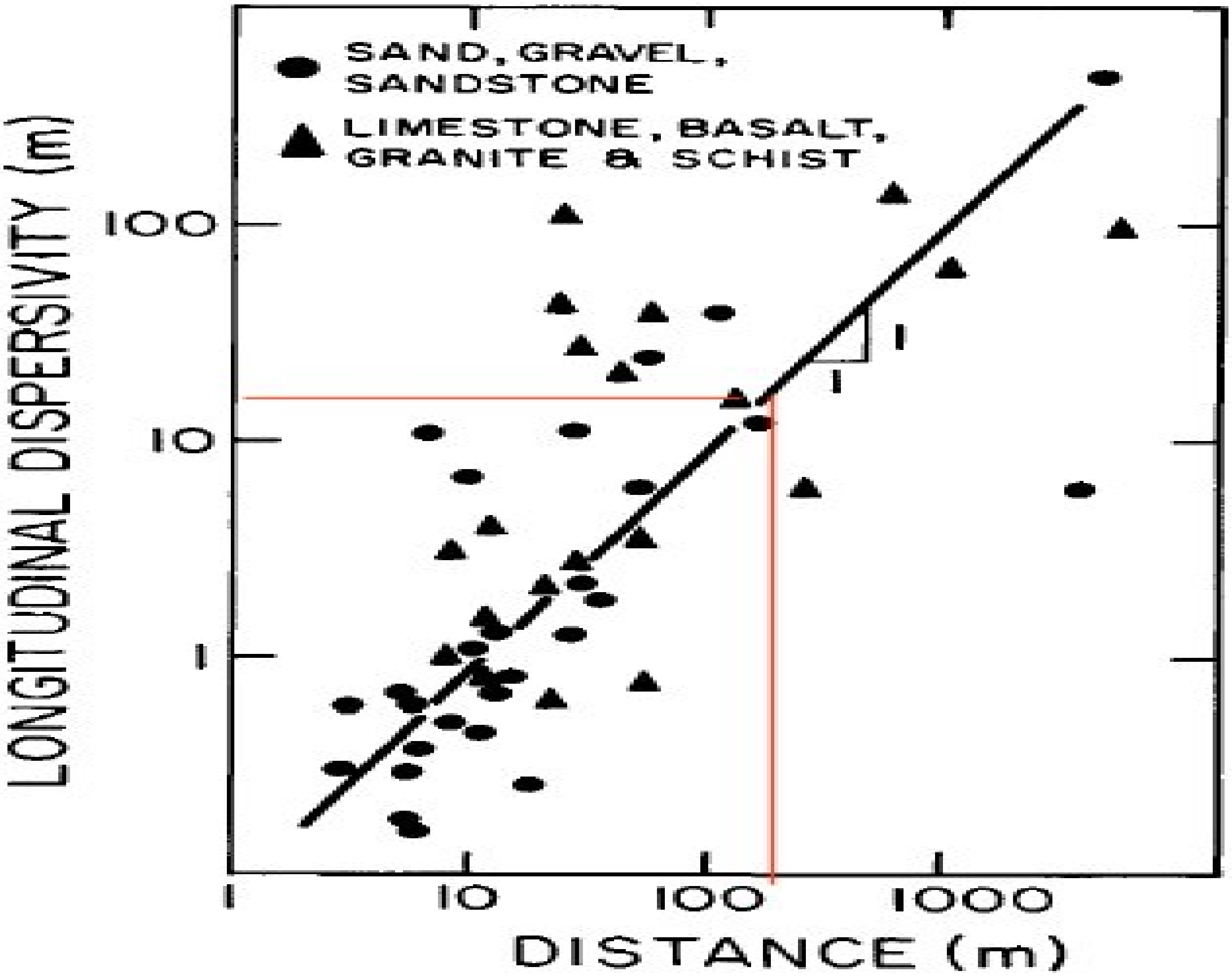
Gard water consultants, inc.

FIGURE 16
Perched Groundwater Table

Date: Feb 2008

Project: Shootaring

File: C:\projects\shootaring\shootaring.ppt



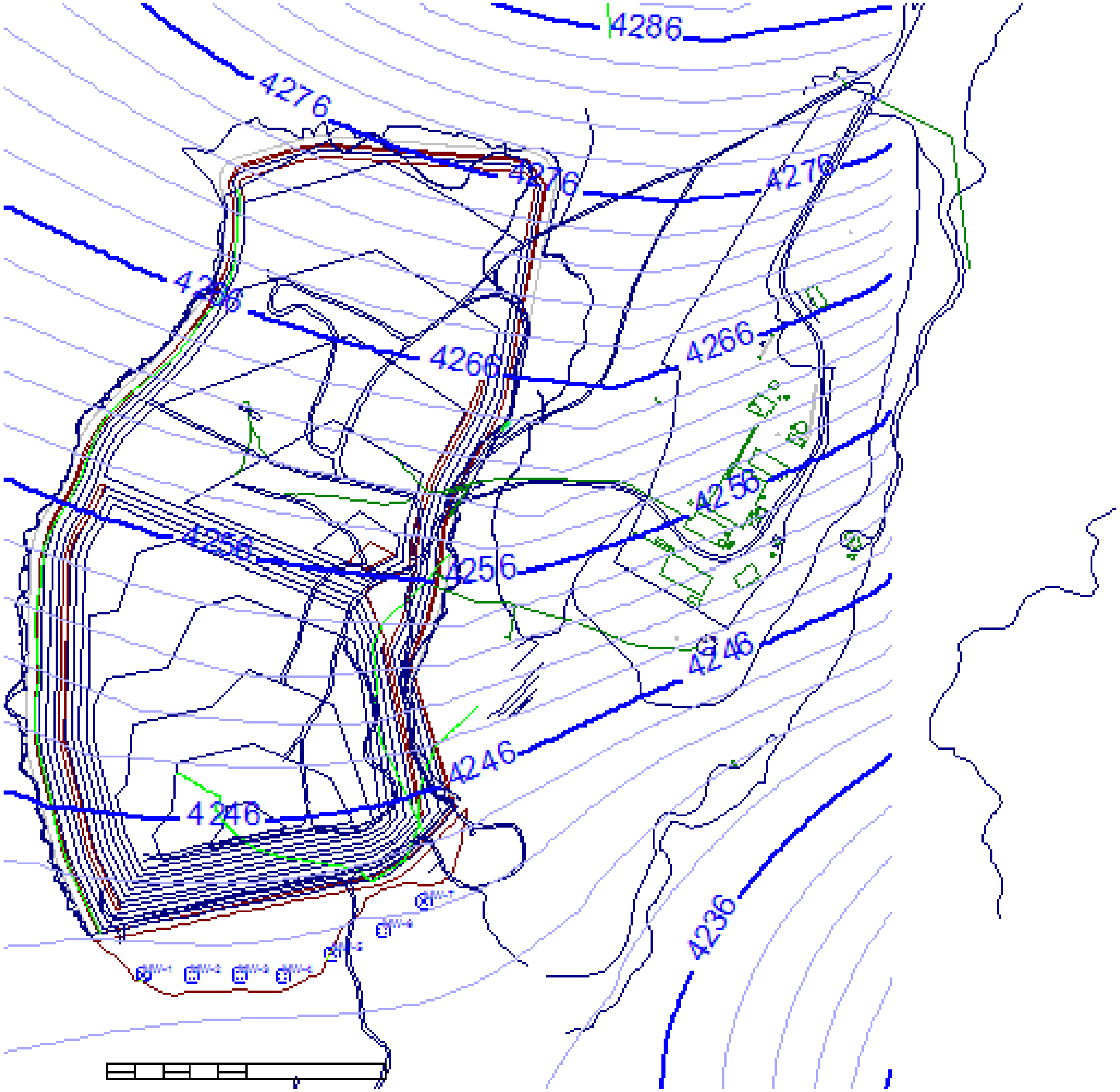
Gard water consultants, inc.

Figure 17
Dispersion Estimation

Date: Feb 2008

Project: Shootaring

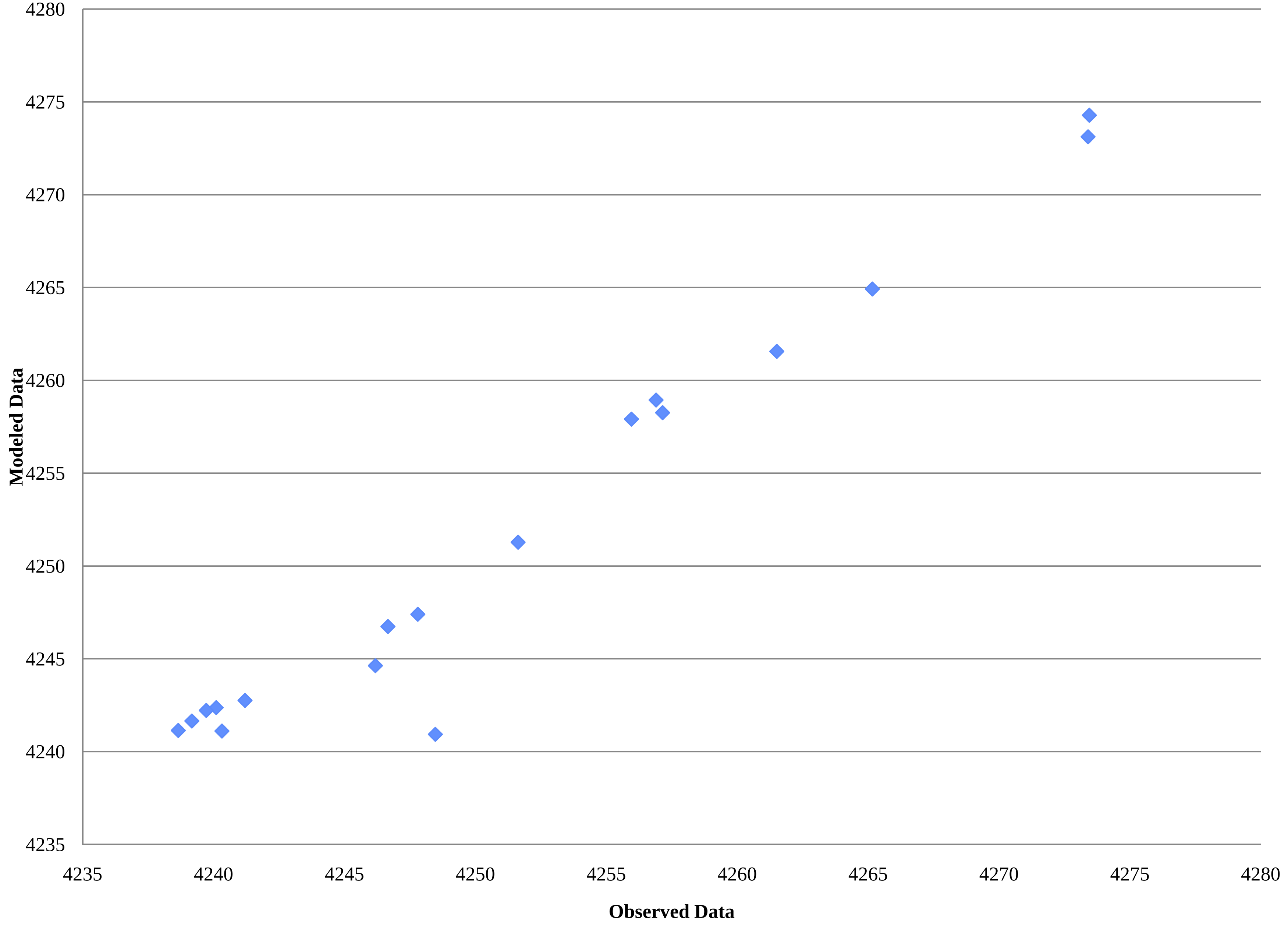
File: C:\projects\shootaring\shootaring.ppt



Gard water consultants, inc.

Figure 18
Modeled Groundwater Elevations

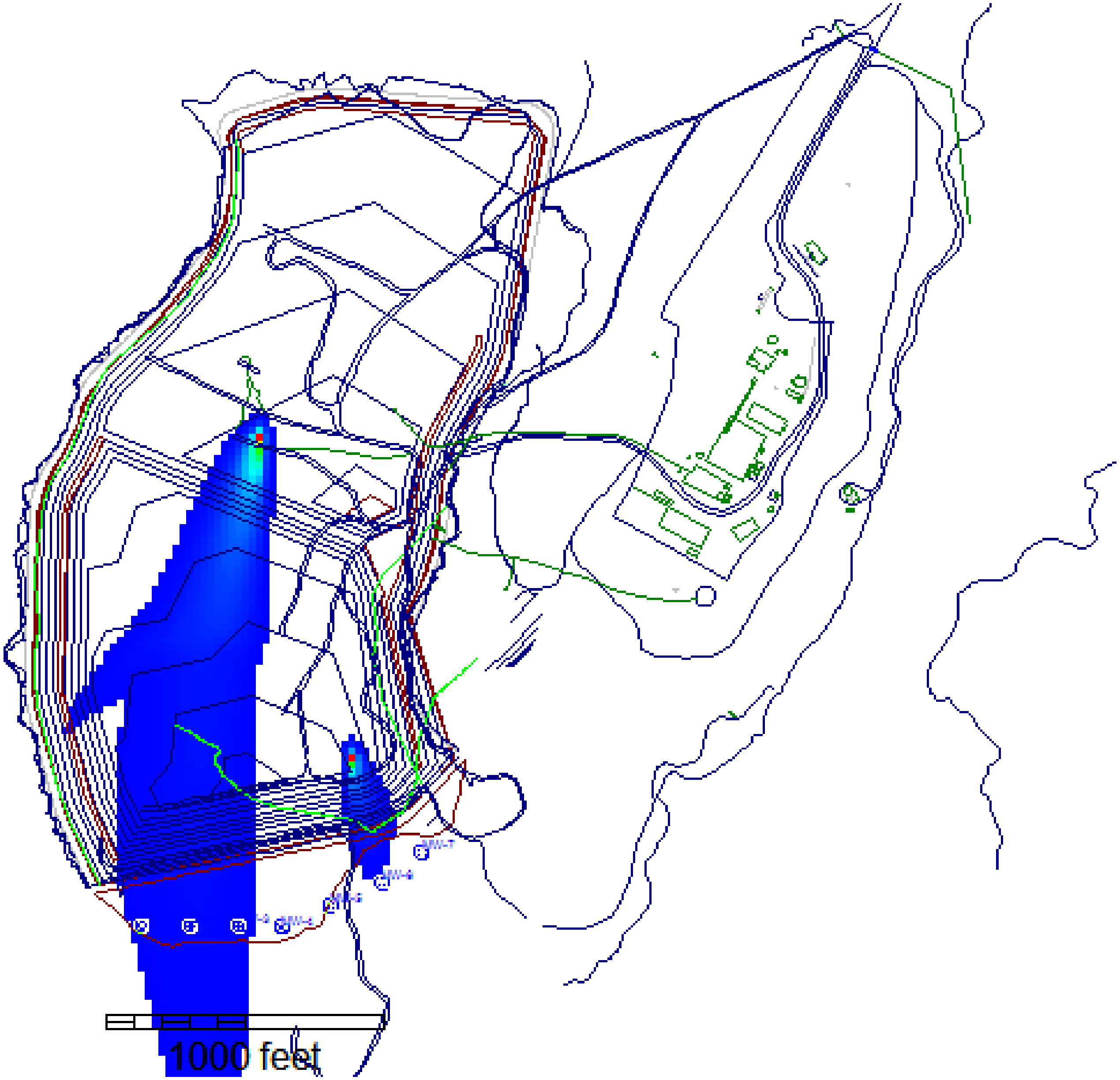
Date:	Feb 2008
Project:	Shootaring
File:	C:\projects\shootaring\shootaring.ppt



Gard water consultants, inc.

Figure 19
Modeled Versus Measured Heads

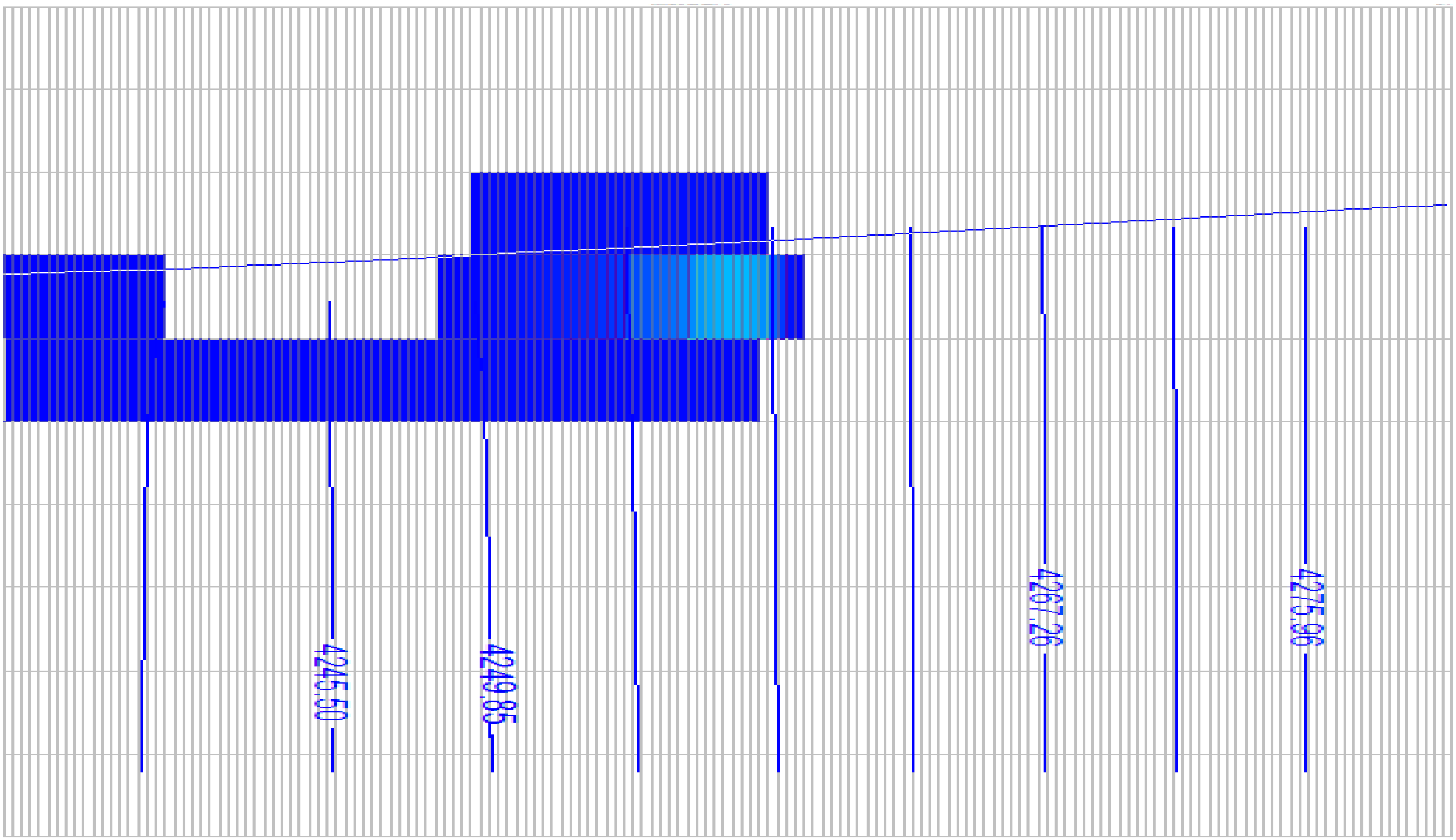
Date:	Feb 2008
Project:	Shootaring
File:	C:\projects\shootaring\shootaring.ppt



Gard water consultants, inc.

Figure 20
Stochastic Modeling Results
(minimum concentration = 100 ppm)

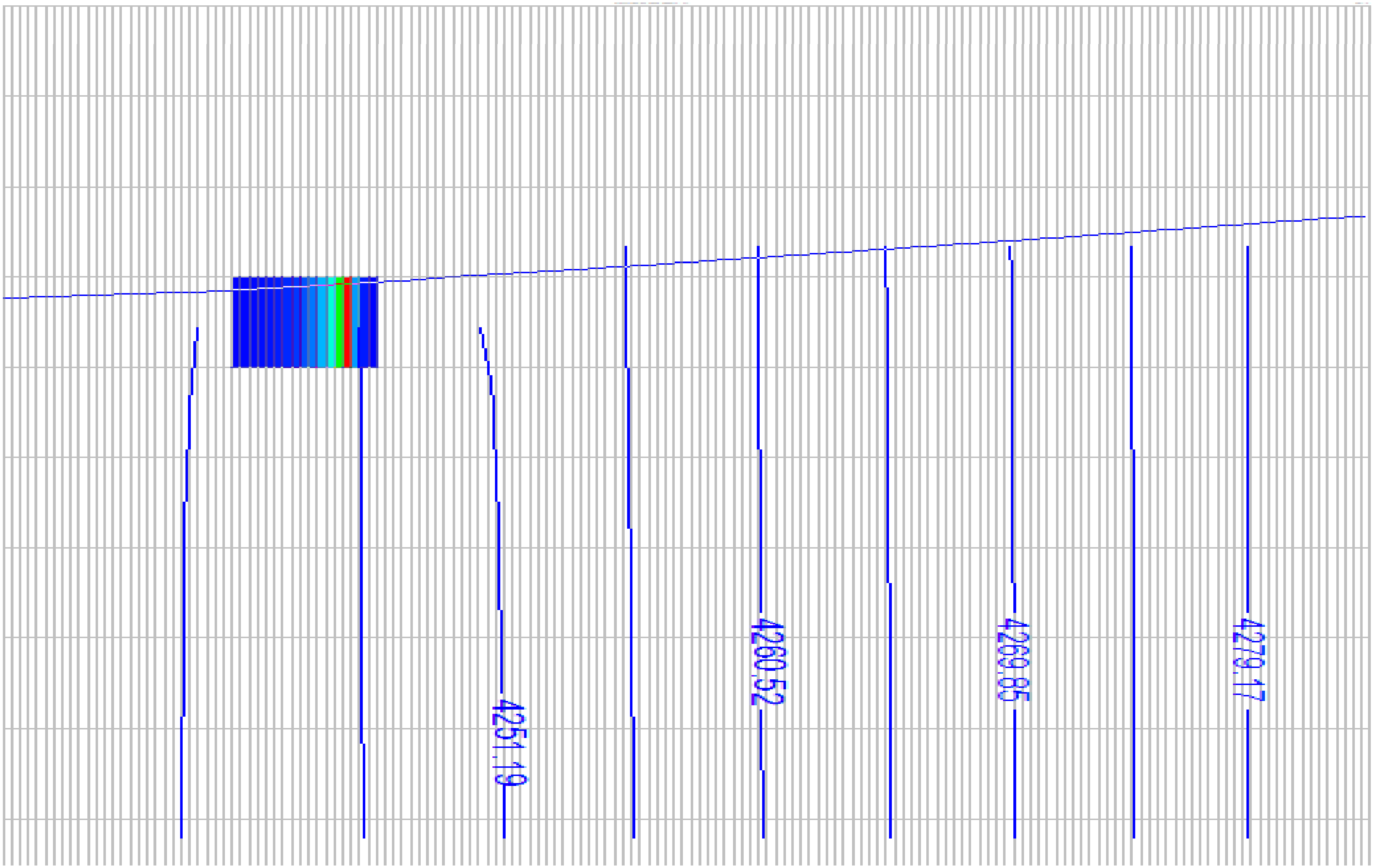
Date:	Feb 2008
Project:	Shootaring
File:	C:\projects\shootaring\shootaring.ppt



Gard water consultants, inc.

Figure 21
Cross Sectional View of Modeled Plume
Column 37

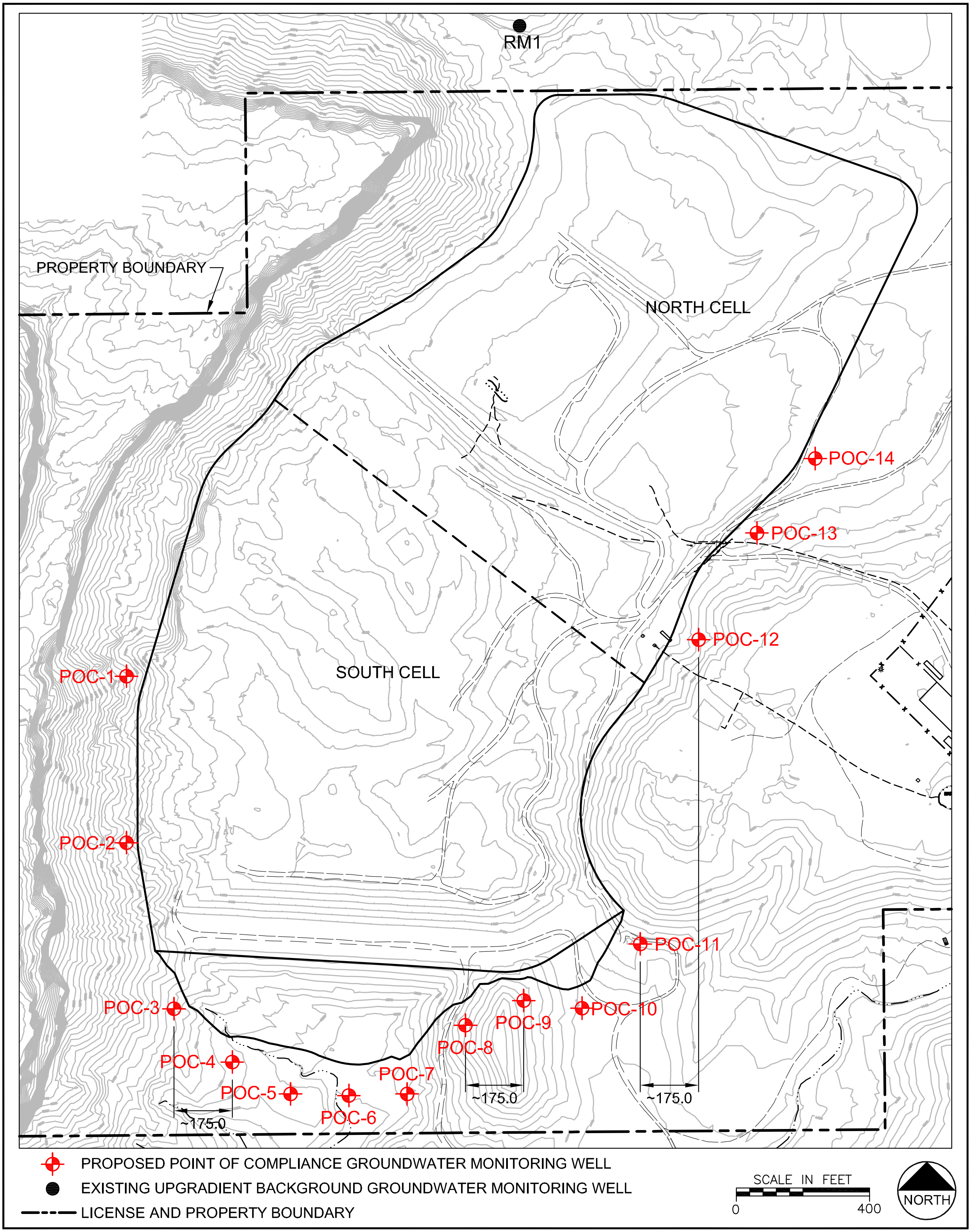
Date:	Feb 2008
Project:	Shootaring
File:	C:\projects\shootaring\shootaring.ppt



Gard water consultants, inc.

Figure 22
Cross Sectional View of Modeled Plume
Column 51

Date: Feb 2008
Project: Shootaring
File:C:\projects\shootaring\shootaring.ppt

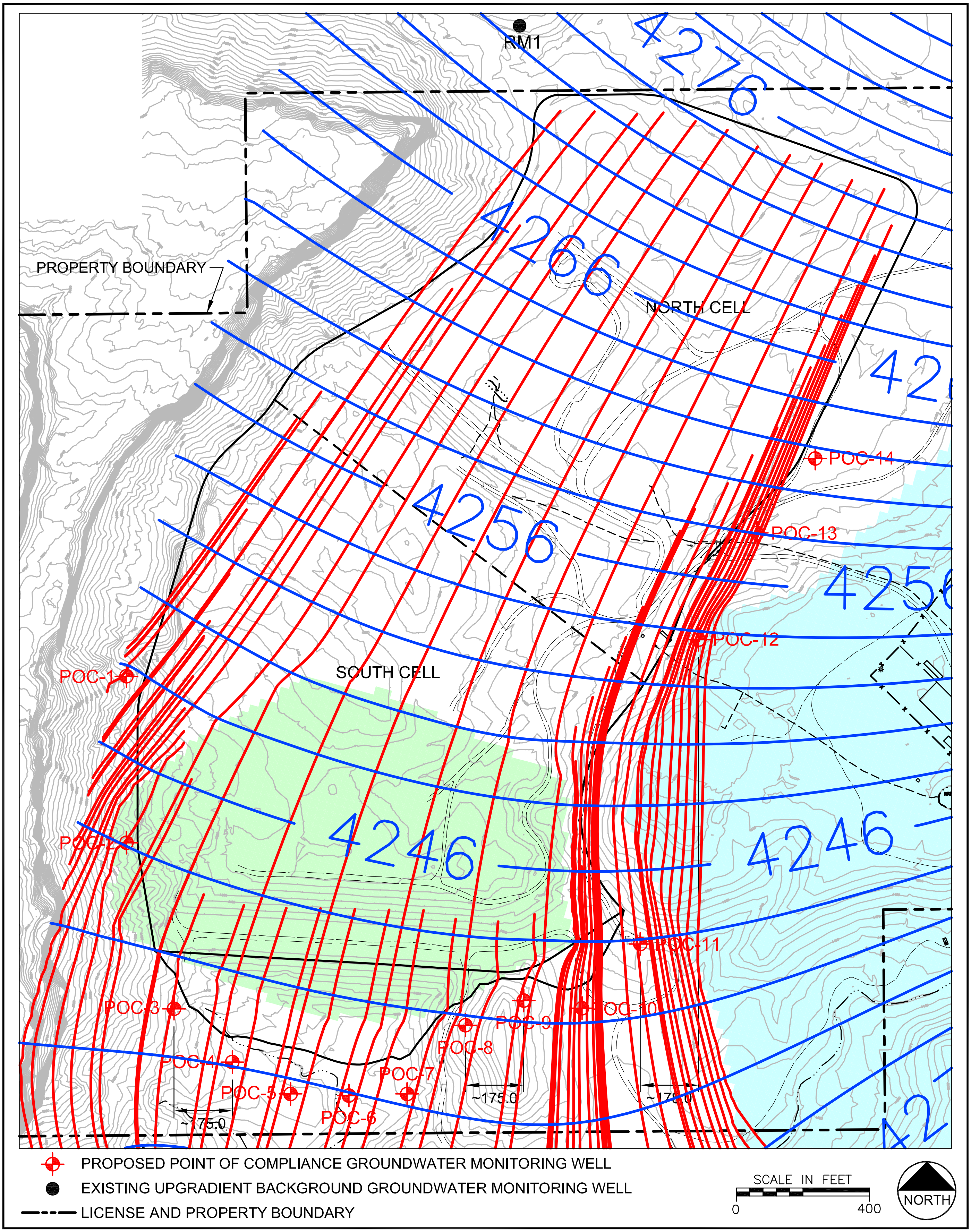


E:\181692\general\mon-pro-01.dwg SAVED: 7/10/08 PRINTED: 7/10/08 BY: TOM.BOEHLER

Project No. 181692

June 2008

Figure 23
Approximate Location of Proposed Monitoring (POC) Wells



E:\181692\general\mon-pro-01.dwg SAVED: 7/10/08 PRINTED: 7/10/08 BY: TOM.BOEHLER

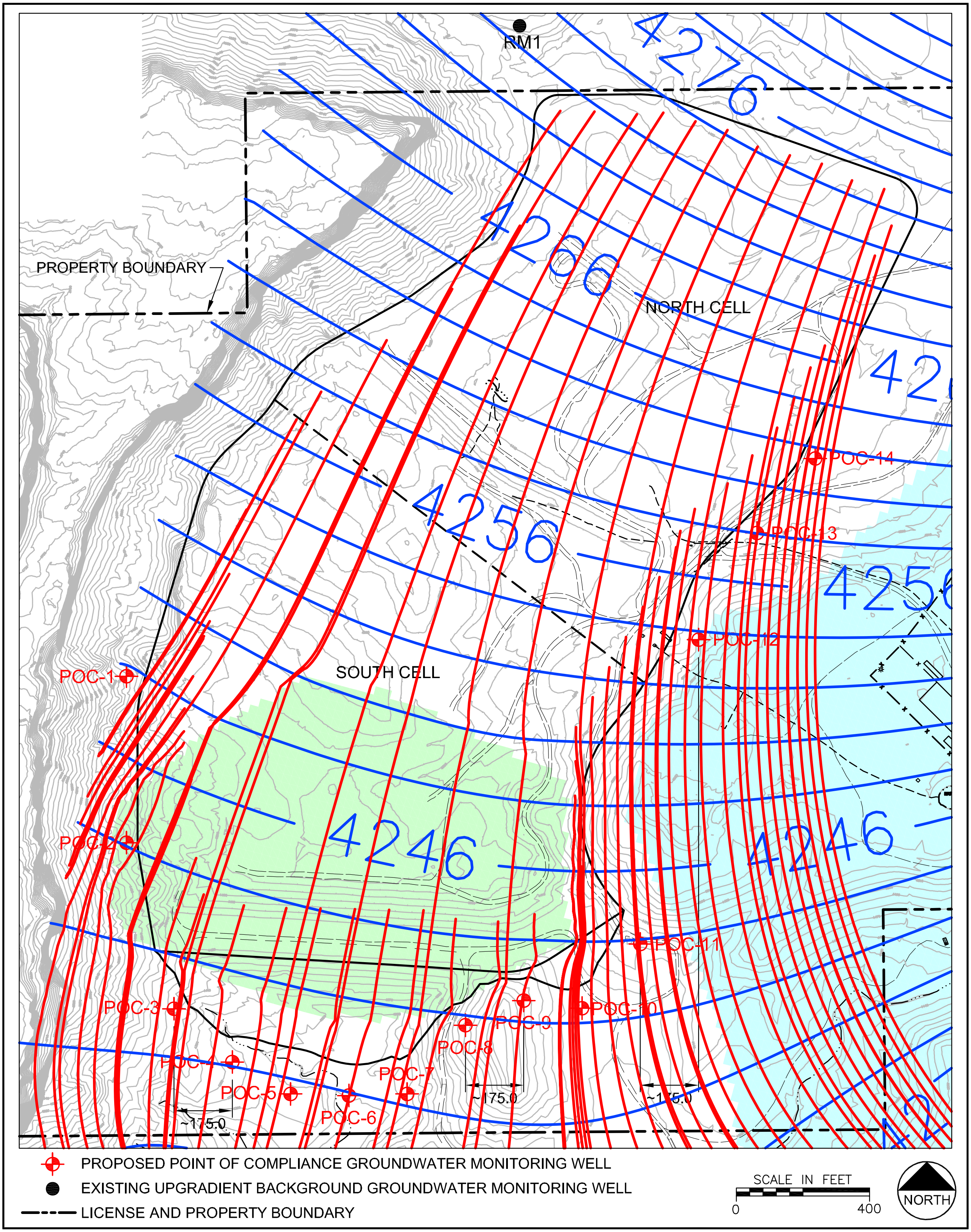
Project No. 181692

June 2008

Figure 24

Modpath Analysis with 100 Year Annotations
Conductivity of Eastern Block = 0.08 feet per day

E:\181692\general\mon-pro-01.dwg SAVED: 7/10/08 PRINTED: 7/10/08 BY: TOM.BOEHLER



Project No. 181692

June 2008

Figure 25

Modpath Analysis with 100 Year Annotations

Conductivity of Eastern Block = 0.16 feet per day