GROUNDWATER CONTAMINANT MIGRATION MODELING FOR THE ST. LOUIS AIRPORT SITE

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for

U. S. Department of Energy
Formerly Utilized Sites Remedial Action Program

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1.0 INTRODUCTION

Groundwater at the St. Louis Airport Site (SLAPS) has been contaminated with radionuclides, principally isotopes of uranium, resulting from storage of uranium-bearing residues at the site from 1946 until 1966. At present, the contamination is largely confined to the southwestern region of the site, east of Coldwater Creek, in the upper groundwater system above Unit 3M. Coldwater Creek and the deeper groundwater system do not seem to have been significantly affected. Modeling of flow and transport in both upper and lower groundwater systems was undertaken to assess the future effects of the present contamination on Coldwater Creek and the deeper groundwater system, including water-bearing zones of limestone bedrock.

The widely used, well documented computer code MODFLOW was used to model groundwater flows (McDonald and Harbaugh 1988); the companion code MT3D was used to model transport (Zheng 1990). MODFLOW was used in the steady-state mode to simulate average groundwater conditions. MT3D, on the other hand, was used to simulate the evolution of the contamination plume with time in the MODFLOW-generated groundwater flow field.

This report describes the modeling of flow and transport in groundwater at SLAPS. The discussion includes steady-state flow modeling, transport modeling for a time period to peak concentrations in the deep groundwater system, and the sensitivity analysis performed to assess parameter uncertainty on the results. The hydrogeologic characterization leading up to the conceptual model of the groundwater flow at SLAPS, the conceptual model itself, and parameter evaluation are described in the various references cited in this report. The results of the work described here were presented in various meetings to the Expert Geohydrologic Panel appointed by the St. Louis Area Task Force.

2.0 FLOW MODELING

2.1 MODEL DOMAIN

The model domain (Figure 1) was determined so that groundwater conditions at its boundaries are known with reasonable assurance, and so that it is large enough to contain areas where contamination is present and where it is likely to migrate in the future. The model domain consists of the local upper and the lower groundwater systems underneath the area including SLAPS and the ballfields. The area extends from Coldwater Creek (north and west) to Banshee Road to the south.

2.2 MODEL GRID

The rectangular model grid consists of 50-ft-by-50-ft block-centered, finite-difference cells along 44 columns and 30 rows. The local coordinates of the southwestern corner of the rectangular grid block (row 30 column 1) is 745 feet easting and 1025 feet northing at Banshee Road. The southern boundary of the model grid (row 30) is aligned with Banshee Road. The grid covers an area of 2,200 ft by 1,500 ft (75.76 acres). The vertical extent of the model domain (defining the upper and lower groundwater systems) is defined by six model layers. Figure 1 shows the model grid.

2.3 MODEL BOUNDARIES

The boundaries of the model (active cells) are defined as follows (see also Figure 1): Coldwater Creek is defined as a discharge boundary where groundwater discharge occurs if the potentiometric surface exceeds specified elevations (a drain boundary in MODFLOW terminology). The invert elevation of the channel of Coldwater Creek is the specified elevation at the cells where Coldwater Creek channel lies. Potentiometric heads are specified (specified head boundary) along row 30 (Banshee Road). A no-flow boundary to the east is specified for the upper groundwater system. The top of the upper groundwater system is specified as recharge boundary defined by model-generated water table. The bottom of the model domain is defined as a no-flow boundary set at an arbitrary depth within the limestone or shale bedrock.

2.4 STRATIGRAPHY

The sequence of the various stratigraphic units is shown schematically in a vertical cross-section in Figure 2. The thickness of a stratigraphic unit at any block-centered node was interpolated from borehole data obtained as part of site characterization (BNI 1994) and presented as contour maps or isopachs in Figures 3 through 7. An assumed 25-ft thickness of bedrock was also incorporated in the model to address concern about the contamination of limestone bedrock (Post-Maquoketa aquifer). The six layers of the model have the following correspondence to the stratigraphic units: Layer 1 - Unit 2; Layer 2 - Unit 3T; Layer 3 - Unit 3M; Layer 4 - Unit 3B; Layer 5 - Unit 4; and Layer 6 - bedrock (limestone or shale).

2.5 HYDROGEOLOGIC PARAMETERS

Horizontal and vertical conductivity and effective porosity are the essential hydrogeologic parameters for hydraulic head and flow velocity determinations. Cell-by-cell horizontal hydraulic conductivity values are derived from kriged values of the shallow and deep aquifer slug test results shown in Table 1 and Figures 8, 9, and 10. The shallow system horizontal conductivity distribution thus derived was assigned to Layers 1 and 2, and the deep system distribution was assigned to Layers 3 through 5. The horizontal conductivity of Layer 6 (a constant value for the layer) was derived as the geometric mean of four field permeability test results in Units 5 and 6 (BNI 1994). The data are shown in Table 1.

The vertical conductivity for the model layers is the geometric mean of vertical laboratory determined conductivity values from the site characterization report (BNI 1994) as shown in Table 2. MODFLOW simulates flow between model layers based on the vertical conductance at the layer interface, computed as the thickness-weighted average vertical conductivity of the adjacent layers.

The porosity and effective porosity were quantified as part of site characterization (BNI 1994). For each stratigraphic unit, these parameters were each assumed to have a constant value equal to the mean of the measured values.

2.6 MODEL CALIBRATION

The groundwater flow model was calibrated against the average groundwater levels observed in the various observation wells in the upper and lower groundwater systems. The average groundwater levels were obtained by time-averaging the observed water levels in each well over approximately a 2.5-year period of record (November 16, 1990, to June 3, 1993). Data from periods when the wells were suspected to be plugged were excluded.. The unknown recharge to the groundwater system was used as the calibration parameter. It was assumed to be uniform across the model domain. Different recharge rates were assumed until a good match between the observed and modeled groundwater levels was obtained. Table 3 presents the calibration statistics for a recharge rate of 2.0 in./year. Figure 11 shows a comparison between the observed and modeled groundwater levels at the observation wells. The coefficient of determination R^2 of the fit is 0.92, indicating a good fit. The root-mean-square of the calibration residuals is 1.3.

A recharge rate of 2.0 in./year corresponds to a base flow of about 1.8 cfs at the site, using a groundwater contributing area of about 12 mi^2 at SLAPS. The contributing area is assumed to equal the area of the drainage basin of Coldwater Creek at SLAPS. The base flow of 1.8 cfs thus obtained appears to be reasonable based on visual observations of dry-weather flows at SLAPS, as well as examination of flow records at the former USGS station downstream (drainage area of 43.6 mi^2).

Figures 12 through 17 show the potentiometric heads and velocity vectors in Layers 1 through 6. Figure 18 shows the flow pattern in a vertical section taken parallel to and about 230 ft north of Banshee Road. The flow and head patterns are consistent with the conceptual model developed from site characterization data (BNI 1994).

3.0 TRANSPORT MODELING

MT3D simulates advection, dispersion, and chemical reactions of contaminants in the groundwater flow system. The model parameters and the results are summarized below.

3.1 TRANSPORT PARAMETERS

The fate and transport parameter values used in the modeling are summarized in Table 4. Distribution coefficient value was assumed to be one-tenth its geometric mean value for SLAPS (BNI 1994).

An unretarded diffusion coefficient of 1.0×10^{-6} cm^2/s was used in this study. This is a typical value for diffusion of any solute through saturated media (EPA 1985). Values for longitudinal, transverse, and vertical dispersivities were based on relations given in Sharp-Hansen et al. (1990):

$$\alpha_L = 0.1\ X$$
$$\alpha_T = \alpha_L/3.0$$
$$\alpha_v = 0.056\alpha_L$$

where: α_L = longitudinal dispersivity
X = characteristic horizontal distance
α_T = transverse dispersivity
α_v = vertical dispersivity

Only the transport of total uranium was simulated because its concentration in the groundwater is by far the highest of all the radionuclides present in the groundwater.

3.2 INITIAL CONCENTRATIONS

The initial concentrations were based on the highest observed concentrations averaged over a year (Figure 19; Table 5). The highest concentrations were recorded during 1991 (SAIC 1993). It was assumed that these relict concentrations will not be exceeded in the future and that no significant introduction of contaminants into the groundwater is currently occurring. The concentrations were assumed to be uniform across the two layers of the upper system. The initial concentrations in the lower groundwater system were assumed to be zero (i.e., at background levels).

The maximum concentrations of total uranium in groundwater are observed in samples taken mostly from old wells installed by Weston. It is suspected that the concentrations in samples from these wells do not reflect dissolved concentrations only, because naturally occurring constituents in groundwater such as calcium and magnesium also have much higher concentrations in these samples than in other samples. It is suspected that the samples from the old wells contained a high proportion of particulates, and because measurements were made on unfiltered samples, the reported concentrations reflect a high proportion of concentrations in the sorbed phase. Thus, the initial concentrations of total uranium used in this study, which are meant to be the dissolved concentrations, are conservative—i.e., higher than actual.

The way initial concentrations were prescribed is also conservative. Contours of equal concentrations were first drawn based on observed concentrations (Figure 20). These were then used to assign initial concentration values at the block-centered nodes. In reality, points of observed high concentrations are very likely localized. The use of contouring to assign concentration values at neighboring points effectively spreads the initial concentration over a wider area.

3.3 BOUNDARY CONDITIONS

The no-flow boundaries in the upper two layers to the east and at the bottom of the model domain were treated as zero flux boundaries. At the drain and prescribed-head boundaries, the concentration gradient was assumed to be zero.

3.4 RESULTS

Figures 21 through 25 show the total uranium concentration contours in the various layers at 100; 500; 1,000; 5,000; and 10,000 years. Figure 26 shows total uranium plume in a sectional view at 100; 500; 1,000; 5,000; and 10,000 years. The section was taken parallel to and approximately 230 ft north of Banshee Road, where it traverses the area with highest concentrations of total uranium. Figure 27 shows concentration evolution with time at a selected cell in the various layers. The particular cell was selected because the concentration was a maximum there for the layer in question. The peak values of concentration were realized in each layer within the simulation time (20,000 years) except in Layer 6. At 20,000 years, the maximum concentration in the limestone bedrock is 24.7 pCi/L (see Table 6).

Figure 28 shows the total uranium discharge in curies per year into Coldwater Creek as a function of time. The total uranium discharge at any time was calculated by multiplying the concentration in curies per cubic foot by the groundwater discharge in cubic feet per year at a drain node and summing up the product over the entire reach of Coldwater Creek affected by contaminated groundwater. The maximum annual total uranium loading to Coldwater Creek was found to be 0.0028 pCi/year at about 14,000 years (see Table 7 and Figure 28).

4.0 SENSITIVITY ANALYSIS

4.1 NO 3M UNIT

To evaluate the time of arrival of the uranium plume into the deep groundwater system, flow and transport simulations were performed with the assumption that Unit 3M, which restricts flow into the deep groundwater system, does not exist across the site. New flow modeling was performed by setting the vertical conductance of Layer 3 to that of Unit 3B. The calibration statistics obtained from the revised flow model are shown in Table 8. The sum of squares of the calibration residuals compares well with the base case, meaning that no change is necessary in model parameters and no additional runs are needed to achieve better calibration (thus, the recharge rate remains the same).

The discharge of total uranium into Coldwater Creek has not changed from the base case as shown in Table 7. The maximum concentrations in the future are shown in Table 9. Slight increases in peak concentrations are observed in model Layer 3 relative to the base case, indicating that Unit 3M was somewhat effective in retarding the transport of uranium from the upper into the deeper aquifer. Also, peak concentration (at 1,000 years) in Layer 3 now occurs in the southwestern area of the model domain (Unit 3M is removed) rather than the southeastern area as it was for the base case.

4.2 LOW RETARDATION

In the base case, the distribution coefficient (K_d) used in the model was set conservatively at 10 percent of the average value for the uranium K_d for the site. A zero value for K_d means that uranium will advect at the same rate as water, with no retardation. A case of no retardation could not be evaluated because the computer run time would require days. Therefore, the base case K_d was reduced 100 times (a factor of 1,000 reduction of the average value), and a simulation was made to assess the impact. Low K_d means also less mass of uranium in the system (amount of uranium adsorbed to the aquifer soils).

The flux of uranium into Coldwater Creek is given in Table 7. As can be inferred from the table, peak flux occurs in less than 100 years as compared to about 14,000 years in the base case (see Figure 28). The maximum concentrations in the groundwater system are shown in Table 10.

5.0 RECOMMENDATIONS

A calibrated groundwater model for SLAPS is in place and is consistent with the currently available characterization data and interpretation. The model will be refined as needed when more characterization data, especially for the deep groundwater system, become available. At present, the existing contamination in the shallow groundwater system has no significant impact on either

Coldwater Creek or the deep groundwater system. Modeling results indicate that it will take hundreds of years for the contaminants to reach bedrock at levels that appear to be insignificant. Results also indicate that it will take hundreds of years for contaminant loading at Coldwater Creek to attain maximum values, also at apparently insignificant levels.

6.0 REFERENCES

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FIGURES

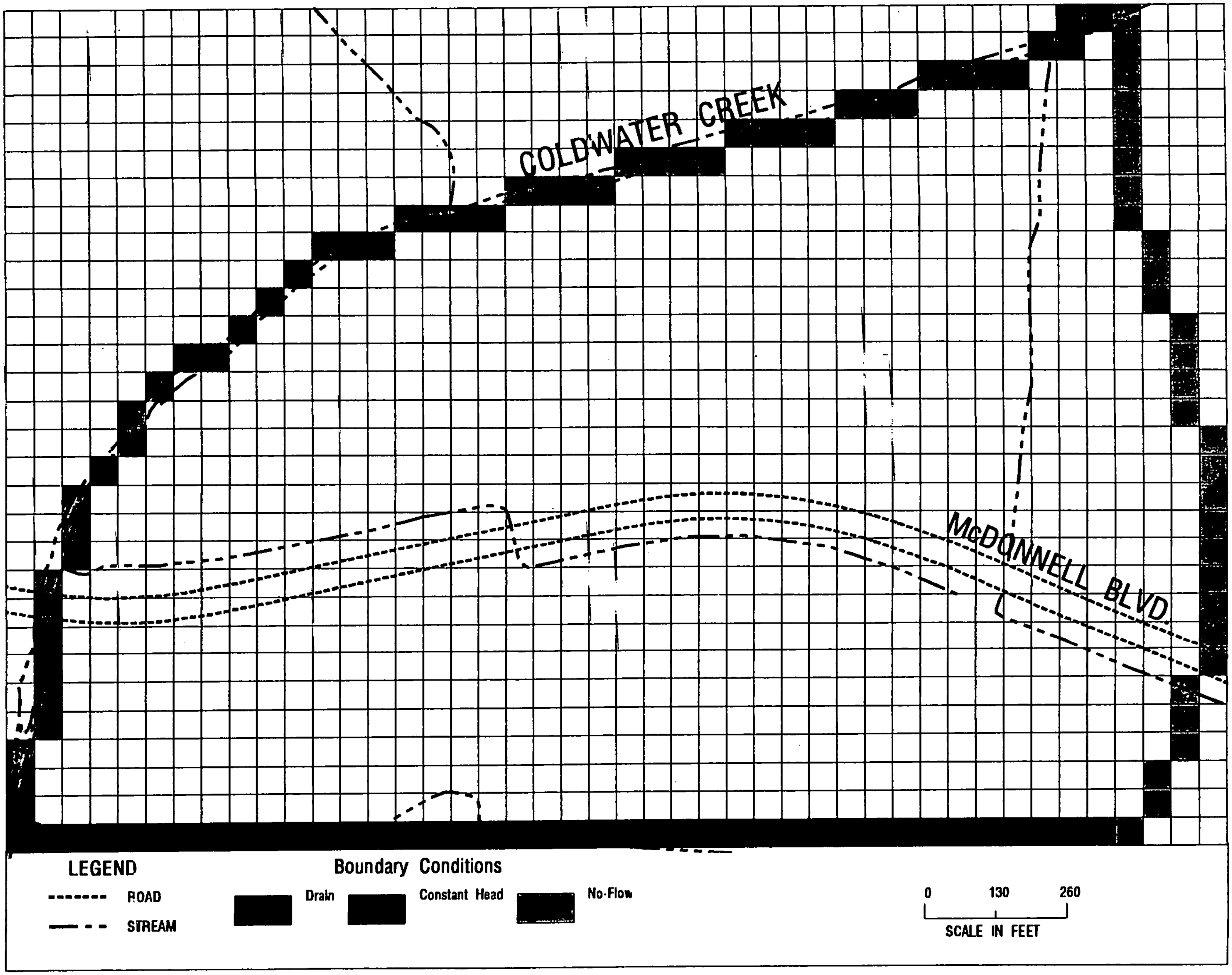

Figure 1. Model Grid and Boundary Conditions (Layer 1)

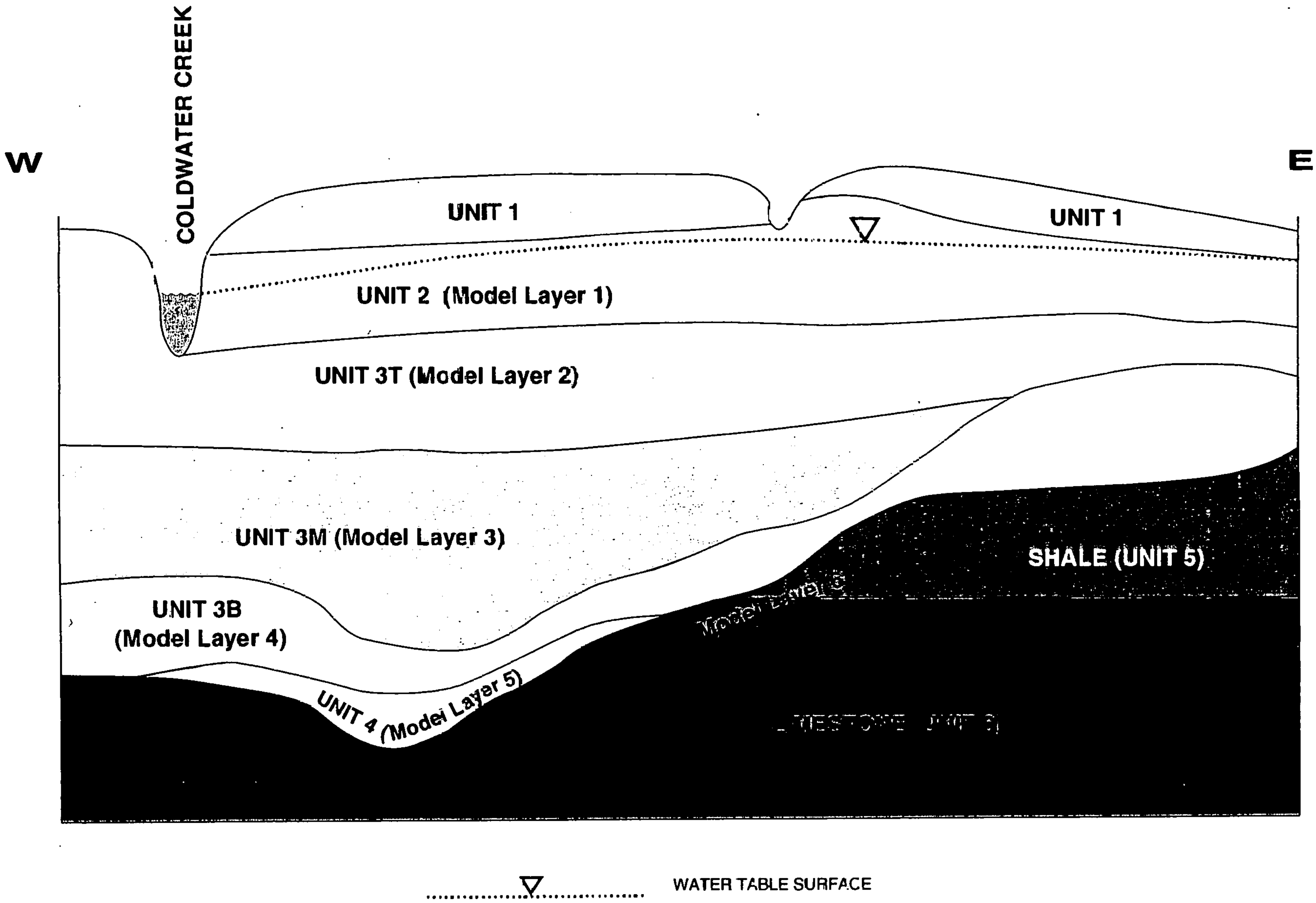

Figure 2
Schematic of the Stratigraphy

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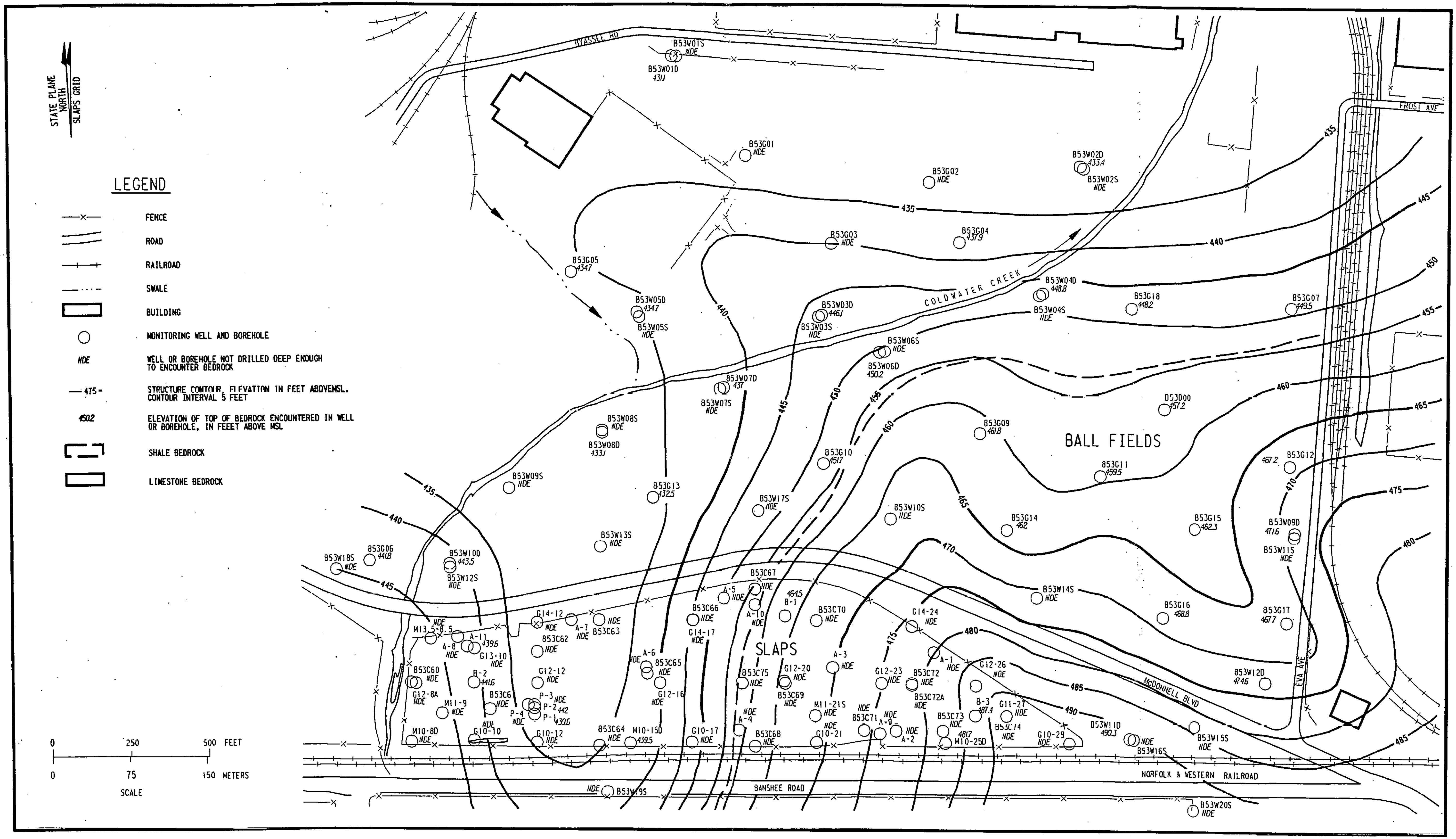

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Figure 3
Structure Contour Map of Top of Bedrock

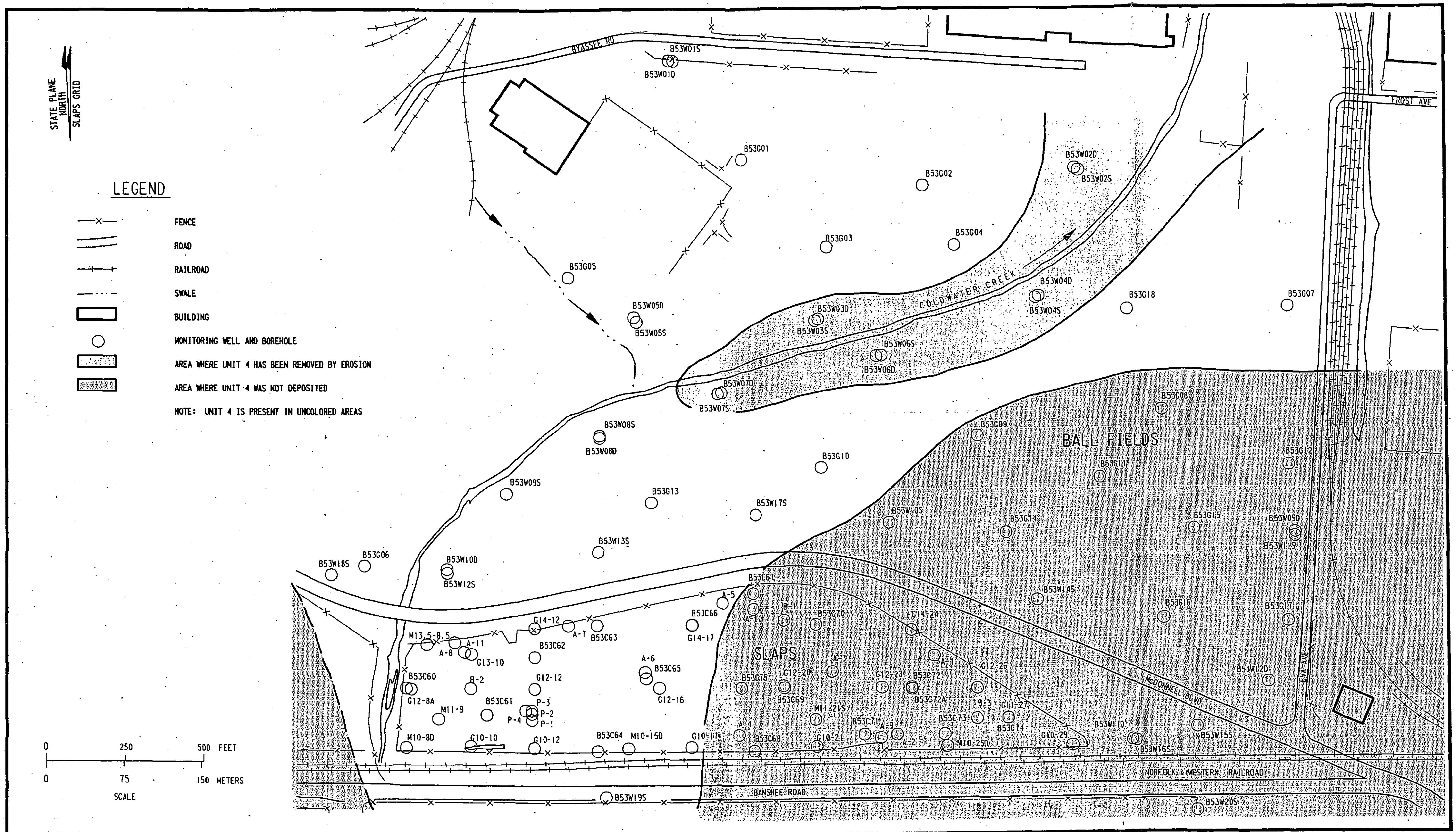

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Figure 4
Distribution of Unit 4

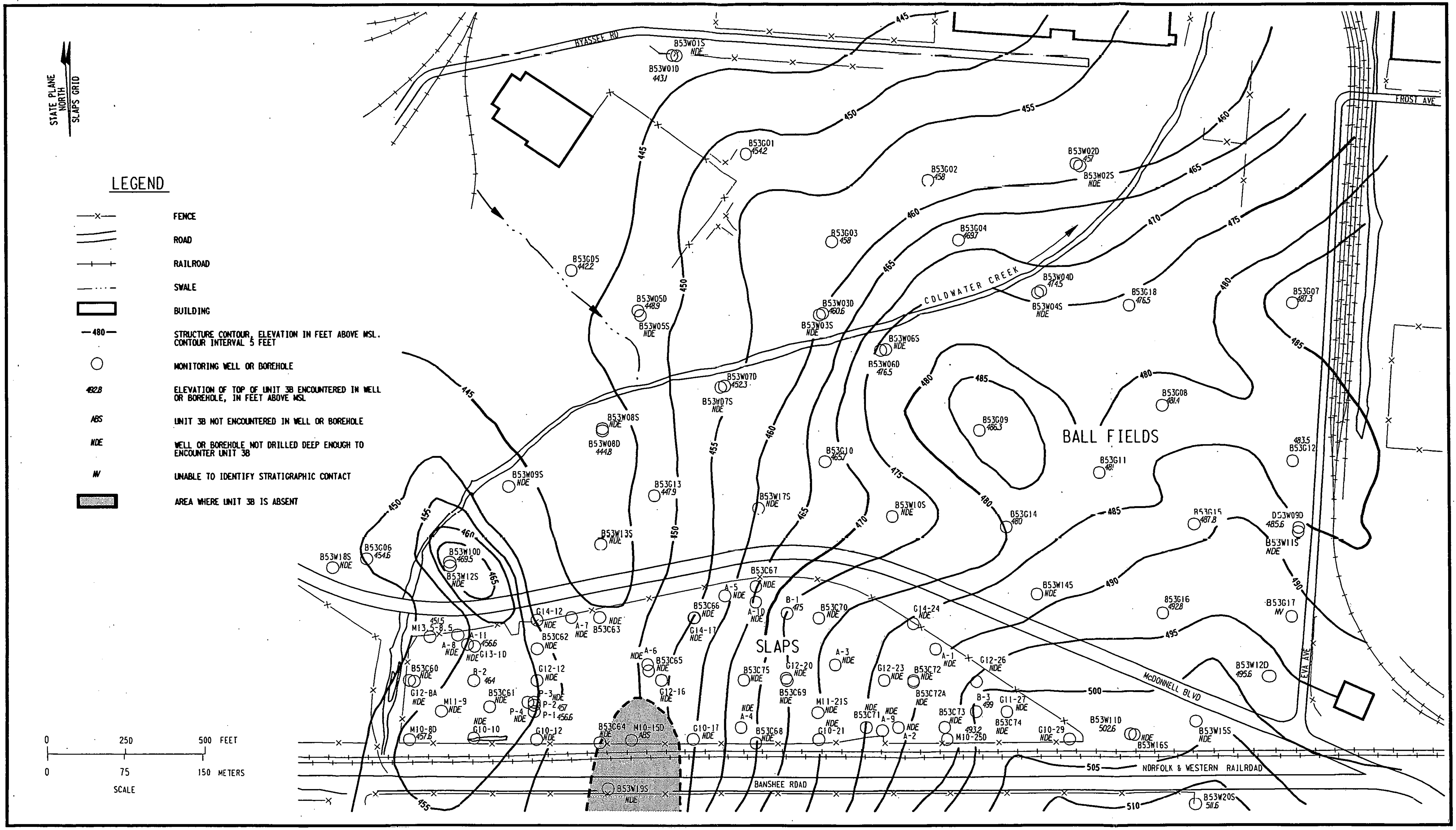

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Figure 5
Structure Contour Map of Top of Unit 3B

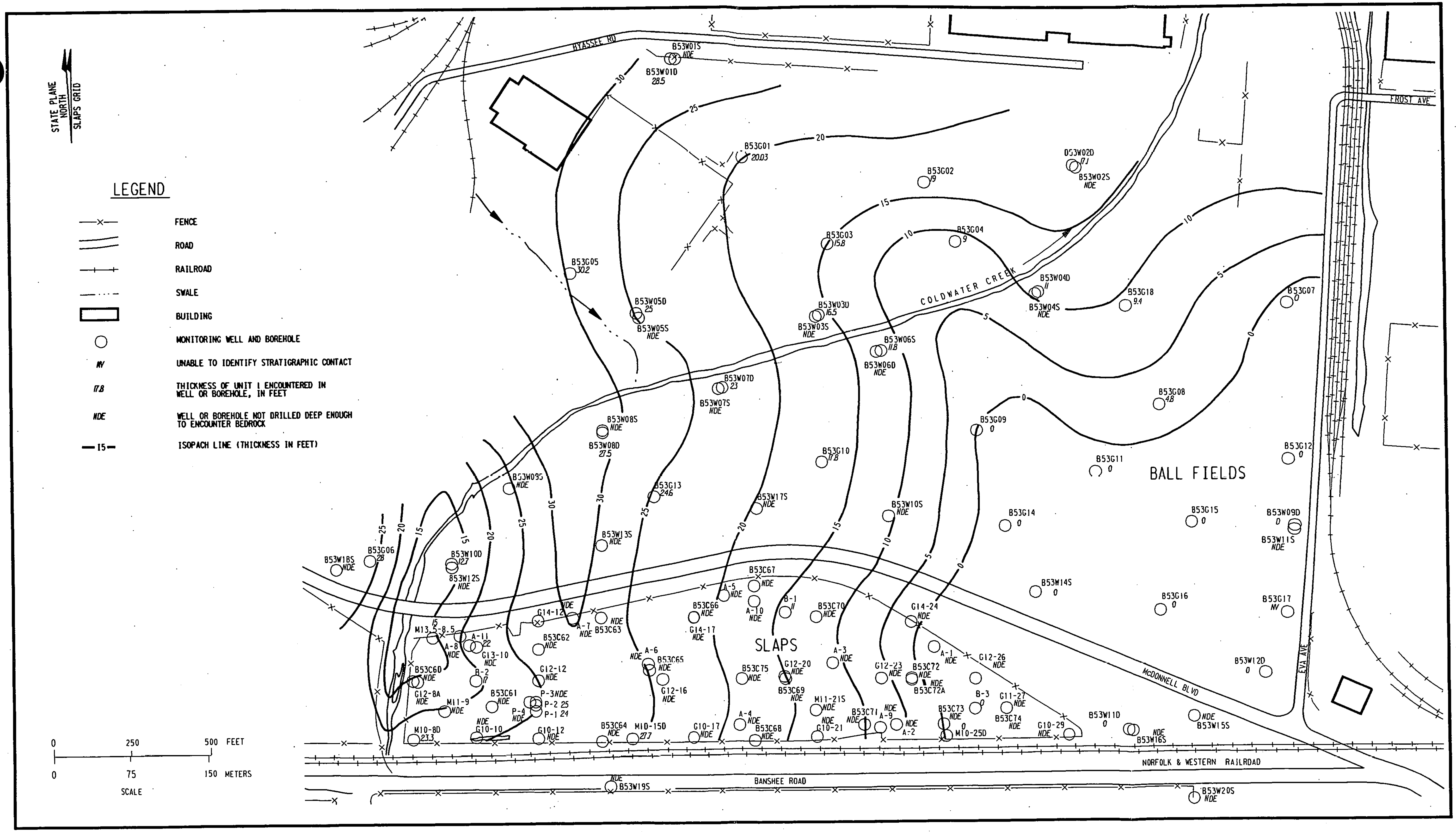

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Figure 6
Isopach Map of Unit 3M

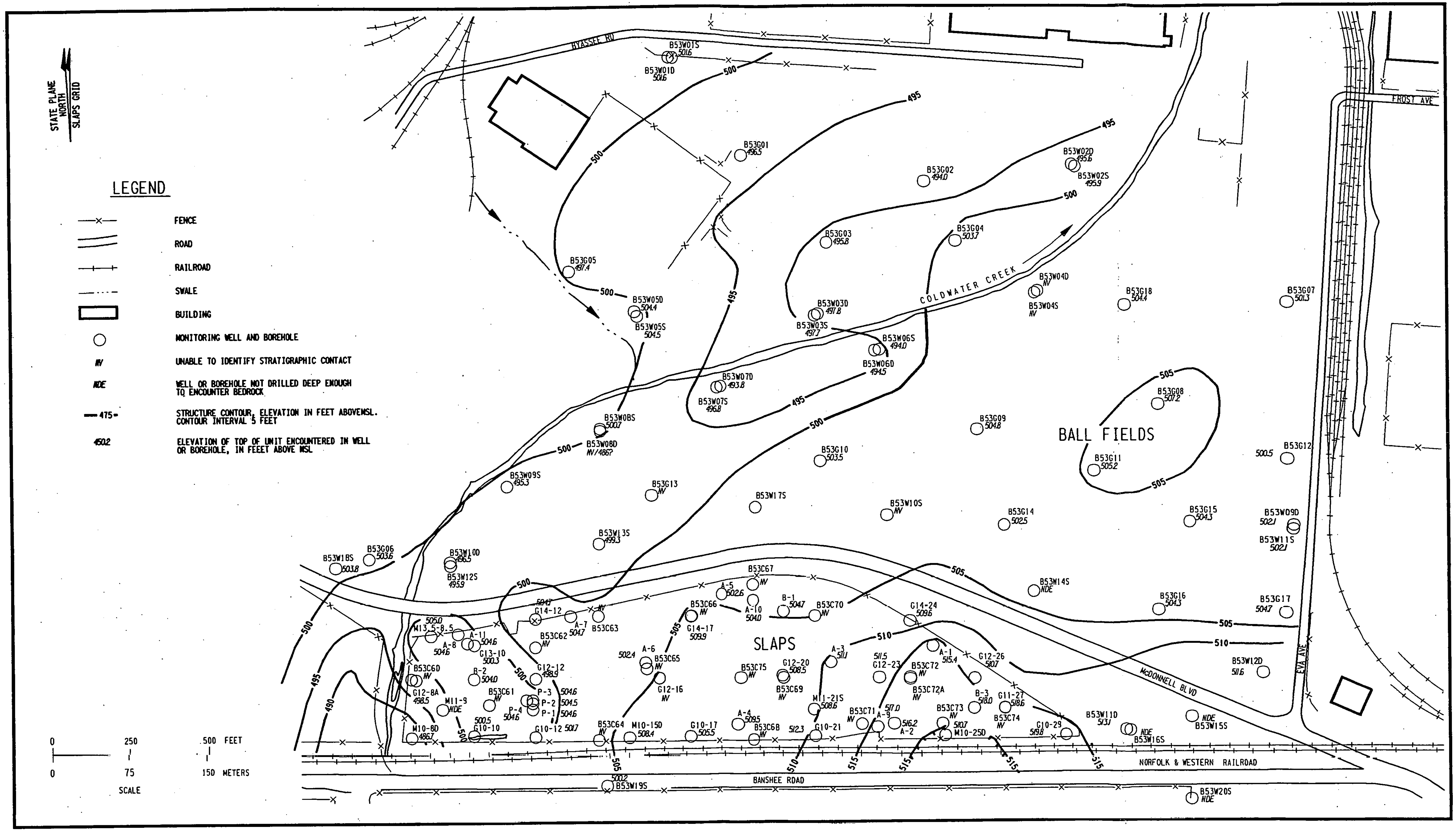

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Figure 7
Structure Contour Map of Top of Unit 3

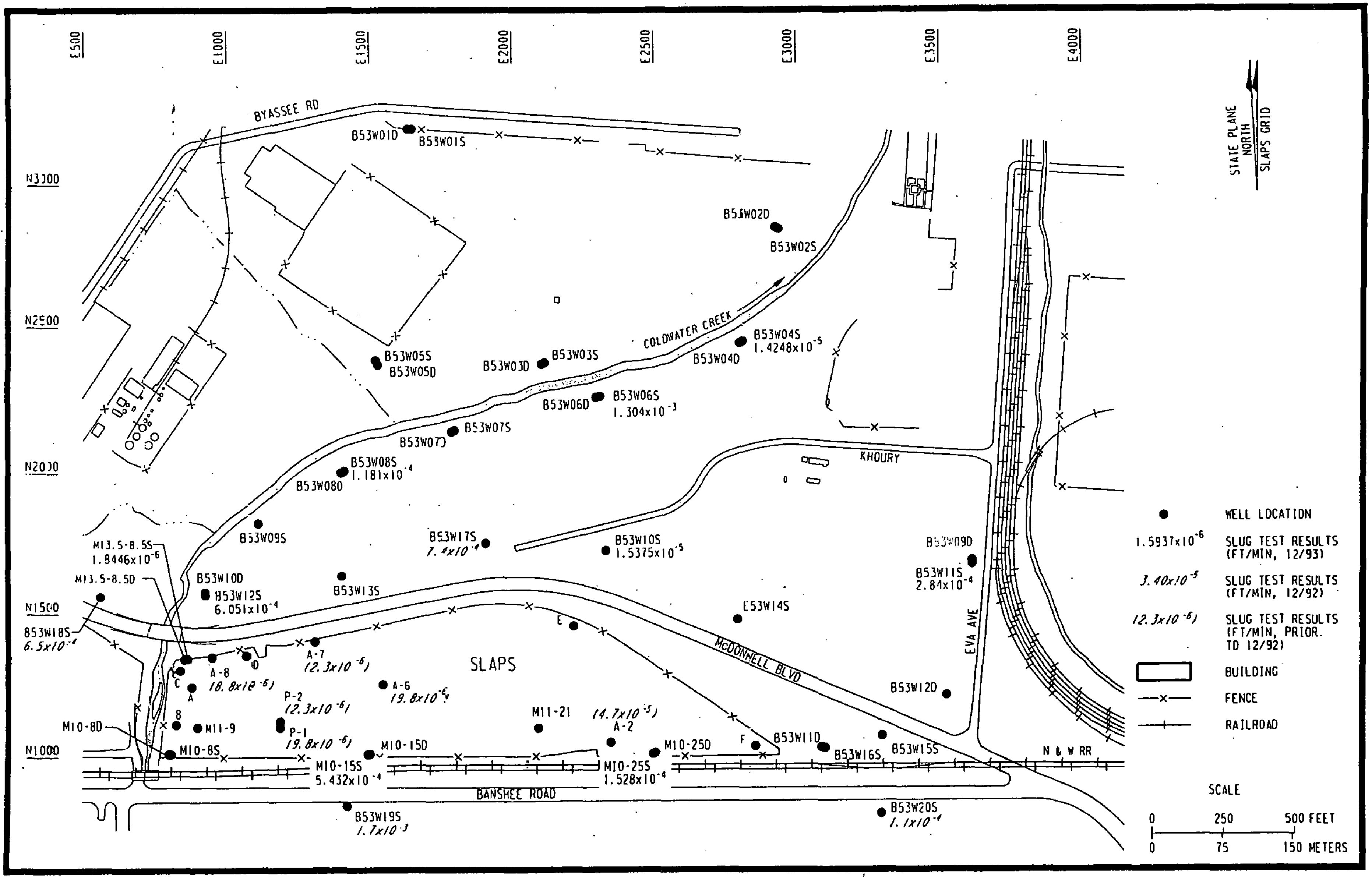

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Figure 8
Shallow Well Slug Results
Falling Head Test

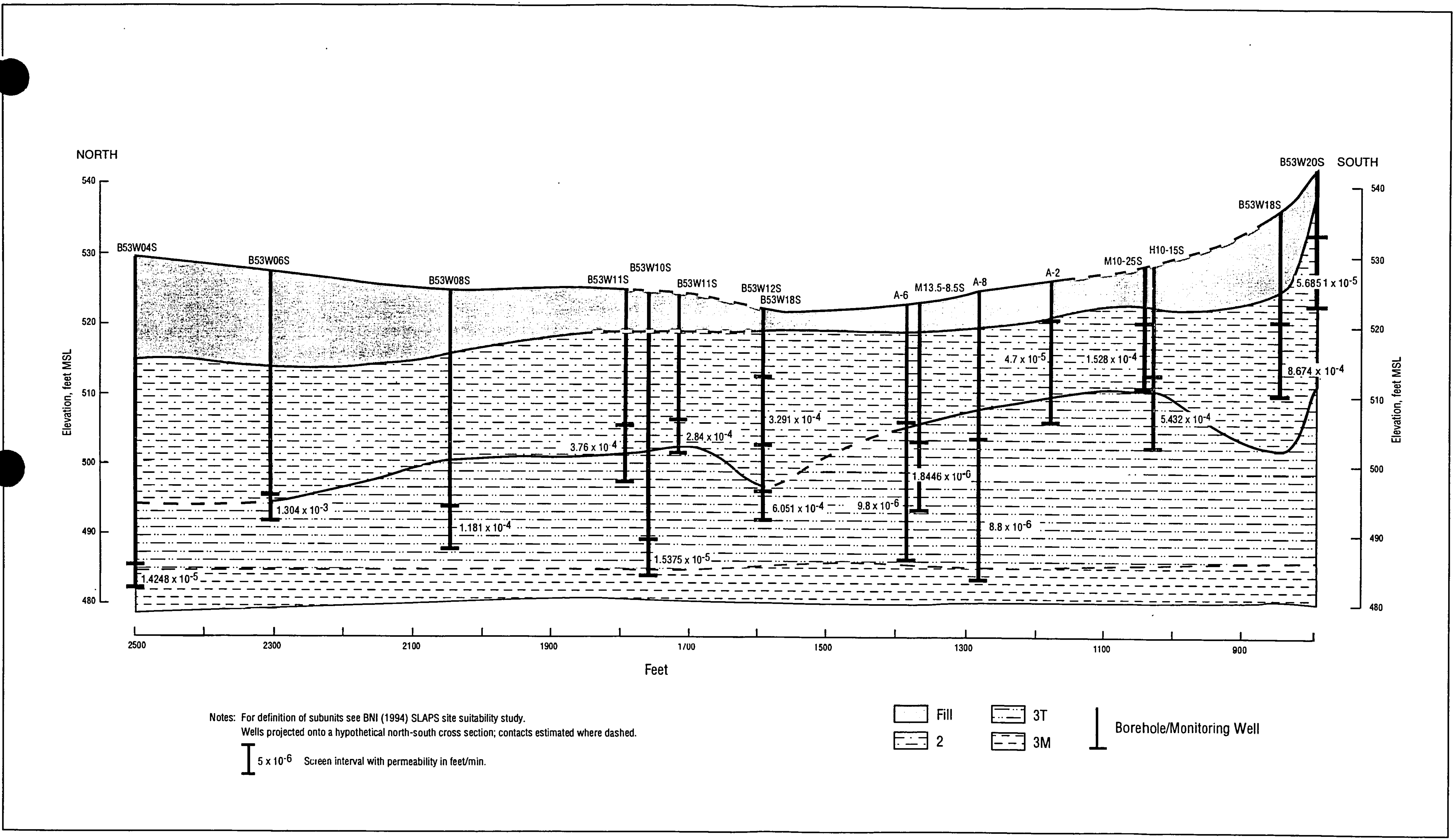

Figure 9
Schematic Cross Section Through SLAPS Showing Field Permeabilities

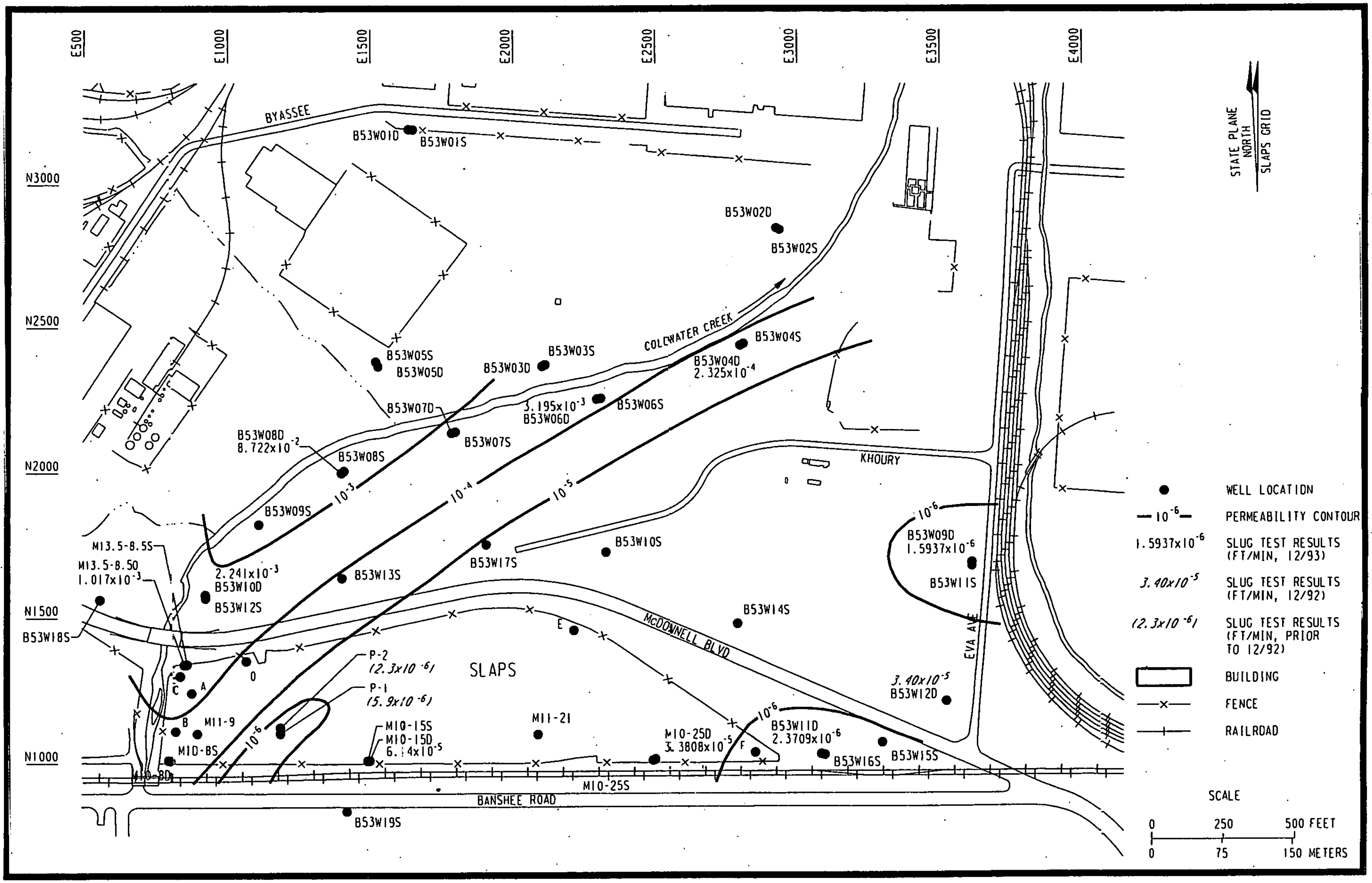

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Figure 10
Deep Well Slug Results
Falling Head Test

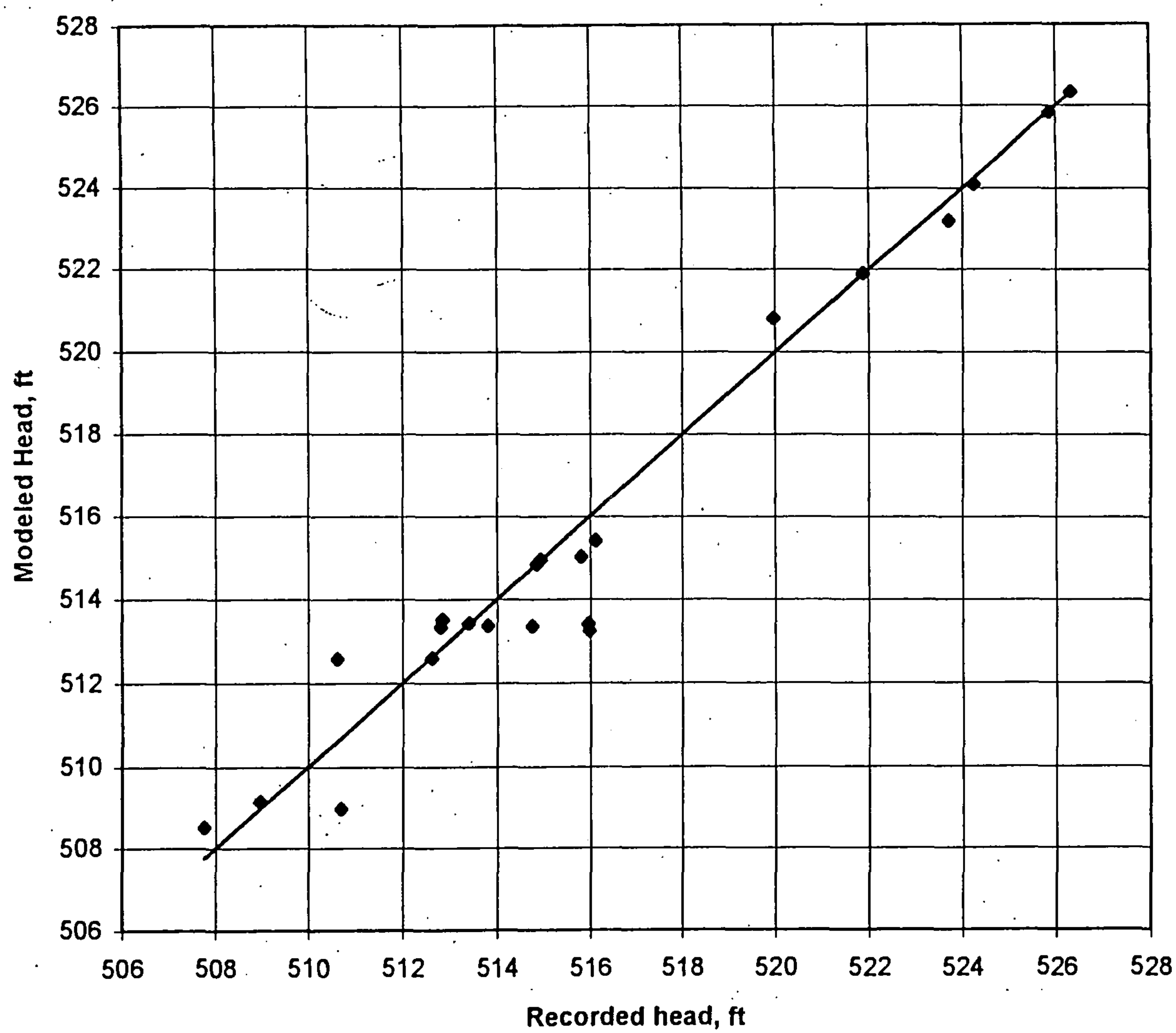
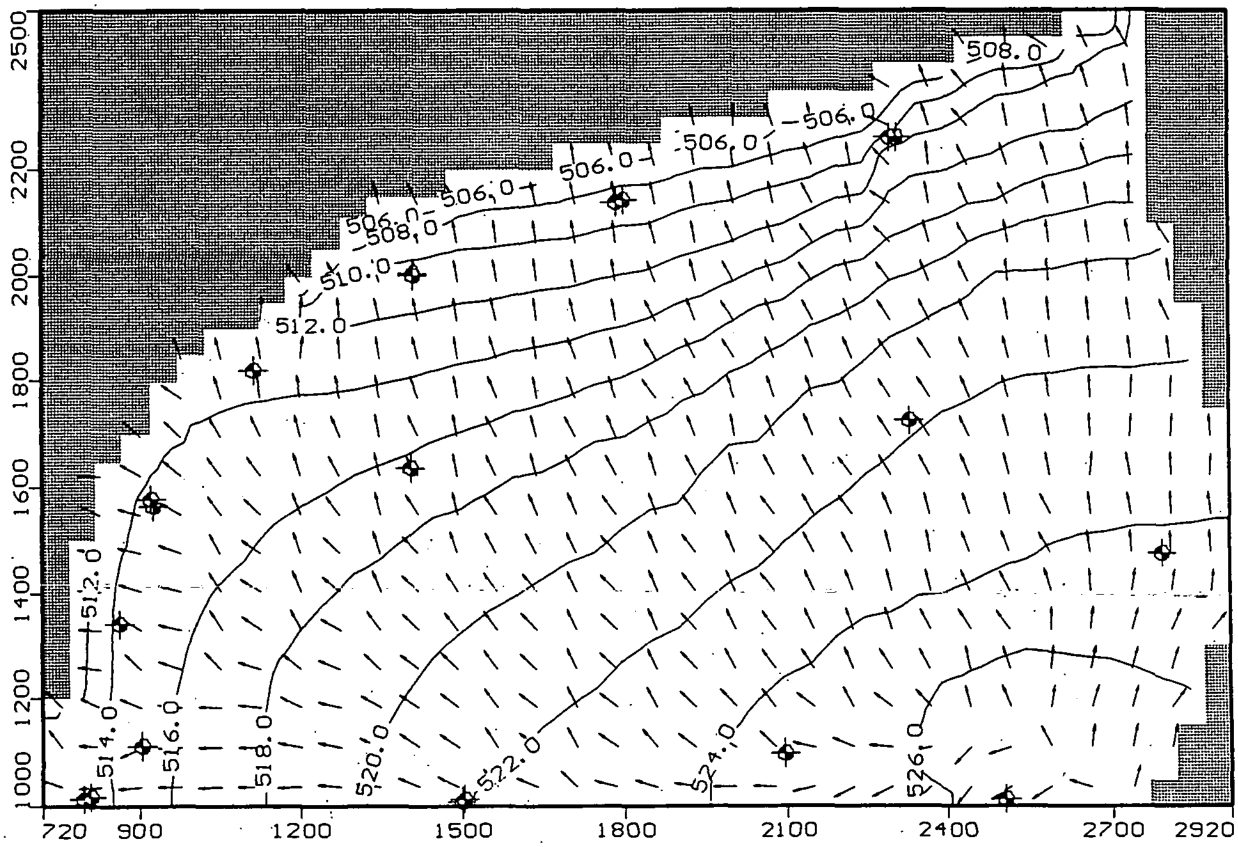
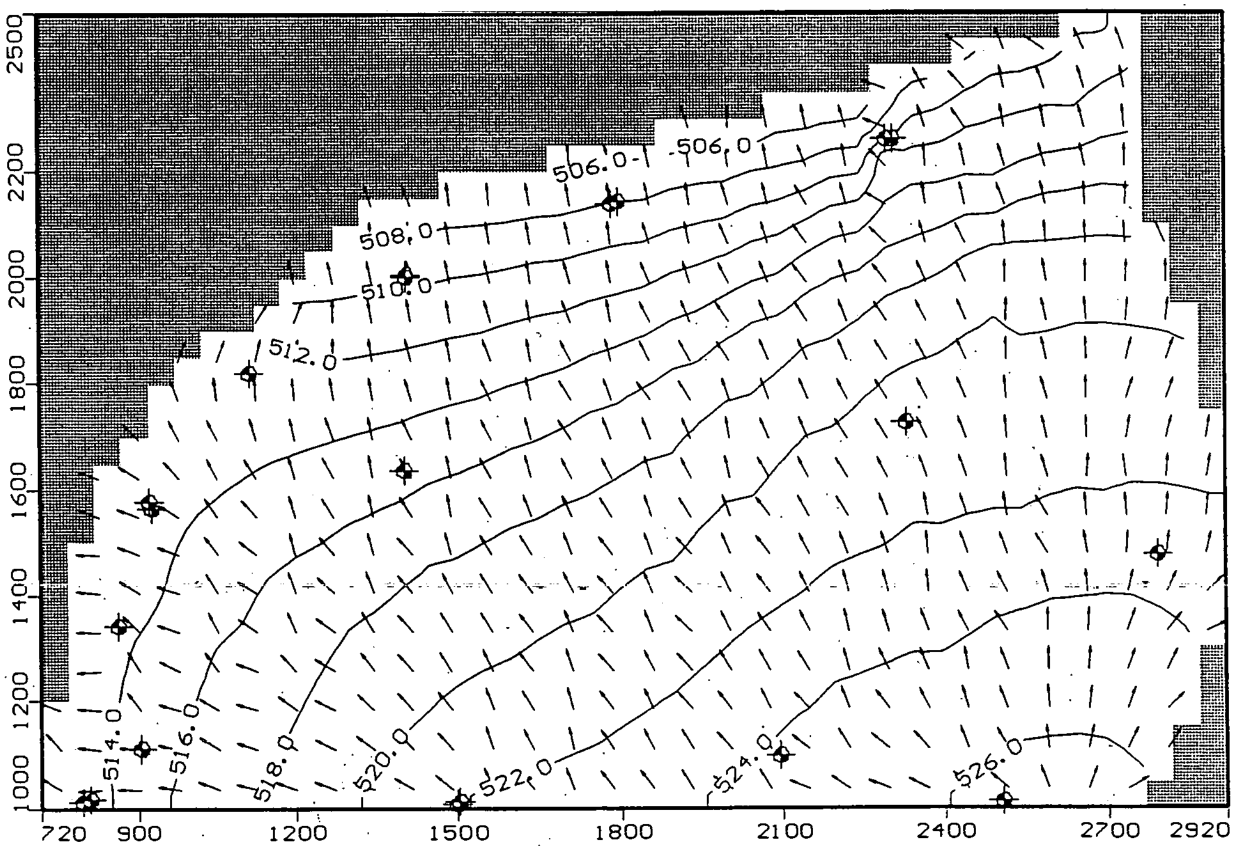


Figure 11
Model Calibration: Modeled vs Recorded Heads



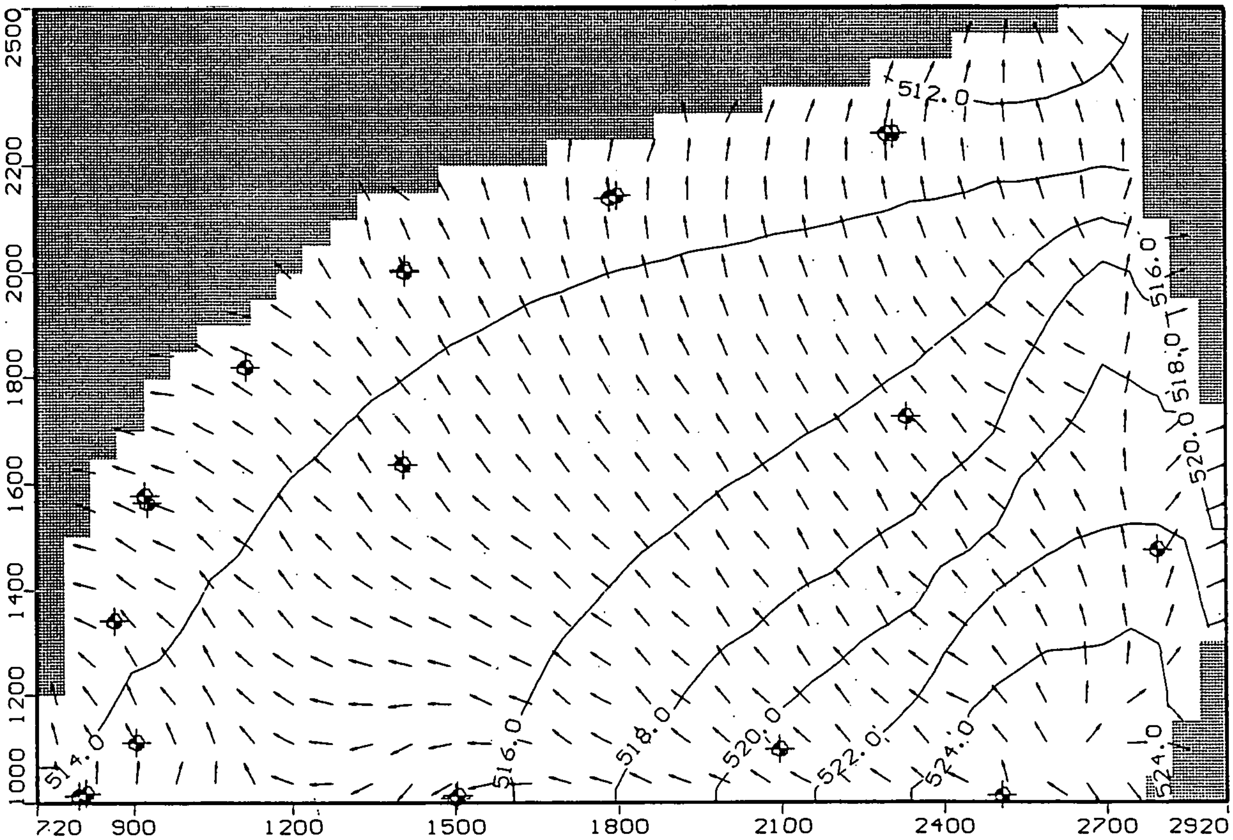
Bechtel Envr – Oak Ridg, TN Project: SLAPS Description: Flow Field Modeller: Vefa Yucel 20 Mar 96	Visual MODFLOW v.1.50, (c) 1995 Waterloo Hydrogeologic Software NC: 44 NR: 30 NL: 6 Current Layer: 1

Figure 12
Potentiometric Heads and Flow Field - Layer 1



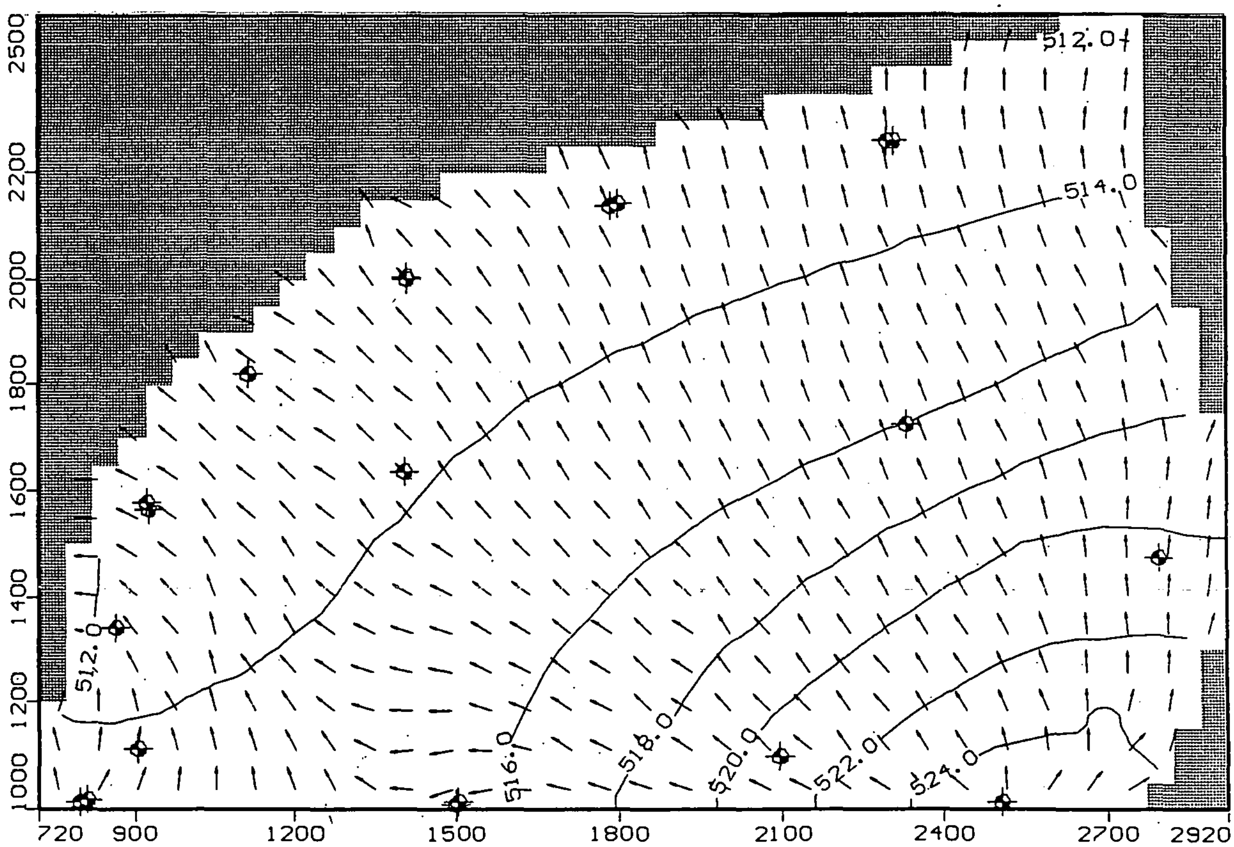
Bechtel Envr – Oak Ridg, TN Project: SLAPS Description: Flow Field Modeller: Vefa Yucel 20 Mar 96	Visual MODFLOW v.1.50, (c) 1995 Waterloo Hydrogeologic Software NC: 44 NR: 30 NL: 6 Current Layer: 2

Figure 13
Potentiometric Heads and Flow Field - Layer 2



Bechtel Envr – Oak Ridg, TN Project: SLAPS Description: Flow Field Modeller: Vefa Yucel 20 Mar 96	Visual MODFLOW v.1.50, (c) 1995 Waterloo Hydrogeologic Software NC: 44 NR: 30 NL: 6 Current Layer: 3

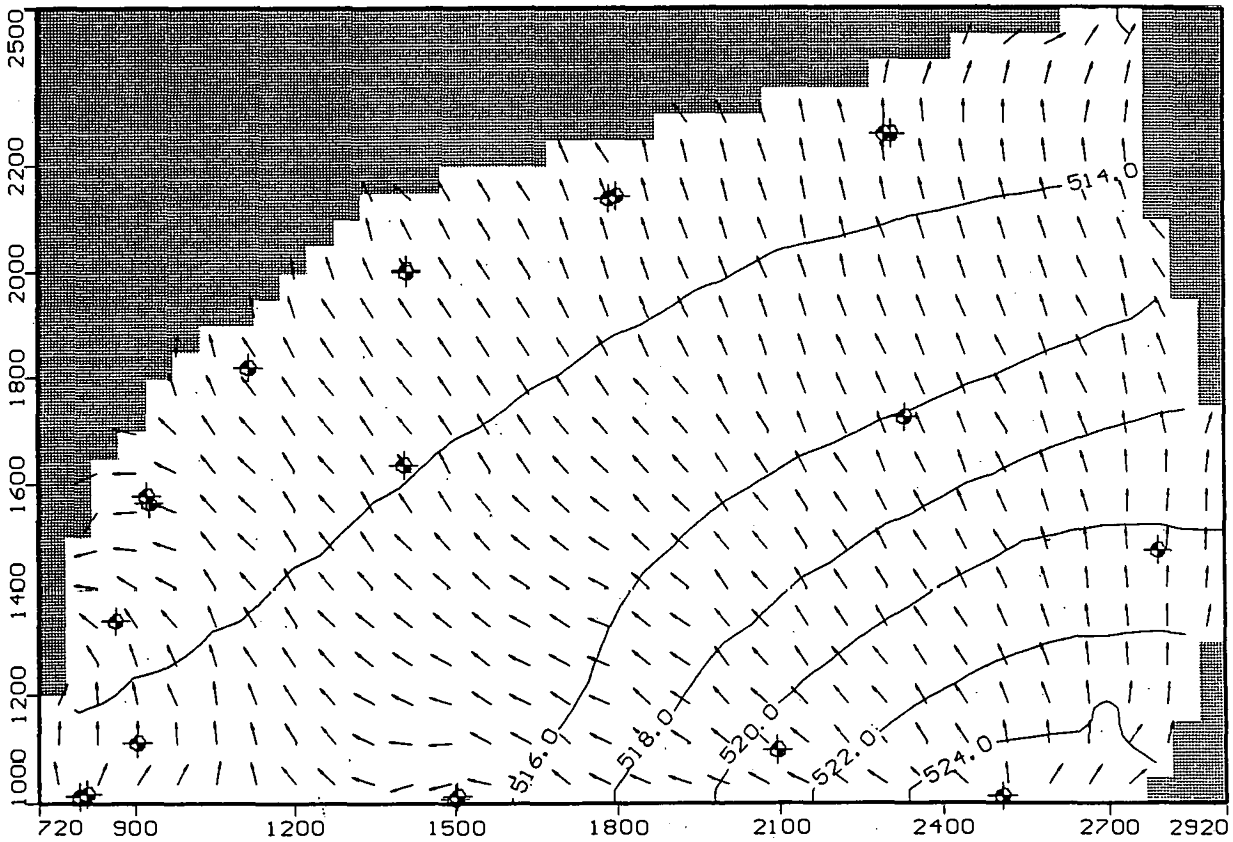
Figure 14
Potentiometric Heads and Flow Field - Layer 3



Bechtel Envr – Oak Ridg, TN
Project: SLAPS
Description: Flow Field
Modeller: Vefa Yucel
20 Mar 96

Visual MODFLOW v.1.50, (c) 1995
Waterloo Hydrogeologic Software
NC: 44 NR: 30 NL: 6
Current Layer: 4

Figure 15
Potentiometric Heads and Flow Field - Layer 4



Bechtel Envr – Oak Ridg, TN Project: SLAPS Description: Flow Field Modeller: Vefa Yucel 20 Mar 96	Visual MODFLOW v.1.50, (c) 1995 Waterloo Hydrogeologic Software NC: 44 NR: 30 NL: 6 Current Layer: 5

Figure 16
Potentiometric Heads and Flow Field - Layer 5

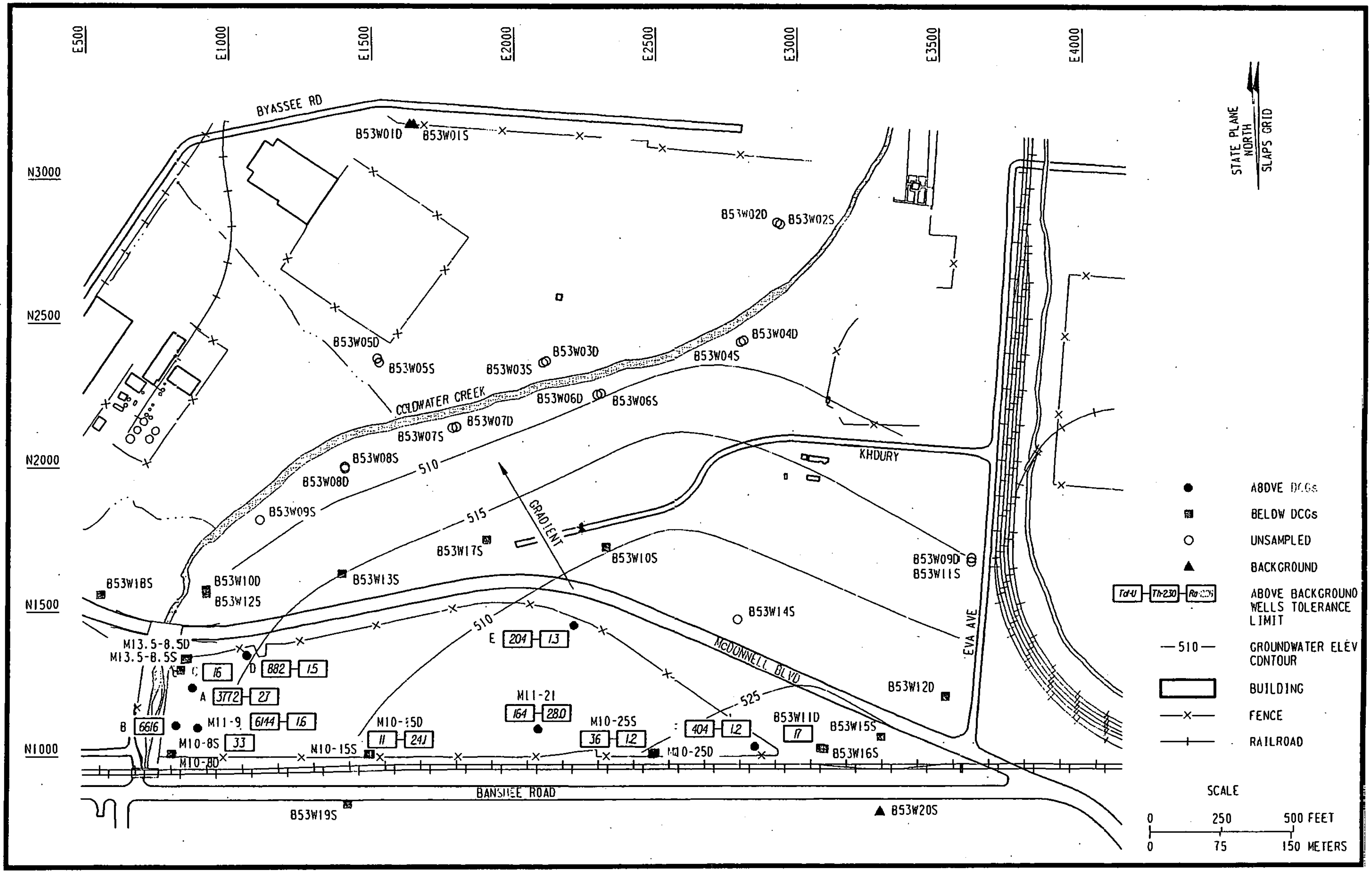


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Figure 19
Radionuclide Contamination of Groundwater at St. Louis Airport Site and Adjacent Vicinity Properties
1991 Annual Averages

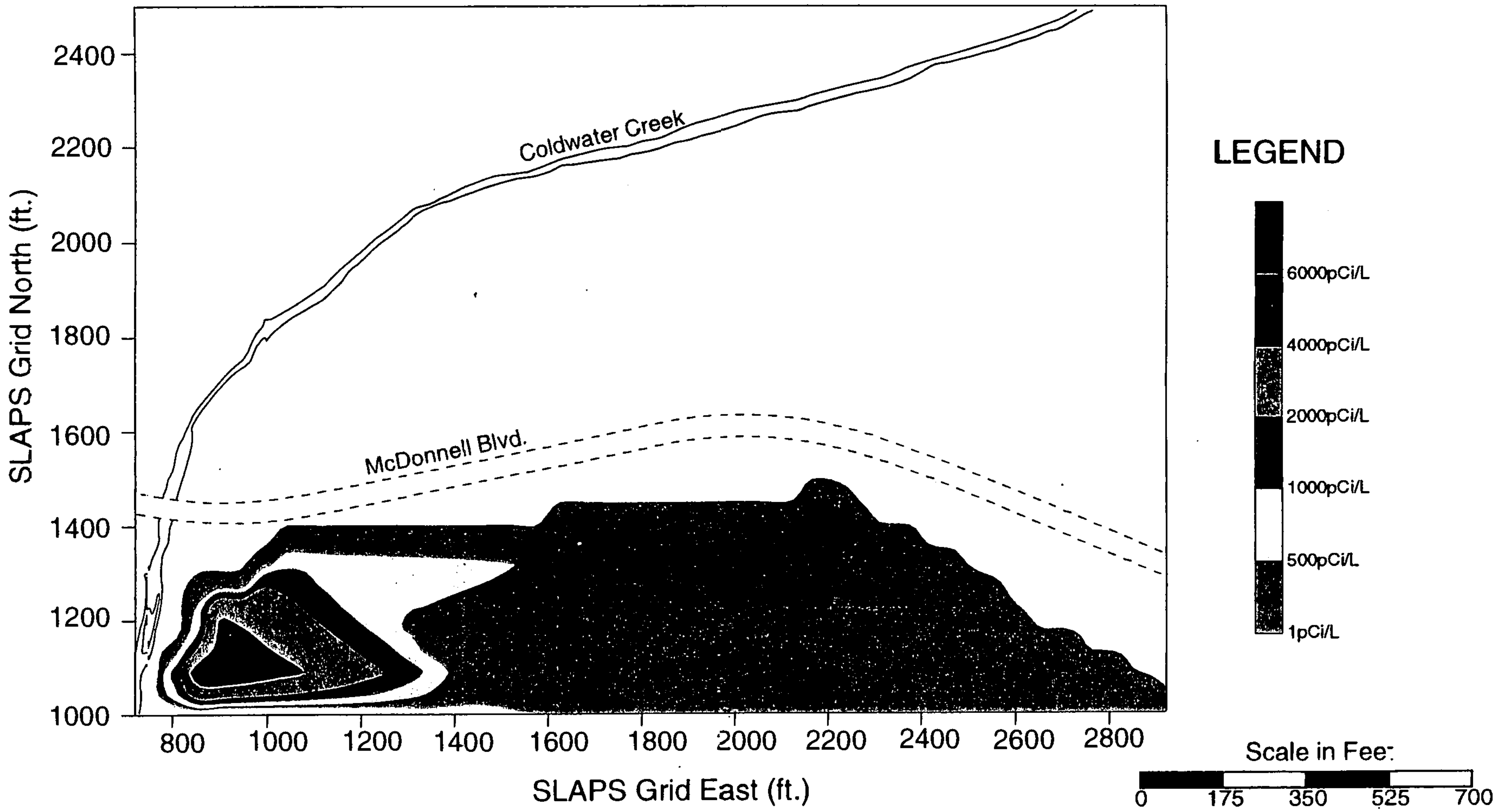

Figure 20. Initial Total Uranium Concentration Contours in the Upper Groundwater System

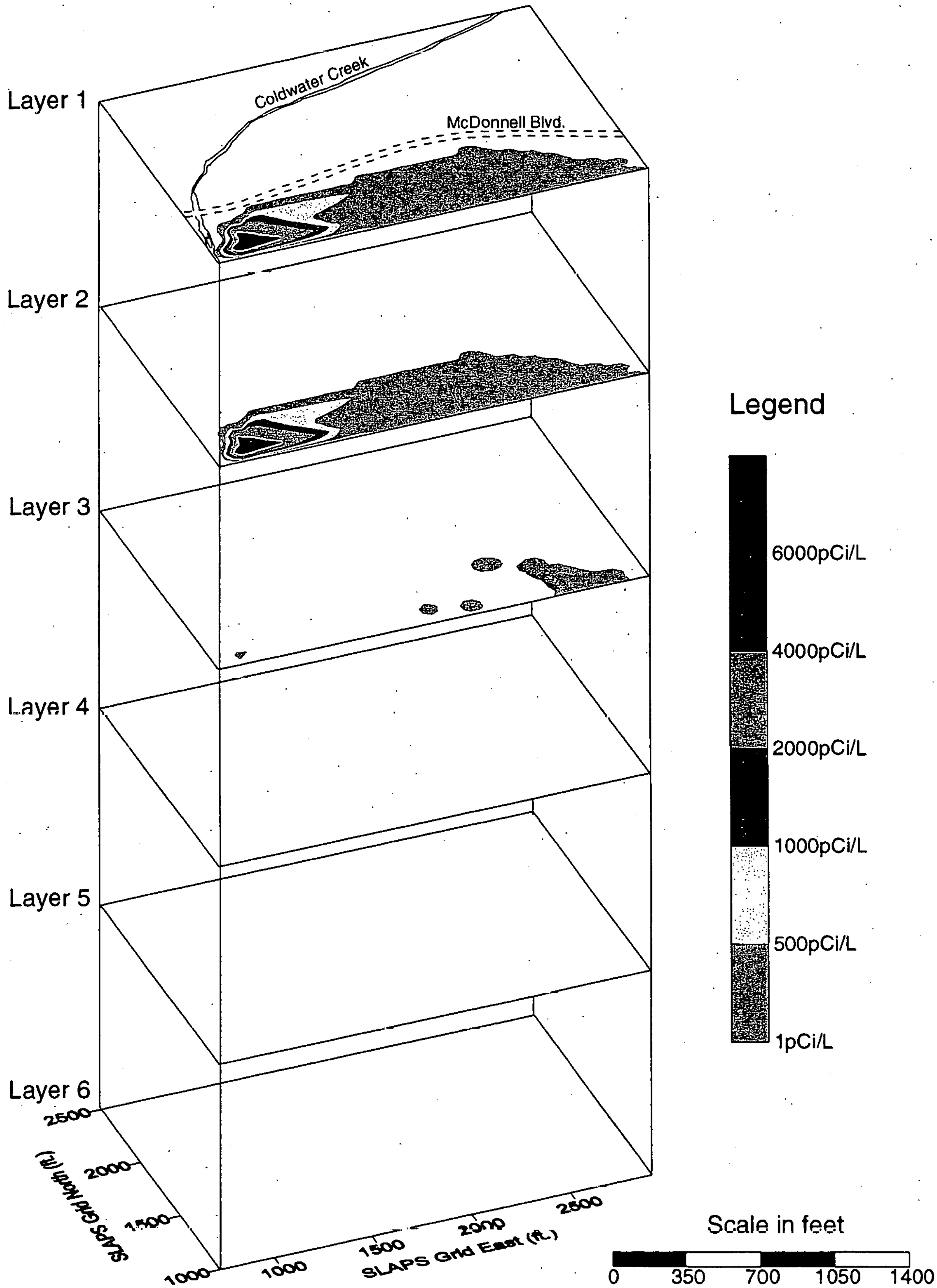

Figure 21. Total Uranium Concentration in Layers 1 through 6 at 100 Years

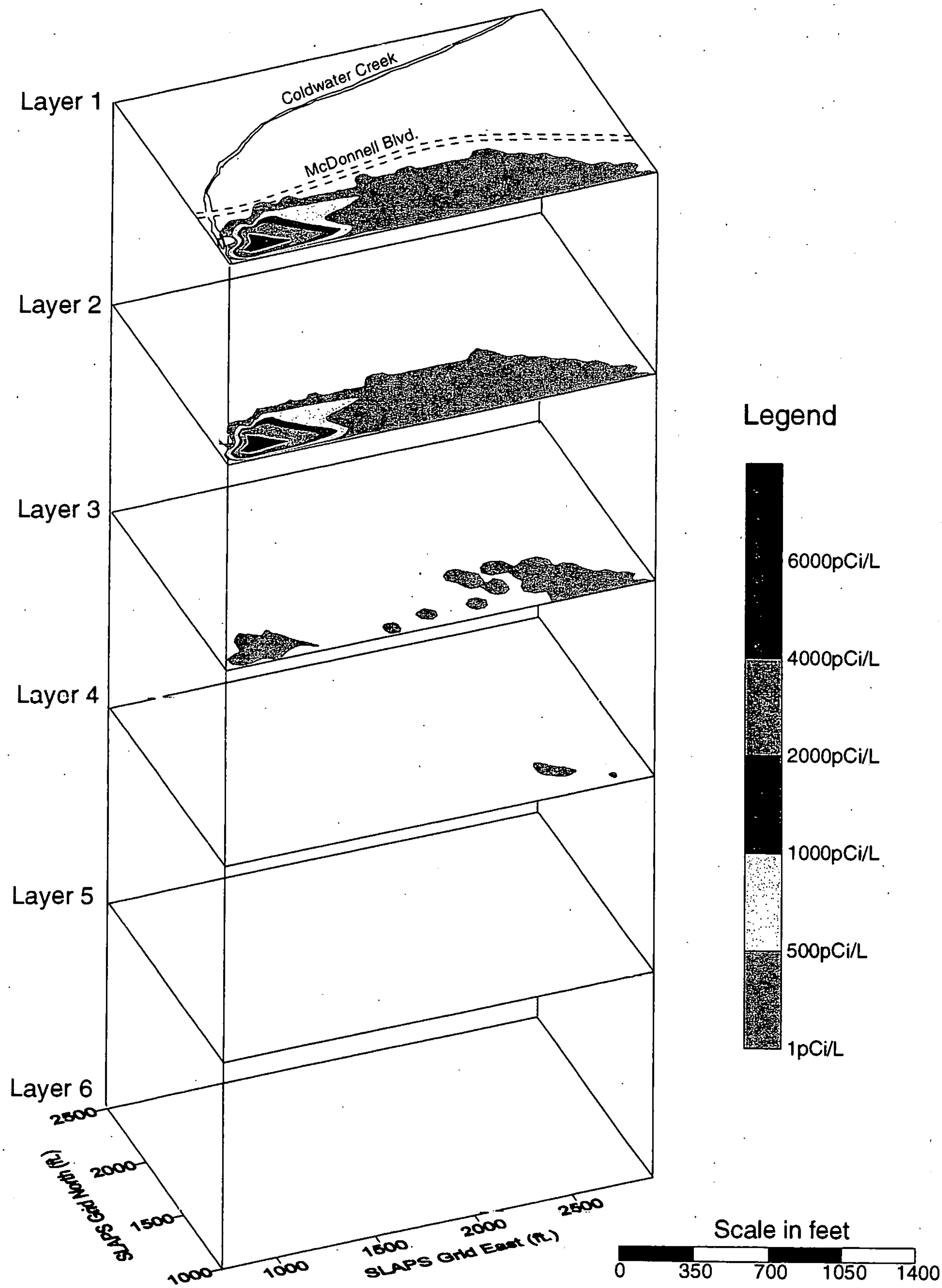

Figure 22. Total Uranium Concentration in Layers 1 through 6 at 500 Years

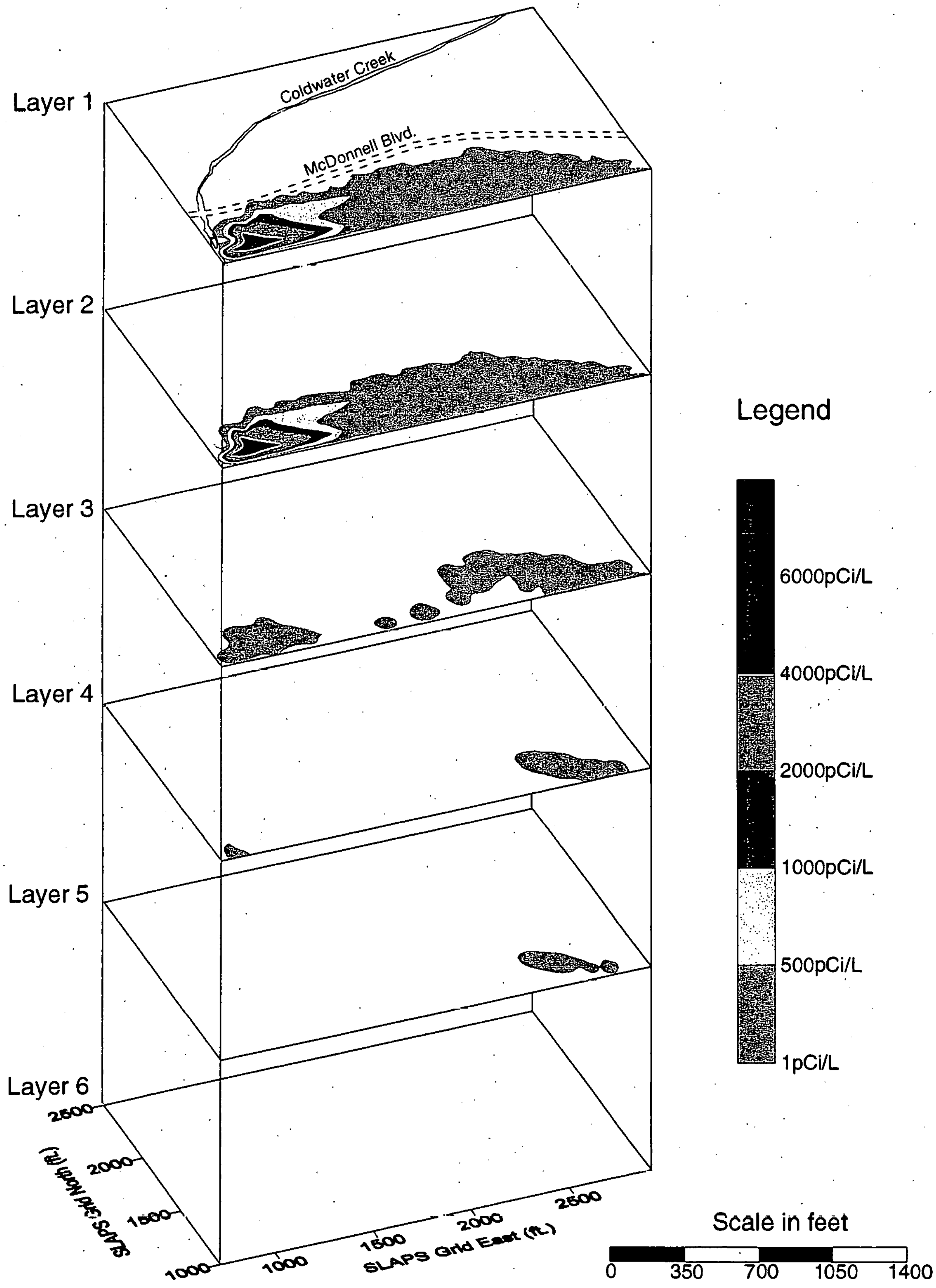

Figure 23. Total Uranium Concentration in Layers 1 through 6 at 1,000 Years

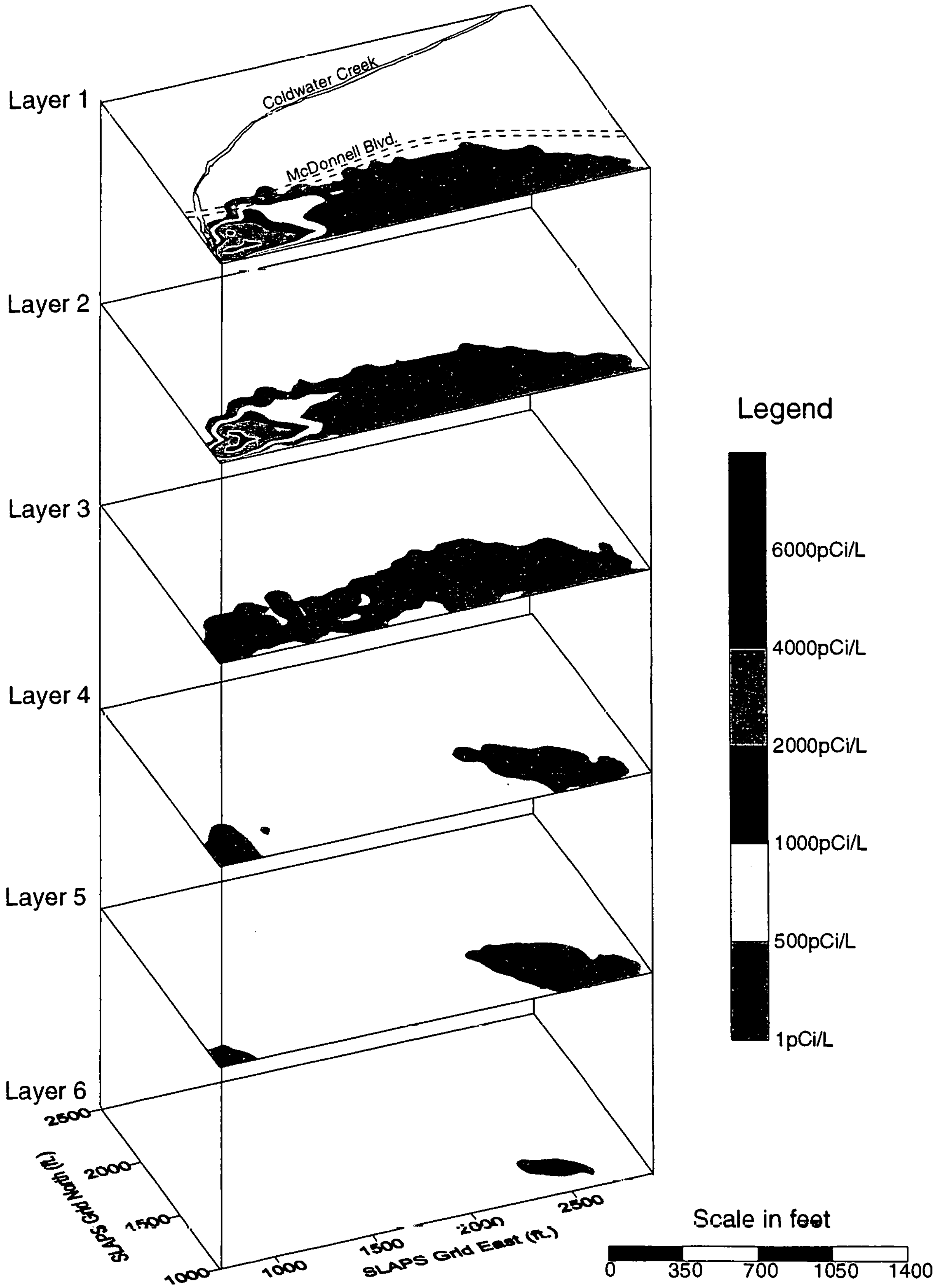

Figure 24. Total Uranium Concentration in Layers 1 through 6 at 5,000 Years

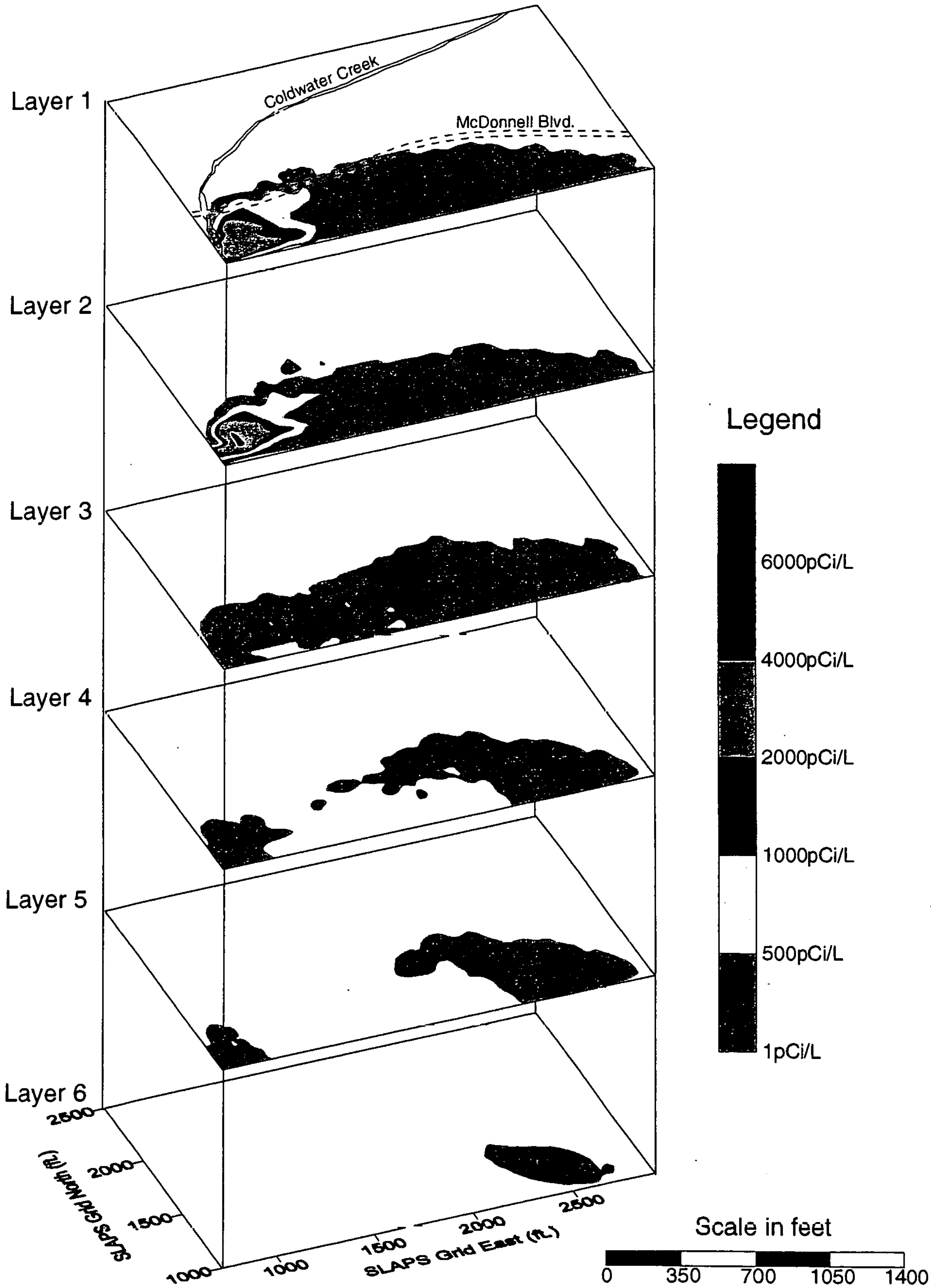

Figure 25. Total Uranium Concentration in Layers 1 through 6 at 10,000 Years

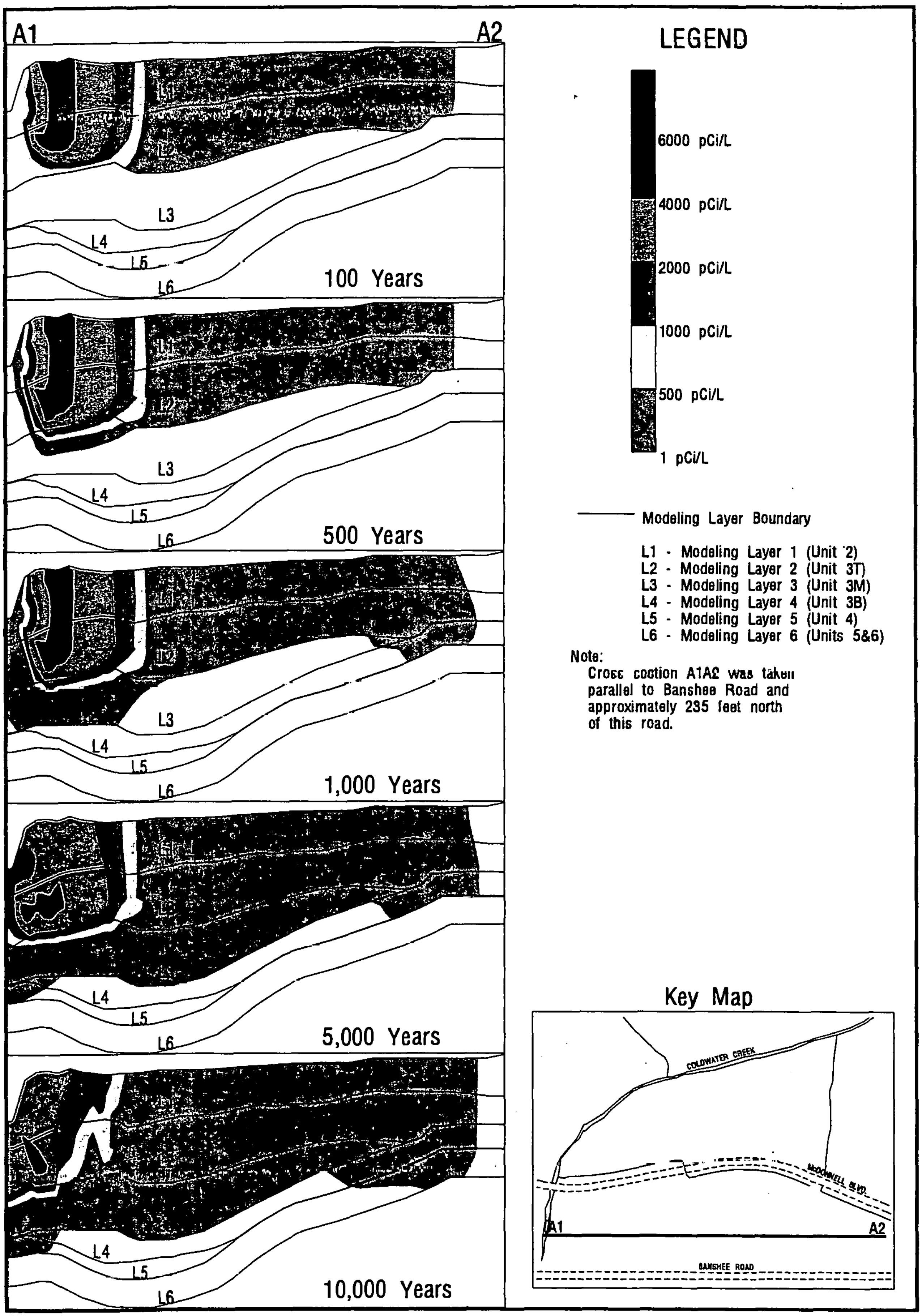

Figure 26. Sectional Views Showing Evolution of Total Uranium Plume

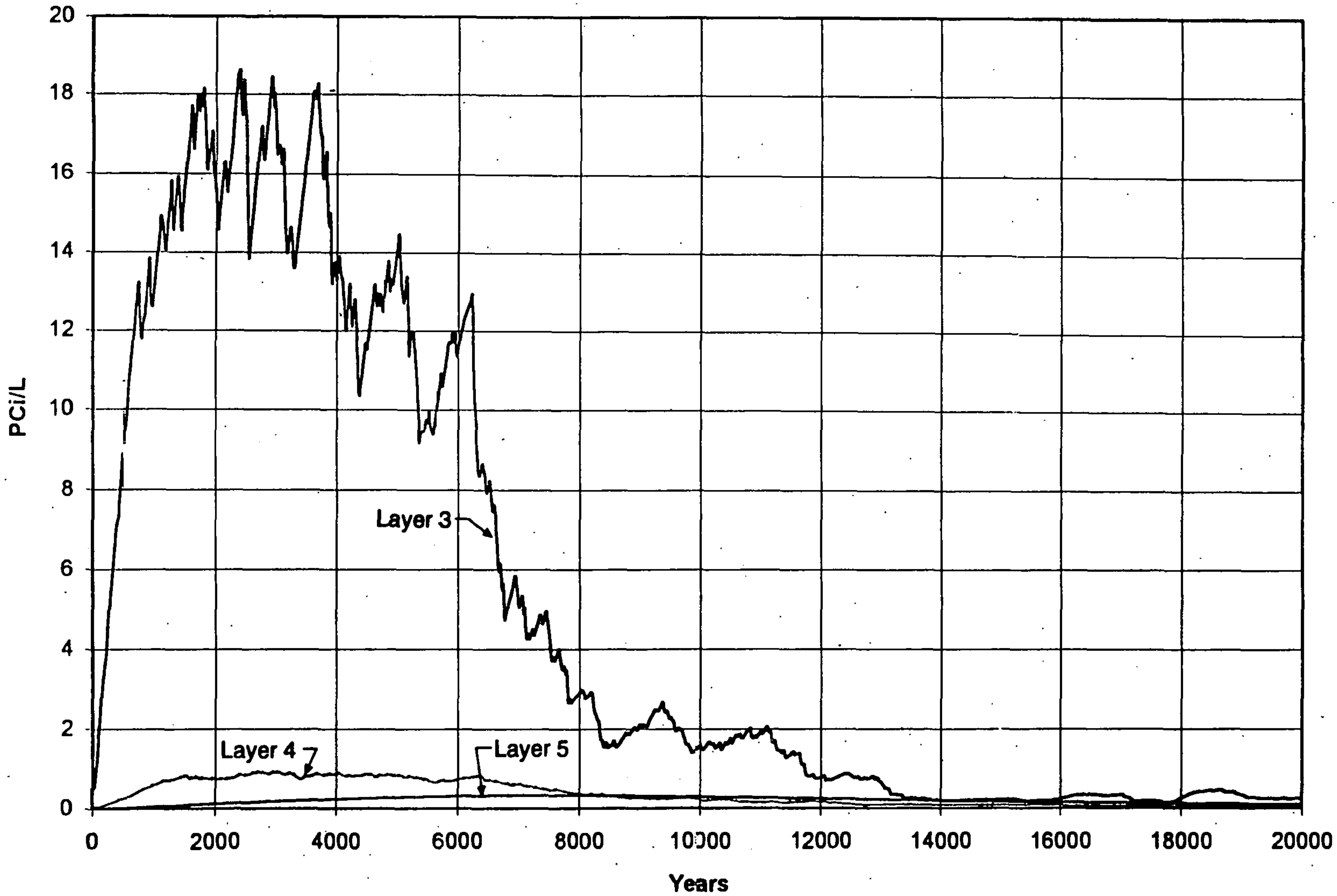

Figure 27
Typical Concentration Breakthrough at Cell 29,3 (Base Case)

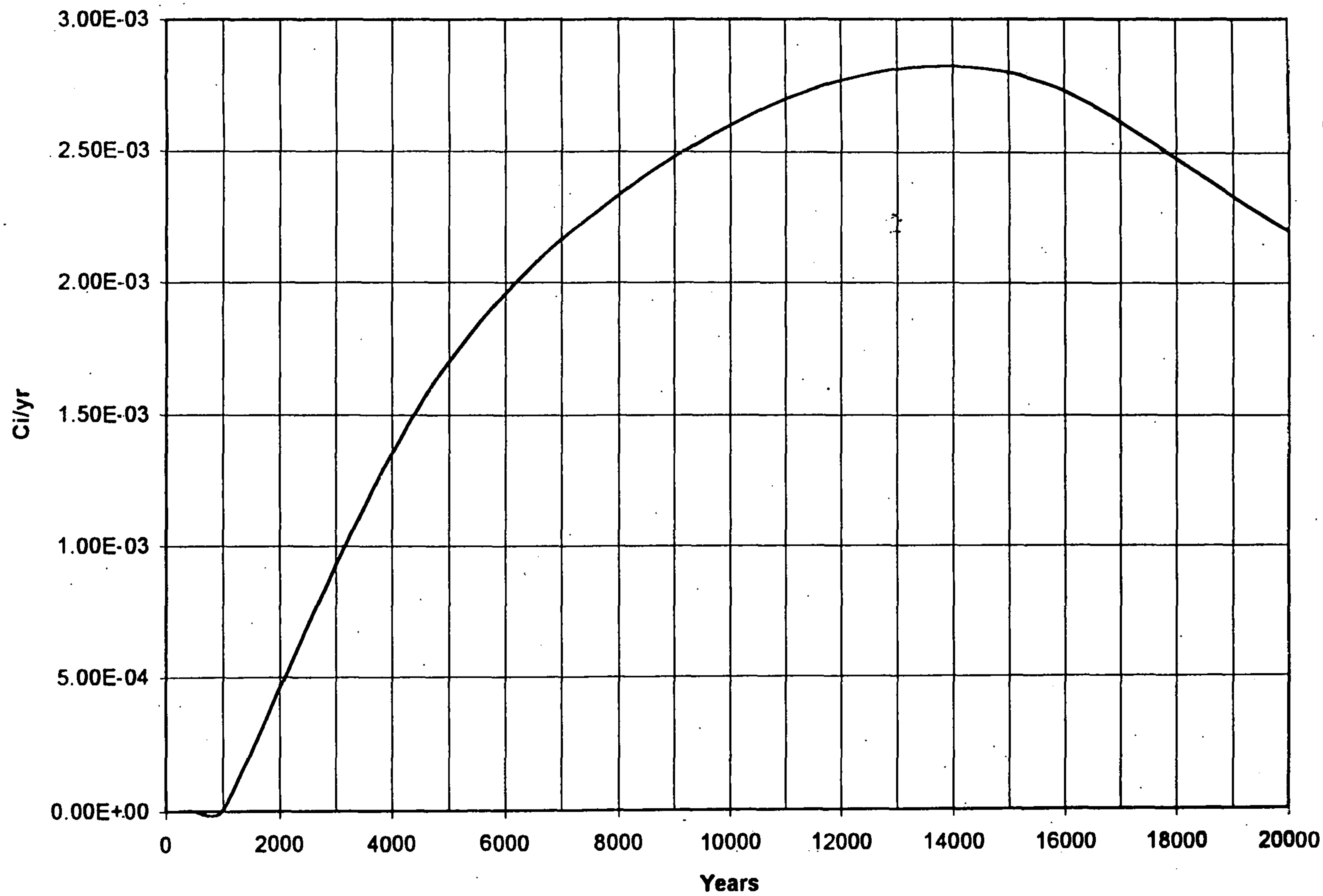

Figure 28
Discharge of Total Uranium into Coldwater Creek (Base Case)

Table 1
Hydraulic Conductivity Data at SLAPS

Table 1a - Shallow Well Slug Test Results

Row	Col	Well	Kh, ft/min	Kh, ft/day
24	3	M13.5-8.5S	1.85E-06	2.66E-03
24	5	A-8	8.80E-06	1.27E-02
22	12	A-7	2.30E-06	3.31E-03
25	17	A-6	9.80E-06	1.41E-02
30	15	M10-15S	5.43E-04	7.82E-01
30	33	A-2	4.70E-05	6.77E-02
19	5	B53W12S	6.05E-04	8.71E-01
16	32	B53W10S	1.54E-05	2.22E-02
15	24	B53W17S	7.40E-04	1.07E+00
10	14	B53W08S	1.18E-04	1.70E-01
5	32	B53W06S	1.30E-03	1.88E+00
1	42	B53W04S	1.42E-05	2.05E-02

Table 1b - Deep Well Slug Test Results

Row	Col	Well	Kh, ft/min	Kh, ft/day
30	16	M10-15D	6.14E-05	8.84E-02
30	36	M10-25D	3.38E-05	4.87E-02
30	44	B53W11D	2.37E-06	3.41E-03
29	9	P-1	5.90E-06	8.50E-03
28	9	P-2	2.30E-06	3.31E-03
24	3	M13.5-8.5D	1.02E-03	1.46E+00
19	4	B53W10D	2.24E-03	3.23E+00
10	14	B53W08D	8.72E-02	1.26E+02
5	32	B53W06D	3.20E-03	4.60E+00
1	42	B53W04D	2.33E-04	3.35E-01

Table 1c - Hydraulic Conductivity - Bedrock

Borehole	Test interval (ft)	Unit	Field permeability (cm/s)	Test Method
B53W09D	61.1-71.1	5	7.5E-08	Slug test in monitoring well
B53W11D	68.5-78.5	5	1.6E-07	Slug test in monitoring well
B53G16	89.0-99.6	6	7.5E-07	Packer test in rock
B53G18	83.6-95.5	6	1.1E-05	Packer test in rock
		Geometric mean	**5.6E-07**	

Table 2
Vertical Conductivity Data at SLAPS

Model layer	Unit	Conductivity cm/s	Conductivity ft/day
1	2	2.5E-06	7.087E-03
2	3T	2.7E-06	7.654E-03
3	3M (includes unit 3B as well)	5.5E-08	1.559E-04
4	3B	3.1E-07	8.78E-04
5	4	1.3E-06	3.685E-03
6	limestone or shale Units 5 and 6	1/10 of horizontal conductivity 5.6E-08	1.59E-05

Table 3
Calibration Statistics

MODFLOW BCF File Name:	basefl.bcf		
MODFLOW BAS File Name:	basefl.bas		
Target Information in:	basefl.trg		
Model-Computed Heads in:	basefl.hds		
Well Name	**Target Head**	**Model Head**	**Residual**
B53W06S	510.70	508.97	1.73
B53W07S	507.75	508.50	-0.75
B53W08S	508.97	509.14	-0.17
B53W09S	510.62	512.58	-1.96
B53W10S	519.97	520.81	-0.84
B53W12S	512.85	513.52	-0.67
B53W13S	516.12	515.41	0.71
B53W14S	523.71	523.20	0.51
M10-15S	521.89	521.90	-0.01
M10-25S	526.33	526.34	-0.01
M10-8S	512.63	512.60	0.03
M11-21	524.25	524.09	0.16
M11-9	515.80	515.04	0.76
M13-8S	512.80	513.33	-0.53
B53W06D	514.75	513.34	1.41
B53W07D	515.97	513.40	2.57
B53W08D	515.99	513.24	2.75
B53W10D	513.81	513.35	0.46
M10-15D	514.86	514.85	0.01
M10-25D	525.86	525.83	0.03
M10-8D	514.94	514.95	-0.01
M13-8D	513.40	513.43	-0.03
----- Summary Statistics For Entire Model -----			
Residual Mean	= 0.279334		
Residual Standard Dev.	= 1.063132		
Residual Sum of Squares	= 26.582090		
Absolute Residual Mean	= 0.731817		
Minimum Residual	= -1.960811		
Maximum Residual	= 2.748972		
Observed Range in Head	= 18.580000		
Residual Standard Dev./Range	= 0.057219		

Table 3
(continued)

Statistics for Layer 2	
Number of Targets	= 14
Residual Mean	= -0.074364
Residual Standard Dev.	= 0.851548
Residual Sum of Squares	= 10.229284
Absolute Residual Mean	= 0.631315
Minimum Residual	= -1.960811
Maximum Residual	= 1.728625
Observed Range in Head	= 18.580000
Residual Standard Dev./Range	= 0.045831
Statistics for Layer 3	
Number of Targets	= 1
Residual Mean	= -0.027551
Residual Standard Dev.	= Undefined
Residual Sum of Squares	= 0.000759
Absolute Residual Mean	= 0.027551
Minimum Residual	= -0.027551
Maximum Residual	= -0.027551
Observed Range in Head	= 0.000000
Residual Standard Dev./Range	= Undefined
Statistics for Layer 4	
Number of Targets	= 1
Residual Mean	= -0.010012
Residual Standard Dev.	= Undefined
Residual Sum of Squares	= 0.000100
Absolute Residual Mean	= 0.010012
Minimum Residual	= -0.010012
Maximum Residual	= -0.010012
Observed Range in Head	= 0.000000
Residual Standard Dev./Range	= Undefined

Table 3
(continued)

Statistics for Layer 5	
Number of Targets	= 4
Residual Mean	= 1.156211
Residual Standard Dev.	= 1.049173
Residual Sum of Squares	= 9.750351
Absolute Residual Mean	= 1.156211
Minimum Residual	= 0.010024
Maximum Residual	= 2.748972
Observed Range in Head	= 2.180000
Residual Standard Dev./Range	= 0.481272
Statistics for Layer 6	
Number of Targets	= 2
Residual Mean	= 1.299583
Residual Standard Dev.	= 1.269600
Residual Sum of Squares	= 6.601596
Absolute Residual Mean	= 1.299583
Minimum Residual	= 0.029983
Maximum Residual	= 2.569182
Observed Range in Head	= 9.890000
Residual Standard Dev./Range	= 0.128372

Table 3
(continued)

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 1 IN STRESS PERIOD 1		
CUMULATIVE VOLUMES L**3		

IN:		
STORAGE	=	0.00000
CONSTANT HEAD	=	776.26
DRAINS	=	0.00000
RECHARGE	=	1102.5
TOTAL IN	=	1878.8
OUT:		
STORAGE	=	0.00000
CONSTANT HEAD	=	128.19
DRAINS	=	1751.2
RECHARGE	=	0.00000
TOTAL OUT	=	1879.4
IN - OUT	=	-0.59583
PERCENT DISCREPANCY	=	-0.03

Table 4
Transport Parameters

Parameter	Value	Source
Longitudinal dispersivity (ft)	1	Sharp-Hansen et al. 1990
Ratio of horizontal transverse to longitudinal dispersivity	0.3333	Sharp-Hansen et al. 1990
Ratio of vertical transverse to longitudinal dispersivity	0.056	Sharp-Hansen et al. 1990
Diffusion coefficient (cm^2/s)	1.0E-06	EPA 1985
Effective porosity	0.33	BNI 1994
Bulk density (lb/ft^3)	96.7	BNI 1994
K_d (ft^3/lb)	1.83	BNI 1994
Decay constant (day^{-1})	4.2503E-13	BNI 1994

Table 5
Total Uranium Concentrations - Model Initial Conditions

1991 Annual Average Total Uranium Concentrations (pCi/L)			
Row	**Column**	**Well**	**Concentration (pCi/L)**
30	2	M10-8S	33
29	3	Well 6	6616
29	4	M11-9	6144
26	4	Well A	3772
24	7	Well D	882
30	16	M10-15S	11
30	36	M10-25S	36
30	41	Well F	404
30	44	B53W11D	17
28	28	M11-21	164
22	30	Well E	204

Reference: SAIC, 1993

Table 6
Base Case - Simulated Maximum Concentrations of Total Uranium in the Groundwater System

Year	Layer 1		Layer 2		Layer 3		Layer 4		Layer 5		Layer 6	
	Location (row, column)	Concentration (pCi/L)	Location (row, column)	Concentration (pCi/L)	Location (row, column)	Concentration (pCi/L)	Location (row, column)	Concentration (pCi/L)	Location (row, column)	Concentration (pCi/L)	Location (row, column)	Concentration (pCi/L)
100	29,3	6575.6	29,3	6603.8	30,38	146.6	30,39	3.15	25,35	0.27	30,39	1.20E-01
500	29,3	6056.4	29,3	6402.5	30,41	324.3	29,41	4.3	25,35	1.4	30,40	3.70E-01
1,000	29,3	5752.7	29,3	6187.0	30,41	314.6	29,41	27.6	29,41	9.3	30,39	1.14E+00
5,000	29,2	3902.3	29,2	4707.4	26,7	564.3	27,38	96.7	26,38	60	26,37	2.68
10,000	28,1	2386.6	29,3	4516.7	27,8	720.1	28,41	121.7	28,41	72	26,37	8.9
15,000	28,2	1729.0	28,3	4474.3	26,7	579.9	28,40	137.7	26,38	82.1	25,37	16.3
20,000	27,1	1204.2	27,2	4262.5	23,4	379.6	26,38	137.3	26,38	97.2	25,37	24.7

Table 7
Total Uranium Flux into Coldwater Creek

Year	Base Case	No M3 Unit	Low Retardation
100	3.5E-07	3.5E-07	0.00331
500	2.0E-06	2.0E-06	0.00255
1,000	4.74E-06	4.8E-06	0.00013
5,000	0.0017	0.00178	0.00013
10,000	0.0026	0.00242	2.38E-06
15,000	0.0028		
20,000	0.0022		

Table 8
Sensitivity Analysis Calibration Statistics

Calibration Statistics	
MODFLOW BCF File Name:	nom3.bcf
MODFLOW BAS File Name:	nom3.bas
Target Information in:	nom3.trg
Model-Computed Heads in:	nom3.hds

Well Name	**Target Head**	**Model Head**	**Residual**
B53W06S	510.70	509.30	1.40
B53W07S	507.75	508.75	-1.00
B53W08S	508.97	509.24	-0.27
B53W09S	510.62	512.50	-1.88
B53W10S	519.97	519.36	-0.61
B53W12S	512.85	513.39	-0.54
B53W13S	516.12	515.15	0.97
B53W14S	523.71	522.30	1.41
M10-15S	521.89	521.90	-0.01
M10-25S	526.33	526.34	-0.01
M10-8S	512.63	512.60	0.03
M11-21	524.25	523.54	0.71
M11-9	515.80	514.98	0.82
M13-8S	512.80	513.24	-0.44
B53W06D	514.75	513.39	1.36
B53W07D	515.97	513.48	2.49
B53W08D	515.99	513.34	2.65
B53W10D	513.81	513.43	0.38
M10-15D	514.86	514.85	0.01
M10-25D	525.86	525.83	0.03
M10-8D	514.94	514.95	-0.01
M13-8D	513.40	513.38	-0.02

Summary Statistics For Entire Model	
Residual Mean	= 0.396242
Residual Standard Dev.	= 1.030214
Residual Sum of Squares	= 26.803656
Absolute Residual Mean	= 0.775860
Minimum Residual	= -1.884883
Maximum Residual	= 2.654856
Observed Range in Head	= 18.580000
Residual Standard Dev./Range	= 0.055447

Table 8
(continued)

Statistics for Layer 2	
Number of Targets	= 14
Residual Mean	= 0.127475
Residual Standard Dev.	= 0.899951
Residual Sum of Squares	= 11.566253
Absolute Residual Mean	= 0.722589
Minimum Residual	= -1.884883
Maximum Residual	= 1.410378
Observed Range in Head	= 18.580000
Residual Standard. Dev./Range	= 0.048437
Statistics for Layer 3	
Number of Targets	= 1
Residual Mean	= 0.019019
Residual Standard Dev.	= Undefined
Residual Sum of Squares	= 0.000362
Absolute Residual Mean	= 0.019019
Minimum Residual	= 0.019019
Maximum Residual	= 0.019019
Observed Range in Head	= 0.000000
Residual Standard. Dev./Range	= Undefined
Statistics for Layer 4	
Number of Targets	= 1
Residual Mean	= -0.010012
Residual Standard Dev.	= Undefined
Residual Sum of Squares	= 0.000100
Absolute Residual Mean	= 0.010012
Minimum Residual	= -0.010012
Maximum Residual	= -0.010012
Observed Range in Head	= 0.000000
Residual Standard Dev./Range	= Undefined
Statistics for Layer 5	
Number of Targets	= 4
Residual Mean	= 1.101676
Residual Standard Dev.	= 1.024240
Residual Sum of Squares	= 9.051033
Absolute Residual Mean	= 1.101676
Minimum Residual	= 0.010024
Maximum Residual	= 2.654856
Observed Range in Head	= 2.180000
Residual Standard Dev./Range	= 0.469835

Table 8
(continued)

Statistics for Layer 6	
Number of Targets	= 2
Residual Mean	= 1.258475
Residual Standard Dev.	= 1.228492
Residual Sum of Squares	= 6.185908
Absolute Residual Mean	= 1.258475
Minimum Residual	= 0.029983
Maximum Residual	= 2.486968
Observed Range in Head	= 9.890000
Residual Standard Dev./Range	= 0.124216

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 1 IN STRESS PERIOD 1	
CUMULATIVE VOLUMES	L**3
IN:	
STORAGE	= 0.00000
CONSTANT HEAD	= 810.21
DRAINS	= 0.00000
RECHARGE	= 1102.5
TOTAL IN	= 1912.7
OUT:	
STORAGE	= 0.00000
CONSTANT HEAD	= 144.92
DRAINS	= 1767.9
RECHARGE	= 0.00000
TOTAL OUT	= 1912.8
IN - OUT	= -0.85815E-01
PERCENT DISCREPANCY	= 0.00

Table 9
No Unit M3 Case - Simulated Maximum Concentrations of Total Uranium in the Groundwater System

Year	Layer 1		Layer 2		Layer 3		Layer 4		Layer 5		Layer 6	
	Location (row, column)	Concentration (pCi/L)	Location (row, column)	Concentration (pCi/L)	Location (row, column)	Concentration (pCi/L)	Location (row, column)	Concentration (pCi/L)	Location (row, column)	Concentration (pCi/L)	Location (row, column)	Concentration (pCi/L)
100	29,3	6575.6	29,3	6604	30,40	258.2	30,41	3.6	25,35	0.27	30,39	1.30E-01
500	29,3	6056.4	29,3	6402.5	30,41	337.3	30,40	4.1	25,35	2.1	30,41	4.00E-01
1,000	29,3	5754.7	29,3	6187.1	28,4	548	29,39	61.6	29,39	26.1	30,41	1.19E+00
5,000	29,2	3955.2	29,2	4915.8	28,4	1289.7	26,37	83.6	26,38	58.8	28,39	3.3
10,000	28,3	2247.4	26,3	4590.9	27,3	883.2	28,40	136.1	26,39	77.8	26,36	10.5

Table 10
Low Retardation Case - Simulated Maximum Concentrations of Total Uranium in the Groundwater System

Year	Layer 1		Layer 2		Layer 3		Layer 4		Layer 5		Layer 6	
	Location (row, column)	Concentration (pCi/L)	Location (row, column)	Concentration (pCi/L)	Location (row, column)	Concentration (pCi/L)	Location (row, column)	Concentration (pCi/L)	Location (row, column)	Concentration (pCi/L)	Location (row, column)	Concentration (pCi/L)
100	29,2	2467.4	26,4	3289.2	28,38	200.9	27,38	61.7	26,37	39.4	26,36	5.9
200	28,1	1167.9	26,2	2305.3	27,37	144	26,38	70.5	26,38	51.5	26,37	13.8
500	22,2	94.3	27,1	425.9	25,34	54	26,41	38.9	24,38	28.3	25,37	24.5
700	30,37	53	13,7	107.9	9,21	36	27,40	27.5	27,40	23.9	25,37	23.1
1,000	30,37	22.5	13,7	21	6,21	28.9	27,40	17.3	27,40	15.3	23,35	17.5

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