Flow and Transport Modeling for SLAPS Groundwater System

Bechtel Environmnetal, Inc.
Oak Ridge, TN 37831

Computer Codes Used

- Flow - Modflow
- Transport - MT3D

Model Domain

- See Figure 1. Uniform grid 50’ by 50’

Stratigraphy

- Based on Figures 3-7, -8, -9, -10, and -11 of Ref. 1 (BNI, 1994)
- A thickness of 25 ft. for the bedrock (Limestone or Shale) layer is assumed

Parameter Values

- Hydraulic Conductivity
  - Upper system - based on Figure E-1 of Ref. 1 (BNI, 1994)
  - Aquitard Units 3M and 3B - Table 3-3 of Ref. 1 (BNI, 1994)
  - Lower system - based on Figure E-3 of Ref. 1 (BNI, 1994)
  - Bedrock (Units 5-Shale, and 6-Limestone) - From Table A-2 of Ref. 1 (BNI, 1994)

  Vertical Conductivities are taken from Table 3-3 of Ref. 1 (BNI, 1994)
- Total Porosity
  - Upper System - 0.41
  - Aquitard Units 3M and 3B - 0.43
  - Lower System - 0.44

  Effective porosity is assumed to be 80% of the total porosity

Parameter Values

- Bulk Density
  - Upper System - 1.54 g/cc
  - Aquitard Units 3M and 3B - 1.42 g/cc
  - Lower System - 1.48 g/cc
- Uranium Distribution Ratio

  Assume to be 1/10 th of the geometric mean values given in Table 5-1, Ref. 1 (BNI, 1994)
  - Upper System - 11.4 cc/g
  - Aquitard Units 3M and 3B - 5.85 cc/g
  - Lower system - 11.2 cc/g

Parameter Values

- Diffusion and Dispersion Coefficients
  - Diffusion Coefficient - 1.0e-04 ft ** 2/day
  - Dispersion Coefficients
    - Longitudinal Dispersivity - 5 ft
    - Transverse Dispersivity - 1/3 longitudinal
    - Vertical Dispersivity - 0.056 Longitudinal

Major Assumption

- Any ongoing introduction of contaminants to the groundwater system is negligible compared to the relict contamination already present in the groundwater

Initial and Boundary Conditions

- Coldwater creek as discharge boundary for both the lower and upper systems
- Prescribed heads at the southern boundary (Banshee Road) based on average observed heads
- No-flow boundary to the east along an interpreted streamline for the upper system. Prescribed heads for the lower system
- Initial concentration of total uranium in the upper system based on Figure 2-25 of Ref.2 (SAIC, 1993). Zero initial concentration in the lower system
- Zero total uranium flux along boundaries

Calibration Target

- Average groundwater levels as recorded in the wells of both the upper and lower groundwater systems were used as calibration target. Average groundwater levels at any well was determined by time-averaging the water level data for a 5-year period (1988-93).
- NOTE: Some of the data used for averaging may not be representative of actual water levels because of well plugging. The overall effect of these data on the average levels is not believed to be significant; however, these data will be screened out in the future refinements.

Preliminary Results

- Recharge rate is found to be about 2 in./yr. yielding the calibration statistics presented in Table 1. This recharge rate corresponds to a base flow at SLAPS of about 1.8 cfs. Figure 2 shows the modeled versus the observed heads.
- The simulated total uranium concentration evolution for units 3M (layer 3), 3B (layer 4), 4 (layer 5), and bedrock (layer 6) is shown in Figure 3.
- The total uranium flux into Coldwater Creek at 100, 1,000 and 10,000 years is estimated, respectively, to be 8.8 - E6, 7.7 - E4, and 1.7 -E3 Ci/yr.

References

- 1. BNI, 1994. Site Suitability Study for St. Louis Airport Site, Vols. 1 & 2
- 2. SAIC, 1993. Remedial Investigation Addendum Report for the St. Louis Site

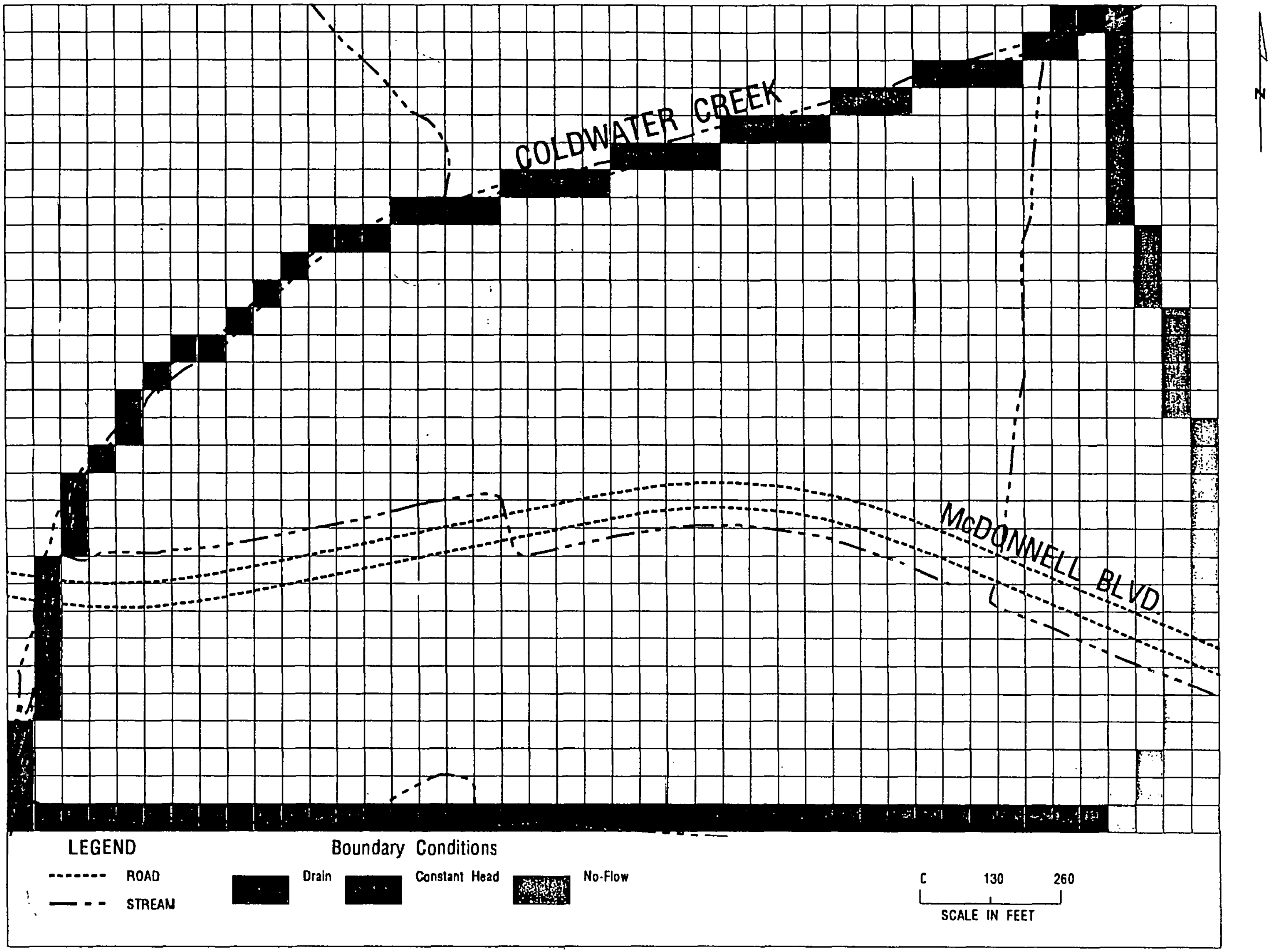
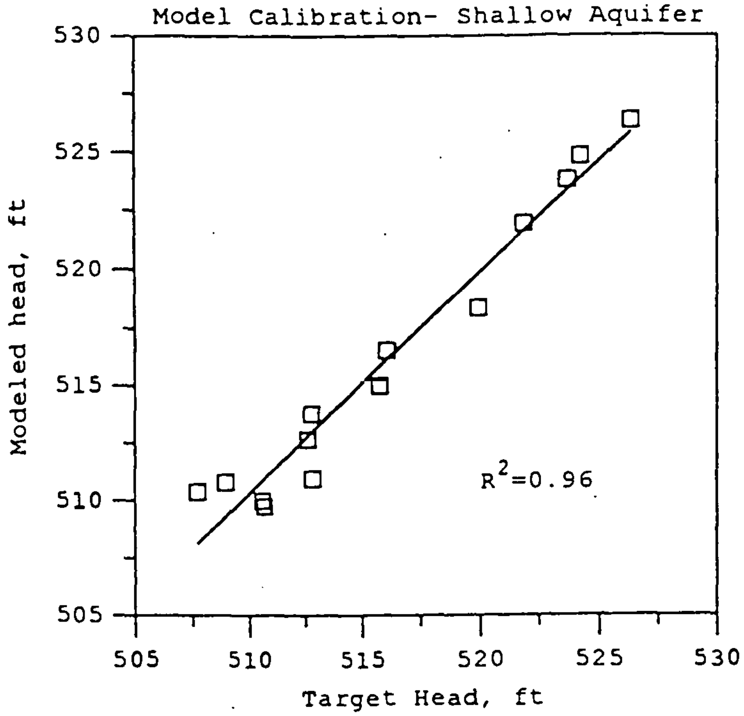


Figure 1 Model Grid and Boundary Conditions (Layer 1)



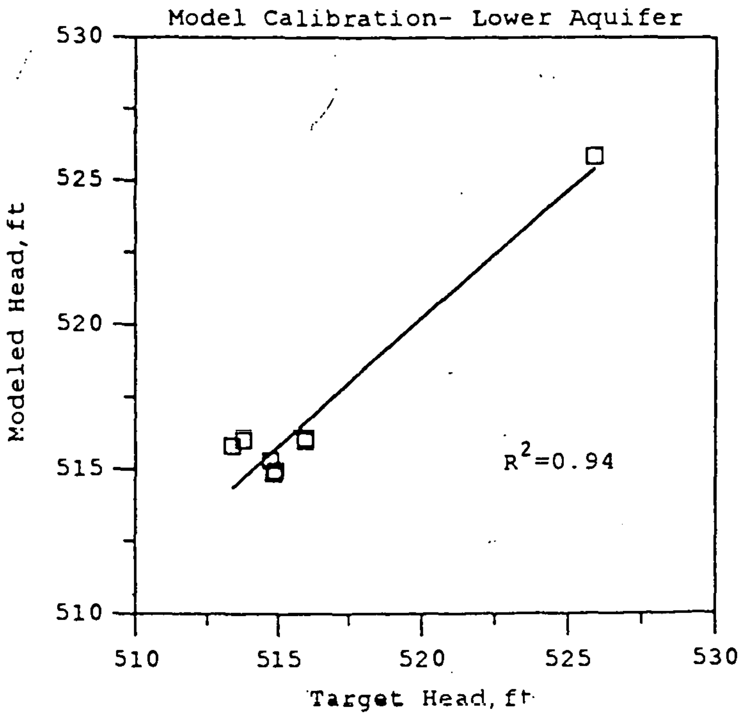


Figure 2. Model Versus Observed Heads

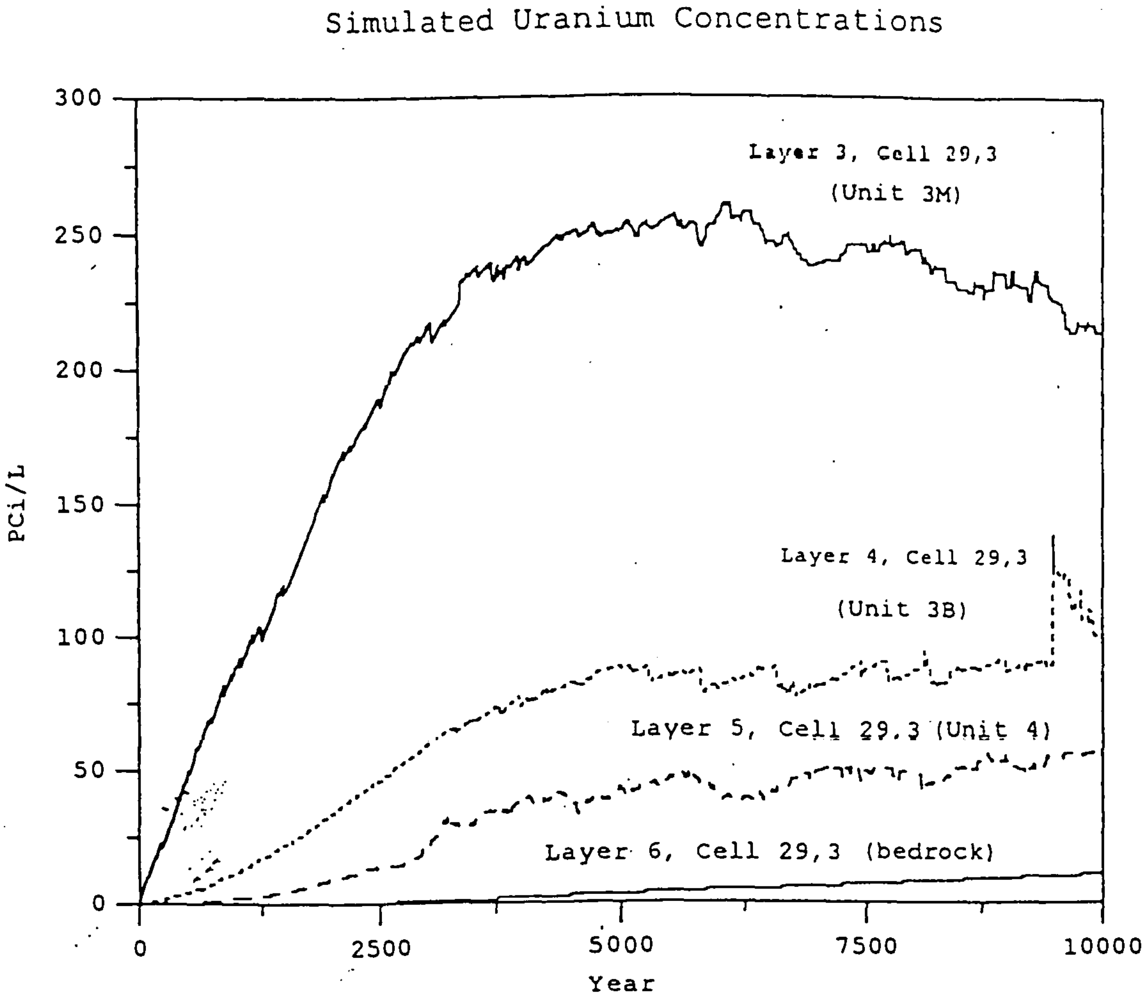


Figure 3. Total Uranium Concentration Evolution in Various Units

Table 1. Model Calibration Statistics

Well Name	Target Head	Model Head	Residual
B53W06S	510.70	509.69	1.01
B53W07S	507.75	510.33	-2.58
B53W08S	508.97	510.74	-1.77
B53W09S	510.62	509.95	0.67
B53W10S	519.97	518.28	1.69
B53W12S	512.85	510.89	1.96
B53W13S	516.12	516.47	-0.35
B53W14S	523.71	523.77	-0.06
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	524.77	-0.52
M11-9	515.80	514.92	0.88
M13-8S	512.80	513.73	-0.93
B53W06D	514.75	515.28	-0.53
B53W07D	515.97	515.97	-0.00
B53W08D	515.99	516.10	-0.11
B53W10D	513.81	516.01	-2.20
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	515.80	-2.40

```
- --- Summary Statistics For Entire Model -----
 Residual Mean              = -0.236651
 Residual Standard Dev.     = 1.160951
 Residual Sum of Squares    = 30.883840

 Absolute Residual Mean     = 0.806921
 Minimum Residual           = -2.576904
 Maximum Residual           = 1.955621

 Observed Range in Head     = 18.580000
 Res. Std. Dev./Range       = 0.062484

----- Statistics for Layer   1 -----
 Number of Targets          = 14
 Residual Mean              = 0.000173
 Residual Standard Dev.     = 1.194428
 Residual Sum of Squares    = 19.973222

 Absolute Residual Mean     = 0.890250
 Minimum Residual           = -2.576904
 Maximum Residual           = 1.955621

 Observed Range in Head     = 18.580000
 Res. Std. Dev./Range       = 0.064286
```

Table 1. (Contd. ...)

----- Statistics for Layer 5 -----

Number of Targets	= 8
Residual Mean	= -0.651095
Residual Standard Dev.	= 0.969486
Residual Sum of Squares	= 10.910617
Absolute Residual Mean	= 0.661096
Minimum Residual	= -2.401270
Maximum Residual	= 0.029983
Observed Range in Head	= 12.460000
Res. Std. Dev./Range	= 0.077808

Table 1. (Contd. ...)

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 1 IN STRESS PERIOD 1

CUMULATIVE VOLUMES	L**3	RATES FOR THIS TIME STEP	L**3/T
IN:		IN:	
STORAGE =	0.00000	STORAGE =	0.00000
CONSTANT HEAD =	194.35	CONSTANT HEAD =	194.35
DRAINS =	0.00000	DRAINS =	0.00000
RECHARGE =	1067.1	RECHARGE =	1067.1
TOTAL IN =	1261.4	TOTAL IN =	1261.4
OUT:		OUT:	
STORAGE =	0.00000	STORAGE =	0.00000
CONSTANT HEAD =	310.50	CONSTANT HEAD =	310.50
DRAINS =	950.67	DRAINS =	950.67
RECHARGE =	0.00000	RECHARGE =	0.00000
TOTAL OUT =	1261.2	TOTAL OUT =	1261.2
IN - OUT =	0.23083	IN - OUT =	0.23083
PERCENT DISCREPANCY =	0.02	PERCENT DISCREPANCY =	0.02

REFERENCED FIGURES AND TABLES

Regulation and Regulating Entity	Citation and Status of Regulation	Description of Regulation	Media and Specific Standards/Dose Limits	Comments: Future Direction
NRC: *Licensing Requirements for Land Disposal of Radioactive Waste: Protection of the General Population from Releases of Radioactivity*	10 CFR 61.41 Effective in December 1982	Operations at land disposal facilities are conducted in compliance with 10 CFR Part 20 except for releases of radioactivity in effluents from the land disposal facility, which is governed by 10 CFR 61.41. Every reasonable effort shall be made to maintain radiation exposures ALARA.	Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity n effluents to the general environment ALARA.	
NRC: *Radiological Criteria for Decommissioning*	Proposed Rule 59 FR 43200, August 22, 1994 To be codified at 10 CFR Parts 20, et al	This rule proposes specific radiological criteria for the decommissioning of lands and structures.	The proposed rule establishes a dose limit for release of a decommissioned site of 15 mrem per year TEDE for residual radioactivity distinguishable from background. The proposed rule also requires that the licensee reduce any residual radioactivity to as close to indistinguishable from background as reasonable achievable (ALARA). All readily removable residual radioactivity should be removed from a site before it is decommissioned (i.e. removable using non-destructive, common, housekeeping techniques).	TEDE means total effective dose equivalent, or the sum of the deep-dose equivalent for external exposures and the committed effective dose equivalent for internal exposures. Site radiological criteria may be met through land use restrictions or other types of institutional controls.

Regulation and Regulating Entity	Citation and Status of Regulation	Description of Regulation	Media and Specific Standards/Dose Limits	Comments: Future Direction
DOE: *Occupational Radiation Protection*	10 CFR Part 835 Subpart C and Appendix A Final Rule Effective January 13, 1993. facilities must comply with the provisions of the rule by January 1, 1996	This rule codifies the provisions of DOE Order 5480.11 relating to radiation protection standards. In it, DOE followed the *Radiation Protection Guidance to Federal Agencies for Occupational Workers*, January 20, 1987, which is generally consistent with recommendations published by the International Commission on Radiological Protection (ICRP). The *Guidance* follows ICRP methodology.	The occupational exposure to general employees resulting from DOE activities, other than planned special exposures and emergency exposure situations shall be controlled so the following annual limits are not exceeded: (1) a total effective dose equivalent of 5 rems (0.05 Sv); (2) the sum of the deep dose equivalent for external exposures and the committed dose equivalent to any organ or tissue other than the lens of the eye of 50 rems (0.5 Sv); (3) a lens of the eye dose equivalent of 15 rems (0.15 Sv); and (4) a shallow dose equivalent of 50 rems (0.5 Sv) to the skin or to any extremity. DAC values are listed in Appendix A. Any member of the public exposed to radiation and/or radioactive material during direct on-site access at a DOE site or facility shall not exceed 0.1 rem (0.001 Sv) total effective dose equivalent in a year.	DOE developed its standards so that they are consistent with NRC standards in using the committed dose method for evaluation against the regulatory dose limits. DOE established more rigorous standards than NRC for contamination control, posting, and dosimetry. Deep dose equivalent means the dose equivalent derived from external radiation at a depth of 1 cm in tissue.

Regulation and Regulating Entity	Citation and Status of Regulation	Description of Regulation	Media and Specific Standards/Dose Limits	Comments: Future Direction
DOE: *Radiation Protection of the Public and the Environment*	10 CFR Part 834 Proposed Rule, 56 FR 16268, March 25, 1993 DOE Order 5400.5	This Order and proposed rule establish standards and requirements for operations of DOE and DOE contractors with respect to protection of members of the public and the environment against undue risk from radiation.	Generic guidelines for residual concentrations of Ra-226, Ra-228, Th-230 and Th-232 in soil are: (1) 5 pCi/g, averaged over the first 15 cm of soil below the surface; and (2) 15 pCi/g, averaged over 15-cm-thick layers of soil more than 15 cm below the surface. Residual radioactive materials in soil are those concentrations in excess of background concentrations averaged over an area of 100 square meters. These derivations are obtained by means of environmental pathway analysis and basic dose limits. Procedures for these derivations are given in DOE/CH-8901. Residual concentrations of radionuclides in the air and water shall not exceed 100 mrem (1 mSv) per year. Exposures to members of the public from all radiation sources shall not cause an effective dose equivalent to be greater than 100 mrem (1 mSv) per year. Exposures to members of the public from all radiation sources released into the atmosphere shall not cause an effective dose equivalent to be greater than 10 mrem (0.1 mSv) per year. (cont'd. in next column)	(cont'd. from previous column): Public radiation doses resulting from DOE Operations are calculated using the Derived Concentration Guides (DCG) for air and water. DCGs for water ingestion, air inhalation, and immersion in a gaseous cloud are provided as reference values. These DCGs are based on a committed effective dose equivalent of 100 mrem for the radionuclide taken into the body by ingestion or inhalation during one year. The DCG values apply to only one mode of exposure, i.e., either ingestion or inhalation. For known mixtures of radionuclides the sum of the ratios of the observed concentration of each radionuclide to its corresponding DCG must not exceed 1.0.

Summary of Potential FUSRAP Cleanup Guidelines and modeled and measured concentrations for radionuclides and TCE in water at the St. Louis Site

Standards

	Soil/Sediment (pCi/g)	Water (pCi/L)		
		Current[a]	Proposed[b]	DOE (order)
Ra-226	5/15[c]	5[d]	20[e]	5
Th-230	5/15[c]	NA	79[f]	12
Total uranium	100	NA	30[g]	24
TCE	NA	5 µg/L[a]	NA	5 µg/L

Coldwater Creek Surface Water

Location on Coldwater Creek	radium-226 (pCi/L)		thorium-230 (pCi/L)		total uranium (pCi/L)	
	measured	modeled	measured	modeled	measured	modeled
Upstream of SLAPS	0.5		0.5		4.5	
McDonnell Blvd. Bridge	1.9	0.2 pCi/L current stormflow load to CWC	0.6	4.0 pCi/L current stormflow load to CWC	2.9	0.2 pCi/L current stormflow load to CWC
Mouth of Ballfield Ditch	0.8		0.4		6.0	
1 mi. from mouth of CWC	2.6		1.0		4.5	

[a] From 40 CFR 141

[b] From the July 1991 Proposed Rule, 40 CFR 141, 142, FR 56 No. 138.

[c] 5 pCi/g in the surface (0 to 15 cm interval) 15 pCi/g in each 15 cm interval below the surface interval. The limit is applicable to the sum of the Ra-226 and Th-232 above background concentrations (or Th-230 and Th-232 if Th-230 is greater than Ra-226).

[d] The current EPA Maximum Contaminant Level (MCL) of 5 pCi/g applies to total radium (Ra-226 and Ra-228).

[e] The proposed EPA MCLs for radium are 20 pCi/L for Ra-226 and 20 pCi/L for Ra-228.

[f] Based on the proposed alpha emitter concentration limits listed in Appendix C of FR 56 No. 138.

[g] The proposed total uranium MCL is 20 µg/L. Based on EPA assumptions in FR 56 No. 138, 20 µg/L is approximately 30 pCi/L.

[h] Modeling indicates that no shallow groundwater transport of radionuclides is currently occurring to Coldwater Creek.

Groundwater

For measured radionuclide concentrations in groundwater see Table 3-21 (provided) from the Remedial Investigation Addendum Report for the St. Louis Site.

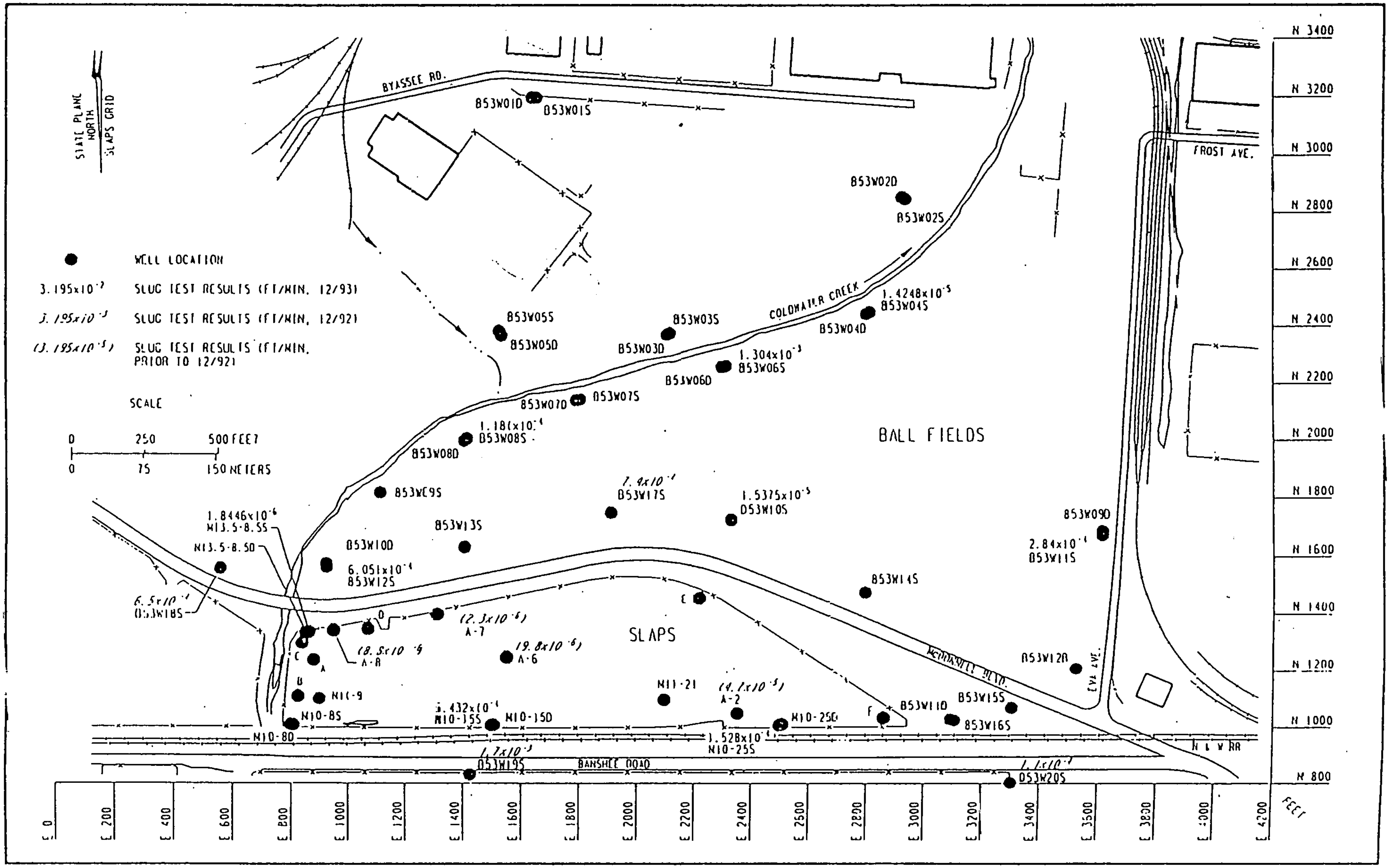
The results of the MODFLOW and MT3D models

Modeled total uranium concentrations (pCi/L)				
Stratigraphic unit	100 yr	1,000 yr	10,000 yr	Projected maximum
3M	11	85	210	260
3B	nb	10	100	140
4	nb	2	56	56
Limestone bedrock	nb	nb	10	12
contribution to base flow (2 cfs) concentrations in Coldwater Creek	5.0 E-3	0.4	1	not estimated

nb = No break-through has yet occurred.

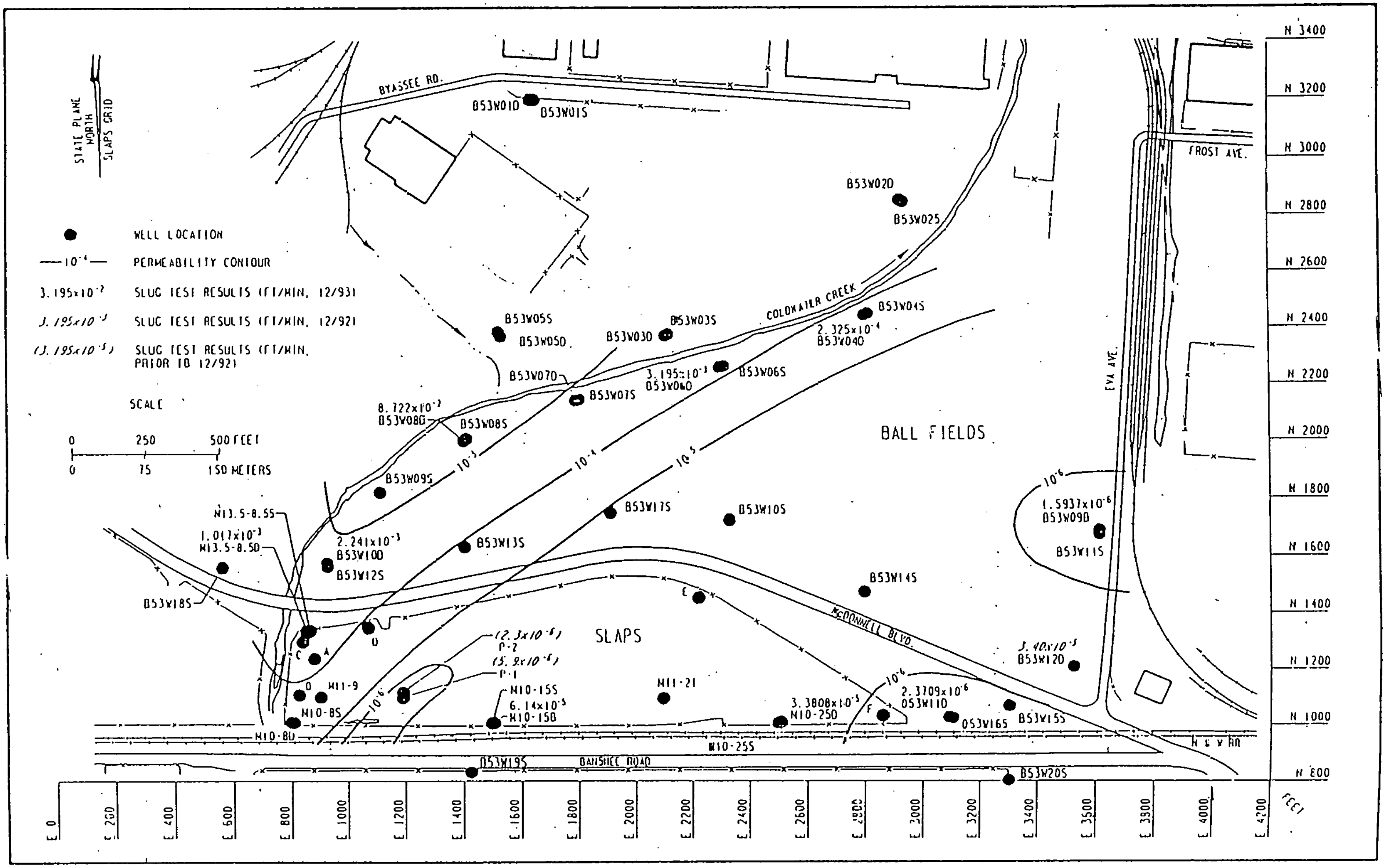
For TCE in groundwater, the following measurements were performed:

Well	TCE (µg/L)	year
B	110	1989
M11-9	130	1989
B53W12S	not detected	1992
B53W17S	1400, 1200	1992 & 1993 respectively
B53W18S	not detected	1992
B53W19S	19	1992
B53W20S	not detected	1992



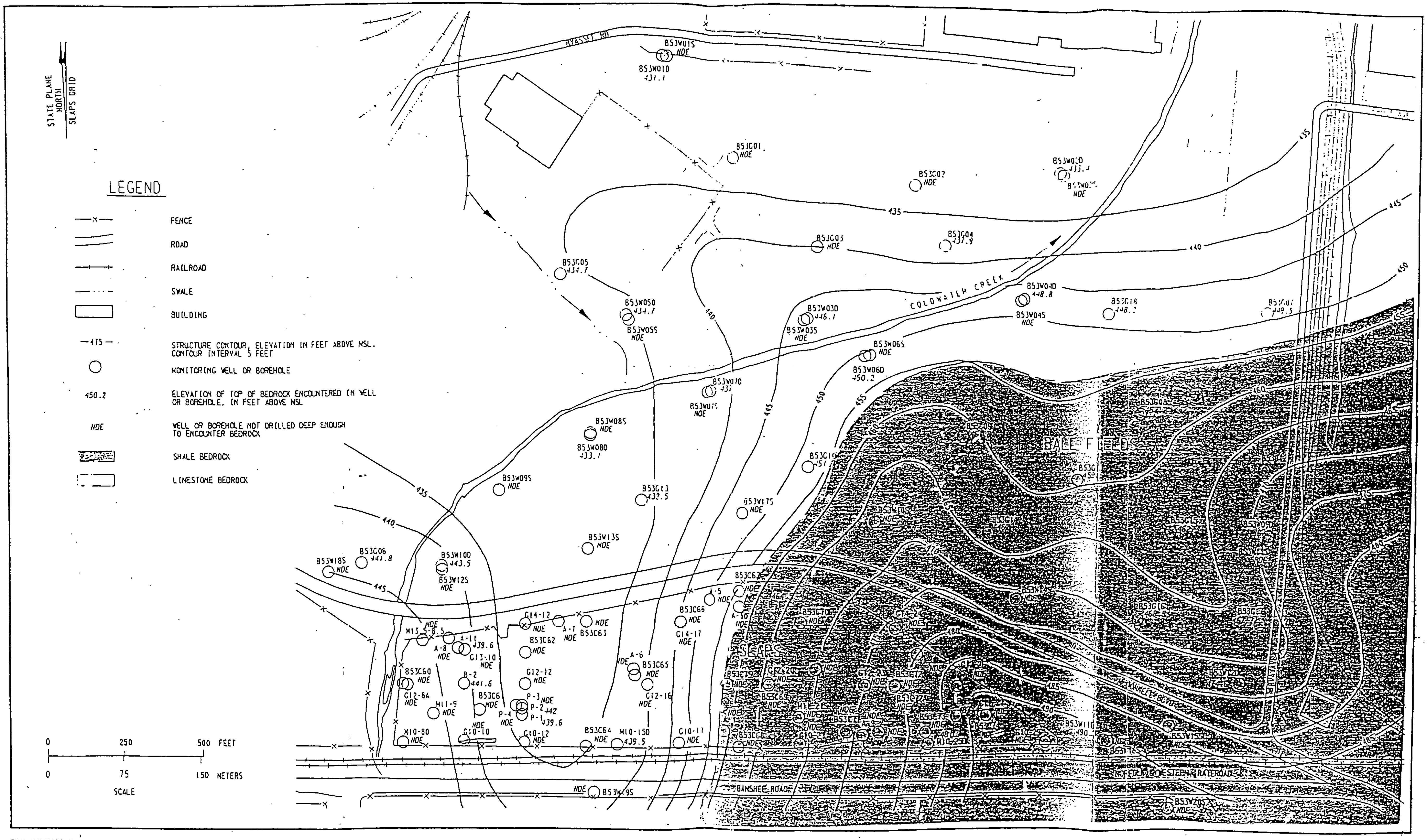
R02F036.DGN

Figure E-1
Shallow Well Slug Results
Falling Head Test



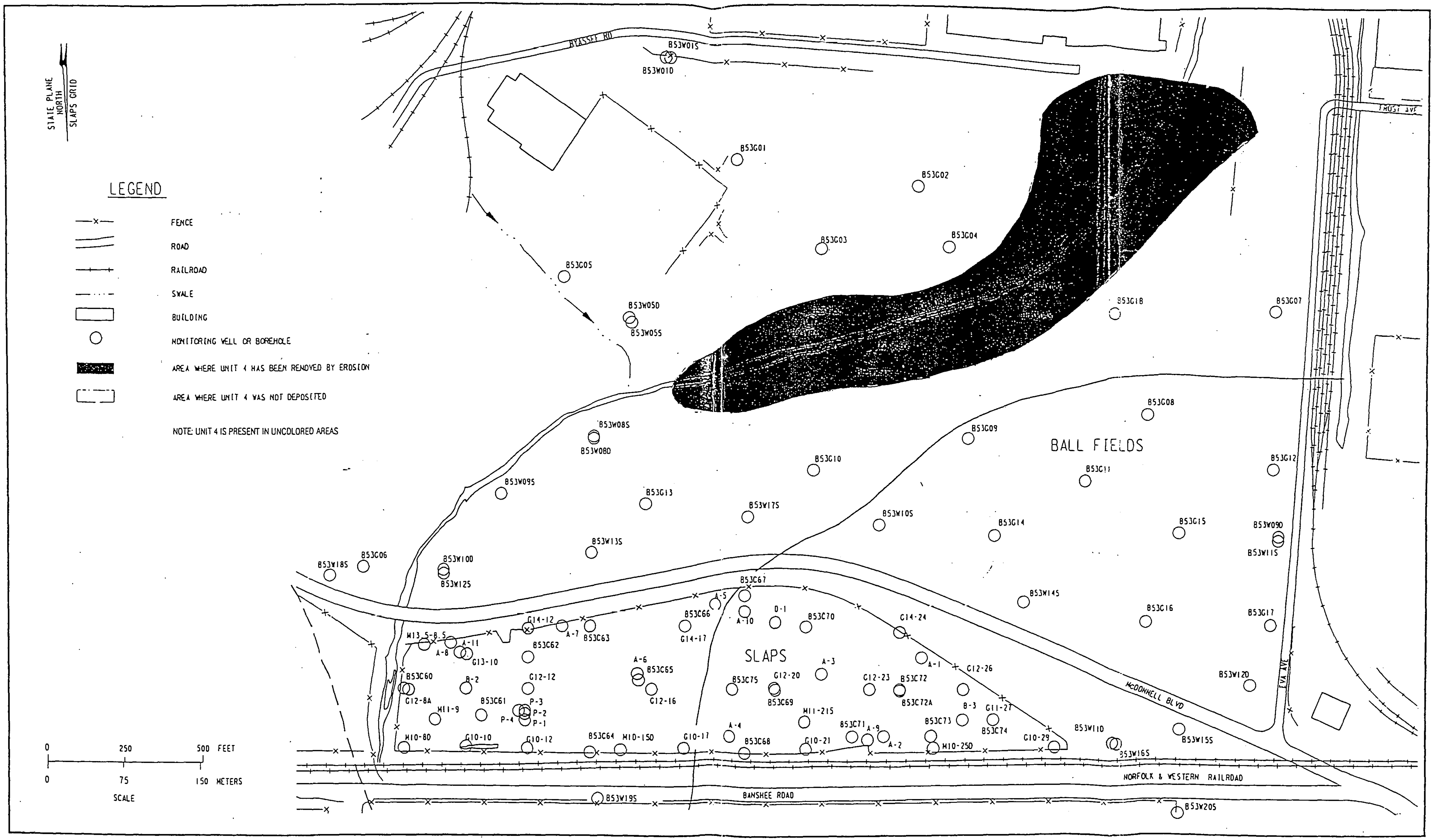
R02F035.DGN

Figure E-3
Deep Well Slug Results
Falling Head Test



R02 R02F033.DGN

Figure 3-7
Structure Contour Map of Top of Bedrock



R02 R02F032.DGN

Figure 3-8
Distribution of Unit 4

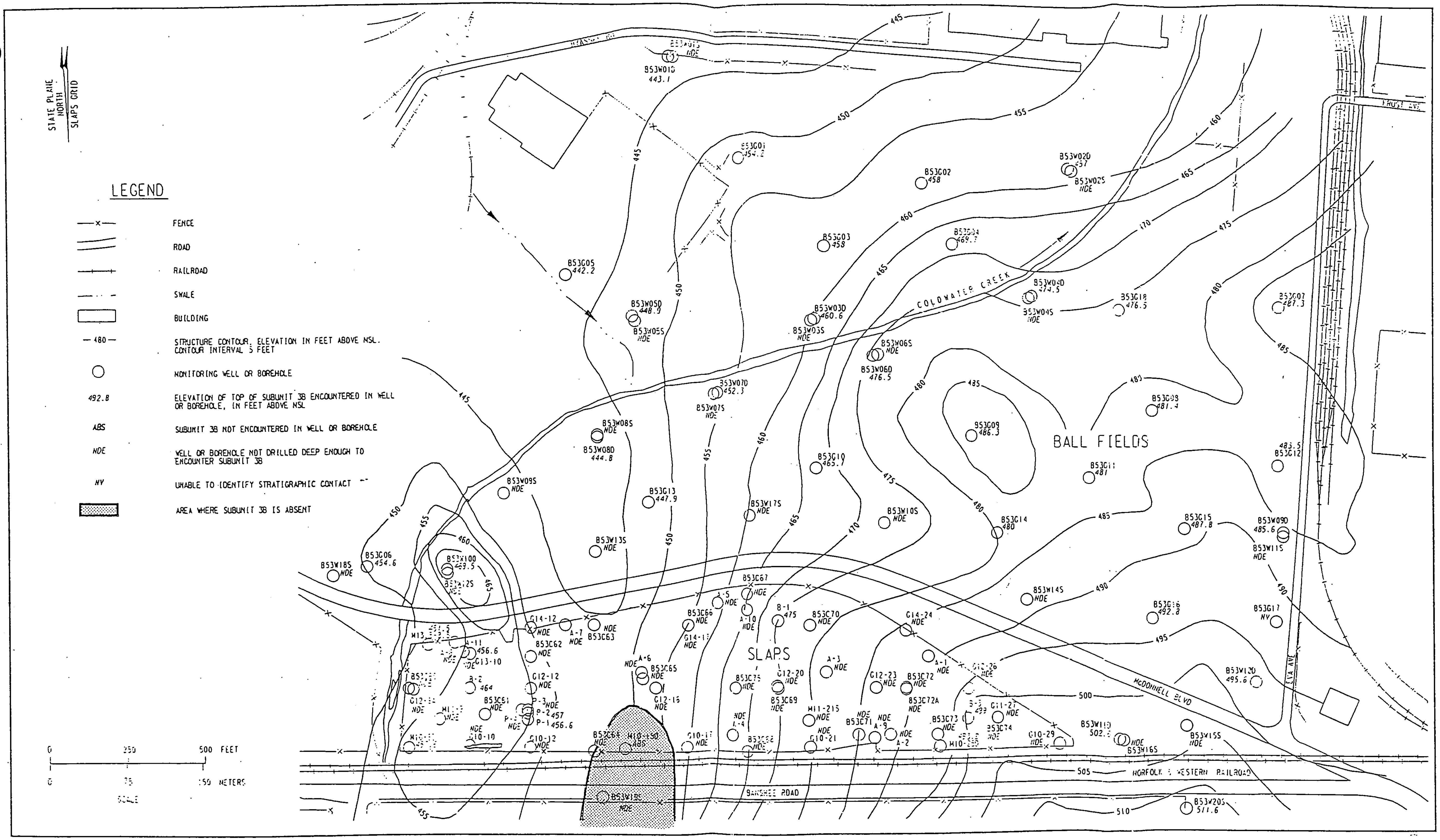
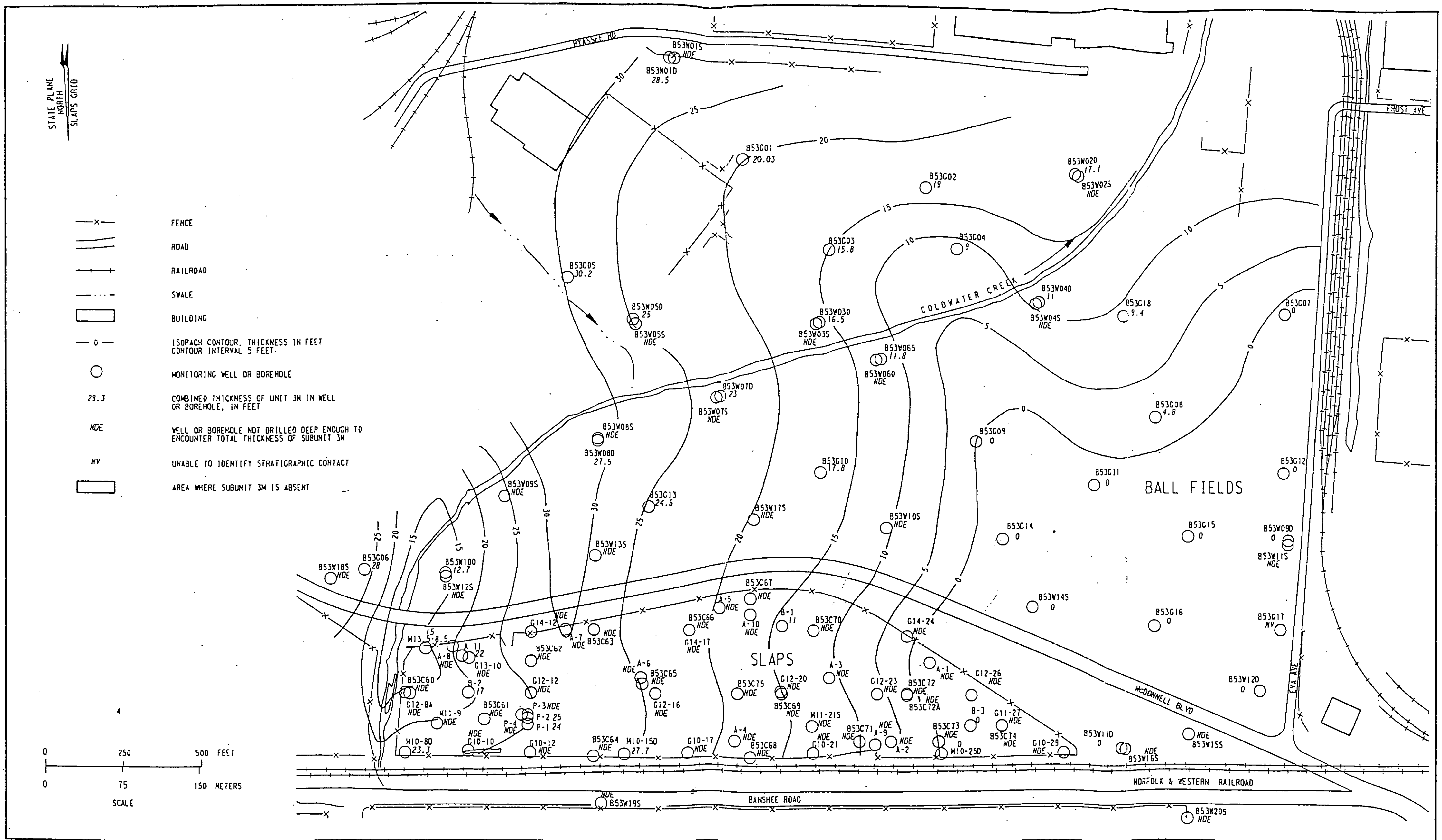


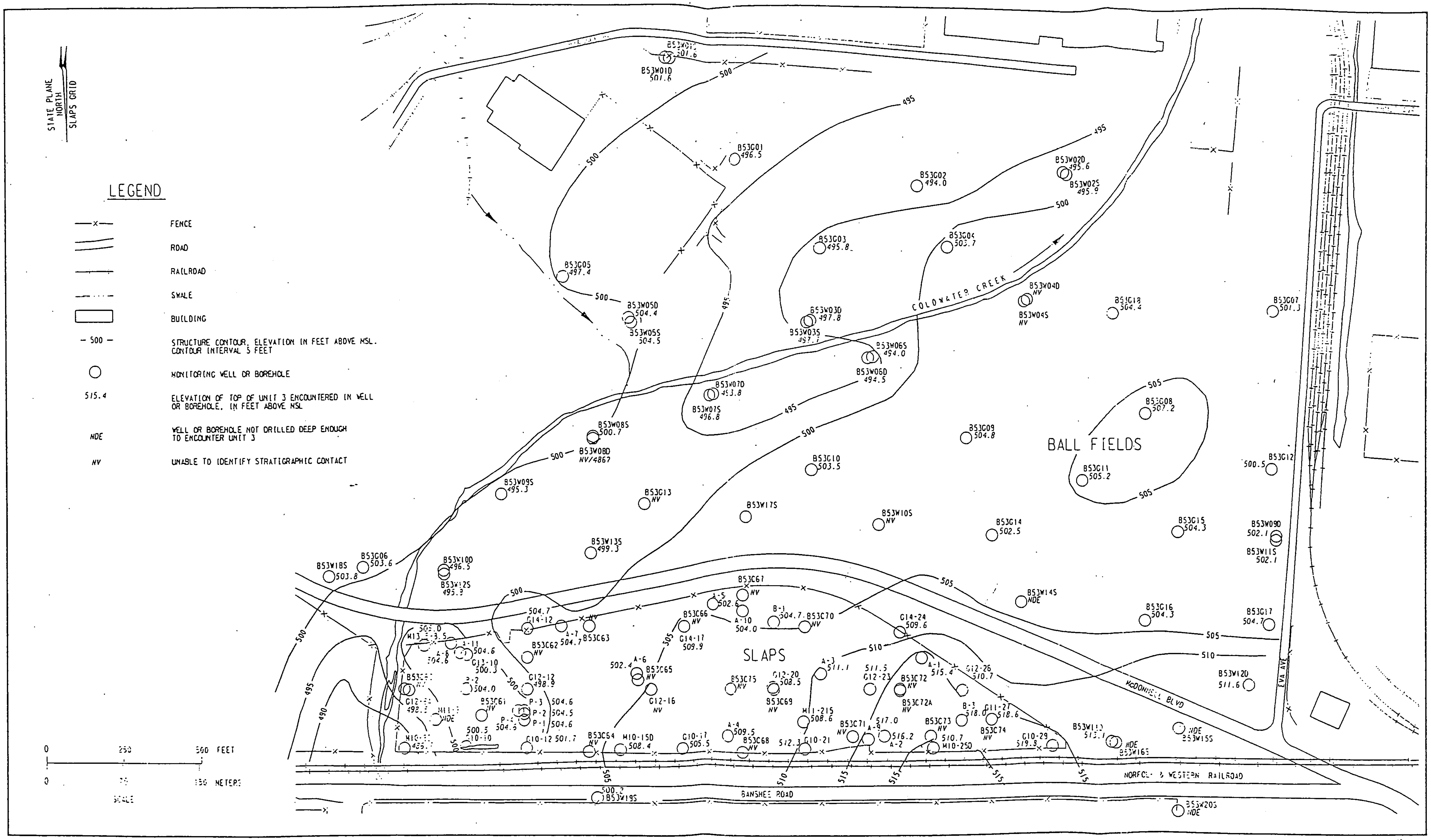
Figure 3-9
Structure Contour Map of Top of Subunit 3B

R02 302F031.DGN



R02F037.DGN

Figure 3-10
Isopach Map of Subunit 3M



R02 R02F030.DGN

Figure 3-11
Structure Contour Map of Top of Unit 3

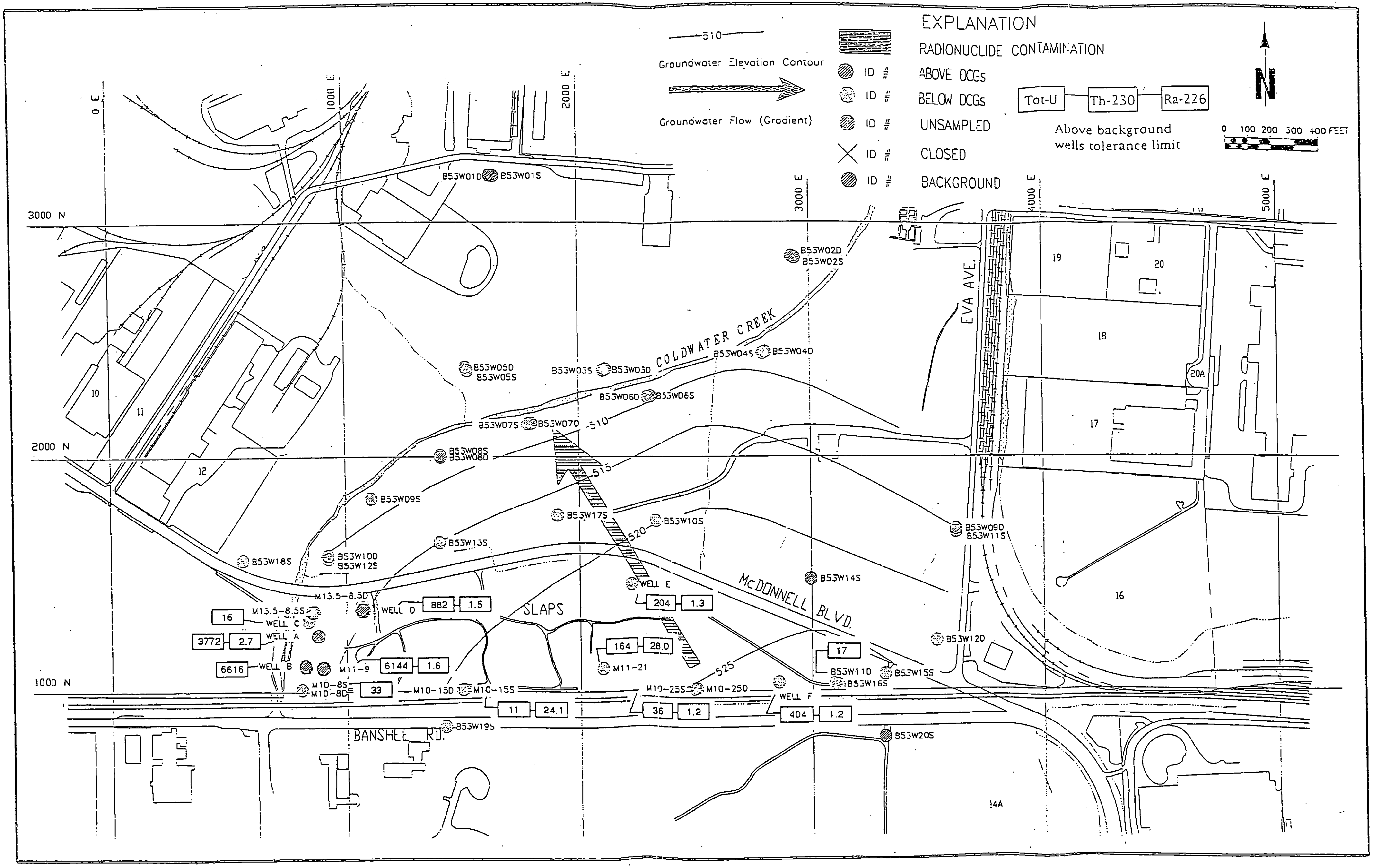


Figure 2-25. Radionuclide Contamination of Groundwater at St. Louis Airport Site and Adjacent Vicinity Properties - 1991 Annual Averages

Table A-2

(continued)

Borehole	Test Interval (ft)	Unit	Field Permeability (cm/s)	Test Method[a]
B53W10D	71.1-81.1	4	5.8×10^{-5}	Slug-W
M10-15D	80-85	4	4.1×10^{-6}	Slug-W
B53G04	79	4	2.2×10^{-4}	Fh-Oe
B53W09D	61.1-71.1	5	7.5×10^{-8}	Slug-W
B53W11D	68.5-78.5	5	1.6×10^{-7}	Slug-W
B53G16	89-99.6	6	7.5×10^{-7}	Ch-P
B53G18	83.6-95.5	6	1.1×10^{-5}	Ch-P

[a]Test Methods:

Slug-Ah = Slug test in open auger hole (horizontal permeability)
Fh-Oe = Falling head in open end casing (mean permeability)
Slug-W = Slug test in monitoring well (horizontal permeability)
Ch-P = Constant-head packer test in rock (horizontal permeability)

Table 3-3

Porosity and Permeability of Sediments[a] at SLAPS

Unit	Mean Porosity[b] (%)	Geometric Mean Vertical Laboratory Permeability (cm/s)	Geometric Mean Field Permeability (cm/s)
2	41.6 (10)[c]	2.5×10^{-6} (9)	1.2×10^{-4} (5)
3T	41.0 (11)	2.7×10^{-6} (13)	1.1×10^{-5} (8)
3M	45.3 (4)	5.5×10^{-8} (4)	3.1×10^{-5} (1)
3B	37.8 (2)	3.1×10^{-7} (2)	1.5×10^{-5} (7)
4	44.3 (2)	1.3×10^{-6} (4)	3.7×10^{-5} (3)
5	[d]	[d]	1.1×10^{-7} (2)
6	[d]	[d]	2.9×10^{-6} (2)

[a]A complete list of all data is presented in Appendix A.

[b]Porosity is calculated from dry unit weight and specific gravity.

[c]The numbers in parentheses represent the number of analyses.

[d]Test not performed on unit.

Restatement of the questions to be answered by the Expert Geohydrologic Panel for the St. Louis Airport Site

For the FUSRAP St. Louis Airport site (SLAPS) and Ballfields, the key issues to be addressed by the panel are (note that the objectives of the original questions remain the same, but the text has been modified for clarification):

1) To what degree is the presence of radionuclides in the soil and shallow groundwater impacting, or expected to impact, the water or sediment quality in Coldwater Creek via a groundwater pathway?

2) To what degree is the presence of radionuclides in stormflow runoff impacting, or expected to impact, the water or sediment quality in Coldwater Creek?

3) Is the presence of radionuclides expected to have a significant impact on the "deep" bedrock groundwater within the foreseeable future (e.g. next 100 years)?

Impacts are broadly defined as changes in the water or sediment quality that produce, or may produce, discernible deleterious effects to either human health or the environment.

The task force has been encouraged to participate in framing the questions. The following comments and questions have been submitted in writing.

From Kay Drey (stated as "Some questions of concern to area residents" submitted to the panel on September 15, 1995 in a document titled "Some Facts and Questions About the St. Louis Airport Site."):

1) "To what extent are the radioactive wastes at the Airport Site in contact with the <u>groundwater</u>? If in contact, to what extent are they impacting upon the groundwater, and in turn, to what extent, if any, is the groundwater impacting upon Coldwater Creek?"

2) "To what extent, if any, are <u>surface water</u> runoff and eroding soil contaminating Coldwater Creek -- including both the amount washing into the creek out of the ditches along the north and south boundaries, and that percolating through the gabion wall along the site's western boundary?"

"Or as a combined question: If the wastes stay buried at the Airport Site, will contaminated groundwater and runoff surface water continue to impact significantly upon Coldwater Creek?"

From Dan Wall (EPA) (from Telefax of September 20, 1995):

"In addition to an assessment of impacts to Cold Water Creek, our interest in the report of the Expert Panel will be in how it speaks to the following:

1. Assessment of the effectiveness of the #M and #B units as a barrier to vertical advective transport.

2 Assessment of the potential for contaminant migration via diffusion through the 3B and 3 M subunits.

3. Assessment of the significance of the downward flow potential in the southern and eastern parts of the SLAPS with respect to the potential for contaminant migration to lower groundwater system.

4. Assessment of the adequacy of the available subsurface information in addressing the above issues, e.g., with what level of confidence have we defined the thickness and continuity of the 3M and 3B subunits, the hydraulic conductivities of these units, contaminant mobility, etc.