

St. Louis FUSRAP Site Expert Geohydrologic Panel

MEETING SIGN-IN

September 15, 1995

Name: Key Drey

Affiliation: _____

Address: _____

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES _____ NO _____

Name: Don Wall

Affiliation: EPA

Address: _____

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES _____ NO _____

Name: TOM BINZ

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Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES _____ NO _____

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Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES ☐ NO ☒

Name: JEFF BRAUN
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Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES ☐ NO ☒

Name: Jim ~~Dwyer~~ Dwyer
Affiliation: SLSRTP Facilitator
Address: _____

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES ☐ NO ☐

Name:

Dave Adler

Affiliation:

DOE

Address:

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES _____ NO _____

Name:

David S. Miller

Affiliation:

SAIC

Address:

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES _____ NO _____

Name:

Theresa Portero

Affiliation:

SAIC

Address:

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES _____ NO _____

Name:

Mimi Gerstang

Affiliation:

MDA

Address:

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES _____ NO _____

NL = No
Lunch

Name: Sandy Delcours + Jacob
Affiliation: concerned citizen / stream team
Address: _____

(NL)

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES _____ NO _____

Name: JULIE MANN
Affiliation: NATIONAL CENTER OF ENVIRONMENTAL INFO + TECHNOLOGY
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(NL)

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Name: J. K. GRANT
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(NL)

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES _____ NO _____

Name: _____
Affiliation: _____
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Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES _____ NO _____

Name:

Thomas Aley

Affiliation:

Ozark Underground Authority (PANEL MEMBER)

Address:

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES ☐ NO ☐

Name:

John Rockaway (PANEL MEMBER)

Affiliation:

Address:

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES ☐ NO ☐

Name:

David Miller

Affiliation:

Geraghty & Miller (PANEL MEMBER)

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Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES ☐ NO ☐

Name:

James Cox (PANEL MEMBER)

Affiliation:

Address:

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES ☐ NO ☐

Name: George Stephens
Affiliation: SAIC
Address: _____

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES _____ NO _____

Name: Steve Lanter
Affiliation: SAIC
Address: _____

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES _____ NO _____

Name: Ken Skinner
Affiliation: BNI
Address: _____

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES _____ NO _____

Name: Bruce Diel
Affiliation: SAIC
Address: _____

Do you wish to be added to the Task Force mailing list and receive information about future meetings? YES _____ NO _____

INTRODUCTION

The purpose of this document is to present hydrogeological, hydrological, and radionuclide transport information on the St. Louis Airport site (SLAPS) to the Task Force Expert Panel. SLAPS is part of the Formerly Utilized Sites Remedial Action Program (FUSRAP), which is managed by the United States (U.S.) Department of Energy (DOE). The objective of FUSRAP is to identify and clean up or otherwise control sites where residual radioactivity remains from the early years of the nation's atomic energy program or from commercial operations causing conditions that Congress has authorized DOE to remedy.

The hydrological/hydrogeological characteristics of the site are presented here in an effort to determine the impact of the radionuclides on Cold Water Creek (CWC) and the deep bedrock groundwater. Information was gathered during previous investigations to determine the nature and extent of residual radioactivity at the St. Louis airport site and to evaluate the suitability of the site as a location for a disposal facility.

PURPOSE

The St. Louis Task Force was created in August of 1994 to make a recommendation to DOE regarding a remedy for the St. Louis site. Before they make any recommendation on the SLAPS portion of the site they wish to have a better understanding of any current or future potential for radionuclide migration from the site. The task force has selected a panel of professionally qualified independent experts to address the following questions.

- (1) To what degree is the presence of radionuclides at the St. Louis Airport site expected to impact the water and sediment quality in Cold Water Creek, either currently or in the future?
- (2) What are the current or future impacts to Coldwater Creek's water and sediment quality of surface water runoff from the St. Louis Airport site.
- (3) Is the presence of radionuclides at the St. Louis Airport site expected to have any significant impact on the "deep" bedrock groundwater within the foreseeable future (e.g. next 100 years)?

In order to answer these questions, the panel will be asked to participate in a series of meetings focused on reviewing existing site data, to review conclusions drawn by DOE from this data set, and ultimately to provide their independent opinions on the adequacy of the existing data and the validity of the conclusions being drawn by DOE.

Hydrologic Pathways of Radionuclide Transport at the St. Louis Airport Site

The focus of this panel is on the transport of radionuclides by water from the St. Louis Airport Site and the significant impacts to water and sediment quality of that transport.

Identification of Transport Pathways

1) Groundwater

- a) transport to Coldwater Creek
- b) movement to deeper hydrostratigraphic formations

2) Stormflow

a) Surface

- i) particulate entrainment
- ii) capture of pore water (dissolved)

- b) Shallow subsurface - unlikely because of low hydraulic conductivities and shallow surface gradients

When considering radionuclide transport, it is important to take into account:

- a) travel time to potential receptors,
- b) concentration of radioactive compound at the receptor, and
- c) the dose and health effects that result from exposure to the radionuclides.

Therefore, the measurements and models must allow estimation of the travel times and concentrations of the radioactive compounds as they arrive at potential receptors.

This presentation will focus on the measurement and modeling of the physical and chemical parameters that control the rate and concentrations of radioactive compounds in the water at St. Louis Airport Site.

I'll call the parameters that govern the transport and concentrations of the radionuclides the **controls**.

Controls of Radionuclide Transport

Groundwater Transport

- a) Mechanical Energy (Potential)
 - depends on elevation and pressure
 - rate of net recharge is important to development of pressure.
- b) Hydraulic Conductivity of Hydrostratigraphic Units
 - strongly controlled by depositional environment. Important parameters include mineralogy and grain-size distribution.
 - Also controlled by post-depositional changes including diagenesis, tectonics, and weathering.
- c) Solubility of Radioactive Compounds
- d) Kinetics of Dissolution
- e) Concentrations of radionuclides in substrates along flow paths

Surface Transport

a) Surface Transport of Particulates

i) critical shear stress of soil

- erosivity (size, cohesiveness)
- vegetative cover strongly affects the availability of particles for transport

ii) tractive stress of flow ($\rho g d s$)

- flow depth (rainfall rate and runoff important)
- slope of topographic surface.

iii) surface concentrations of radioactive compounds

b) Surface Transport of Dissolved Constituents

i) solubility

ii) kinetics of dissolution

iii) concentration of radioactive compounds in soil at the surface.

Regional Stratigraphy with Emphasis on the Major Regional Groundwater Zones⁽¹⁾

The St. Louis Area (as of 1974) used 1200 million gallons per day of water.

82% came from the Mississippi River,
15% came from the Missouri River, and
1-2% was pumped from bedrock and
alluvial aquifers.

The bedrock units are assigned to five groups based on similar lithologic characteristics, geographic distribution, and overall similarity of water quality.

(1) Miller, Don E. (Missouri Geological Survey and Water Resource) (1974), and L.F. Emmett, John Skelton, H.G. Jeffery, and J.H. Barks (U.S. Geological Survey). *Water Resources of the St. Louis Area, Missouri*. Water Resources Report 30, Rolla, MO.

Group 1 Post-Maquoketa - includes all bedrock units above the Maquoketa Shale. Pennsylvanian rocks at the upper boundary of Group 1 are relatively impermeable and yield very little water to wells.

Group 2 Kimmswick-Joachim - includes all aquifers between the base of the Maquoketa Shale and the base of the Joachim Dolomite.

Group 3 St. Peter-Everton - includes the St. Peter Sandstone and the Everton formation.

Group 4 Powell-Gasconade - includes the entire Ordovician Canadian series.

Group 5 Eminence-Lamotte - includes all units beneath the base of the Gasconade.

Major alluvial aquifers are water-saturated sands and gravels in the basal part of the alluvium underlying the floodplains of the Mississippi, Missouri, and Meramec rivers.

Wells finished in the Potosi Dolomite (Eminence-Lamotte Group) have yielded up to 500 gallons per minute.

The Gasconade and Roubidoux formations (Powell-Gasconade Group) have yielded maximums of 300 gallons per minute.

The St. Peter Sandstone yields up to 140 gallons per minute.

The Kimmswick-Joachim Group yields 3 to 50 gallons per minute.

The Mississippian rocks of the Post-Maquoketa Group yield 5 to 50 gallons per minute.

The Pennsylvanian rocks of the Post-Maquoketa Group yield 0 to 10 gallons per minute.

The Pleistocene loess and glacial tills above bedrock are essentially not water yielding.

Groundwater recharge to the bedrock aquifers occurs from the precipitation on the land surface and depends on the configuration and physical character of the land surface, the amount and type of vegetation, the distribution and quantity of precipitation, and the composition and moisture content of the soil, subsoil, and underlying rock.

Recharge also occurs via natural infiltration of river water into bedrock and alluvial aquifers that are hydraulically connected to the rivers.

Coldwater Creek Hydrologic Parameters

Annual Precipitation ⁽¹⁾	37.6 inches
Maximum	55 inches (1982)
Minimum	22 inches (1976)
Approximate Annual Evapotranspiration ⁽²⁾	26 inches
Mean Flow at Gaging Station ⁽³⁾ (equivalent to 12.7 in/yr of runoff distributed over 43.6 square mile basin above gaging station)	41 cfs or 12.7 in/yr over basin
Low Flow at Gaging Station ⁽³⁾ (equivalent to 0.6 to 1.5 in/yr distributed over 43.6 square mile basin above gaging station)	2 to 5 cfs or 0.6 to 1.5 in/yr over basin

(1) Precipitation recorded at Lambert-St. Louis Int'l. Airport (1964-1990).

(2) Based on evapotranspiration equal to 70% of mean annual precipitation for the dissected till plains physiographic province as determined by Sharp, 1984 in *Groundwater*, Vol. 22, No. 6, November-December, pp. 683-689.

(3) U.S. Geological Survey Gaging Station (6-9365) (1959-1965).

Coldwater Creek Water Quality⁽¹⁾

An Environmental Protection Agency 208 toxic agent study of Coldwater Creek water was completed by the East-West Gateway Coordinating Council (EWGCC) in January 1983.

Eight stream locations were monitored to determine the relative magnitude of point and non-point source loadings of 129 priority toxic pollutants.

Based on the sampling results, the study concluded that Coldwater Creek is relatively free of priority pollutants.

Four of the 129 priority pollutants were consistently in violation of EWGCC/Metropolitan Sewer District water quality criteria: chromium, lead, cyanide and copper.

(1)

U.S. Army Corps of Engineers, (1987). *Coldwater Creek, Missouri Feasibility Report and Environmental Impact Statement*, St. Louis District, Lower Mississippi Valley Division. May.

A survey of the aquatic benthic community shows somewhat contradictory results. The USCOE stated in their Feasibility Report and Environmental Impact Statement that the "poor water quality of Coldwater Creek has limited the species diversity and type of aquatic organisms present in the watershed."

They cited three studies.

- 1) A qualitative survey of benthic invertebrates was performed in March 1981 for the EWGCC and an extremely low diversity of aquatic organisms was found. The fauna was made up of pollution tolerant sludge worms (Tubificidae) and blood worms (Chironomidae).
- 2) A fish survey at eight collection sites along the length of Coldwater Creek was conducted in March 1977, but no fish were captured.⁽²⁾

(2) Kevin, Thomas M. (1978). *A Distributional and Faunistic Analysis of Small Stream Fishes of St. Louis and St. Charles County, Missouri*. M.S. thesis. Southern Illinois University. 188 p.

- 3) Field sampling done by the U.S. Fish and Wildlife Service in 1981 indicated that the stream supported populations of pollution tolerant fish such as fat head minnows, golden shiners, and black bullheads.

The USCOE hypothesizes that short-term stormwater pollution may carry salt, oil, and anti-freeze into the creek. The presence of these substances may have been missed because of a relatively short sampling period and the transience of these substances in stormwater.

SLAPS/Ballfield Hydrostratigraphic Parameters

Hydraulic conductivity ranges		
Unit	Geometric Mean Vertical Permeability (cm/s)	Geometric Mean Field Permeability (cm/s)
2	2.5×10^{-6} (9)	1.2×10^{-4} (5)
3T	2.7×10^{-6} (13)	1.1×10^{-5} (8)
3M	5.5×10^{-8} (4)	3.1×10^{-5} (1)
3B	3.1×10^{-7} (2)	1.5×10^{-5} (7)
4	1.3×10^{-6} (4)	3.7×10^{-5} (3)
5	test not performed	1.1×10^{-7} (2)
6	test not performed	2.9×10^{-6} (2)

The numbers in parentheses represent the number of analyses.

Groundwater Flux Calculations and Modeling

The shallow groundwater flow and radionuclide transport for the St. Louis Airport Site were modeled using the three dimensional model MODFLOW (flow) and MT3D (radionuclide transport).

The stratigraphy was developed based on the characterization data available for the site.

The hydraulic conductivity assigned to the shallow groundwater system varied spatially and the values used were based on in-situ field permeability tests.

Coldwater Creek was the discharge boundary

The potentiometric surface of 03 December 1992 was used as a target for calibration.

The 3M unit was modeled as an impermeable boundary.

The values of the hydrogeologic parameters used for modeling of the upper groundwater system are as follows:

Hydraulic conductivity range	1.2×10^{-6} to 5.3×10^{-4} cm/s
Geometric mean of hydraulic conductivity	3.6×10^{-6} cm/s
Range of saturated thickness	7.9 to 13.7 m
Arithmetic mean bulk density	1.54 g/cm ³
Arithmetic mean total porosity	0.41
Range of hydraulic gradient	0.007 to 0.022
Range of average linear velocity	0.005 to 7.8 m/s
Maximum observed total uranium concentrations in wells used as dissolved radionuclide loading (decay neglected)	202 to 6,616 pCi/l

Two different distribution coefficients were used:

1st case	$K_d=114.4 \text{ ml/g}$
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This resulted in a flux of $8.2 \times 10^{-4} \text{ Ci/year}$ to Coldwater Creek.

2nd case	$K_d=11.4 \text{ ml/g}$
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This resulted in a flux of $5.6 \times 10^{-3} \text{ Ci/year}$ to Coldwater Creek.

Results of Groundwater Modeling

Groundwater contribution to Coldwater Creek is 0.022 cfs/mi². The entire area of concern is approximately 90 acres so that the daily flux to Coldwater Creek of groundwater from this area is 0.003 cfs. Low flow in the SLAPS vicinity is approximately 2 cfs.

Based on the results of the modeling, future loading, after break-through, to Coldwater Creek from groundwater discharge is approximately .001 Ci/year. At low flow this results in approximately 0.44 Ci/l.

Soil Loss Estimation

The Modified Universal Soil Loss Equation (MUSLE) (EPA 1988) was used to estimate the annual soil loss from the St. Louis Airport Site resulting from storm generated runoff.

The Universal Soil Loss Equation used is:

$$A = RKLSCP$$

A = average annual soil loss, tons/acre

R = rainfall factor

K = soil erodability factor

LS = slope length and steepness factor

C = cropping and management factor

P = conservation practice factor

Areas with the highest surface soil contamination within the St. Louis Airport Site were used to obtain radionuclide activity values for transport.

The following values were used for the parameters:

R (R varies from 200 in northern Missouri to 250 in southern Missouri)	225 ft-lb-s
K Value obtained from USDA for SLAPS soils	0.32
LS based on maximum length of stormflow channel and channel slope	0.36
C Assumes bare ground	0.45
P most conservative value	1

Results from the MUSLE

Based on the values for the parameters above, the radionuclide loading to Coldwater Creek from soil erosion is on the order of .001 to .01 Ci per year.

Radionuclide Loading Resulting from Pore Water Eroded During Surficial Erosion

Radionuclide loading resulting from pore water eroded during surficial erosion was also estimated.

It was assumed that total uranium was in equilibrium in the pore water and the soil was saturated.

The pore water volume was determined base on the porosity of the soil.

The depth of erosion was determined from the weight and bulk density of the eroded soil.

Results of the estimate of loading to Coldwater Creek from eroded pore-water.

Radionuclide loading from pore-water in the eroded depth is of the order of 1.0×10^{-5} Ci/year to Coldwater Creek.

Summary of Estimates of Radionuclide Loading to Coldwater Creek by Surface and Groundwater Pathways

Groundwater

Based on the results of the modeling, future loading, after break-through, to Coldwater Creek from groundwater discharge is approximately .001 Ci/year. At low flow this results in approximately 0.44 Ci/l added to background concentrations.

Surface Water

Based on the Modified Universal Soil Loss Equation, the radionuclide loading to Coldwater Creek from soil erosion is on the order of .001 to .01 Ci per year. It is probably not reasonable to evaluate this loading for low flows of the creek. But, for purposes of comparison to the groundwater condition, the maximum loading at low flow would result in approximately 4.4 Ci/l added to background conditions.

Summary (continued)

Pore Water Loading

Radionuclide loading from pore-water in the eroded depth is of the order of 1.0×10^{-5} Ci/year to Coldwater Creek. This loading is small compared to that estimated for groundwater and surface water.

Current Sampling Results

Surface water concentrations of radionuclides for the year 1992 (most recent year for which data is available).

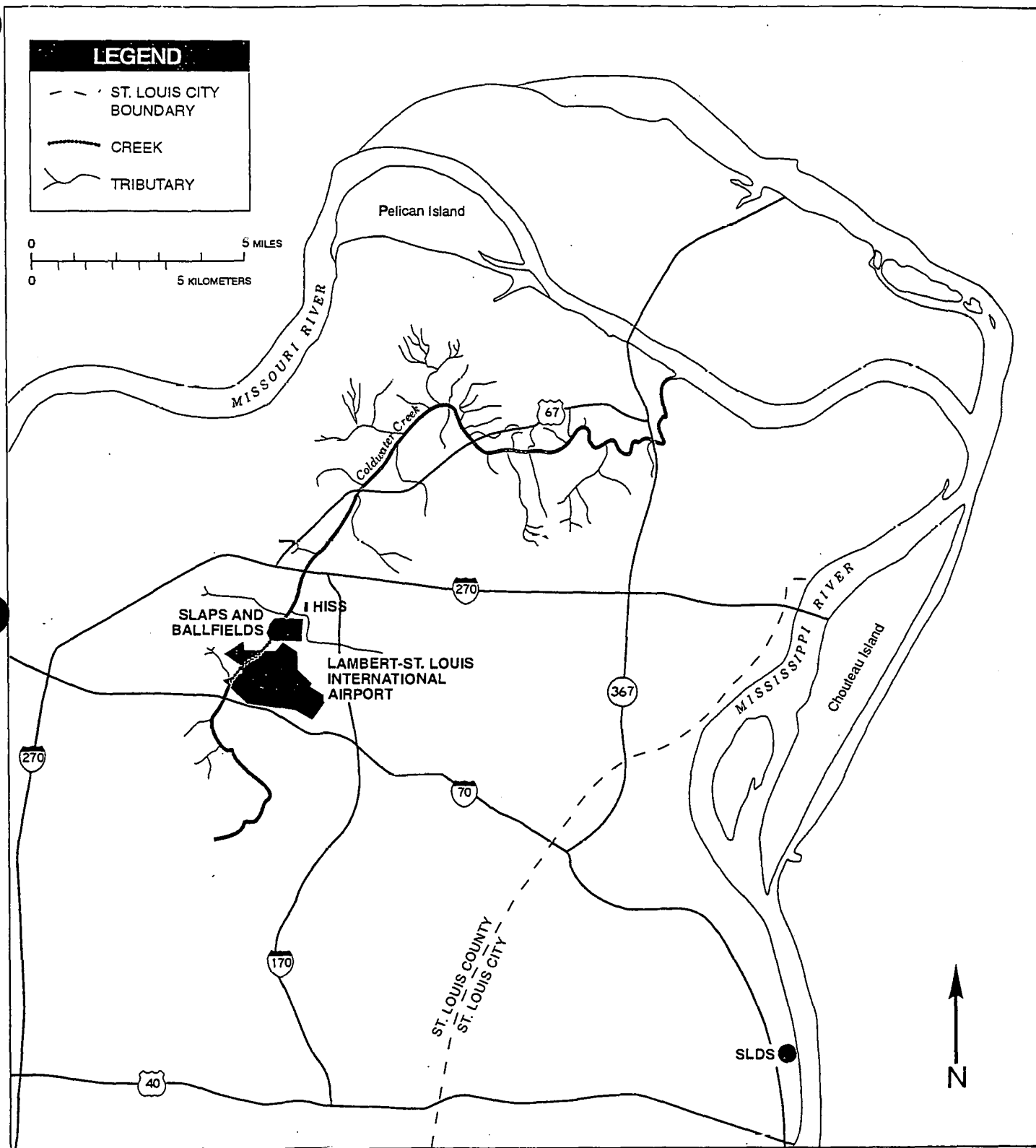
Data in pCi/l. Samples were unfiltered and background was not subtracted from values.

Location	Ra-226	Th-230	Total U
South side of airport upstream of SLAPS	0.5	0.46	4.52
Coldwater Creek just downstream of mouth of northern McDonnell Blvd. Ditch	1.9	0.64	2.91
Mississippi River south of mouth of Missouri River	0.34	0.38	1.84
Mississippi River south of mouth of Missouri River	1.98	0.30	2.39
Coldwater Creek 1 mile from mouth	2.59	1.09	4.46
Missouri River 1 mile upstream of mouth of Coldwater Creek	1.22	0.55	2.11
Coldwater Creek just downstream of mouth of Ballfield ditch	0.75	0.38	5.97

Groundwater concentrations of radionuclides for the year 1992 (most recent year for which data is available).

Data in pCi/l. Samples were unfiltered and background was not subtracted from values.

Location	Ra-226	Th-230	Total U
Downgradient			
M10-8S	0.85	0.91	6.05
M10-8D	0.88	0.32	0.06
M11-9	n/a	1.41	5620.45
M13.5-8.5S	2.56	0.84	10.19
M13.5-8.5D	1.76	0.39	0.62
B53W10S	1.26	0.88	2.82
B53W13S	1.66	<0.37	9.02
B53W14S	1.76	0.34	0.42
Upgradient Wells			
B53W11D	33.8	8.90	18.59
B53W15S	2.29	0.60	6.15



SLAPS Location Map

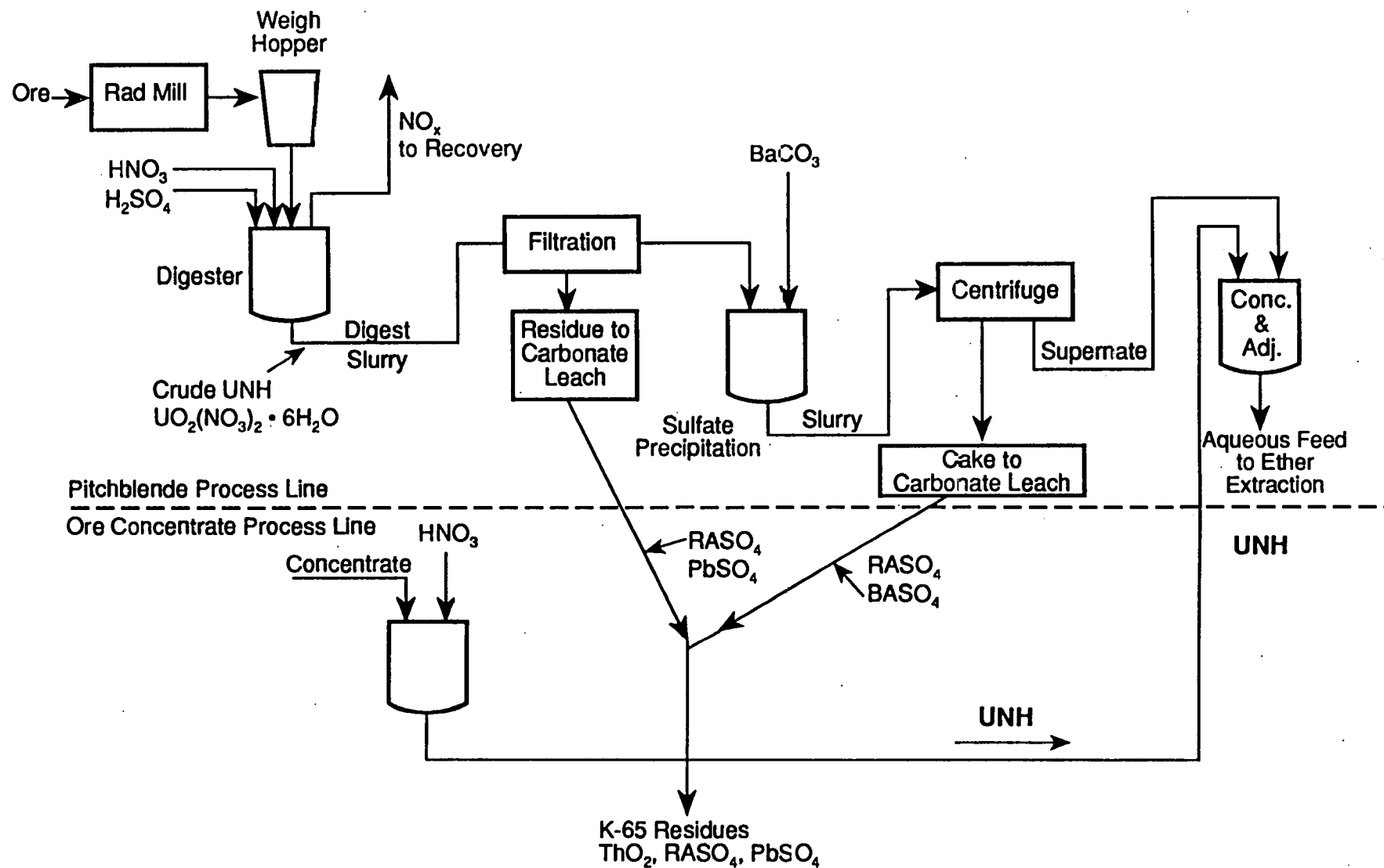
MALLINCKRODT URANIUM PRODUCTION PROCESSES

- ▶ Original feed material was uranium black oxide, U_3O_8
 - previously extracted from ore and concentrated elsewhere
 - relatively free of radium and its daughters

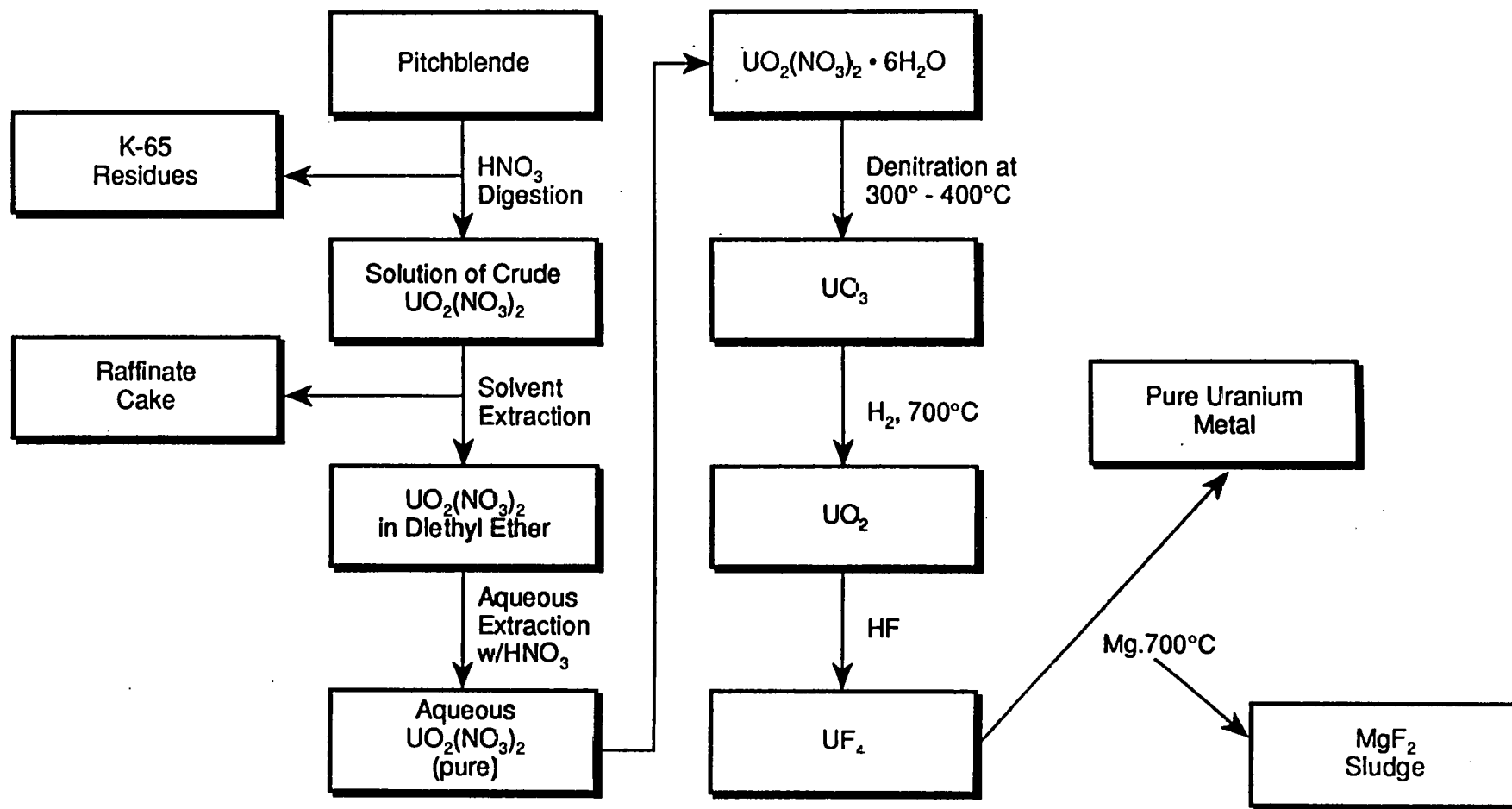
- ▶ Later (1944) extracted and purified uranium from Belgian Congo ores
 - ores contained $\geq 30\text{wt}\%$ uranium
 - Radium content of $\sim 0.3 \text{ Ci/T}$ of uranium (0.3 g/T)

DIGESTION OF ORE / ORE CONCENTRATES

- ▶ Digestion of Ore in Nitric Acid
- ▶ Extraction of $\text{UO}_2(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, from Aqueous Phase into Diethyl Ether
- ▶ $\text{UO}_2(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ Stripped from Ether Phase back into Water
- ▶ High-Temperature Denitration to UO_3
- ▶ High-Temperature Reduction, Under Hydrogen, to UO_2
- ▶ Fluorination to UF_4
- ▶ Reductive Dehalogenation to Pure Uranium Metal



Mallinckrodt Ore Digestion Process



Uranium Production Process

ANTICIPATED WASTE PRODUCTS

► K-65 Residues

- filtercake generated by filtration of crude Uranyl Nitrate Hexahydrate (UNH), $\text{UO}_2(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$
- undigested ore / tailings, contained limited-solubility ThO_2
- PbSO_4 / RaSO_4 filtercake (transferred off-site)
- BaSO_4 / RaSO_4 filtercake (transferred off-site)
- RaSO_4 activity as high as 450,000 pCi / g
- Thorium activity as high as 0.1 x Ra-activity

ANTICIPATED WASTE PRODUCTS

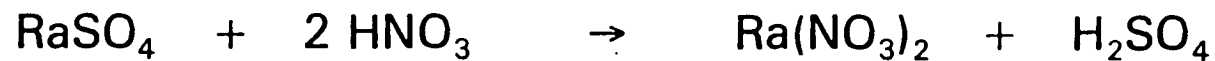
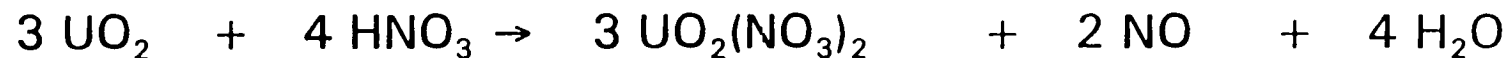
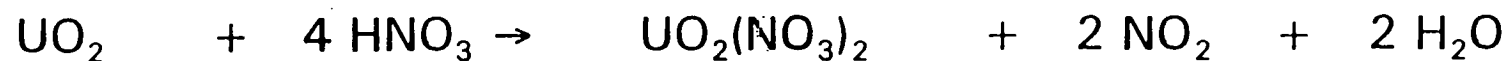
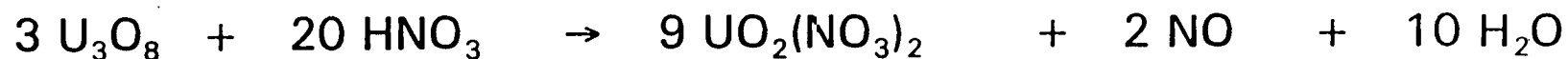
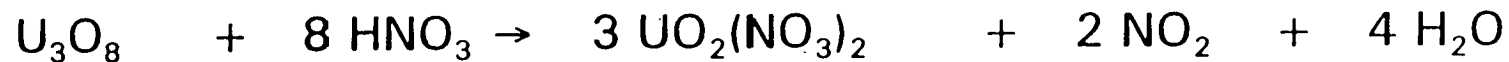
► Raffinate cake

- filtercake generated by lime precipitation of raffinate (aqueous stream after extraction of **UNH** into ether)
- contained thorium, probably as $\text{Th}(\text{OH})_4$

► MgF_2 sludge

- product of reductive dehalogenation of UF_4 (using Mg metal)
- contained uranium metal
- U-recovery from sludge examined at Wayne, NJ FUSRAP site

DIGESTION OF ORE CONCENTRATES



SLAPS TIMELINE

DATE	ACTIVITY	VOLUME
1942		
1945		
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MED/AEC contracted with
Mallinckrodt to process
uranium ores

Uranium-bearing residues
from SLDS stored at SLAPS

Radioactive material
from SLAPS stored
at Latty Avenue

Wastes purchased by Continental Mining and Milling Company of Chicago.
Stored at Latty Avenue.
Residues acquired by Commercial Discount Corporation.
Material shipped to Colorado for Cotter Corporation.

Remaining material sold to Cotter.
Residues shipped to Cannon City, Colorado.

Ownership of SLAPS transferred to St. Louis Airport Authority.
Cotter shipped undried raffinate to Canon City and transported leached barium sulfate
mixed with topsoil to West Lake Landfill in St. Louis County.

Latty Avenue property purchased by Jarboe Realty and Investment.

Contaminated soil and material excavated from Futura site during construction; placed at HISS.

Street improvements along Latty Avenue. Contaminated soil excavated and placed at HISS.

Street improvements along Latty Avenue. Contaminated soil excavated and placed at HISS.
Sewer installed along Latty Avenue. Contaminated soil excavated and added to HISS.

SLAPS placed on NPL.

MED acquired SLAPS.

①RAFFINATE (Solid
uranium-containing
residues) - AM-10
②BARIUM SULFATE
PRECIPITATE - AJ-4
③PITCHBLEND
RAFFINATE - AM-7

④URANIUM-CONTAINING
MAGNESIUM FLUORIDE
SLAG - C-701
⑤DOLOMITE LINING OF
REACTION VESSELS -
SLAG DUMP

- 13 tons of uranium;
32,500 tons of leached
barium sulfate containing
7 tons of uranium.

- 10,000 tons of Colorado
raffinate; 8,700 tons of
leached barium sulfate.

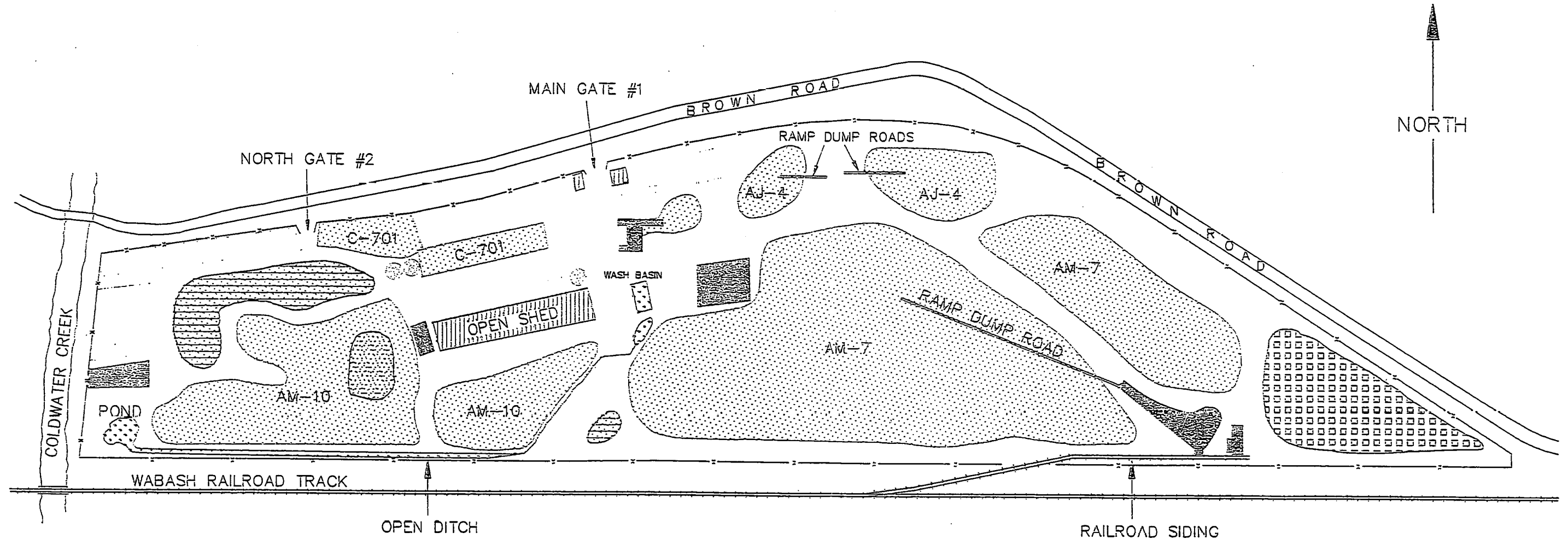
- 9,900 m³ (13,000 yd³).

- 3,517 m³ (4,600 yd³).

- 10,700 m³ (14,000 yd³).
- 3,500 m³ (4,600 yd³).

ST. LOUIS AIRPORT SITE

FORMER AREAS OF USE AND STORAGE



	BARREL STORAGE		BUILDINGS		DUMP SITES	AM-7 : PITCHBLENDE RAFFINATE
	EMPTY BARREL STORAGE		LOADING RAMPS & DOCKS		WET AREAS	AM-10 : RAFFINATE
	METAL SCRAP		DOLOMITE SLAG DUMP		GAS TANKS	AJ-4 : BARIUM CAKE
			OIL DUMP		FENCE	C-701 : TAILINGS OF URANIUM SCALPING OPERATIONS FROM MAGNESIUM FLUORIDE SLAG

☆ NOT TO SCALE

DEPICTION OF AREAS AND NAMES OF ENTITIES CA. 1955

1. Superior Upland
2. Continental Shelf (not shown)
3. Coastal Plain
4. Piedmont province
5. Blue Ridge province

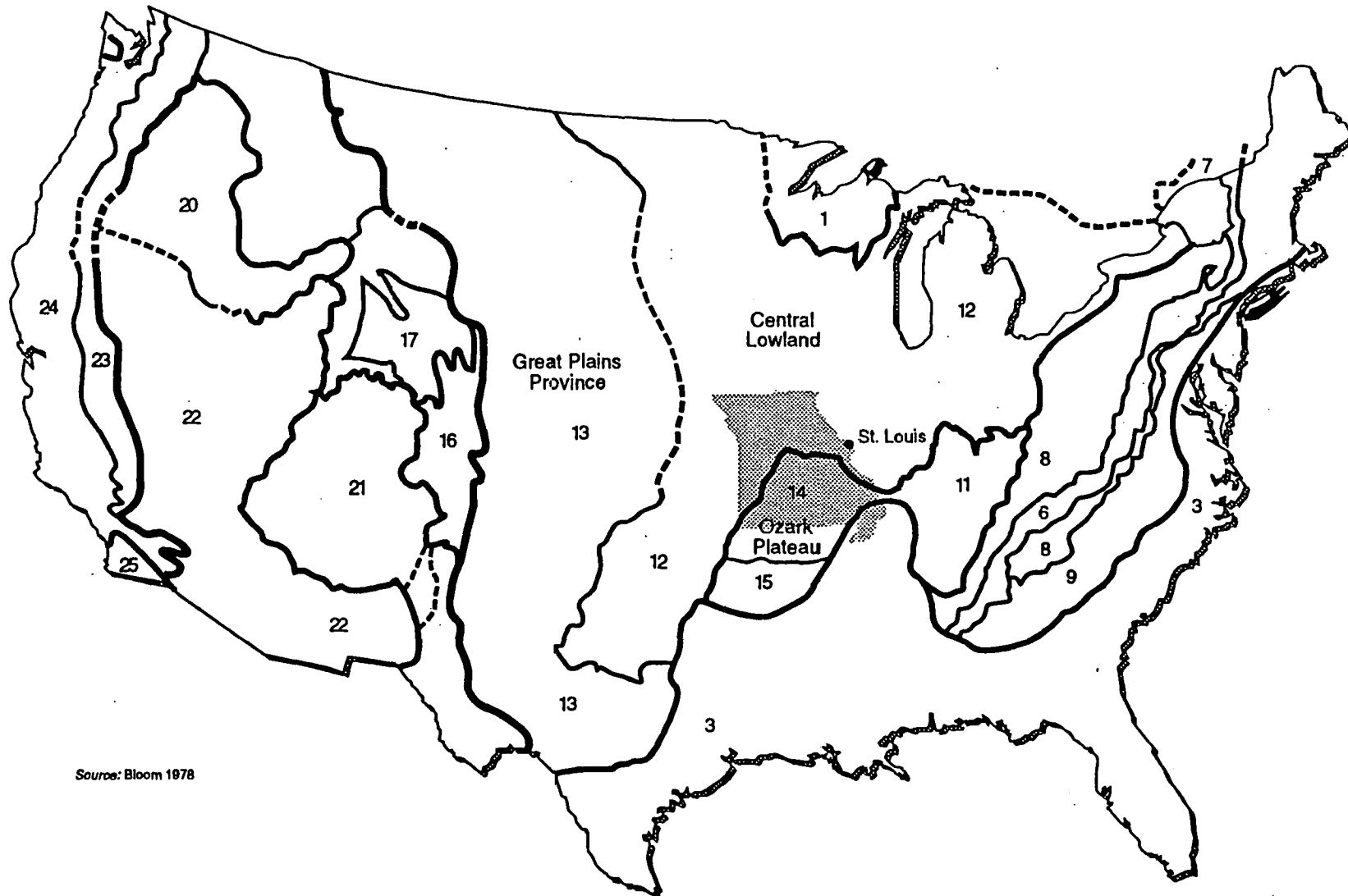
6. Valley and Ridge province
7. St. Lawrence Valley
8. Appalachian Plateaus
9. New England province
10. Adirondack province

11. Interior Low Plateaus
12. Central Lowland
13. Great Plains province
14. Ozark Plateaus
15. Ouachita province

16. Southern Rocky Mountains
17. Wyoming Basin
18. Middle Rocky Mountains
19. Northern Rocky Mountains
20. Columbia Plateaus

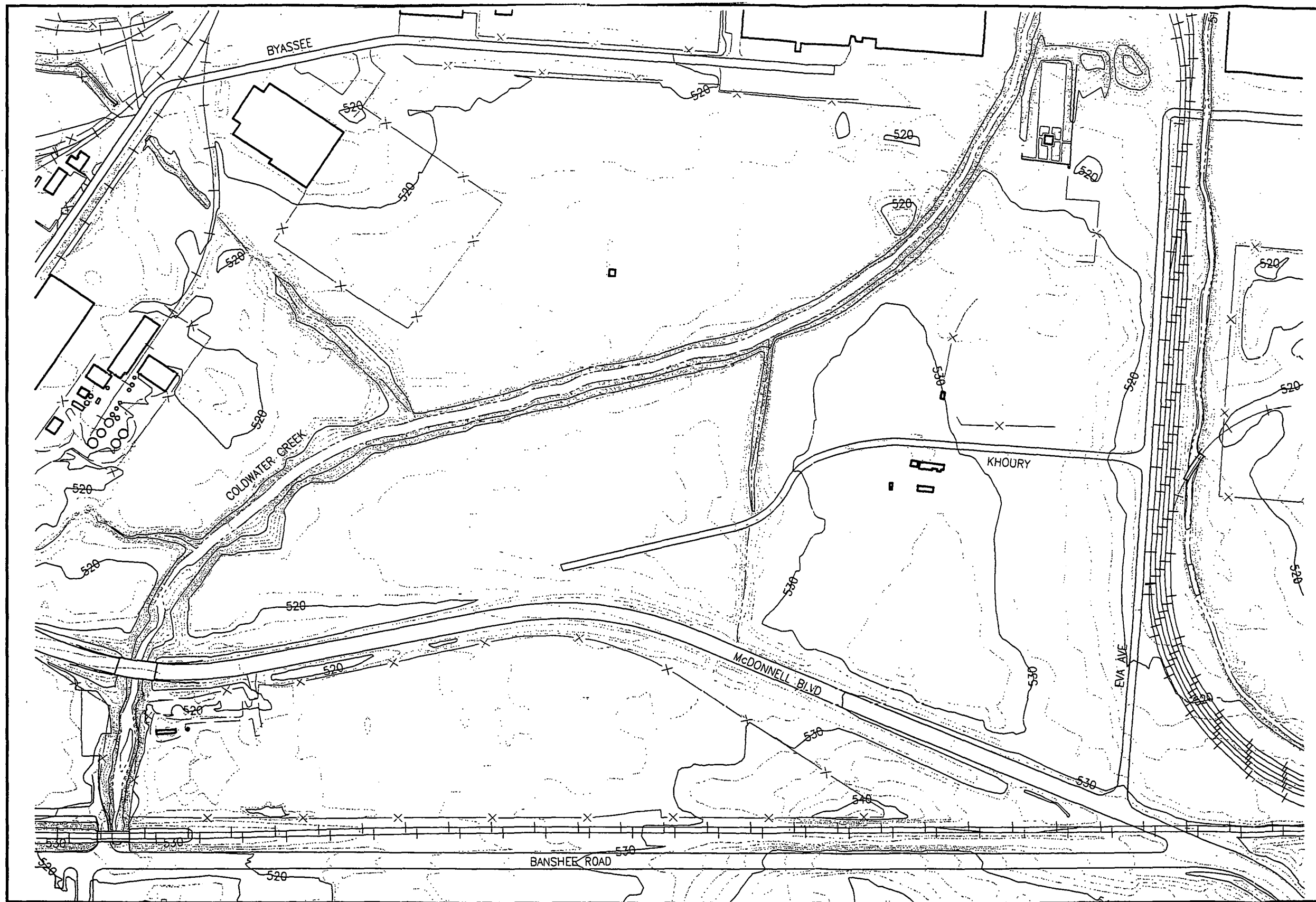
21. Colorado Plateaus
22. Basin and Range province
23. Cascade-Sierra Mountains
24. Pacific Border province
25. Lower Californian province

Source: Bloom 1978



Source: Bloom 1978

Physiographic Map of the United States

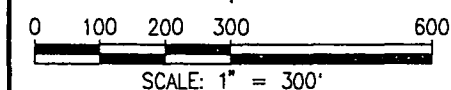


LEGEND:

- BUILDING
- ASPHALT ROAD
- GRAVEL ROAD
- RAILROAD
- STREAM
- FENCE LINE
- 520 TOPOGRAPHIC CONTOUR (10' INT.)
- TOPOGRAPHIC CONTOUR (2' INT.)
- GRID TIC (SLAPS GRID)

NOTES:

- 1.) BASE MAP INFORMATION PROVIDED BY BECHTEL SEPT. 1995.



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International Corporation

ST. LOUIS AIRPORT SITE

REVISION	DRAWN BY:	CHKD. BY:	DATE:
0	R. BEELER	S. LANIER	09-11-95

XREFERENCES	PLOT FILES
	/95032/PLOT/22211X17.JP

SHT 1 OF 1
DRAWING #

/95032/DWGS/22211X17
CAD FILE #

SITE TOPOGRAPHIC MAP

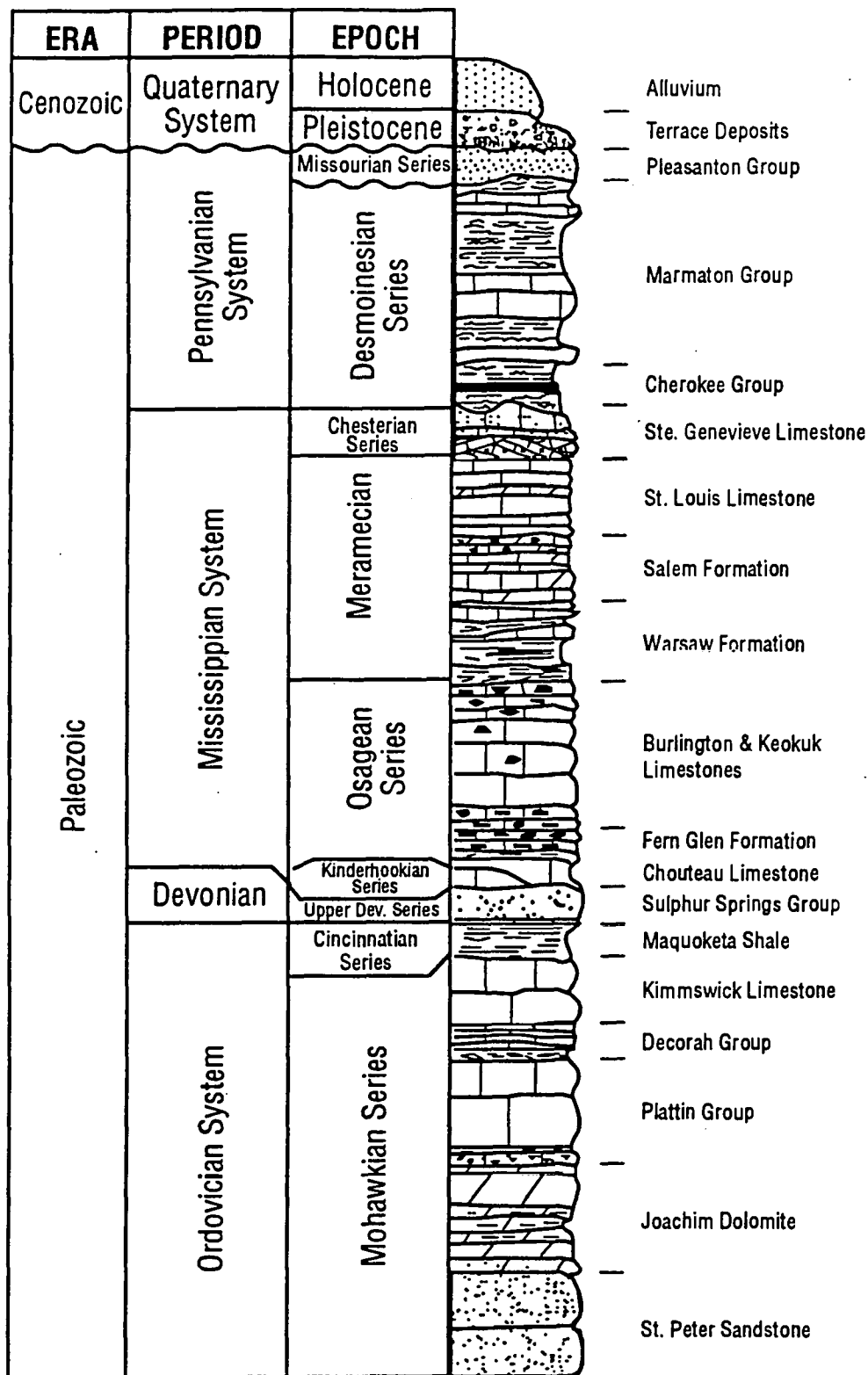
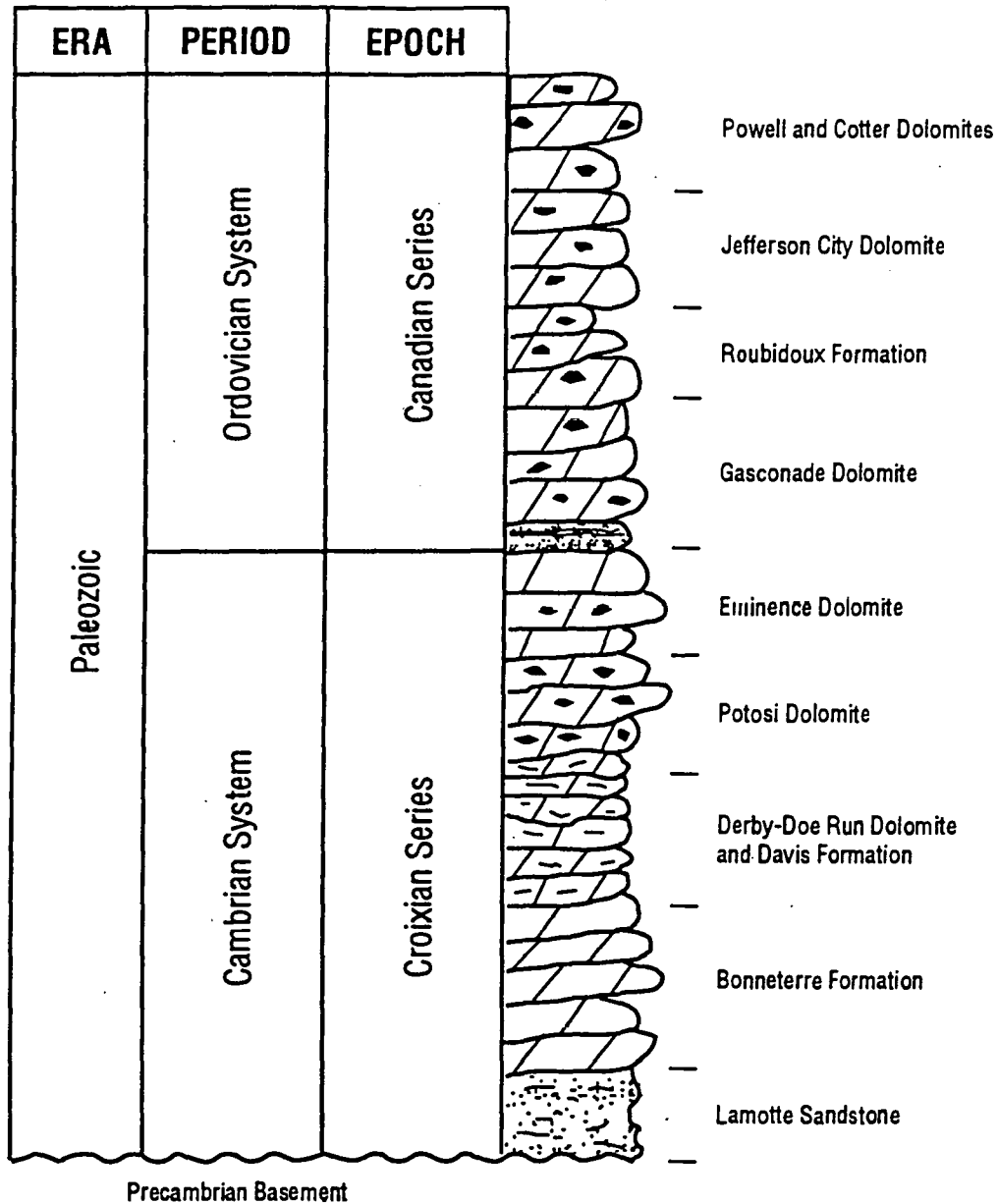


Figure continued on following page.

Sources: Brill 1991, Howe and Koenig 1961 and modified from MDNR 1993.

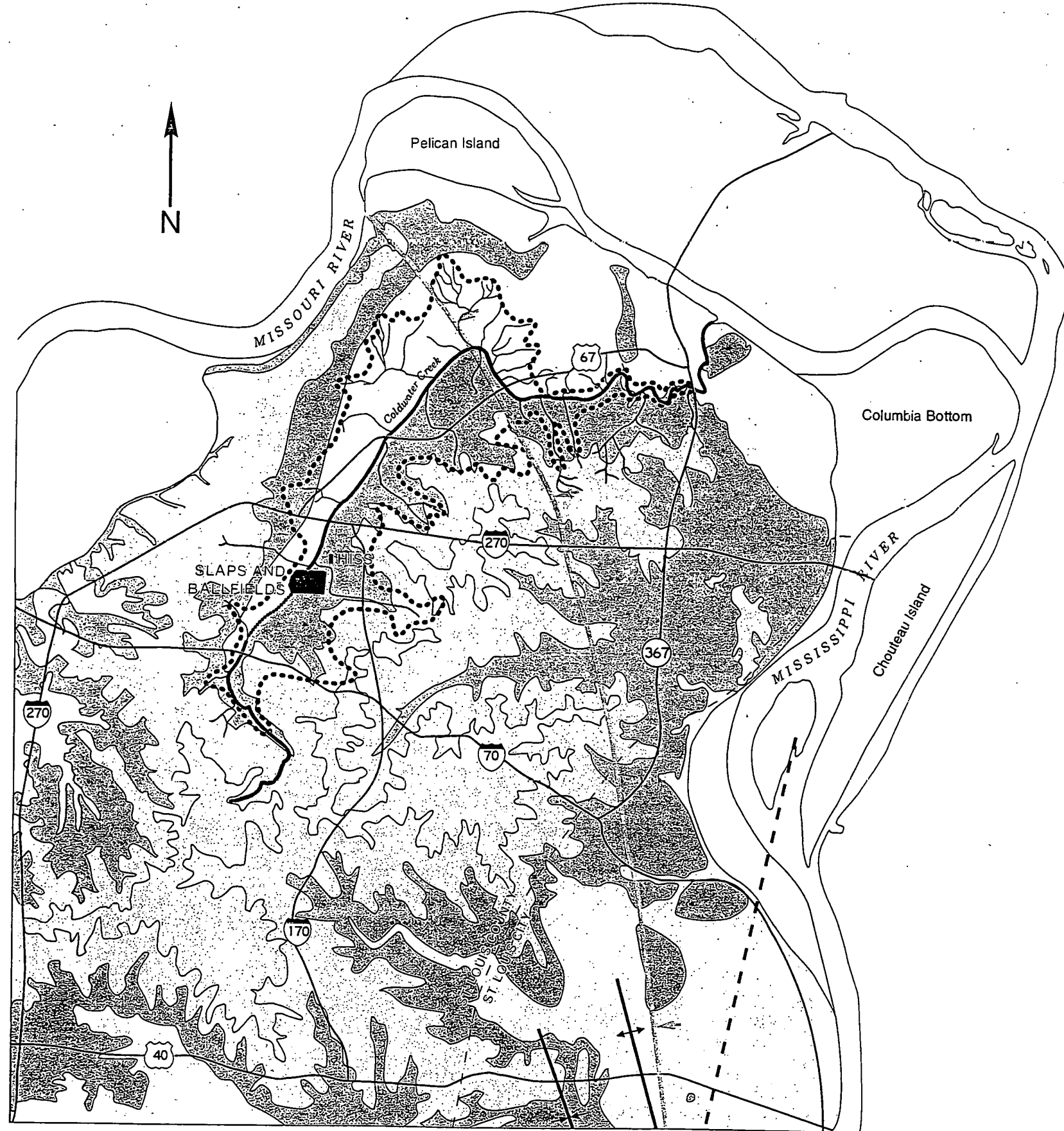
FUS St. Louis 06/95














Figure continued from previous page.

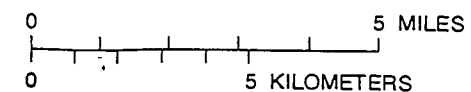


Sources: Brill 1991, Howe and Koenig 1963 and modified from MDNR (1993).

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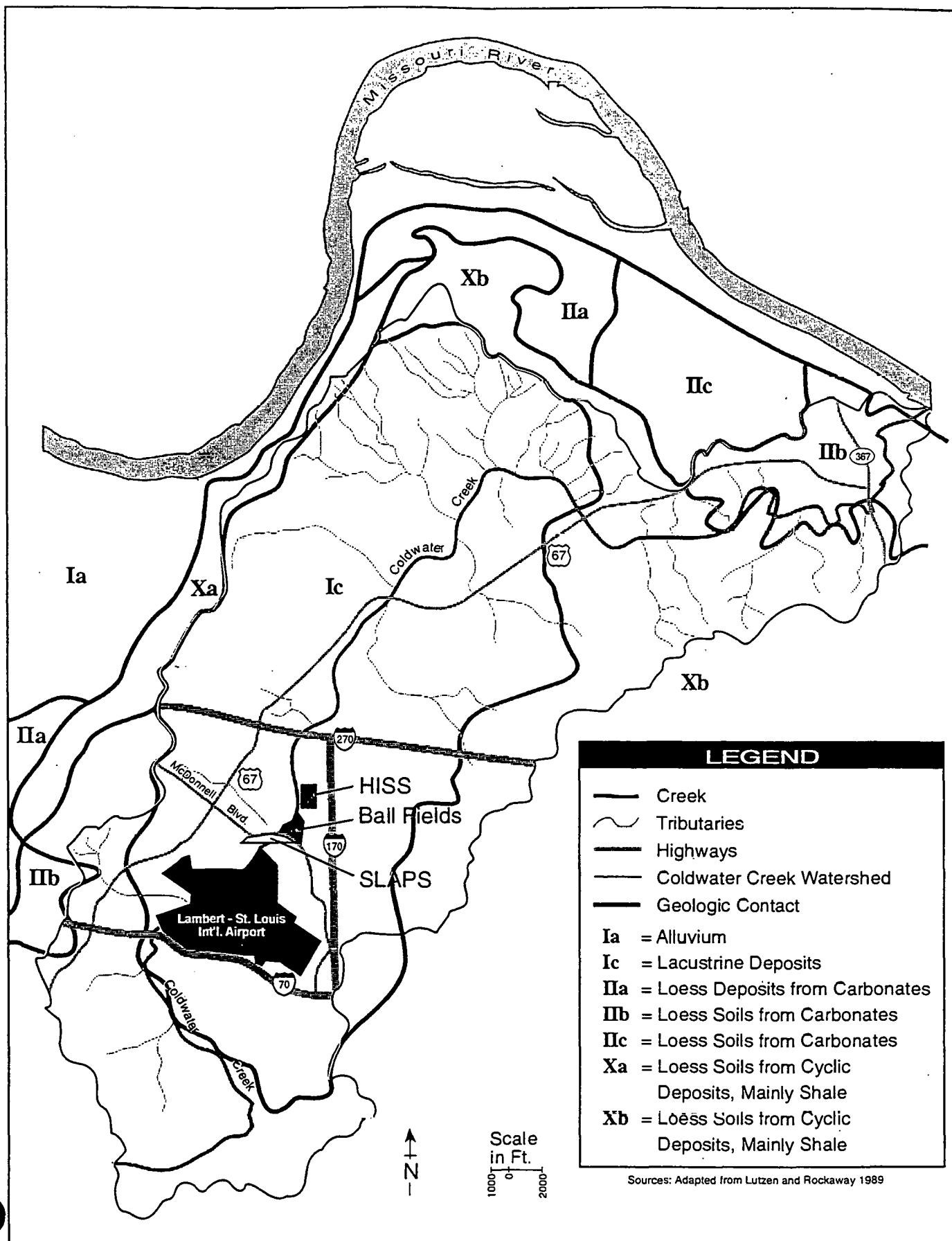


-  ALLUVIUM AND TERRACE DEPOSITS (QUATERNARY). OTHER SURFICIAL DEPOSITS NOT SHOWN
-  PLEASANTON GROUP (PENNSYLVANIAN)
-  MARMATON GROUP (PENNSYLVANIAN)
-  CHEROKEE GROUP (PENNSYLVANIAN)
-  STE. GENEVIEVE, ST. LOUIS, AND SALEM
-  APPROXIMATE BOUNDARY OF FLORISSANT BASIN (AFTER GOODFIELD 1965)
-  APPROXIMATE WESTERN LIMIT OF GLACIATION (AFTER ANDERSON 1979)
-  ST. LOUIS FAULT (INACTIVE), APPROXIMATELY LOCATED. U, UPTHROWN SIDE; D, DOWNTOWN SIDE
-  ANTICLINE
-  SYNCLINE
-  ST. LOUIS CITY BOUNDARY
-  CREEK
-  TRIBUTARY

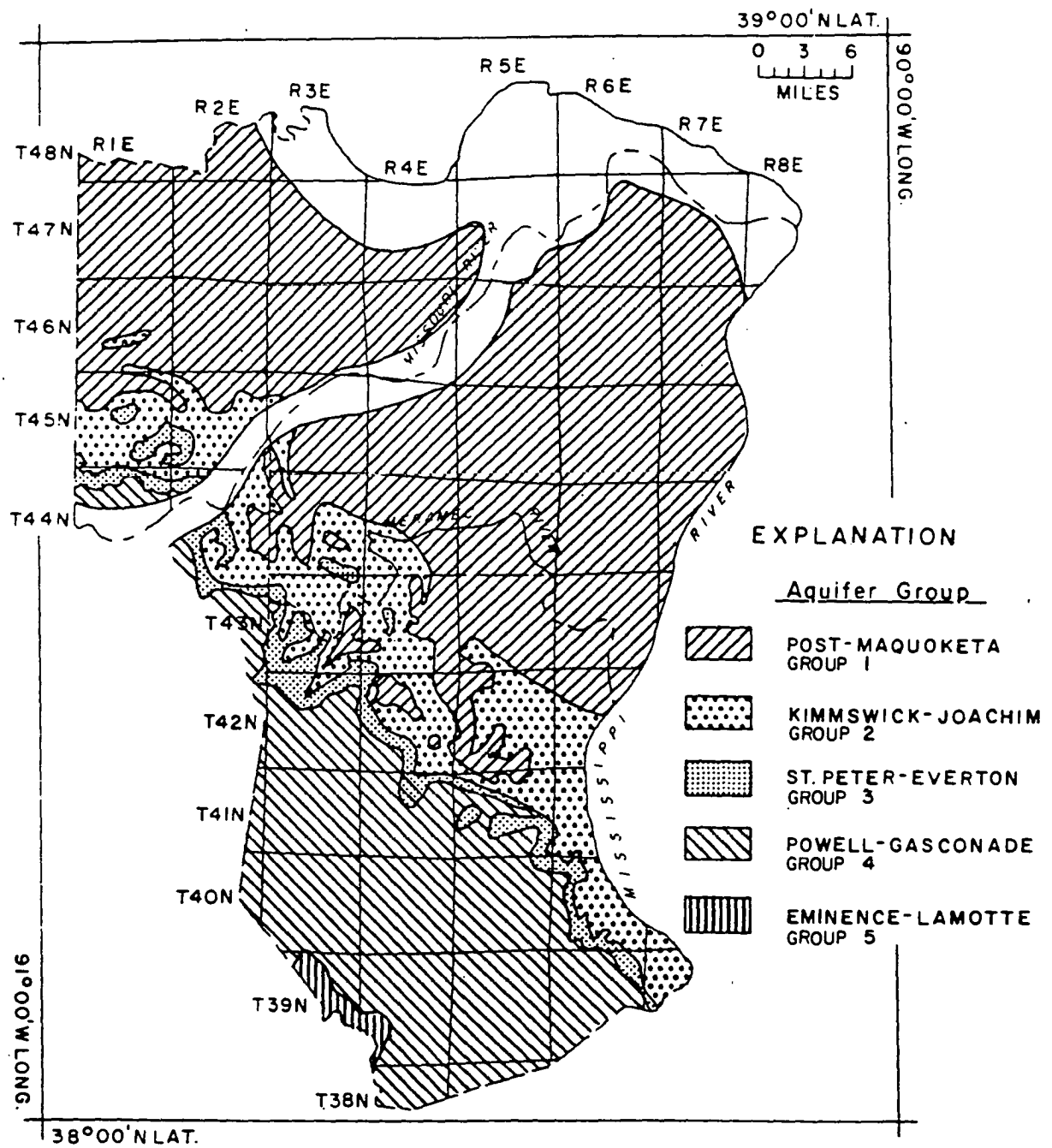


Sources: Adapted from Brill 1991

Generalized Geologic Map of the St. Louis Area



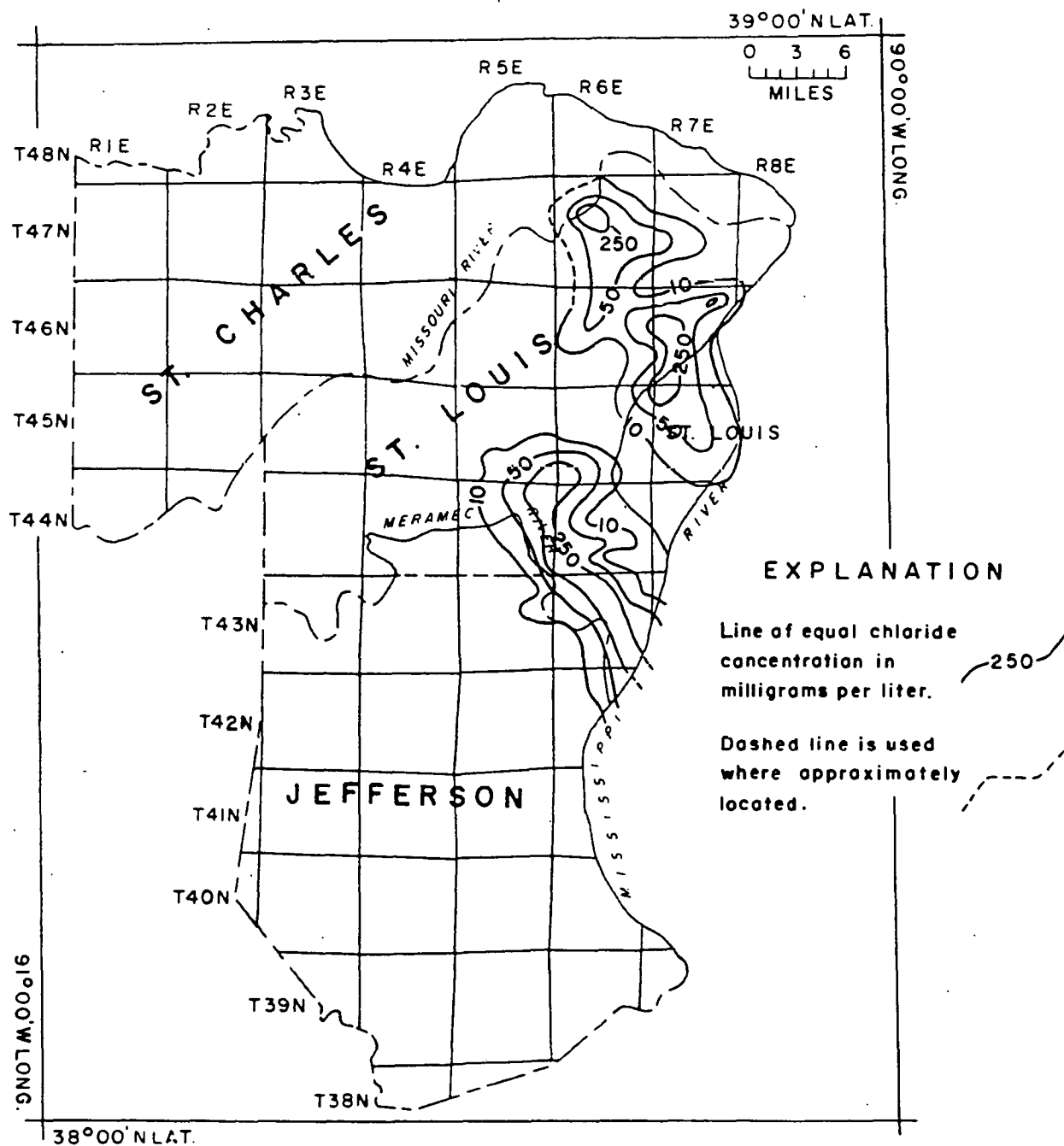
Generalized Surface Geologic Map of the St. Louis Area



Source: (Miller, 1974)

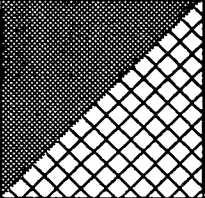
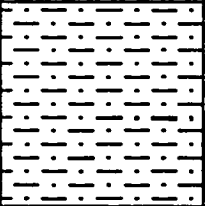
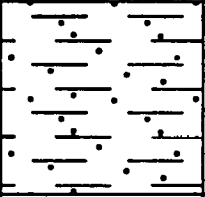

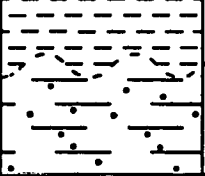
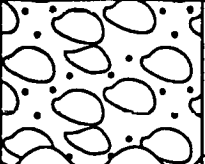
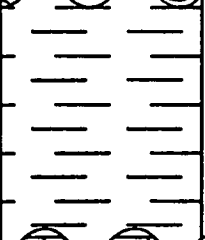
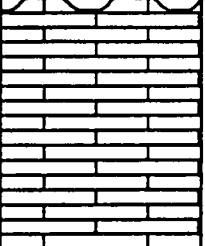
Geologic map showing distribution of aquifer groups. Numerals indicate aquifer groups.
(See table 1 for more detail.)

WATER RESOURCES OF THE ST. LOUIS AREA, MISSOURI



Source: (Miller, 1974)

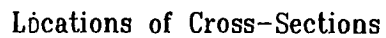
Distribution of chloride in Group 1 (Post-Maquoketa) aquifers.

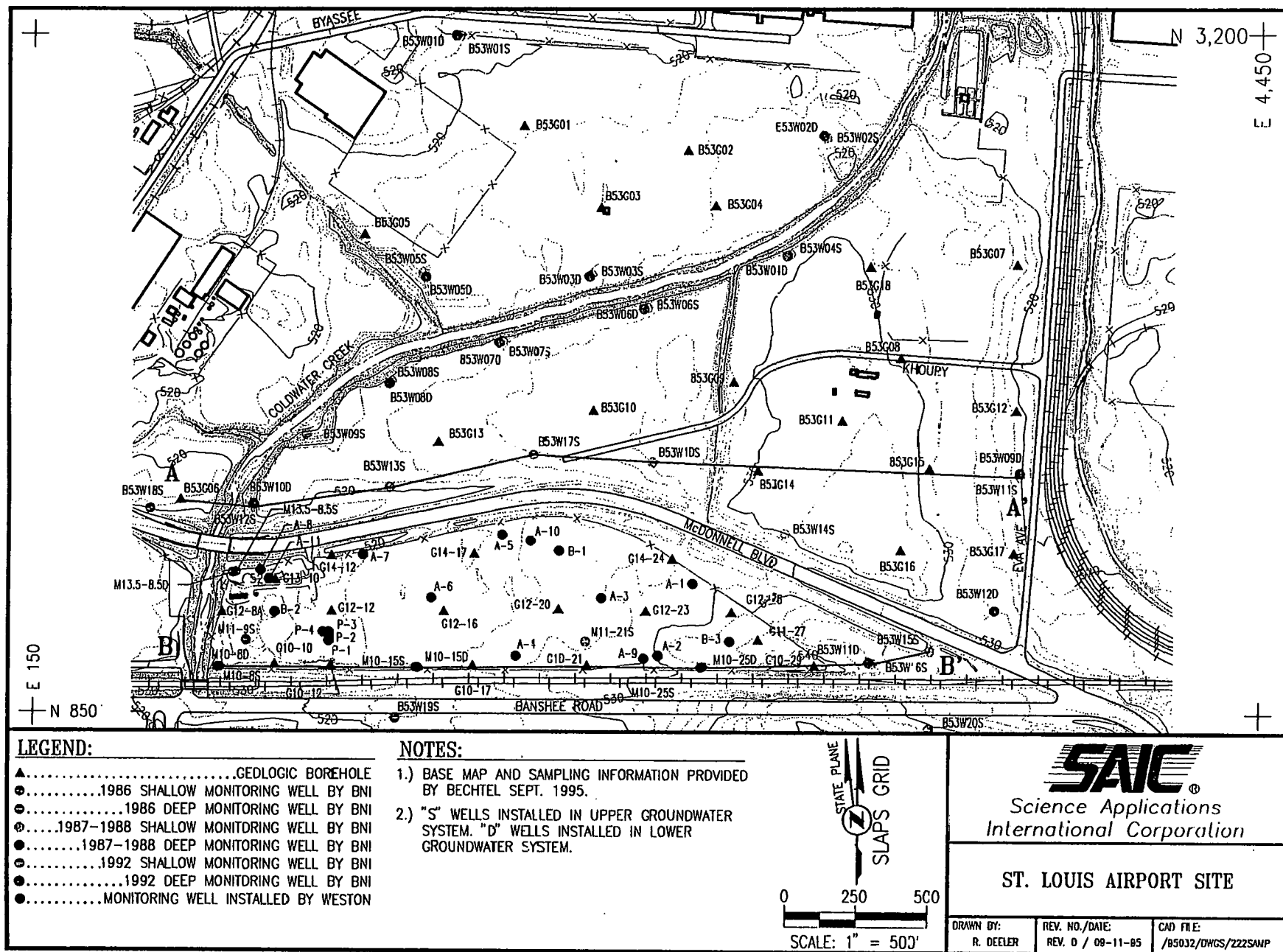
Period	Epoch	Stratigraphic	Columnar	Thickness (ft.)	Description
Quaternary	Holocene	FILL/TOPSOIL		0-14	UNIT 1 Fill – Sand, silt, clay, concrete, rubble. Topsoil – Organic silts, clayey silts, wood, fine sand.
	Pleistocene	LOESS (CLAYEY SILT)		11-32	UNIT 2 Clayey silts, fine sands, commonly mottled with iron oxide staining. Scattered roots and organic material, and a few fossils.
		GLACIO-LACUSTRINE SERIES:		19-75 (3)	UNIT 3 Silty clay with scattered organic blebs and peat stringers. Moderate plasticity. Moist to saturated. (3T)
		SILTY CLAY		9-27 (3T)	
		VARVED CLAY		0-8	Alternating layers of dark and light clay as much as 1/16 inch thick. (3M)
		CLAY		0-26	Dense, stiff, moist, highly plastic clay. (3M)
		SILTY CLAY		0-29	Similar to upper silty clay. Probable unconformable contact with highly plastic clay. (3B)
Pennsylvanian		BASAL CLAYEY & SANDY GRAVEL		0-6	UNIT 4 Glacial clayey gravels, sands, and sandy gravels. Mostly Chert.
		CHEROKEE (?) GROUP (undifferentiated)		0-35	UNIT 5 BEDROCK: Interbedded silty clay/shale, lignite/coal, sandstone, and siltstone. Erosionally truncated by glaciolacustrine sequences.
Mississippian		STE. GENEVIEVE (?) LIMESTONE		10+	UNIT 6 BEDROCK: Hard, white to olive, well-cemented, sandy limestone with interbedded shale laminations.

Sources: BNI 1993

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Generalized Stratigraphic Column for the SLAPS/Ball Field Area

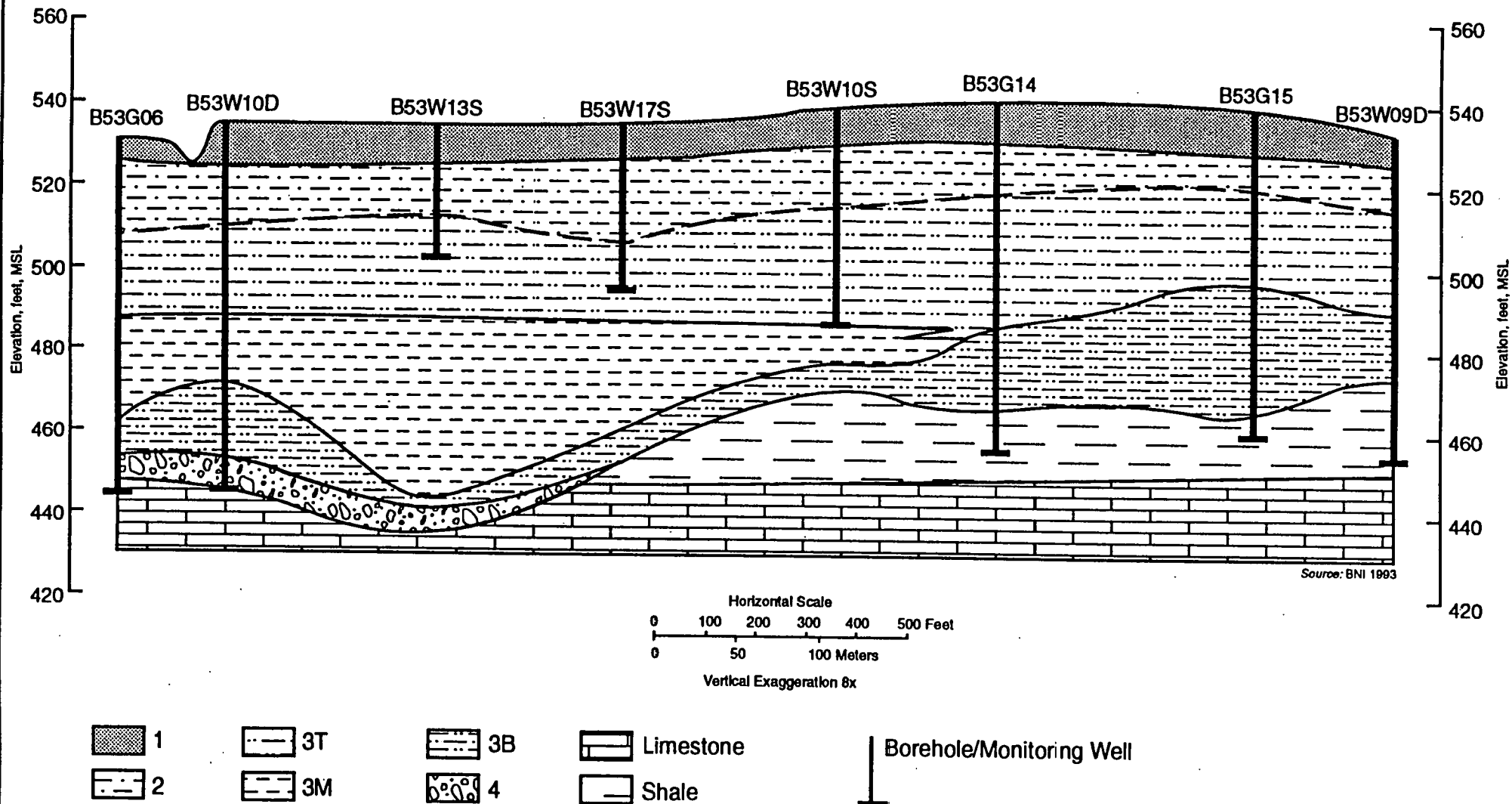




Locations of Cross-Sections

WEST
A

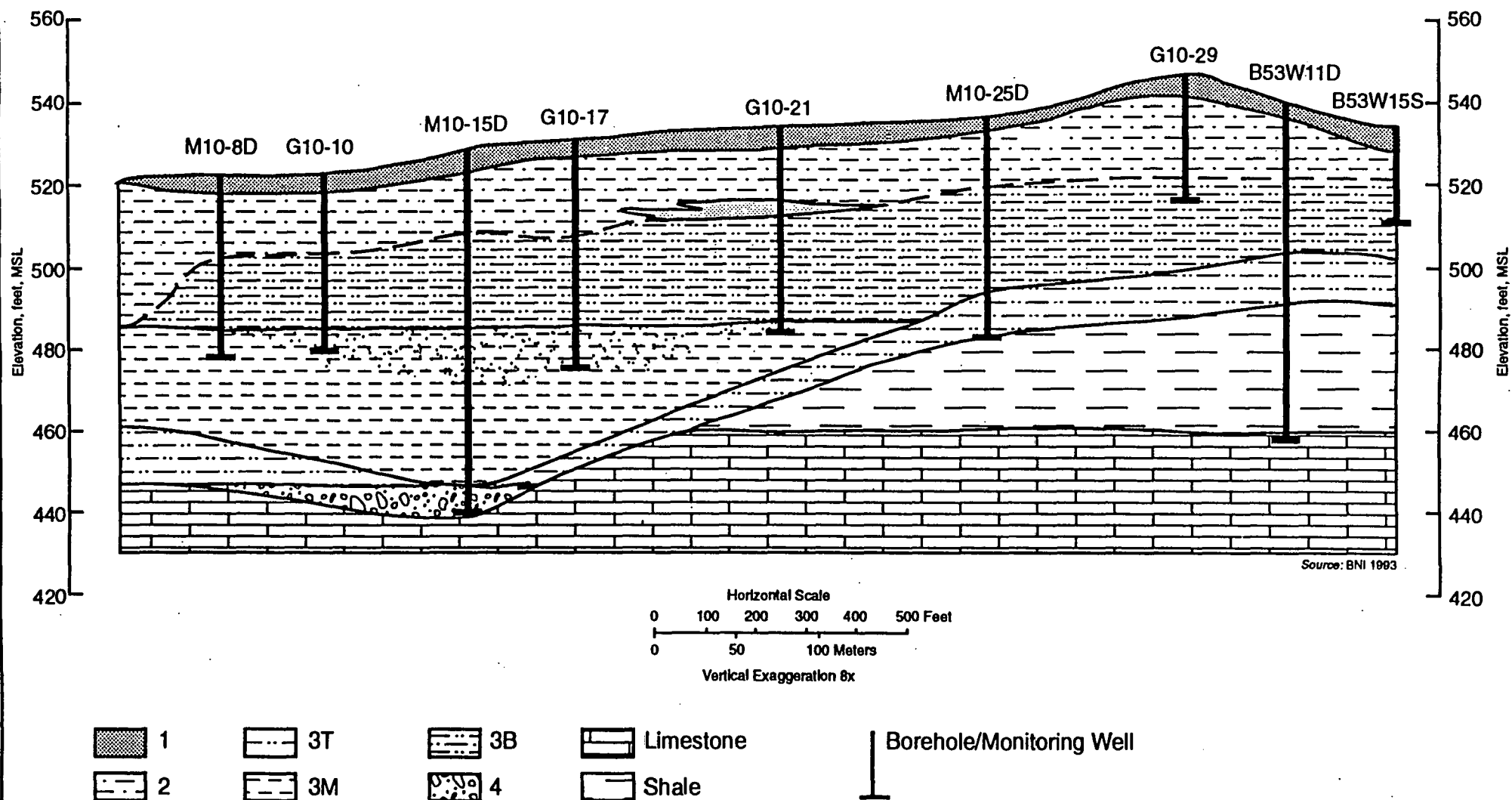
EAST
A



Cross Section A - A

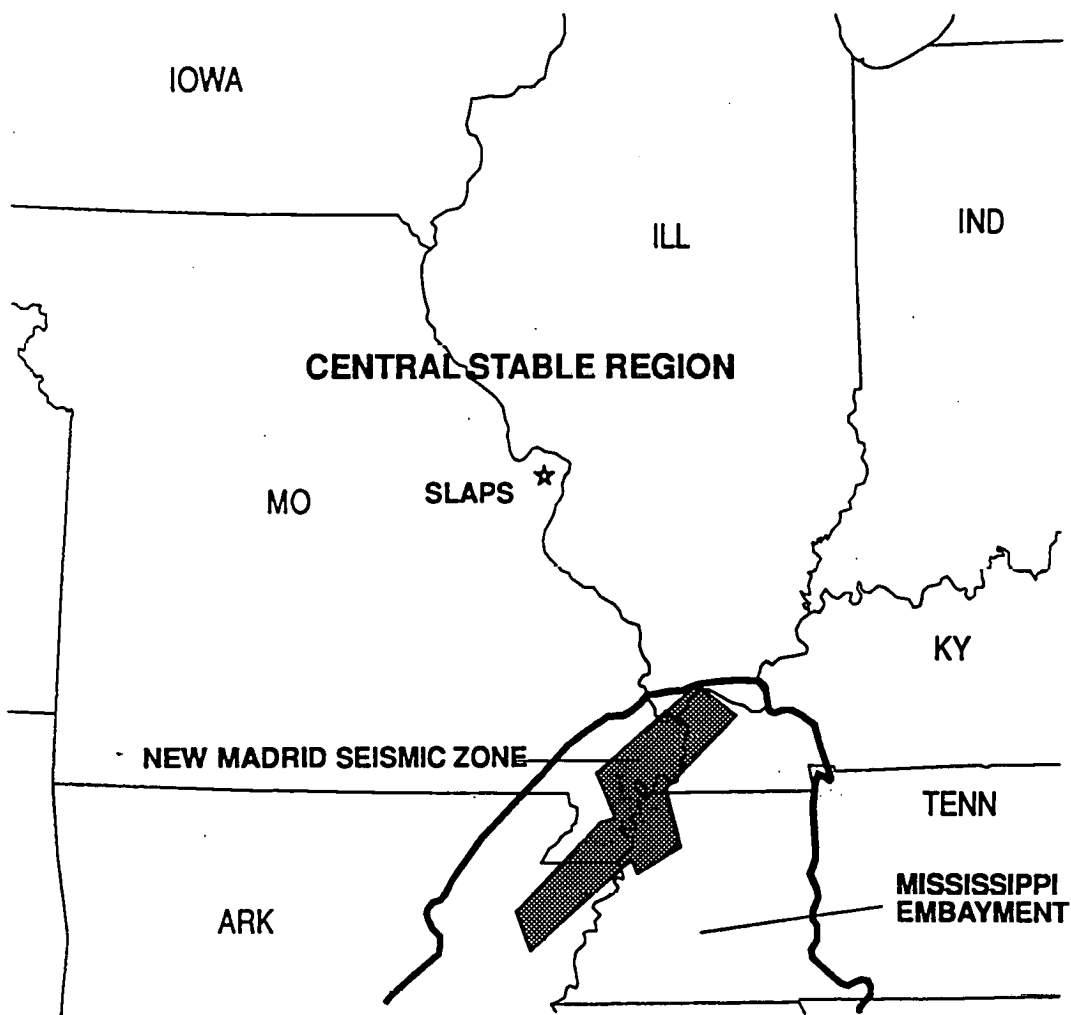
WEST
B

EAST
B

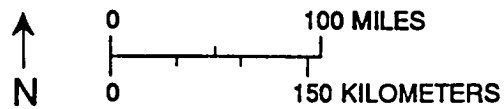


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Cross Section B - B



Source: BNI 1993



Tectonic Elements of the SLAPS Region

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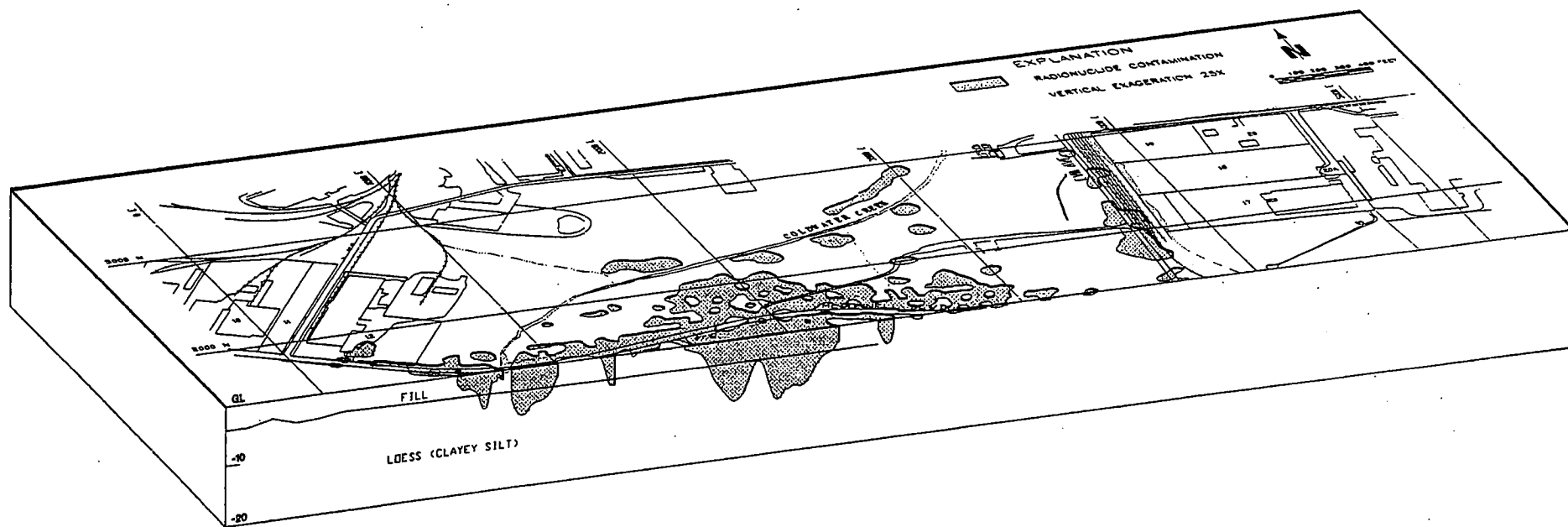


Figure 2-6. Vertical Extent of Radionuclide Contamination in Soil at St. Louis Airport Site and Adjacent Vicinity Properties

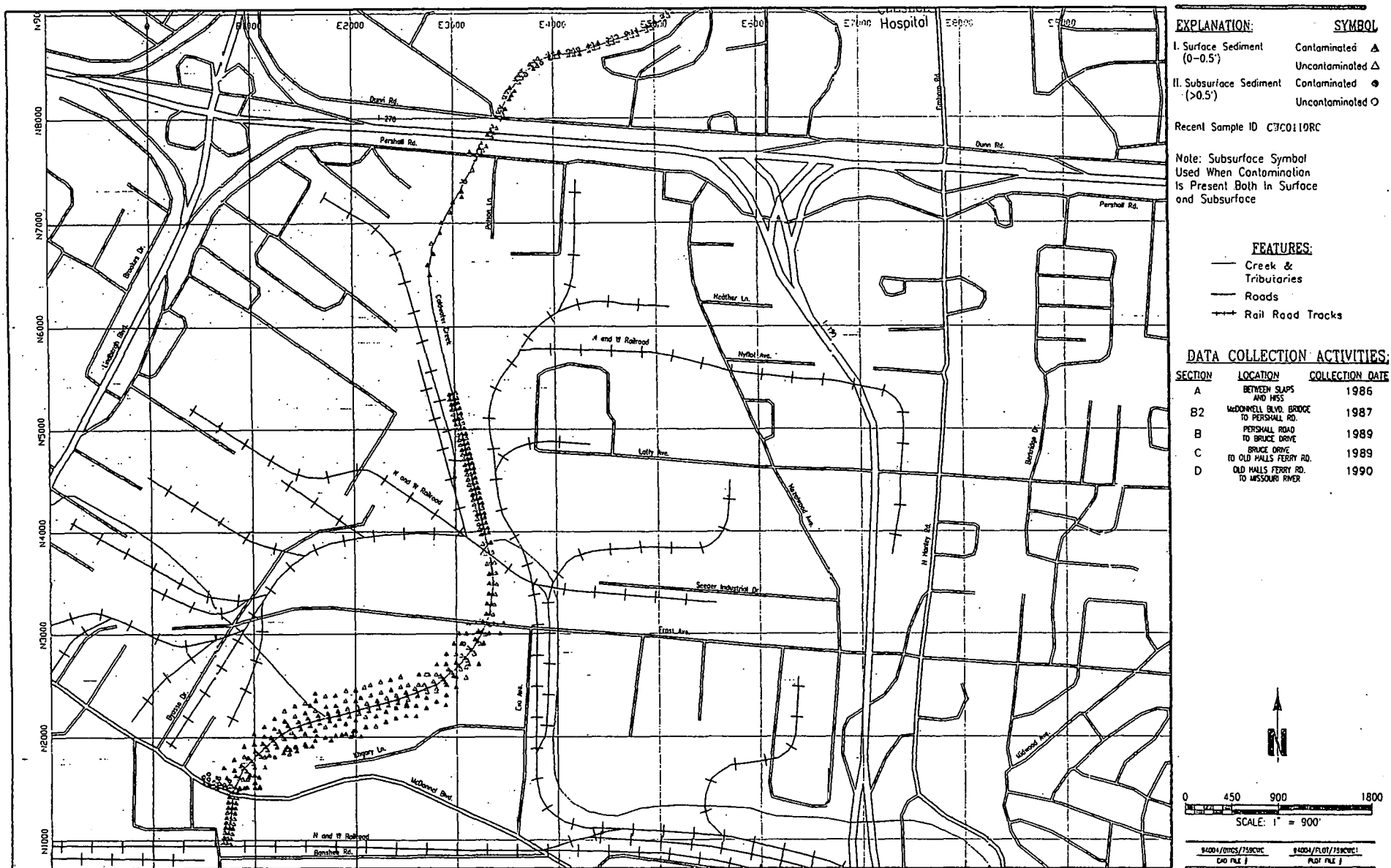
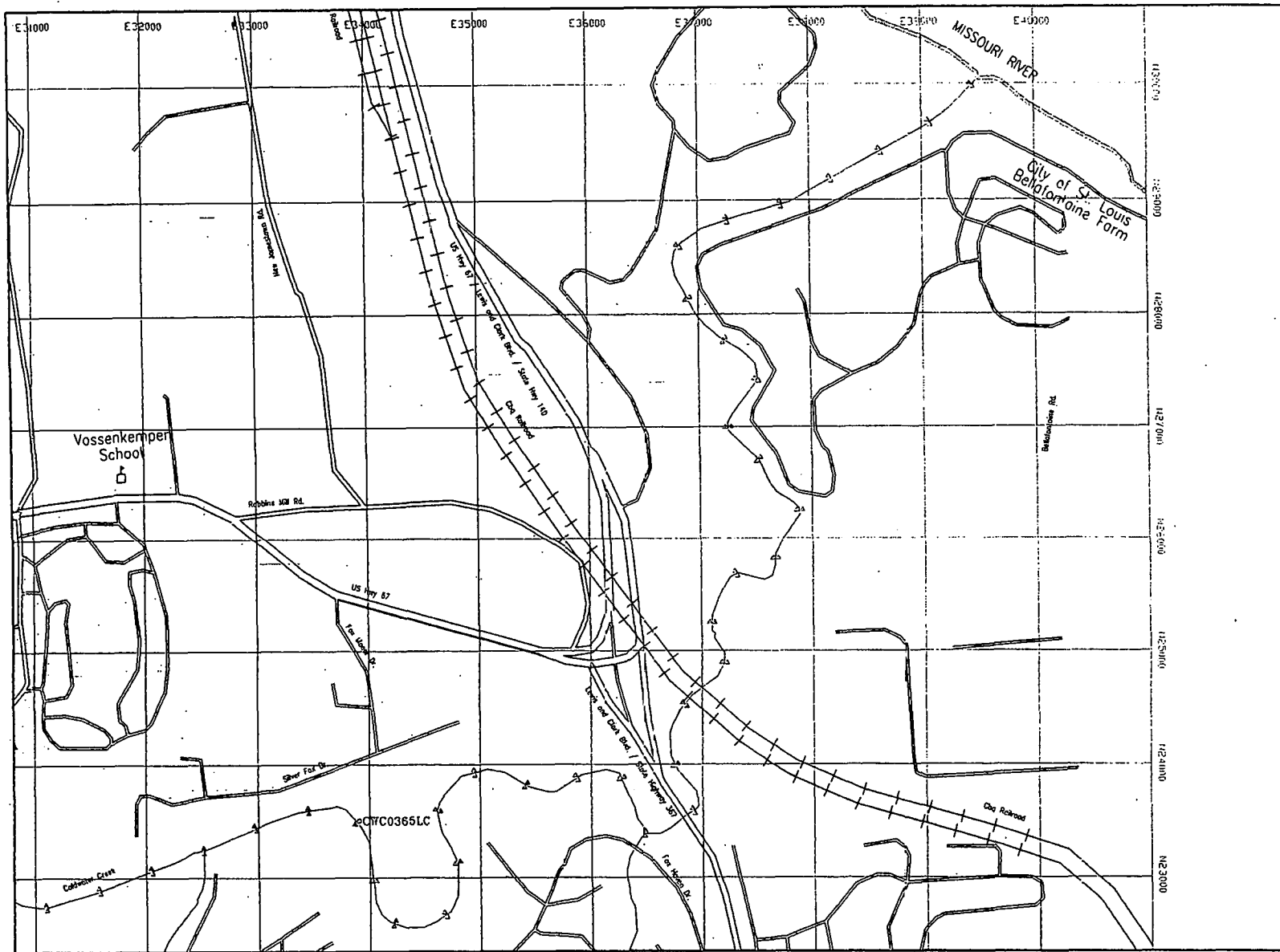


Figure 2-13(1). Radionuclide Contamination in Sediment Along Coldwater Creek Map 1 of 5



Figure 2-13(4). Radionuclide Contamination in Sediment Along Coldwater Creek Map 4 of 5



EXPLANATION:

EXPLANATION:	SYMBOL
I. Surface Sediment (0-0.5')	Contaminated Δ
	Uncontaminated ∇
II. Subsurface Sediment (>0.5')	Contaminated \odot
	Uncontaminated \oslash

Recent Sample ID C7C0110RC

Note: Subsurface Symbol Used When Contamination Is Present Both in Surface and Subsurface

FEATURES:

- Creek & Tributaries
- Roads
- Rail Road Tracks

DATA COLLECTION ACTIVITIES:

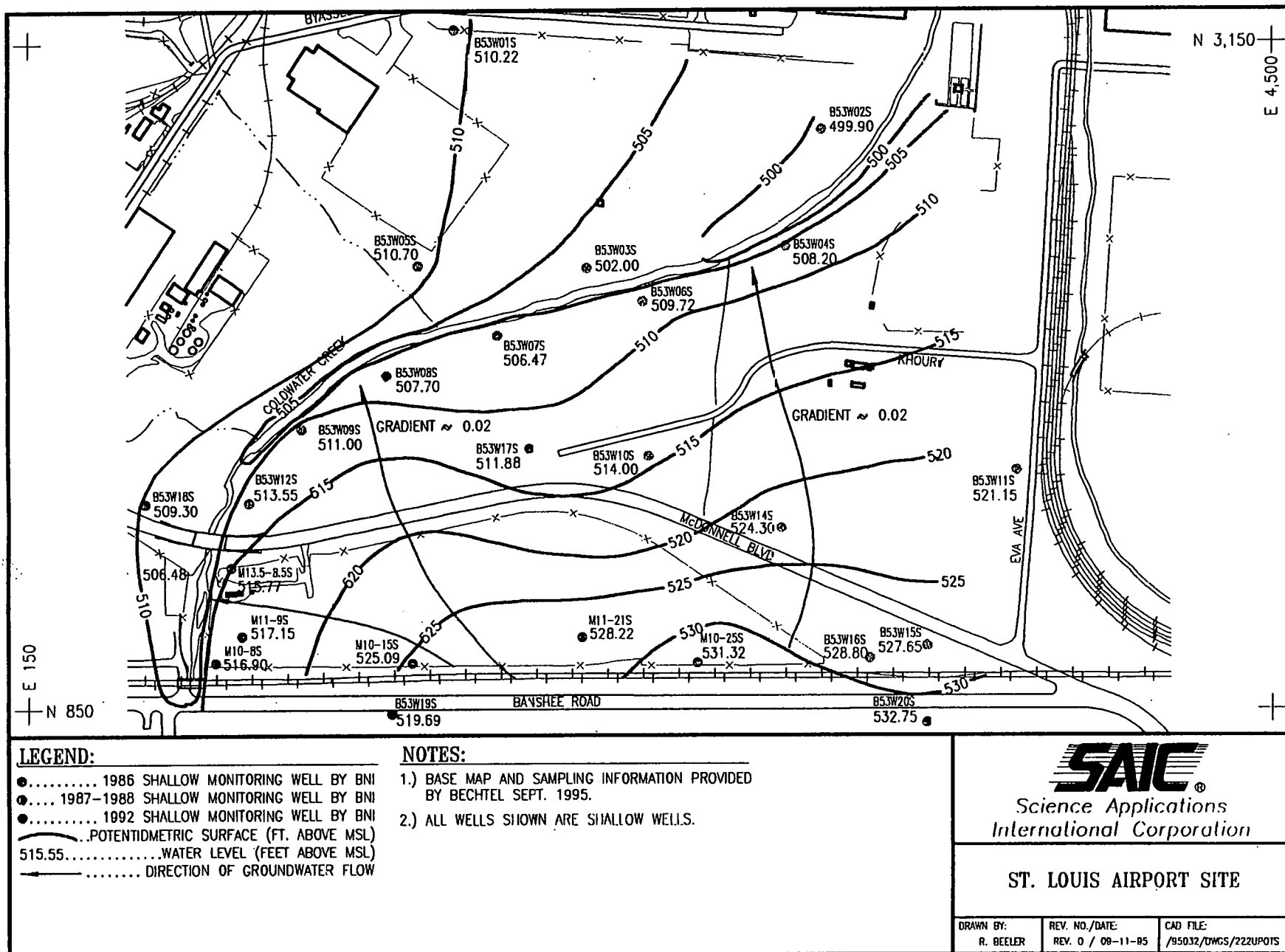
SECTION	LOCATION	COLLECTION DATE
A	BETWEEN SLAPS AND HISS	1986
B2	WADSWELL BLVD. BRIDGE TO PERSHALL RD.	1987
B	PERSHALL ROAD TO BRUCE DRIVE	1989
C	BRUCE DRIVE TO OLD HALLS FERRY RD.	1989
D	OLD HALLS FERRY RD. TO MISSOURI RIVER	1990



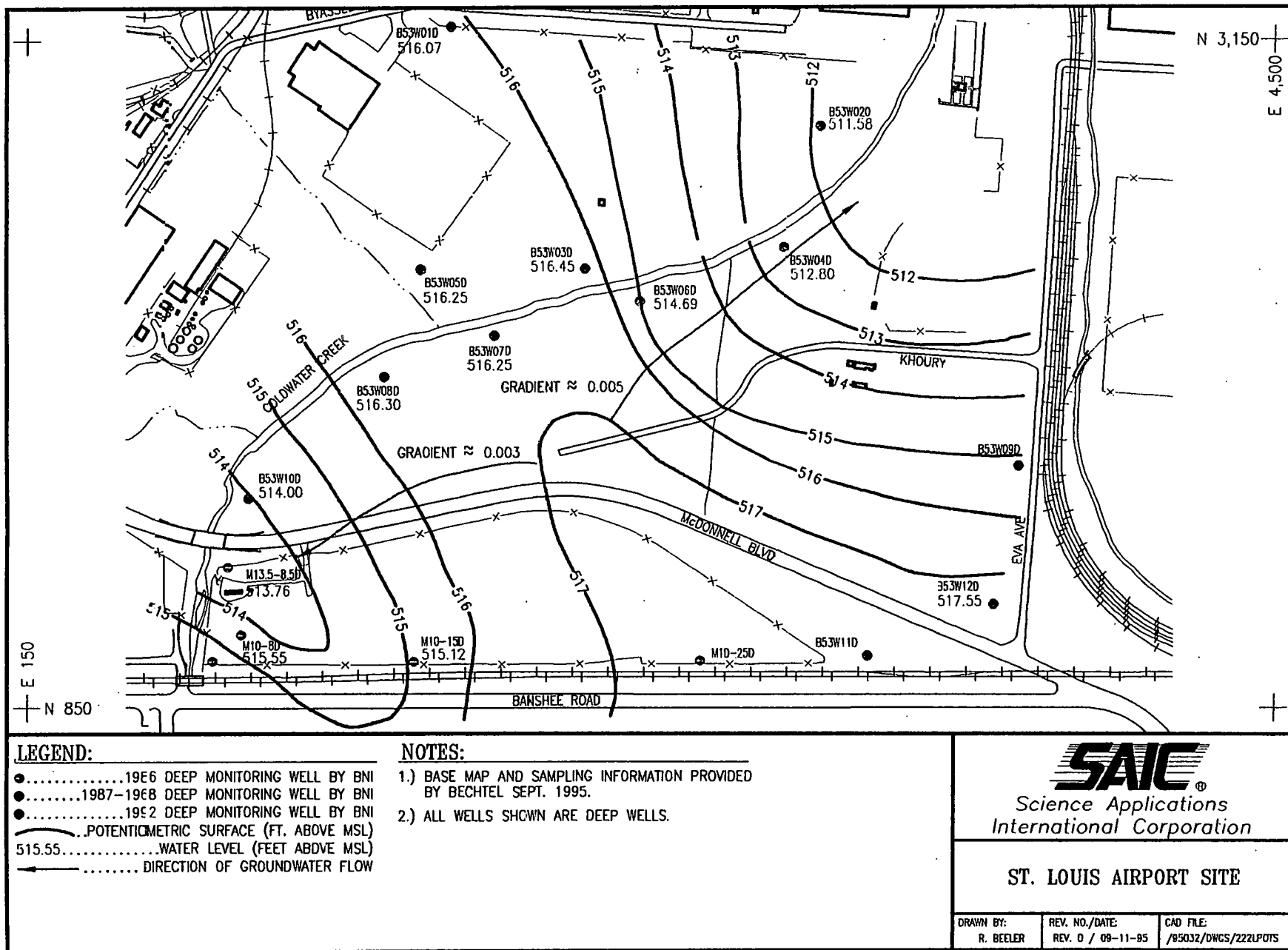
0 450 900 1800
SCALE: 1" = 900'

SH04/TRC1/TR90C SH04/PL01/TR90C
CIP FILE I PLOT FILE I

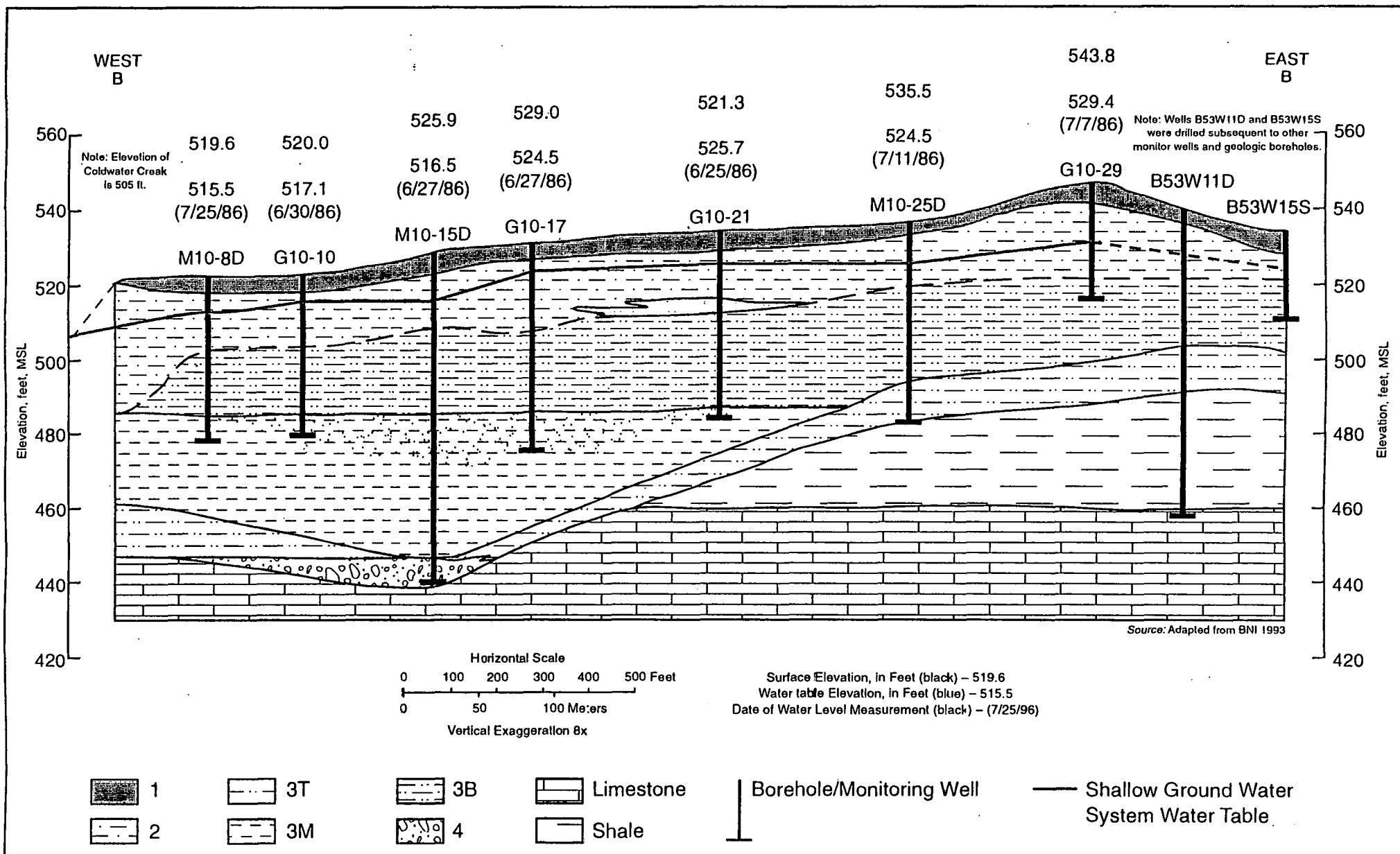
Figure 2-13(5). Radionuclide Contamination in Sediment Along Coldwater Creek Map 5 of 5



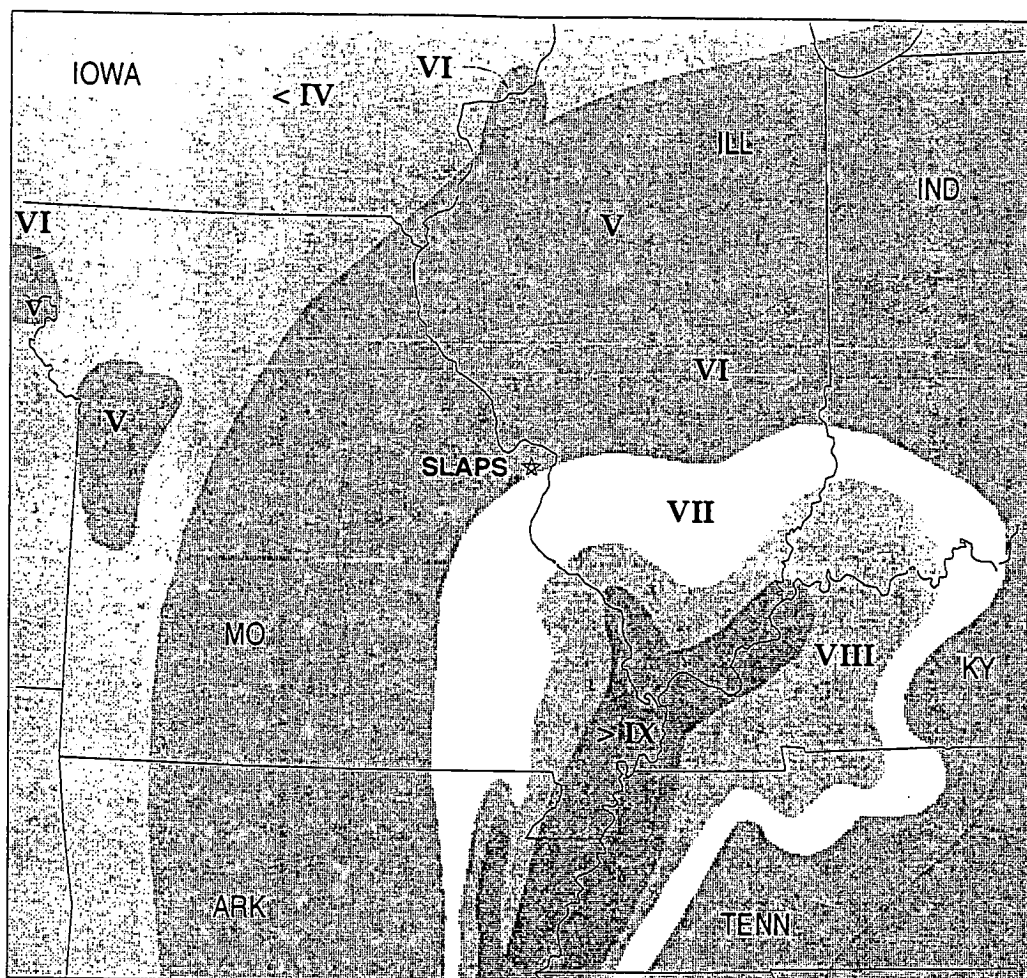
POTENTIOMETRIC SURFACE OF THE UPPER GROUNDWATER SYSTEM



POTENTIOMETRIC SURFACE OF THE LOWER GROUNDWATER SYSTEM

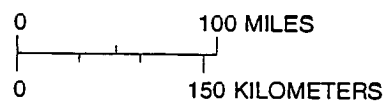


Cross Section B - B. Water Table Positions of Shallow Ground Water System During Drilling of Monitoring Wells and Geologic Boreholes in June and July 1986, as Observed by the Drill Rig Geologist.

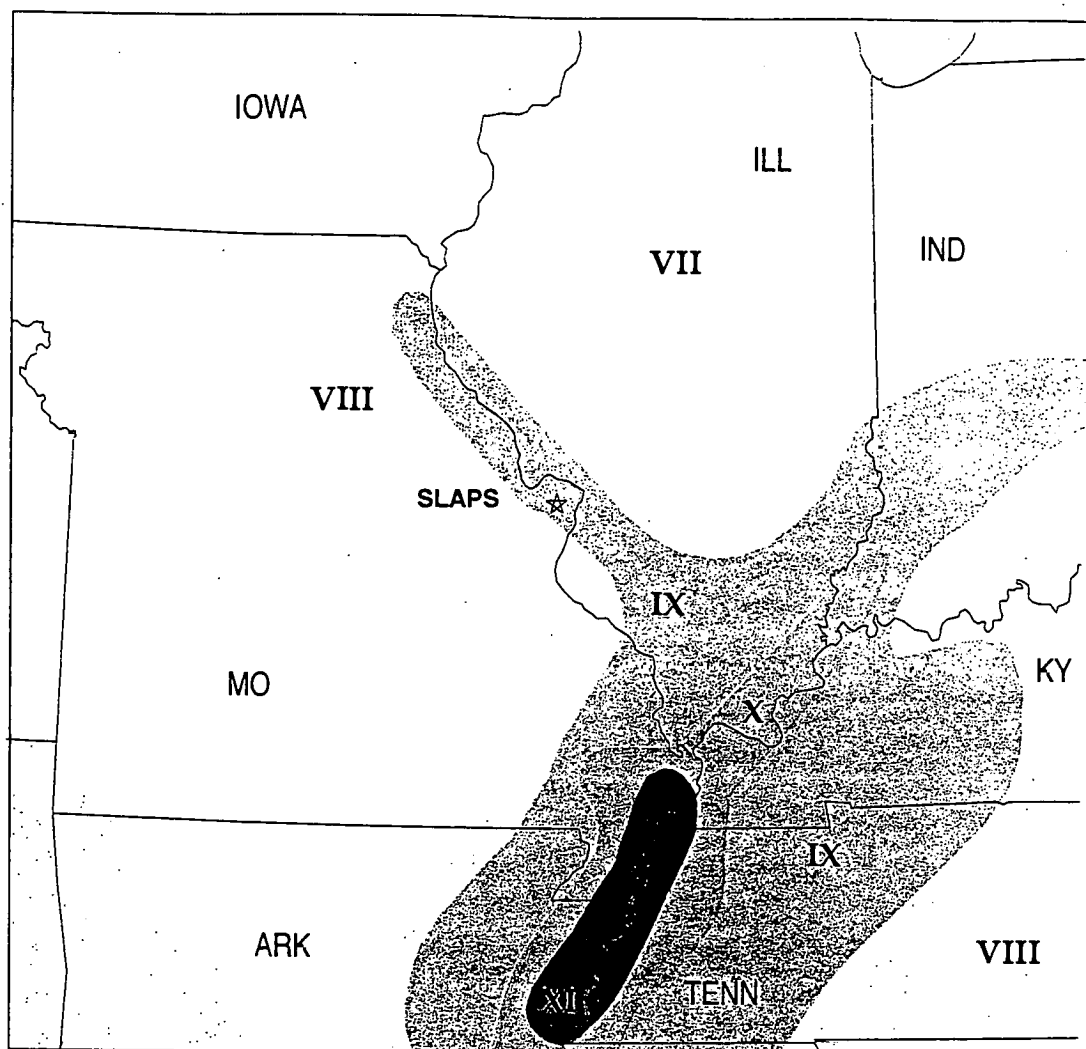


FUS St. Louis 09/95

Source: Adapted from USCGS 1967.

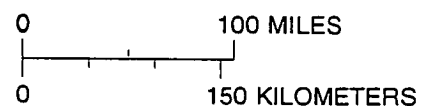


Reported Maximum MMIs for the Historical
Record Through 1965

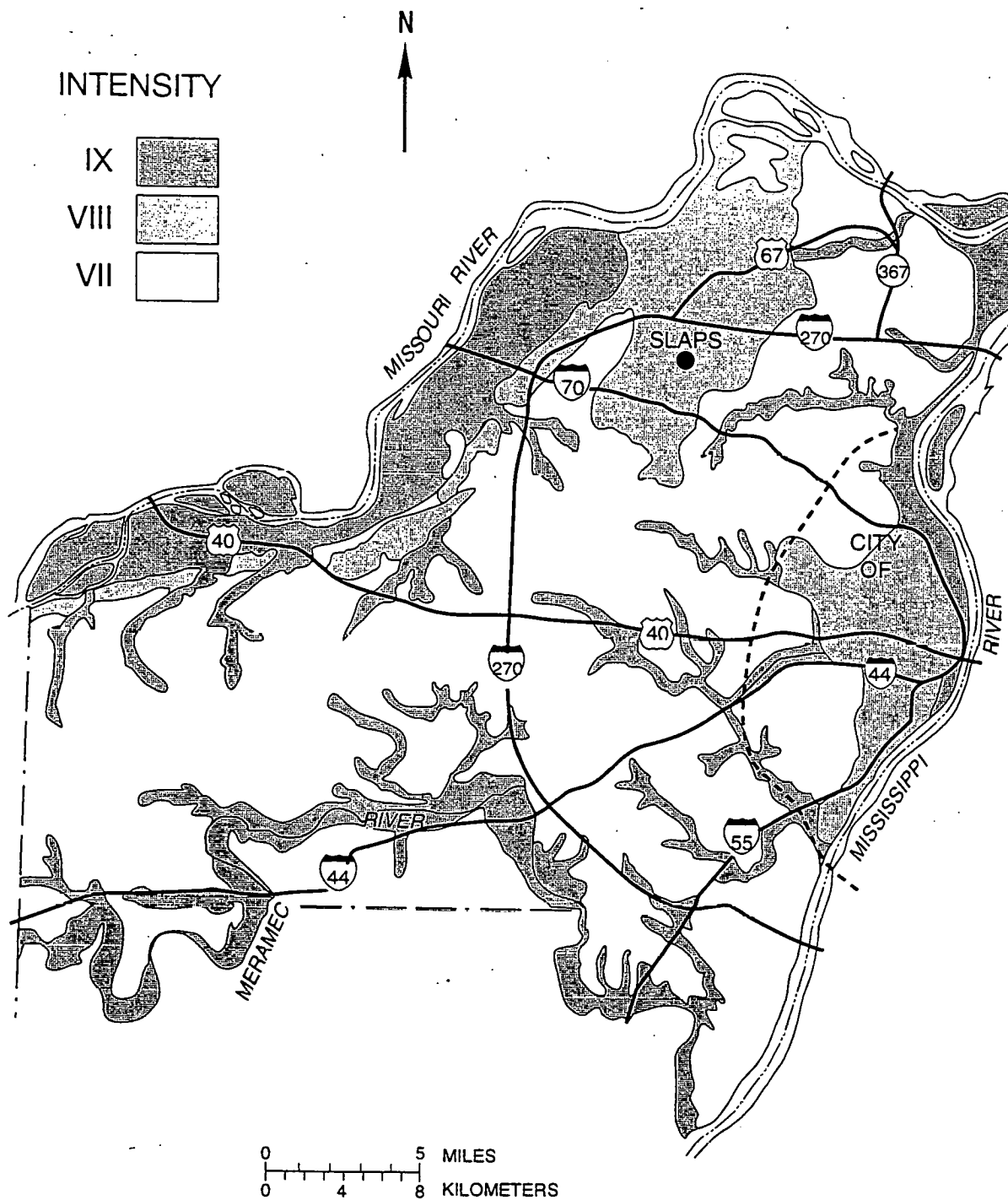


FUS St. Louis 09/95

Source: Adapted from Algermissen and Hopper 1984.

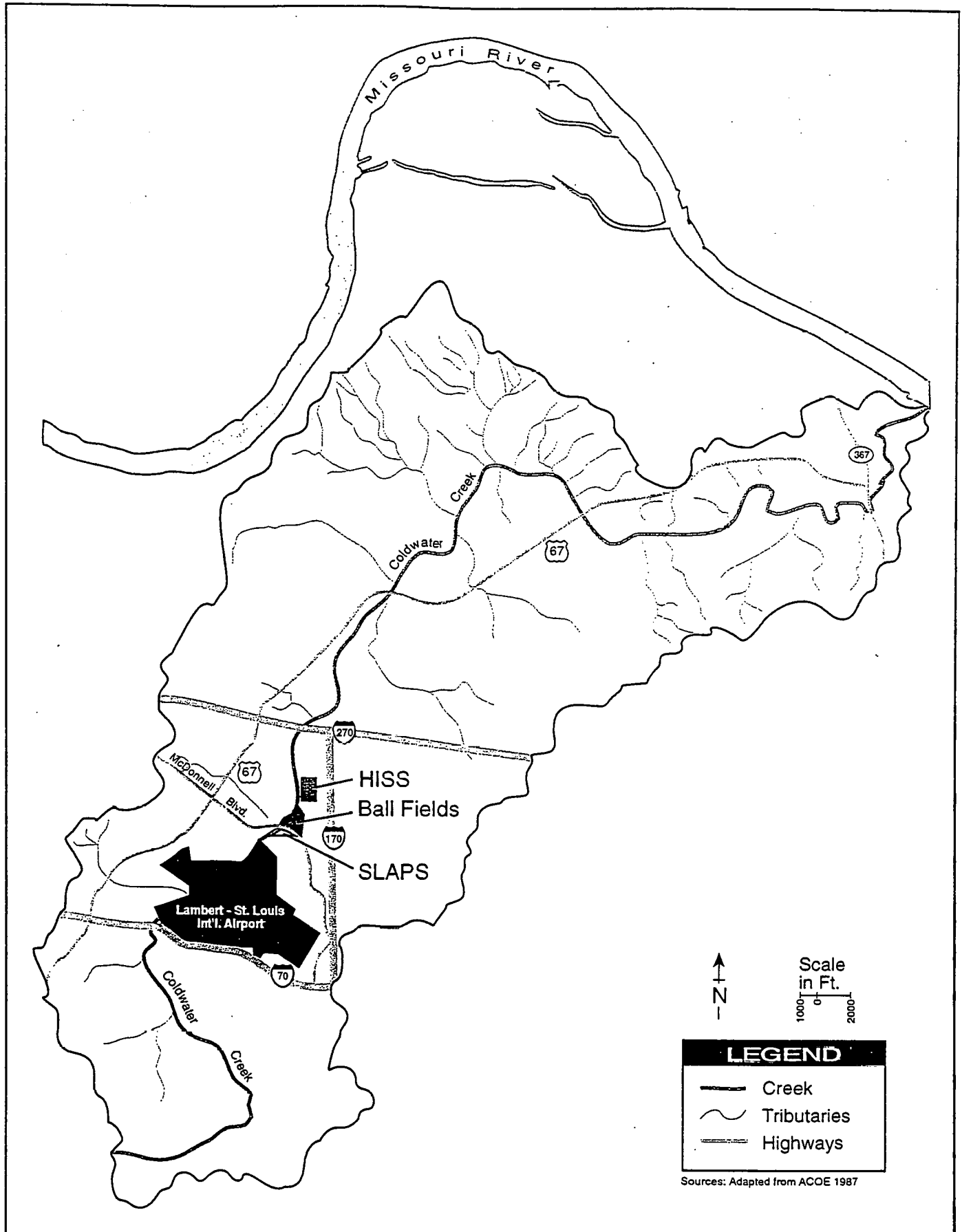


Estimated Maximum MMIs for a Hypothetical Earthquake of Richter
Magnitude 8.6 Anywhere along the New Madrid Seismic Zone



Source: O'Rourke 1988.

Estimated MMIs for a Hypothetical Earthquake of Richter Magnitude 8.6
Near the Northern End of the New Madrid Seismic Zone

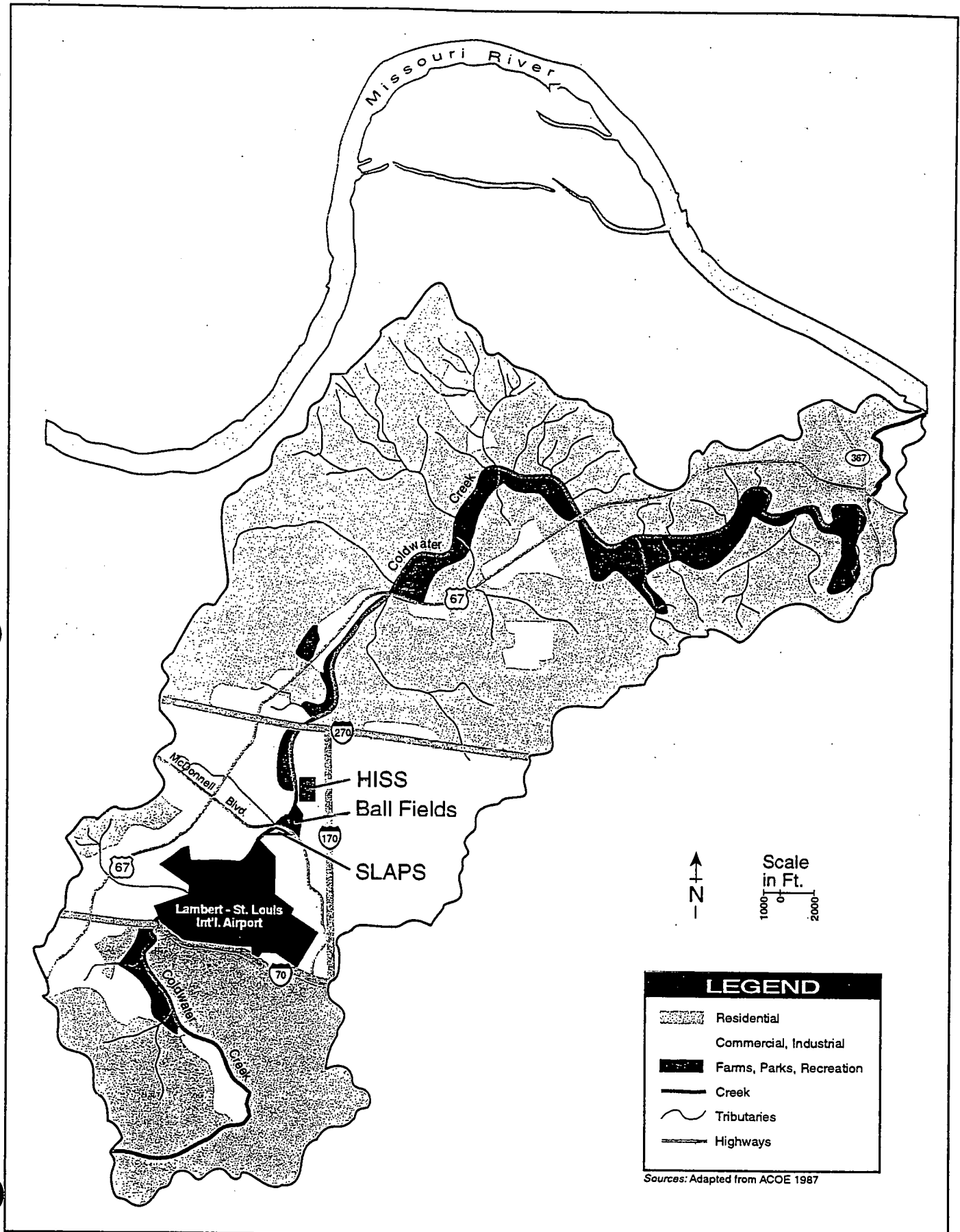


LEGEND

- Creek
- - - Tributaries
- Highways

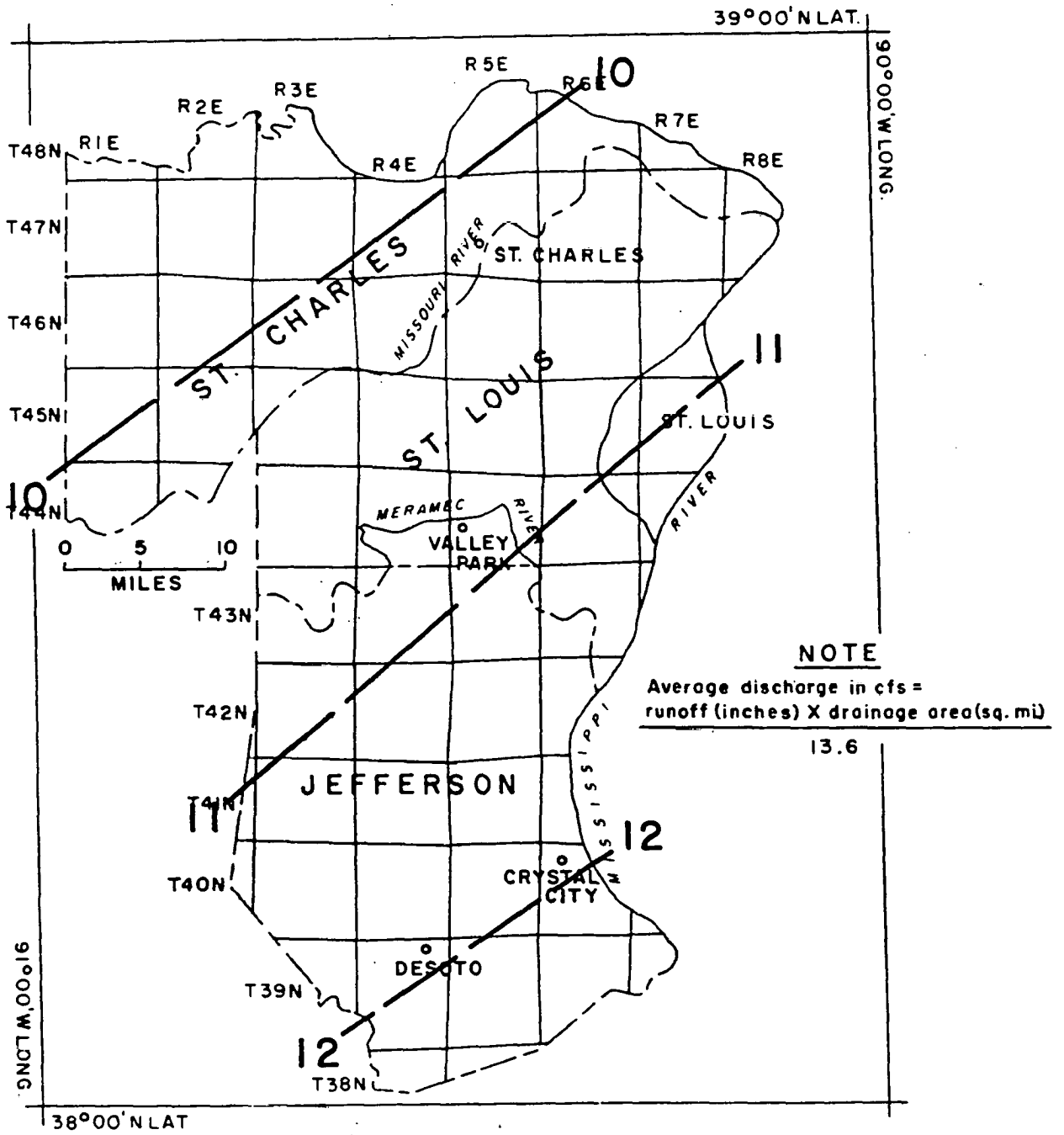
Sources: Adapted from ACOE 1987

Coldwater Creek Watershed

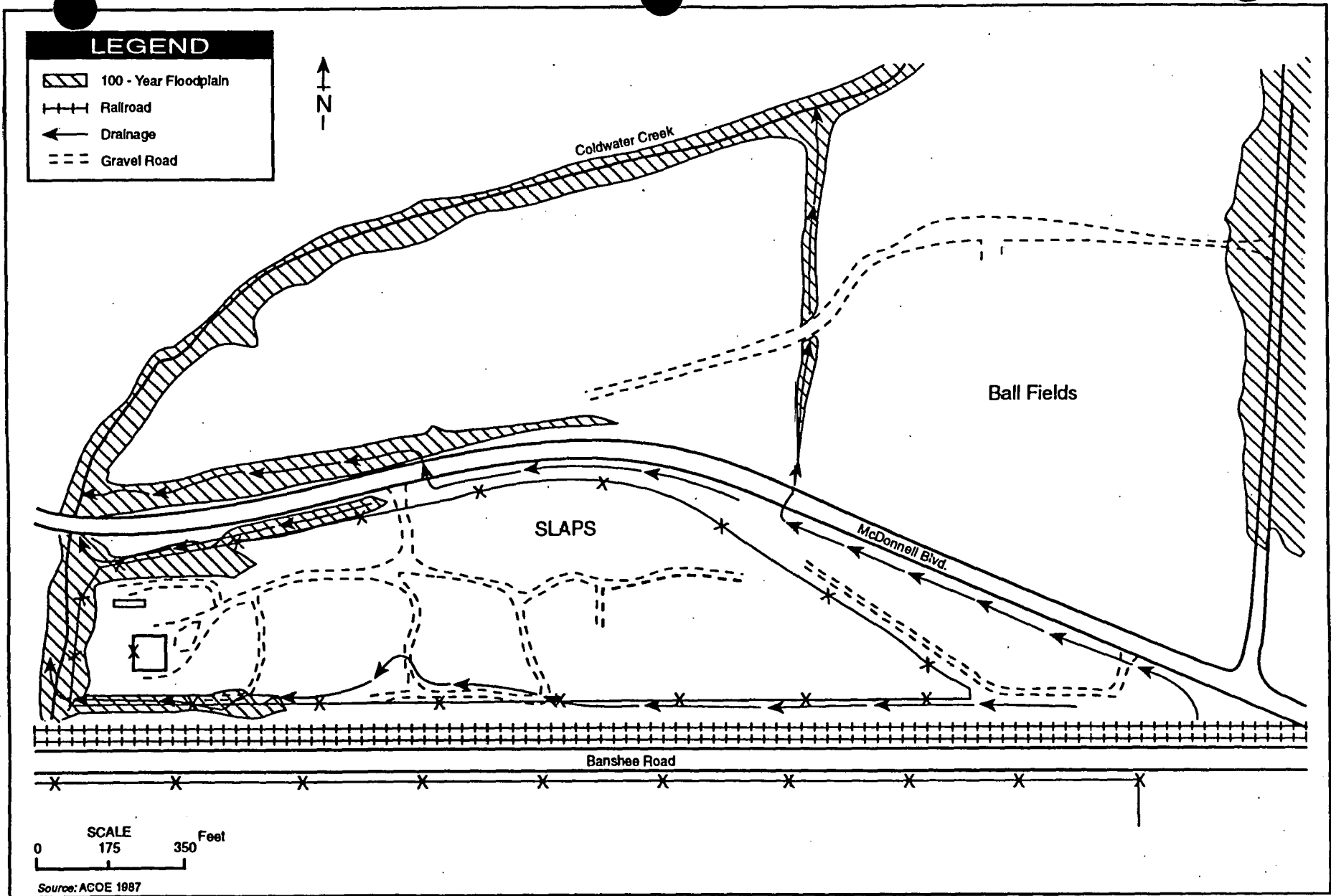


Coldwater Creek Watershed Land Use

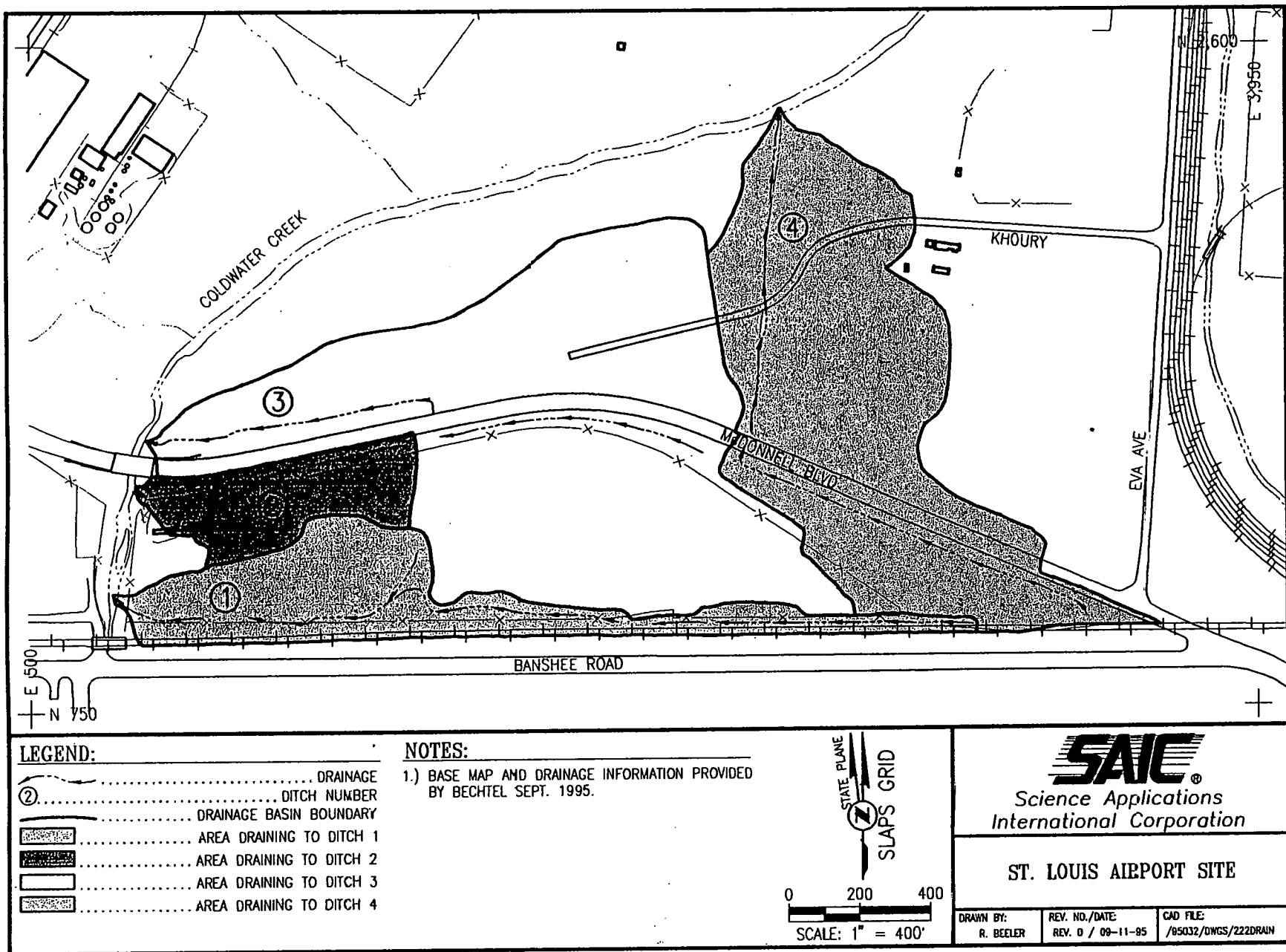
Source: (Miller, 1974)



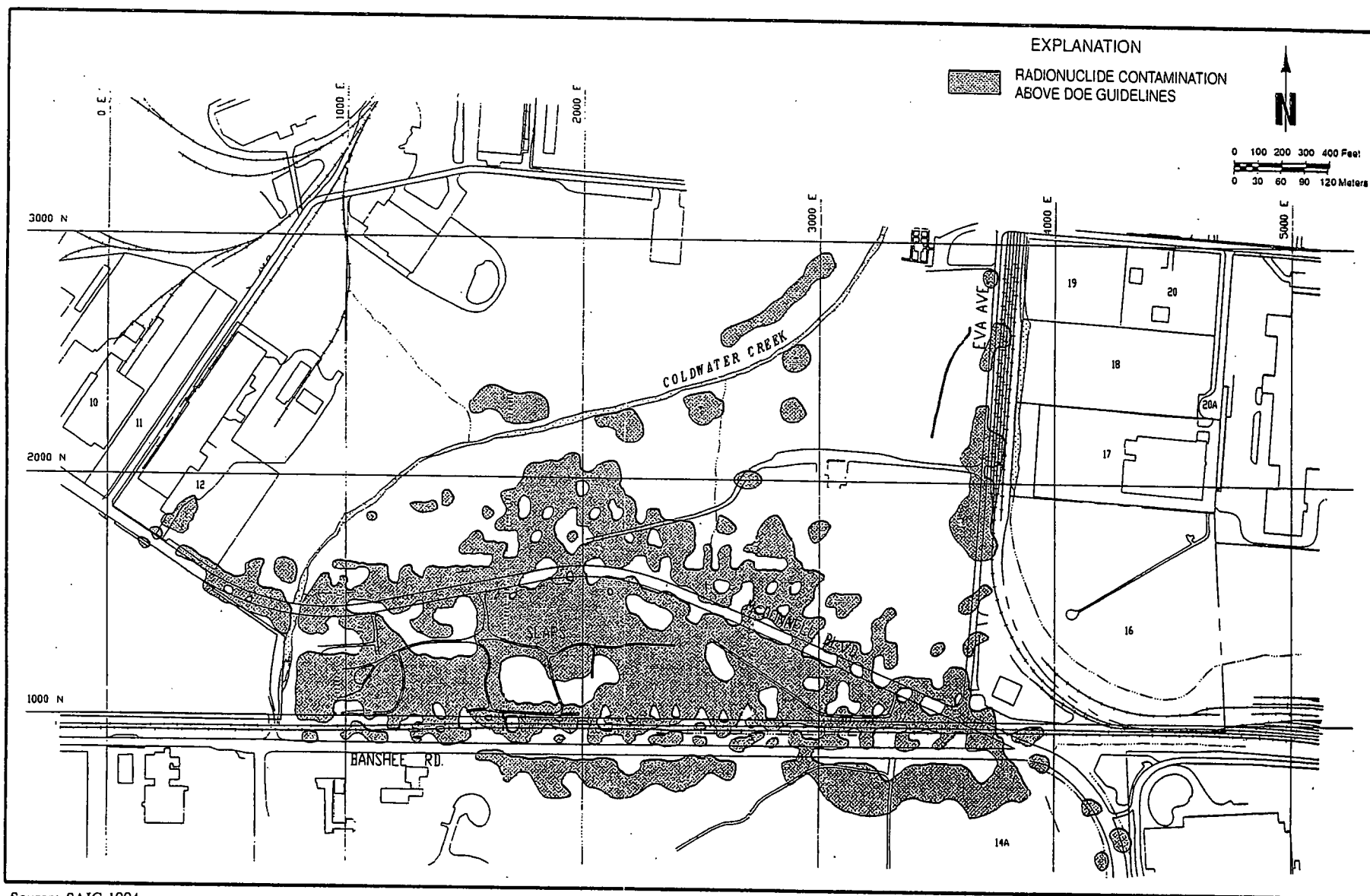
Mean natural annual runoff, in inches, for tributary streams in the St. Louis area.



SLAPS 100-Year Floodplain Without Implementation of COE Plan



SITE DRAINAGE AREAS



Source: SAIC 1994

Extent of Radiological Contamination at SLAPS

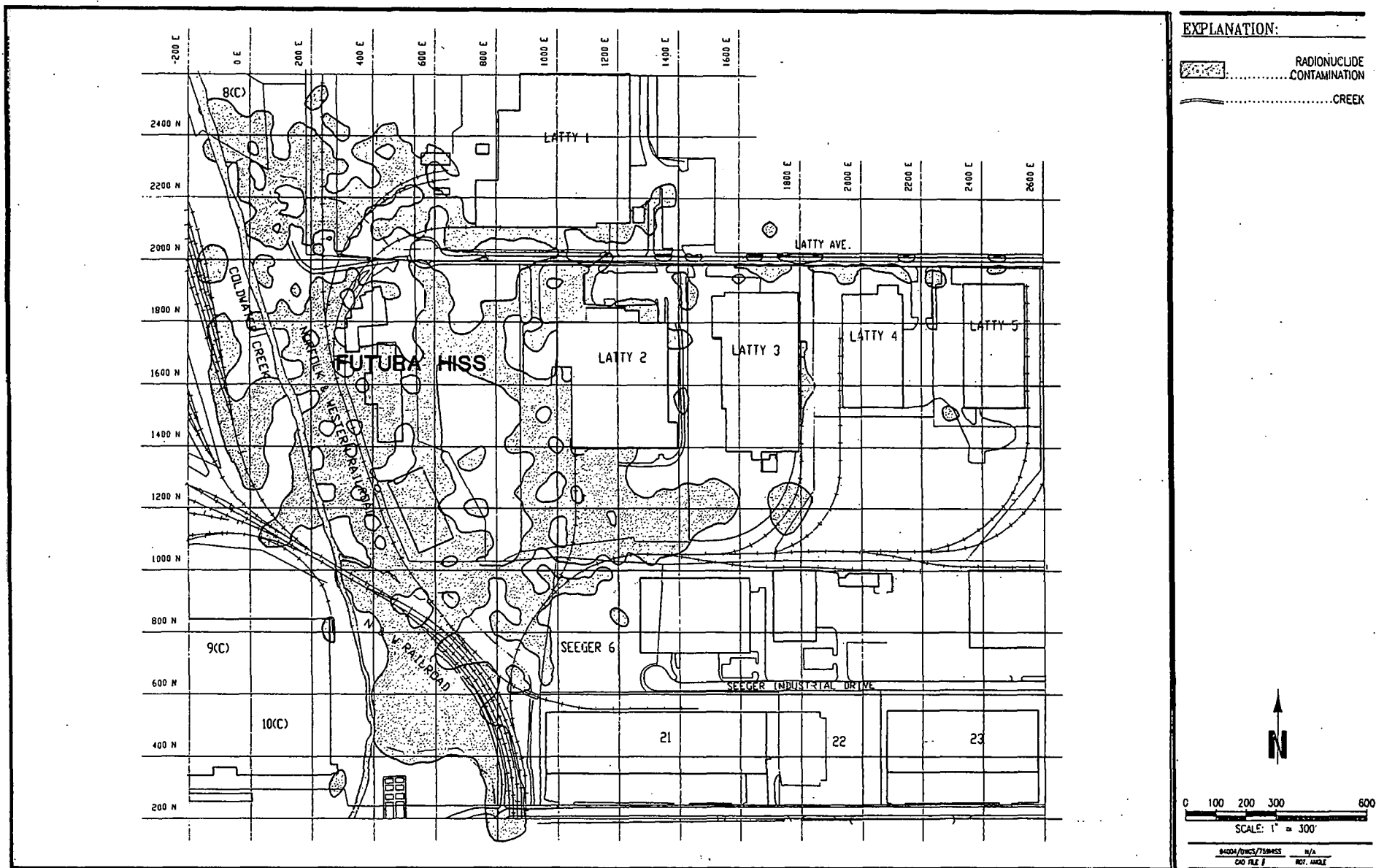
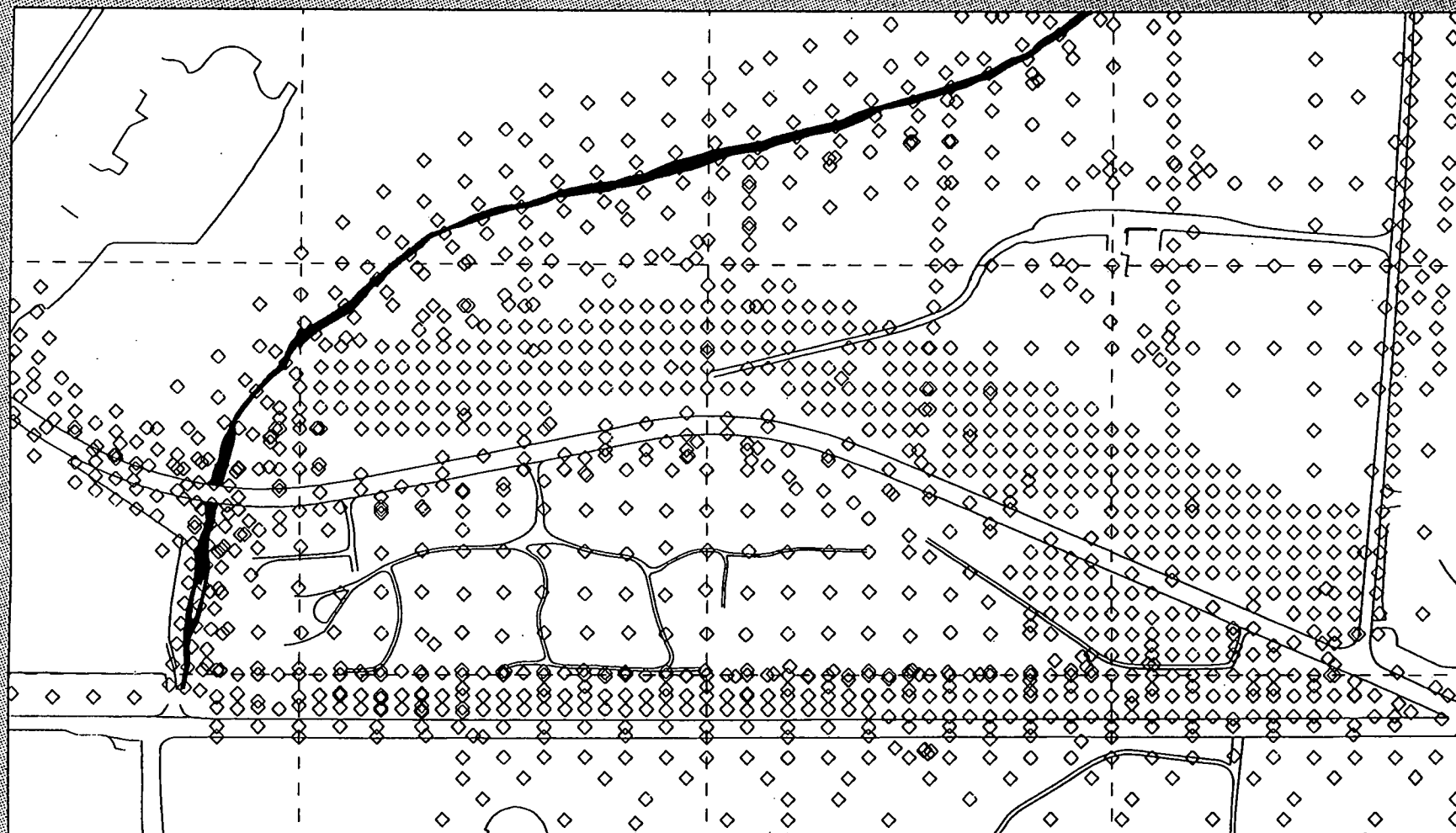
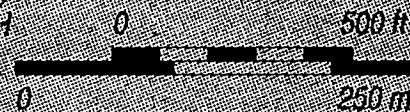


Figure 2-9. Areal Extent of Radionuclide Contamination in Soil at HISS-Futura and Adjacent Vicinity Properties



BOREHOLE LOCATIONS

SLAPS
NORTH



SAIC

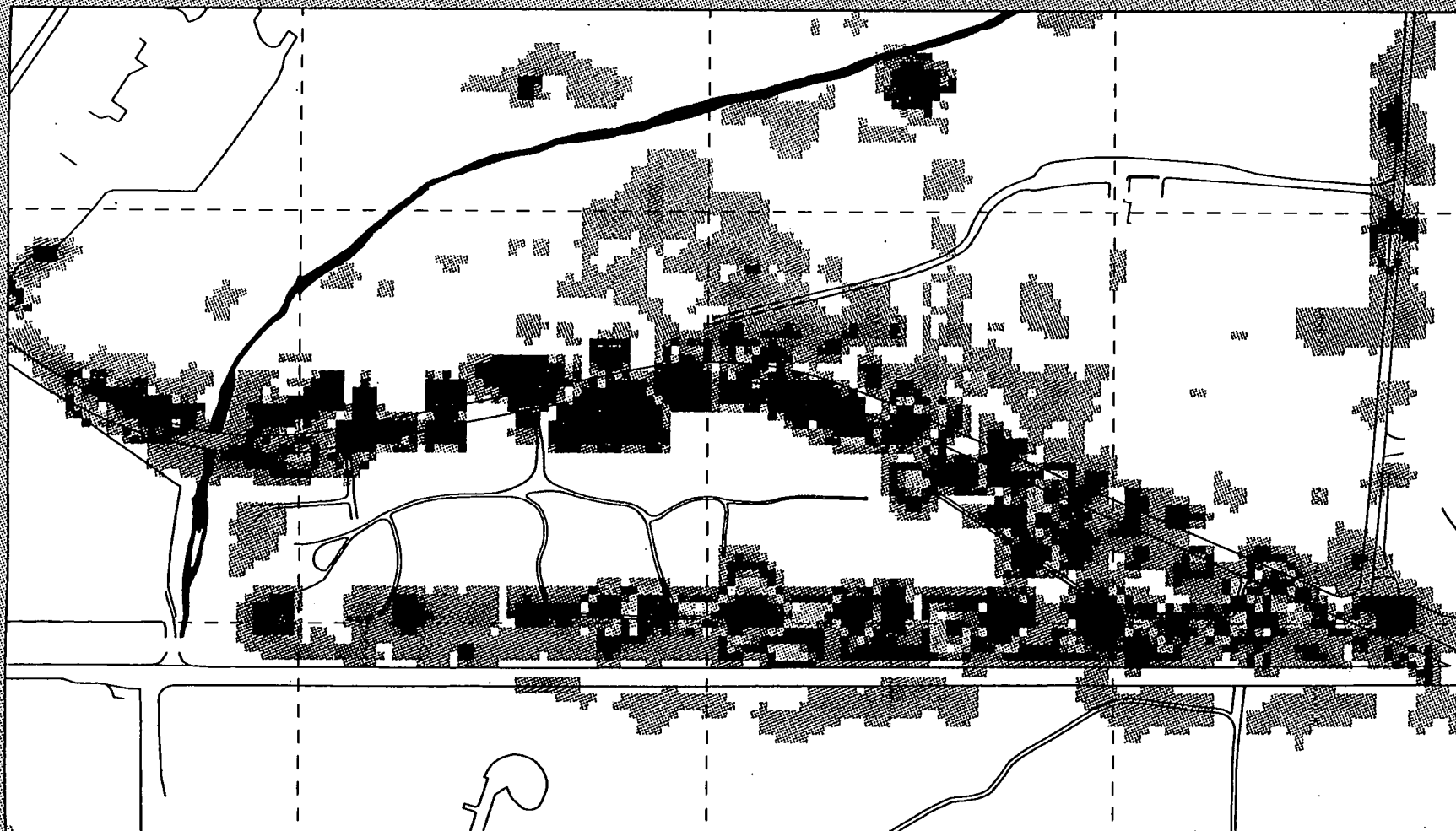
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International Corporation

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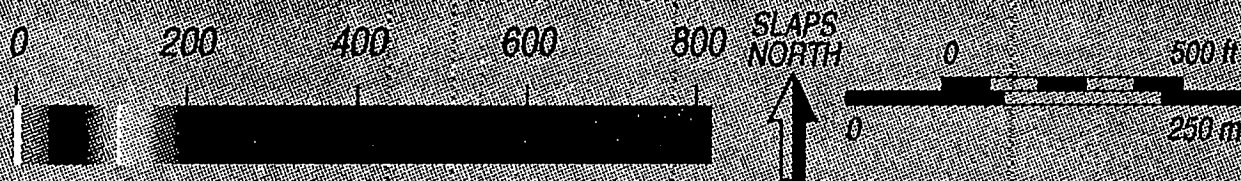
GS BY
STRONG

DATE
1-11-93

PG FILE
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TH-230 Contours (pCi/g) at Depth: 0 to 0.5 ft



SAIC

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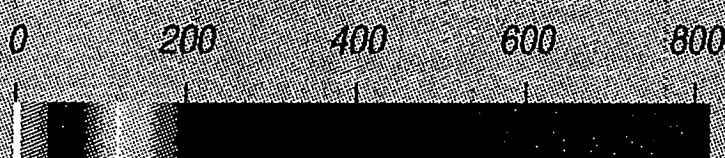
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S. THARRS

DATE
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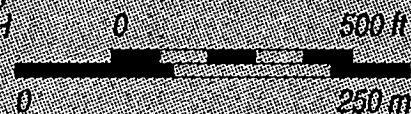
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TH-230 Contours (pCi/g) at Depth: 0.5 to 3.5 ft



SLAPS
NORTH



SAIC

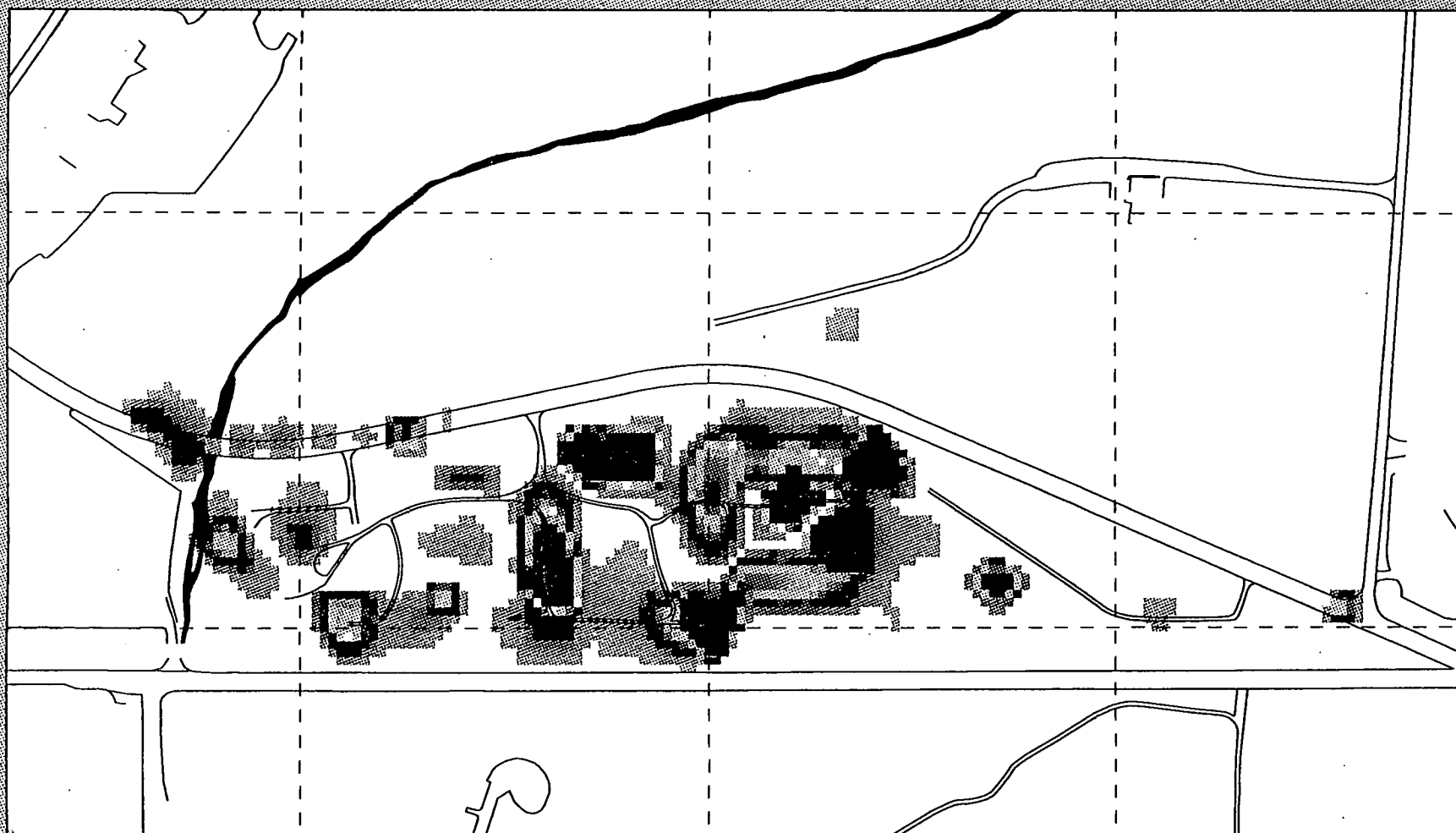
Science Applications
International Corporation

ST LOUIS AIRPORT SITE

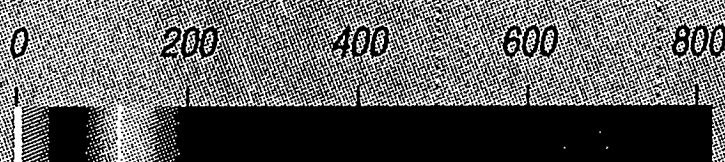
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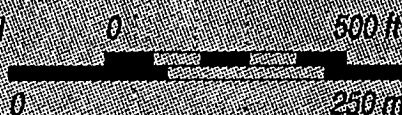
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TH-230 Contours (pCi/g) at Depth: 3.5 to 6.5 ft



SLAPS
NORTH



SAIC

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GIS BY:
STANARD

DATE:
8-14-95

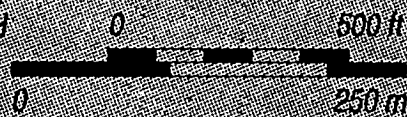
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TH-230 Contours (pCi/g) at Depth: 6.5 to 9.5 ft



SLAPS
NORTH



SAIC

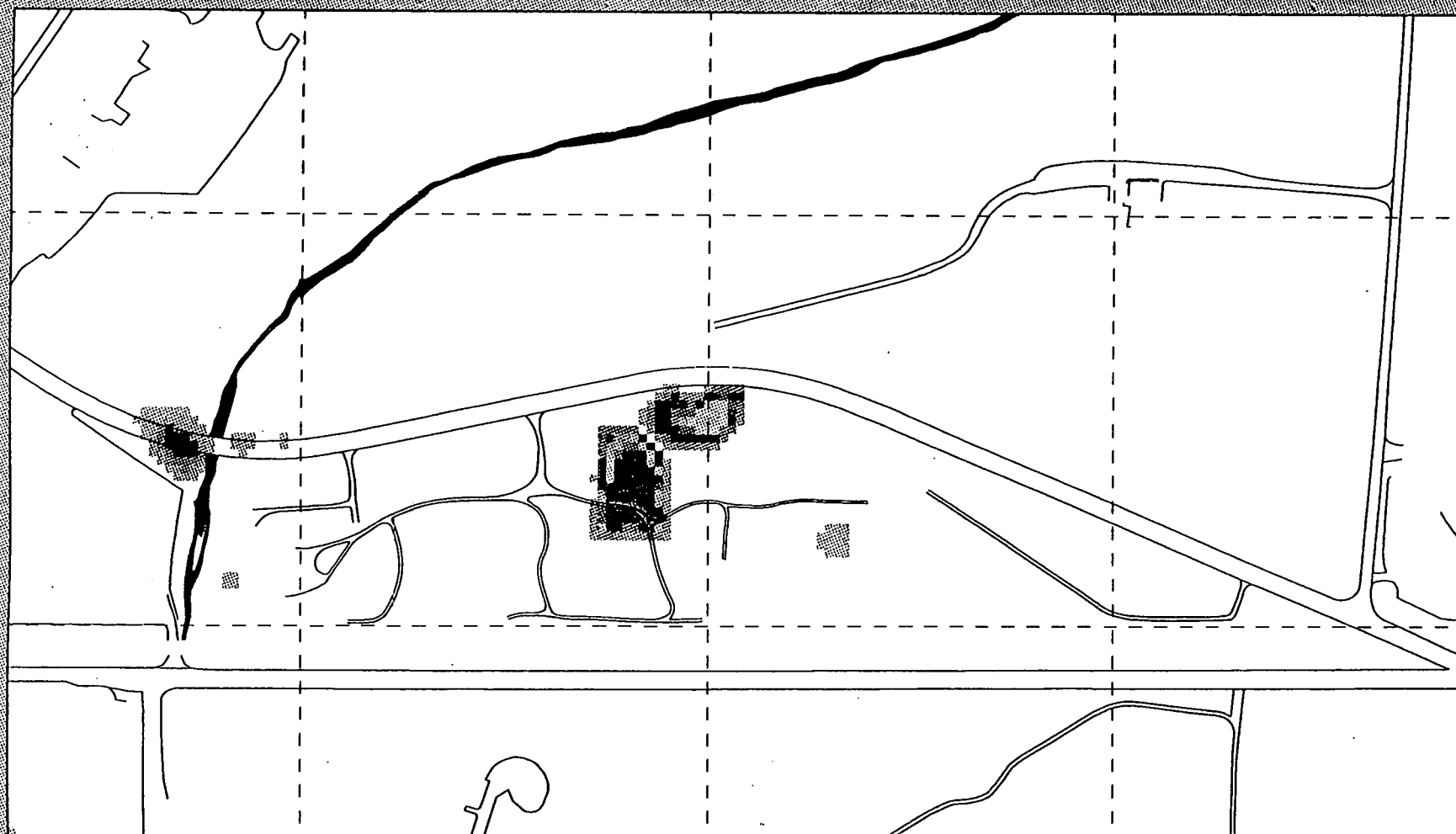
Science Applications
International Corporation

ST. LOUIS AIRPORT SITE

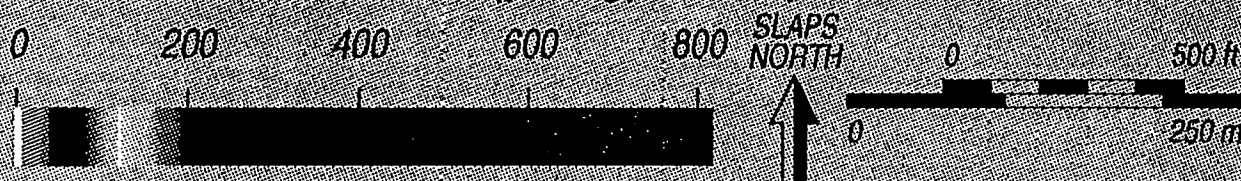
CHG BY:
S. THORNS

DATE:
8-14-05

PS FILE:
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TH-230 Contours (pCi/g) at Depth: 9.5 to 12.5 ft



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ST LOUIS AIRPORT SITE

GIS BY:
STH/AMH

DATE:
4-14-95

PG FILE:
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RA-226 Contours (pCi/g) at Depth: 0 to 0.5 ft



SAIC

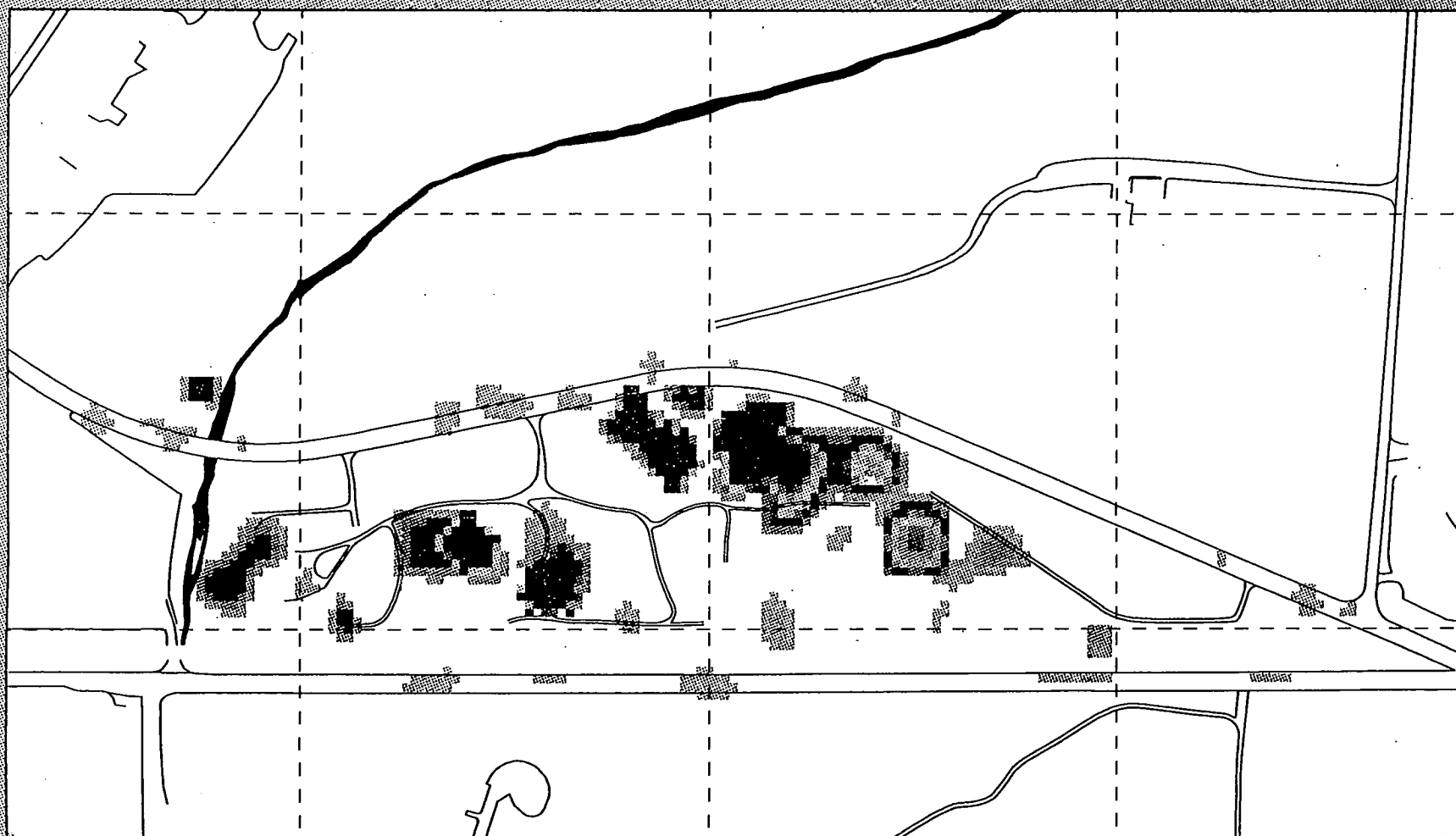
Science Applications
International Corporation

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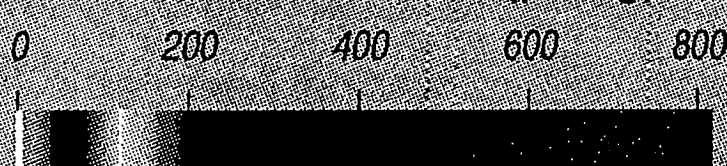
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DATE
4-14-93

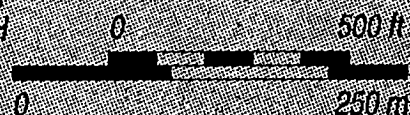
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RA-226 Contours (pCi/g) at Depth: 0.5 to 3.5 ft



SLAPS
NORTH



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STARRING

DATE:
8-14-95

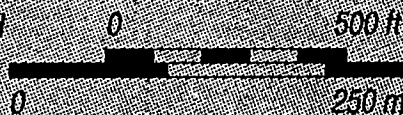
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RA-226 Contours (pCi/g) at Depth: 3.5 to 6.5 ft



SLAPS
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ST LOUIS AIRPORT SITE

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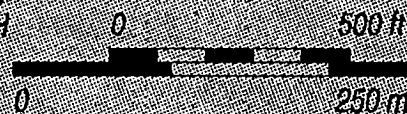
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RA-226 Contours (pCi/g) at Depth: 6.5 to 9.5 ft



SLAPS
NORTH



SAIC

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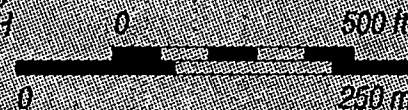
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RA-226 Contours (pCi/g) at Depth: 9.5 to 12.5 ft



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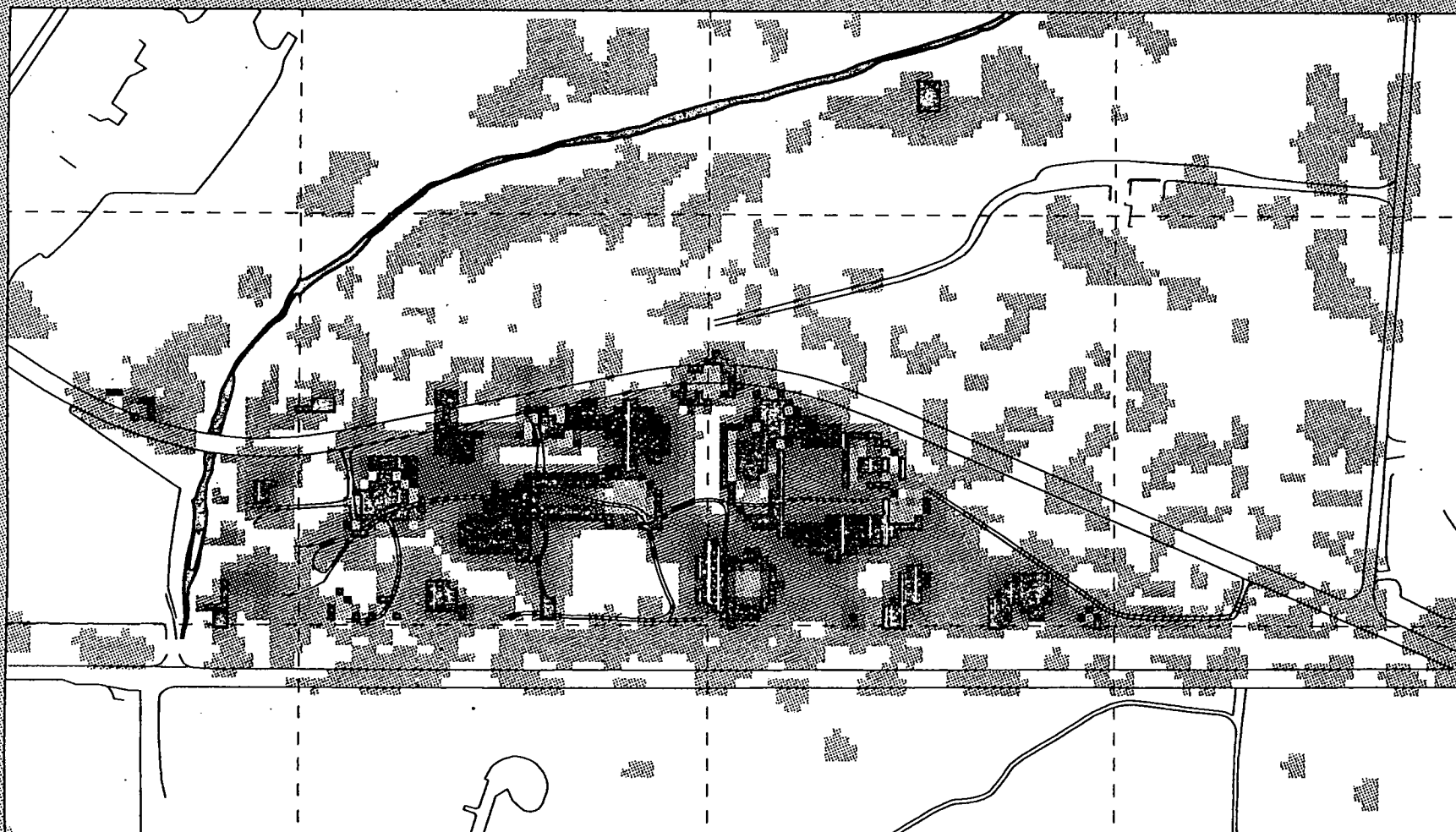
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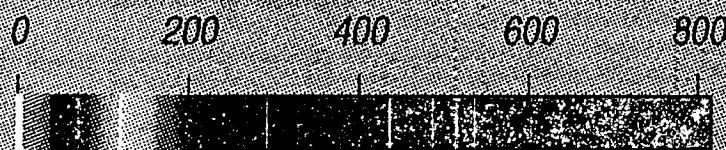
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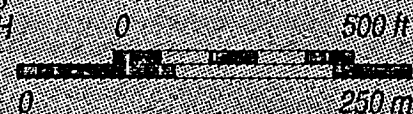
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U-238 Contours (pCi/g) at Depth: 0 to 0.5 ft



SLAPS
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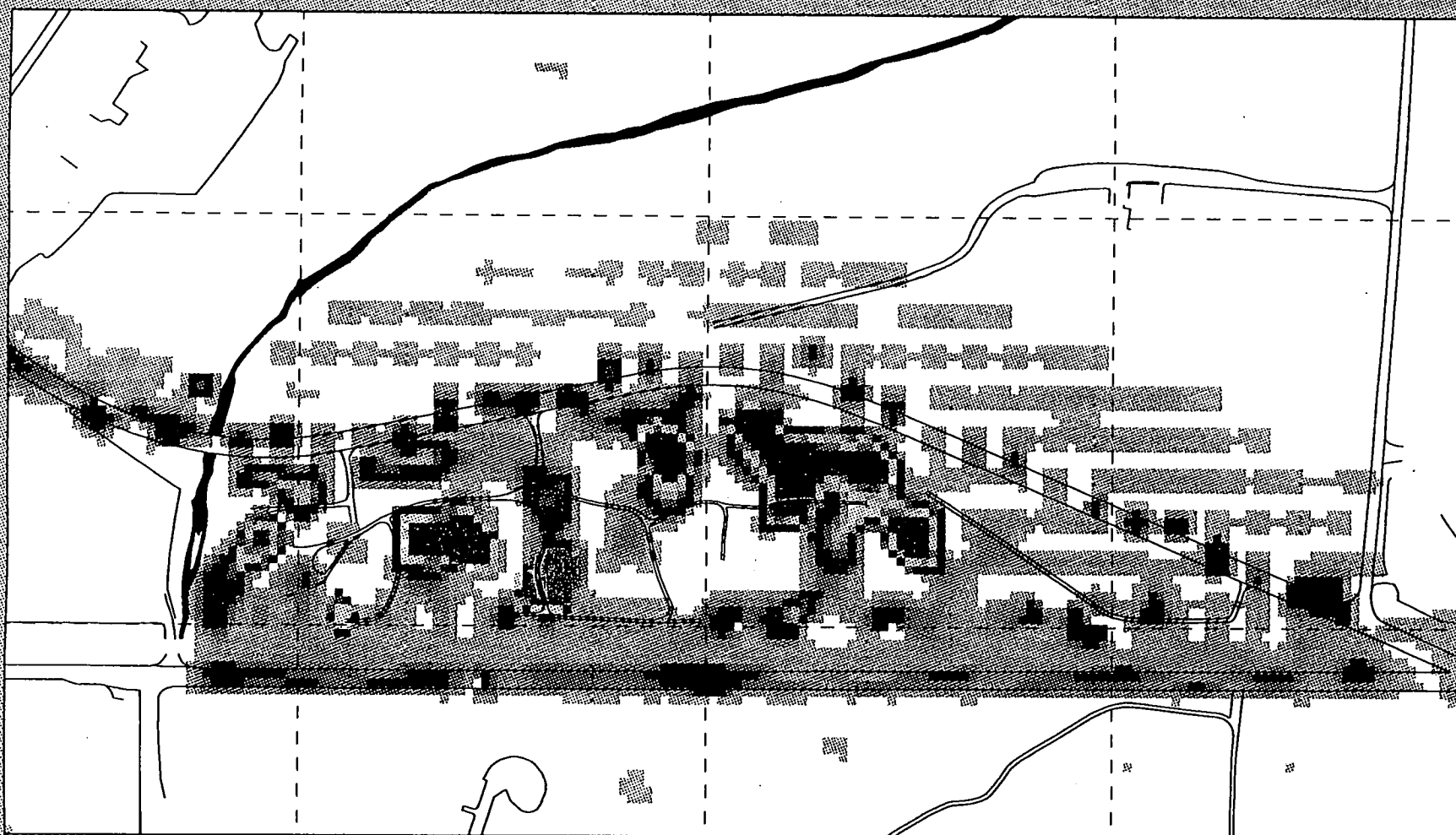
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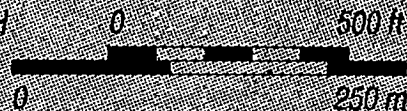
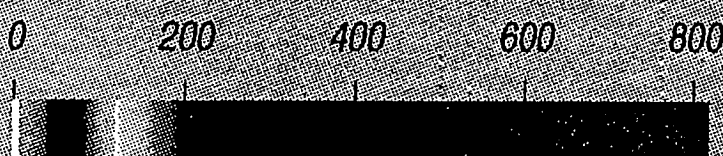
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PG FILE
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U-238 Contours (pCi/g) at Depth: 0.5 to 3.5 ft



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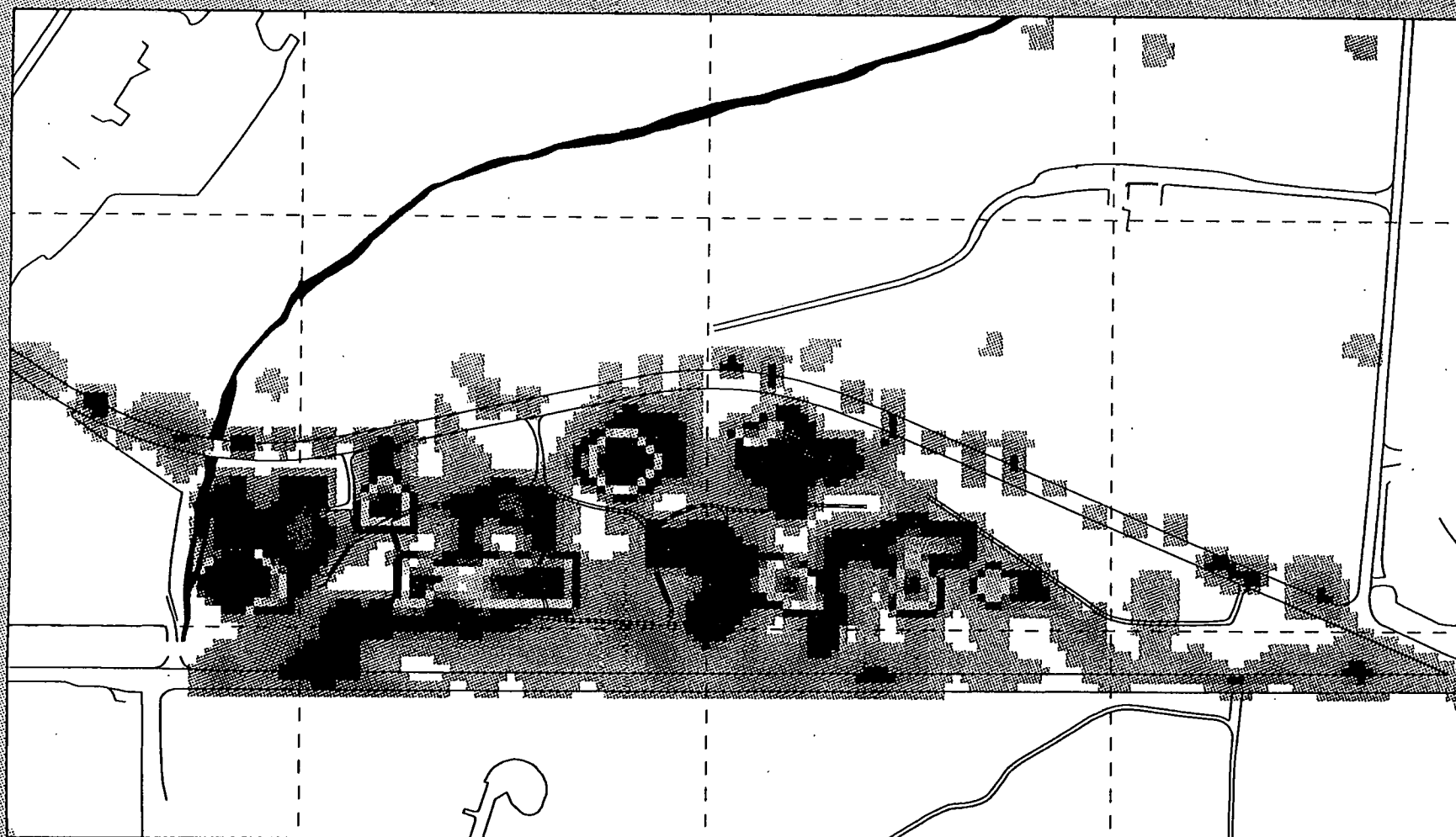
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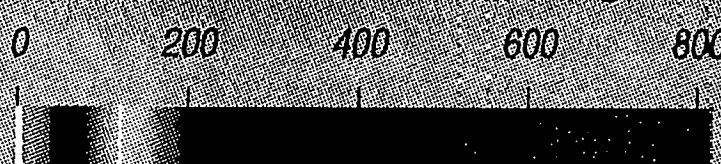
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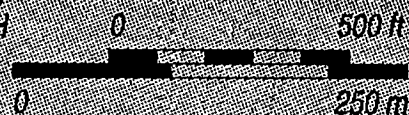
PG FILE
950301/11071-238.gis 3.5m



U-238 Contours (pCi/g) at Depth: 3.5 to 6.5 ft



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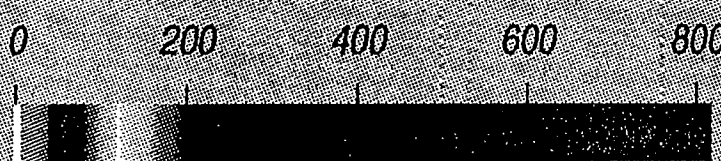
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S. THAMMONGKOL

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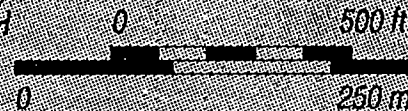
FIG. FILE:
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U-238 Contours (pCi/g) at Depth: 6.5 to 9.5 ft



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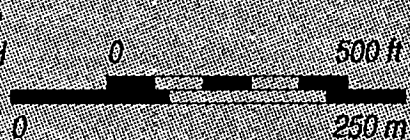
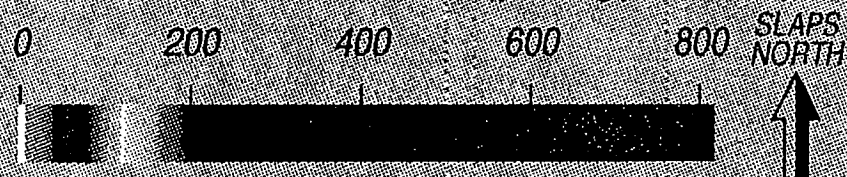
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U-238 Contours (pCi/g) at Depth: 9.5 to 12.5 ft



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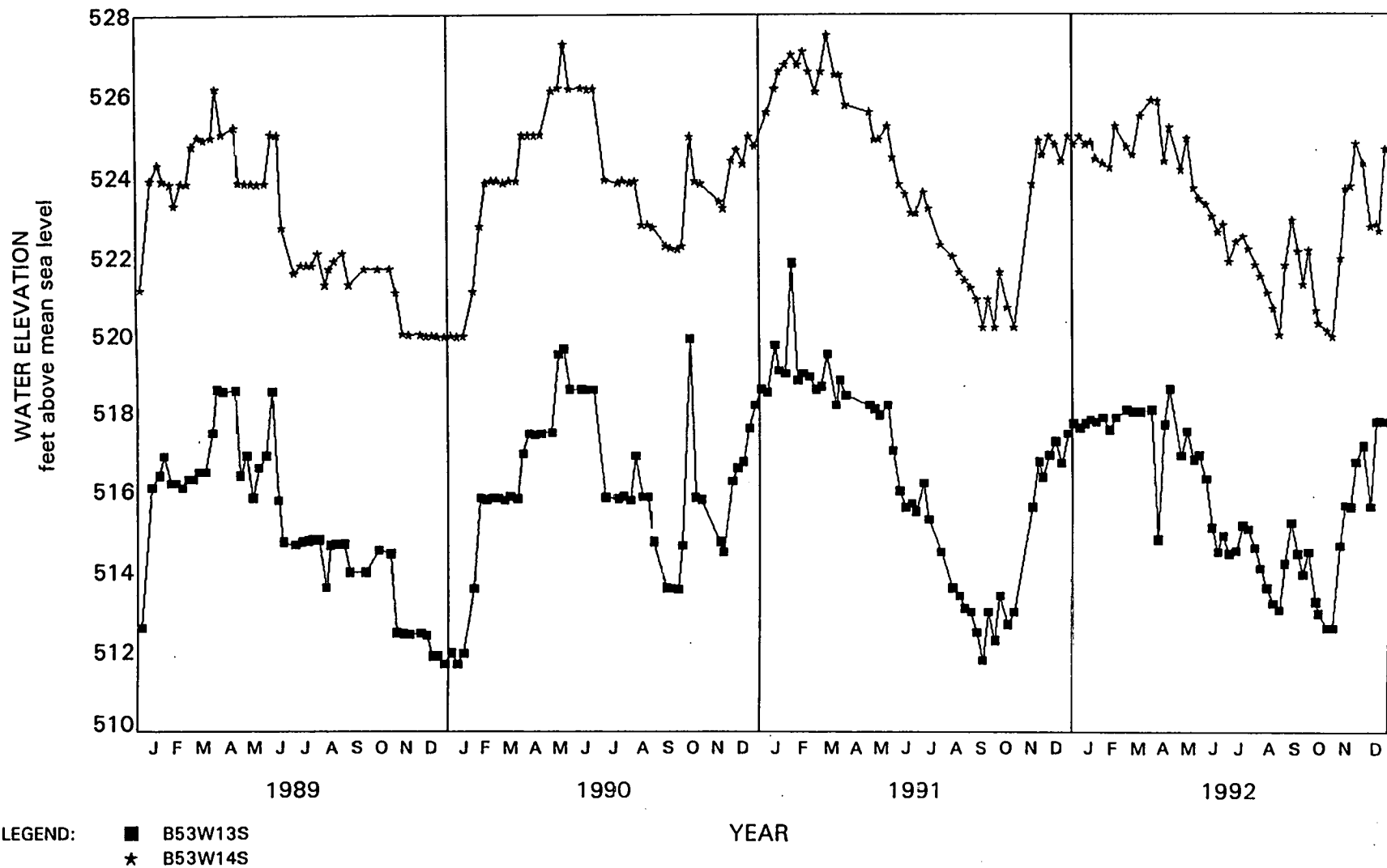
Science Applications
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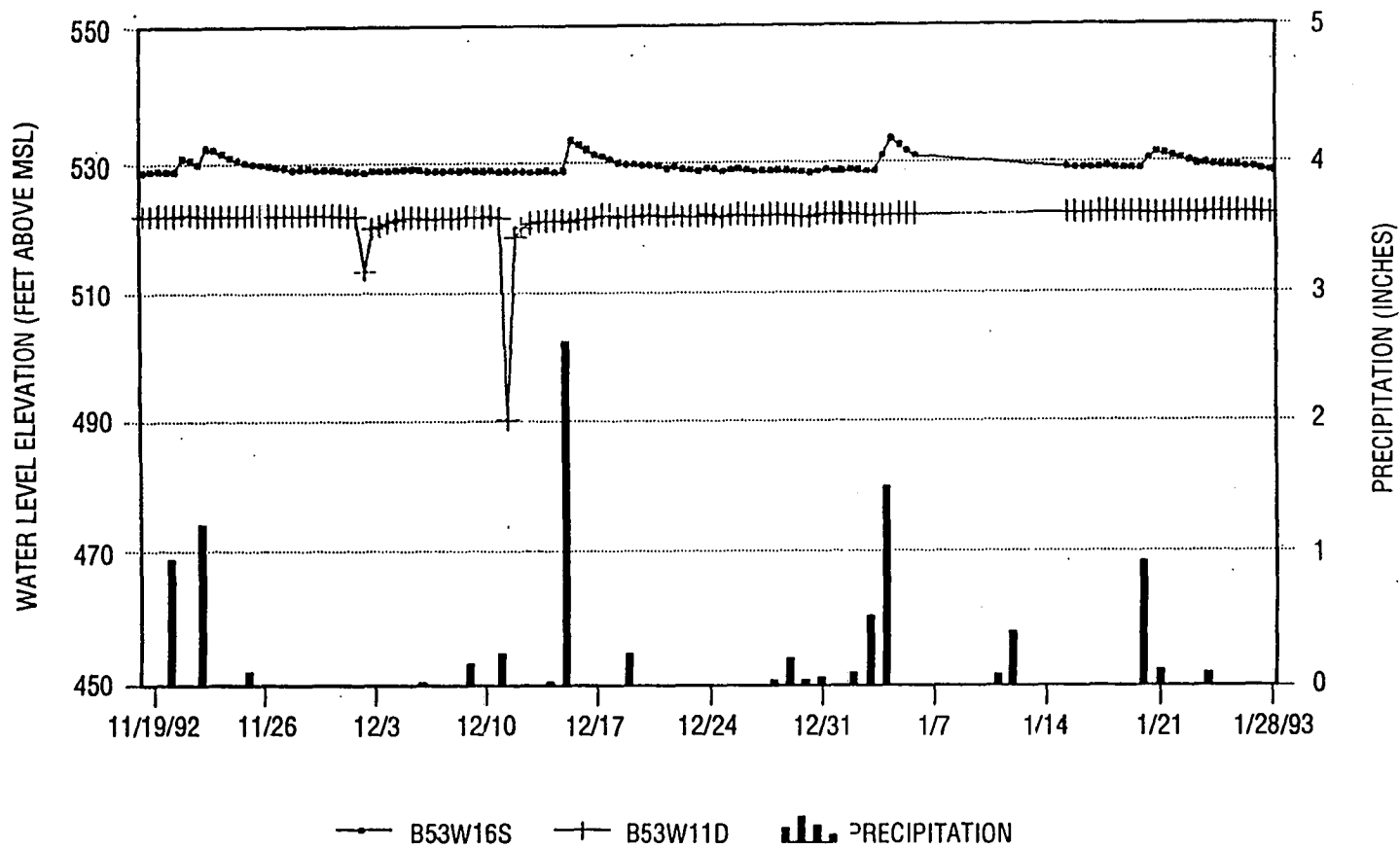
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FIG FILE:
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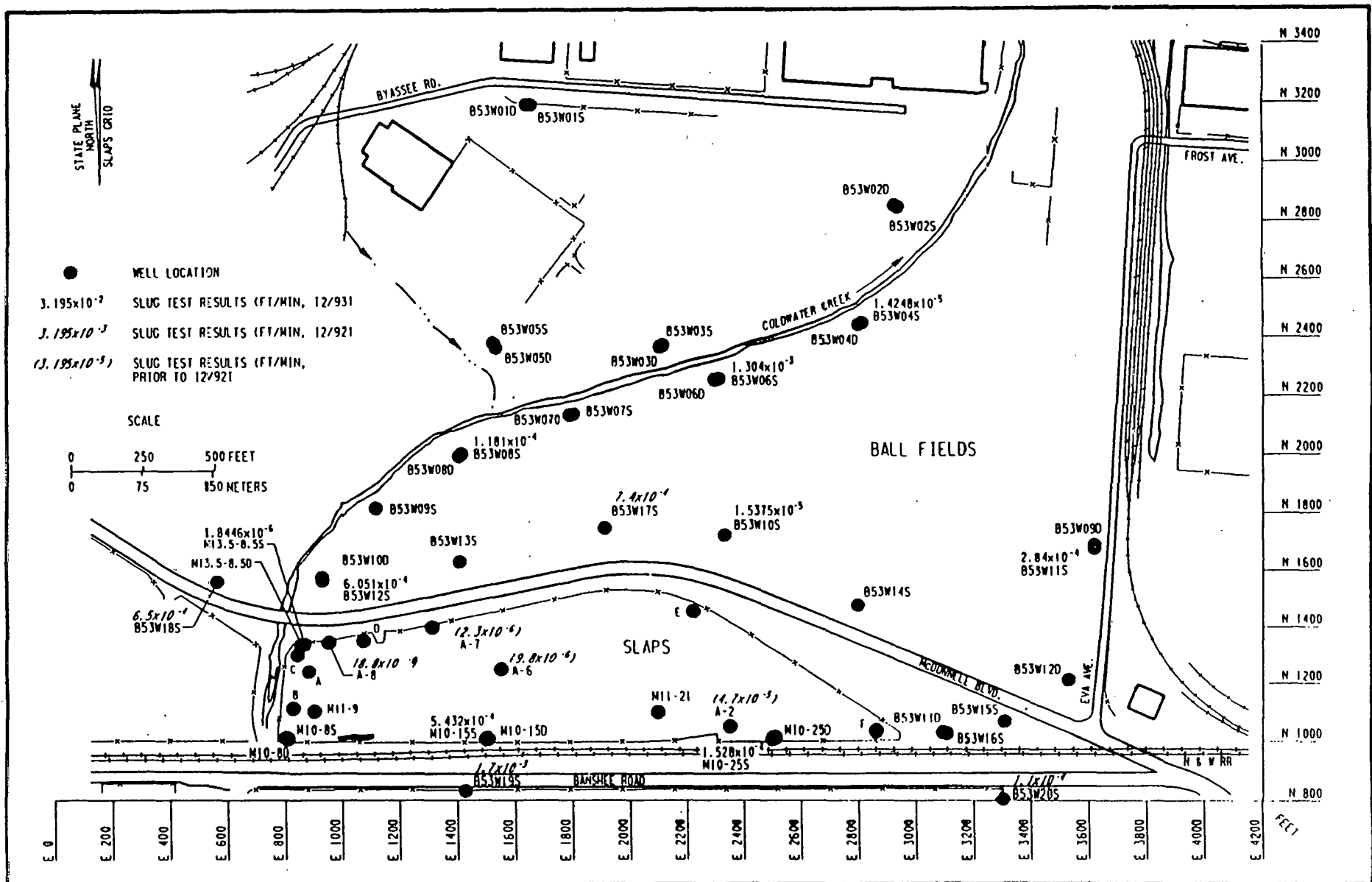
Hydrograph of Upper Groundwater System Wells B53W13S and B53W14S



Water level elevations obtained using automatic water level recorder

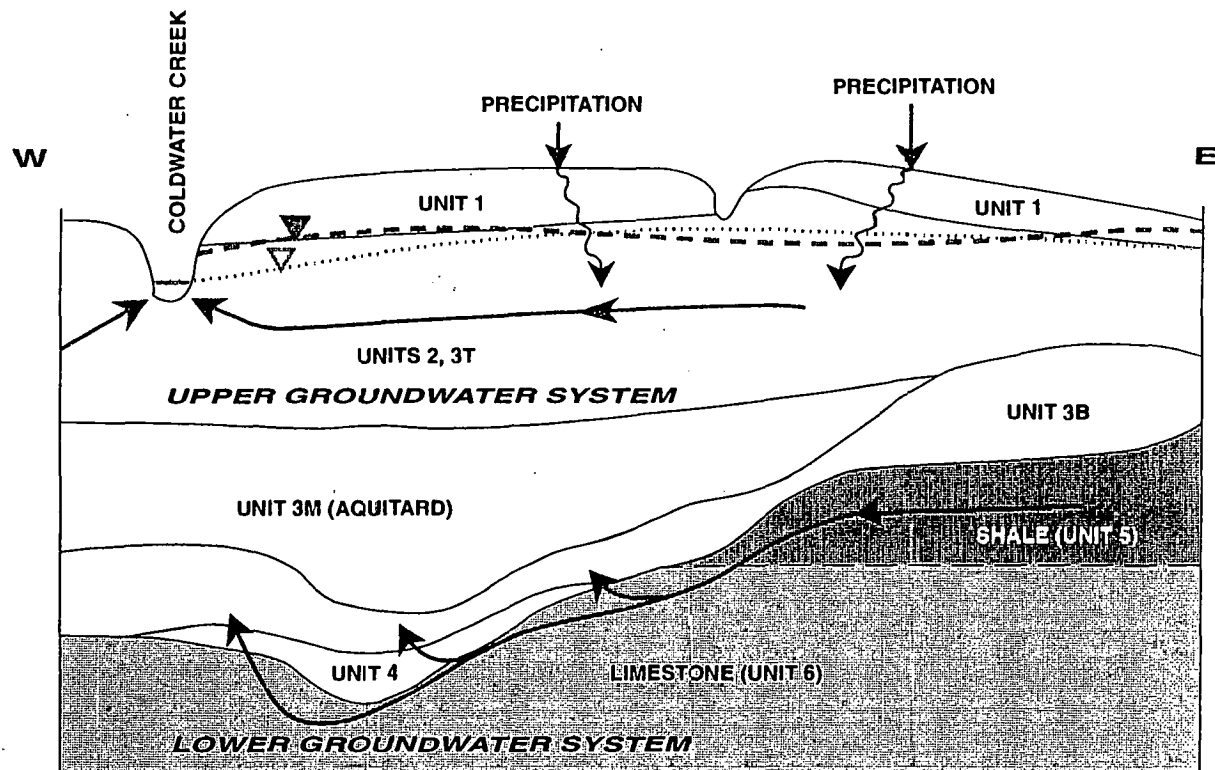
Source: BNI 1993

Hydrograph of Wells B53W11D and B53W16S



ELEVATION, FEET ABOVE MSL

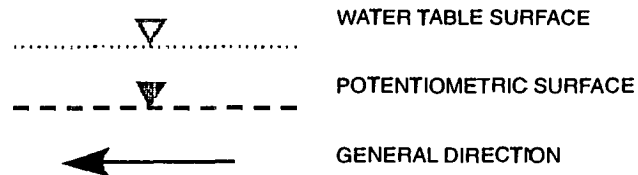
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480 -
470 -
460 -
450 -
440 -
430 -



Sources: (BNI 1993)

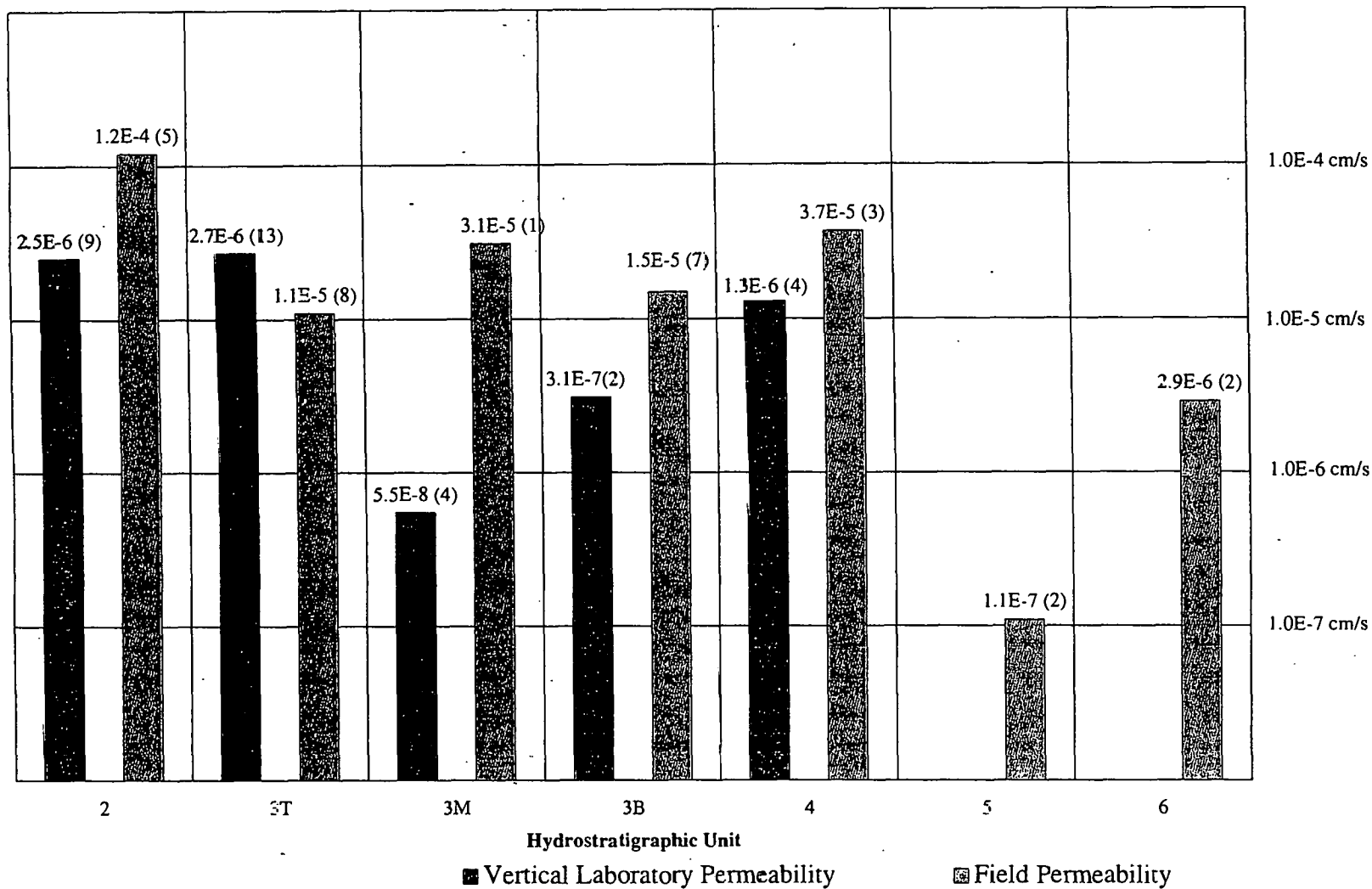
0 200 400 FEET
0 50 100 METERS

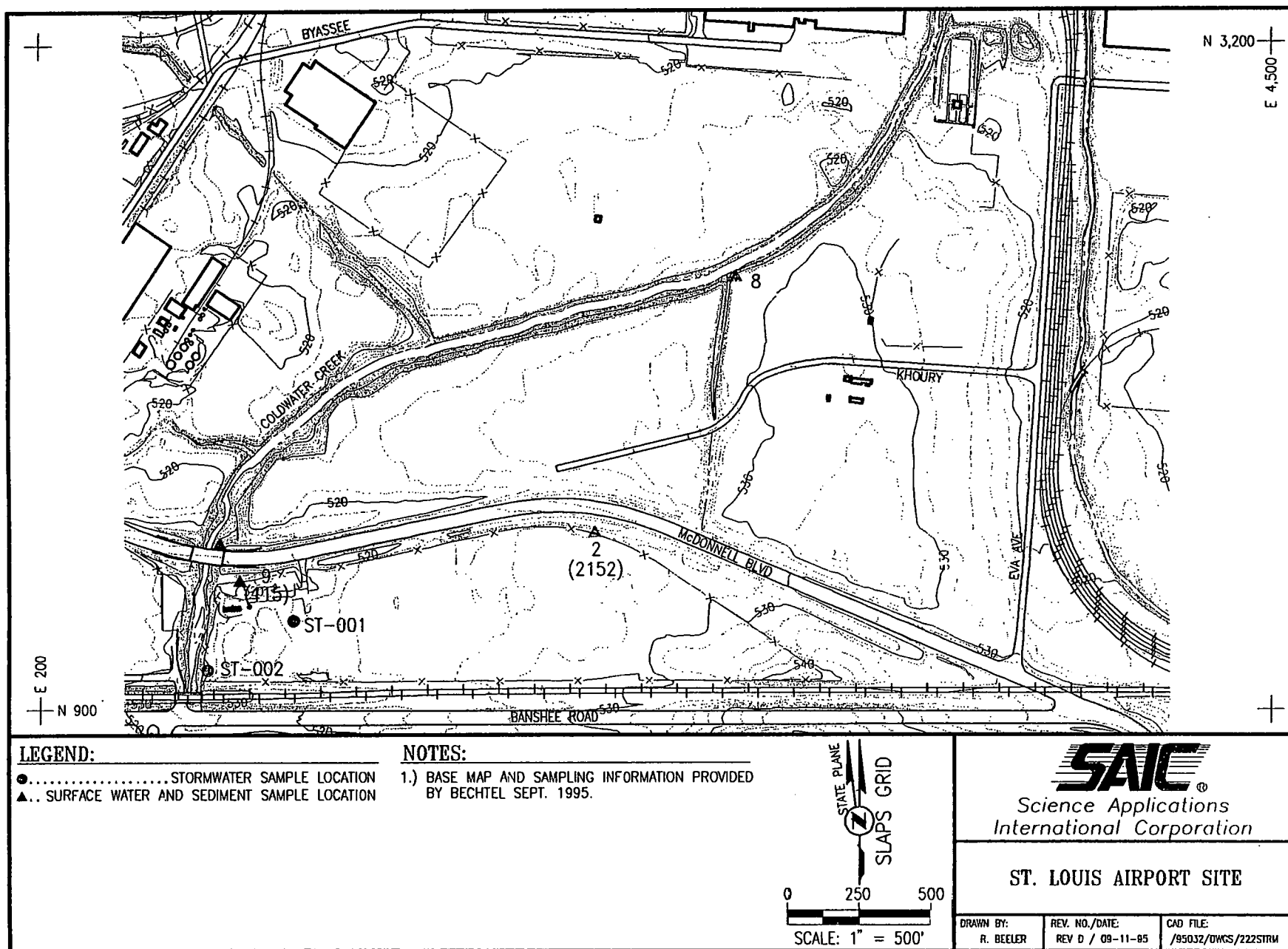
VERTICAL EXAGGERATION 17X



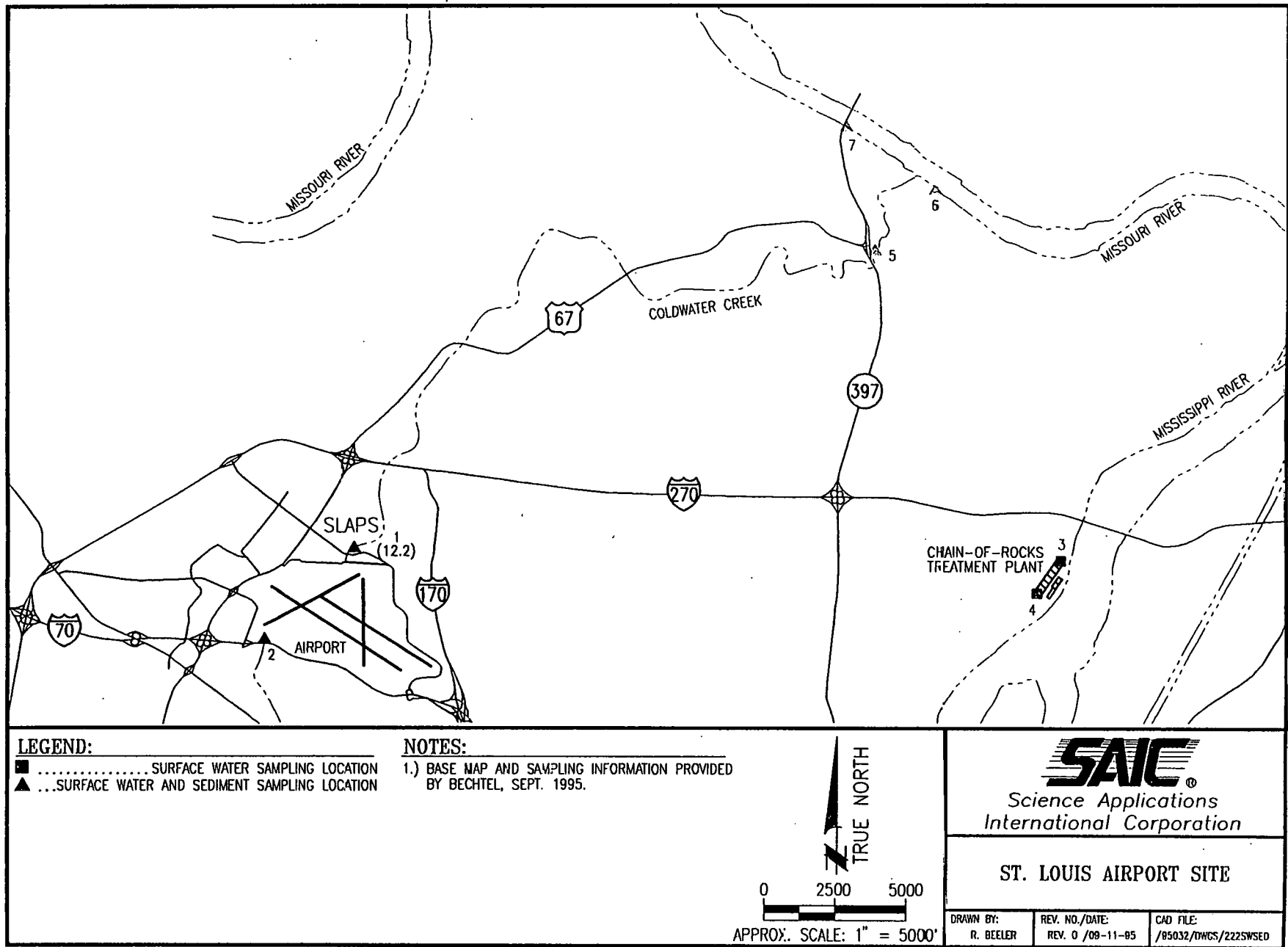
Conceptual Model of Groundwater Flow at SLAPS

Insitu Field and Vertical Laboratory Permeabilities for Hydrostratigraphic Units at the SLAPS





SLAPS SURFACE WATER, SEDIMENT, AND STORMWATER SAMPLING LOCATIONS



OFFSITE SURFACE WATER AND SEDIMENT SAMPLING LOCATIONS IN SLAPS AREA

Distribution Coefficients for Radionuclides of Concern at SLAPS

Radionuclide	Half-Life (years)	Solubility ^a (mg/L)	pH	Distribution Coefficient ^b (ml/gm)	Source ^c	Notes
Uranium	4.5 x 10 ⁹	6 (Uranyl peroxide)	2	0	A	
			8	100		
			10	600		
			13	50		
			2.2	1.3	B	
			7.7	23,000		
			4 - 9	45	C	Geometric mean; geometric standard deviation = 3.7
			6.5	62,000	D	Silt loam; hexavalent uranium; calcium saturated
			6.5	4,400		Clay soil; hexavalent uranium; with calcium nitrate
			5.5	300		Clay soil; 1 ppm uranium oxide ion
Thorium	1.41 x 10 ¹⁰	16,500 (Thorium sulfate)	10	2,000		Clay soil; 1 ppm uranium oxide ion
			12	270		Clay soil; 1 ppm uranium oxide ion
			2	500	A	
			5	3,000		
			7	50,000		
			13	50		
			2.2	1.2	B	
			7.7	80,000		

Distribution Coefficients for Radionuclides of Concern at SLAPS (continued)

Radionuclide	Half-Life (years)	Solubility ^a (mg/L)	pH	Distribution Coefficient ^b (ml/gm)	Source ^c	Notes
Thorium (continued)	1.41 x 10 ¹⁰	16,500	4 - 9	60,000	C	Geometric mean; geometric standard deviation = 4.5
		(Thorium sulfate)	6.5	160,000	D	Silt loam; calcium-saturated clay
			6.5	400,000		Montmorillonite; calcium saturated
			6.5	160,000		Clay soil; 5 mM calcium nitrate
			8.15	270 - 10,000		Silt/clay
			3.2	120		Illite; 1 gm/L thorium
			3.2	1,000		Illite; 0.1 gm/L thorium
			>6	<100,000		Illite; 0.1 gm/L thorium
Radium	1,620	0.02	2	0	E	
		(Radium sulfate)	4	12		
			6	60		
			7	100		
			2.2	13	B	
			7.7	2,400		

^aSource: CRC 1985

^bDistribution coefficient is measured for all isotopes of the same valence state of a given element; it is not isotopic-specific.

^cSources:

- A = Rancon 1973
- B = Gee et al. 1980
- C = Baes and Sharp 1983
- D = Isherwood 1981
- E = U.S. Nuclear Regulatory Commission 1980

Rpt. in BNI 1994 *Site Suitability Study for the St. Louis Airport Site*, Vol. I (Final)

Health Physics
4/88

416

Paper

COMPARATIVE UPTAKE OF U AND Th BY NATIVE PLANTS AT A U PRODUCTION SITE

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(Received 15 April 1987; accepted 3 November 1987)

Abstract—During a 3- to 4-year period, concentrations of ^{238}U , ^{234}U , ^{230}Th , ^{232}Th and ^{228}Th were determined in soils and native vegetation at various sites around a typical U mining and milling operation in Wyoming. Plant/soil concentration ratios (CR) for U and Th isotopes were estimated for (1) exposed, weathered tailings, (2) the edge of a tailings impoundment, (3) an area downwind from exposed tailings, (4) a reclamation area and (5) several background, native range locations. The $^{238}\text{U}/^{234}\text{U}$ concentration ratio of 0.9 to 1.1 in soil and vegetation indicated near-radioactive equilibrium of both radionuclides at all locations. Mean concentrations of the U and Th isotopes in background soil ranged from 44 to 52 mBq g $^{-1}$. Concentrations of ^{238}U and ^{230}Th in soil and vegetation were elevated above background at all sites disturbed by mining and milling activities. Uranium concentrations in tailings and invading vegetation were an order of magnitude greater than in the background locations, whereas ^{230}Th concentrations were elevated above background by some two orders of magnitude. No demonstrable differences in radionuclide concentrations between plant groups and collection years were found. The observed CR values for ^{238}U and ^{230}Th of 0.81 and 0.69 for vegetation growing on exposed tailings were elevated above native range by factors of 9.0 and 3.6, respectively, and generally higher than other published values. Exceptionally high CR values for ^{230}Th (1.9–2.9) observed near the tailings impoundment demonstrate that under certain conditions, vegetation can accumulate ^{230}Th to a much greater extent than previously reported. Vegetation concentrations were lower for ^{232}Th relative to ^{230}Th and ^{228}Th at locations where they are present at similar soil concentrations.

INTRODUCTION

URANIUM extraction from ore requires disposal of waste tailings containing various potentially hazardous substances. Uranium mill tailings contain nearly all of the original ore activity of ^{230}Th , ^{226}Ra and progeny of ^{222}Rn , notably ^{210}Pb and ^{210}Po , in addition to the unextracted fraction of U isotopes. Although the vast majority of tailings are adequately confined and controlled, elevated concentrations of associated radioactivity may occur in soil, water and biota on and adjacent to areas where tailings are stored. Contamination of the terrestrial food chain with radionuclides is normally considered for human radiation dose assessment of U mill tailings. The first step in the food-chain movement of tailings radionuclides is their accumulation by forage plants. Despite numerous uptake studies for U and Th radionuclides, there is little information concerning their transport from U mill tailings to vegetation.

Concentrations of the major α -emitting isotopes of U and Th (i.e., ^{238}U , ^{234}U , ^{230}Th , ^{232}Th and ^{228}Th) were measured in soil and native plants under natural conditions and those resulting from U mining and milling. Thorium-230 is found in association with natural U while ^{232}Th and ^{228}Th occur in Th minerals. Great variations in concentrations of radionuclides, soil moisture, pH and

texture, as well as chemical species occurred within our study area. It was hypothesized that such variables would cause differences in plant/soil relationships for radionuclides. Of specific interest were the relative differences in concentrations and plant/soil concentration ratios among sites, plant species groups, and radionuclides. Comparable investigations for ^{226}Ra , ^{210}Pb and ^{210}Po from the same study sites have been recently published (Ib82; Ib87).

MATERIALS AND METHODS

Study site

The study was conducted at a U mine and mill complex located in the southeastern high plains region of Wyoming in the United States at an elevation of about 2300 m. The rolling, semi-arid landscape receives about 25 cm of precipitation annually and is dominated by grasses, forbs and sagebrush. The mine has open pits up to 120 m in depth and the adjacent mill uses a sulfuric acid leach process. Up to 1.4×10^6 kg of mill tailings are pumped to an adjacent impoundment daily. Tailings slurry is a sand-slime-water mixture of pH \sim 1.8. Exposed, weathered tailings in the impoundment area are also acidic with pH values ranging from 2 to 5. Large mine overburden piles have been reclaimed by contouring, covering with topsoil, and seeding with native species mixtures. Control

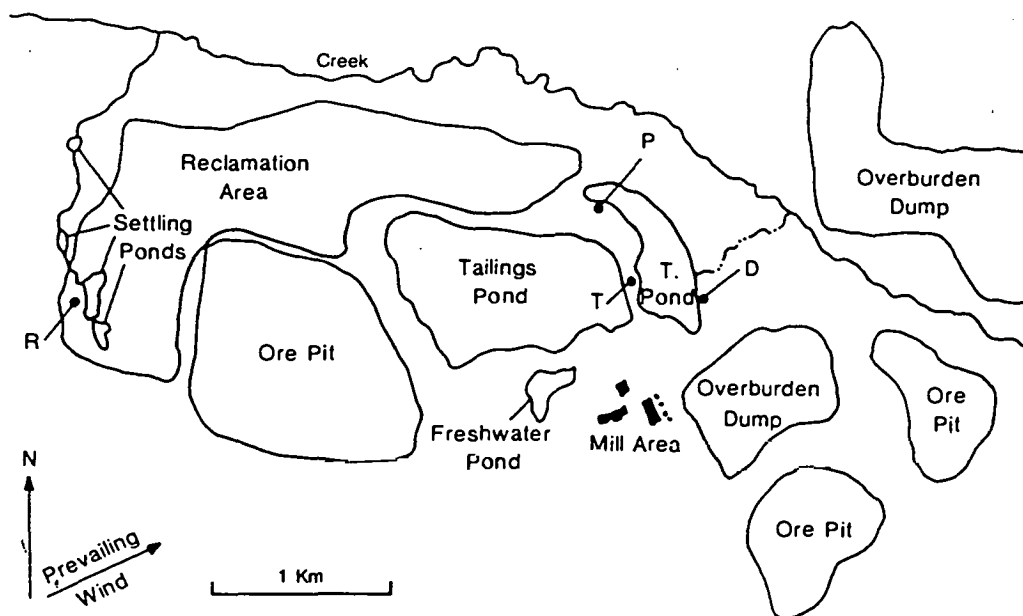


Fig. 1. Approximate configuration of the study area. Soil and vegetation sampling locations shown are: reclamation area (R), exposed tailings (T), tailings pond edge (P) and downwind from tailings dam (D). Background sampling locations are off the map to the west.

sites on native, undisturbed rangeland upwind from the mining and milling operation were sampled for comparison.

Sample collection and preparation

Soil and vegetation samples were collected from the reclamation area, directly on exposed, weathered tailings, at the water-saturated tailings pond edge, and 40 and 160 m downwind from the tailings impoundment dam (Fig. 1). Other samples were collected in undisturbed native rangeland areas 1–16 km northwest and southwest of the mine site. The current annual above-ground growth of vegetation was clipped to provide a representative sample of 15–50 g dry weight. Samples for U and Th analyses were collected consecutively in mid-summer for 3 and 4 y respectively. Plant groups sampled were mixed grasses (genera: *Agropyron*, *Koeleria*, *Hordeum* and *Oryzopsis*); mixed forbs (genera: *Melilotus*, *Kochia*, and *Salsola*); and big sagebrush (genus: *Artemisia*). Soil samples of about 1 kg were collected by trowel from the major root zone areas (0–20 cm) of the actual plants which were sampled. Samples were individually placed in plastic bags to minimize cross contamination.

Although big sagebrush and grass root systems are sometimes capable of reaching several meters into the soil, they are concentrated primarily in the upper 20–30 cm of the soil profile (Re86; Si77; Ta64). Uranium and Th concentrations in the undisturbed soil profile are as-

sumed to be reasonably uniform with depth at all locations except downwind from exposed tailings. Reasonable uniformity within exposed tailings is expected since U-bearing ore is blended to achieve a uniform grade before the milling process.

Vegetation was washed ultrasonically* for 10 min in detergent,** followed by two 10-min ultrasonic rinses in distilled water. This washing regime was undertaken to remove surficial dust and associated radioactivity. Plant and soil samples were oven-dried at 70°C for about 12 h and allowed to equilibrate with room air for 12 h before weighing. Plant material (3–10 g) was wet-ashed using concentrated nitric and perchloric acids. Soils and tailings (3 g) were decomposed in Pt containers using pyrosulfate fusion to ensure complete matrix dissolution (Si77).

Radiochemical analysis

Separation of U isotopes involved coprecipitation of U with iron hydroxide and isopropyl ether extraction to remove Fe (Ca77). Uranium was separated from most interfering elements with an anion exchange resin column. The U was eluted from the column with 1.0 M HCl, electrodeposited onto Pt disks (EM72) and counted by α -spectrometry using 300 mm² surface barrier detectors† and a multichannel analyzer and data acquisition system‡. The low-background (0.001–0.004 cpm), high-resolution counting system has a counting efficiency of 30%. Uranium-232, obtained from the U.S. Department of Energy's

* Model 32 Branson, Ultrasonic Cleaner, Branson Cleaning Equipment Co., Shelton, CT.

** Biodegradable Alconox, Fisher Scientific Co., Pittsburgh, PA.

† TR-24-450-100, EG&G ORTEC, Oak Ridge, TN 37830.

‡ TN-4000 Nuclear Spectroscopy System, Tracor Northern, Middleton, WI 53562.

Environmental Measurements Laboratory (EML), New York, NY, was used as an internal tracer to determine the chemical yield.

The procedure for the determination of Th isotopes in vegetation was modified from Singh et al. (Si79). Thorium was coprecipitated with iron hydroxide and extracted into 30% Aliquat-336 (mixed trioctyle and tridecyl methyl ammonium nitrate) in xylene. This extractant replaced TLA (Tri-n-laurylamine) due to better availability and lower cost. This modification did not reduce the chemical yield for Th extraction in experiments using plant samples spiked with ^{234}Th tracer that was freshly purified from uranyl nitrate (Si74). Thorium was back-extracted from the organic phase, electrodeposited and analyzed by α spectrometry. Soil and tailings were analyzed for Th isotopes using the procedure outlined by Sill (Si77). Chemical yield was estimated from an internal tracer (^{229}Th) obtained from Oak Ridge National Laboratory, Oak Ridge, TN (Wr78).

Critical level of detection and data treatment

The critical level L_C (minimum level of detection) for the U and Th isotopes ranged from 0.19 to 0.56 mBq per sample. L_C was calculated from acid blank activity and background count rate of the detectors (Cu68). Most of the samples analyzed in this study contained activity well above the L_C except a few values for ^{232}Th in plant samples. However, all measured values were used in data presentation and in statistical comparisons, regardless of their relation to the critical level.

Data for soil and vegetation concentrations were expressed as arithmetic means \pm one standard error of the mean. Statistical comparisons were based on standard analysis of variance procedures. The relative radionuclide uptake from soil by plants was expressed as a concentration ratio (CR), defined as the ratio of the plant concentration to the soil concentration (ER76). Gilbert and Simpson (Gi83) stated that the ratio of the means estimator (\bar{y}/\bar{x}) for the CR performs reasonably well for both normally and lognormally distributed data. Thus, the computing formula used to estimate the CR was:

$$\bar{y}/\bar{x} = \frac{\text{mean activity g}^{-1} \text{ dry vegetation}}{\text{mean activity g}^{-1} \text{ dry, underlying soil}}$$

RESULTS AND DISCUSSION

Radionuclide concentrations in soil and vegetation

The mean concentrations of ^{238}U , ^{228}Th , ^{230}Th and ^{232}Th in soil and plants are given by site in Table 1. Statistical comparisons (Table 2) of mean plant and soil concentrations of ^{238}U and ^{230}Th suggest a number of significant differences among sites and radionuclides, but no demonstrable differences between plant species groups. Thus, plant concentrations shown in Table 1 represent the mean value for sagebrush, grasses and forbs combined. Mean concentrations of the U and Th isotopes in background soil were somewhat higher than reported for var-

ious U.S. locations (NC75), but were within the world range (UN77). The $^{238}\text{U}/^{234}\text{U}$ ratio in soil and plants ranged from 0.9–1.1 indicating near-radioactive equilibrium at all locations. Thorium-232, ^{230}Th and ^{228}Th in background soil were in near-radioactive equilibrium. On the other hand, ^{232}Th concentrations in vegetation from the same locations were significantly lower ($p \leq 0.01$) than for ^{230}Th and ^{228}Th (Table 1).

Soil concentrations in the reclamation area were elevated over background. This may have been the result of naturally higher levels in some overburden material. Ambient γ -radiation surveys of the reclamation area revealed several scattered locations which were elevated by a factor of 2–4 above background areas. The higher concentrations of ^{238}U and ^{230}Th in reclamation area soil were not reflected by higher concentrations in vegetation relative to background.

Soil sampled at the edge of the tailings impoundment was undisturbed, except that it was saturated with acidic (pH 1.8), pond-derived water, and contained elevated concentrations of U series radionuclides. Measured soil pH at the edge of the impoundment ranged from 2–4. Soil and particularly vegetation concentrations for ^{238}U and ^{230}Th at this location were substantially elevated above background. Levels of both radionuclides in soil and vegetation decreased with distance from the impoundment edge but remained elevated at 10 m from the edge. The data from this location showed considerable variability, which was probably due to several sampling dates and temporal fluctuations in the water level of the tailings impoundment.

Levels of ^{238}U and ^{230}Th in tailings were significantly elevated above background as expected. Exposed tailings contained eightfold less ^{238}U than ^{230}Th since the mill extraction process removes about 90% of the U from the ore. Vegetation growing directly on exposed tailings was very sparse and consisted mostly of invading weedy species.

Uranium-238 and ^{230}Th concentrations in natural soil downwind from the exposed tailings area were clearly elevated due to the presence of windblown tailings. Soil concentrations at this location decreased with distance from exposed tailings and the contamination was confined to the top few centimeters of soil (Sm82). Vegetation concentrations for ^{238}U and ^{230}Th at this location were similarly elevated above background and decreased with distance from exposed tailings.

Vegetation samples were ultrasonically washed to remove surficial dust prior to radioassay. However, a removal efficiency of the surficial soil mass on sagebrush (*Artemisia*) of only 74% was estimated with Ti tracer for the ultrasonic washing procedure described in this paper (Sk82). Therefore, residual surficial activity probably contributed somewhat to the observed values. Resuspension of soil by wind and rain spattering are undoubtedly important mechanisms of radionuclide transfer to plants in semi-arid ecosystems (Dr84; Ha75).

A limited number of ^{238}U and ^{230}Th analyses were performed on unwashed vegetation. Also, an estimate of

Table 1. Uranium and Th radionuclides concentration^a in soils and plants from various sites.

Location ^b	²³⁸ U		²³² Th		²³⁰ Th		²³² Th	
	Soil	Plants	Soil	Plants	Soil	Plants	Soil	Plants
Natural Background	50 ± 9.0 (4)	4.4 ± 0.7 (29)	49 ± 16 (4)	11 ± 1.5 (20)	48 ± 12 (4)	9.3 ± 1.9 (31)	44 ± 14 (4)	1.9 ± 0.4 (26)
Reclamation Area	142 ± 23 (7)	5.6 ± 1.5 (21)	43 ± 4.4 (7)	7.4 ± 2.2 (8)	481 ± 126 (7)	5.9 ± 1.1 (19)	42 ± 5.9 (7)	1.5 ± 0.4 (16)
Tailings Impoundment: at the edge	407 ± 322 (3)	130 ± 48 (18)	50 ± 27 (2)	19 ± 3.7 (8)	296 ± 107 (4)	851 ± 167 (13)	41 ± 17 (2)	2.2 ± 0.2 (8)
1 to 10 m from the edge	171 ± 44 (14)	41 ± 18 (13)	54 ± 16 (6)	9.6 ± 2.2 (12)	192 ± 56 (4)	363 ± 170 (10)	50 ± 16 (6)	3.3 ± 1.1 (11)
Bare Tailings	503 ± 63 (10)	407 ± 85 (27)	46 ± 9.6 (11)	15 ± 5.2 (8)	4107 ± 888 (12)	2849 ± 1073 (27)	43 ± 6.3 (11)	2.6 ± 0.4 (12)
Downwind from Tailings: at 40 m	363 ± 34 (4)	27 ± 11 (11)	NS	22 ± 2.6 (8)	2109 ± 407 (2)	56 ± 7.4 (8)	NS	0.4 ± 0.4 (8)
at 160 m	200 ± 48 (3)	9.6 ± 0.7 (5)	NS	15 ± 3.7 (4)	NS	41 ± 4.1 (4)	NS	0.0 ± 0.2 (4)

^a Concentrations given in mBq g⁻¹. Data represent mean ± S.E. (n).^b See Fig. 1.

NS—Not Sampled.

external dust mass was made by filtering the wash and rinse waters after the ultrasonic cleaning and weighing of the oven dried residues. The mean attached soil masses

Table 2. Statistical comparisons of mean plant and soil concentrations between sites.

Comparison between sites	Significant at probability level	
	²³⁸ U	²³⁰ Th
Background vs. Reclamation, soil	0.05	0.01
Background vs. Reclamation, mixed grasses	NS	NS
Background vs. Edge of tailings impoundment, soil	0.01	0.01
Background vs. Edge of tailings impoundment, mixed grasses	0.05	0.01
Background vs. Bare tailings, soil	0.01	0.01
Background vs. Bare tailings, mixed grasses	0.05	0.01
Background vs. Downwind from tailings, soil	0.01	IS
Background vs. Downwind from tailings, all plants	0.01	0.01
Reclamation vs. Edge of tailings impoundment, mixed grasses	0.05	0.05
Reclamation vs. Bare tailings, mixed grasses	0.05	0.01
Background + Reclamation vs. Bare tailings + edge of tailings impoundment, mixed grasses	0.05	0.01
Background vs. 1-10 m from edge of tailings impoundment, sagebrush	0.01	0.05
Background vs. 1-10 m from edge of tailings impoundment, mixed grasses + sagebrush	0.01	0.01

NS—Not significantly different (alpha ≤ 0.05).

IS—Insufficient sample size.

removed were 3, 9 and 28 mg g⁻¹ plant material for mixed grasses, sagebrush and mixed forbs, respectively. Variations found between and within plant groups may be related to plant surface structure (degree of branching, presence of hairy leaves, etc.). Soil attachment to above ground parts of vegetation at Rocky Flats, CO, estimated by Ti tracer, was 18 mg g⁻¹ (Ar82). The concentrations of ²³⁸U and ²³⁰Th for unwashed forbs and grasses were higher by a factor of 2 over the washed vegetation from background sites. Concentrations of these radionuclides in unwashed vegetation were also higher by a factor of 4 over the washed vegetation growing at the edge of the tailings impoundment. Radioactivity attached to unwashed plant surfaces may be estimated by multiplying soil activity by soil mass attached to plants as noted above. Using this approach, the maximum potential for plant contamination (forbs) due to tailings attachment was estimated to be 14 and 115 mBq g⁻¹ for ²³⁸U and ²³⁰Th, respectively.

Plant/soil concentration ratios

Mean concentration ratios for U and Th isotopes in all plant groups combined are shown by collection site in Fig. 2. The data for ²³⁸U and ²³⁰Th demonstrate a general tendency for high values for the tailings impoundment and exposed tailings relative to all other sites. The observed CR for ²³⁸U ranged from 0.04 at the reclamation area to 0.81 for plants growing on exposed tailings. For ²³⁰Th, CR values ranged from 0.01 at the reclamation area to 2.9 for plants growing at the edge of the tailings impoundment. Vegetation uptake of ²³⁸U was comparable to ²³⁰Th at all sites except at the tailings impoundment.

The exceptionally high CR values observed for ²³⁰Th in plants growing at the edge of the tailings impoundment relative to all other locations may be due to several factors.

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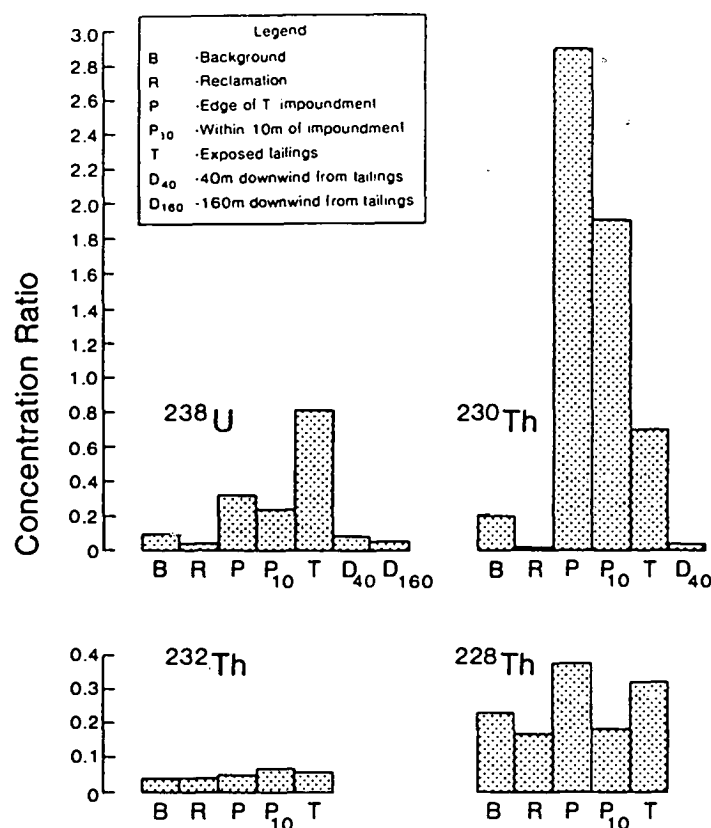


Fig. 2. Uranium and Th concentration ratios for all plants at the various sites.

It is possible that the acidity and wet condition at this site tend to enhance the solubility and availability of ^{230}Th for plant uptake. Higher uptake was also noted for ^{230}Th in beans grown in spiked nutrient solution than plants grown in soil due to the lack of exchange sites (D'So70). Additionally, foliar deposition of pond water spray containing elevated ^{230}Th concentration and subsequent foliar absorption may be another important uptake mechanism at this location. The reason for the higher CR values of ^{230}Th relative to ^{238}U at the impoundment edge is not known. The concentrations of ^{230}Th and ^{238}U in tailings water were 4.7 Bq mL^{-1} and 0.48 Bq mL^{-1} , respectively (Wh83), while present in similar concentrations in soil at the impoundment edge. The concentration ratio calculated on the basis of the soil concentration may not reflect all possible plant uptake mechanisms involving tailings water at this site. Thus, CR values for ^{230}Th at the impoundment may be artificially high because of the difficulty in defining the substrate actually contributing to plant uptake. There was a tendency for CR values of both radionuclides to decrease as a function of distance from the edge of the impoundment.

The observed mean CR values for plants growing on exposed tailings were 0.81 and 0.69 for ^{238}U and ^{230}Th , respectively. Comparatively low CR values for ^{238}U and ^{230}Th (0.03–0.08) were observed for plants growing downwind from the tailings source. Soil contamination at these locations was confined to the upper 2–3 cm of soil, thus most of the root mass would not be in contact

with the contamination. The concentration ratios for ^{238}U and ^{230}Th in plants growing on exposed tailings were greater than those reported for ^{226}Ra , ^{210}Pb and ^{210}Po at this location (Ib82; Ib87). The high concentration of sulfate in the tailings impoundment tends to promote the precipitation of ^{210}Pb and ^{226}Ra as sulfates. Since ^{210}Po is derived from the decay of ^{210}Pb , its activity will be limited to that of ^{210}Pb . It is likely that Th and U will form complexes with Cl^- and SO_4^{2-} in tailings and prevent the formation of the insoluble hydroxide species.

The comparison between the concentration ratios for ^{232}Th and ^{228}Th in plants from all locations indicate higher assimilation for ^{228}Th by a factor of 3–7 relative to ^{232}Th . One possible explanation of the difference is the ingrowth of ^{228}Th from ^{228}Ra and/or ^{228}Ac (a rare earth-like element) preferentially taken up by plants in addition to the direct uptake of ^{228}Th . The ^{230}Th concentration ratio in plants from the background locations was also elevated relative to ^{232}Th values. From this observation, we suggest that ^{230}Th is associated to a considerable degree with its parent mineral (Nat-U) and that isotopic exchange between ^{230}Th and ^{232}Th (in the natural Th minerals) cannot be expected in soil.

The apparent differences found among sites, the high CR values for plants growing at the edge of the tailings impoundment and exposed tailings, and the comparatively low values for plants downwind from tailings, suggests that root uptake for U and Th may, under certain situations, be a significant mechanism by which these ra-

dionuclides enter the plant. This concept is strengthened by the large differences in CRs between Th isotopes (Fig. 2), as well as the calculation of the maximum potential concentration due to tailings dust on plants, relative to observed values in Table 1.

Comparisons with earlier work

The concentration ratio is difficult to compare generically since it is highly dependent upon a large array of physical, chemical and biological factors. Nevertheless, reported values from various circumstances provide a bank of information that can be used to assess general ranges of values and the magnitude of uncertainty in food-chain transport calculations.

Studies on the extent of plant uptake of radionuclides from U mill tailings have been extensively reviewed (Ra82). Several studies have focused on the concentration ratios of U by plants growing on or near U mill tailings. CR values obtained from these studies vary widely. Rayno (Ra80) found ^{238}U concentration ratios of 0.1 for Russian thistle and ricegrass growing within 0.5 km of the Anaconda tailings embankment. Concentration ratios for vegetation growing in U contaminated soils at Los Alamos varied from 0.02 to 0.10 (Mi78). Dreesen and Marple (Dr79) reported a U concentration ratio of 5.5×10^{-3} for plants grown in alkaline tailings in a greenhouse. Their data suggest higher concentration ratios for plants growing in the field than for those growing under greenhouse conditions. One probable cause is that radionuclides can reach the foliage in the field by aerial mechanisms in addition to root uptake. Moffett and Tellier (Mo77) carried out an investigation on the uptake of U by four grasses growing on established tailings plots and reported CR values sim-

ilar to those found by Dreesen and Marple (Dr79). These values are generally lower than our mean CR value of 0.81 for a tailings substrate; however, earlier work by Whicker at Wyoming U mills resulted in ^{238}U CR values ranging from 0.27 to 3.3 for unwashed vegetation (Wh78).

Thorium uptake by plants has not been studied as extensively as other U series radionuclides. A concentration ratio of 0.9 for ^{230}Th in kidney beans was obtained for plants cultured in a nutrient solution (D'So70). However, Bondietti and Sweeton (Bo77) reported much lower values for ^{232}Th in vegetation ($\sim 10^{-3}$) from laboratory experimentation with Th contaminated soil. In the latter work, U was more readily assimilated by plants than Th (CR $\sim 10^{-2}$). Linsalata et al. (Li85) reported CR values for ^{232}Th on the order of 10^{-4} for plants growing near a Th deposit in Brazil. The only ^{230}Th data found for plants growing on U tailings indicate a value of 0.1 for ricegrass (Ra80), which is sevenfold lower than the value reported herein for plants growing directly on exposed tailings. The exceptionally high CR values for ^{230}Th in vegetation growing at the tailings impoundment edge reported in our study demonstrate that, under certain conditions, aboveground vegetation can accumulate Th to a much greater extent than previously reported.

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-- from Kay Drey, a member of the
St. Louis Site Remedial Action
Task Force. 9/15/95

SOME FACTS AND QUESTIONS ABOUT THE ST. LOUIS AIRPORT SITE --
for the Coldwater Creek geology panel.

Background information:

On April 24, 1942, scientists and engineers at the Mallinckrodt Chemical Works, near downtown St. Louis, began to determine how to purify uranium in tonnage quantities for use in the production of the atomic bomb (as a part of the Manhattan Project). At that time only a few grams of pure uranium metal existed anywhere. Mallinckrodt achieved success in only fifty days.

All the uranium used in the Fermi pile for the world's first self-sustaining nuclear chain reaction -- below Stagg Field at the University of Chicago, in December 1942 -- was purified by Mallinckrodt.

In 1946 the Army condemned a 22-acre tract of farmland along the northern boundary of the Airport for the storage and disposal of residues and wastes from the processing of uranium. Starting at that time, radioactive materials were trucked to the site around the clock -- in such forms as sludges (raffinates), pulverized solids, liquids and scrap. A bulldozer was used to spread out and flatten the piles at night. Disposal of residues and wastes continued at SLAPS until 1957 when the Mallinckrodt Uranium Division was moved to a new facility -- at Weldon Spring in St. Charles County. (Mallinckrodt continued processing uranium and thorium for nuclear weapons at Weldon Spring for another ten years, or for a total of about 25 years).

A primary source of the uranium processed at the St. Louis Downtown Site was Belgian Congo (Zaire) pitchblende. Whereas the U.S. Atomic Energy Commission was willing to purchase any ore containing at least one-tenth of one percent uranium, the Belgian Congo ore was 60-65% pure. Uranium-235 is found in nature at only 0.7%, compared with uranium-238's natural abundance of 99%. Therefore, because of the high quality of the ore processed in St. Louis, daughter products of uranium-235, which are not detected elsewhere in the United States in natural soils, are found in the St. Louis Site wastes (such as actinium-227 and protactinium-231, two particularly radiotoxic substances. Another U-235 daughter, radon-219, is also found here.)

Radium residues, relatively a small percent of the volume that was trucked to the site, were kept isolated in an open concrete storage pit at the Airport Site for eventual shipment to Belgium. They were ultimately shipped instead to the Fernald uranium feed materials plant near Cincinnati; some went to an abandoned ordnance works at Niagara Falls. (The Belgian firm no longer owns the

residues. Incidentally, they are the hottest wastes at Fernald!)

Some other Airport Site materials were sent elsewhere. For example, for five months, starting in late 1969, some of the materials were dug up and trucked about one-half mile to Latty Avenue in Hazelwood. Most of those materials were kiln-dried there and then sent by train to the Cotter Corporation (a Commonwealth Edison mining subsidiary) in Canon City, Colorado, for the retrieval of potentially usable materials. (In 1973 some of the remaining Latty Avenue materials were trucked to the West Lake Landfill in Bridgeton, next to Earth City, and were illegally dumped there.)

While some of the Airport Site materials were dispersed to other locations, a large but unknown volume of uncontained radioactive waste remains on site -- a mixture of liquids, fine sand, greasy mud, and solid wastes, according to one of the six truck drivers who transported the materials from the Downtown Site to the Airport, around the clock, over a twelve-year period (1946-1958).

Radioactive contamination associated with spillage over the years from dump trucks and rail cars has been discovered in St. Louis City and County along all corridors surveyed to date.

The Airport Site's impact on the human environment:

A. Evidence that radioactive materials remain on site includes air, water, and soil radiological surveillance data.

1. Re air: "Based on our review, eight representative [Formerly Utilized Sites Remedial Action Program] sites were selected for further study including the St. Louis Storage Site which appears to have the greatest emissions of radionuclides to air. . . . The radiological survey of the site identified significant surface and subsurface contamination both on- and off-site." (from Radionuclides -- Background Information Document, Final Rules, National Emission Standards for Hazardous Air Pollutants, EPA 520/1-84-0222-2, Oct.1984, Vol.II, p.B-14.

2. Re water:

a. Uranium-238 has been found in groundwater monitoring wells in concentrations as high as 8671 picocuries per liter (SLAPS Annual Site Environmental Report: Calendar Year 1986, p.22). In comparison, uranium is reported to occur naturally in Missouri groundwater in levels from 0.71 to 3 picocuries per liter. (Oak Ridge National Laboratory: "Uranium in U.S. Surface, Ground, and Domestic Waters," Vol. 1, April 1981, p. 116, and DOE/Bechtel SLAPS Annual Site Env.Report: 1990, p.47, respectively.)

b. "For thorium-230, annual averages [in groundwater] range from ... 0.1 to 52 pCi/L." (Remedial Investigation Report, Jan.1994, p.3-41.) "Thorium-230 concentrations were only slightly above background levels except for those in well M11-21, which were

elevated. Well M11-21 is located in an area of known contamination, which might explain elevated levels of thorium-230." (SLAPS Annual Site ER: 1990, p.18. Well M11-21 is located in the center of the site, near Banshee Rd.)

3. Re soil:

a. High levels of thorium-230, the primary contaminant of concern at the St. Louis Site, have been found in the soil. Reported average background concentrations in St. Louis soil of thorium-230 range from 0.2 picocuries per gram to 1.2 pCi/g, according to the Radiological and Limited Chemical Characterization Report, St. Louis Airport Site, Bechtel Natl., Inc., August 1987, p.25; and Radiological Characterization Report for FUSRAP Properties in St. Louis, Bechtel Natl., Inc., August 1990, p.2-16, respectively.

(1) According to Bechtel's Radiological and Limited Chemical Characterization Report for the St. Louis Airport Site, August 1987: "Concentrations of thorium-230 ranged from 0.6 to 2600 pCi/g" (p.21)

(2) According to Rust Federal Services, Clemson Technical Center, a sample of Airport soil measured 22,410 picocuries of Th-230 per gram. (DOE FUSRAP - St. Louis Site Treatability Study: Interim Characterization Report. Jan. 16, 1995. Figure 27.)

b. Gamma radiation: The average background gamma radiation exposure rate for St. Louis is usually listed as 8 or 10 microrads per hour (or sometimes, from 42 to 100 millirads per year).

"Gamma radiation exposure rates [at SLAPS] ranged from 9 to 261 microrads per hour. The average ... was 84 microrads per hour." (BNI: Rad. and Limited Chem.Char.Report, Aug.1987, p. 20) Gamma levels at a site near the north fence line reached 2128 millirads per year in 1988 -- or 2.1 rads. (SLAPS Annual ER - 1990, p.32)

B. A portion of SLAPS lies in the floodplain of Coldwater Creek which flows along the western boundary of the site, and according to all documents I have seen, the groundwater from the upper aquifer at the Site flows into the creek. For example:

1. "Groundwater flow directions in the upper aquifer are to the north-northwest and north-northeast towards Coldwater Creek. ... Recharge to the upper groundwater system occurs from precipitation, offsite inflow of groundwater, vertical flow from the underlying system where an upward potential exists, and creek bed infiltration during high creek stage. Discharge occurs by seepage into Coldwater Creek during low creek stage, and vertical seepage into the underlying groundwater system." (Feasibility Study/EIS for the St. Louis Site, April 1994; pp. 2-32, 2-34. See also: Remedial Investigation Report for the St. Louis Site, January 1994; by Bechtel

National, Inc. [BNI] for DOE; p.3-52)

2. Of related interest: "Hydrogeologic investigations indicate that two groundwater systems exist in the unconsolidated deposits at the properties. The upper groundwater system is contained in ... (loess and lacustrine deposits). The lower groundwater system is present in ... (lacustrine and glacial deposits). The two groundwater systems are separated by an aquitard composed of ... (lacustrine deposits). However, in the eastern portion of the properties, the aquitard is absent and the upper and lower systems become a single groundwater system." (emphasis added; RI Report, 1/94, p. 3-48)

3. And finally: "Composite water level data collected over a six-month period show wide fluctuations in the position of the shallow groundwater table (units 2, 3, and 4) in response to unusually heavy precipitation. Depth to the zone of saturation in the central portion of the site has been less than 3 feet." (Roy F. Weston, Inc., for Union Carbide/BNI: FUSRAP - SLAPSS. Technical Series, Vol. 2, No. 1 - Conceptual Design for In Situ Stabilization of Low Level Radioactive Residues., Jan.1982. pp. 2-25, 3-7.)

Some questions of concern to area residents:

Information about the following questions is needed to help determine if the wastes buried at the Airport Site should be excavated -- or if they can remain there to serve as the base of a disposal bunker in which the dispersed St. Louis City and County radioactive weapons wastes could be consolidated (that is, wastes from the Downtown Site, Latty Avenue, West Lake Landfill, haul roads, Coldwater Creek sediment, and vicinity properties):

1. To what extent are the radioactive wastes at the Airport Site in contact with the groundwater? 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?

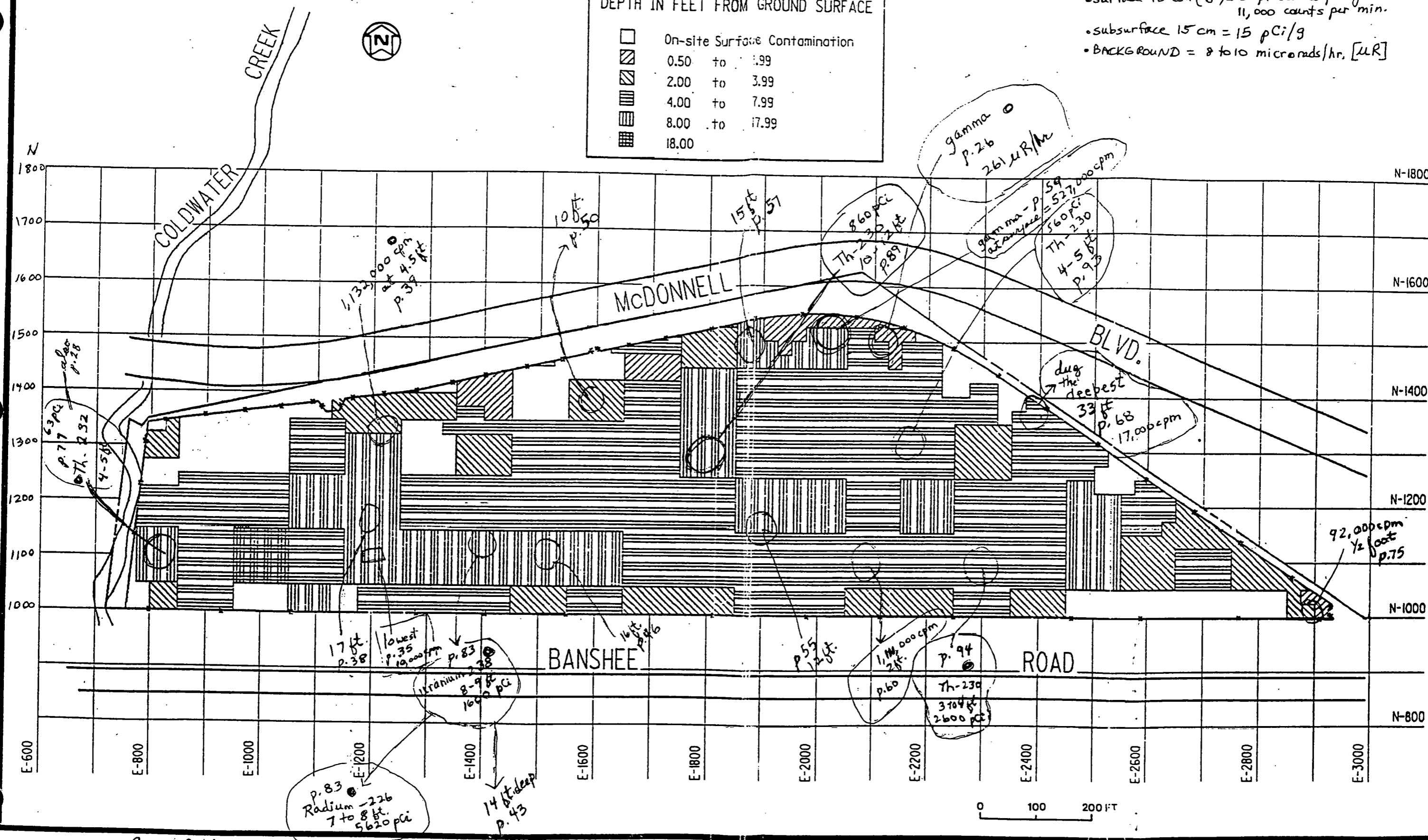
2. To what extent, if any, are surface water runoff and eroding soil contaminating Coldwater Creek -- including both the amount washing into the creek out of the ditches along the north and south boundaries, and that percolating through the gabion wall along the site's western boundary?

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?

DEPTH IN FEET FROM GROUND SURFACE	
□	On-site Surface Contamination
▨	0.50 to 1.99
▩	2.00 to 3.99
▧	4.00 to 7.99
▦	8.00 to 17.99
■	18.00

DOE Cleanup Guidelines:

- surface 15 cm (6") = 5 picocuries per gram
11,000 counts per min.
- subsurface 15 cm = 15 pCi/g
- BACKGROUND = 8 to 10 microrads/hr, [uR]



Bechtel Natl. Inc
for DOE-8/87

FIGURE 5-1 AREAS AND DEPTHS OF RADIOACTIVE CONTAMINATION AT THE SLAPS

St. Louis Airport
Characterization
22 Report

Figure 5-1.
Depth of contamination

00-1759

Formerly Utilized Sites Remedial Action Program (FUSRAP)

ADMINISTRATIVE RECORD

for the St. Louis Site, Missouri



U.S. Department of Energy

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