PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS

Prepared for:

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SEQUOYAH FUELS CORPORATION

PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS

November 27, 1996

1. INTRODUCTION

1.1. Scope and Purpose

An examination of the groundwater flow and mass transport characteristics of nitrate (NO_3 as N), arsenic (As), and uranium (U) was conducted for the groundwater at the Sequoyah Fuels Corporation (SFC) facility (Facility) using computer modeling techniques. A map of the SFC area, including various study areas (SA) is provided on Figure 1. This NACP also identifies the current Institutional Controls Boundary (ICB) for completion of decommissiong the Facility. The objectives of this phase of work included:

- Developing a mathematical representation of the hydraulic properties (flow direction and gradient) of the shallow bedrock groundwater system including the shallow portions of the terrace groundwater system, and alluvium groundwater;
- Simulation of dissolved nitrate, arsenic, and uranium migration (mass transport) yielding predictions of future solute migration;
- Estimation of projected solute concentrations at key observation points; and
- Analyzing the results in terms of natural attenuation processes.

1.2. Model Identification and Overview of Theory

The simulation of groundwater flow and mass transport was completed using the computer program Method of Characteristics (MOC). This program was originally developed by the United States Geologic Survey by

Konikow and Bredehoeft in 1978. It was later modified to incorporate decay, equilibrium controlled sorption, or ion exchange (Goode and Konikow, 1989).

MOC is a two-dimensional flow and mass transport model. The model is capable of depicting the length, width, and thickness of the zone of saturation. As a two-dimensional model, however, key input parameters (such as hydraulic conductivity or solute concentration) can only be varied across the model area in the X and Y plane and are assumed to be homogeneous throughout the thickness of the zone of saturation. MOC uses finite difference approximation where the study area is depicted as a grid system of regularly spaced square or rectangular cells. Each cell is assigned mathematical attributes depicting important flow properties including a lower base, starting head, hydraulic conductivity, and recharge. Other variables required for mass transport include the solute concentration, dispersivity, the ratio between lateral to transverse dispersivity, dry bulk density, effective porosity and solute distribution coefficient.

For steady state conditions a single, static, piezometric surface is calculated by the model. This piezometric surface is assumed to represent an average flow condition and is held constant throughout the time domain of the simulation. Each general head cell is defined by a set of equations fundamentally derived from Darcy's Law. Here, the water level in a cell is described by the flow (Q) across a cell boundary and the defined hydraulic conductivity (K). The piezometric surface for all cells across the grid is calculated based on these hydraulic conditions as well as imposed hydraulic stress such as pumping or recharge. This is accomplished by simultaneously solving a series of mathematical equations describing each cell. To provide mathematical stability, a certain number of known values must be defined yielding a system of equations consisting of *n*-equations for *n*-unknowns. These known values are supplied through the use of boundary conditions which are described below. Correctly defining the boundary conditions and flow variables will produce a calculated head distribution across the model grid that approximates the actual piezometric surface found on the study site. Once the flow field is accurately developed mass transport modeling can be performed.

Boundary conditions are cells specifically identified as having either constant head or constant flow. Constant flow cells produce the effects of pumping wells, recharge, or evapotranspiration and may or may not be used in a MOC simulation. Constant head cells; however, are required for all MOC simulations. A constant head condition sets the water table elevation for a cell at fixed value throughout the simulation. At a minimum, all the cells comprising either the top and bottom rows of the grid, or the left and right columns must be defined as constant heads. These cells are technically excluded from the active portion of the model domain.

For steady state conditions two-dimensional head distribution is expressed as:

Equation 1

$$\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}=-\frac{R}{T}$$

or, in terms of matrix notation as:

Equation 2

$$\frac{h_{i-1,j}-2h_{i,j}+h_{i+1,j}}{(\Delta x)^2}+\frac{h_{i,j-1}-2h_{i,j}+h_{i,j+1}}{(\Delta y)^2}=-\frac{R}{T}$$

Where:

h = head differential in the x, y or i, j direction

R = recharge

T = transmissivity (hydraulic conductivity times saturated thickness)

Equation 2 is applied to each cell of the grid. This set of equations is then simultaneously solved through finite difference approximation using linear algebraic techniques. First, a user specified initial head value is assigned to each cell. Next, the model successively guesses head values and examines the numerical difference between the calculated results of each iteration. The results determined in the prior iteration are used for the starting values for the next approximation which gradually begins to center on the unknown head value. This sequence of prediction and correction continues until the amount of error (closure criteria) is less than that defined by the user (usually 0.01 to 0.001 feet).

Once the flow field has been established MOC determines mass transport (solute migration) based on the following equation:

Equation 3

$$Rf * \frac{\partial(Cb)}{\partial t} = \frac{1}{b}\frac{\partial}{\partial x_i}(bD_{i,j}\frac{\partial C}{\partial x_j}) - \frac{\partial C}{\partial x_i}V_i - \frac{W(C-C')}{\varepsilon b} - RfC$$

Where:

C = solute concentration

D = coefficient of hydrodynamic dispersion

b = saturated thickness of the aquifer

C′ = solute concentration at the source

W = water flux per unit area

V = seepage velocity

ε = effective porosity

Rf = Retardation factor

The retardation factor (Rf) is a term that effectively slows the rate of solute migration in response to solute/soil sorption phenomena. For linear sorption retardation is described as:

Equation 4

$$Rf = 1 + \frac{Pb \cdot Kd}{\varepsilon}$$

Where:

Pb = bulk density of soil/aquifer media

Kd = distribution coefficient

The Method of Characteristics solves the mass transport equation by placing between four (4) to sixteen (16) theoretical tracer particles in a regularly spaced geometric pattern in each cell of the finite-difference grid. An initial concentration is ascribed to each particle collectively defining the total solute concentration in a cell. For each time step, the tracer particles are moved a distance proportional to the length of the time increment, seepage velocity, and flow direction with allowances made for solute retardation and dispersion. In this way, movement is dictated by both ground water flow (advection) and dispersive effects. Advection is the component of overall ground water flow. Dispersion is the spreading effect caused predominantly by solute moving around aquifer particles and by anisotrophic flow conditions. After all particles have been moved for a time step, the concentration at each node is temporarily assigned the average of the concentrations of all points then located geometrically within the area of that cell. This creates a new average concentration for each cell and establishes the conditions to simulate the next time step. Mass transport results can be viewed for the entire grid for each time step. Additionally, predicted solute concentration can be calculated at user defined observation points for much finer time increments.

1.3. Flow Model Development and Assumptions

A finite difference modeling grid was established over the study area (Figure 2). This grid was defined as 9,000 feet in the horizontal, x-direction; and 6,000 feet in the vertical, y-direction and is divided into 1,350, unit cells each 200 by 200 foot square.

Locally, the Illinois and Arkansas Rivers comprise the Robert S. Kerr Reservoir. The confluence of these two rivers is roughly orthogonal. Therefore, the top and left boundaries of the model grid were oriented to approximately parallel the Illinois and Arkansas rivers respectively, thus satisfying the constant head requirements along those sides. Those constant head cell values were set to a mean seal level (MSL) elevation of approximately 461 feet. Groundwater piezometric surface elevations for the constant head cells along the lower and right boundaries were estimated based on site topography, and where depth-to-groundwater typically occurs approximately 10 to 30 feet below ground level.

Based on the understanding of the hydrogeology of the study area, solute transport can be approximated by a two-dimensional model through the proper application of certain simplifying assumptions. The local groundwater system is comprised of numerous stratigraphic units including terrace deposits, various shale and sandstone bedrock units, and river alluvium. Though each unit is geologically distinctive, a single, contiguous flow field has been envisioned with regard to shallow solute migration. In this case, a solute is thought to move through a unified water table aquifer by seeping into various successive aquifer units where they comprise the local aquifer system. Flow through a geologic unit is, therefore, differentiated by changes in hydraulic conductivity.

As shown on Figure 3, three different zones of hydraulic conductivity were defined across the grid. A hydraulic conductivity (K) of 6.7E-5 cm/sec was ascribed to the terrace/shallow bedrock system according to slug test data collected since 1990. Based on slug test data and professional judgment, a K value of 1E-3 cm/sec was set for the alluvial system. Anomalous groundwater elevations were recently found in the newly installed MW106. The resulting piezometric surface could best be facilitated in the model by assuming a clay zone with K = 1.2E-6 cm/sec partially circumscribing an area around that well. This assumption is also supported by the fact that:

- There is significantly reduced nitrate concentrations near MW106 even though it is near a potential source area;
- There is a marshy area immediately upgradient from MW106 suggesting impedance of groundwater flow in that area;
- It is impossible to develop the westward orientation of the existing nitrate plume across the study area unless flow is inhibited towards MW106.

A small amount of recharge was required in certain areas to develop head distribution in the model similar to that actually exhibited across the study area (Figure 4). Five inches of annual recharge was introduced to cells containing unlined ponds. Elsewhere, recharge rates ranged from zero (0) to one (1) inch per year. The final recharge distribution and volumes actually used in the model were varied until the model was accurately calibrated.

Several estimated flow variables were defined for use in the model. These included:

- Soil bulk density = 1.88 g/cm^3;
- Porosity = 0.10; and
- Aquifer thickness ≈ 20 feet.

Steady state flow conditions were assumed for the simulation. Output from the flow portion of the model, Figure 5, conforms very well to existing piezometric surface maps of the site. Mass transport simulation, the next phase in the modeling effort, was dependent upon the accurate development of this flow field.

1.4. <u>Mass Transport Development and Assumptions</u>

The predicted movement of nitrate, arsenic, and uranium was determined through mass transport modeling. In each case, contaminant mass loading was assumed to be a finite pulse defined by the current (April, 1996) concentration and distribution of the dissolved nitrate, arsenic, or uranium plume in groundwater. This concept is predicated on the fact that all source areas are closed or are scheduled for closure or abatement in the near future. Estimated variables included:

- Longitudinal dispersivity = 180.0; and
- Ratio of longitudinal to transverse dispersivity = 0.25.

The coefficient of longitudinal dispersion was determined according to Neuman (1990) as:

Equation 5

$$D_l = 0.0175L^{1.46}$$

Where:

D_l	=	Longitudinal dispersivity, and
L	=	Apparent dispersed length of plume.

Nitrate is an anion (negatively charged) and is not expected to sorb significantly to negatively charged clay micelle particles. Therefore, nitrate was assumed to migrate at the same velocity as the groundwater. This active rate of migration can easily be seen by reviewing historical plume maps for the site.

Uranium strongly sorbs to the soil matrix as shown by the historical lack of measurable subsurface movement over time. Therefore, uranium was modeled assuming active retardation via linear sorption. The distribution coefficient (Kd) was estimated using in-situ isotherm data from the Facility Environmental Investigation Findings Report (1991) reproduced here on Figure 6. Though data on that figure are scattered, a lower limit exists that defines a conservative Kd of 3.08 cm^3/g. This Kd produces an Rf = 58.9 using Equation 4. Therefore, uranium is assumed to migrate at approximately 1/60th the normal seepage velocity. This calculated Kd conforms with reported literature values for iron bearing soils (Waite, 1993).

Arsenic isotherm data have not been developed for the SFC facility. Historical data, however, indicate little arsenic movement. Kd values ranging from 3.3 to 31 cm^3/gr are shown in the literature (U.S.E.P.A. 1996a and 1996b). The most conservative Kd value (3.3 cm^3/gr) was used here producing a relative velocity of 1/63^{ed} normal groundwater seepage velocity.

1.5. General Methods and Input Parameters

The modeling effort involved linking a number of different computer programs together as described in the following procedures:

- **Step 1:** AutoCad maps were created for the piezometric surface and for solute concentration using the most recent field data;
- **Step 2:** An Autolisp program in AutoCad was used to produce an ASCII file containing the coordinates and data values for numerous discrete points along each isopleth contour. This produces three dimensional flat file containing X, Y, and Z data values.
- **Step 3:** Each ASCII data set was recontoured using the program Surfer. Surfer produces an output file that interpolates a data value for each cell of the model grid. For the piezometric surface the constant head values along the parameter of the grid were isolated using subsequent spreadsheet manipulation.
- **Step 4:** Surfer grid files were then introduced to the model using the program ModelCad 386. ModelCad is a general preprocessor for many computer models including MOC. It provides a limited graphical environment to input basic modal parameters. Data can be introduced directly by hand, or by reading input files saved in Surfer grid or ASCII flat file format;

- **Step 5**: Values for global data like porosity or soil density were entered into ModelCad 386. Spatially variable recharge values were also added here by hand.

- **Step 6**: ModelCad is used to generate an input file containing the requisite data to successfully run MOC;

- **Step 7**: The input file created by ModelCad is used to run MOC;

- **Step 8**: If the simulation is successful MOC generates a series of output files summarizing the input parameters and listing model output in a digital manner;

- **Step 9**: Output files from MOC mostly consist of strings of numbers representing model results in a matrix format. To view model results in a graphical, map-format, MOC output data must be further synthesized using a post processor program. Here, MOC2SURF was used to transform MOC output files into a series of Surfer compatible grid files.;

- **Step 10**: Grid files from MOC2SURF were contoured by Surfer for each time step;

- **Step 11**: Surfer contour maps were transformed to an AutoCad compatible format by printing them in graphical DXF file format; and

- **Step 12**: These DXF files were read by AutoCad which was then used to superimpose model output over an existing Facility base map.

As discussed above, recharge distribution and flux across the study area was unknown. Therefore, Steps 5 through 12 were repeated iteratively using varying recharge values until a satisfactory calibration of the piezometric surface map was achieved. Concentration data was then imported to the model for each solute and Steps 4 through 12 were repeated again to model mass transport.

2. RESULTS

2.1. Nitrate Migration and Attenuation Potential

Predicted nitrate migration over a 250 year time period is shown on Figures 7 through 17. These maps also show the location of three observation points (OBS-1, 2, and 3) which were defined in the model specifically to track predicted nitrate concentration at those discrete points with respect to time (Figures 18 through 20).

Nitrate does not sorb to soil. Consequently, its movement is not retarded and mass transport velocity for this solute is at a maximum for this groundwater system. Two distinct migration patterns are evident. Solute in the SA-2 area migrates towards the west and northwest intersecting the Illinois River branch of the Robert S. Kerr Reservoir. Nitrate from the SA-5 area follows a predominantly westerly path discharging to both the Illinois and Arkansas River branches.

The potential for nitrate attenuation via natural processes has been qualitatively assessed. Based on data from the RFI report, the aquifer system is largely oxidized. This condition infers that there is little possibility for natural dissimilatory nitrate reduction through in-situ bacterial processes. Similarly, for modeling purposes, assimilatory nitrate reduction through plant uptake is also believed to be of less significance because the depth to water over much of the site is below the depth of significant root penetration. Therefore, at the SFC site reduction of nitrate is assumed to be accomplished mostly through dispersive flow.

Currently, nitrate concentrations exceed 2,000 mg/L in both the SA-2 and SA-5 areas; however, through dispersion, lower concentrations are predicted in the future along the periphery of the study area. The southwestward flow path from the SA-1 area towards OBS-1 is relatively short (≈1,000 ft). Therefore, at that point a maximum concentration of approximately 200 mg/L is predicted in about 15 years. Travel distances to OBS-2 and OBS-3 are longer (≈ 3,000 ft) with a predicted nitrate concentration of 360 mg/L in 25 years and 150 mg/L in 35 years respectively, for each point.

2.2. Uranium Migration and Attenuation Potential

Predicted uranium migration was tracked over a 1,000 year time interval as shown on Figures 21 through 32. Three observation points (OBS-4, 5, and 6) were established in the model (Figures 33 through 35). Uranium is mostly found only in the far northeastern quarter of the facility (mostly in SA-3, 4, and 6). The groundwater flow direction for uranium is radial. Groundwater flow is towards the northwest for the area around SA-4 and SA-6 and towards the west for the area near SA-3.

Uranium decay is negligible over the simulated time period and was not incorporated into the model. As discussed above, this element is, however, strongly sorbed to the soil so movement is highly retarded. Over the 1,000 year simulation time there is a potential for small amounts of uranium (< 50 ug/L) to reach the facility boundary from the northwestern migration path emanating from the SA-4 and SA-6 source areas. The model predicts that maximum uranium concentrations at OBS-4 will peak at approximately 52 µg/L in 600 years. This is the only area where uranium concentrations are expected to reach the facility boundary.

OBS-5 and OBS-6 are located well within the facility boundaries and near the source areas. The maximum concentrations of uranium at 1,000 years for OBS-5 and OBS-6 are estimated to be 43 µg/L and 150 µg/L respectively.

2.3. Arsenic Migration and Attenuation Potential

Predicted arsenic migration over a 1000 year time period is shown on Figures 36 through 47. The source area for arsenic is mostly in the SA-1 and SA-2 area so solute movement is generally westward towards the Illinois River branch of the reservoir. One observation point, OBS-7, was established in the predicted path of the plume at the facility boundary. Arsenic movement is retarded through interactions with the aquifer matrix and concentrations are reduced through diffusive processes during mass transport.

Onsite, maximum arsenic concentrations currently exceed 3,000 µg/L in small isolated areas only. As shown on Figure 48, the maximum expected concentration at OBS-7 is expected to only be approximately 80 µg/L occurring in about 1,000 years.

3. CONCLUSIONS

Groundwater flow and mass transport of nitrate, arsenic, and uranium has been simulated using the computer program MOC. The flow field calibration in the model process closely matches the piezometric surface found on the site today. This was accomplished primarily by:

- Setting the elevation of constant head boundary cells to best match conditions of the study area;
- Laterally varying hydraulic conductivity to conform to the lithotype found on-site during past field investigations;
- Introducing spatially variable recharge affects.

Attenuation or natural decay is not considered significant for any solute. Nitrate attenuation through dissimilatory reduction or via assimilatory plant uptake is not significant under current site conditions where the groundwater is largely oxygenated and below root penetration depth. Decreases in concentration, however, do occur with solute migration due to dispersive processes.

Nitrate is not sorbed to the soil, so movement of this solute is expected to occur rapidly. Uranium and arsenic, however, are sorbed to the soil and are expected to migrate at approximately $1/60^{th}$ the normal flow velocity.

Solute flow direction is largely controlled by source area location. Flow from source areas located in the north or northwestern portions of the facility (including SA-2, 4, and 6) are expected to move in a northwesterly direction towards the headwaters of the Robert S. Kerr Reservoir. Here, the flow path to the reservoir is short and, consequently, solute concentrations are predicted to be higher with faster arrival times to the facility boundary. Along this boundary, the maximum concentration for nitrate is predicted to be 200 mg/L in about 15 years. For arsenic and uranium however, the maximum concentration in 1,000 years is expected to be only 80 µg/L and 52 µg/L respectively.

Solute from sources in a southeastern or central portion of the Facility (including SA-3 and SA-5) are shown to move in a westerly direction towards the headwaters of the Robert S. Kerr Reservoir. Only nitrate and uranium are expected to move in this direction. At the facility boundary, the maximum nitrate concentration is expected to be 360 mg/L occurring in about 25 years. Though uranium is expected to flow in a westerly direction its migration is highly retarded and moves only a short distance from the source area in 1,000 years.

The groundwater systems at and downgradient of the Facility have been extensively investigated and characterized. As indicated herein, impacts do exist in the groundwater systems. However, groundwater at the Facility is of low yield and has been classified in accordance with both EPA guidelines and State of Oklahoma guidelines (i.e., Final RCRA Facility Investigation Report, SFC, October 14, 1996). The EPA classification was determined to be Class IIIA-Insufficient Yield and the Oklahoma classification was determined to be Class III-Limited Use Groundwater. Further, there are no groundwater users downgradient between the Facility and the Robert S. Kerr Reservoir. Therefore, groundwater is not a feasible exposure pathway for downgradient receptors. Accordingly, in consideration of the fate and transport analysis findings, passive attenuation with monitoring is the recommended groundwater remediation strategy.

4. REFERENCES CITED

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Waite, T. David, and T.E. Payne, 1993. Uranium Transport in the subsurface environment: Koongarra - a case study; in: Metals in Groundwater, Allen, Herbert, E. Michael Perdue, David S. Brown, eds., Lewis Pub., 349-410

FIGURES

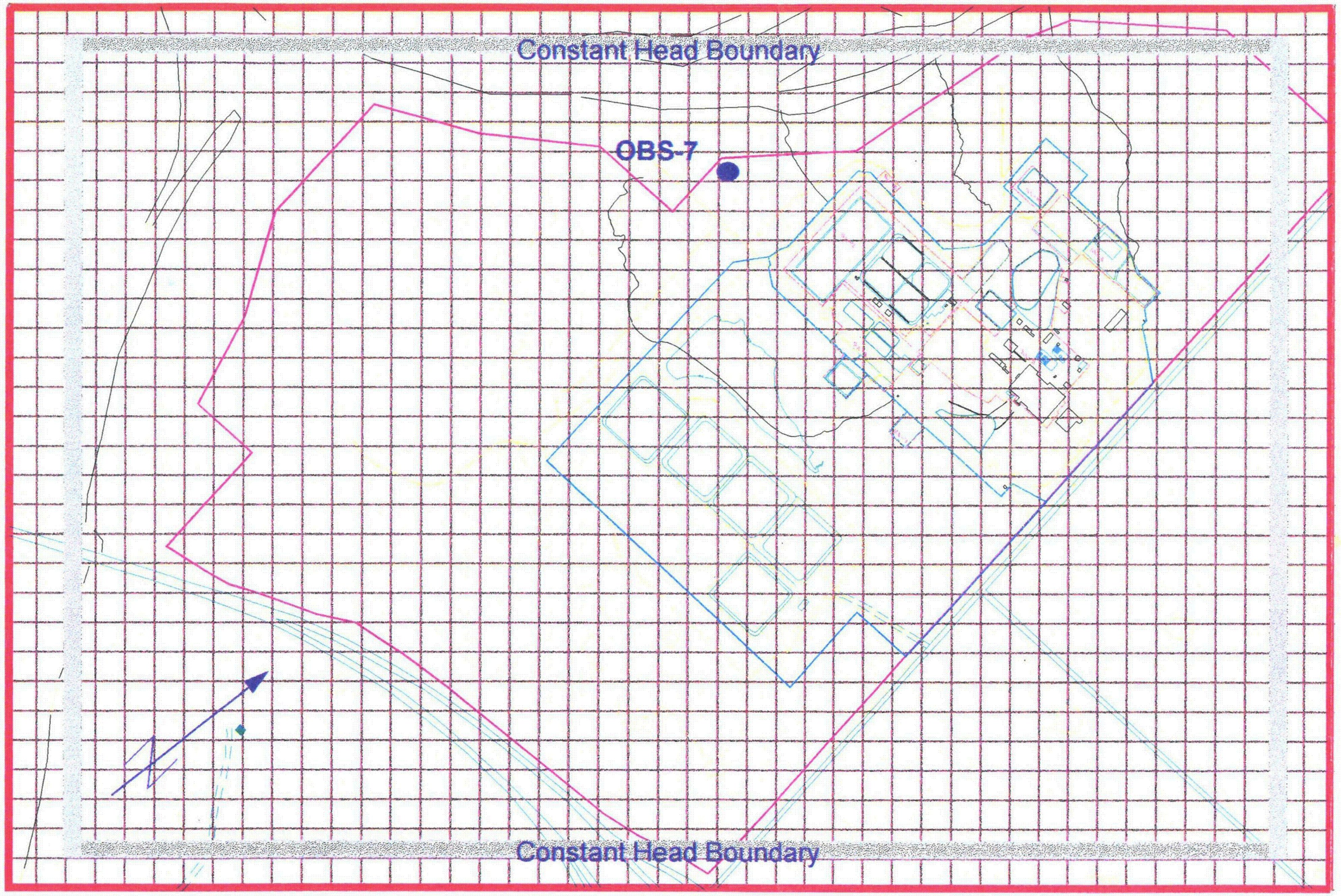
THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

THAT CAN BE VIEWED AT THE RECORD TITLED: DRAWING NO. FIGURE 1, "STUDY AREA AND ICB BOUNDARY LOCATIONS"

WITHIN THIS PACKAGE... OR BY SEARCHING USING THE DOCUMENT/REPORT NO. FIGURE 1

D-01

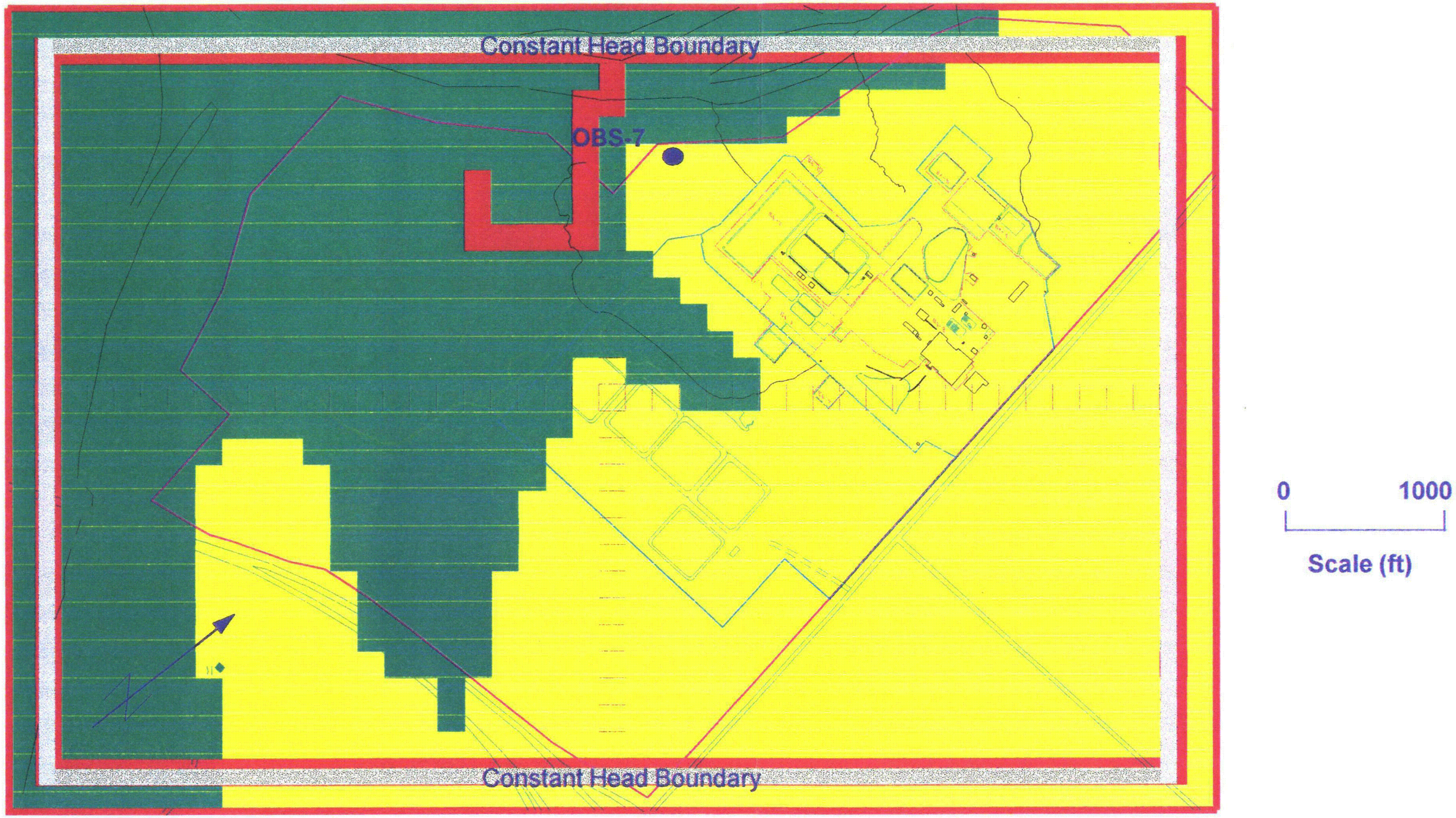
S.F.C. Facility



Finite Element Grid

Client: SEQUOYAH FUELS CORPORATION		Figure Title: FINITE ELEMENT GRID	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895	DATE: 11/20/96	PREPARED BY: LK	
	SCALE: AS SHOWN	CHECKED BY: BS	
		DRAFTED BY: LK	
	PROJECT NO: 9611401 PPT	FIGURE NO.: 2	

S.F.C. Facility



Computer Simulation Hydraulic Conductivity Distribution

Hydraulic Conductivity (cm/sec)

- 1.2e-6
- 1e-3
- 6.7e-5

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION HYDRAULIC CONDUCTIVITY DISTRIBUTION	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
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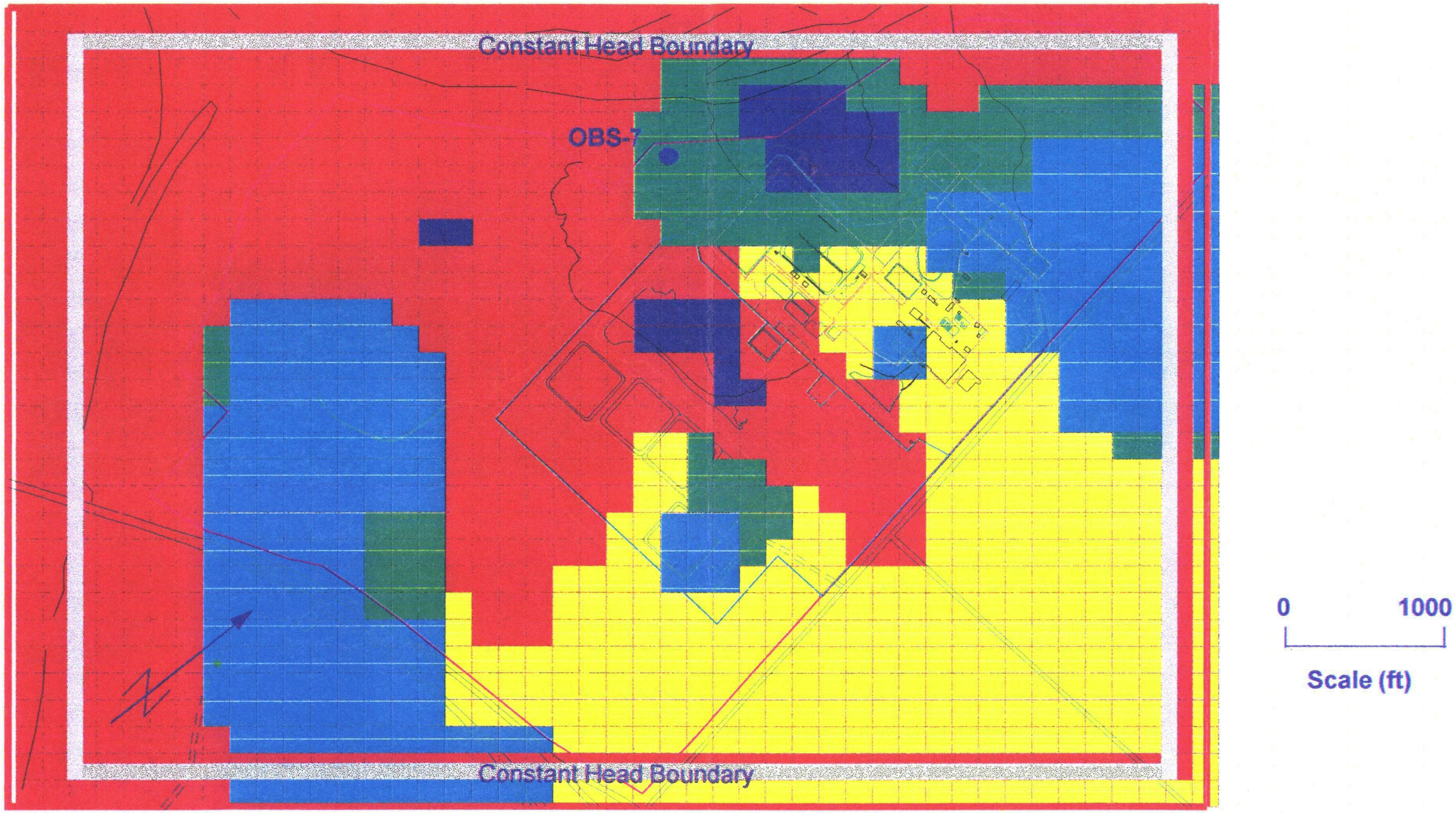
	PROJECT NO: 9611401 PPT	FIGURE NO.: 3	

S.F.C. Facility



Computer Simulation
Recharge Distribution

Recharge (in/year)

0.00	1.00
0.03	5.00
0.50	

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION RECHARGE DISTRIBUTION	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
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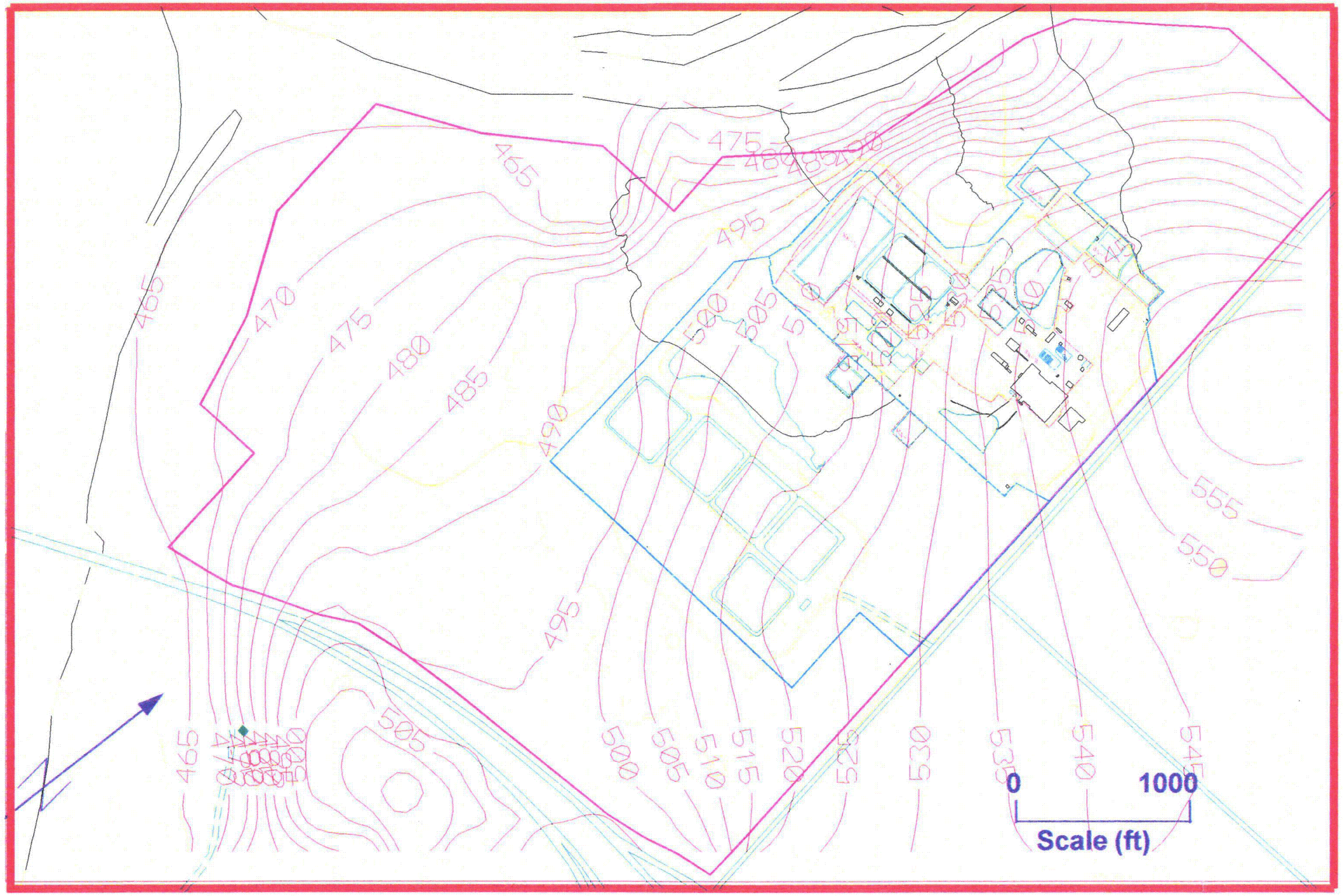
		PROJECT NO: 9611401 PPT	FIGURE NO.: 4

S.F.C. Facility



Computer Simulation
Piezometric Surface (ft)

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION PIEZOMETRIC SURFACE, FEET ABOVE MSL	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
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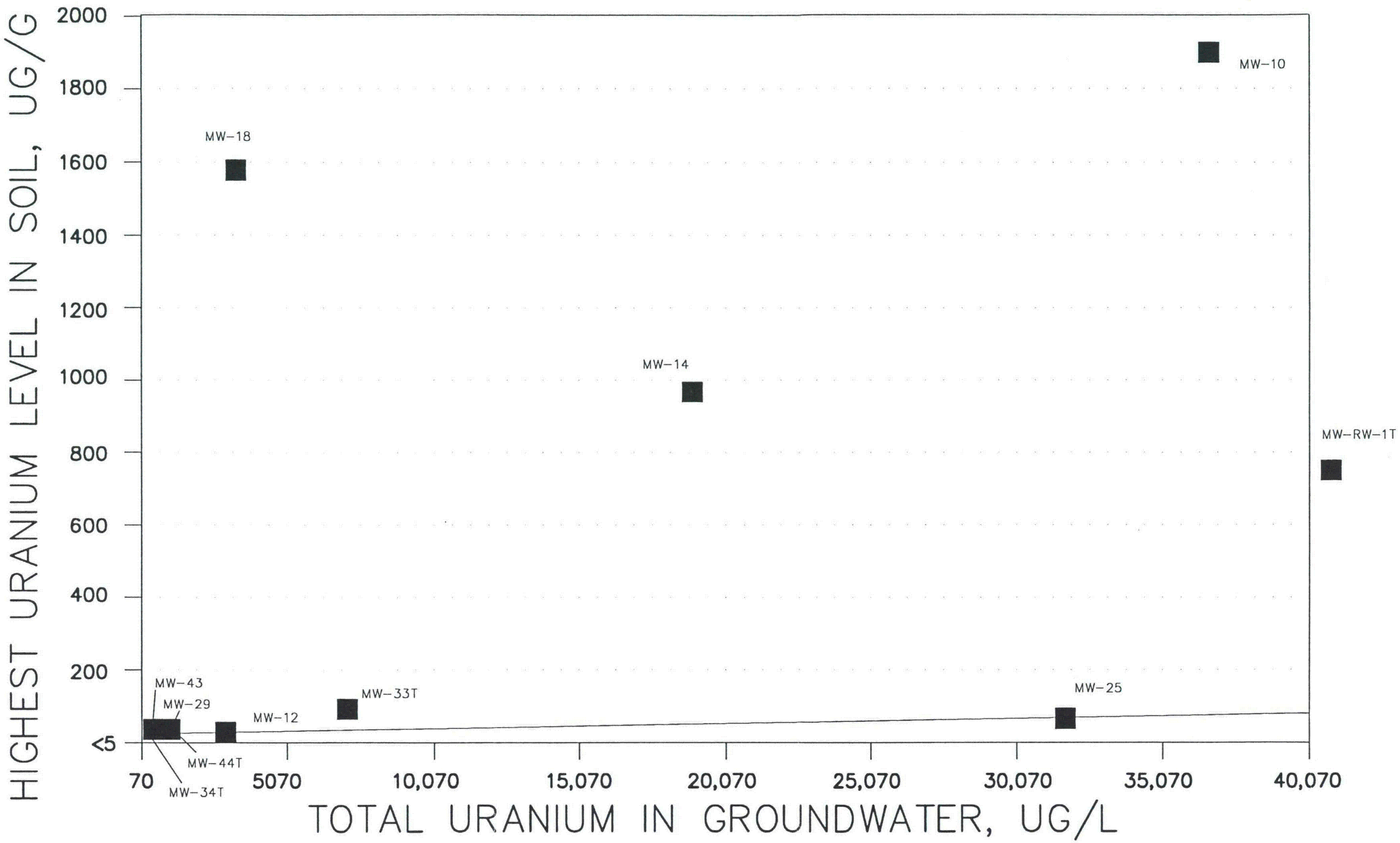
		DRAFTED BY: LK	
	PROJECT NO: 9611401 PPT	FIGURE NO.: 5	



Client: SEQUOYAH FUELS CORPORATION		Figure Title: URANIUM INSITU ISOTHERM	
Location: GORE, OKLAHOMA		Document Title:	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895	DATE: 11/24/96	PREPARED BY: BS	
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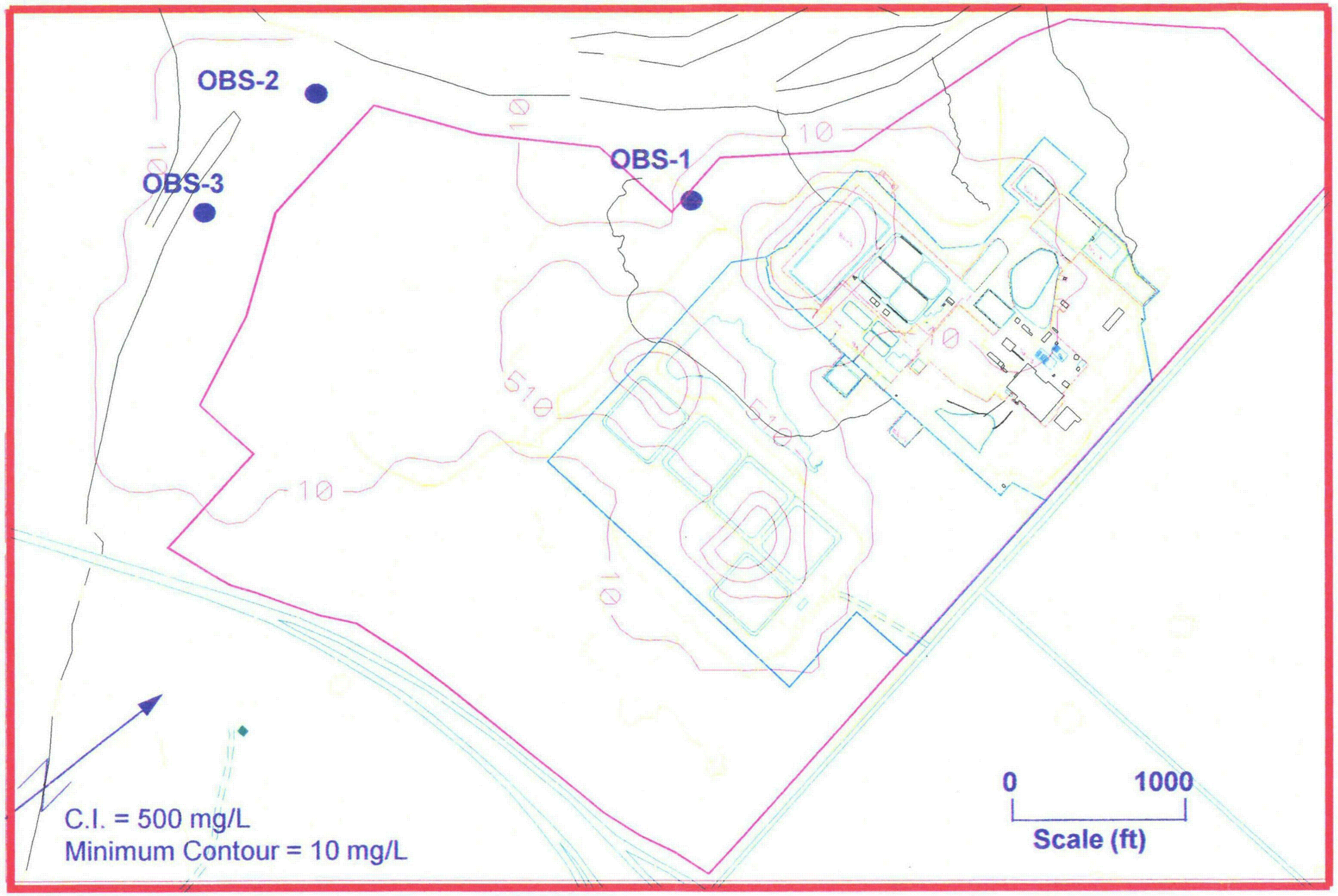
S.F.C. Facility



Computer Simulation Nitrate Plume (mg/L)

Years = 0

Client:	SEQUOYAH FUELS CORPORATION	Figure Title:	COMPUTER SIMULATION NITRATE PLUME
Location:	GORE, OKLAHOMA	Document Title:	PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS
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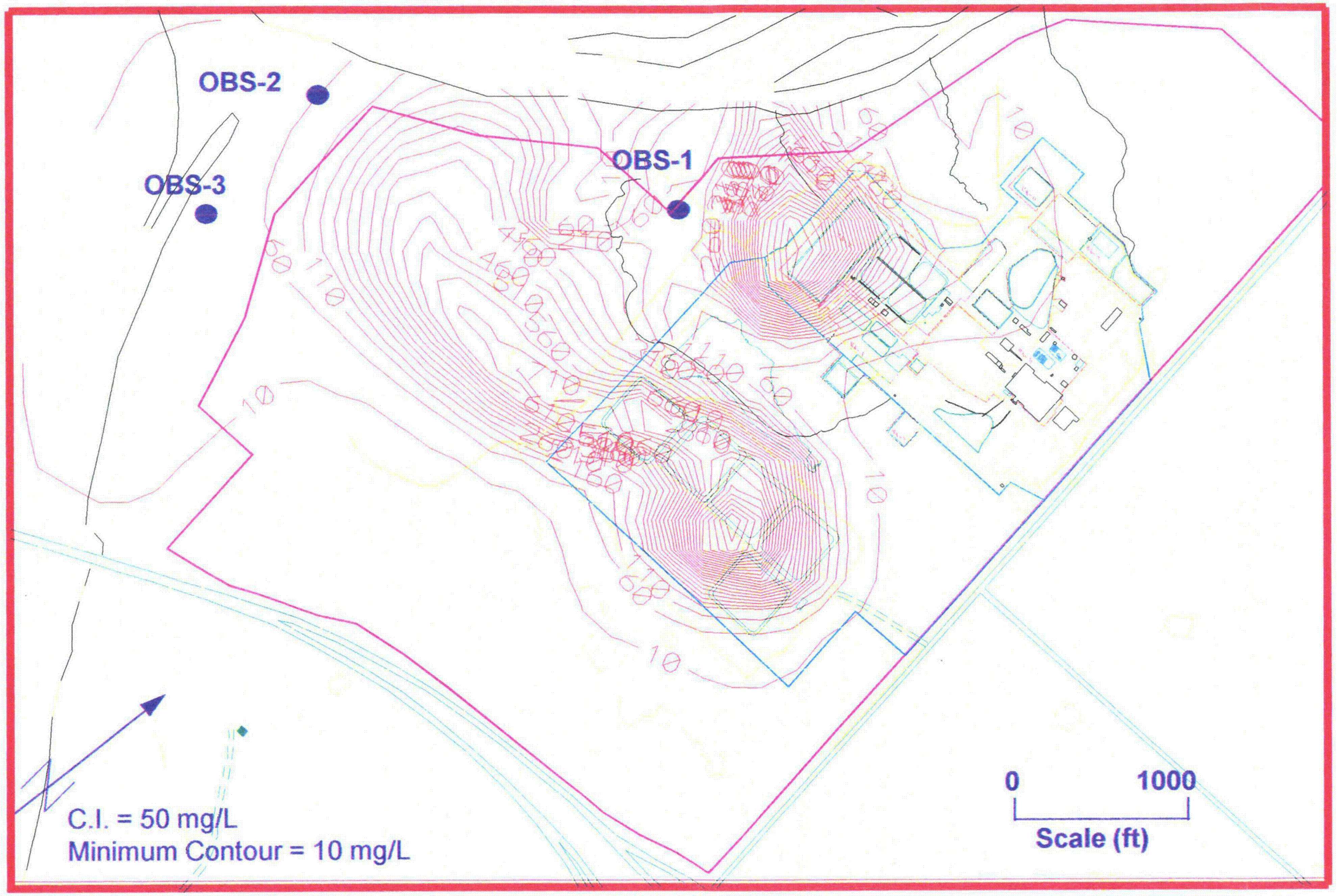
		PROJECT NO: 9611401 PPT	FIGURE NO.: 7

S.F.C. Facility



Computer Simulation Nitrate Plume (mg/L)

Years = 10

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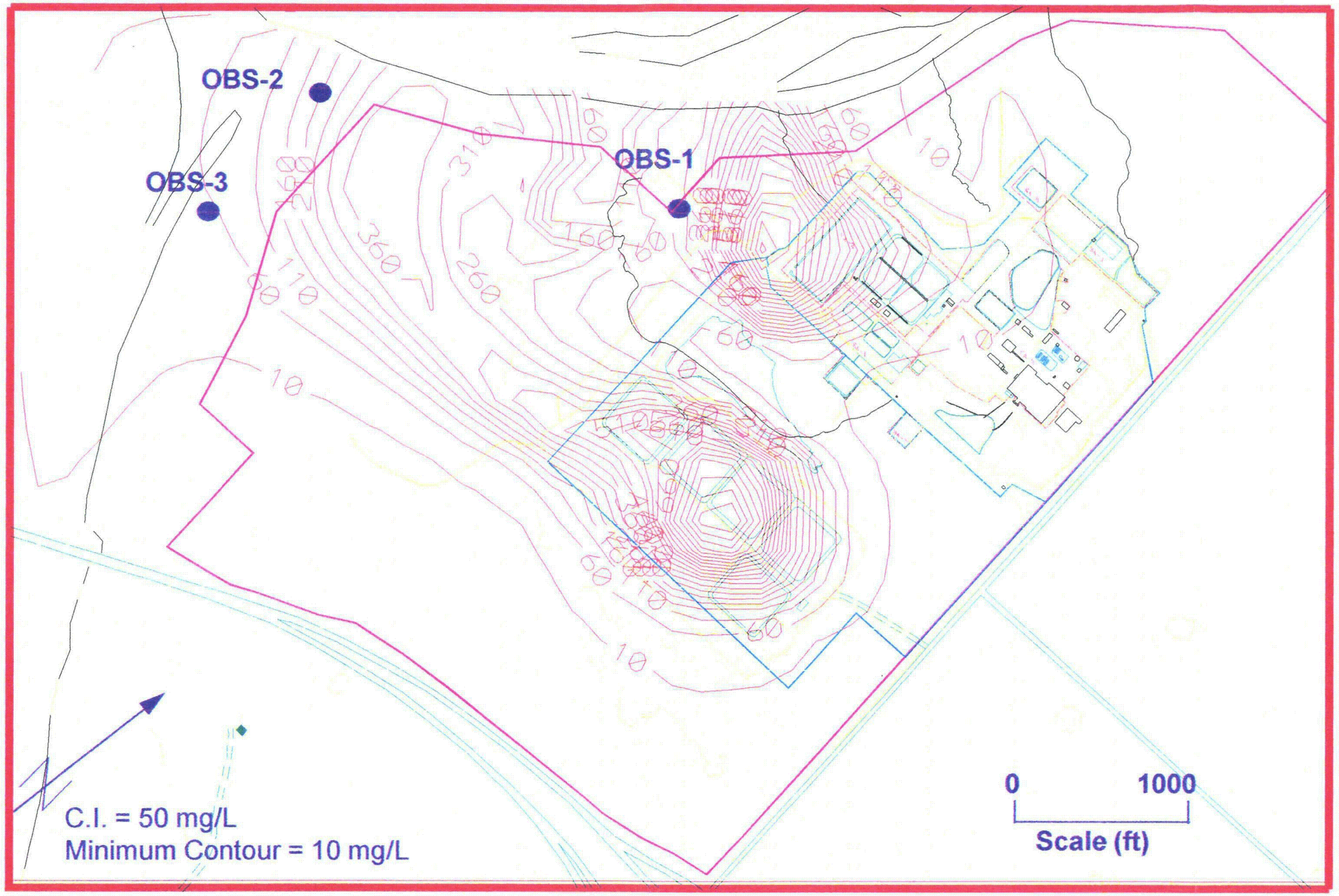
PROJECT NO: 9611401 PPT	FIGURE NO.: 8

S.F.C. Facility

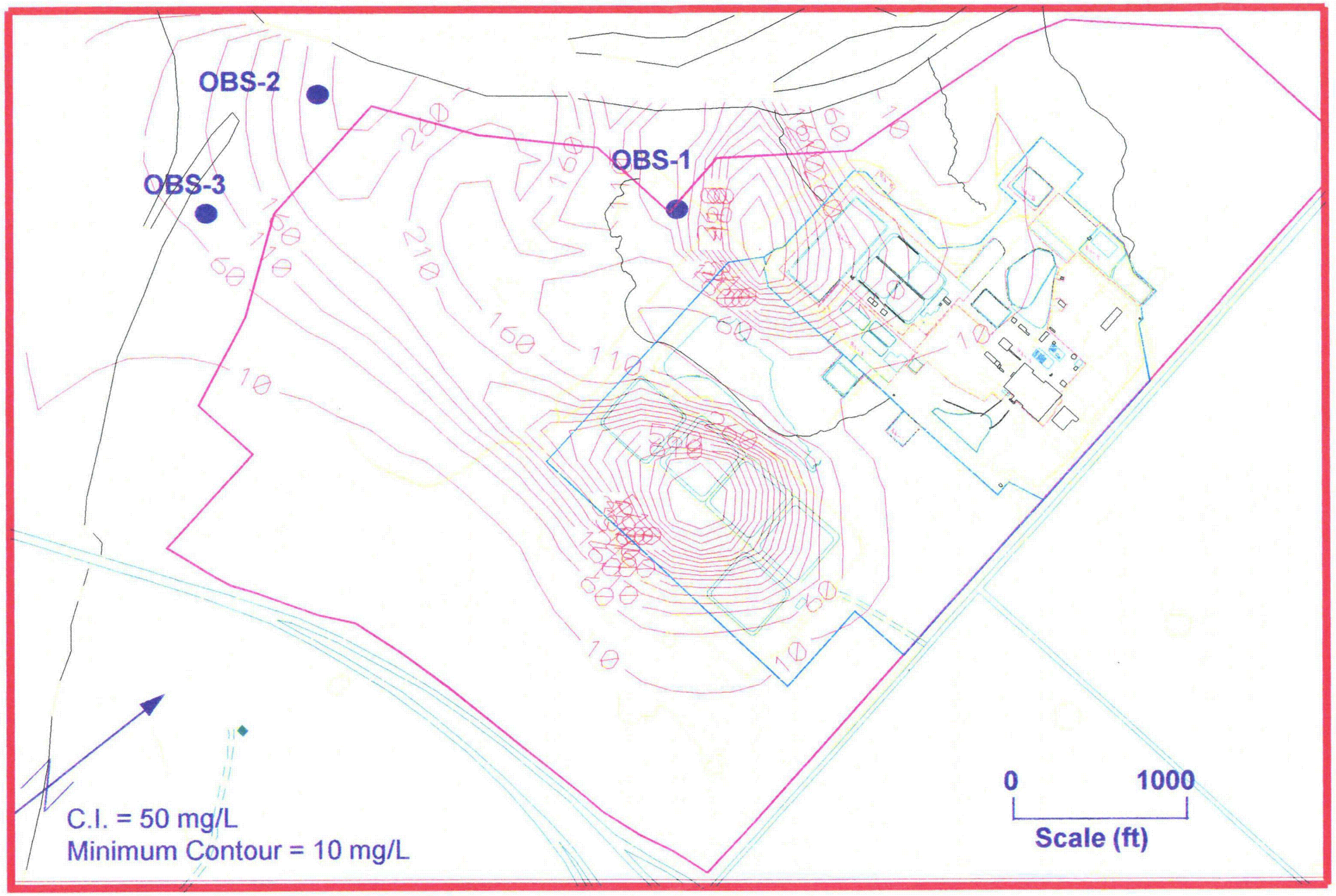


Computer Simulation
Nitrate Plume (mg/L)

Years = 20

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION NITRATE PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895	DATE: 11/20/96	PREPARED BY: LK	
	SCALE: AS SHOWN	CHECKED BY: BS	
		DRAFTED BY: LK	
	PROJECT NO: 9611401 PPT	FIGURE NO.: 9	

S.F.C. Facility

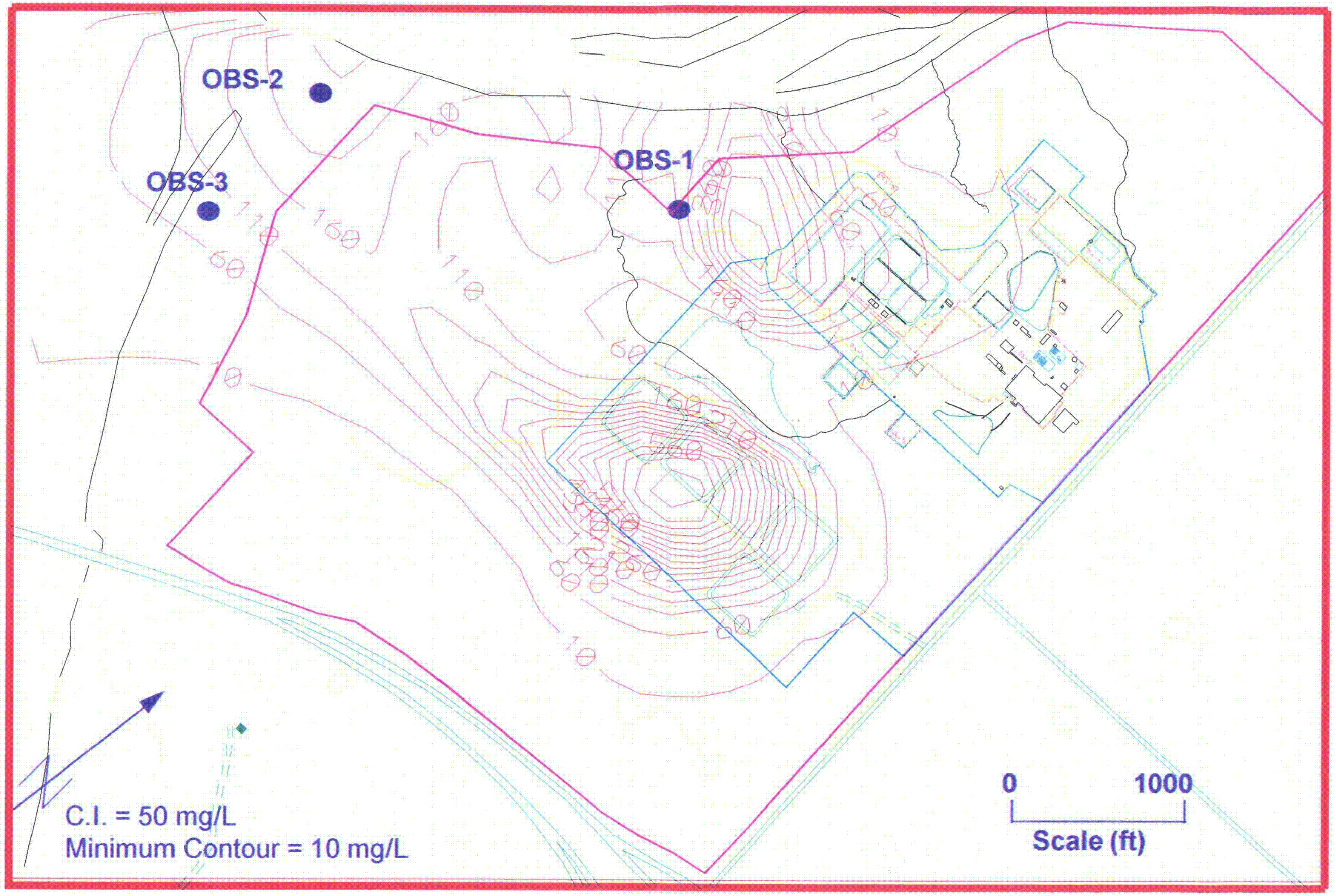


Computer Simulation
Nitrate Plume (mg/L)

Years = 30

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION NITRATE PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895	DATE: 11/20/96	PREPARED BY: LK	
	SCALE: AS SHOWN	CHECKED BY: BS	
		DRAFTED BY: LK	
	PROJECT NO: 9611401 PPT	FIGURE NO.: 10	

S.F.C. Facility

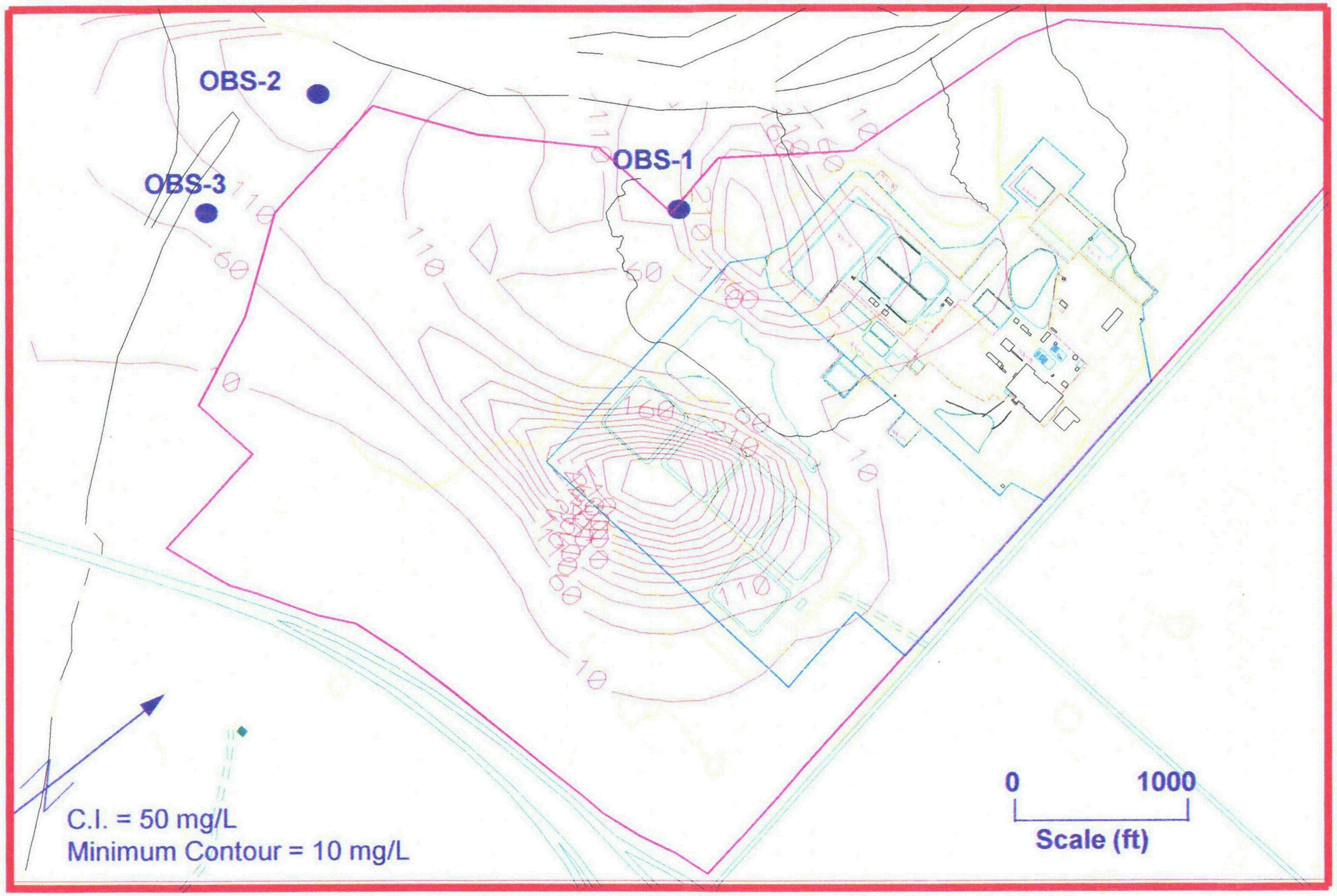


Computer Simulation Nitrate Plume (mg/L)

Years = 40

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION NITRATE PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895		DATE: 11/20/96	PREPARED BY: LK
		SCALE: AS SHOWN	CHECKED BY: BS
			DRAFTED BY: LK
		PROJECT NO: 9611401 PPT	FIGURE NO.: 11

S.F.C. Facility

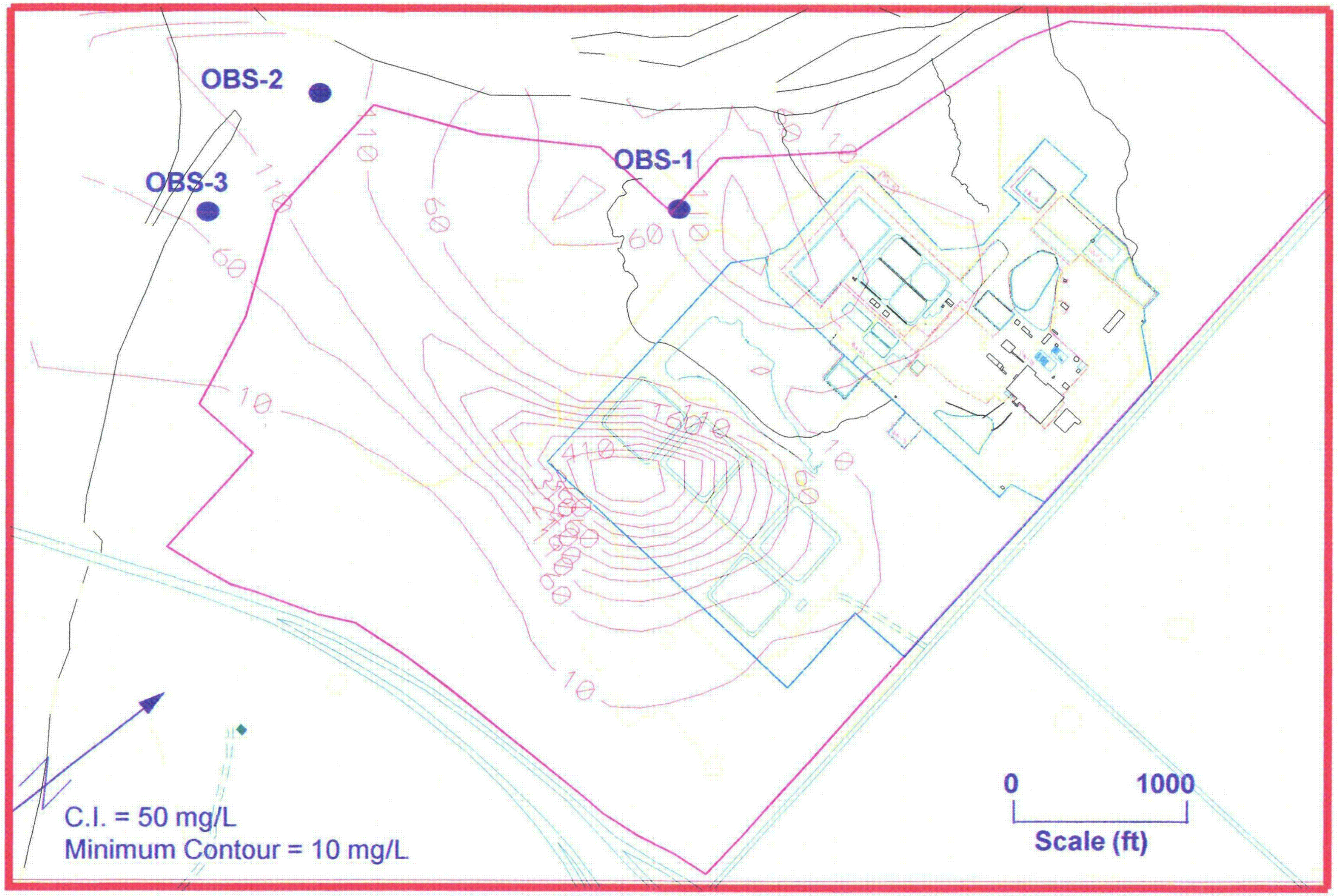


Computer Simulation Nitrate Plume (mg/L)

Years = 50

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION NITRATE PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895	DATE: 11/20/96	PREPARED BY: LK	
	SCALE: AS SHOWN	CHECKED BY: BS	
		DRAFTED BY: LK	
	PROJECT NO: 9611401 PPT	FIGURE NO.:12	

S.F.C. Facility

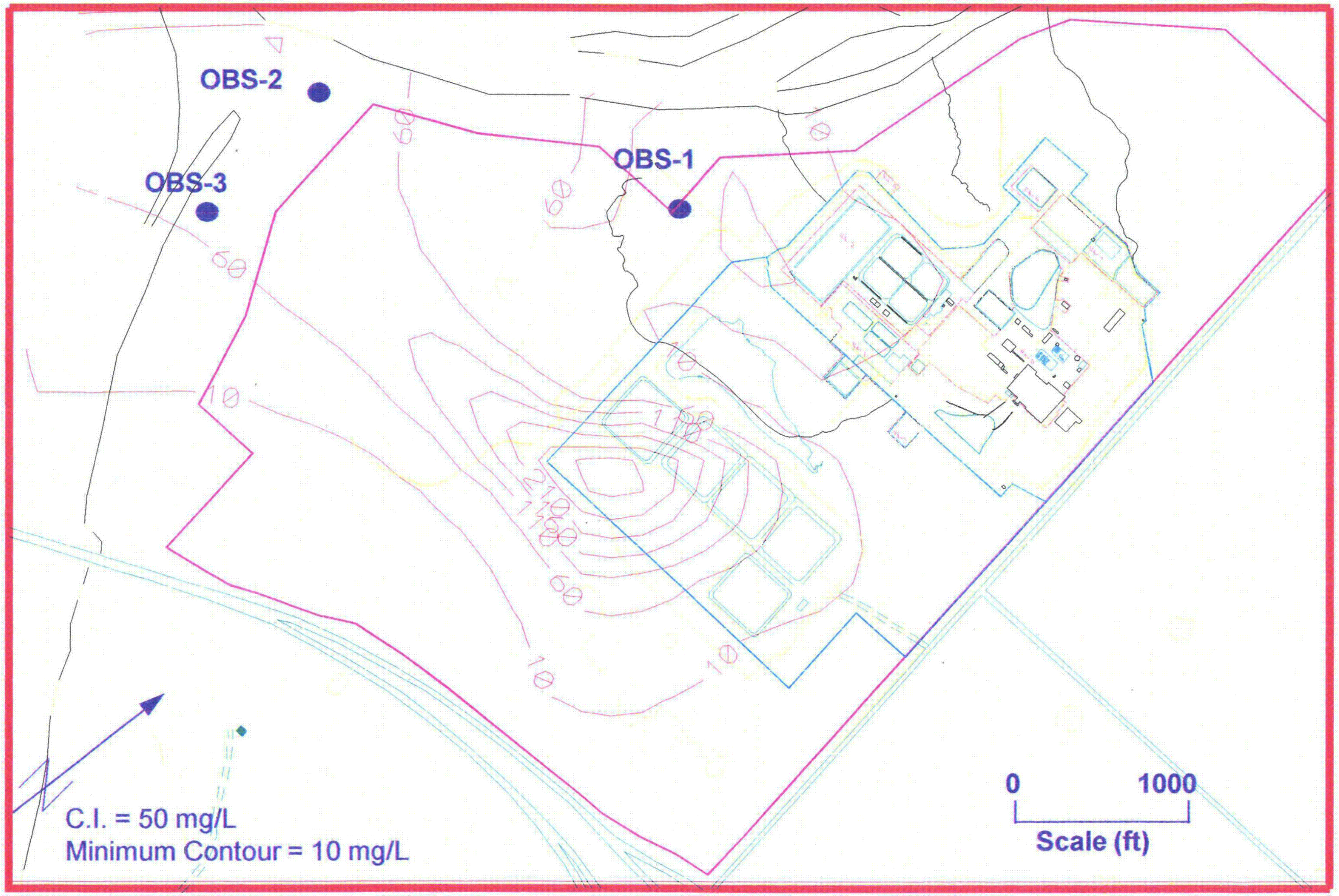


Computer Simulation
Nitrate Plume (mg/L)

Years = 70

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION NITRATE PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895		DATE: 11/20/96	PREPARED BY: LK
		SCALE: AS SHOWN	CHECKED BY: BS
			DRAFTED BY: LK
		PROJECT NO: 9611401 PPT	FIGURE NO.: 13

S.F.C. Facility

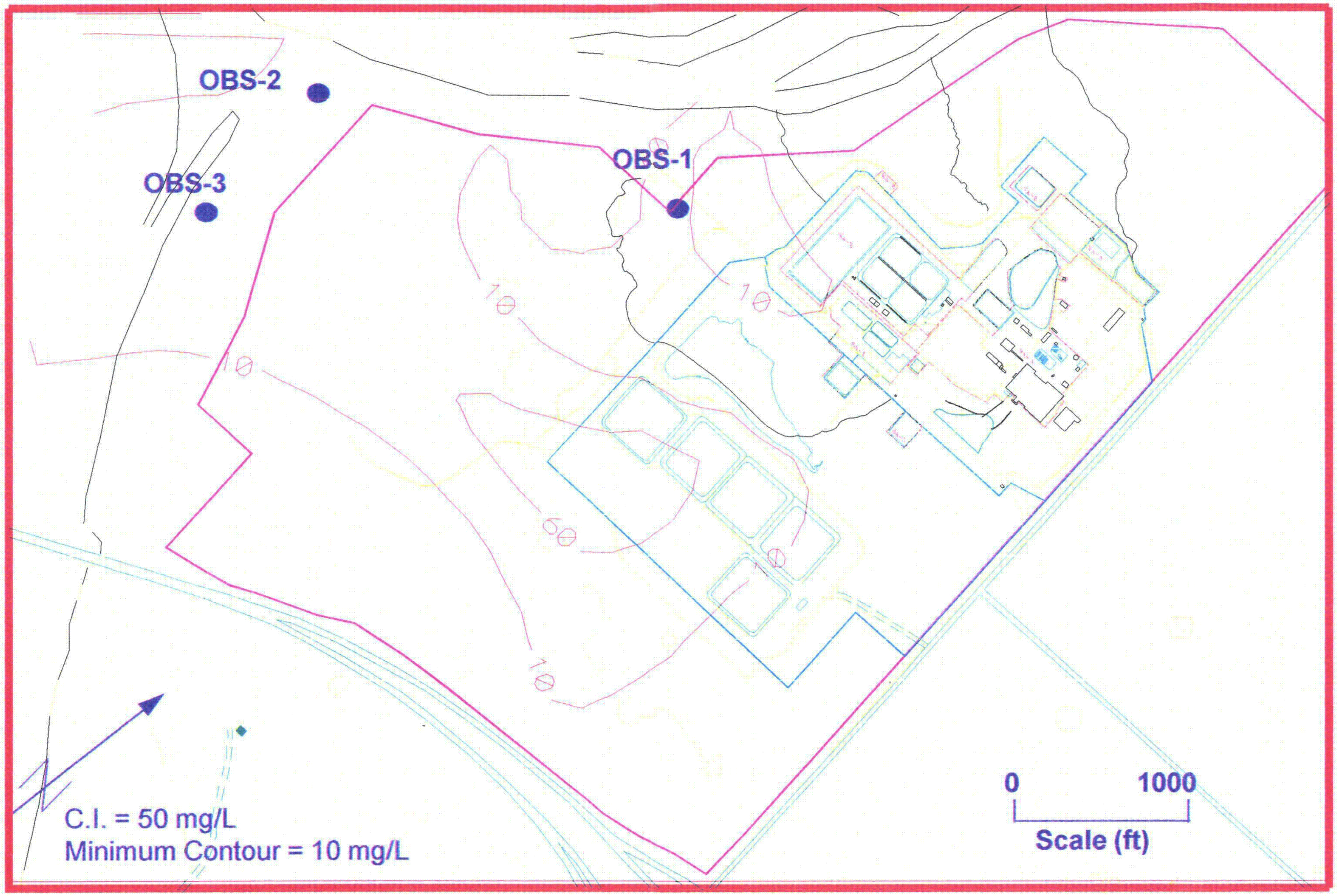


Computer Simulation
Nitrate Plume (mg/L)

Years = 100

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION NITRATE PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895		DATE: 11/20/96	PREPARED BY: LK
		SCALE: AS SHOWN	CHECKED BY: BS
			DRAFTED BY: LK
		PROJECT NO: 9611401 PPT	FIGURE NO.: 14

S.F.C. Facility

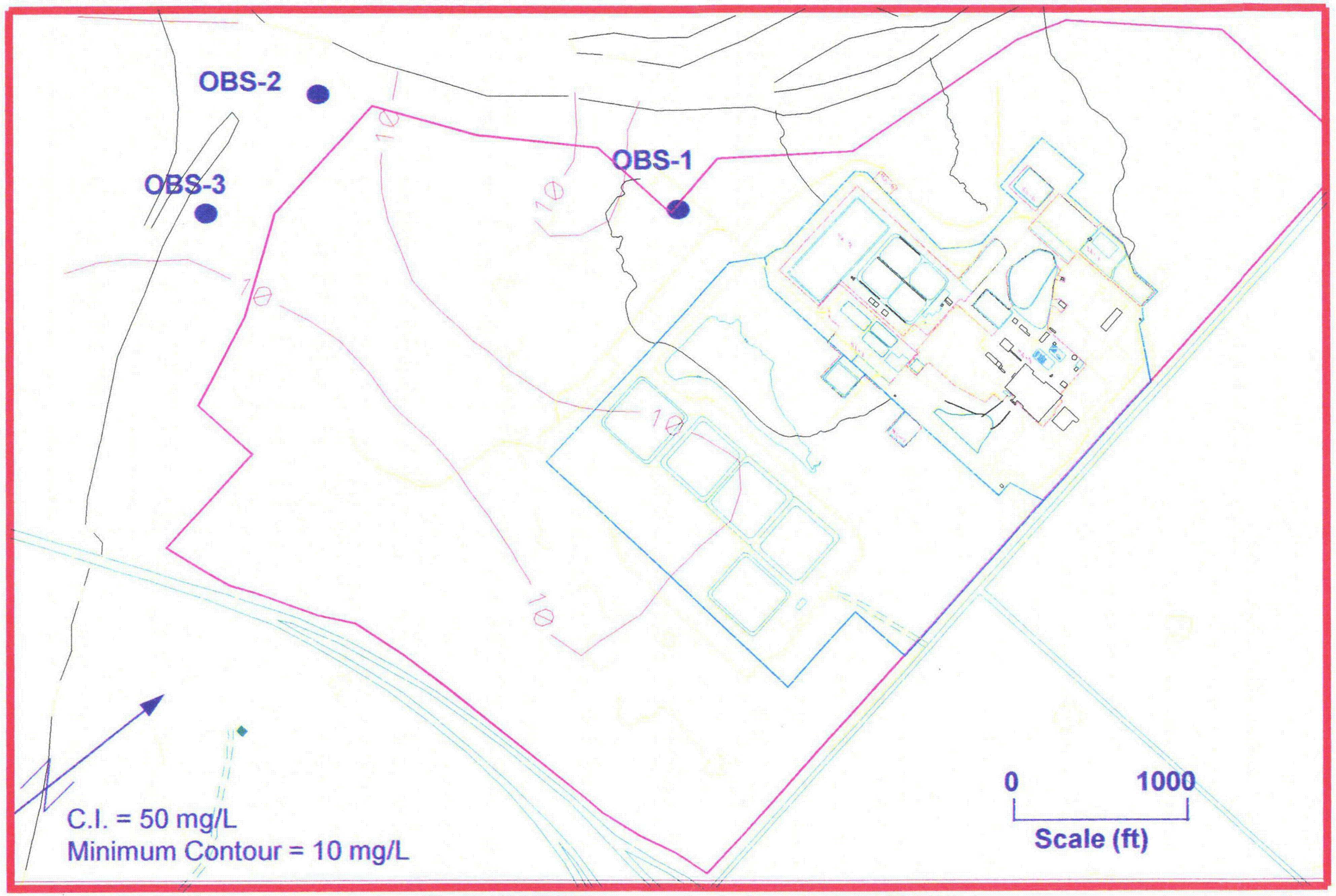


Computer Simulation
Nitrate Plume (mg/L)

Years = 150

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION NITRATE PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895	DATE: 11/20/96	PREPARED BY: LK	
	SCALE: AS SHOWN	CHECKED BY: BS	
		DRAFTED BY: LK	
	PROJECT NO: 9611401 PPT	FIGURE NO.: 15	

S.F.C. Facility

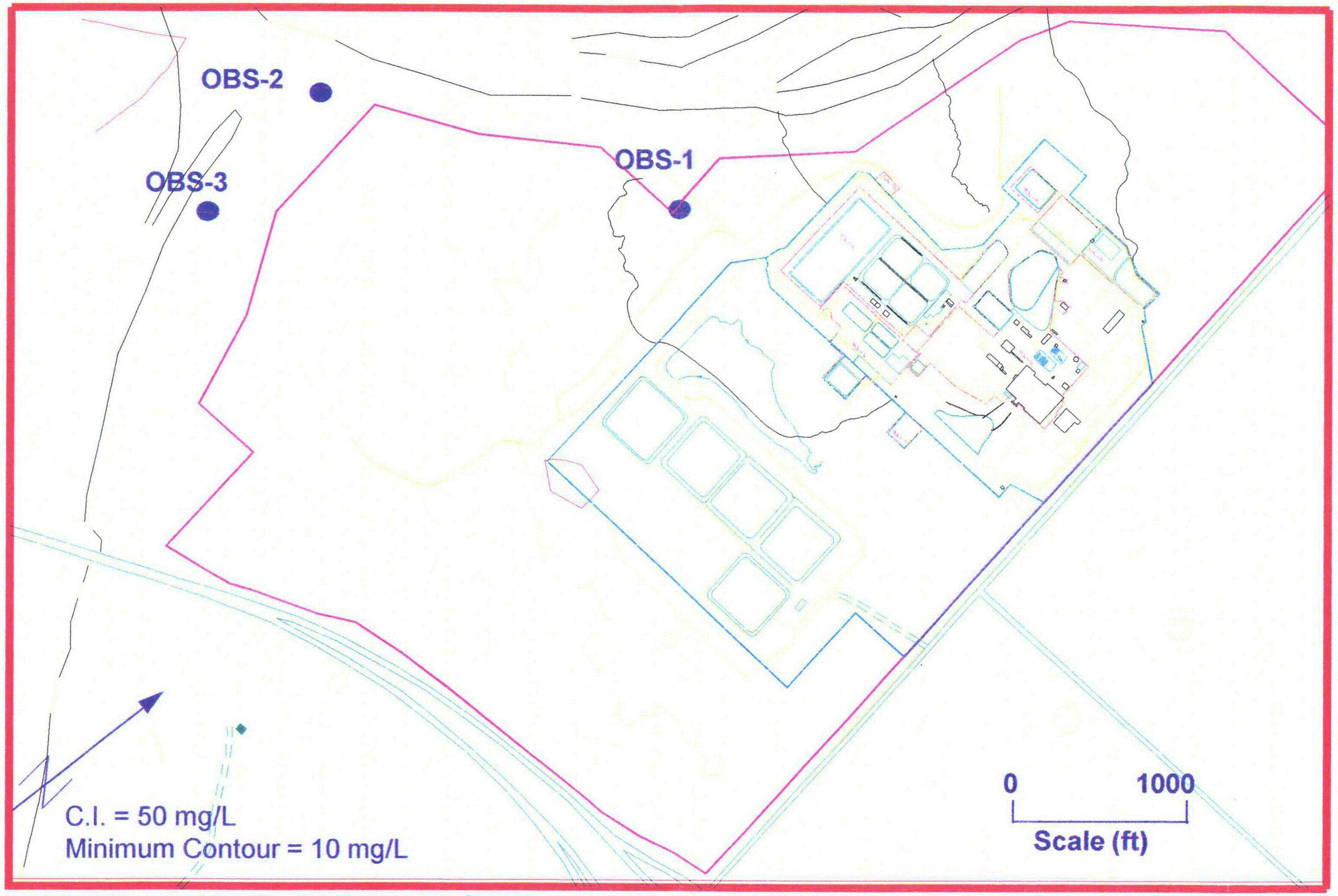


Computer Simulation
Nitrate Plume (mg/L)

Years = 200

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION NITRATE PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895	DATE: 11/20/96	PREPARED BY: LK	
	SCALE: AS SHOWN	CHECKED BY: BS	DRAFTED BY: LK
	PROJECT NO: 9611401 PPT	FIGURE NO.: 16	

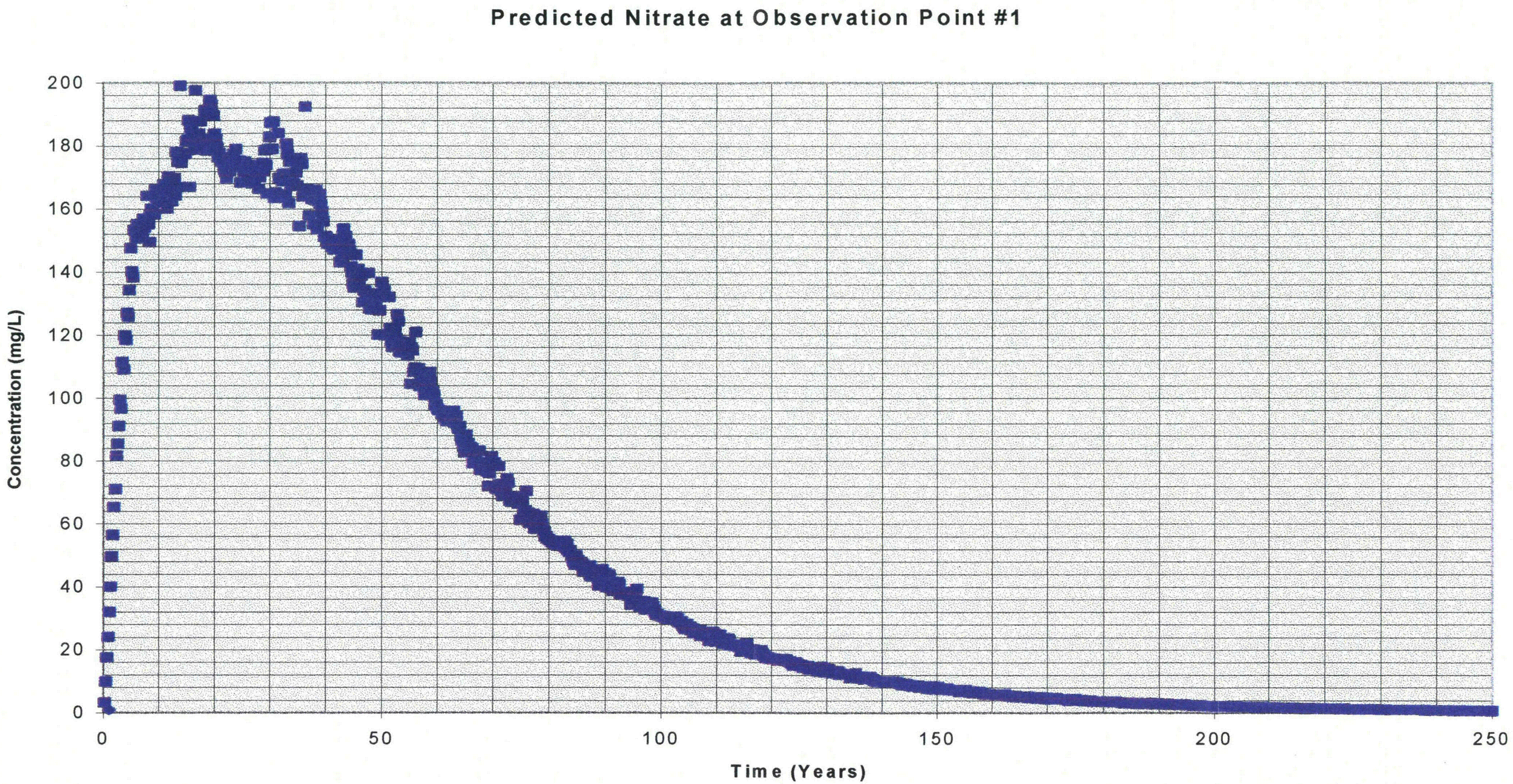
S.F.C. Facility



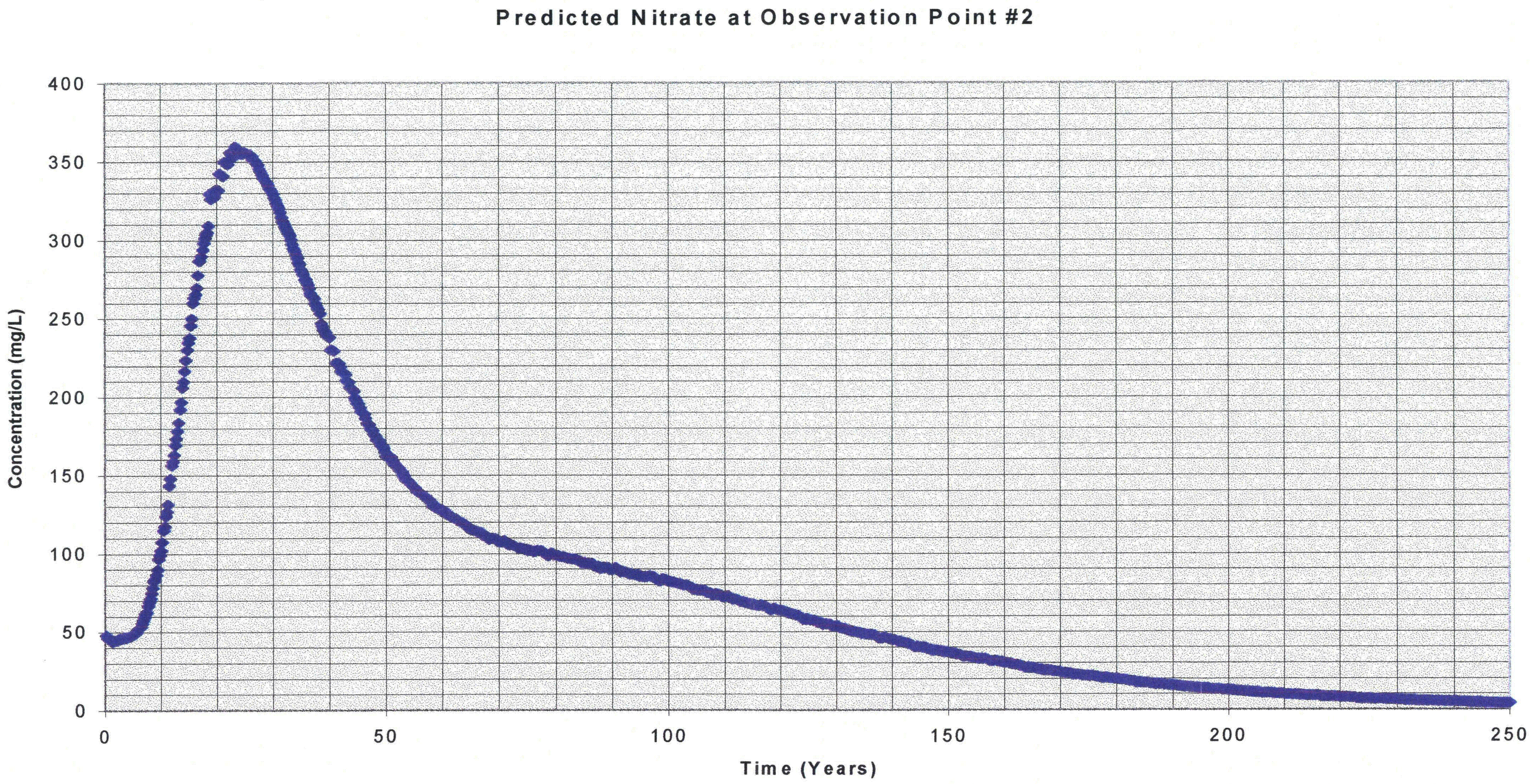
Computer Simulation
Nitrate Plume (mg/L)

Years = 250

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION NITRATE PLUME		
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS		
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895		DATE: 11/20/96	PREPARED BY: LK	
		SCALE: AS SHOWN	CHECKED BY: BS	
			DRAFTED BY: LK	
		PROJECT NO: 9611401 PPT	FIGURE NO.: 17	



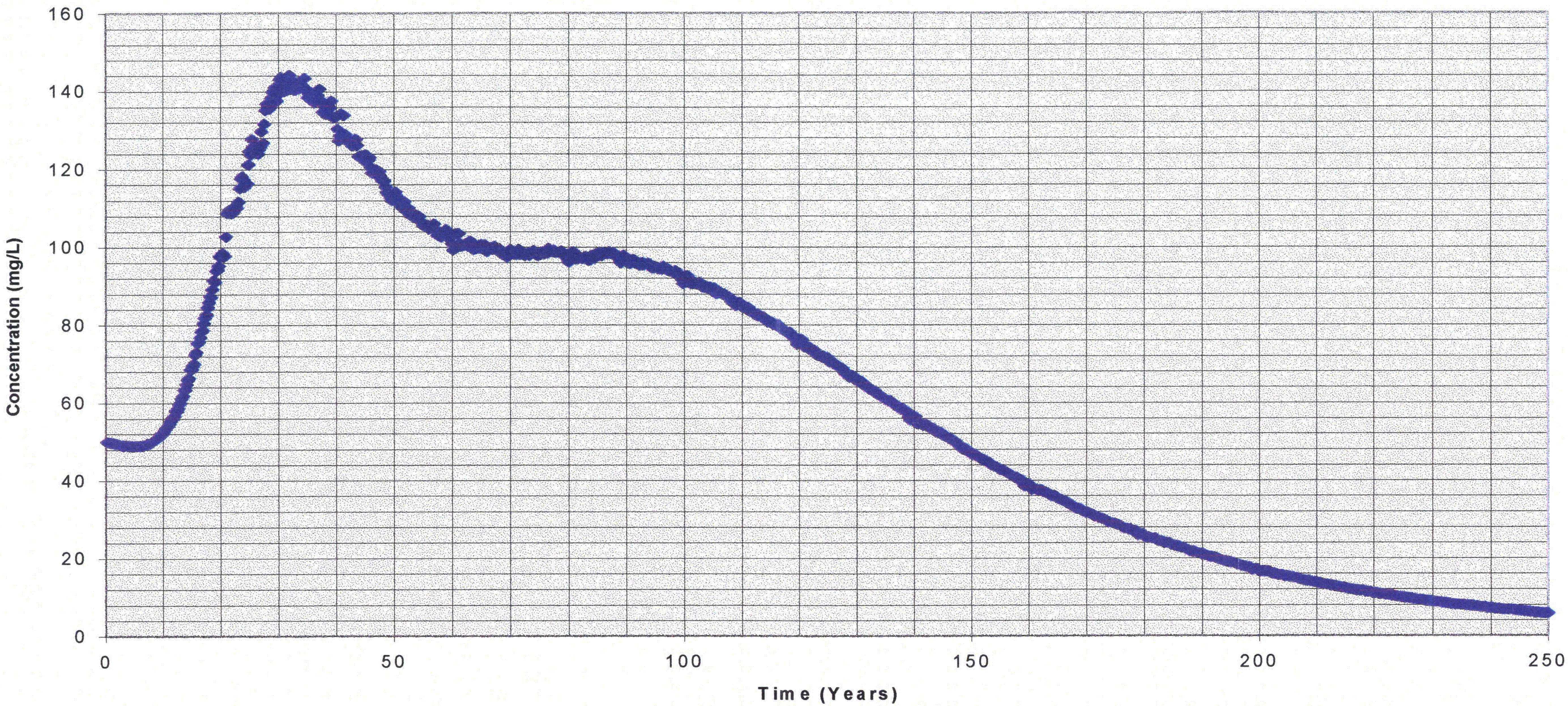
Client: SEQUOYAH FUELS CORPORATION		Figure Title: PREDICTED NITRATE AT OBSERVATION POINT #1	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895	DATE: 11/20/96	PREPARED BY: LK	
	SCALE: AS SHOWN	CHECKED BY: BS	
		DRAFTED BY: LK	
	PROJECT NO: 9611401 F01	FIGURE NO.: 18	



Client:	SEQUOYAH FUELS CORPORATION	Figure Title:	PREDICTED NITRATE AT OBSERVATION POINT #2
Location:	GORE, OKLAHOMA	Document Title:	PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS

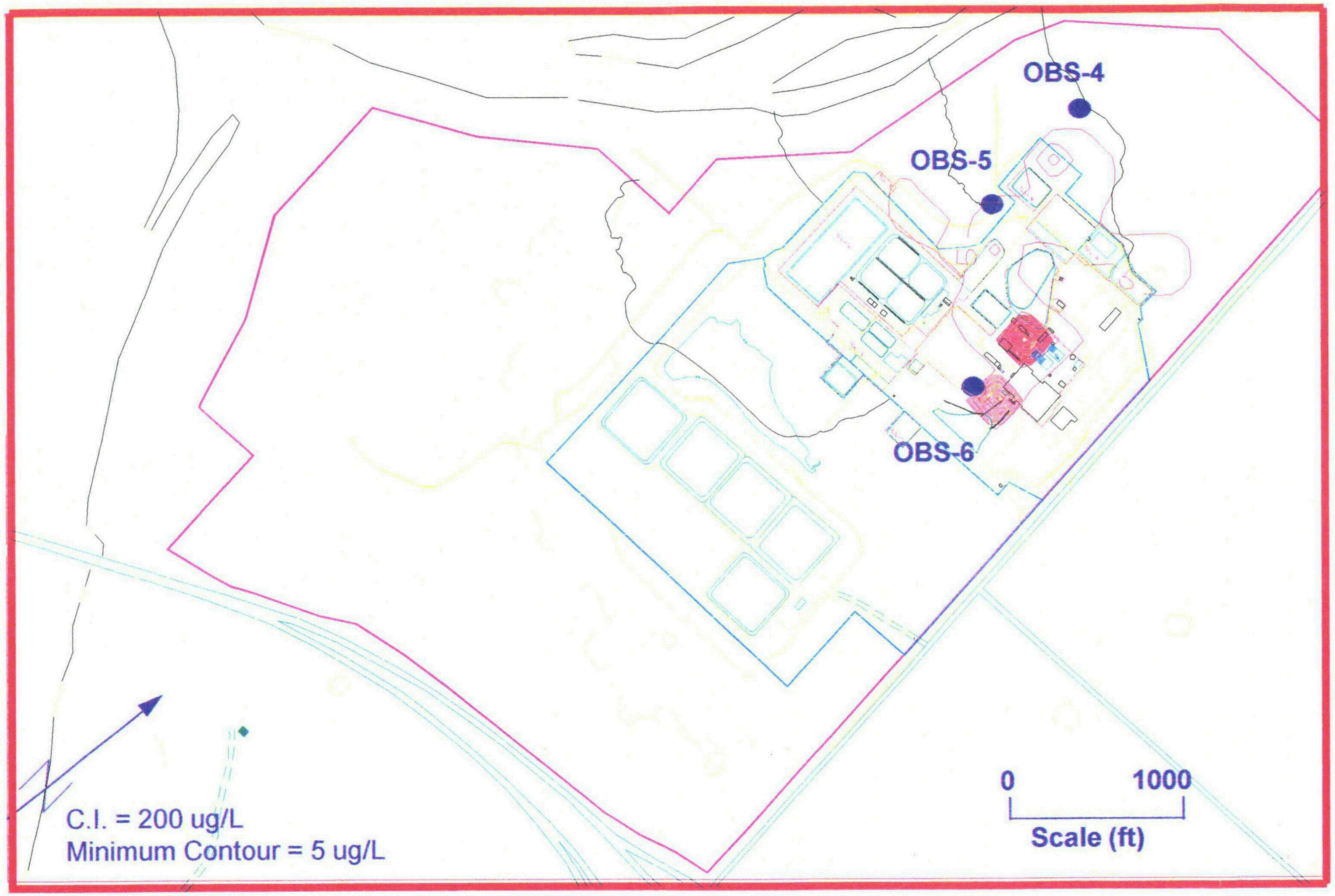
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895	DATE: 11/20/96	PREPARED BY: LK
	SCALE: AS SHOWN	CHECKED BY: BS
		DRAFTED BY: LK
	PROJECT NO: 9611401 F01	FIGURE NO.: 19

Predicted Nitrate at Observation Point #3



Client: SEQUOYAH FUELS CORPORATION		Figure Title: PREDICTED NITRATE AT OBSERVATION POINT #3	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895		DATE: 11/20/96	PREPARED BY: LK
			CHECKED BY: BS
		SCALE: AS SHOWN	DRAFTED BY: LK
		PROJECT NO: 9611401 F01	FIGURE NO.: 20

S.F.C. Facility

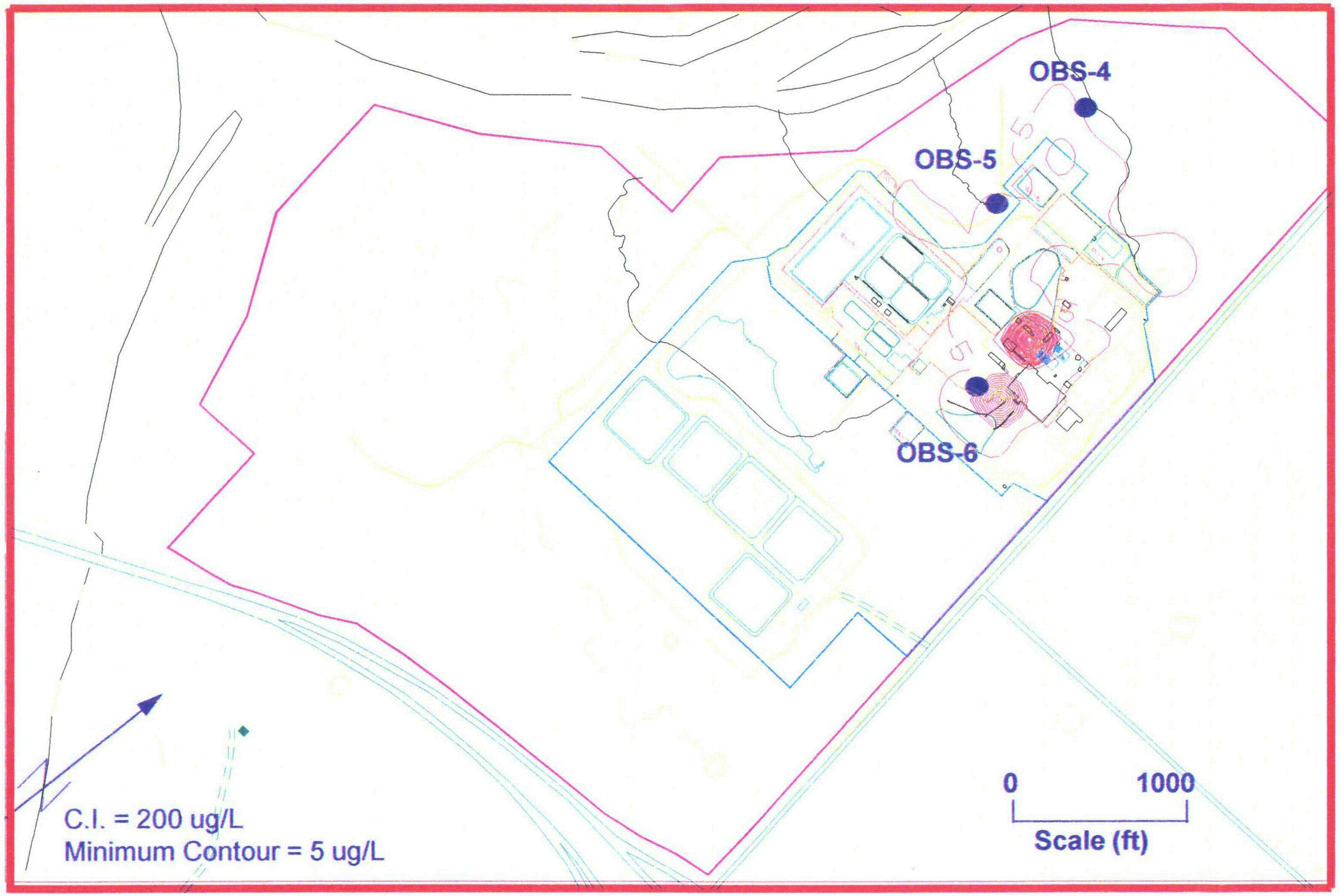


Computer Simulation
Uranium Plume (ug/L)

Years = 0

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION URANIUM PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895		DATE: 11/20/96	PREPARED BY: LK
		SCALE: AS SHOWN	CHECKED BY: BS
			DRAFTED BY: LK
		PROJECT NO: 9611401 PPT	FIGURE NO.: 21

S.F.C. Facility

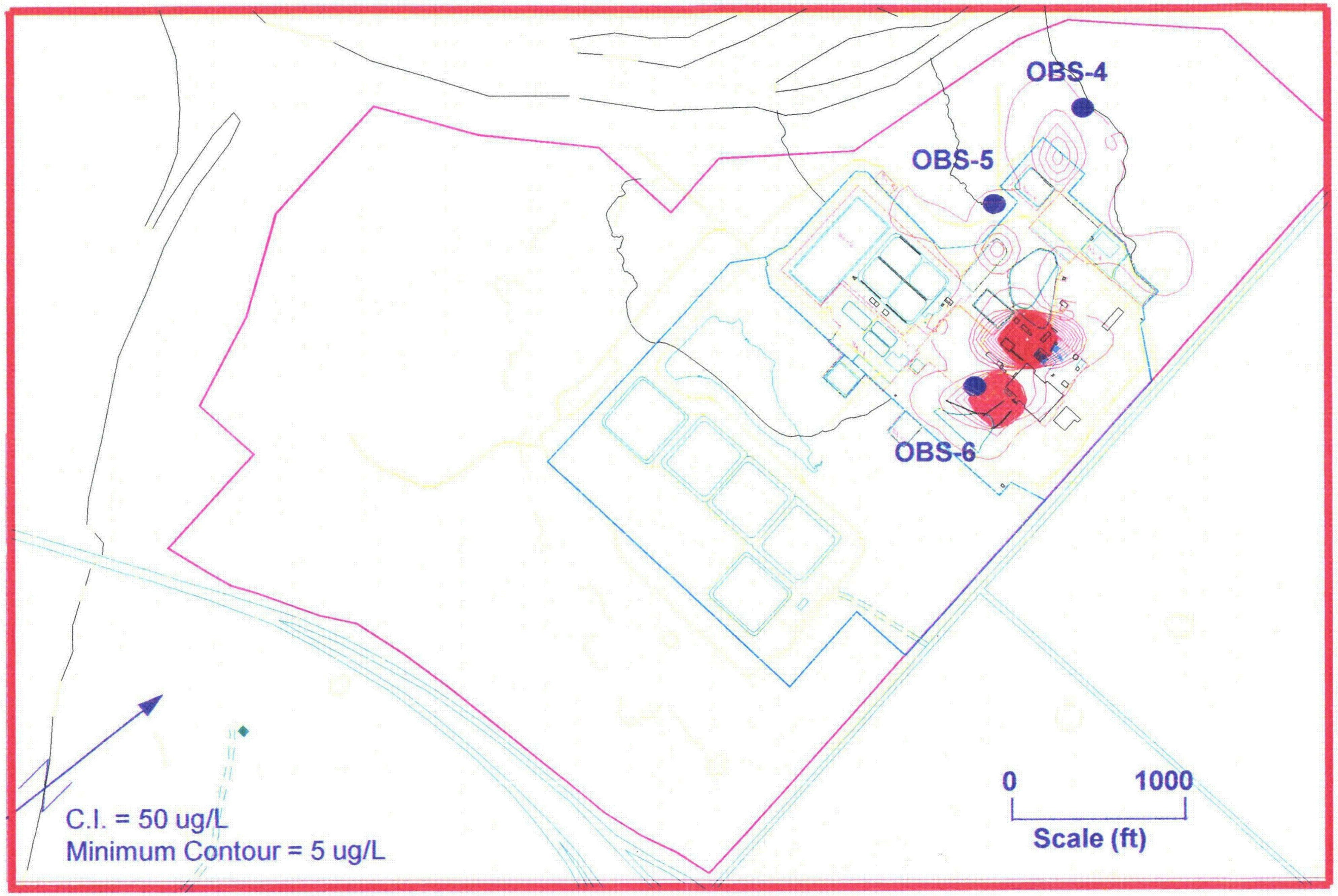


Computer Simulation
Uranium Plume (ug/L)

Years = 50

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION URANIUM PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895	DATE: 11/20/96	PREPARED BY: LK	
	SCALE: AS SHOWN	CHECKED BY: BS	
		DRAFTED BY: LK	
	PROJECT NO: 9611401 PPT	FIGURE NO.: 22	

S.F.C. Facility

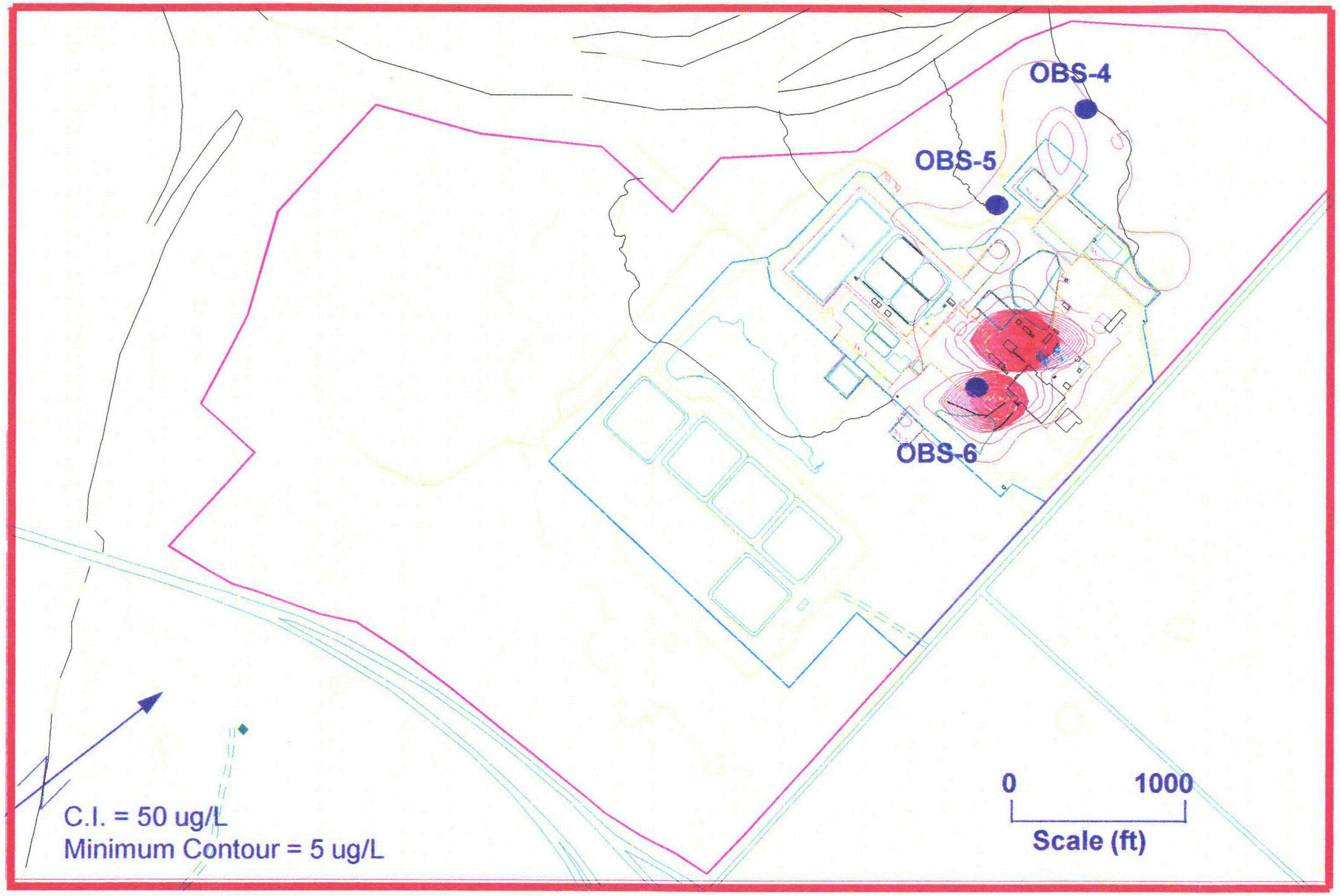


Computer Simulation Uranium Plume (ug/L)

Years = 100

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION URANIUM PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895	DATE: 11/20/96	PREPARED BY: LK	
	SCALE: AS SHOWN	CHECKED BY: BS	
		DRAFTED BY: LK	
	PROJECT NO: 9611401 PPT	FIGURE NO.: 23	

S.F.C. Facility

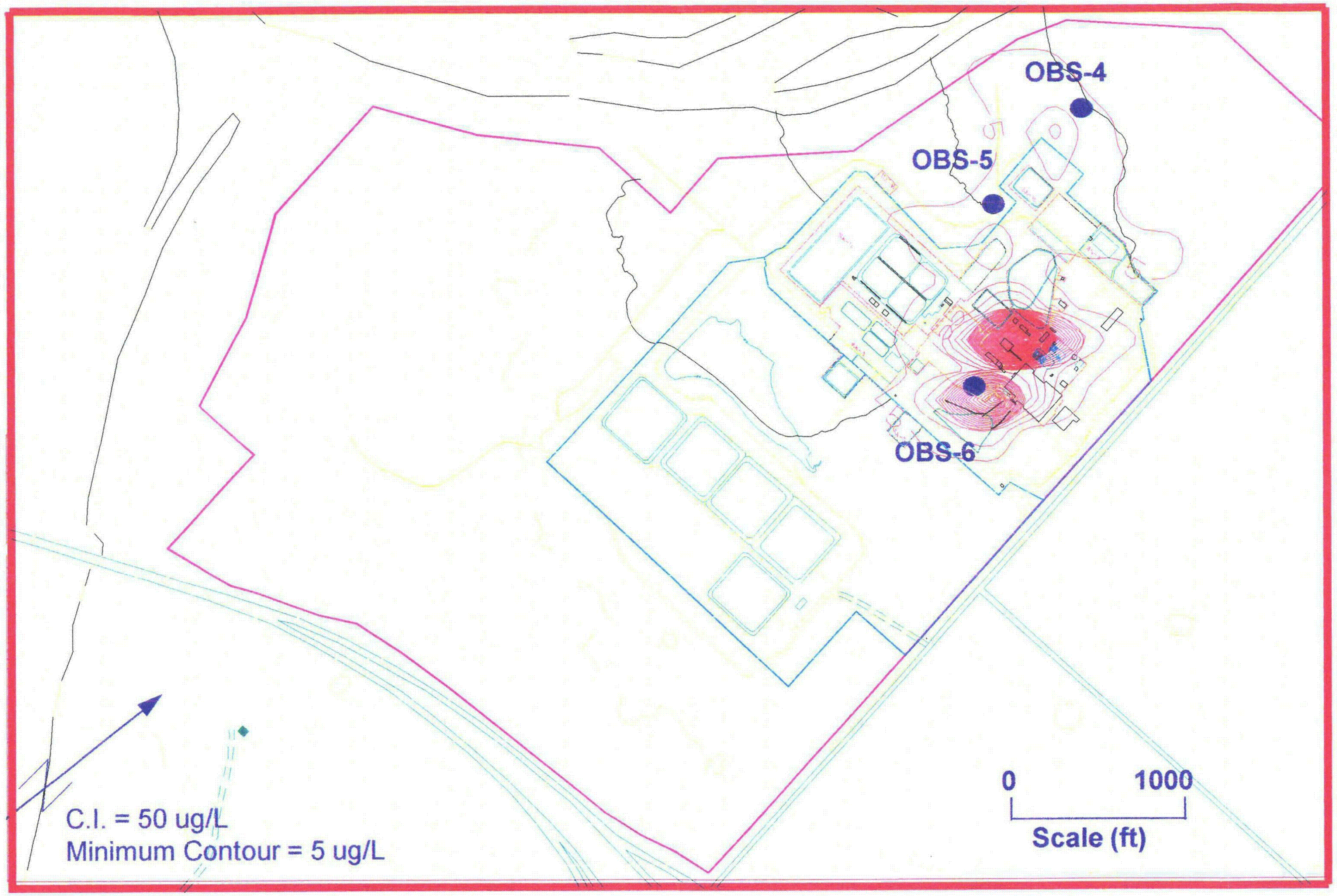


Computer Simulation
Uranium Plume (ug/L)

Years = 200

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION URANIUM PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895	DATE: 11/20/96	PREPARED BY: LK	
	SCALE: AS SHOWN	CHECKED BY: BS	
		DRAFTED BY: LK	
	PROJECT NO: 9611401 PPT	FIGURE NO.: 24	

S.F.C. Facility

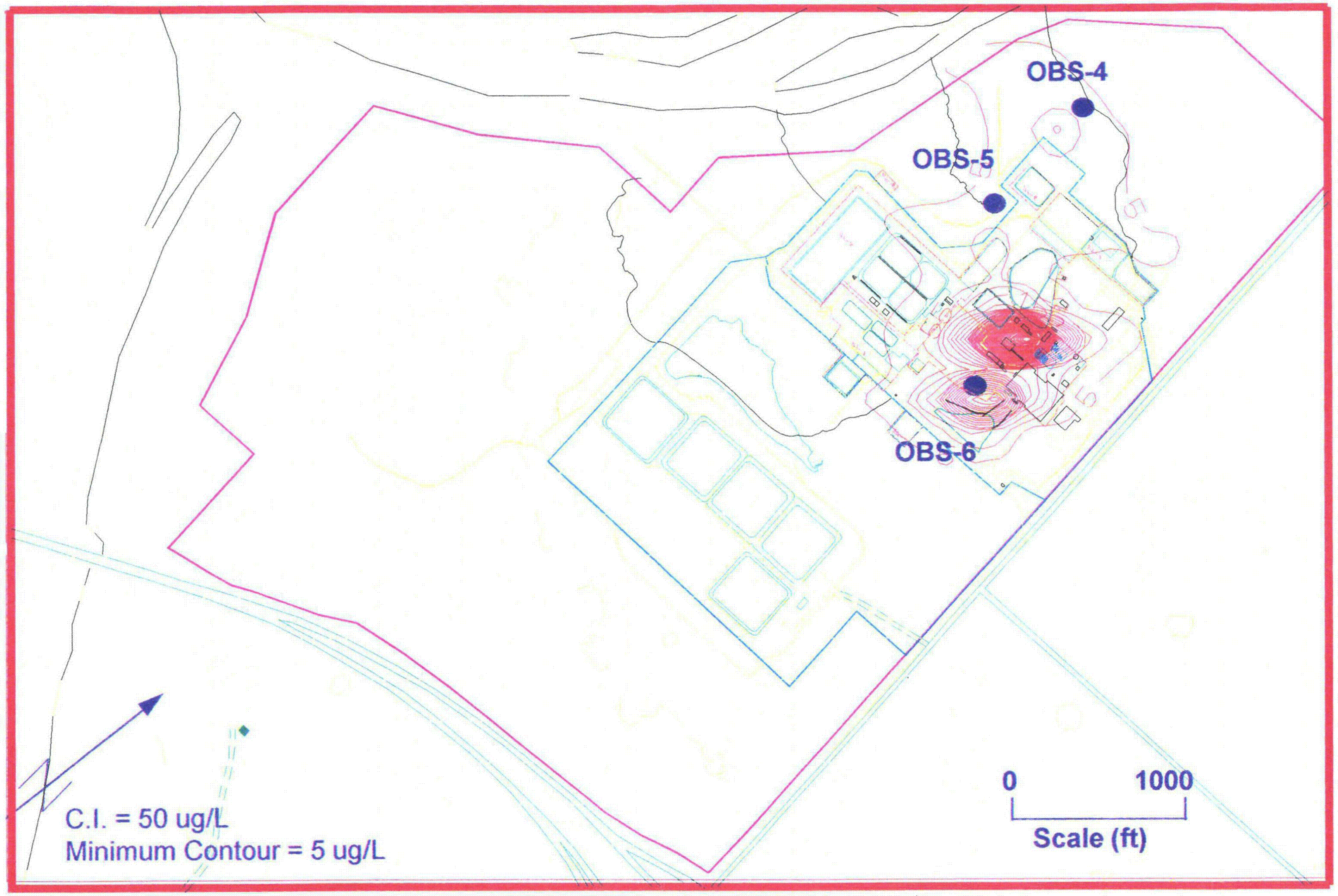


Computer Simulation
Uranium Plume (ug/L)

Years = 300

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION URANIUM PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895		DATE: 11/20/96	PREPARED BY: LK
		SCALE: AS SHOWN	CHECKED BY: BS
			DRAFTED BY: LK
		PROJECT NO: 9611401 PPT	FIGURE NO.: 25

S.F.C. Facility

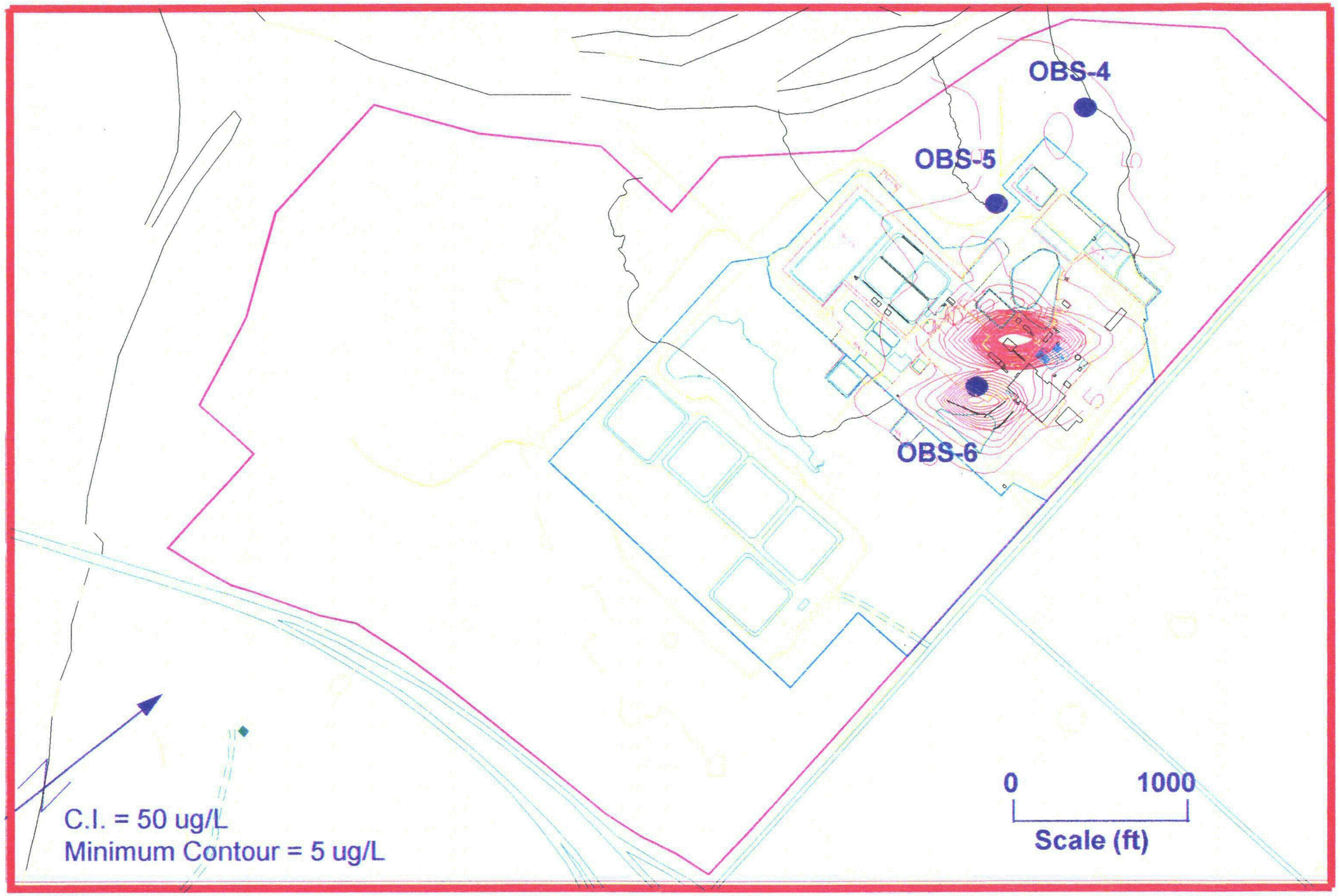


Computer Simulation
Uranium Plume (ug/L)

Years = 400

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION URANIUM PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895	DATE: 11/20/96	PREPARED BY: LK	
	SCALE: AS SHOWN	CHECKED BY: BS	
		DRAFTED BY: LK	
	PROJECT NO: 9611401 PPT	FIGURE NO.: 26	

S.F.C. Facility

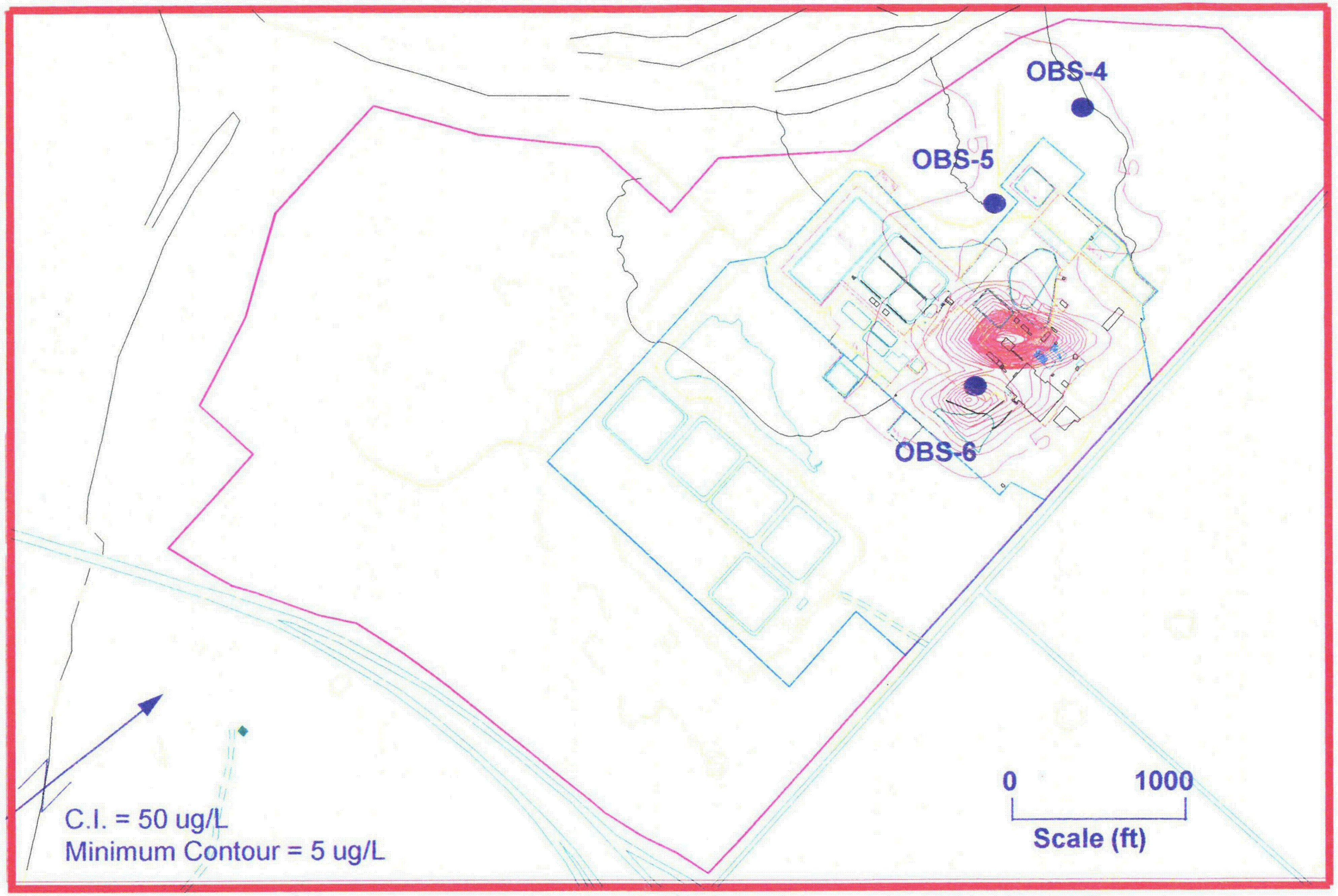


Computer Simulation
Uranium Plume (ug/L)

Years = 500

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION URANIUM PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895		DATE: 11/20/96	PREPARED BY: LK
		SCALE: AS SHOWN	CHECKED BY: BS
			DRAFTED BY: LK
		PROJECT NO: 9611401 PPT	FIGURE NO.: 27

S.F.C. Facility



Computer Simulation
Uranium Plume (ug/L)

Years = 600

Client: SEQUOYAH FUELS CORPORATION		Figure Title: COMPUTER SIMULATION URANIUM PLUME	
Location: GORE, OKLAHOMA		Document Title: PASSIVE ATTENUATION OF GROUNDWATER CONSTITUENTS	
ROBERTS/SCHORNICK & ASSOCIATES, INC. Environmental Consultants 3700 West Robinson, Suite 200 Norman, Oklahoma 73072 (405) 321-3895	DATE: 11/20/96	PREPARED BY: LK	
	SCALE: AS SHOWN	CHECKED BY: BS	
		DRAFTED BY: LK	
	PROJECT NO: 9611401 PPT	FIGURE NO.: 28	