R-009-205.7

4273

SOUTH PLUME REMOVAL ACTION GROUNDWATER MODELING REPORT MARCH 1993 REVISION NO. 4

DOE-FN/EPA

75
REPORT

South Plume Removal Action Groundwater Modeling Report

Fernald Environmental Management Project
March 1993
Revision No. 4

Submitted by:
U.S. Department of Energy
Fernald Office
P.O. Box 398705
Cincinnati, Ohio 45239-8705

4273

South Plume Removal Action Groundwater Modeling Report

Fernald Environmental Management Project
March 1993
Revision No. 4

Submitted by:
U.S. Department of Energy
Fernald Office
P.O. Box 398705
Cincinnati, Ohio 45239-8705

Prepared by:
PARSONS
Fairfield, Ohio

Prepared for:
Fernald Environmental Restoration
Management Corporation

PARSONS

Fluor Daniel Environmental
FERMCO
Restoration Management Corporation

2

South Plume Removal Action
Groundwater Modeling Report

CONTENTS

SECTION

1.0 Introduction 1-1
- 1.1 Study Objectives 1-1
- 1.2 Study Approach 1-1
- 1.3 Removal Action History 1-2

2.0 Groundwater Model Development 2-1
- 2.1 FEMP Hydrogeology and Conceptual Model 2-1
- 2.2 Groundwater Model 2-2

3.0 Evaluation of the Model 3-1
- 3.1 Overview 3-1
- 3.2 Model Improvement Plan 3-3
- 3.3 Comparison of Model and Monitoring Results 3-2
- 3.4 Assessment of the Model 3-4

4.0 Modeling Results 4-1
- 4.1 Introduction 4-1
- 4.2 Methodology 4-3
- 4.3 No Action Alternative 4-4
- 4.4 Evaluation of Alternative Well Field Design 4-5
- 4.5 More Detailed Analysis at Selected Locations 4-7
- 4.6 Sensitivity Analysis 4-12

5.0 Conclusions and Recommendations 5-1
- 5.1 Design Parameters 5-1
- 5.2 Model Limitations/Implications to Removal Action 5-2
- 5.3 Additional Remediation Considerations 5-2

6.0 References 6-1

LIST OF APPENDICES

4273

A Reprint of the South Plume EE/CA Modeling Report

B 1990 to 1992 Uranium Analytical Results

LIST OF ILLUSTRATIONS

FIGURES

1-1 Removal Action Study Area and Vicinity
1-2 South Plume Removal Action Process Flowchart
1-3 Design, Monitoring, Evaluation Program Plan Flowchart
1-4 Prior Location of South Plume EE/CA Interceptor Wells

2-1 Groundwater Flow in the Vicinity of the FEMP
2-2 Local Area Model Grid
2-3 Model Layer 1 Aquifer and Bedrock Blocks
2-4 Model Layer 2 Aquifer and Bedrock Blocks
2-5 Model Layer 3 Aquifer, Clay Layer, and Bedrock Blocks
2-6 Model Layer 4 Aquifer and Bedrock Blocks
2-7 Model Layer 5 Aquifer and Bedrock Blocks
2-8 April 1986 Groundwater Elevations Used for Calibration
2-9 Predicted Potentiometric Surface
2-10 Simulated Layer 1 Uranium Plume Prior to Pumping - 1989

3-1 Six Quarter Average of Monitored Uranium Data 2000 Series Wells
3-2 Six Quarter Average of Monitored Uranium Data 3000 Series Wells

4-1 Simulated Layer 1 Uranium Plume Prior to Pumping - 1993
4-2 Simulated Layer 2 Uranium Plume Prior to Pumping - 1993
4-3 Simulated Layer 4 Uranium Plume Prior to Pumping - 1993
4-4 Simulated Layer 5 Uranium Plume Prior to Pumping - 1993
4-5 Simulated Layer 1 Uranium Plume Without Pumping - 1997
4-6 Simulated Layer 1 Uranium Plume Without Pumping - 2002
4-7 Simulated Layer 2 Uranium Plume Without Pumping - 2002
4-8 Simulated Layer 4 Uranium Plume Without Pumping - 2002
4-9 Simulated Layer 5 Uranium Plume Without Pumping - 2002
4-10 Simulated Layer 1 Uranium Plume Without Pumping - 2012
4-11 Simulated Layer 1 Uranium Plume Without Pumping - 2062
4-12 Predicted Effect of Modifying the Pumping Center on Inorganic and Organic Groundwater Plumes
4-13 Predicted Effect of Moving the Well Field North on Inorganic and Organic Plumes
4-14 Predicted Effect of Removal Action Wells on Inorganic and Organic Groundwater Plumes
4-15 Simulated Layer 1 Uranium Plume With Pumping - 1997
4-16 Simulated Layer 1 Uranium Plume With Pumping - 2002

LIST OF ILLUSTRATIONS (Continued)

4-17 Simulated Layer 2 Uranium Plume With Pumping - 2002
4-18 Simulated Layer 4 Uranium Plume With Pumping - 2002
4-19 Simulated Layer 5 Uranium Plume With Pumping - 2002
4-20 Simulated Layer 1 Uranium Plume With Pumping - 2012
4-21 Simulated Layer 1 Uranium Plume With Pumping - 2062
4-22 Average Well Field Concentration
4-23 Well Field Uranium Removal Rate
4-24 Cumulative Well Field Uranium Removal
4-25 Predicted Drawdown Due to Removal Action Well Field - Far Field
4-26 Predicted Drawdown Due to Removal Action Well Field - Near Field
4-27 Predicted Potentiometric Surface With Pumping - Far Field
4-28 Predicted Potentiometric Surface With Pumping - Near Field
4-29 Capture Zone - Superimposed on Model Layer 1 Plume
4-30 Capture Zone - Superimposed on 2000 Monitoring Well Plume
4-31 Capture Zone - Superimposed on 3000 Monitoring Well Plume
4-32 Capture Zone - YZ
4-33 Forward Tracking Capture - Nominal K_h Case - XY
4-34 Forward Tracking Capture - Nominal K_h Case - YZ
4-35 Forward Tracking - South Field Plume to Property Line
4-36 Forward Tracking Capture - 1.5X Nominal K_h Case - XY
4-37 Forward Tracking Capture - 1.5X Nominal K_h Case - YZ
4-38 Forward Tracking Capture - 1.75X Nominal K_h Case - XY
4-39 Forward Tracking Capture - 1.75X Nominal K_h Case - YZ
4-40 Forward Tracking Capture - 3X Nominal K_h Case - XY
4-41 Forward Tracking Capture - 3X Nominal K_h Case - YZ
4-42 Forward Tracking Capture - 0.7X Nominal K_h Case - XY
4-43 Forward Tracking Capture - 0.7X Nominal K_h Case - YZ
4-44 Forward Tracking Capture - 0.4X Nominal K_h Case - XY
4-45 Forward Tracking Capture - 0.4X Nominal K_h Case - YZ
4-46 Forward Tracking Capture - 0.25X Nominal K_h Case - XY
4-47 Forward Tracking Capture - 0.25X Nominal K_h Case - YZ
4-48 Forward Tracking Capture - 0.1X Nominal K_h Case - XY
4-49 Forward Tracking Capture - 0.1X Nominal K_h Case - YZ

LIST OF ILLUSTRATIONS (Continued)

TABLES

3-1 Model Improvement Tasks

4-1 Alternate Removal Action Well Field Configuration
4-2 Great Miami Aquifer - Horizontal Hydraulic Conductivities Determined through Pump Tests
4-3 Sensitivity Analysis Result Summary

5-1 Removal Action Recovery Well Design Parameters

LIST OF ACRONYMS AND ABBREVIATIONS

A&W	Albright & Wilson Americas Co.
DOE	United States Department of Energy
DMEPP	Design, Monitoring and Evaluation Program Plan
EE/CA	Engineering Evaluation/Cost Analysis
ESD	Explanation of Significant Difference
gpm	gallons per minute
FEMP	Fernald Environmental Management Project
FERMCO	Fernald Environmental Restoration Management Corporation
IAWWT	Interim Advanced Waste Water Treatment
OU	Operable Unit
PRRS	Paddy's Run Road Site
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
SOWC	Southwestern Ohio Water Company
SPMR	South Plume Removal Action Groundwater Modeling Report
US EPA	United States Environmental Protection Agency
WEMCO	Westinghouse Environmental Management Company of Ohio

SECTION 1

INTRODUCTION

Pursuant to the *Work Plan for the South Groundwater Contamination Plume Removal Action - Part 5 - Groundwater Modeling and Geochemical Investigation* (Part 5 Work Plan - DOE 1991a), groundwater modeling has been performed to set design parameters for the South Plume Removal Action groundwater recovery wells. This *South Plume Removal Action Groundwater Modeling Report* (SPMR) was prepared to document the findings of this study. Earlier draft versions of this report were prepared by IT Corporation under the direction of Westinghouse Materials Company of Ohio (WEMCO) while this version has been prepared by Parsons under the direction of Fernald Environmental Restoration Management Corporation (FERMCO).

1.1 Study Objectives

Subsequent to the issuance of the Engineering Evaluation/Cost Analysis South Plume (South Plume EE/CA - Appendix A - DOE 1990b), a decision was made to relocate the recovery well field. This study addresses this relocation by supplementing the modeling performed in the South Plume EE/CA. This study redefines the design parameters of the selected alternative based on conditions of the new location. The objectives of this study are (DOE 1991 as modified):

1) To set the initial locations, sizes, and pumping rates (design parameters) for the removal action groundwater recovery wells

2) To determine the effect on the 20 μg/l boundary of the uranium plume that results from placing the removal action wells north of the Albright and Wilson Plant

3) To determine the impact of using a revised uranium retardation factor of 12 in place of the previous value of 9

4) To investigate the potential impacts of pumping on the inorganic and organic plumes associated with the Paddy's Run Road Site (PRRS)

5) To evaluate the impact of model limitations and uncertainty in model predictions on the selection of design criteria

6) To establish with sensitivity analysis a range of horizontal hydraulic conductivity at which the initial recovery system design can effectively achieve its objectives.

1.2 Study Approach

This report summarizes the results of an application of the site groundwater model. This report is not intended to document the construction, calibration, and verification of the groundwater model; these efforts have been described in other reports (Groundwater Report [DOE 1990a - Part IV], IT 1990). A summary of these efforts is provided in Section 2 for the convenience of the reader.

This report includes:

1) Background information on the South Plume Removal Action history.

2) A summary of the hydrogeology; the conceptual model development; and the construction, calibration, and verification of the site groundwater model.

3) An evaluation of the model and an assessment of model limitations to better understand how to appropriately use the model.

4) A presentation of the results of the modeling work to select an approximate location for the well field.

5) A presentation of the results of further modeling work at the selected location to optimize the design, to assess Paddy's Run Road Site impact, to assess impact on the South Plume, and to analyze capture.

6) Sensitivity analysis to assess the impact on plume capture and the PRRS plumes to the variation of hydraulic conductivity.

7) A presentation of conclusions and recommendations based on the results. Recommendations include design parameters. In addition, criteria are established for a range of acceptable hydraulic conductivities that will allow use of the model for this exercise (see discussion in Section 4.2.3).

1.3 Removal Action History

Operable Unit 5 (OU-5) - Environmental Media, which is a part of the Fernald Environmental Management Project (FEMP) Remedial Investigation/ Feasibility Study (RI/FS), includes those environmental media that serve as migration pathways and/or environmental receptors of radiological or chemical releases from the FEMP. RI/FS findings have determined that an area south of the FEMP property has been affected by the existence of a uranium contaminant plume in the regional aquifer.

Figure 1-1 shows a general site plan of the area while the plume is depicted in Sections 2 and 3. Because of the associated potential threats to human health and the environment, a Removal Action to address this plume outside of the FEMP boundary has been planned. The 1990 Consent Agreement between the Department of Energy (DOE) and the United States Environmental Protection Agency (US EPA). Section IX, A.3, required the submission of a proposal for additional monitoring wells, the South Plume EE/CA, and a work plan for the South Plume Removal Action.

Figures 1-2 and 1-3 are flowcharts summarizing the process that has been and will be followed for the South Plume Removal Action. Figure 1-2 defines the overall process while Figure 1-3 provides additional detail regarding tasks associated with the Design, Monitoring and Evaluation Program Plan (DMEPP) (PARSONS 1992). The South Plume Modeling Report is highlighted on Figure 1-3 in order to show its relationship with the other program elements. Selected elements shown on this chart are described below. A more detailed description of this process is contained in the DMEPP which now serves as the primary planning document for system design and operation.

1.3.1 South Plume EE/CA

The South Plume EE/CA was initially submitted in May 1990 and, after the public comment process (and resolution to the dispute between the US EPA and DOE), it was finalized in November 1990. The South Plume EE/CA identified one primary and two secondary objectives for the South Plume Removal Action:

1) Primary Goal: Protection of public health by limiting access to and use of groundwater with uranium concentrations exceeding the derived concentration limit of 30 μg/l for uranium in drinking water, as well as other appropriate, risk-based levels for various potential exposure scenarios.

2) Secondary Goals:
   (1) Protection of the groundwater environment which, in this case, is represented by a sensitive, sole-source aquifer
   (2) Control of plume migration toward additional receptors further south.

To meet the goals of the EE/CA, a groundwater modeling investigation was undertaken in 1990 to determine number, placement, and pumping rates of interceptor wells for the South Plume EE/CA. The modeling work used an interim calibration of the solute transport model which used a retardation factor of 9 to simulate the uranium plume. This calibration, although not completely refined, was able to simulate large changes in the solute transport system such as would be caused by pumping wells. Appendix A contains a copy of this modeling report.

The South Plume EE/CA groundwater modeling tested several possible scenarios for dealing with uranium-contaminated groundwater. These included a no-action alternative, an alternative water supply

alternative, and a pumping alternative with a goal of plume interception. The South Plume EE/CA selected an alternative which included groundwater pumping and discharge, an alternative water supply for two industrial users, installation of an interim advanced wastewater treatment system, and enhanced monitoring and institutional controls. The original location of recovery wells, based on groundwater modeling simulation (DOE 1990b), was along New Haven Road just west of its intersection with State Route 128 (Figure 1-4).

To facilitate the design process, the selected alternative was originally divided into the following four parts (DOE 1009b, Pg. ES-7):

1) Alternative Water Supply
2) Pumping and Discharge System
3) Interim Advanced Waste Water Treatment System
4) Groundwater Monitoring and Institutional Controls

1.3.2 Relocation of Well Field

Subsequent to finalizing the EE/CA, information obtained from a separate remedial investigation performed by the PRRS, has identified additional concerns in the South Plume area. The PRRS consists of several industries (e.g., Mobil Mining, Albright & Wilson Americas Co. [A&W], and Ruetgers and Nease) that, over the past years, have reportedly released both organics and inorganics into the environment which have now found their way to the Great Miami Aquifer. Some of these contaminants include cumene, toluene, benzene, arsenic, and others. The PRRS contaminants have been determined to extend near the original location of the proposed recovery well field as described in the November 1990 South Plume EE/CA. Therefore, operation of a uranium recovery well field at the original location could result in the extraction and discharge of PRRS contaminants to the Great Miami River (Interim Advanced Waste Water Treatment [IAWWT] system will only address uranium) and could result in the further spreading or shifting of the PRRS plumes.

As a result of these conditions, it was necessary to relocate the Part 2 well field to an area north of the PRRS. In addition, it was necessary to modify the South Plume EE/CA with an addendum which restructured the EE/CA objectives to accommodate these conditions. This addendum was called the "Explanation of Significant Difference Document" (ESD) (WEMCO 1991), which justifies the changes in the South Plume EE/CA. The relocation of the Part 2 well field has generated the following additional requirements.

1) The new location is in an area of higher uranium concentration which jeopardizes the equivalent mass treatment concept as described in the South Plume EE/CA. Accordingly, the Part 3 IAWWT system has been expanded in size to provide the additional treatment necessary to meet the previously agreed upon equivalent mass concept. The removal capacity of the IAWWT has

been increased so that no more than 1,700 pounds of uranium per year is discharged to the Great Miami River.

2) Based on field sampling data and groundwater modeling simulations from the South Plume EE/CA, the relocated well field is upgradient of an area containing more than 30 micrograms per liter (μg/l) uranium contamination. In addition, computer modeling for the South Plume EE/CA predicts that other areas could also exist where the level of uranium concentration is above 30 μg/l. Therefore, an additional investigation will be performed under a new Part 5 of the removal action. The Part 5 investigation work plan includes hydropunching of the area south of the well field to New Haven Road. The investigation will identify the location of the 30 μg/l uranium isopleth. Because the US EPA has recently issued a proposed revised limit of 20 μg/l for uranium in drinking water, the investigation will also identify the location of the 20 μg/l isopleth. The information obtained will be used to allow the FEMP to limit access to this water until additional response actions in this area are implemented.

3) Additional groundwater modeling to support preliminary design efforts at the revised location was also identified as a task in the new Part 5 Work Plan. This modeling will be used to set the initial design parameters of the recovery wells and to establish an acceptable hydraulic conductivity range for use of the model. This requirement is the basis of this South Plume Modeling Report.

4) Because a portion of the plume may be south of the recovery (and not captured) and because of complications created by the PRRS plumes, it is envisioned that the final remediation of the South Plume will be addressed by dividing the area into three zones. The purpose of the zones is to distinguish the areas of contamination for purposes of treatment. The zones are as follows:
   (1) Zone 1 would be the area of the aquifer containing only uranium as the contaminant of concern. This will be the area addressed by the South Plume Removal Action project described in the ESD document, as mentioned above.
   (2) Zone 2 would be the area of the aquifer containing the uranium, inorganics, and organics of concern.
   (3) Zone 3 would include inorganics and organics as contaminants of concern. The area may also contain uranium contamination, but at a level below the planned cleanup level for the Operable Unit 5 Record of Decision (ROD).

1.3.3 Design, Monitoring and Evaluation Program Plan

Pursuant to the requirements of the Part 2 and 3 Work Plan, the DMEPP (formerly the O&M Manual, PARSONS 1992) was developed. This program plan defined a program of design confirmation, monitoring and system evaluation activities associated with the South Plume groundwater recovery system

(see Figure 1-3). Revision 0 of the DMEPP was prepared in July 1992 and a Revision 1 (revised with US EPA comments) is due out in the early spring of 1993.

A design confirmation program has been included within the DMEPP to verify and improve (if necessary) the design and operation of the recovery system. Because of the high transmissivity of the aquifer, the long duration and high pumping rates necessary for an unconfined aquifer pumping test and the extreme difficulties of managing large volumes of uranium-contaminated water, a site-specific pump test could not be performed until water handling facilities were available. In addition, the complexities of land acquisition, design and construction interdependencies, and Consent Agreement schedules required that recovery well design proceed prior to and in parallel with conducting the pump test and collecting additional characterization data. Therefore, an approach to meet the Consent Agreement schedule was developed. The approach consisted of using the groundwater model and field data to preliminarily design the system, add conservatism and flexibility into the design, include confirmation processes to check the design, and provide a mechanism to make future changes to the design. Also included within the DMEPP is a model post audit program to continue to evaluate the accuracy of the model and to make necessary changes to the model based on these evaluations.

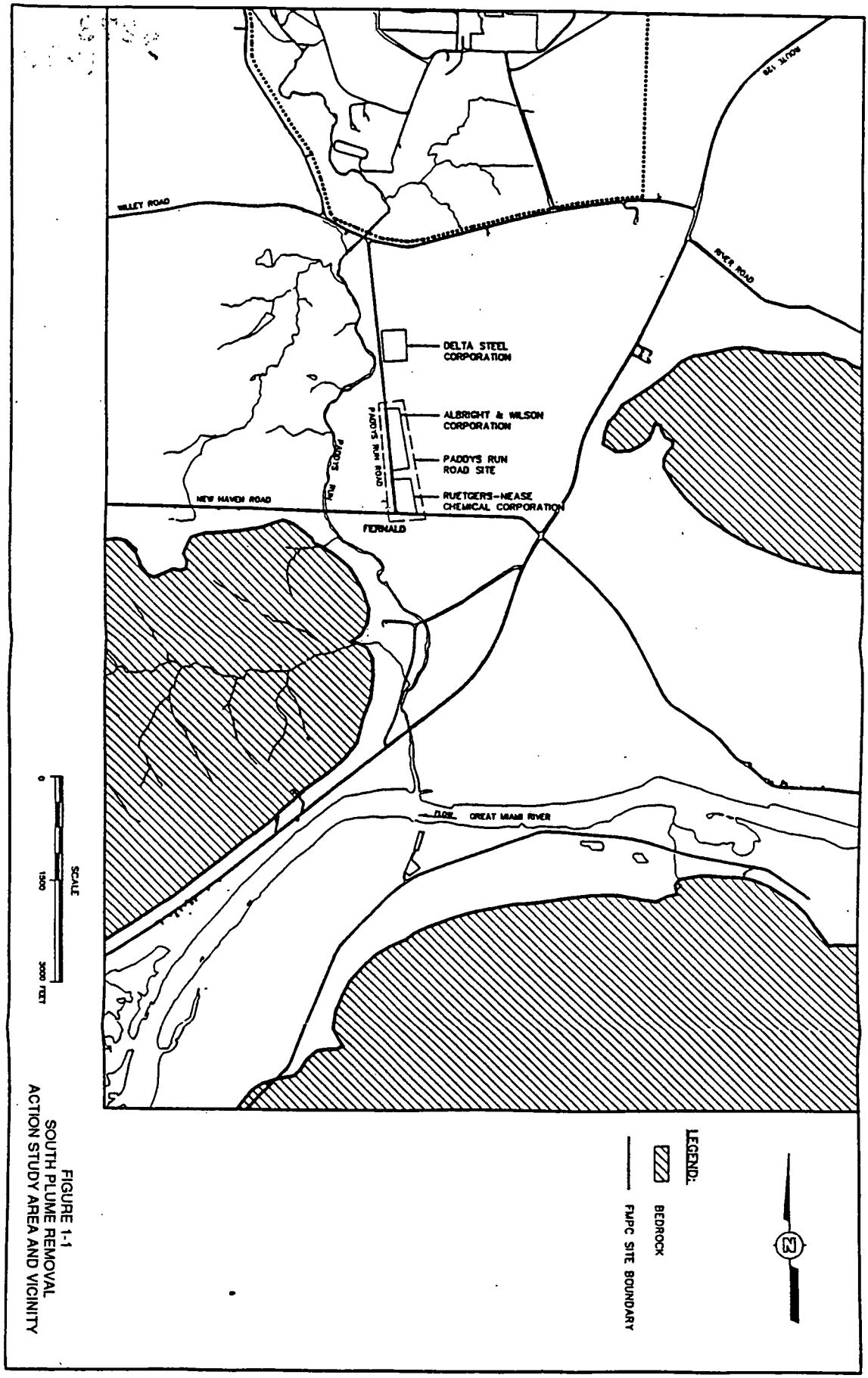


FIGURE 1-1
SOUTH PLUME REMOVAL
ACTION STUDY AREA AND VICINITY

Figure 1-1 - Removal Action Study Area and Vicinity

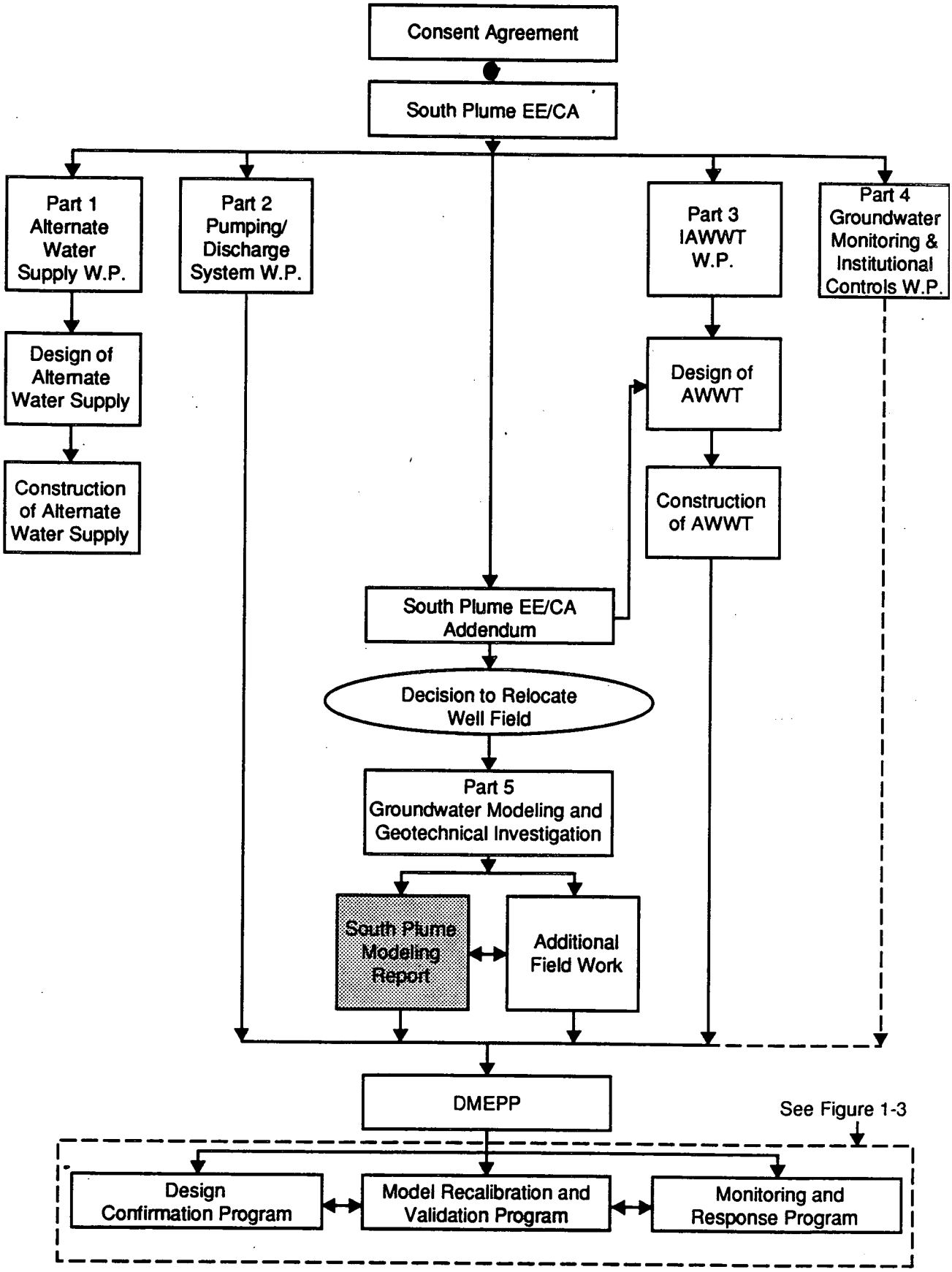


Figure 1-2 - South Plume Removal Action Process Flowchart

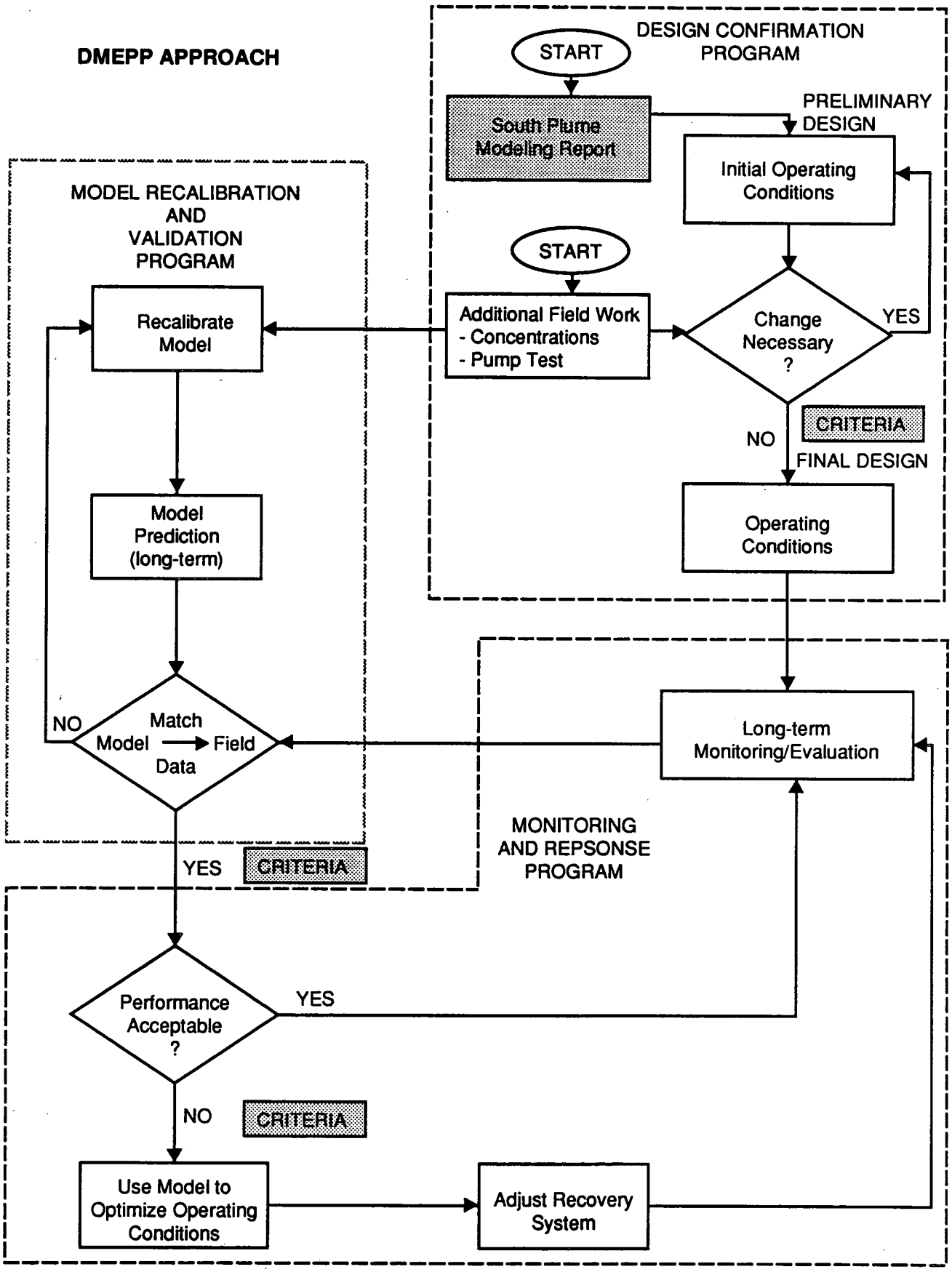


Figure 1-3 - Design, Monitoring, Evaluation Program Plan Flowchart

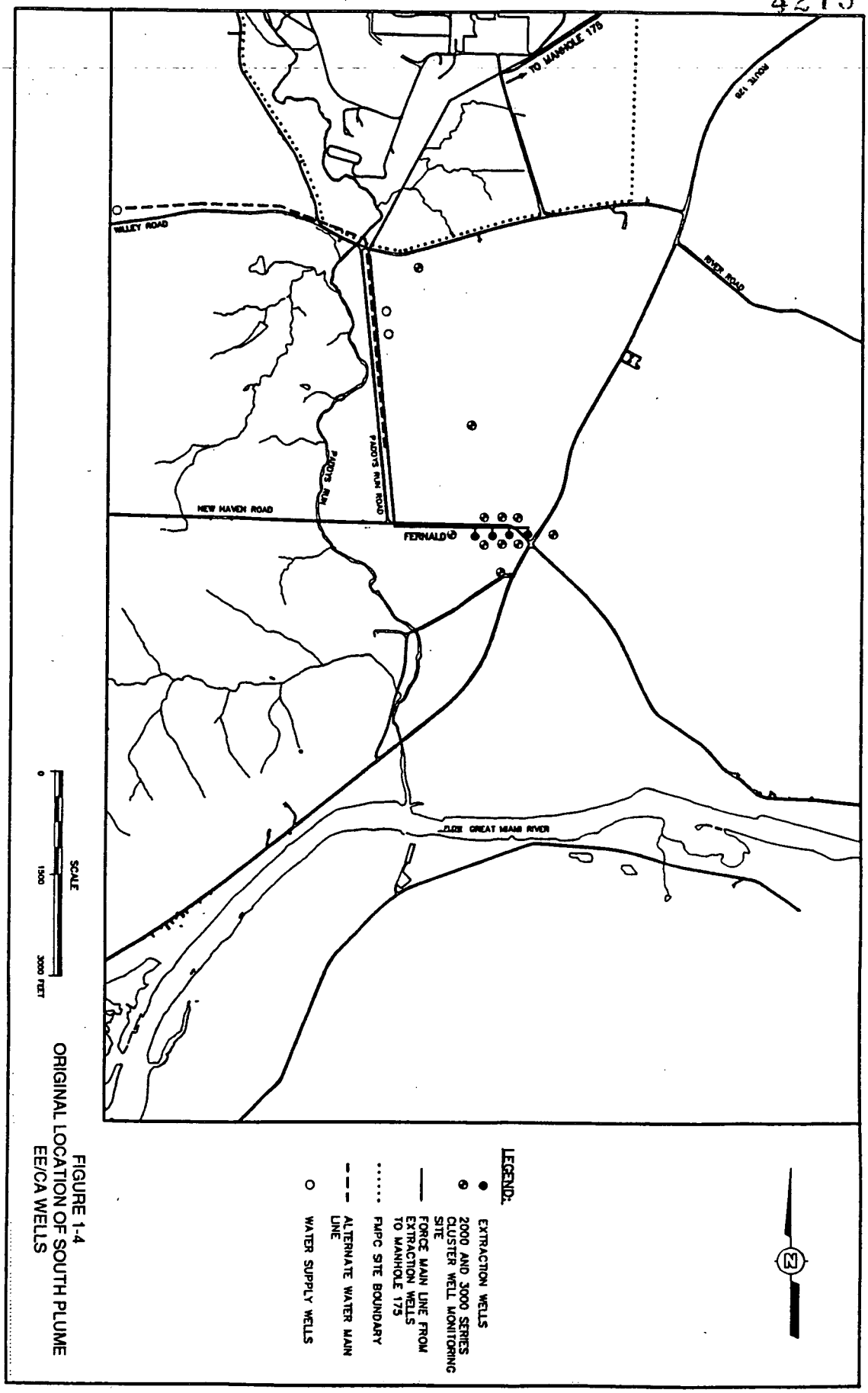


FIGURE 1-4
ORIGINAL LOCATION OF SOUTH PLUME
EE/CA WELLS

Figure 1-4 - Prior Location of South Plume EE/CA Interceptor Wells

SECTION 2

GROUNDWATER MODEL DEVELOPMENT

A summary of the hydrogeology and groundwater model development is provided for background information. This information is not intended to be comprehensive, but rather to provide a convenient summary for the reader. For more detailed analysis, see other site reports (DOE 1990a, DOE 1990c, DOE 1992).

2.1 FEMP Hydrogeology and Conceptual Model

Within a hydrogeological context, two major types of geologic materials underlie the FEMP:

1) The Ordovician shale and limestone bedrock in which the New Haven Trough has been excavated

2) The unconsolidated glacial and fluvial deposits which overlie the Ordovician bedrock and fill the New Haven Trough

During the retreat of the Illinoian ice sheets, the New Haven Trough was filled with approximately 200 feet of glaciofluvial sand and gravel, which formed what is today the Great Miami Aquifer.

The portion of the Great Miami Aquifer that underlies the FEMP and South Plume areas consists primarily of glaciofluvial sand and gravel outwash deposited during the last two Pleistocene glaciations. Within the coarse-grained sediments of the Great Miami Aquifer lies an interbedded clay layer that underlies most of the FEMP and parts of the surrounding areas. The top of the clay interbed lies about 100 to 125 feet below the surface and generally about 60 to 80 feet below the water table. It ranges from 5 to 15 feet in thickness and consists of a low permeability homogeneous clay which acts as an aquitard within the Great Miami Aquifer. Because of this interbed, the aquifer is divided into upper and lower halves.

The generalized groundwater flow pattern in the Great Miami Aquifer underlying the FEMP study area is shown in Figure 2-1. Groundwater enters the study area from three directions. In the northeast, groundwater moves south-southwest from the Ross area into the portion of the New Haven Trough now occupied by the Great Miami River. The second source of groundwater is the Shandon Tributary which enters the New Haven Trough to the north of the FEMP. The majority of the groundwater from the Shandon Tributary flows under the FEMP plant and travels under the eastern boundary of the FEMP toward the Great Miami River. The third source of groundwater is from the west. The recharge from the Dry Fork area of the Whitewater River, located about two miles west of the FEMP, causes groundwater to move to the east toward the FEMP. This flow runs southward under the southern part

of the FEMP and flows toward the Great Miami River in the glaciofluvial deposits under the southern part of Paddy's Run, termed the Paddy's Run Outlet. A portion of the groundwater from the Shandon Tributary also reaches the Great Miami River via Paddy's Run Outlet.

The geomorphic setting of the Great Miami River and Paddy's Run provides for interaction between the surface water and groundwater. Both surface water systems have eroded through the low permeability glacial overburden material to the Great Miami Aquifer. This contact allows for the direct exchange of water between the surface water and groundwater systems, which is important in relation to increased usage of the aquifer for water supplies and contaminant transport in the FEMP study area.

As the Great Miami River incises the regional aquifer, a portion of its flow originates from surface water while a portion also comes from the aquifer beneath the river. This relationship varies with changing river and groundwater elevations and is also affected by nearby pumping wells. At times when the groundwater elevation is above the river, flow is from the aquifer to the river. Conversely, when groundwater elevations are below the river elevations, flow is from the river to the aquifer and the river loses water. The natural groundwater flow is generally from the aquifer to the river, that is, groundwater discharges into the river. However, pumping of two large capacity collector wells owned by the Southwestern Ohio Water Company (SOWC), which are located close to the river (Figure 2-1), induces recharge to the aquifer by river infiltration. This occurs by creating a local hydraulic gradient, which causes flow from the river to the aquifer. This induced infiltration allows the collector wells to maintain a higher yield from the aquifer than could be achieved if the river was not present.

Paddy's Run also interacts with the Great Miami Aquifer in several different ways that affect groundwater flow and discharge. The stream has eroded through the glacial overburden and into the Great Miami Aquifer from its confluence with the Great Miami River to approximately 15,000 feet upstream. It is directly connected with the Great Miami Aquifer in this reach. South of the FEMP, the elevation of the water table is close to or above the elevation of the stream bottom; consequently, as Paddy's Run is normally dry during most of the year, the stream receives groundwater in this reach. In the vicinity of the FEMP, however, the stream is above the water table and loses water to the regional aquifer. Paddy's Run is generally dry, except during runoff periods following rainfall and snow-melt events. These runoff periods have been found to cause transient groundwater fluctuations which may influence contaminant transport along the western side of the FEMP. Sustained flow has been reported in Paddy's Run during the winter and spring by Dames and Moore (1985) and by stream gaging stations monitored during the Remedial Investigation. Relatively little recharge of the Great Miami Aquifer occurs where Paddy's Run is on the clayey till 15,000 feet north of its confluence with the Great Miami River.

2.2 Groundwater Model

To evaluate groundwater flow and contaminant transport in and around the FEMP, a groundwater computer modeling program was initiated to aid in evaluating the site. The groundwater model was

developed as a tool to evaluate existing hydrogeological data, and then to predict contaminant transport through time.

The selection, verification, and results of the groundwater modeling are presented in two separate reports (DOE 1990a, IT 1990). The groundwater model used in support of the Removal Action is a finite difference computer model of groundwater flow and solute transport. The computer program is SWIFT III Version 2.25 and SWIFT/ 386 Version 2.52. A detailed presentation of the model, its development, and the baseline input data were issued as part of the overall modeling report prepared under the RI/FS (DOE 1990a). Only the most pertinent information is provided here. A comprehensive verification study of the SWIFT III code has also been completed and a report issued (IT 1990).

2.2.1 Development of Model

Steps in the development of the model for application to the FEMP have included:

1) Construction and calibration of a regional, two-dimensional, steady-state, groundwater flow model

2) Construction and calibration of a regional, three-dimensional, steady-state, groundwater flow model

3) Application of two-dimensional analytical solute transport models to help strategize the numerical solute transport model

4) Construction of a local, two-dimensional, transient solute transport model

5) Construction and calibration of a local, three-dimensional, transient solute transport model with uranium concentration data from the monitoring wells

The local model covers a smaller area than the regional model, with model cells 125 feet on a side (Figure 2-2). The smaller area allows the use of a refined grid with a small cell size, which is necessary for solute transport modeling. The smaller grid area was established to include the area of the existing uranium plume. The grid size was selected based on the need to simulate a uranium dispersivity value of 100 feet longitudinally, which was the preferred value based on literature review (DOE 1990a). Using this value, the grid size used was set so as to be able to accommodate dispersivity values as low as 62.5 feet, or half the distance of the local area grid size of 125 feet. As the regional model did not contain a solute transport solution, its grid spacing was much larger, except in the area around the SOWC collector wells, where large groundwater gradients exist. The local model also covered the area for which uranium concentration data are available from monitoring wells. The interrelationship between the local and regional models is established by imposing the steady-state flow field predicted by the

regional model on the local model. Transient groundwater flow was not simulated; thus, transient flow effects such as mounding caused by Paddy's Run were not included.

The regional and local models contain five layers. The uppermost two layers represent the upper and lower parts of the upper alluvial aquifer that underlies the area. The middle layer represents a clay interbed that is present in the immediate vicinity of the FEMP site, and the lowermost two layers represent the upper and lower parts of the lower alluvial aquifer. Where the clay interbed is not present, the middle layer is assigned the same characteristics as the uppermost two layers. The layers extend laterally into bedrock at the edges of a buried valley that contains the alluvium. Figures 2-3 through 2-7 show the location of aquifer and bedrock model blocks for layers 1, 2, 3, 4, and 5. In addition, Figure 2-5 shows the extent of the low permeability clay layer (layer 3). These figures show that the lateral extent of the aquifer in the lower layers is less than the upper layers. This effect is caused by the bedrock walls sloping upward from the center of the bedrock trough. In the South Plume area, the width of the bedrock outlet decreases from layer 1 to layer 4 (compare Figures 2-3, 2-4 and 2-6). There is no layer 5 aquifer in the bedrock outlet as the elevation of the bedrock in this area has increased above the base of layer 4 (see Figure 2-7).

Pumping wells are located in the area spanned by the local model. These include a FEMP production well and three industrial wells located south of the FEMP site. Pumping from each of these wells was assigned to the proper cell and layer in the model. The three industrial wells are within the Removal Action study area.

2.2.2 Calibration of the Flow Model

The calibration of the groundwater flow model was performed by comparing hydraulic heads calculated by the model against heads measured in numerous monitoring wells throughout the FEMP and surrounding areas. This calibration was performed using the regional flow model. Reasonable estimates of hydraulic conductivity and recharge were initially input to the model and then varied within an acceptable range to adjust model-computed heads to agree with observed monitoring well heads. The monitoring well heads used for calibration were measured in 1986 and are shown in Figure 2-8.

Groundwater flow conditions simulated by the model were successfully made to reproduce the observed flow conditions throughout the study area. Based on water levels from 55 wells, the arithmetic mean residual (observed head minus calculated head at the monitoring well) for the calibrated flow model was 0.21 foot. The match of field data portrayed by this residual value is realized when compared to a total change in hydraulic head of approximately 20 feet over the South Plume area. The mean of the absolute values of the residuals was 1.08 feet. When the local model was constructed, a computer program was used to check, cell by cell, the correspondence of heads in the local model with heads in the regional model. The correspondence verified that the flow model calibration was preserved in the solute transport

model; thus, no new flow calibrations were made. This resulting potentiometric surface from the local model is shown in Figure 2-9.

2.2.3 Calibration of the Solute Transport Model

The calibration of the solute transport model involved the following steps:

1) Based on the current understanding of historic patterns of uranium release, designating appropriate cells as source cells where uranium may enter the groundwater system

2) Dividing the model time into source loading periods corresponding to intervals during which source loading was probably significantly different from in other periods

3) Introducing reasonable initial estimates of uranium source loading for each source cell

4) Establishing the best initial estimates of longitudinal and transverse dispersivity, as well as a distribution coefficient for uranium

5) Adjusting source loading, source loading periods, dispersivities, and the distribution coefficient until concentrations calculated by the model are close to concentrations measured in the field

After attempting calibrations with distribution coefficients corresponding to retardation factors of 1, 6, and 9, a retardation factor of 12 was selected as the most representative, based on results of geochemical studies (DOE 1989) and the goals of the solute transport calibrations. Thus, the distribution coefficient was set at 0.022 cubic feet per pound, which corresponds to a retardation factor of 12. The goal was to keep the dispersivities as close to 100 feet as possible and to keep the distribution coefficient as low as possible. The preference for a dispersivity of 100 feet was based on estimates by Anderson (1984, 1989) and Borg (1976). Walton (1988, Figure 2.16) presents a graph of mean travel distance versus longitudinal dispersivity from field studies. Assuming a mean travel distance in the South Plume of 2,500 feet, Walton's graph yields a longitudinal dispersivity slightly over 100 feet. Walton also shows representative longitudinal dispersivities for areal models of alluvial sediments and glacial deposits to be between 39 and 200 feet. The desire to keep the distribution coefficient low was based on results of the geochemical investigation, which found that the uranium is in complexes which have neutral or negative charges; such charges imply low retardation. The geochemical investigation is discussed in detail in a previous report (DOE 1989) and is based on site-specific investigations using analytical data and geochemical speciation models.

Because the plume is narrow and has high concentration gradients away from the center, the concentration patterns could be matched by having either a sufficiently high retardation factor or a sufficiently low dispersivity. Calibration with a retardation factor of 12 yielded the preferred longitudinal dispersivity of

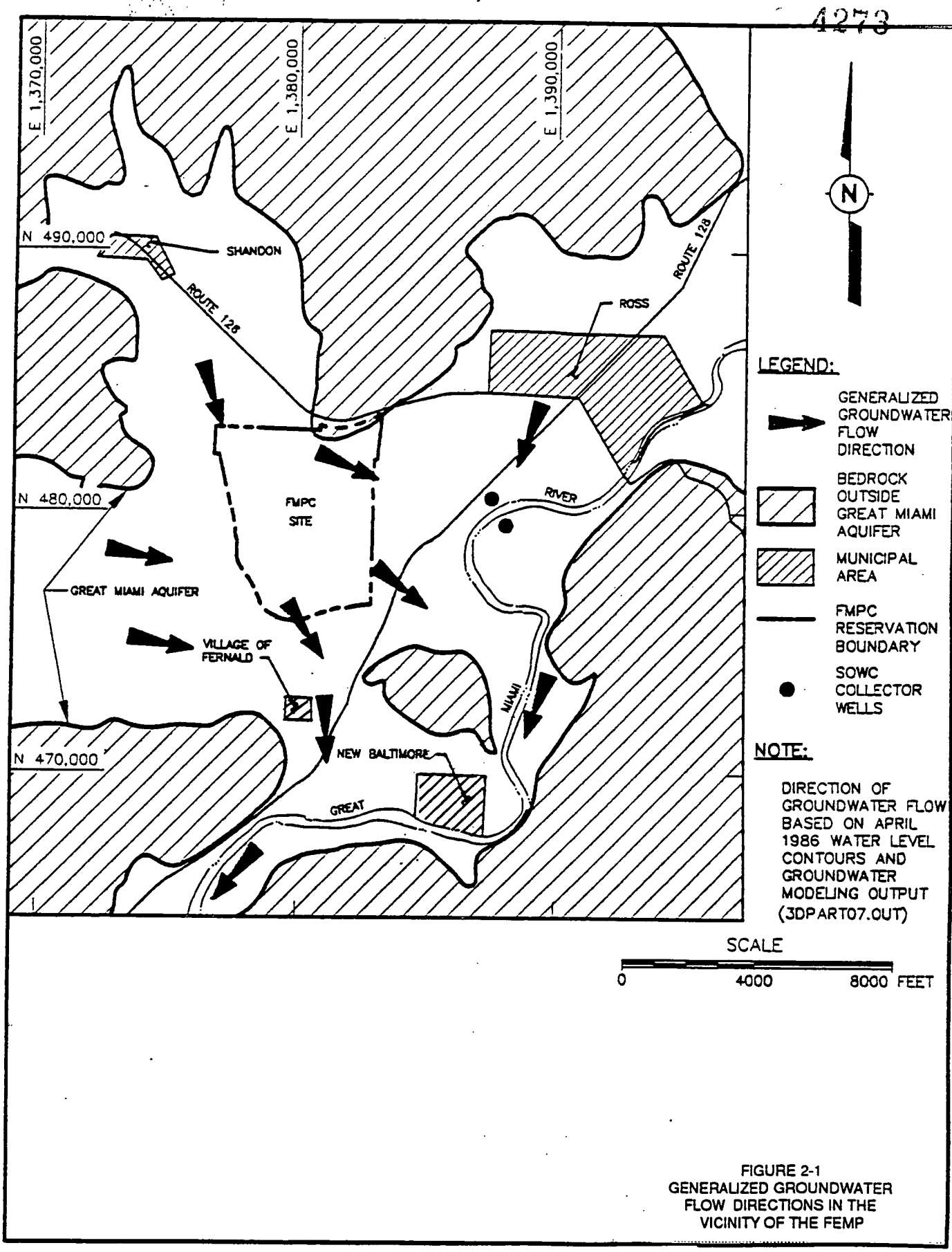
100 feet and transverse dispersivity of 10 feet. The model uses transverse dispersivity for vertical dispersivity, so the calibrated transverse dispersivity tends to be low.

Statistics used to characterize the degree of calibration were based on monitoring data from wells that yielded detectable uranium in all samples. The object of the calibration was to produce a representative simulated plume. Calibration was performed by comparing predicted concentrations to the mean values of concentrations measured at the individual wells. The monitoring well data were obtained from multiple quarterly sampling rounds, with each well having from 2 to 93 sampling rounds, but most with 4 or 5 rounds. It is recognized that time-averaged data are not truly representative of temporal changes in groundwater geochemistry; however, few wells were available in 1990 for calibration of the model particularly south of Willey Road. Multiple sampling rounds were considered as the only viable option for calibrating the model. The majority of these wells used data from the 1988 and 1989 RCRA sampling rounds collected over a 2-year period. The calibration aimed at reducing the difference between the uranium concentration calculated by the model at each well and the mean concentration of the actual population at each well. Consequently, an appropriate goal for calibration is to attempt to put as many calculated concentrations as possible within the 95 percent confidence interval of the true mean. Calculation of confidence intervals for the mean is described in Moody and Graybill (1963, pp. 251-253). This test is a more restrictive one than the outlier test used in preliminary calibrations. Consequently, its application to the final calibration resulted in a more refined model. Hereafter, the 95 percent confidence interval for the true mean concentration at the well will be called the "range."

The result of the calibration with data collected up to April, 1990 was that all of the calculated concentrations in Layer 1 were brought into range, except the concentration at one well and the concentrations at a few wells upgradient from any known sources, upgradient of Paddy's Run, south of the FEMP. Several concentrations at wells screened in lower layers also could not be brought into range. Uranium data from domestic wells with unknown screen depths were not included in this analysis. However, they have been inspected to verify that they contain no concentrations that were inconsistent with the solute transport modeling results.

2.2.4 Simulated Plume

The calibrated solute transport model (Figure 2-10) yielded a predicted uranium plume centered approximately 500 feet south of the FEMP with a peak concentration above 400 μg/l. The model shows the majority of contamination is located within the upper half of the Great Miami Aquifer, with most of the uranium residing in the upper three model layers. The plume's 10 μg/l boundary extends from the FEMP's production area in the north to New Haven Road in the south and from just west of Paddy's Run to approximately 1,500 feet east of Paddy's Run Road. This 10 μg/l line is the outer contour shown in this report and is defined to be the plume's boundary for predictive purposes.



313327-A51 (IS/OU5) (PGH)

FIGURE 2-1
GENERALIZED GROUNDWATER FLOW DIRECTIONS IN THE VICINITY OF THE FEMP

Figure 2-1 - Groundwater Flow in the Vicinity of the FEMP

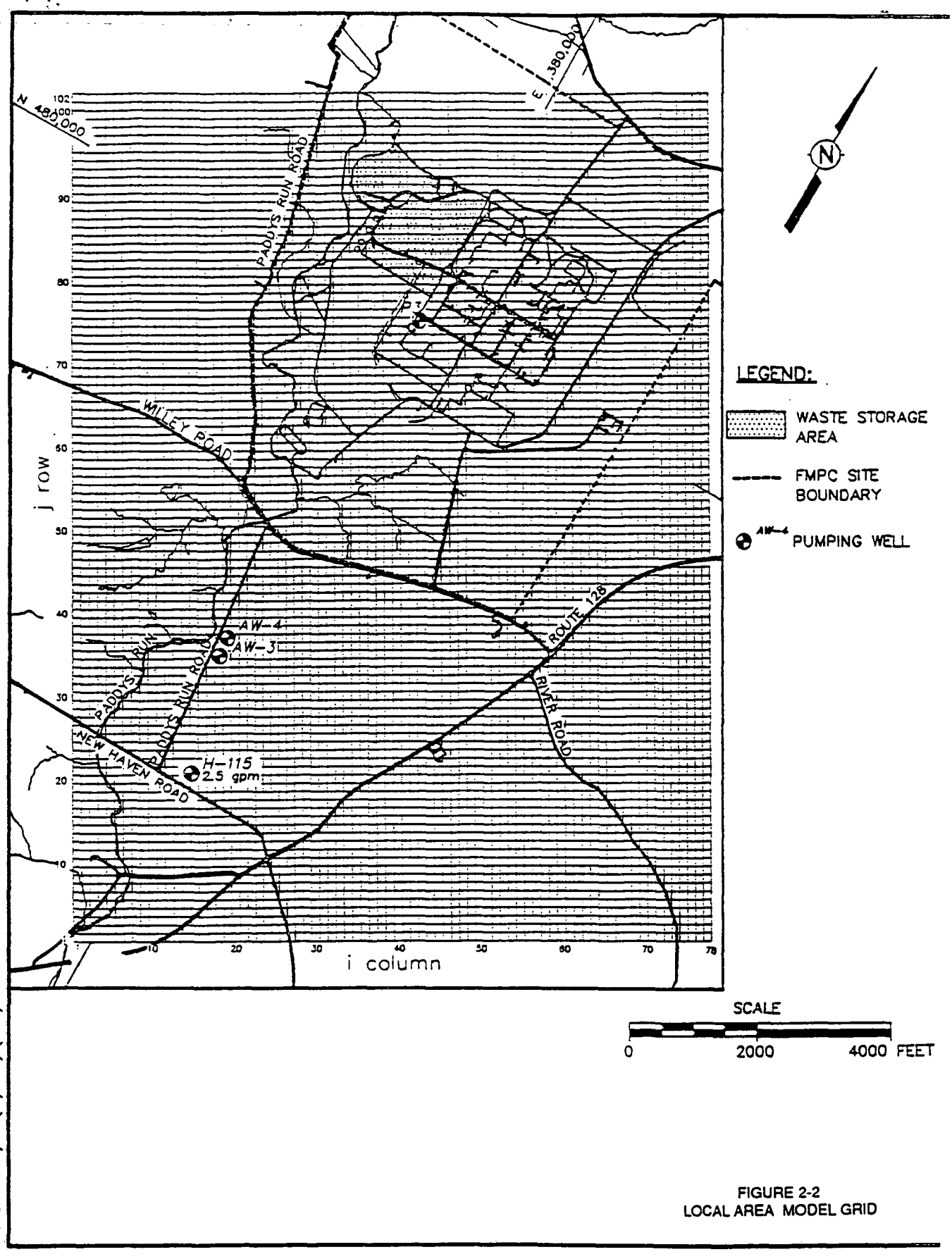


FIGURE 2-2
LOCAL AREA MODEL GRID

Figure 2-2 - Local Area Model Grid

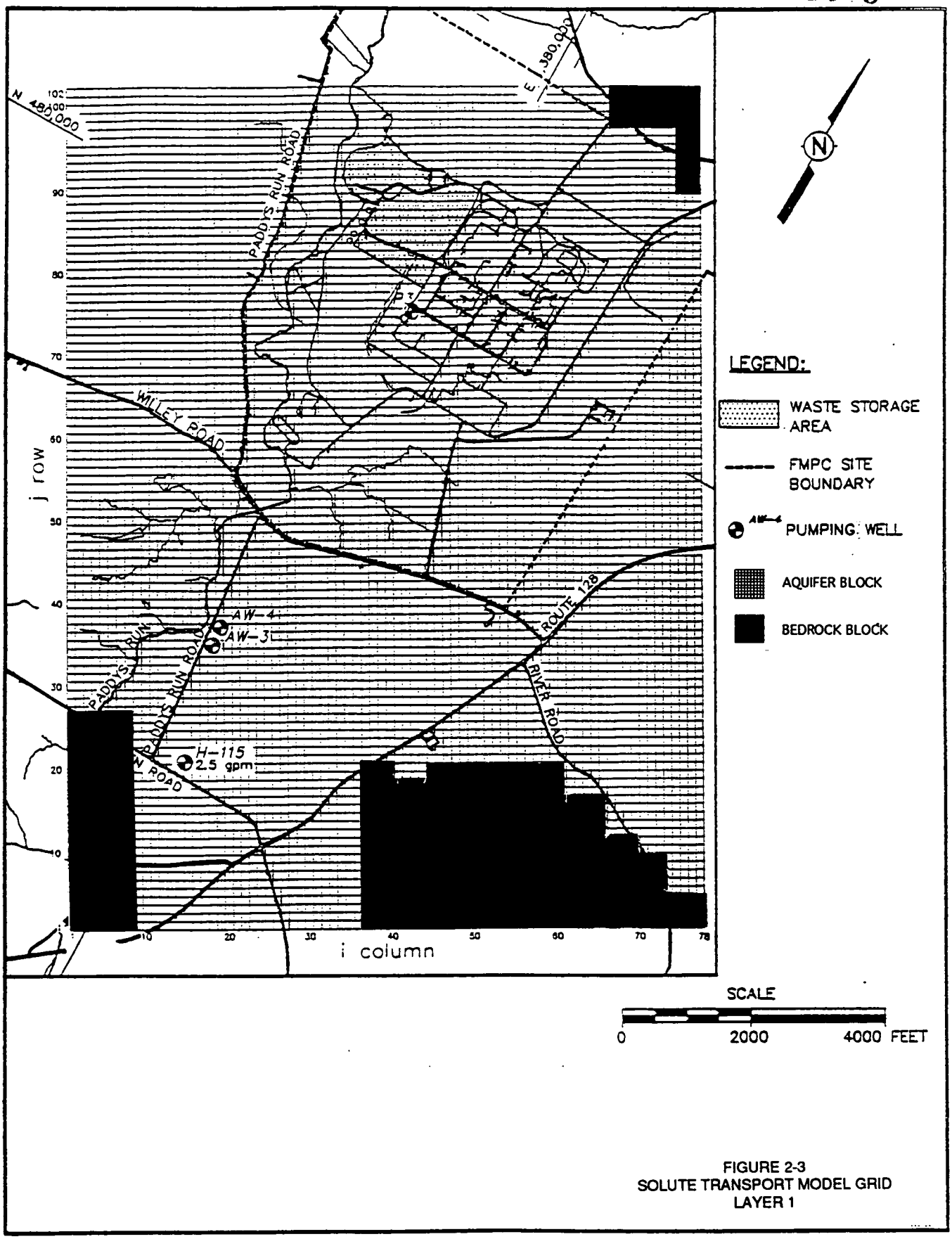
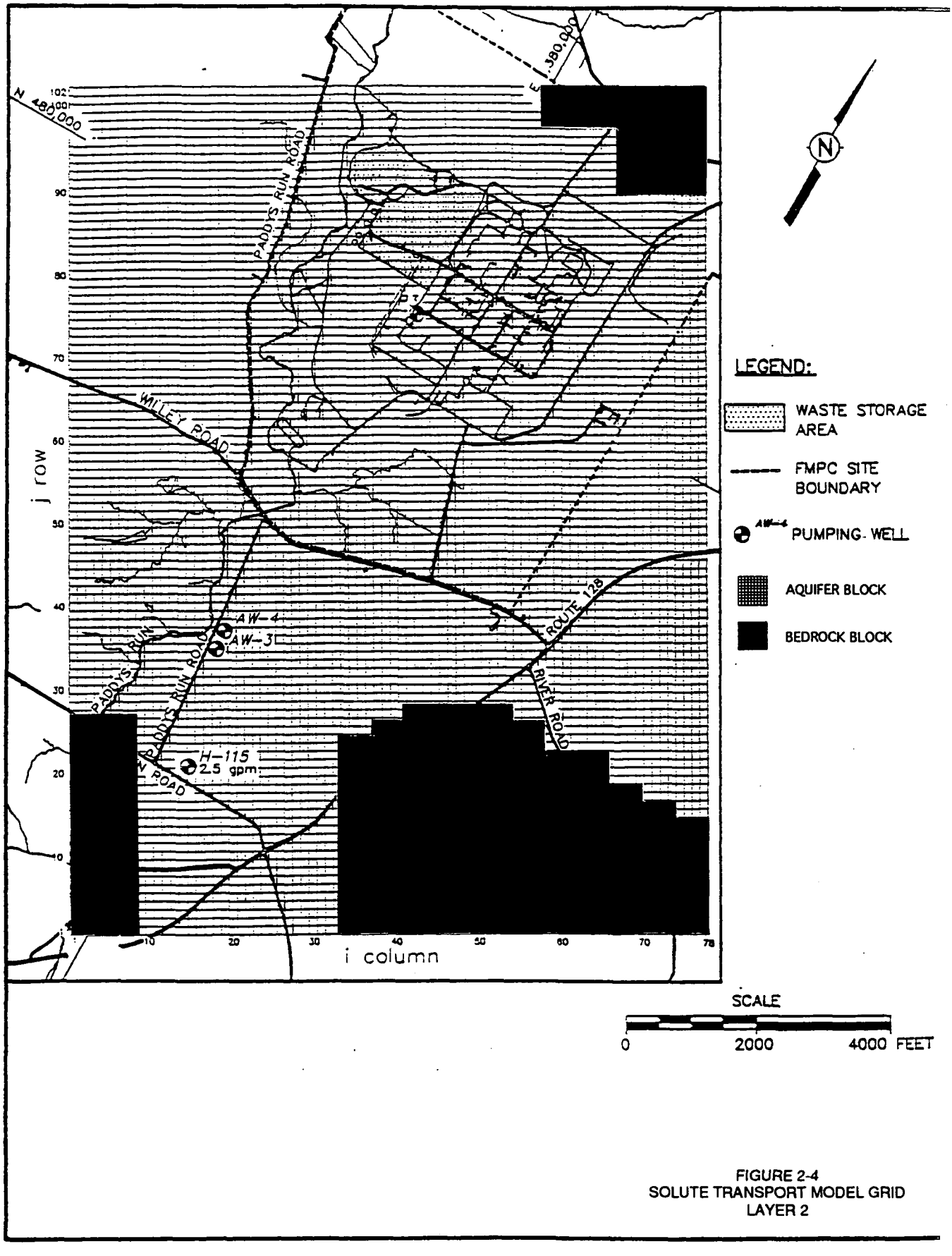


FIGURE 2-3
SOLUTE TRANSPORT MODEL GRID
LAYER 1

313327-A52 /01 (IS/OU5) (PGH)

Figure 2-3 - Model Layer 1 Aquifer and Bedrock Blocks



313327-A52 /01 (IS/OU5) (PGH)

Figure 2-4 - Model Layer 2 Aquifer and Bedrock Blocks

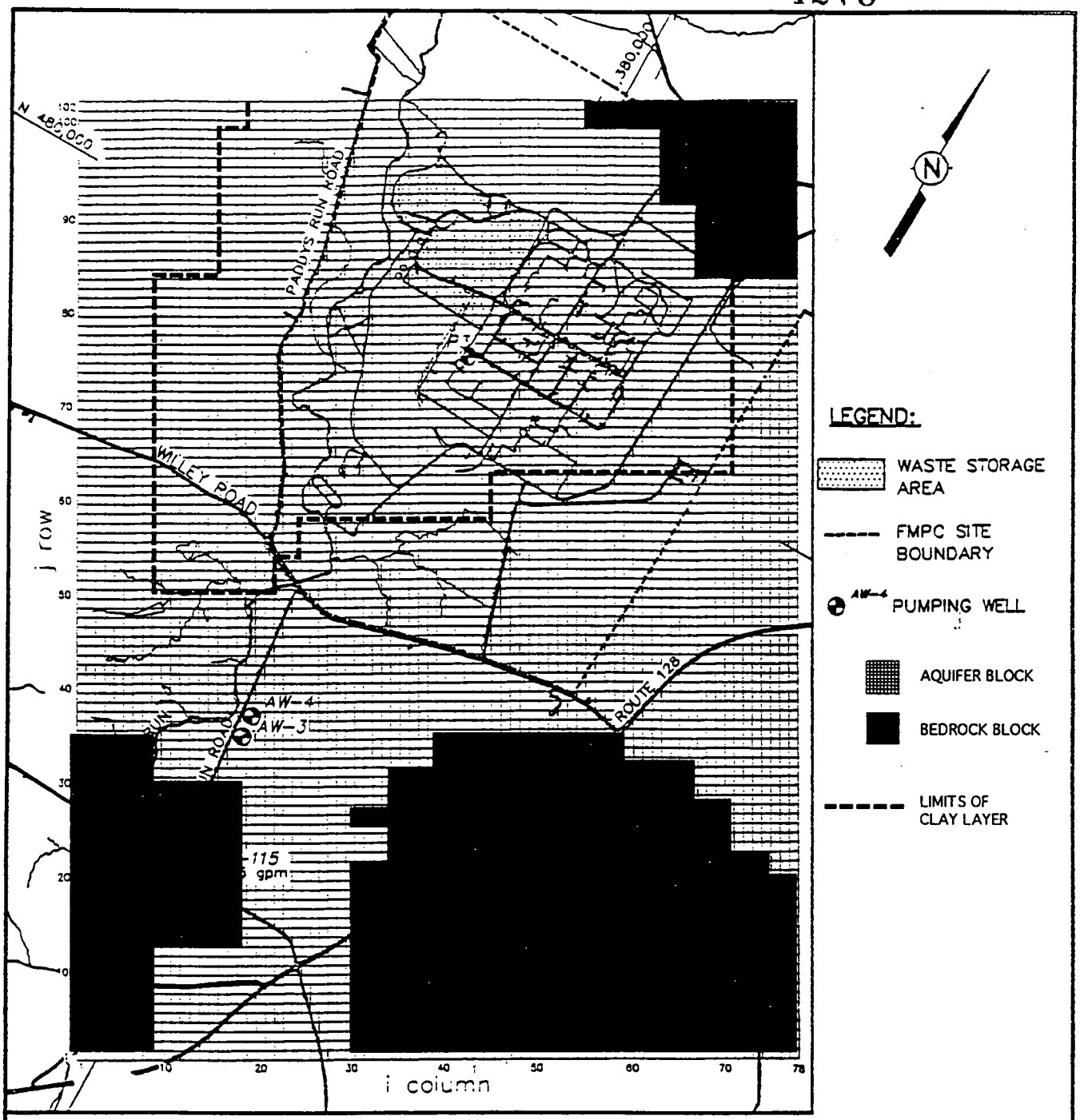
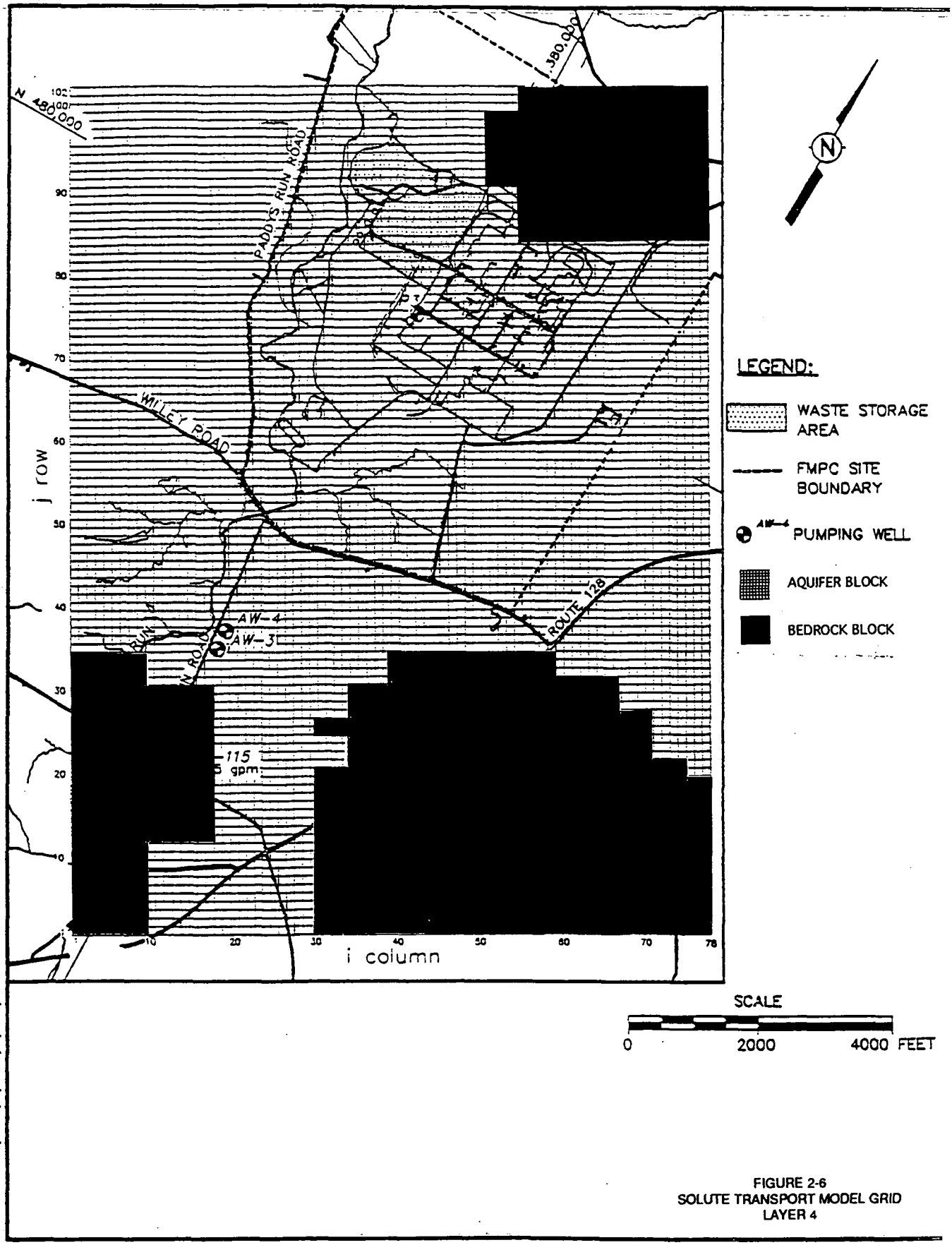


FIGURE 2-5
SOLUTE TRANSPORT MODEL GRID
LAYER 3

313327-A52 /01 (IS/OU5) (PGH)

Figure 2-5 - Model Layer 3 Aquifer, Clay Layer, and Bedrock Blocks



313327-A52 /01 (IS/OU5) (PGH)

FIGURE 2-6
SOLUTE TRANSPORT MODEL GRID
LAYER 4

Figure 2-6 - Model Layer 4 Aquifer and Bedrock Blocks

FIGURE 2-7
SOLUTE TRANSPORT MODEL GRID
LAYER 5

Figure 2-7 - Model Layer 5 Aquifer and Bedrock Blocks

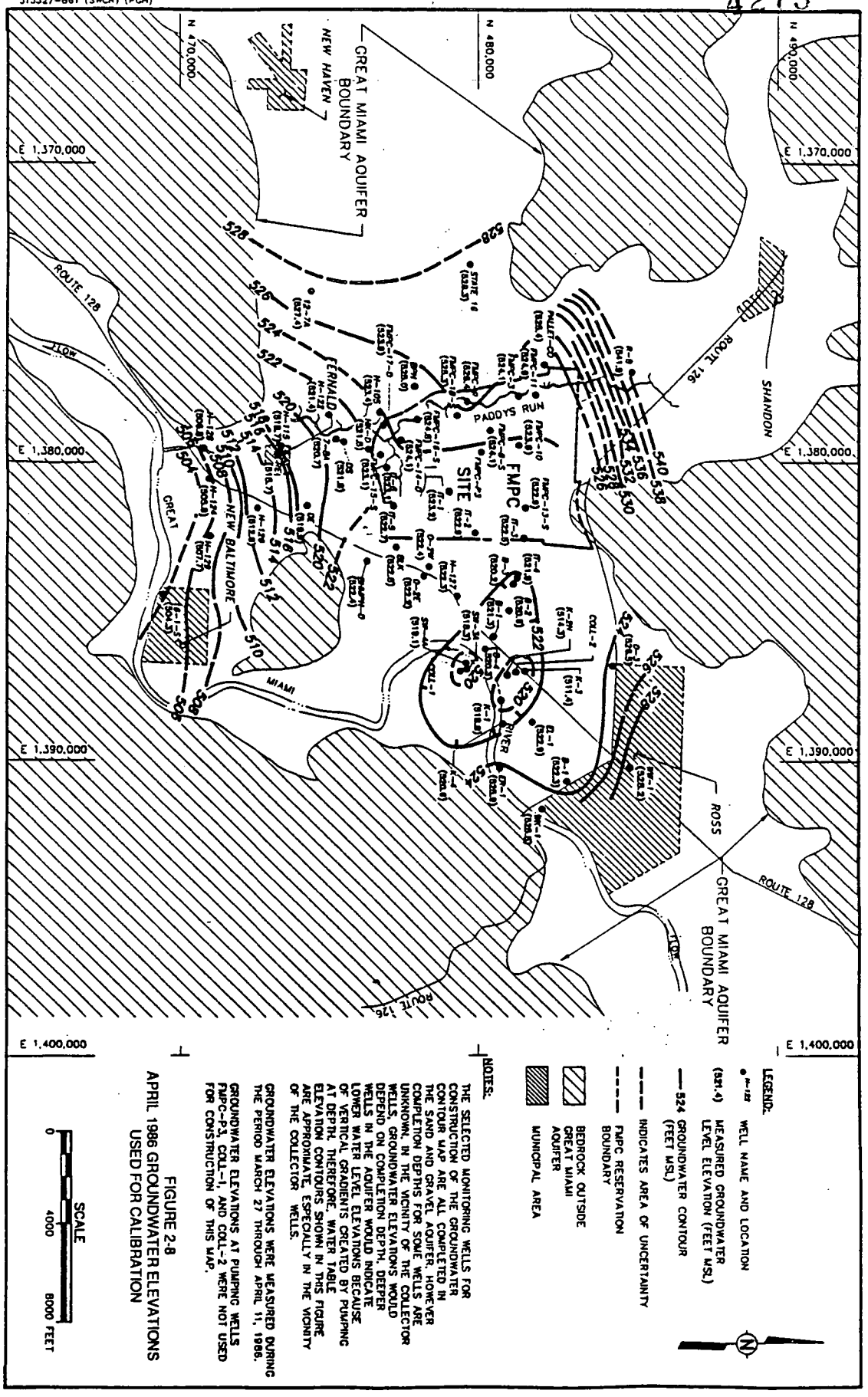


Figure 2-8 - April 1986 Groundwater Elevations Used for Calibration

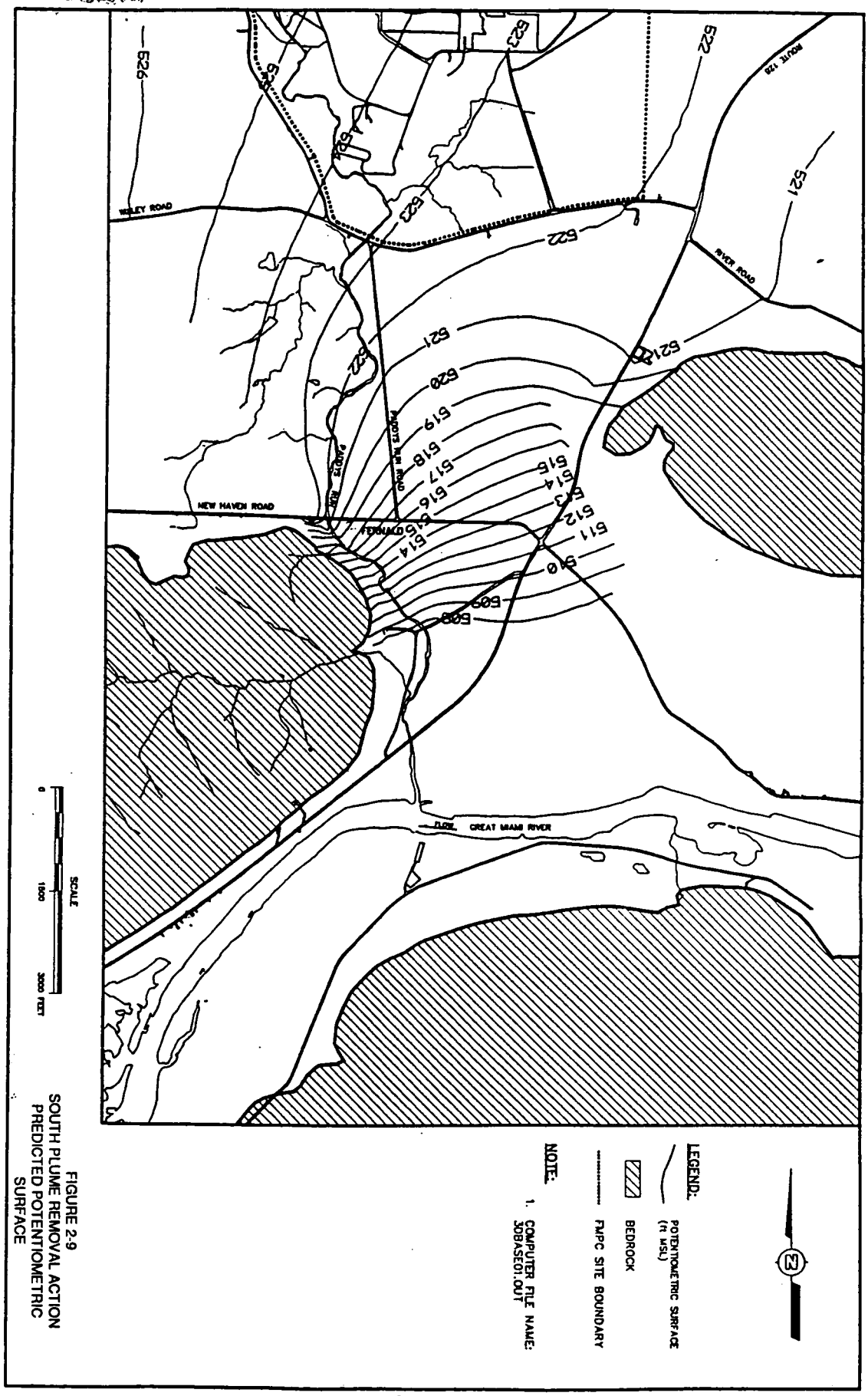


FIGURE 2-9
SOUTH PLUME REMOVAL ACTION
PREDICTED POTENTIOMETRIC SURFACE

Figure 2-9 - Predicted Potentiometric Surface

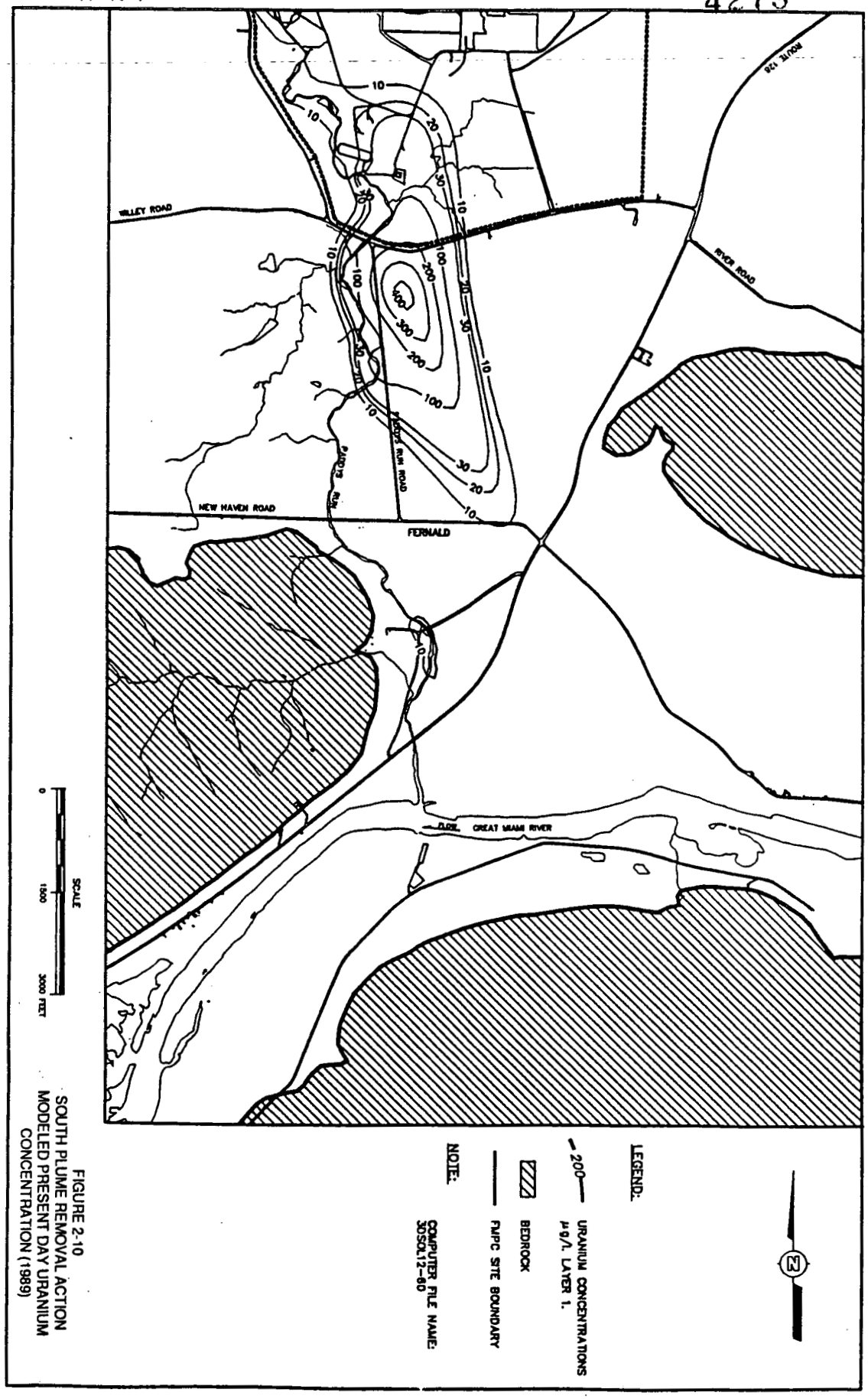


FIGURE 2-10
SOUTH PLUME REMOVAL ACTION
MODELED PRESENT DAY URANIUM
CONCENTRATION (1989)

Figure 2-10 - Simulated Layer 1 Uranium Plume Prior to Pumping - 1989

SECTION 3

EVALUATION OF THE MODEL

By evaluating the FEMP flow and solute transport models, model limitations and uncertainties of using the model will be better defined and an approach to using the model to support the design of the recovery system can be established. Successful applications of models may be independent of model accuracy, provided some idea of the accuracy of the model is known and appropriate steps are taken to incorporate the uncertainty in the application of the model.

3.1 Overview

Predictive results obtained from groundwater models have inherent limitations. There is no perfect model of any site because of the many unidentifiable heterogeneities that exist in the subsurface, the limitations of sampling,and the necessity of simplification of the natural system with a model. A model can only be as accurate as the data, assumptions, and governing equations that are used. Prediction errors may be traced to (NRC 1990):

1) Natural heterogeneity that cannot be completely described with sampling
2) Measurement errors
3) Structural differences between the real world system and the model used to represent it
4) Calibration errors

The groundwater model of the FEMP site has been developed for the purpose of creating a tool to synthesize existing hydrogeological data, to predict contaminant transport through time, and to predict the effects of remediation scenarios (pump and treat). The SWIFT III code has been verified (IT 1990) and the site model has been calibrated to available data (DOE 1990a).

3.2 Model Improvement Program

Weaknesses in the groundwater model have been identified during applications of the model over the last two years. A model improvement program has been developed to address these weaknesses (DOE 1993). The two principle elements of this program are one, the DMEPP activities (pump test, model recalibration, and post audit - see Figure 1-3) and two, the preparation of a model improvement plan based on identified problems with the model.

The preliminary evaluation of the FEMP groundwater model, in preparation for constructing the Model Improvement Plan, has identified the following issues (DOE 1993):

1) The 3D solute transport model was calibrated to uranium concentrations at a relatively small number of wells in the south plume area. The three 2000 series wells, used for calibration of layer 1, had residuals of 161.88, -35.54, 10.43 μg/l uranium. Six wells were used for calibration of layers 2 through 5 with most of these wells located along Paddy's Run. One of these wells also had a high residual (-116.19 μg/l). Since this calibration, new monitoring wells have been constructed and existing monitoring wells have been measured/sampled several times. The calibration needs to be refined with this new data so that there is better spatial coverage of calibration targets. The refining of the calibration should also attempt to reduce the residuals in this area.

2) Values and distributions of input parameters need to be better defined. In some cases, more data analysis of the existing database may satisfy this need. In other cases, the measurement of site specific parameters may be necessary. The most effective methods to understand the input parameters are geostatistics and sensitivity analysis. Geostatistical techniques may be utilized to identify locations where uncertainties of model parameters are the greatest. Sensitivity analysis will determine which parameters affect model output the most (see below).

3) More sensitivity analysis and more evaluation of the existing sensitivity analysis is needed. This analysis will promote a better understanding of model behavior and will help identify key, sensitive parameters. Certain omissions exist; for example, for the flow model, sensitivity analysis of the hydraulic conductivity was not performed for layers 1 and 2. In addition, the flow and transport model relies generally on sensitivity analysis performed on the interim calibration (R=9). A more complete series of sensitivity runs on the calibrated model (R=12) followed by a complete evaluation of the sensitivity data is needed.

4) The steady state assumption may need to be altered for certain uses of the model. For long term fate and transport of contaminants, steady state appears to be a valid assumption. For certain uses of the model which are concerned with a shorter time element, transient conditions may become important. The model user should be aware of possible limitations of the model in these situations and should use the model carefully.

5) A post audit program of the model is needed. This program would evaluate the accuracy of the model over time by comparing predictions with measured results. This effort could lead to further model refinement based on the results of these comparisons.

Based on the review to date, Table 3-1 summarizes the identified and potential model improvement tasks. As the identified tasks are implemented and as new tasks are identified and implemented, confidence in the use of the model will be increased.

TABLE 3-1
MODEL IMPROVEMENT TASKS

Tasks Already Identified

1. Recalibration

   - Flow model based on south plume pump test
   - Solute transport based on latest analytical data

2. Sensitivity Analysis

   - SP Modeling Report - K_h versus capture and PRRS influence
   - K_h on model layers 1 and 2

3. Post Audit Program

   - In the revised DMEPP

4. Geostatistical Analysis

   - Water elevations data
   - Uranium data

Potential Additional Tasks Based on Model Evaluation

1. Steady State vs Transient Use

2. Site Specific Parameters

   - Need for based on sensitivity analysis and geostatistics

3. Further Sensitivity Analysis

4. Further Mesh Refinement

3.3 Comparison of Model and Monitoring Results

The model solute transport results are compared with recent site monitoring data in order to qualitatively assess the accuracy of the solute transport model. The 2000 series well results (screened in the top 10 to 15 feet are compared with model layer 1 results (layer 1 is approximately the top 40 feet of the aquifer). The 3000 series well results (screened 10 feet just above the clay interbed or if missing at the same approximate elevation) are compared with model layer 2 results (layer 2 extends from the clay interbed to the bottom of layer 1 and is approximately 33 feet thick). The monitoring data consists of isoconcentration plots from six quarters of sampling data averaged from 1991 through the first half of 1992 (Appendix B). This data is more recent than the data used to calibrate the model. Monitored screen depths only approximate model layers and monitoring data is biased by possible interpretation errors and a lack of well control in certain areas; however a comparison of these results checks the current model's ability to reproduce the uranium plume.

For the 2000 well/layer 1 comparison, the gross geometric patterns of the modeled South Plume approximate the field measured gross patterns (Figures 2-9 and 3-1). However, the plume determined through monitoring is considerably smaller than the modeled plume. The monitored plume extends just south of Delta Steel with a separate smaller piece (greater than 30 μg/l uranium) further south near Albright and Wilson. The modeled plume is more elongated with its leading edge extending to New Haven Road and contains larger areas of higher concentrations. For example, the 200 μg/l modeled contour (Figure 2-9) is substantially larger than the corresponding 200 μg/l monitored contour (Figure 3-1). The three highest concentration areas reflected in the monitoring data (in south field, crossing Willey Road, and crossing Paddy's Run Road - Figure 3-1) are not well represented in the modeled plume. The modeled plume at these locations shows lower concentrations. In addition, the area further south, east of Paddy's Run Road greater than 20 μg/l uranium, is missed by the elongated modeled plume. The width of the model and monitored plumes is comparable in locations where there is a monitored plume.

For the 3000 well/layer 2 comparison, the patterns are strikingly different (Figures 3-2 and 4-2). The monitored plume shows three relatively small areas with concentrations greater than 20 μg/l uranium and one area (near Delta Steel at the 90 degree bend in Paddy's Run) where the plume exceeds 40 μg/l. The modeled layer 2 plume is similar (although with lower concentrations) to the model layer 1 plume with an elongated plume extending from on site and trending south east to a location south of New Haven Road. The modeled layer 2 plume shows the center of the plume as an elongated area south of Willey Road greater than 200 μg/l. The modeled layer 2 plume includes 2 of the 3 areas greater than 20 μg/l shown of Figure 3-2; it does not reproduce the eastern area. The modeled plume shows considerably larger area of contamination and larger mass of uranium in the aquifer.

In both cases, the modeled plumes are generally larger, have higher concentrations, and contain greater mass than the representations of the monitored plumes. However, as described above, there are locations where monitoring data shows uranium concentrations that are not reflected in the model. The layer 1 model plume is a conservative representation of the plume seen in the 2000 series wells with differences noted above. The layer 2 model plume appears to be an overly conservative representation of the 3000 series well plumes. Because of these differences between modeled and monitored results, the solute transport model should not be relied on for quantitative results. Both model output and monitoring data should be used for design of the recovery wells.

3.4 Assessment of the Model

Based on a preliminary review, the flow model provides a reasonable representation of the groundwater flow system at the FEMP. Verification of the SWIFT code has shown that the code can appropriately represent flow conditions. The construction of the model grid and boundary conditions appears to be acceptable. However, important site specific parameters may be lacking especially the direct measurement of hydraulic conductivity with a pump test. In general, the flow portion of the model appears to be reasonably calibrated. Calibration successfully met the established criteria with mean residual equal to 0.326 feet and mean of the absolute residual equal to 1.083 feet (DOE 1990a). A check of the model was performed by testing the performance of the 2 dimensional flow model during a dry year (1988).

The lack of a site specific pump test upon which the model is based can be corrected for with design conservatism, an after-the-fact pump test, and a better understanding of the sensitivity of plume capture to changes in the hydraulic conductivity. Thus, the flow model can provide an acceptable tool for supporting the preliminary design provided these steps are taken to support the model. Since particle tracking is based exclusively upon flow model elements, particle tracking may be used with the flow model to help understand conservative movement of solutes.

Based on a preliminary review, results from the local solute transport modeling contain greater uncertainties than the flow model. One reason for this is the greater number and more complex set of variables necessary for solute transport modeling when compared to flow modeling. The FEMP solute transport model primarily suffers from limited laboratory analyses of groundwater and aquifer solids south of Willey Road, limited calibration targets south of Willey Road, and a poor match with these limited targets. Although an attempt was made to estimate source terms based on FEMP operations history, nevertheless, substantial changes were made to source terms during model calibration. Therefore, the values of source loading terms remain very uncertain. Comparison of recent monitoring data with model results show substantial (although generally conservative) differences between these results. These factors reduce confidence in the use of the solute transport model. Thus, the concentrations predicted by the solute transport model should only be used as estimates. As a result, the solute transport portion of the

model needs to be de-emphasized for use in selection of the design parameters for the South Plume recovery wells.

Selection of locations and design parameters for recovery wells and pumps needs to be based both on monitoring data and flow model simulations including forward and reverse particle tracking. Solute transport simulations should only be utilized to show gross type trends for comparing uranium capture for "no action" versus "pumping" scenarios or for estimating uranium capture over time.

In addition, as stated above, sensitivity analysis is needed to assess model uncertainties in flow parameters. Since hydraulic conductivity is one of the principal parameters in determining groundwater flow and there is some uncertainty in the model selected value, then the sensitivity of this parameter needs to be assessed. This analysis should be performed by varying model hydraulic conductivity values (at the designed pumping rate) and determining the impact on uranium plume capture and PRRS plume deflection. With these results, an acceptable range of hydraulic conductivity values over which the model effectively simulates capture can be determined.

Since the model is intended to be used to set initial design parameters for the recovery well system, certain safety factors may be included in the design based on the presumed uncertainties of the model. Recommendations for ranges of parameters need to be included in the selection of design parameters.

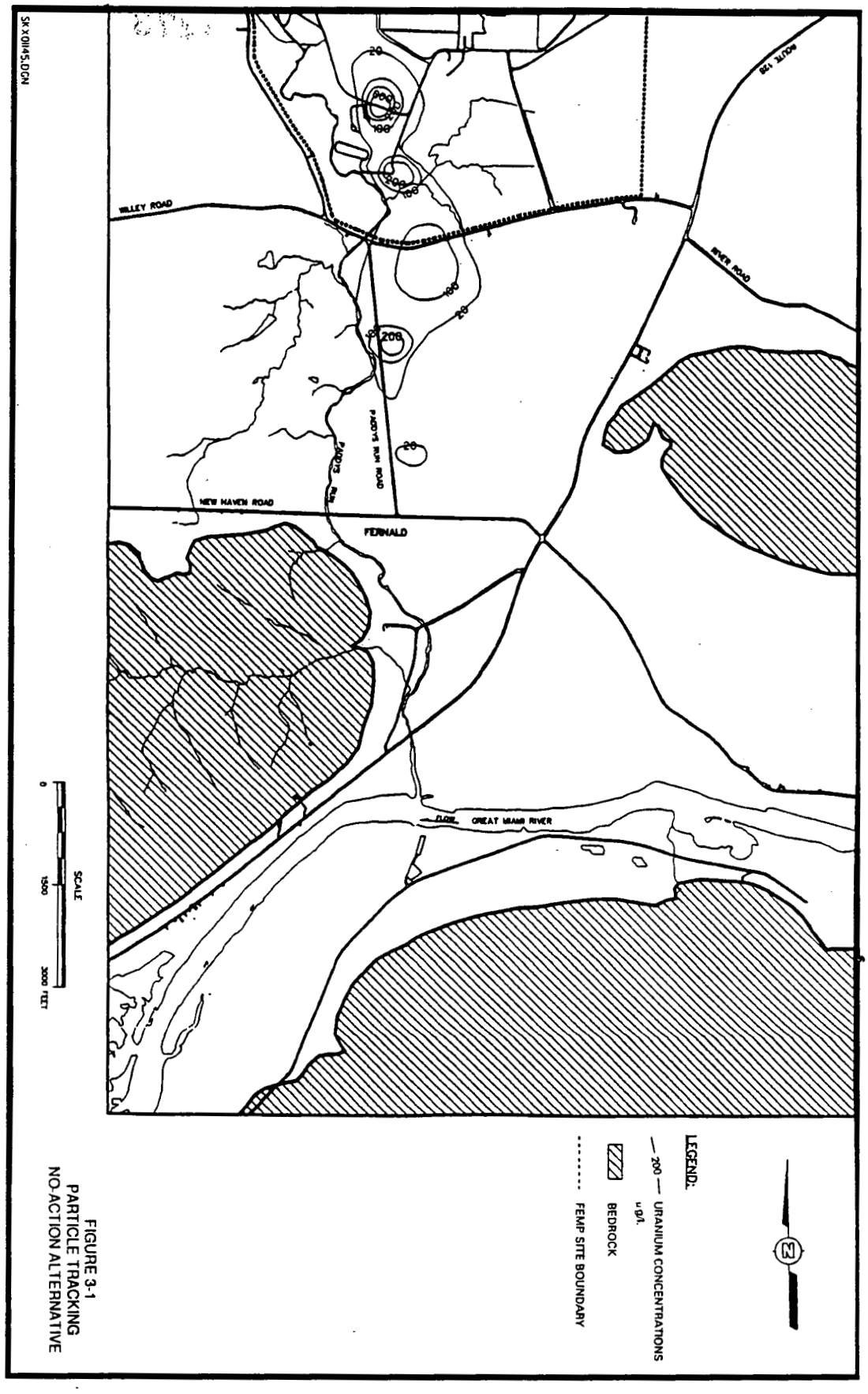


FIGURE 3-1
PARTICLE TRACKING
NO-ACTION ALTERNATIVE

Figure 3-1 - Six Quarter Average of Monitored Uranium Data 2000 Series Wells

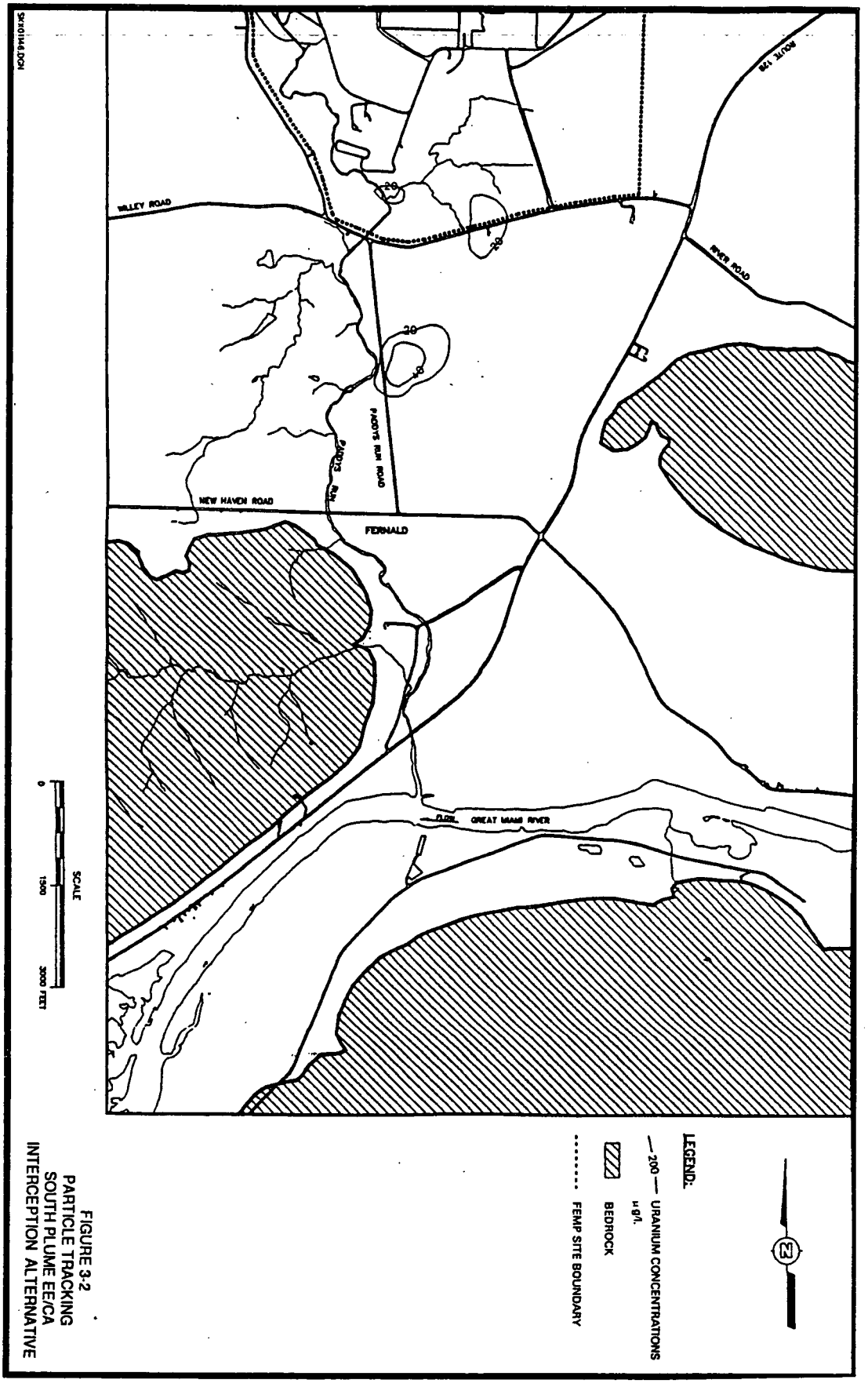


FIGURE 3-2
PARTICLE TRACKING
SOUTH PLUME EE/CA
INTERCEPTION ALTERNATIVE

Figure 3-2 - Six Quarter Average of Monitored Uranium Data 3000 Series Wells

SECTION 4

MODELING RESULTS

Pursuant to the Part 5 Work Plan (DOE 1991), groundwater modeling simulations have been performed to set the design parameters for the South Plume Removal Action groundwater recovery wells based on conditions that have changed since the preparation of the South Plume EE/CA.

4.1 Introduction

4.1.1 System Requirements

To meet the goals of the pumping and discharge system portion of the Removal Action, the primary and secondary goals of the South Plume EE/CA had to be restated and expanded to take into account the impact of the PRRS plumes and to clarify the specific performance criteria of the system at the revised location. The groundwater recovery system needs to meet, to the extent possible, the following four requirements (Parsons 1992):

1) The groundwater extraction wells need to be located at the appropriate location and pumped at the sufficient rate to create a hydraulic barrier along a line running perpendicular to the longitudinal axis of the South Plume in the Great Miami Aquifer, creating an elongated groundwater trough. This hydraulic barrier needs to extend sufficiently outward from the centerline of the South Plume to intercept uranium above the 20 μg/l level.

2) The magnitude of the hydraulic trough needs to be minimized while still meeting Requirement 1, in order to minimize the impact on the overall hydrogeologic system. If extensive capture zones are created, then the PRRS plumes may be pulled toward the extraction wells. Also, minimal disturbance to the local hydrologic system is desired to prevent impacts on groundwater users in the area, to minimize the possible velocity increases to movement of additional on-site plumes, and to not significantly deflect the PRRS contaminant flow trajectory. In addition by minimizing the impact, the recovery system will more likely be consistent with final remediation. The recovery wells, therefore, need to create a hydraulic sink to prevent plume movement by the wells and to minimize capture zones and large-scale reversals of groundwater flow.

3) Contamination within the aquifer needs to be removed as soon as feasible to prevent further plume movement and degradation of the groundwater environment. Removal of contaminants near the source or in the shallow portion of the aquifer is more efficient and prevents further drainage. The recovery system should be operated to prevent further spread of contamination.

To meet these requirements requires that the recovery system balances the opposing factors of creating sufficient drawdown to prevent migration around, between, or beneath the pumping wells and of minimizing drawdown to prevent gradient changes over a large area.

4.1.2 Modeling Approach

To determine the placement and pumping rate of a well field capable of meeting the requirements stated above, additional groundwater modeling was conducted. The calibrated local three dimensional flow and solute transport model of the FEMP site was used, with a retardation factor of 12, in order to utilize the most accurate calibration. The modeling approach was defined based on the evaluation of the model and defined model limitations as described in Section 3. This evaluation identified two elements that will be incorporated into the modeling approach:

1) The flow model with particle tracking will be the primary tool used for setting design parameters. Less reliance will be placed on the use of the solute transport model. Definition of the plume based on site monitoring data should also be relied on in the selection of design parameters. Solute transport simulations can be used to discern gross or relative trends.

2) Sensitivity analysis comparing hydraulic conductivity versus plume capture and PRRS plume deflection is needed to better understand the uncertainty of the flow model. This analysis will set an acceptable range of hydraulic conductivity values that will be compared to pump test results at start-up and determine if the model appropriately represented the flow system.

The following alternatives were evaluated during this modeling study:

1) No action for the establishment of baseline conditions.

2) Options for relocating the recovery wells including:
   (1) Reducing the pumping rates of the wells to create a smaller capture zone while maintaining hydraulic control of the South Plume
   (2) Modifying the pumping center of the well field to pump more from the east side of the uranium plume and less from the west
   (3) Moving the well field location north, away from the organic and inorganic PRRS groundwater plumes, to avoid capture and limit influence of non-uranium containing groundwater

3) More in-depth analysis of pumping at the selected location including:
   (1) PRRS impact
   (2) Other well configurations
   (3) Effect on the South Plume

(4) Capture analysis

4) Sensitivity analysis of hydraulic conductivity versus plume capture and PRRS plume impact.

4.2 Methodology

4.2.1 Locating the Well Field

Before more detailed analysis could be conducted, an approximate location needed to be selected with a screening method. It was necessary to identify a location that would capture the majority of the uranium plume but would not capture or significantly impact the PRRS plumes. Because of the configuration of the plumes, it was necessary to try locations north of the original EE/CA well field at New Haven Road in order to not capture the PRRS plumes. Options of reducing the overall pumping rates or changing the distribution of pumping rates were also tried. The location of the PRRS inorganic plume became the limiting factor, and the furthest southern location along the axis of the uranium plume that would not impact the PRRS inorganic plume was sought.

Particle tracking with particles seeded at identified wells contaminated with PRRS contaminants was the primary method of analysis. Monitoring wells from 10 locations were chosen as being contaminated by the PRRS plumes, based on results of groundwater sampling and analysis as reported by the PRRS. Three of these wells are located within the inorganics plume by Albright & Wilson Americas Co., and the remaining seven wells were within the organics plume by Ruetgers and Nease. These locations were used to test the Removal Action well field's influence on the PRRS plumes. For the purposes of clarity, only six of the ten particle locations are shown on maps detailing particle tracking.

Figures showing a planar representation of model results in the following text show a surface bedrock trace to approximately define the limits of the buried valley aquifer. These bedrock traces approximate the limits of model layer 1. Due to the sloping walls of the bedrock, the width of the aquifer is progressively smaller at greater depths; thus bedrock traces for model layers 2, 4, and 5 would cover a greater area and restrict flow in the aquifer. Figures 2-3, 2-4, 2-6, and 2-7 show the site SWIFT model blocks that have been designated as bedrock or aquifer cells for layers 1, 2, 4, and 5.

4.2.2 Analysis at Selected Location

The second step was to optimize the design parameters at the selected location. More detailed analysis of hydraulic effectiveness, uranium plume capture and PRRS impact at this selected location was conducted to refine the well design parameters. The impact of pumping on two areas in the vicinity of South Field was also assessed with the model.

The local model was applied using three methods to evaluate the effectiveness and the zone of influence of the well field. First of all, drawdown and potentiometric maps were created and inspected to see if potential flowpaths existed between the wells. Secondly, reverse particle tracking was performed to determine the capture zone in the horizontal and vertical planes. Finally, forward particle tracking was conducted to confirm the capture zone of the well field predicted by the reverse tracking and to determine impact on the PRRS plumes. For the forward tracking, a vertical plane was constructed perpendicular to the plume and extending beyond the width of the capture zone identified by reverse tracking. Particles were placed on this plane at model layers 1, 2, and 4. Comparisons of particle tracks from PRRS contaminated wells before and after installation of the interceptor wells allowed the effects of the wells to be quantified.

Forward tracking was also used to assess the pumping system impact on two high concentration areas (greater than 200 μg/l total uranium) in the South Field area north of Willey Road (Figure 3-1). A simulation was conducted to calculate the time it would take these high uranium areas to reach the property line under pumping conditions.

Based on the results of the particle tracking, and once a successful capture zone was established, solute transport modeling simulation was done to predict the effects of the well field on the South Plume through the year 2062. A graphical depiction of the effects of the well field capture of the uranium plume was produced, which also determined if hydraulic control of the South Plume could be achieved.

4.2.3 Sensitivity Analysis

Because of the high transmissivity of the aquifer and the extreme difficulties of managing large volumes of uranium-contaminated water, a site-specific pump test was not performed as the basis for the recovery system design or for model calibration. However, at recovery system start-up (after water handling capability is constructed), a pump test will be performed to provide data for model assessment and recalibration; to confirm the design of the recovery system and revise screen lengths if necessary; and to set initial operating conditions of the recovery system. An approach has been established consisting of using the groundwater model and field data to preliminarily design the system, adding conservatism and flexibility into the design, including confirmation processes to check the design, and providing a mechanism to make future changes to the design (PARSONS 1992).

To help define if a problem with the design does exist, sensitivity analysis was performed as part of this SPMR to better understand the effect of uncertainty in hydraulic conductivity values on predicted plume capture and PRRS influence (see Section 4.6). Hydraulic conductivity has been chosen because it is the principal flow parameter in the model and uncertainty does exist in the values used in the model. A range of hydraulic conductivity over which the model effectively simulates capture at the well field pumping rate of 2000 gpm will be established with this sensitivity analysis.

After the pump test and a site specific value of hydraulic conductivity is obtained, a determination can quickly be made as to whether the model adequately represents plume capture by comparing field results with the predetermined sensitivity results. If the pump test determined value falls within this established hydraulic conductivity range, then it will be assumed that the model predictions (calibrated without the pump test results) reasonably represent the hydraulic system. If the pump test determined value falls outside this established hydraulic conductivity range, then further simulations will need to be conducted. These simulations will determine the revised pumping rate needed to effectively capture the plume or to minimize PRRS plume deflection at the revised hydraulic conductivity value. If changes in pumping rate are unable to solve the identified problem, then an engineering change proposal will be processed. This change proposal will result in the design and construction of new system components as necessary.

4.3 No Action Alternative

The "no action" scenario was shown to not meet the removal action objectives (DOE 1990). The following "no action" simulations are only used to demonstrate present and future uranium plumes without pumping are included to delineate the movement of the plume over time and to provide a reference point for comparison with pumping simulations. Figures 4-1 through 4-11 show predicted plumes for years 1993, 1997, 2002, 2012, and 2062. The layer 1 plume is shown for all the years; in addition, for 1993 and 2002 layers 2, 4, and 5 are shown. For this analysis, it has been assumed that uranium source terms are removed (cleaned up) in 10 years in 2002.

Inspection of the layer 1 figures shows, in general, the plume elongating and diluting with time. For example, areas with concentrations greater than the 200/μg/l contour are smaller in each successive time period until the 200/μg/l contour disappears at 2012. By 2062, only a remnant plume (the 10 μg/l contour) is seen.

Plumes of progressively less concentration are predicted in layers 2, 4, and 5. These plumes also elongate and dilute over time. Predictions in layer 5 (Figures 4-4 and 4-9) show a truncated effect. This is caused by a rise in the bedrock near this location (see Figure 2-6). Layer 5 is terminated at this location and thus flow will occur upward from layer 5 into layer 4.

4.4 Evaluation of Alternative Well Field Design

4.4.1 Reduced Well Field Pumping Rates

Initial modeling runs were made with the interceptor wells which were left in their previously proposed locations (Figure 1-4) but with reduced pumping rates to minimize the capture of the organics plume located adjacent to Ruetgers and Nease. Several simulations were made during which the pumping rates

of all the wells were reduced and during which the western-most wells in the field were moved to the east or turned off.

All of these runs proved unsuccessful. Due to the location of the interceptor well field, the pumping was predicted to have significant influence on the contaminant plumes. The inorganics plume and an eastern portion of the organics plume were captured by the wells, and the remainder of the organics plume was spread to the east. This resulted in a greater impact to the organic and inorganic plumes, due to their spreading, and indicated that the interceptor wells must be moved to increase their distance from these plumes.

4.4.2 Moving the Well Field East of Albright and Wilson

The next series of simulations located the wells further to the north and adjusted the rates of the individual interceptor wells to pump more from the east side of the plume and less from the west. The well field remained unchanged from its previous 2,000 gpm pumping rate and 280 feet well spacing. The wells were located in the area east of the A&W plant, along a line proposed by DOE and Westinghouse Environmental Management Company of Ohio (WEMCO). This alignment ran east from Paddy's Run in the area just north of the A&W plant for approximately 750 feet before turning southeast for another 750 feet (Figure 4-12). This contained the well field within the alluvial terrace within which Paddy's Run flows and allowed the wells to remain near the proposed force main. Several simulations were performed in this general area, by varying well pumping rates and shifting the alignment of the well field. One such simulation is shown in Figure 4-12. The westernmost well in the well field was pumped at a reduced pumping rate of 350 gpm, while the remaining three wells were pumped at 550 gpm each to maintain the 2,000 gpm well field pumping rate. This well field was able to successfully contain the uranium plume to the north of the well field but not without influencing the PRRS plumes. The organics plume was basically unaffected by the wells, but the inorganics plume was both partially captured and shifted by the well fields. Even though the well field's pumping center was shifted to the east, the well field still drew particles from the west into the wells.

4.4.3 Moving the Well Field Farther North than Albright and Wilson

An additional series of runs were made using the 4-well, 2000 gpm well field by moving the well field north, away from the PRRS groundwater plumes. It was found during these simulations that moving the well field north did improve the capture zone of the wells, but that to accomplish the Removal Action objectives, the well field must be located approximately 650 feet north (upgradient) of the PRRS plumes. Simulations which located the well field just upgradient of the inorganics plume (Figure 4-13) resulted in significant shifts of the trajectories of the inorganics plume. Although not captured, the particle tracking indicated the inorganics plume would be shifted due to the influence of the well field. This was deemed unacceptable.

Further well field locations were tested to attempt to minimize the effects of the wells on the inorganics plume. The well field was moved further north in 250-foot increments until its influence on the inorganics plume was minimized. This occurred at a location adjacent to Delta Steel Corporation property, approximately 2,500 feet north of the location proposed in the South Plume EE/CA.

4.4.4 Selected Well Field Location

A final series of simulations were conducted which resulted in the desired performance for the interceptor wells. The 4-well, 2000 gpm well field was located at area slightly south of the highest predicted concentrations of the South Plume. The wells were able to contain the plume (Figure 2-9) and successfully captured contaminated groundwater moving south, away from the FEMP. The portion of the South Plume located south of the well field was not captured by the wells at this location.

4.5 More Detailed Analysis at Selected Location

4.5.1 PRRS Impact

Analysis of the wells showed them to have only minimal impact on the inorganics groundwater plume located by A&W. Groundwater modeling simulations using particle tracking predicted a maximum plume deflection of 20 feet to the east away from its present path. The predicted effect on the organics groundwater plume located by Ruetgers and Nease was less than 1 foot of deflection. Figure 4-14 shows the predicted flowpaths from wells contaminated by both the organic and inorganic groundwater plumes. These flowpaths are shown with the Removal Action wells pumping.

Particle tracking also predicts another effect of the Removal Action wells, namely the slowing of the transport of the PRRS plumes because of the location of the wells to the north of these plumes. The Removal Action wells are pumping upgradient of these groundwater plumes, causing reduced groundwater gradients in this area. This, in turn, slows groundwater velocities and thus the transport rate of the PRRS plumes. Although this effect is small, it will influence the transport of the plumes.

4.5.2 Other Well Configurations

Additional well configurations were also tested in the same area to determine alternate well fields which could be successful. The alternate well field configurations were created by adding or deleting wells in the middle of the well field as necessary. Outside wells in the well field remained at the same locations except for the 2-well configuration. In this case, the wells were placed along the same line as the 4-well field, but were spaced 640 feet apart from each other. The resulting well capture zones were tested using particle tracking sets identical to those used to test the recommended 4-well configuration.

Table 4-1 shows the alternate configurations. The recommended 4-well configuration maintains a low pumping rate without an excessive number of wells. Although additional well field configurations do exist, they are not as efficient as the proposed well field in their operational potential. To be considered operationally efficient, a design was selected which minimized both total well field pumping and the number of pumping wells. This condition was met by the 4-well field, which requires less pumping than the 2-and 3-well configurations, but which matches the pumping rate of the 5-well configuration. It should be noted that if a well becomes nonoperational during its use, the well field can maintain its operation by increasing the pumping rate in the other wells to 750 gpm each. This was tested during the analysis of alternate well fields and was found to function adequately. Well field integrity was maintained with only three wells pumping provided the well pumping rates were increased to 750 gpm each. This was true regardless of the positioning of the last well in the well field. This 3-well configuration should only be maintained for as long as is necessary to effect repairs or replace the fourth well. This will maintain hydraulic control over the South Plume while repairs are effected.

Table 4-1 - Alternate Removal Action Well Field Configuration

Number of Wells	Pumping Rate	Spacing
2	1,500 gpm each	640 feet
3	750 gpm each	375 feet
4	500 gpm each	280 feet
5	400 gpm each	250 feet

4.5.3 Effect of Pumping on the South Plume

Based on the proposed Removal Action groundwater recovery well field location, the effect on the South Plume was evaluated using the local solute transport model. Simulations showing present and future uranium plumes with pumping are included to delineate the movement of the plume over time and the effectiveness of pumping. Figures 4-15 through 4-21 show predicted plumes for years 1997, 2002, 2012, and 2062. The layer 1 plume is shown for all the years; in addition, for 2002 layers 2, 4, and 5 are shown. For this analysis, it has been assumed that time equals "0" in 1992, that pumping begins in 1993 and that uranium source terms (DOE 1990a, Sec. 21) are removed (cleaned up) in 10 years. For 1993 simulations (before pumping began), see Figures 4-1 through 4-4. DOE recognizes that the model limitations discussed in Section 3 apply to the use of these solute transport model results; thus interpretations of these data should be conducted with appropriate reservations.

These figures may be analyzed to determine plume reduction over time and may be compared to the similar time frame "no action" figures (Figures 4-5 through 4-11) to estimate pumping impacts. The 1997 simulation (Figure 4-15) shows a maximum contour (except for a small peak north of Willey Road) after 4 years of pumping in the south plume area of 100 μg/l versus 200 μg/l shown in Figure 4-5. By 2002, almost all the south plume area is below 100 μg/l (Figure 4-16). The plume is dividing near the pumping wells according to the 2012 depiction (Figure 4-20). By 2062, uranium concentrations are below 10 μg/l in this area (Figure 4-21). Uranium concentrations in layers 2, 4 and 5 are also significantly reduced in the 2002 time period from the initial concentrations.

In comparison to the "no action" simulations, pumping is shown to reduce the size and the concentration of the plume at all the designated time periods (for example, compare plumes in Figures 4-5 and 4-15 or Figures 4-6 and 4-16). Similar effects are seen at the lower aquifer layers (for example, compare Figures 4-7 and 4-17).

To further evaluate the extraction efficiency of the proposed Removal Action wells, the solute transport model results were used to derive uranium extraction curves based on the predicted uranium concentration and the wells' pumping rates. The predicted average concentration removed by the well field will decline over time, as shown in Figure 4-22. This decline in concentrations results in a declining uranium removal rate as shown in Figure 4-23. This decline in removal is due to the wells' proximity to the South Plume's predicted center. Initially, the wells are extracting groundwater with the highest uranium concentrations. As time passes, the uranium plume begins to contract in this area and the highest concentrations of uranium contaminated groundwater are removed. At this point, only the central interceptor wells are extracting uranium at high concentrations because of the narrowing of the plume, resulting in lower removal rates. Figure 4-22 shows that the average well field uranium concentration falls below 20 μg/l in approximately the year 2008. The curve showing the predicted cumulative well field removal (Figure 4-24) begins to flatten in approximately the year 2010 showing that removal after that year has become very inefficient. In addition, Figure 4-24 shows that, according to the model, over 50 percent of the total uranium mass contained in the aquifer in 1993 is removed by the year 2010 with the recovery wells pumping a total of 2000 gpm. It should be noted that this result needs to be interpreted in light of the fact that the model contains many assumptions. For example, the model assumes that instantaneous equilibrium is reached between uranium in the liquid and solid states in the aquifer (desorption occurs instantaneously when there is a driving force from solid to liquid states which occurs as the concentration in the liquid is reduced). In fact, this process of desorption is dependent on geochemical conditions and generally will occur at a slower rate. In addition, as described in Section 3, the model prediction of the plume shape does not match very well the plume depicted by recent monitoring data. For these reasons, this 2010 removal estimate may not be accurate.

4.5.4 Capture Analysis

Well field hydraulic performance was analyzed with the model by evaluating drawdown and potentiometric contour surfaces produced by pumping; by performing reverse particle tracking to define capture zones in the XY and YZ planes; and by performing forward tracking in the XY and YZ planes to define potential particle break through.

Drawdown

The far field and near field predicted drawdown of the Removal Action recovery well field is shown in Figures 4-25 and 4-26, respectively. Figure 4-25 shows that the maximum steady-state drawdown forms an ellipse around the Removal Action wells and spreads out throughout Paddy's Run Outlet until bedrock is reached. Figure 4-26 provides detail in the vicinity of the pumping wells with a smaller contour interval (0.2 feet) and shows the specific drawdown patterns near the wells.

The far field and near field predicted potentiometric surface of the Removal Action recovery well field is shown in Figures 4-27 and 4-28, respectively. The recovery wells do have an influence throughout the entire valley (Figure 4-25), but due to the high groundwater velocities in the area, they only capture a small area to the north of their proposed locations (Figure 4-27). Figure 4-28 provides detail in the vicinity of the pumping wells with a smaller contour interval (0.2 feet). The patterns exhibited in Figure 4-28 suggest complete capture along the line of recovery wells.

Reverse Tracking

To define capture zones of recovery wells, particles were reverse tracked from the recovery wells to the point of origin using a modified version of the particle tracker STLINE. Capture zone maps were developed in both the X-Y plane and the Y-Z plane. A large number of particles were seeded at three elevations in a circle adjacent to each well. Projections of these particle paths in the X-Y and Y-Z planes produced the capture zone plots. In the X-Y plane, these capture zones are superimposed on the modeled and monitored plumes.

Figures 4-29, 4-30 and 4-31 show the 5- and 10-year capture zone in the X-Y plane superimposed on the modeled layer 1 plume, the 2000 series well monitored plume, and the 3000 series well monitored plume. Particle tracks produced by reverse tracking demonstrate a capture zone with no identified gaps between the recovery wells. These figures show a traced version of the area covered by the particle tracks so that plumes may be superimposed. In general, the individual reverse particle tracks depict a curved pattern with initial movement (from the well) to the north followed by bending to the northwest and finally to the west. The eastern most recovery well shows a slightly different pattern with the furthest north particle paths curving back to the north.

The capture zone covers the majority of the simulated plume (Figure 4-29); although a small portion of the northeast section of the plume including the 10 and 20 μg/l uranium contour is not captured. The capture zone also covers the majority of the 2000 and 3000 monitoring well plumes (Figures 4-30 and 4-31 - see Section 3.4 for discussion of these plume maps). Three 2000 series well plume areas are missed by the capture zone; one, to the north on the FEMP site, an area greater than 20 μg/l; two, south of the recovery well, an area greater than 20 μg/l, and three, near the recovery wells, a small area greater than 20 μg/l adjacent to Paddy's Run Road. For the 3000 series monitoring well plume, a portion of the easternmost area crossing Willey Road (greater than 20 μg/l) is shown as not captured. In addition, a portion of the plume near the recovery wells is on the southern edge of the capture zone and may not be captured.

Figure 4-32 shows the 10-year capture zone in the Y-Z plane. These particle tracks show capture in all 5 model layers. Since this figure is a vertical projection of all of the particles shown in the horizontal plane, particle tracks could be biased in certain directions in certain layers. Thus, complete capture cannot be definitively shown with this type of reverse tracking. Therefore, forward tracking is conducted to confirm these results (see next subsection). Figure 4-32 also depicts certain particles with strong upward or downward movement. Inspection of the output files indicate that these movements are caused by spurious velocities in the numerical solution amplified by the exaggerated vertical scale.

Forward Tracking

Forward tracking was conducted to confirm the results of reverse tracking for well capture and to provide a baseline for the sensitivity analysis conducted below. A total of seventy five (75) particles were placed in the model layers 1, 2, and 4 at a curvilinear plane located approximately 2300 feet upgradient of the recovery wells. This location was selected to determine the extent of vertical capture that is achieved at the approximate southern boundary of the facility. The length of this plane was defined by the limits of the capture zone defined with reverse tracking (Figure 4-29). Layer 5 was not included in the analysis because there is not confirmed contamination at the bottom of the aquifer and because the layer 5 disappears north of the recovery wells (Figure 2-6). The vertical depth represented by layer 4 depicts a conservative depth of the plume. Particles were also seeded at the locations of the PRRS contaminated wells in a similar manner as above to determine the effect of pumping on the PRRS plumes.

Figures 4-33 and 4-34 show the results of the forward tracking in the XY and YZ planes respectively. All particles seeded upgradient were captured at the design recovery pumping of 4 wells at 500 gpm each or a total well field pumping of 2000 gpm. As reported above, PRRS deflection was minimal (less than 20 feet for the northern most particle representing the inorganic plume) when compared to the no pumping case (see Section 4.5.1).

Summary

The above three analytical techniques demonstrate the recovery well's ability to create an effective hydraulic barrier at the design location at a pumping rate of 2000 gpm for a 4 well recovery system. The capture zone extends toward the site and curves toward the west. According to the model, capture occurs in all 5 model layers; forward tracking confirms capture in model layers 1, 2 and 4.

4.5.5 Effect of Pumping on the South Field Plumes

The fact that the pumping zone of influence extends on site (Figure 4-25) to areas of elevated uranium concentrations (Figure 4-30) runs counter to the objective of being consistent with the final remediation. That is, the South Plume pumping will result in an increased hydraulic gradient resulting in velocity increases causing these on-site plumes to expand. A simulation was conducted to estimate the time of travel from these plumes to the property line under pumping conditions. Particles were seeded at the 200 ppb uranium contours in model layer 1 for these two areas and time of travel for these particles was calculated with the model.

Figure 4-35 shows this simulation. The predicted water time of travel (0 retardation) from the southern 200 contour area was 1.5 years. With the calibrated retardation factor of 12, uranium transport would take approximately 18 years. The predicted water time of travel (0 retardation) from the northern 200 contour area was 3 years. With the calibrated retardation factor of 12, uranium transport would take 36 years.

4.6 Sensitivity Analysis

A range of hydraulic conductivity over which the model effectively simulates capture at the well field pumping rate of 2000 gpm is established with sensitivity analysis. To help direct this sensitivity analysis, the results of previous pump tests of the aquifer are reviewed.

4.6.1 Calculated Hydraulic Conductivity

Table 4-2 shows a compilation of historically determined values of horizontal hydraulic conductivity (K_h) of the Great Miami Aquifer. These values of K_h were calculated based on the results of pump tests on the aquifer. Some of the studies reported a range of K_h while other studies reported a single value. By calculating a simple average between the endpoints of the reported range, then simple statistics may be performed on nine pump test values of K_h. Table 4-2 shows an average K_h of 349 feet/day, a minimum value of 100 feet/day, a maximum of 774 feet/day, and a standard deviation of 174 feet/day.

These values are used to establish a working range of hydraulic conductivity sensitivity analysis.

Table 4-2
Great Miami Aquifer – Horizontal Hydraulic Conductivities Determined Through Pump Tests

Low Range (ft/day)	Average (ft/day)	High Range (ft/day)	Reference
	330		Dove 1961
328	431	534	Smith 1962
	120		Klaer 1968
318	343	368	Klazmann 1950
312	318	323	Klaer and Klazmann 1943
	267		Speiker and Norris 1962
334	369	403	Lewis 1968
	774		Smith 1960
100	190	280	Papadopoulos 1984

Summary Statistics

# of values	9
average	349
minimum	100
maximum	774
stand deviation	174

Notes:
1. If a single value was reported, the reported value was used as the average.
2. If a range of values were reported, then the average was calculated between these two values.
3. Minimum and maximum determined from all reported values.

4.6.2 Results of Sensitivity Simulations

Sensitivity analysis was conducted by varying horizontal hydraulic conductivity above and below the calibrated (nominal) model case (450 feet/day in layers 1, 2, and 3, 600 feet/day in layers 4 and 5 in the calibrated model). Layer 3, the clay interbed, is not present in the south plume area and therefore, is represented in the south plume area with a similar value of K_h as layers 1 and 2. Where the clay interbed is present at locations beneath the FEMP site, the K_h of the interbed (3×10^{-4} feet/day) was left as it was. During the sensitivity simulations, the ratio between model layers 1, 2 and 3 to layers 4 and 5 was kept constant to maintain the flow relationship between layers. For example, if K_h in layers 1, 2 and 3 was raised by a factor of 1.5, then K_h in layers 4 and 5 would be raised by the same factor. Forward particle tracking was utilized to assess the different sensitivity runs. The same procedure as discussed above in Section 4.5.4 (75 seeded particles at a location approximately 2300 feet upgradient in layers 1, 2 and 4) was followed. The nominal case, which is used for comparison of the sensitivity runs, is presented in Section 4.5.4 and Figures 4-33 and 4-34.

Figures 4-36 through 4-49 show the results of the sensitivity runs. Two figures are presented for each case showing the XY and YZ aspects of capture. For clarity, the PRRS particles are not shown on Figures 4-34, 4-37, 4-39, and 4-41. The K_h in the nominal case was multiplied by factors ranging from 0.1 to 3 to produce these simulations. Results are summarized in Table 4-3.

As would be expected, raising and lowering the K_h have opposite effects on the system performance. Raising the K_h moves the system toward uranium break through, but decreases the tendency toward PRRS capture. At 1.5 times nominal, 3 particles from layer 4 are not captured. The effect is magnified as K_h increases; at 1.75 times nominal 4 particles are not captured including 1 from layer 2, at 3 times nominal 21 particles are not captured including 4 each from layers 1 and 2. Break through begins with particles seeded at the western edge of the capture zone in layer 4 (Figures 4-36 and 4-37). As K_h increases, some particles are able to move between the wells without being captured, initially from layer 4 (Figures 4-38 and 4-39) and finally break through from all layers occurs (Figures 4-40 and 4-41). In all simulations with K_h greater than the nominal case, there is less impact on the PRRS plumes than the nominal K_h case.

Lowering the K_h increases the ability of the system to capture the uranium plume, however, the system will have a greater tendency toward PRRS capture. At 0.7 times nominal, PRRS inorganic plume deflection increases to approximately 80 feet; at 0.4 times nominal, PRRS inorganic deflection increases to approximately 500 feet and the organic plume further south is also affected. As K_h decreases further, the PRRS inorganic plume particles are captured (Figures 4-46 and 4-47) and finally both PRRS inorganic and organic plume particles are captured (Figures 4-48 and 4-49).

Based on these results, K_h values of 787 feet/day (Run 3 on Table 4-3) and 315 feet/day (Run 5) represent approximate upper and lower bounds for K_h at which the recovery system can still meet the objectives. Although break through did occur at 787 feet/day, it was primarily from layer 4. Greater PRRS deflection occurred at 315 feet/day, however 80 feet is a relatively minor impact. In addition, either of these effects can be compensated for by raising or lowering the pumping rate of the recovery wells. The process of changing the operational parameters is described in the DMEPP (PARSONS 1992).

Table 4-3
Sensitivity Analysis Result Summary

Run #	Figure #s	Factor Times Nominal	Kh Layers 1-3 (ft/day)	Kh Layers 4,5 (ft/day)	# particle not cptrd layer 1	# particle not cptrd layer 2	# particle not cptrd layer 4	PRRS Impact
1	4-33, 4-34	1	450	600	0	0	0	~ 20 ft deflect inorg particle minimal organic deflection
2	4-35, 4-36	1.5	675	900	0	0	3	< nominal case
3	4-37, 4-38	1.75	787	1050	0	1	4	< nominal case
4	4-39, 4-40	3	1350	1800	4	4	14	< nominal case
5	4-41, 4-42	0.7	315	420	0	0	0	~ 80 ft deflect inorg particle minimal organic deflection
6	4-43, 4-44	0.4	180	240	0	0	0	~ 500 ft deflect inorg particle ~ 80 ft deflect organic particle
7	4-45, 4-46	0.25	112	150	0	0	0	capture inorganic plume particles ~ 400 ft deflect organic particle
8	4-47, 4-48	0.1	45	60	0	0	0	capture inorganic plume particles capture organic plume particles

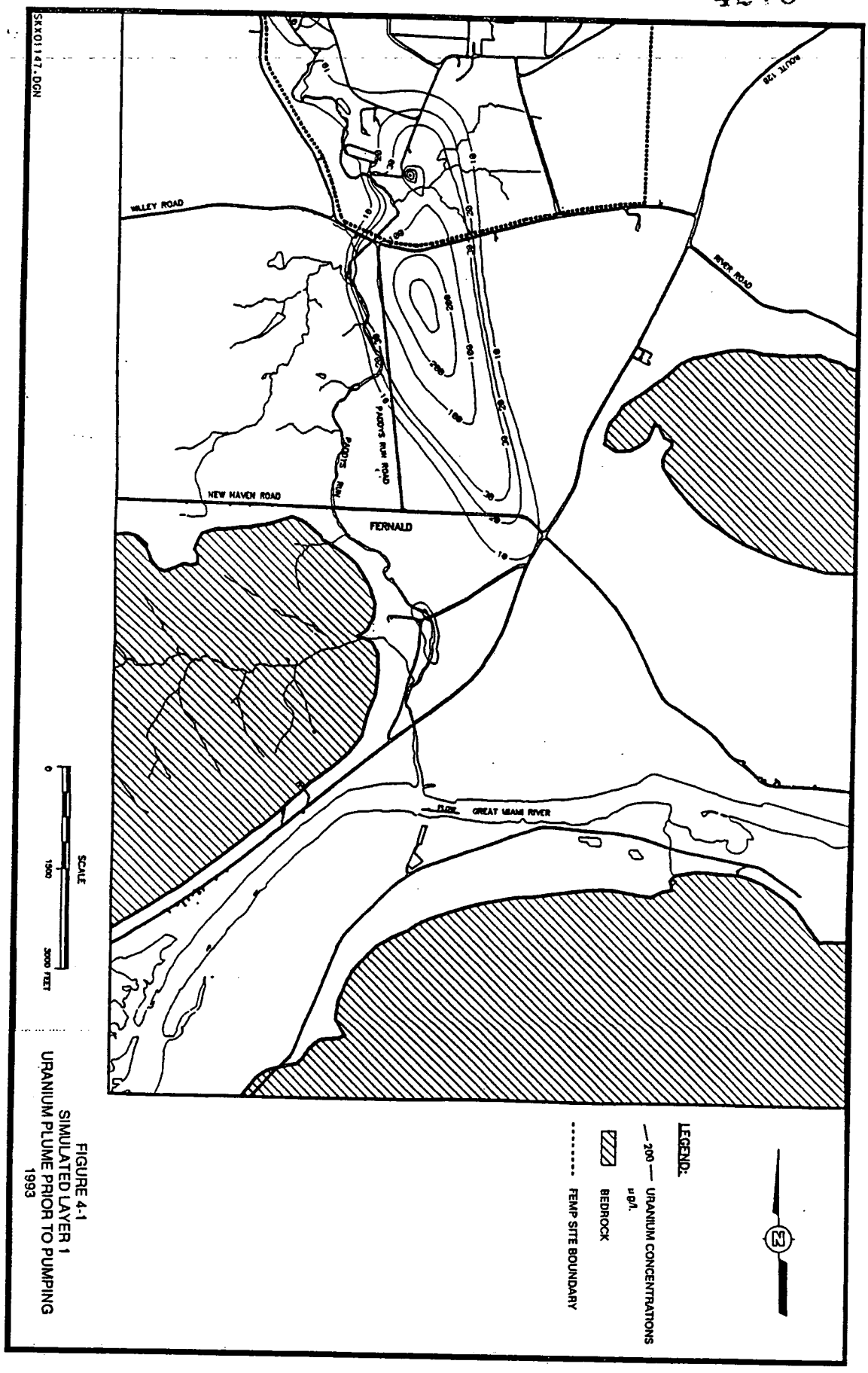


Figure 4-1 - Simulated Layer 1 Uranium Plume Prior to Pumping - 1993

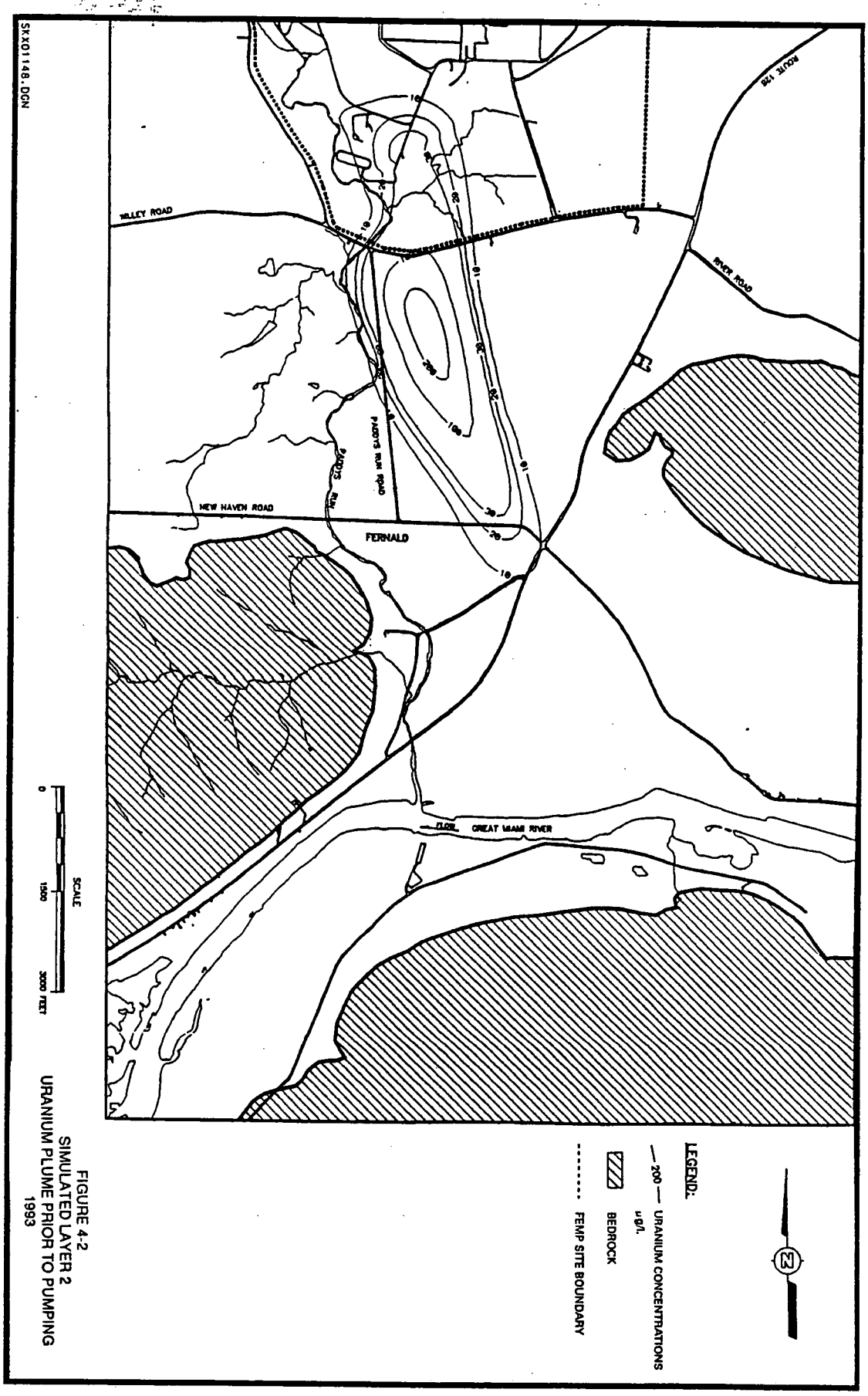


Figure 4-2 - Simulated Layer 2 Uranium Plume Prior to Pumping - 1993

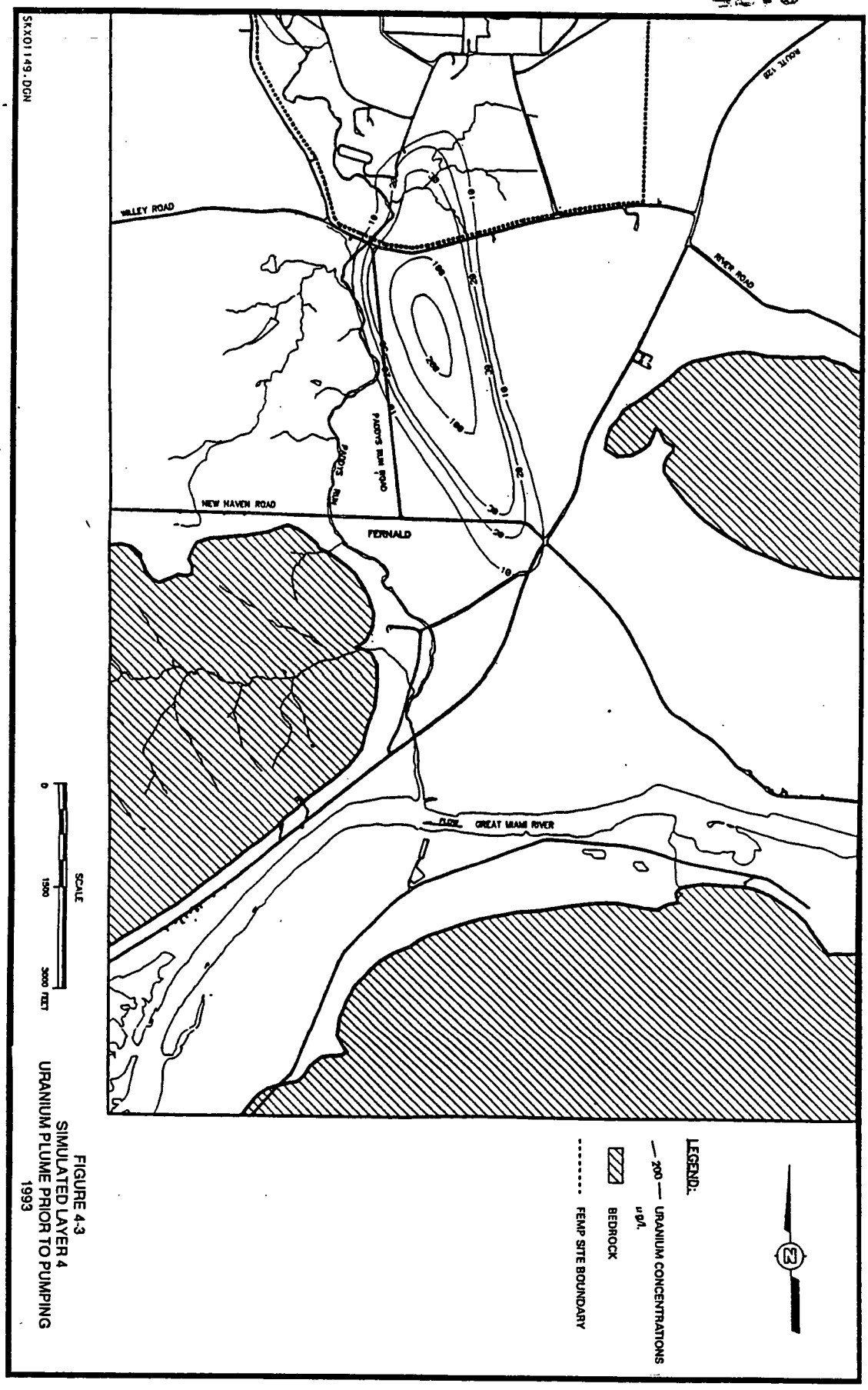


Figure 4-3 - Simulated Layer 4 Uranium Plume Prior to Pumping - 1993

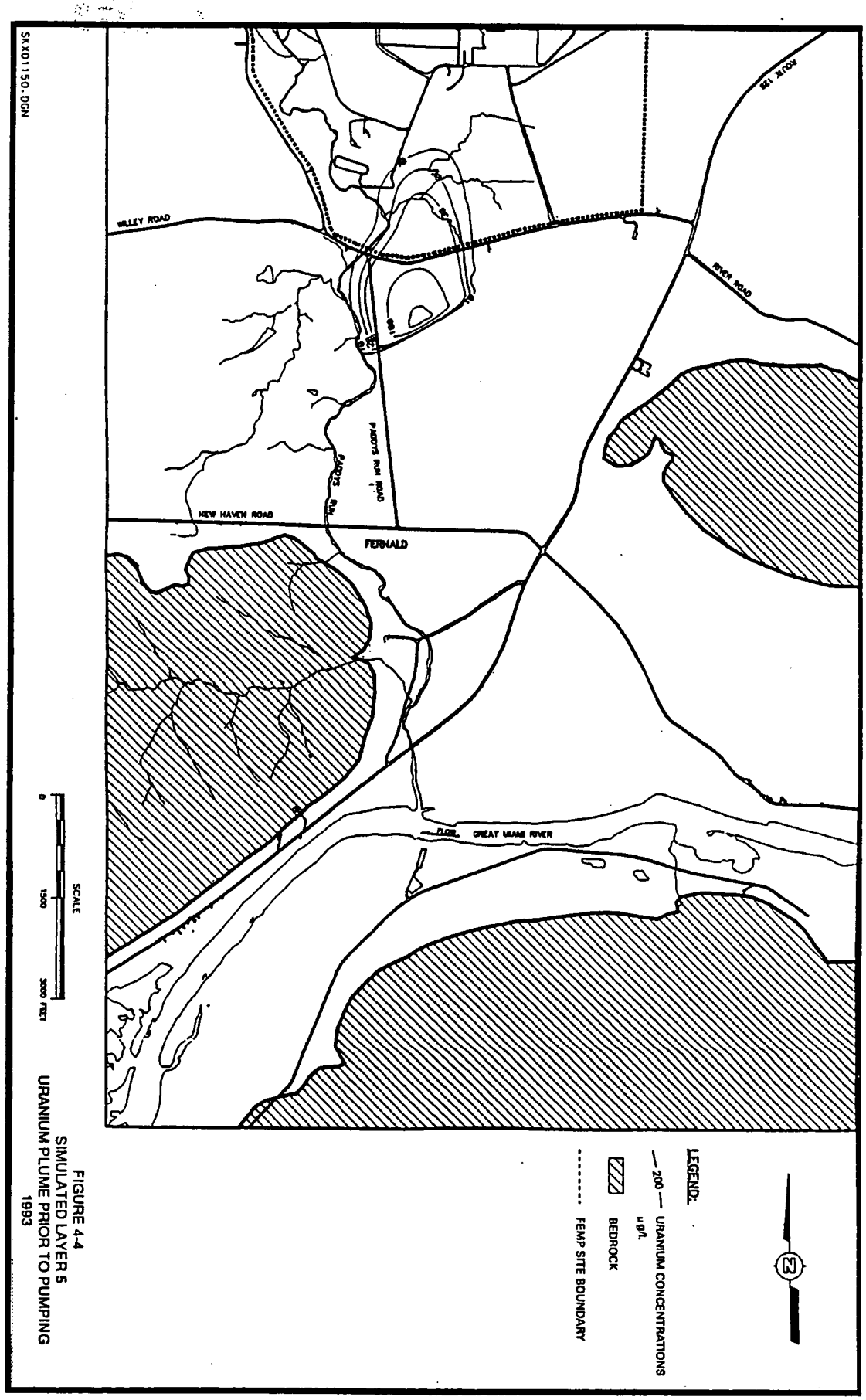


Figure 4-4 - Simulated Layer 5 Uranium Plume Prior to Pumping - 1993

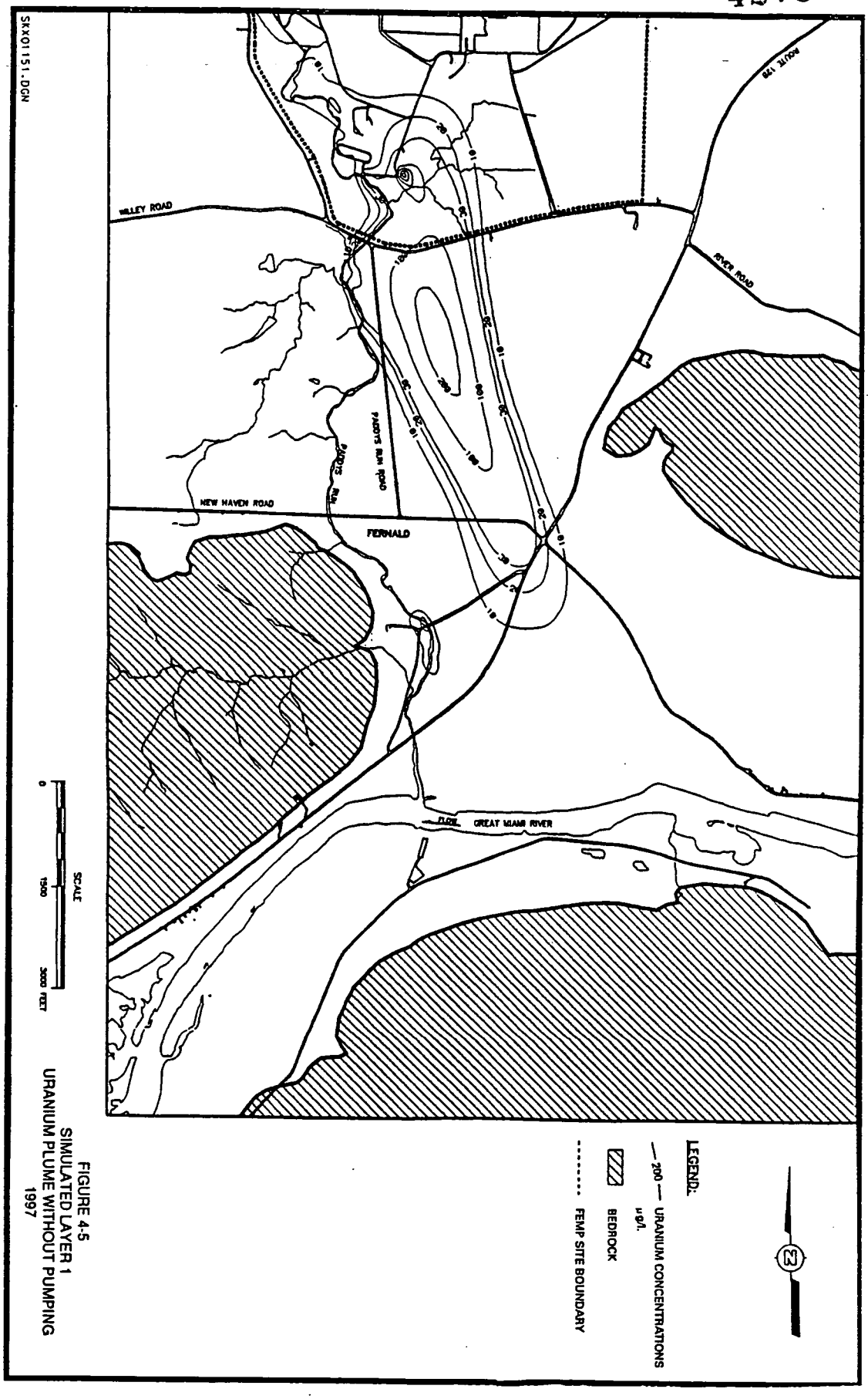


Figure 4-5 - Simulated Layer 1 Uranium Plume Without Pumping - 1997

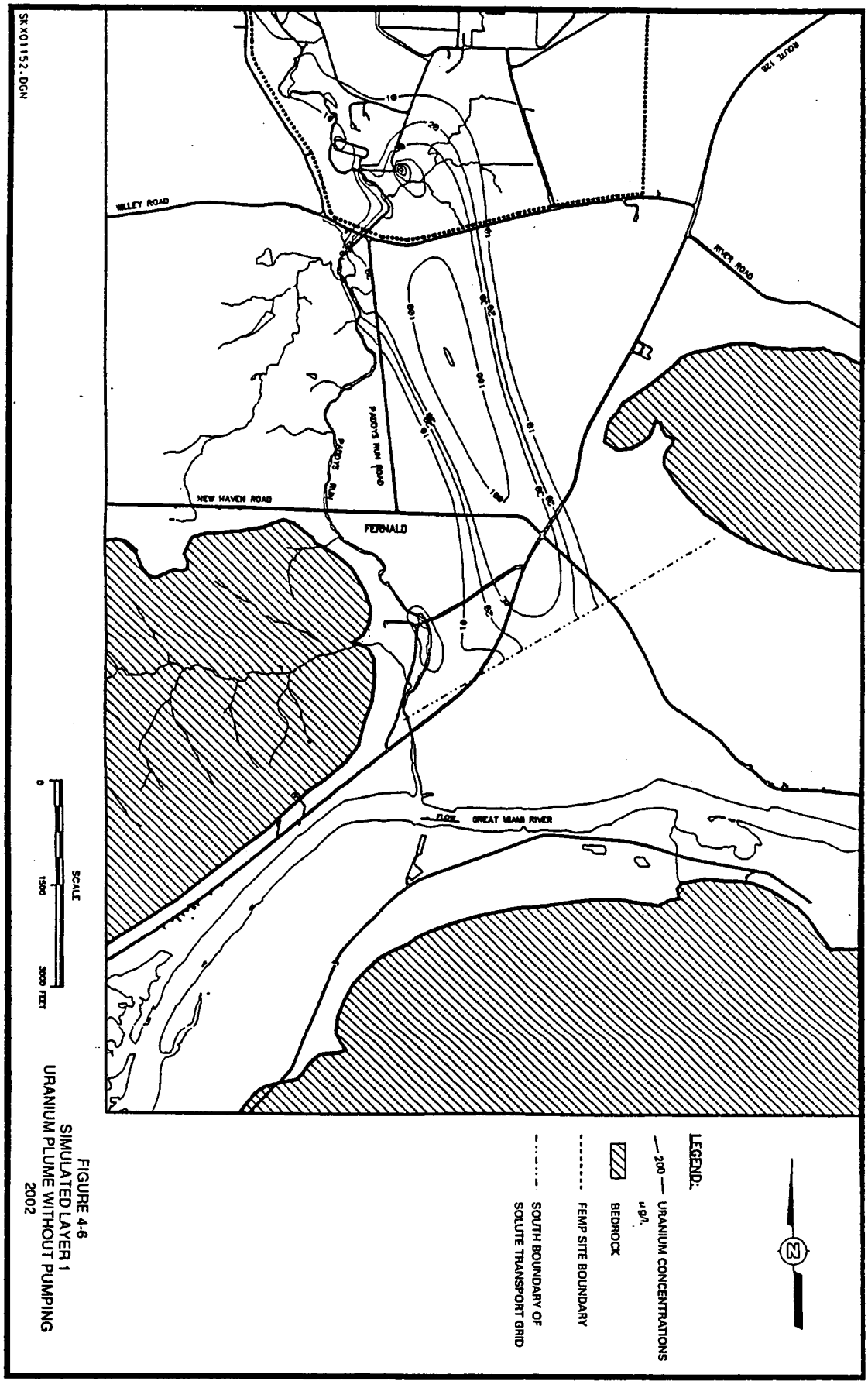


FIGURE 4-6
SIMULATED LAYER 1
URANIUM PLUME WITHOUT PUMPING
2002

Figure 4-6 - Simulated Layer 1 Uranium Plume Without Pumping - 2002

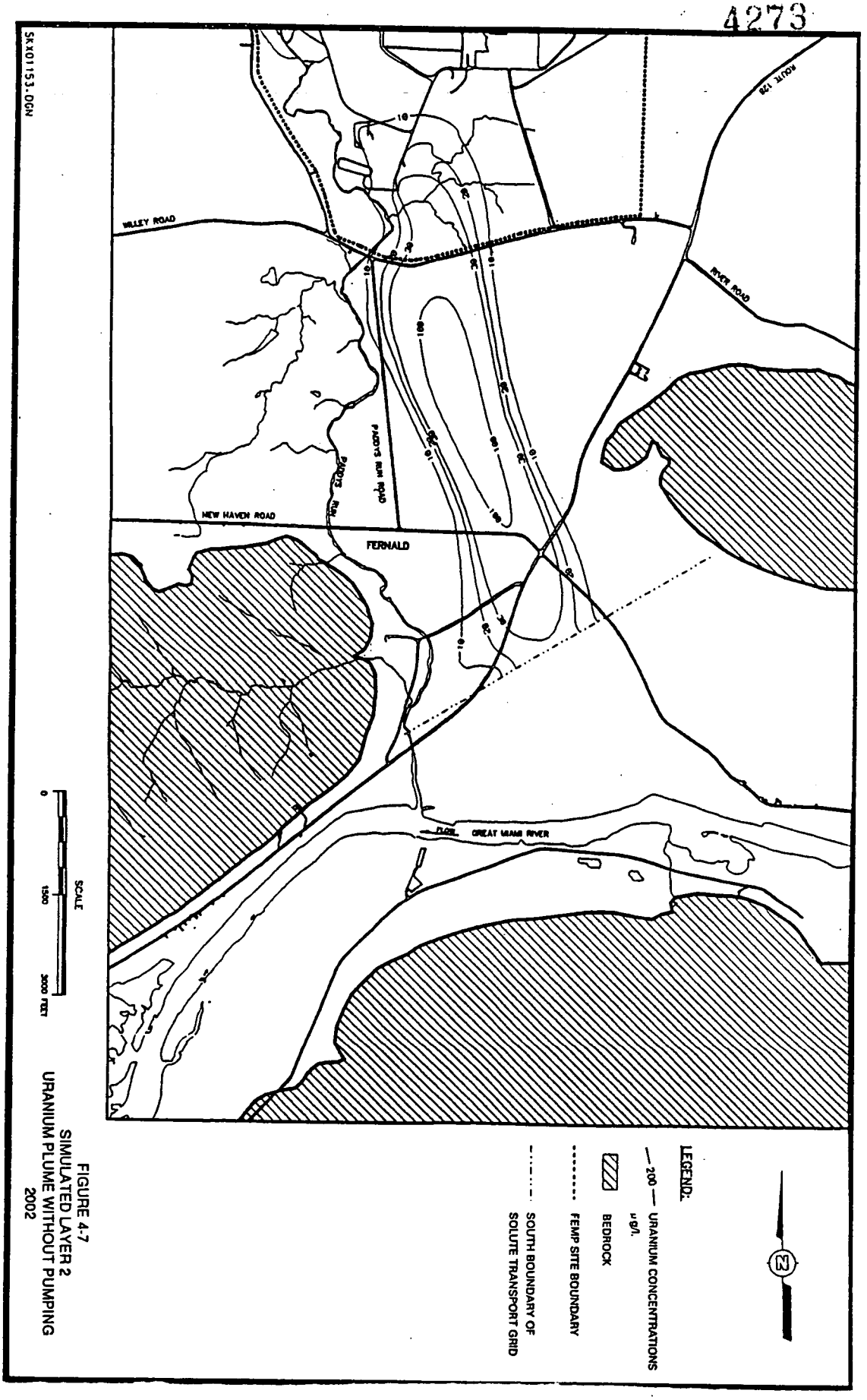


Figure 4-7 - Simulated Layer 2 Uranium Plume Without Pumping - 2002

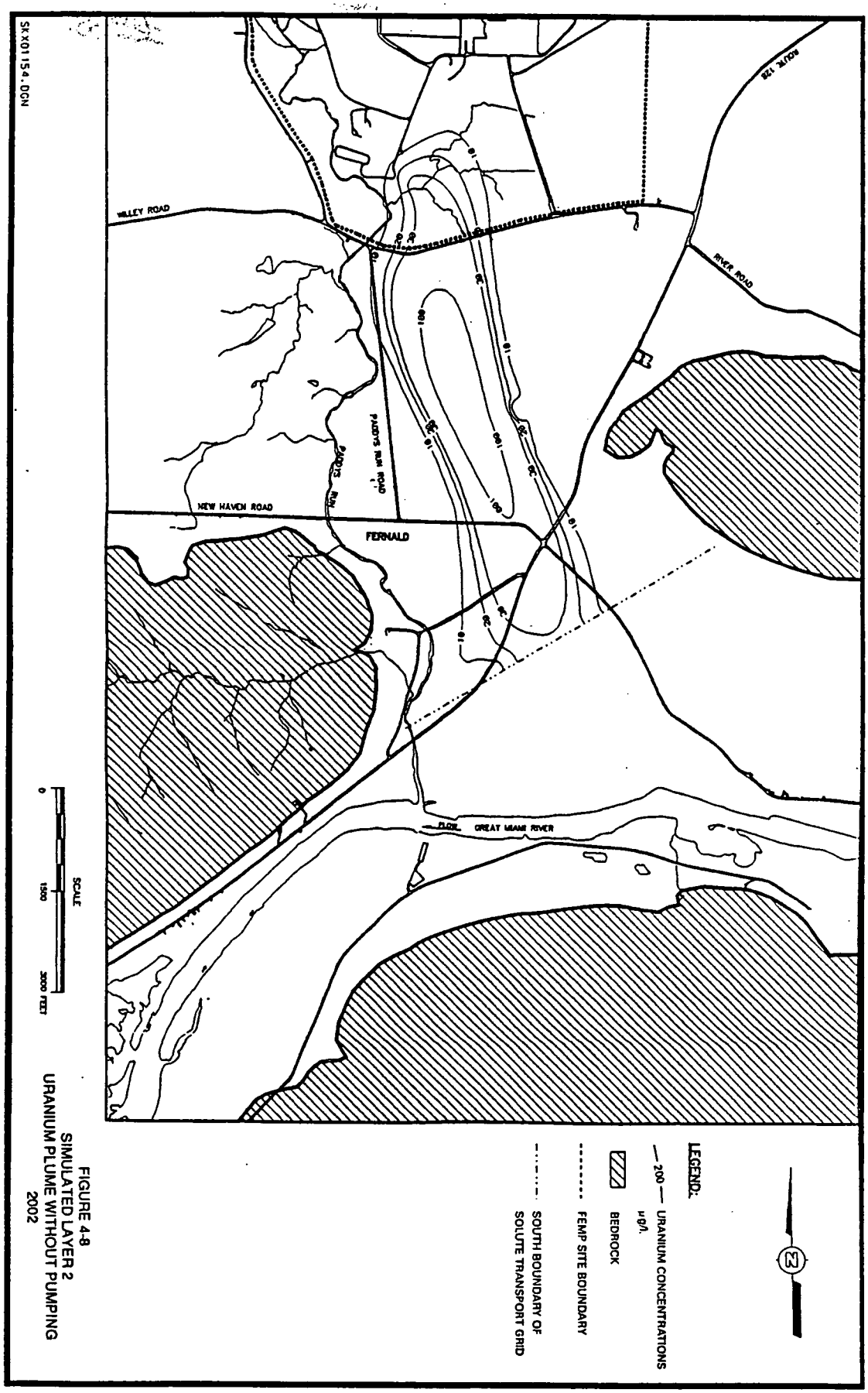


Figure 4-8 - Simulated Layer 4 Uranium Plume Without Pumping - 2002

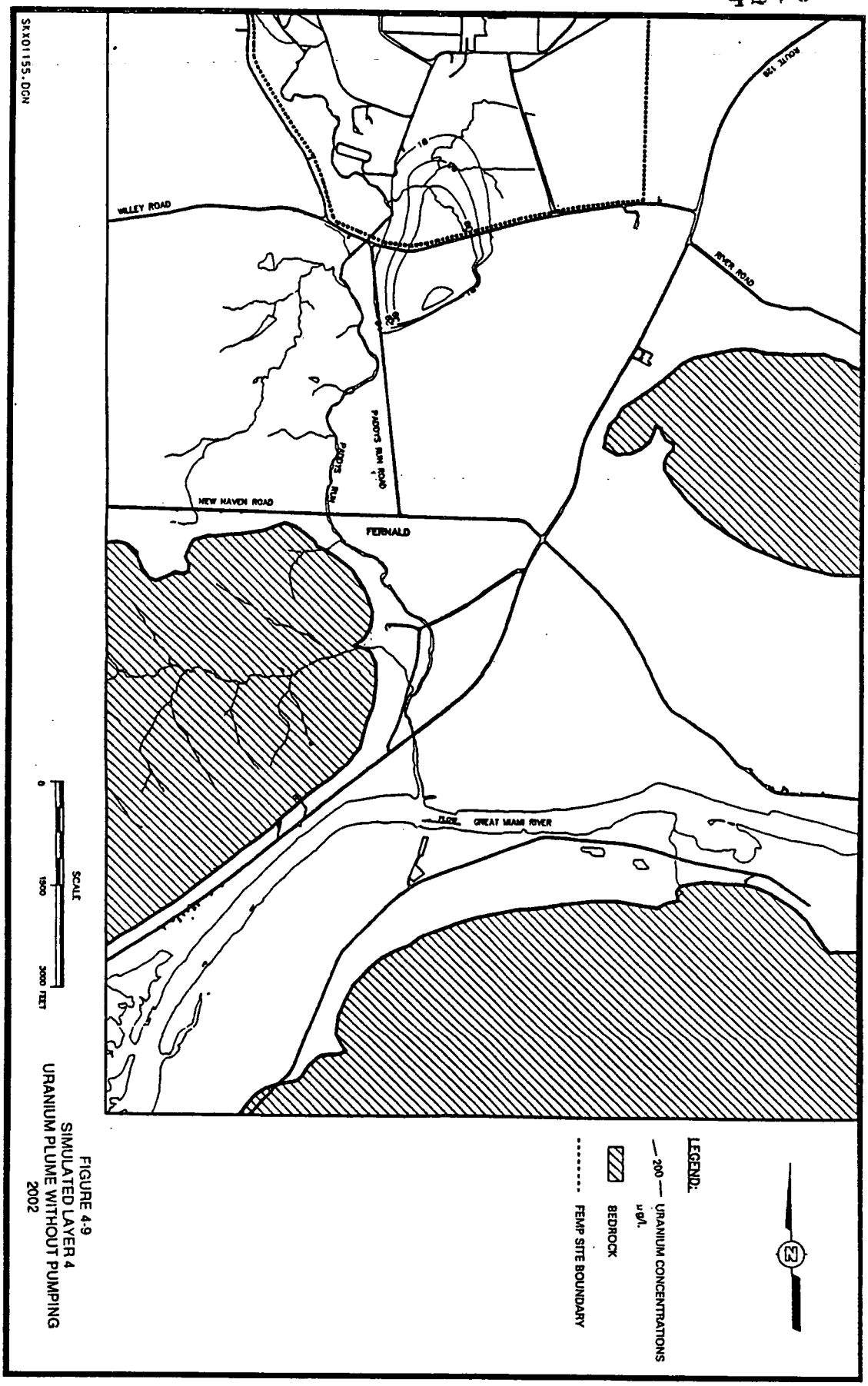


FIGURE 4-9
SIMULATED LAYER 4
URANIUM PLUME WITHOUT PUMPING
2002

Figure 4-9 - Simulated Layer 5 Uranium Plume Without Pumping - 2002

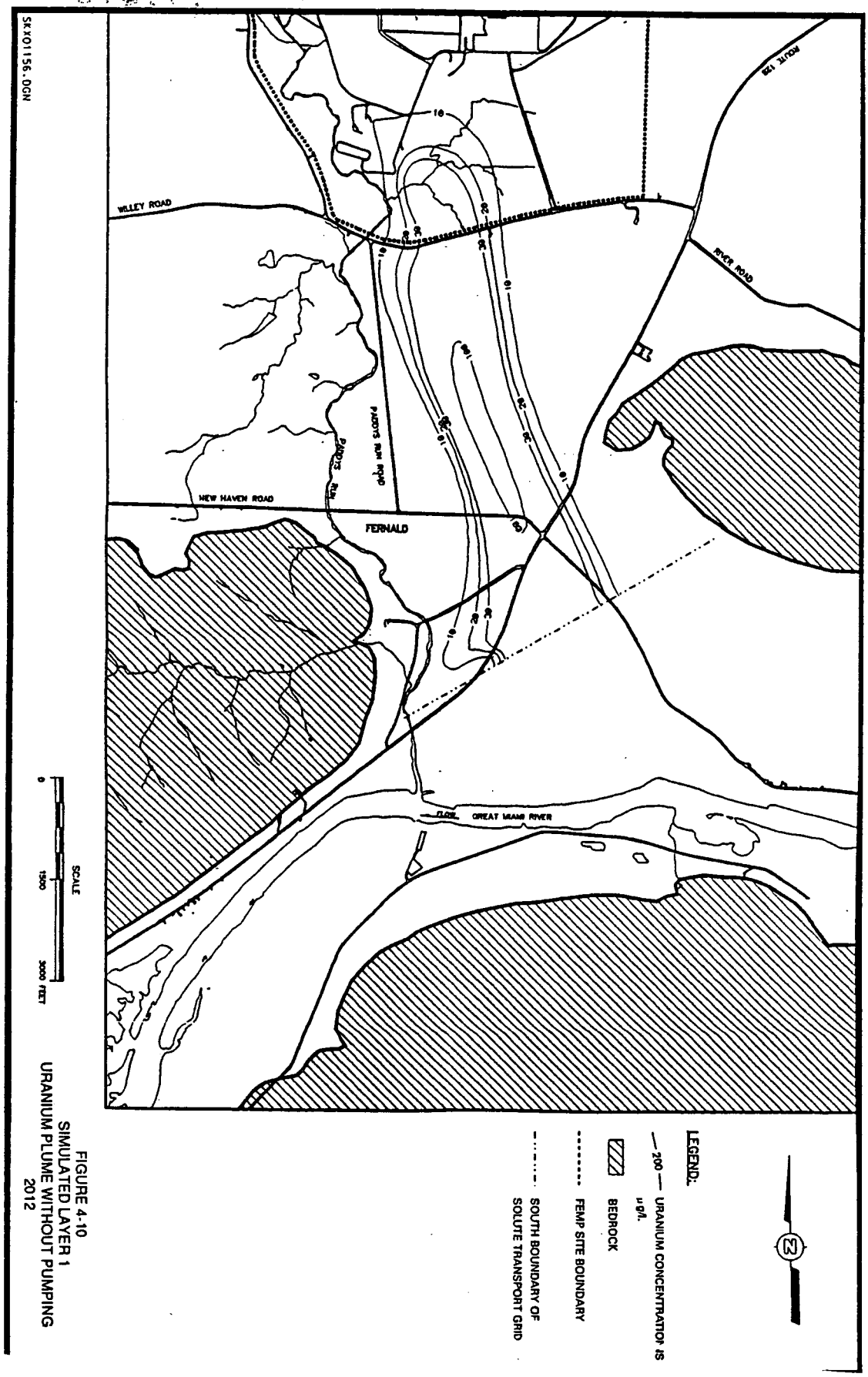


Figure 4-10 - Simulated Layer 1 Uranium Plume Without Pumping - 2012

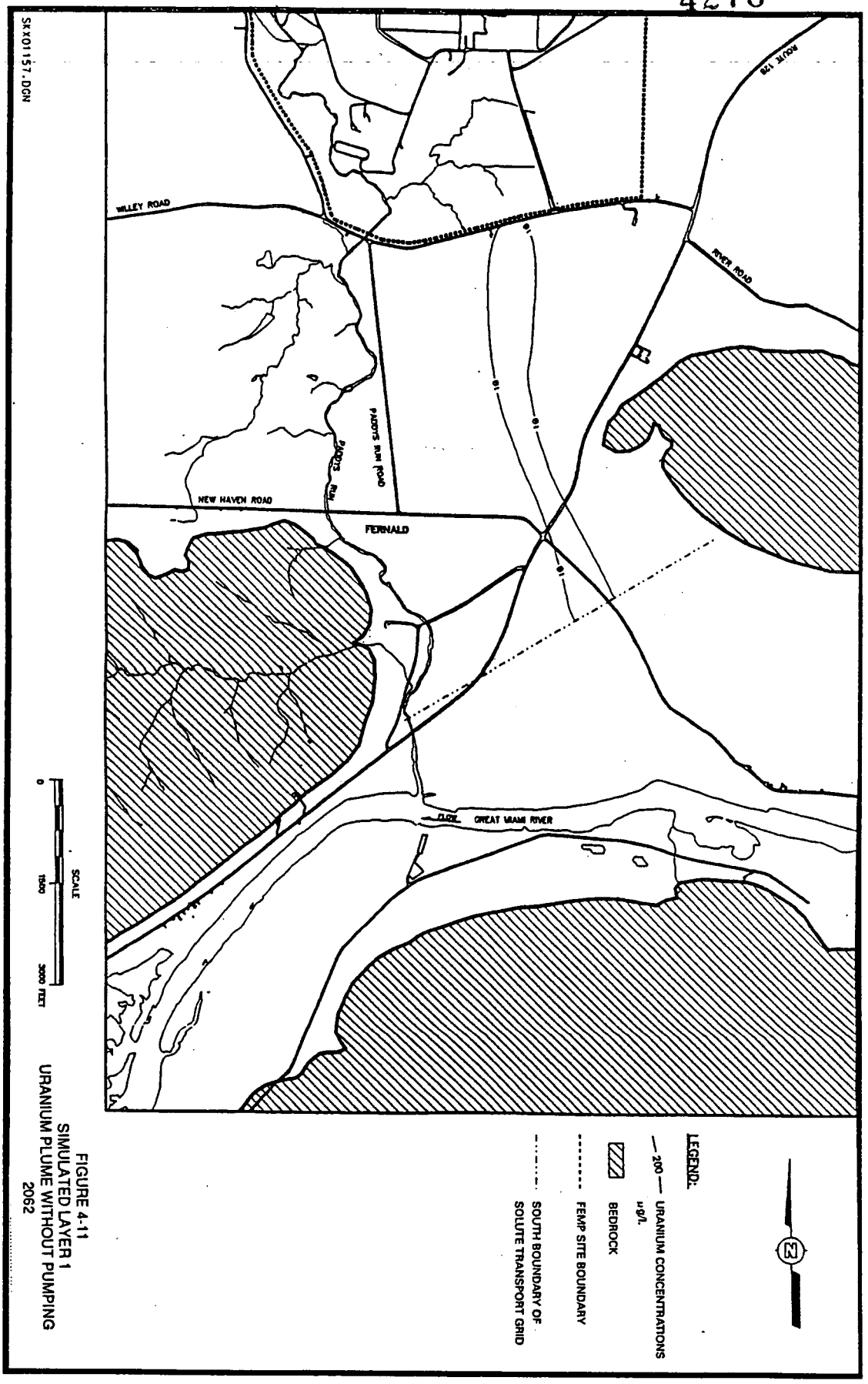


FIGURE 4-11
SIMULATED LAYER 1
URANIUM PLUME WITHOUT PUMPING
2062

Figure 4-11 - Simulated Layer 1 Uranium Plume Without Pumping - 2062

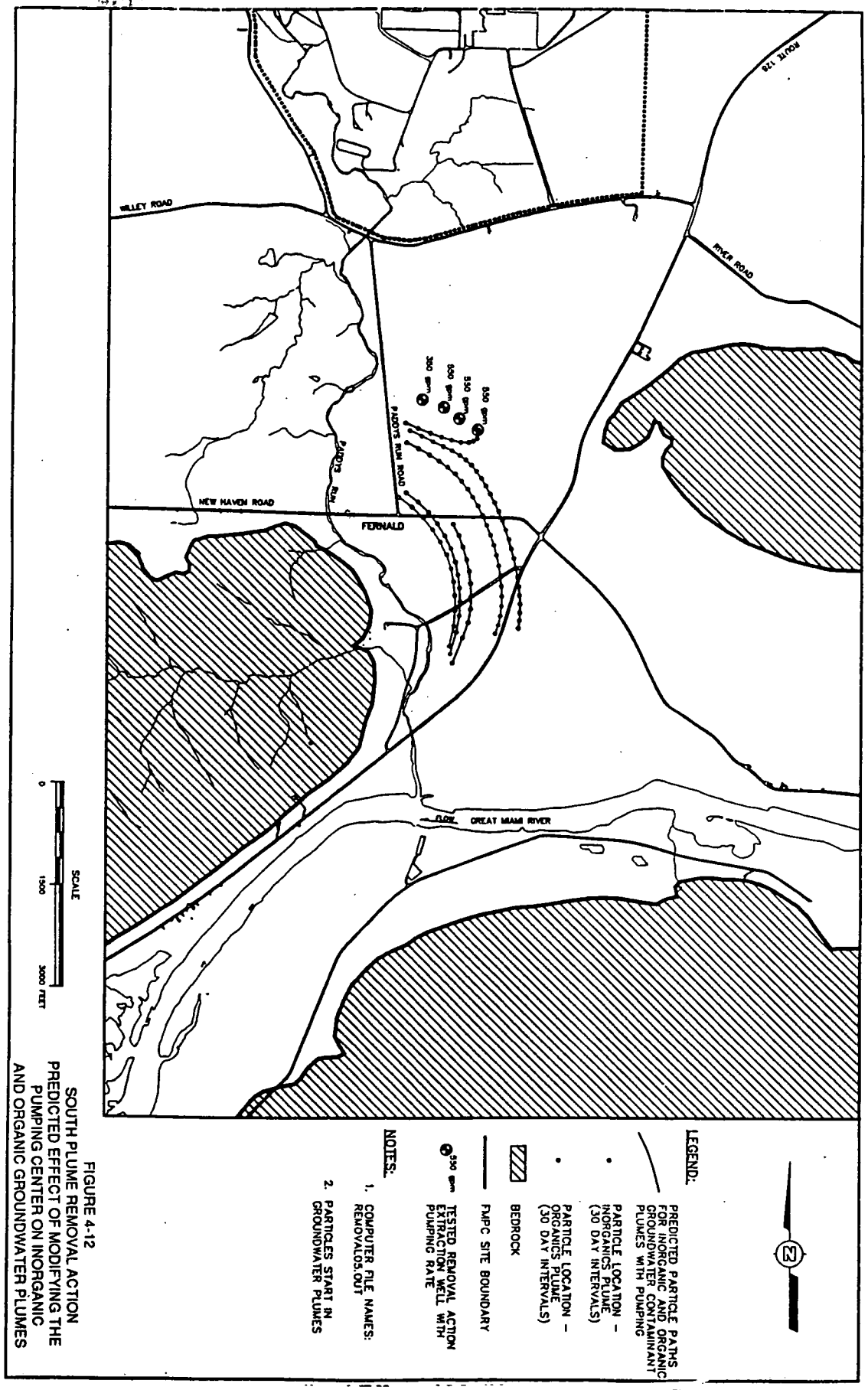


Figure 4-12 - Predicted Effect of Modifying the Pumping Center on Inorganic and Organic Groundwater Plumes

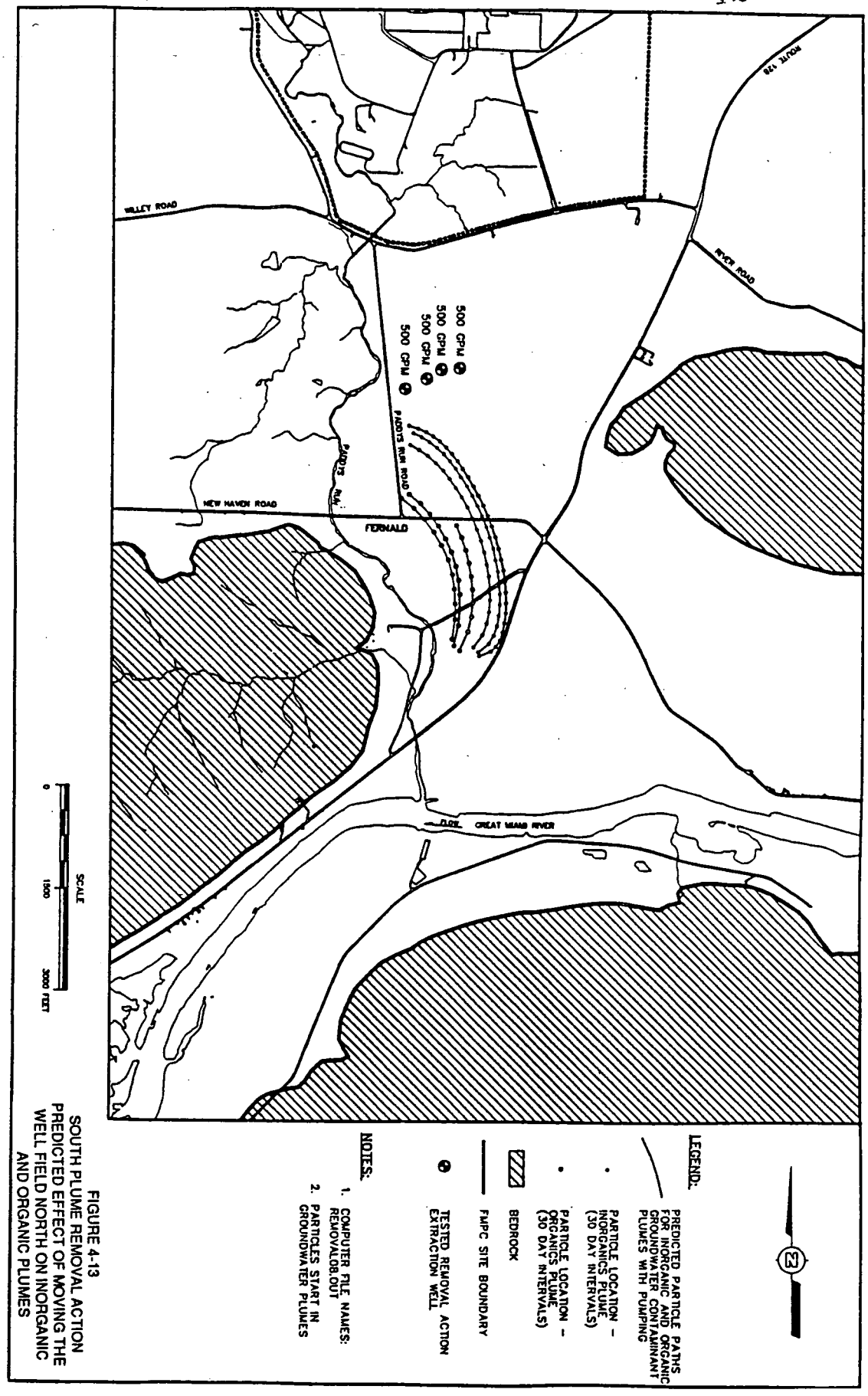


FIGURE 4-13
SOUTH PLUME REMOVAL ACTION
PREDICTED EFFECT OF MOVING THE
WELL FIELD NORTH ON INORGANIC
AND ORGANIC PLUMES

Figure 4-13 - Predicted Effect of Moving the Well Field North on Inorganic and Organic Plumes

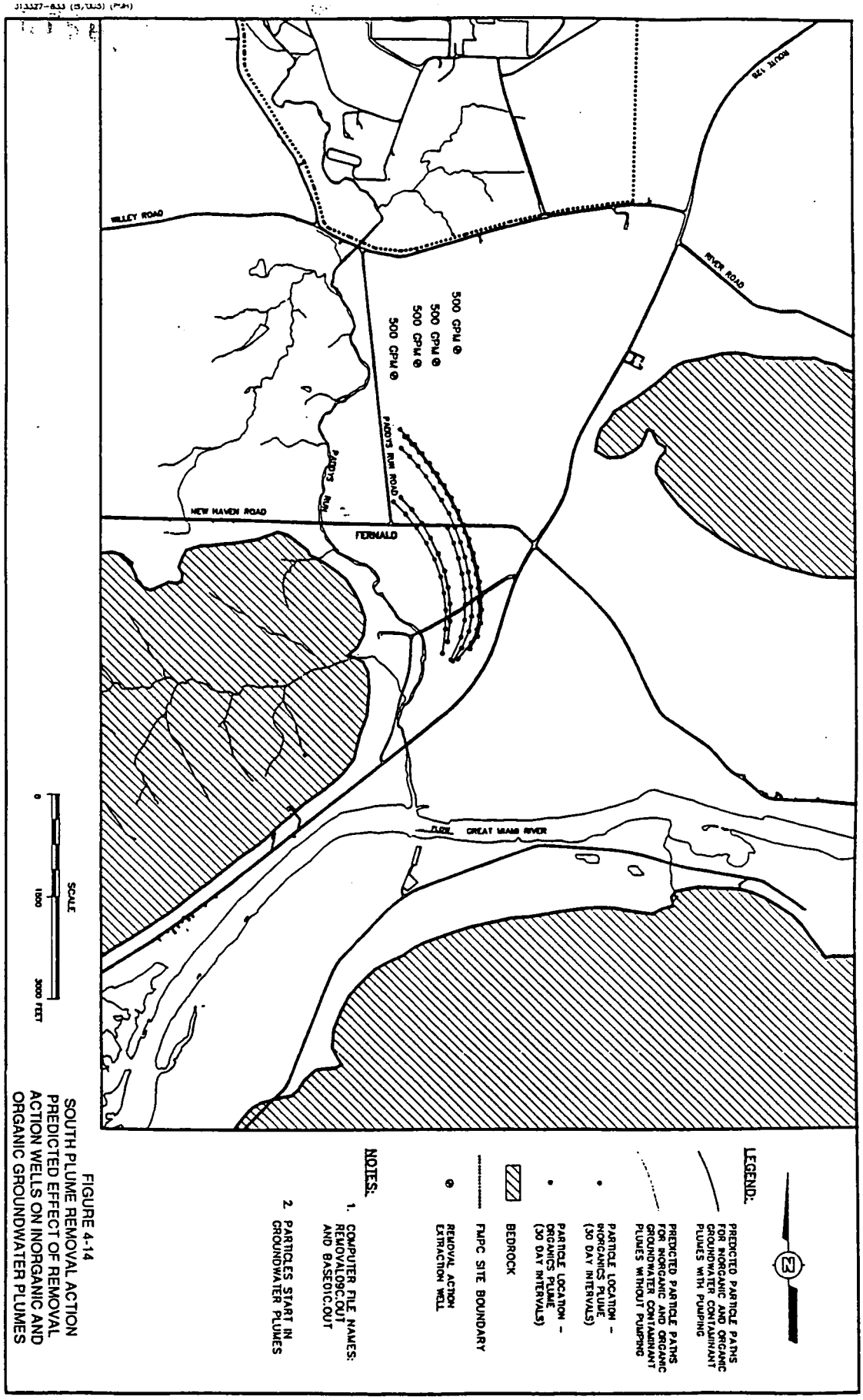


FIGURE 4-14
SOUTH PLUME REMOVAL ACTION
PREDICTED EFFECT OF REMOVAL
ACTION WELLS ON INORGANIC AND
ORGANIC GROUNDWATER PLUMES

Figure 4-14 - Predicted Effect of Removal Action Wells on Inorganic and Organic Groundwater Plumes

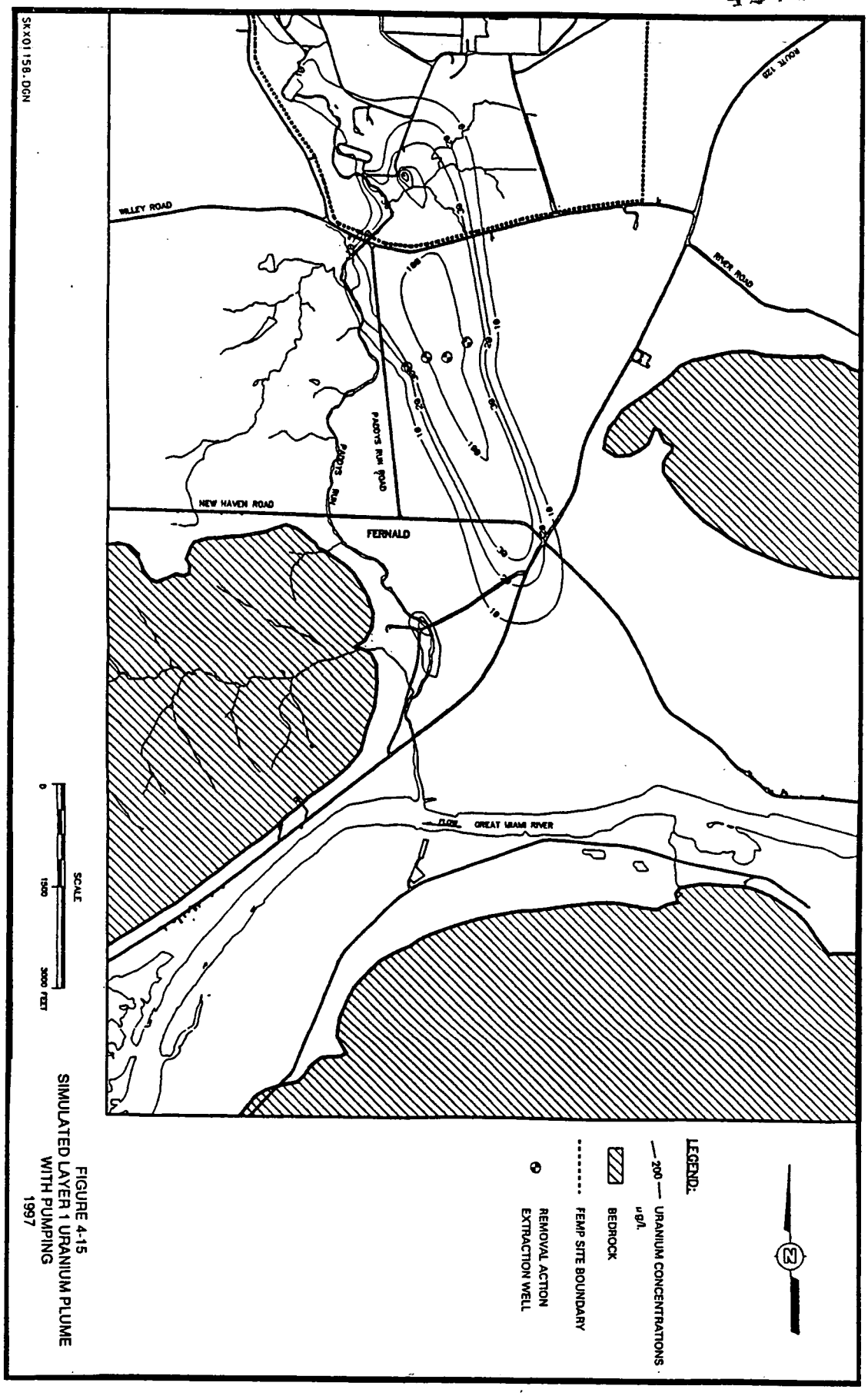


FIGURE 4-15
SIMULATED LAYER 1 URANIUM PLUME
WITH PUMPING
1997

Figure 4-15 - Simulated Layer 1 Uranium Plume With Pumping - 1997

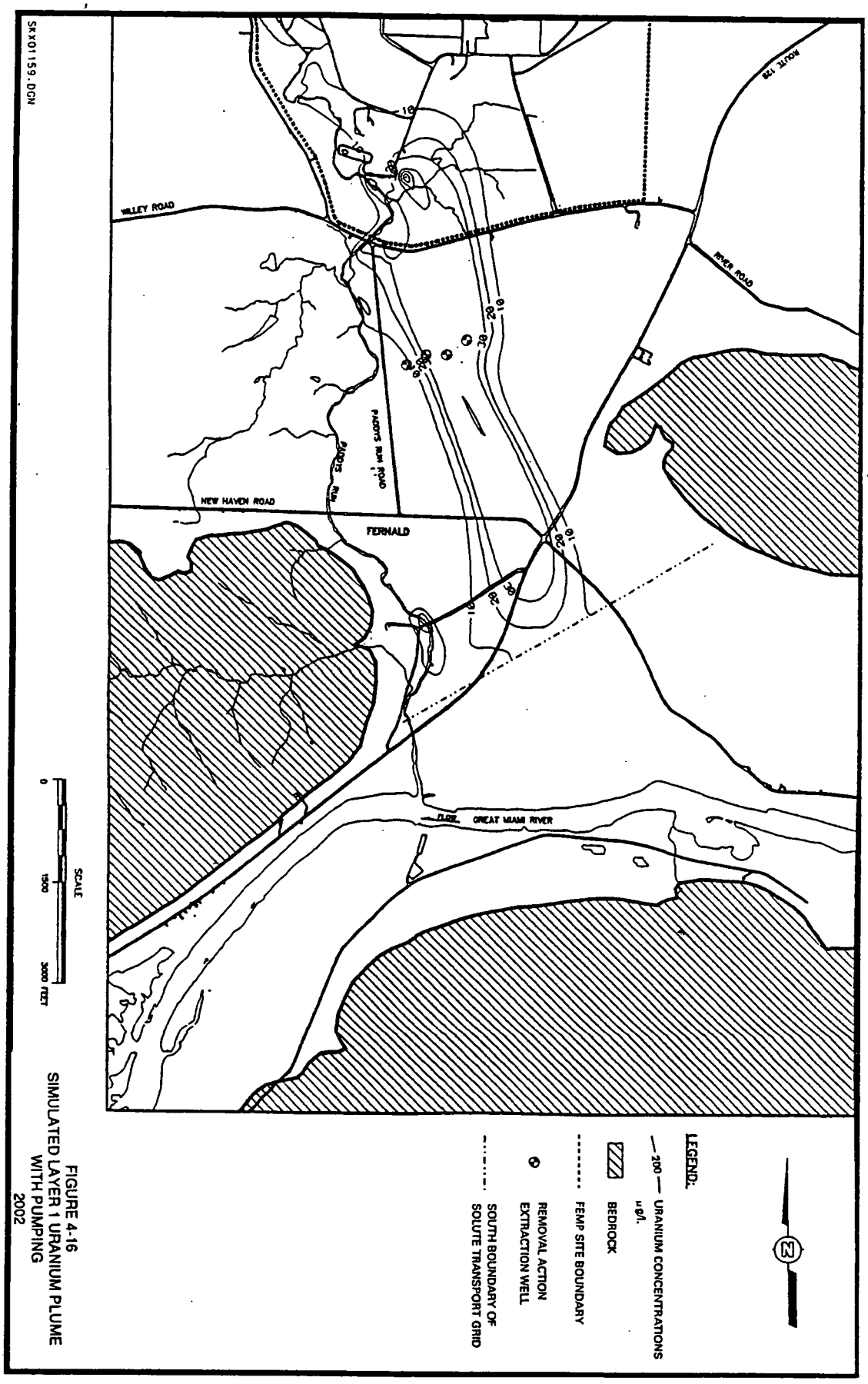


Figure 4-16 - Simulated Layer 1 Uranium Plume With Pumping - 2002

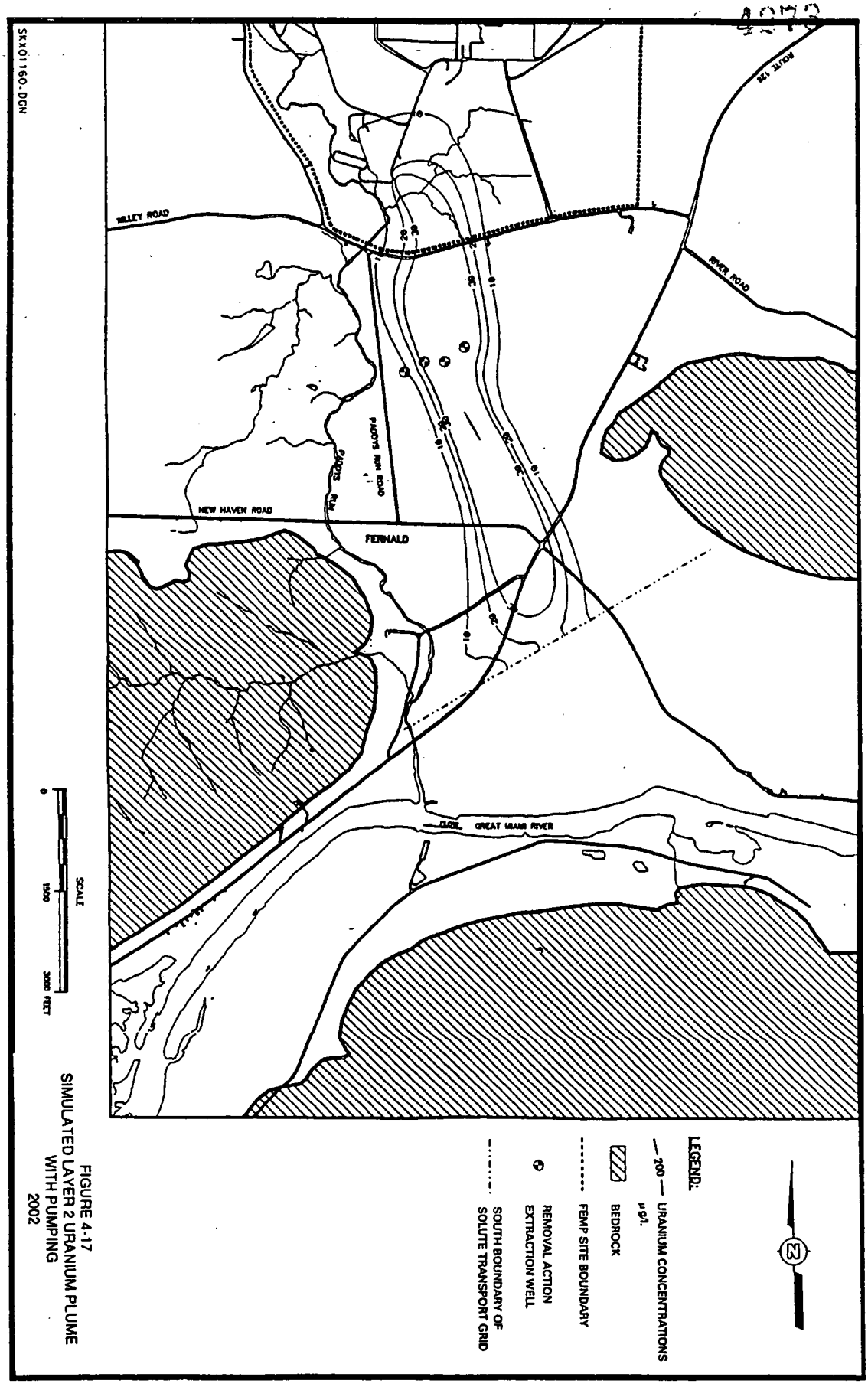


Figure 4-17 - Simulated Layer 2 Uranium Plume With Pumping - 2002

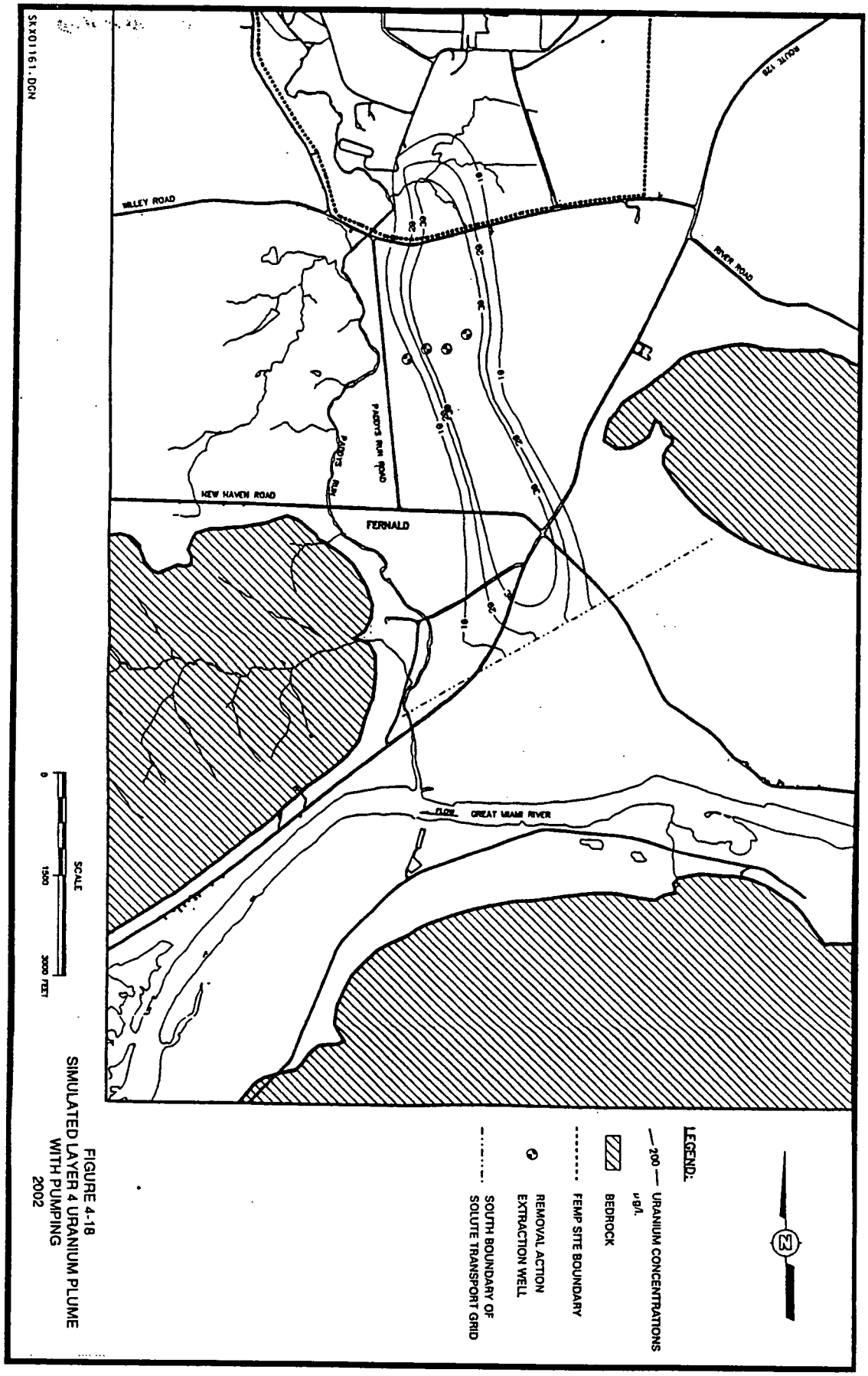


FIGURE 4-18
SIMULATED LAYER 4 URANIUM PLUME WITH PUMPING 2002

Figure 4-18 - Simulated Layer 4 Uranium Plume With Pumping - 2002

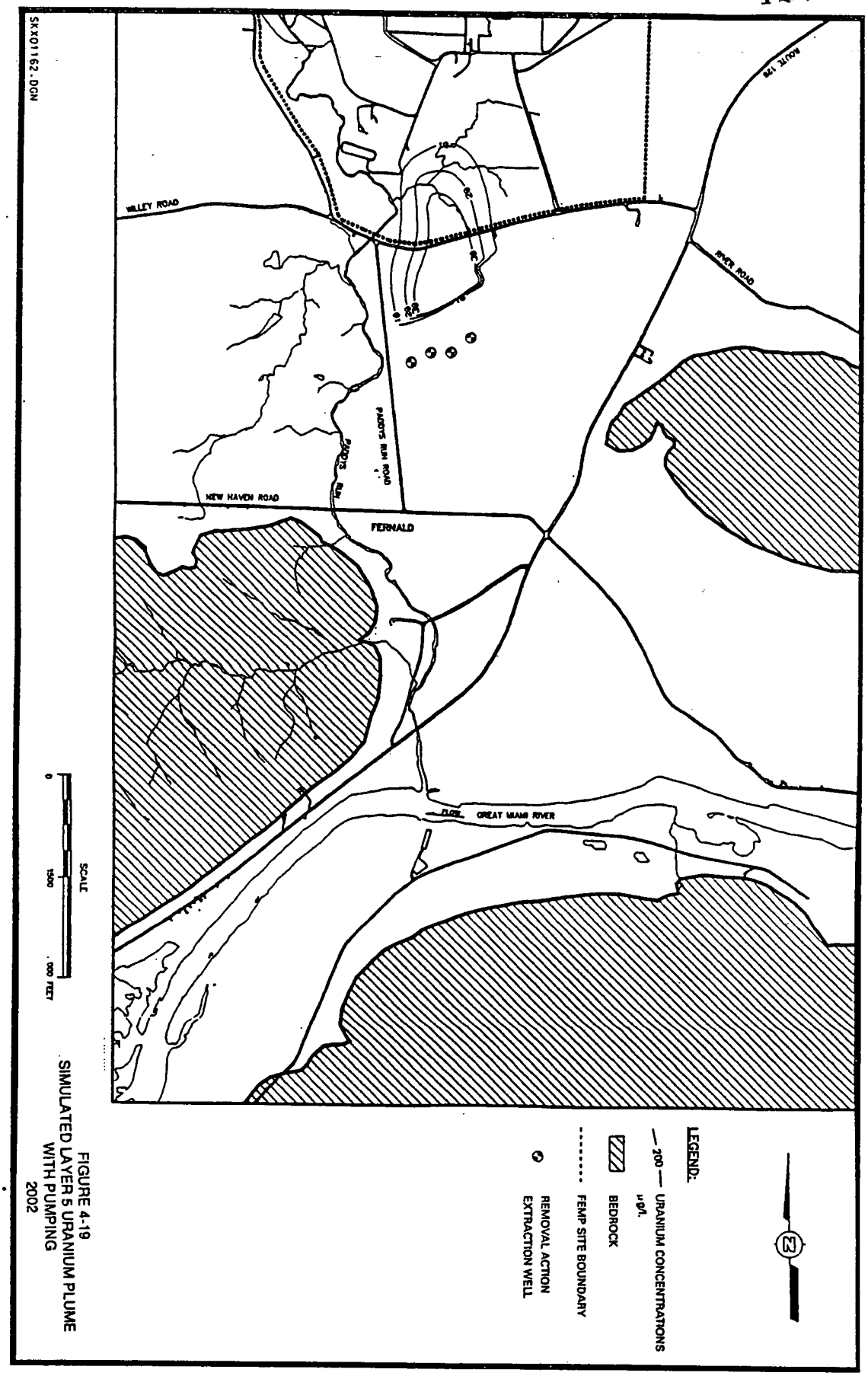


FIGURE 4-19
SIMULATED LAYER 5 URANIUM PLUME WITH PUMPING 2002

Figure 4-19 - Simulated Layer 5 Uranium Plume With Pumping - 2002

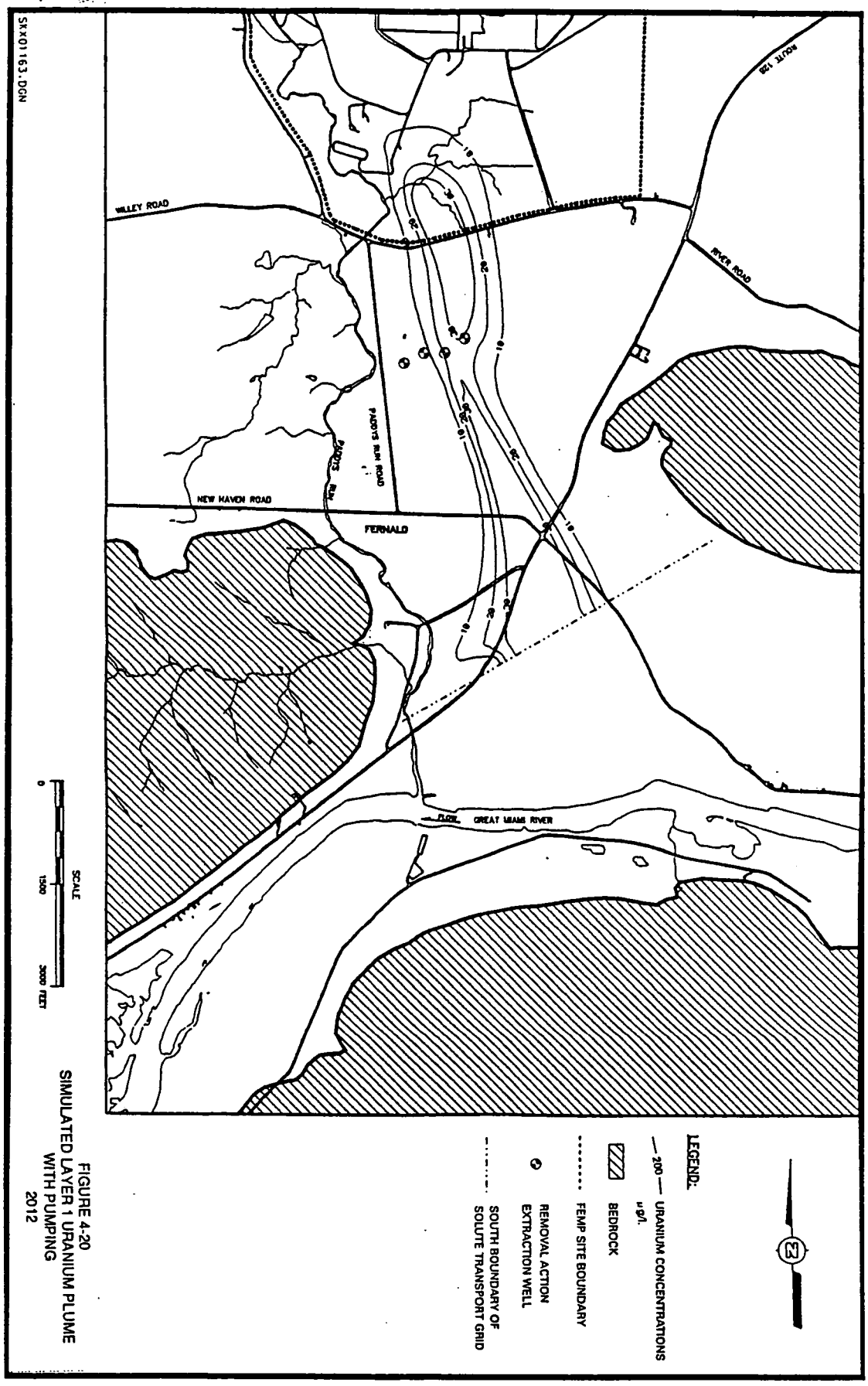


FIGURE 4-20
SIMULATED LAYER 1 URANIUM PLUME
WITH PUMPING
2012

Figure 4-20 - Simulated Layer 1 Uranium Plume With Pumping - 2012

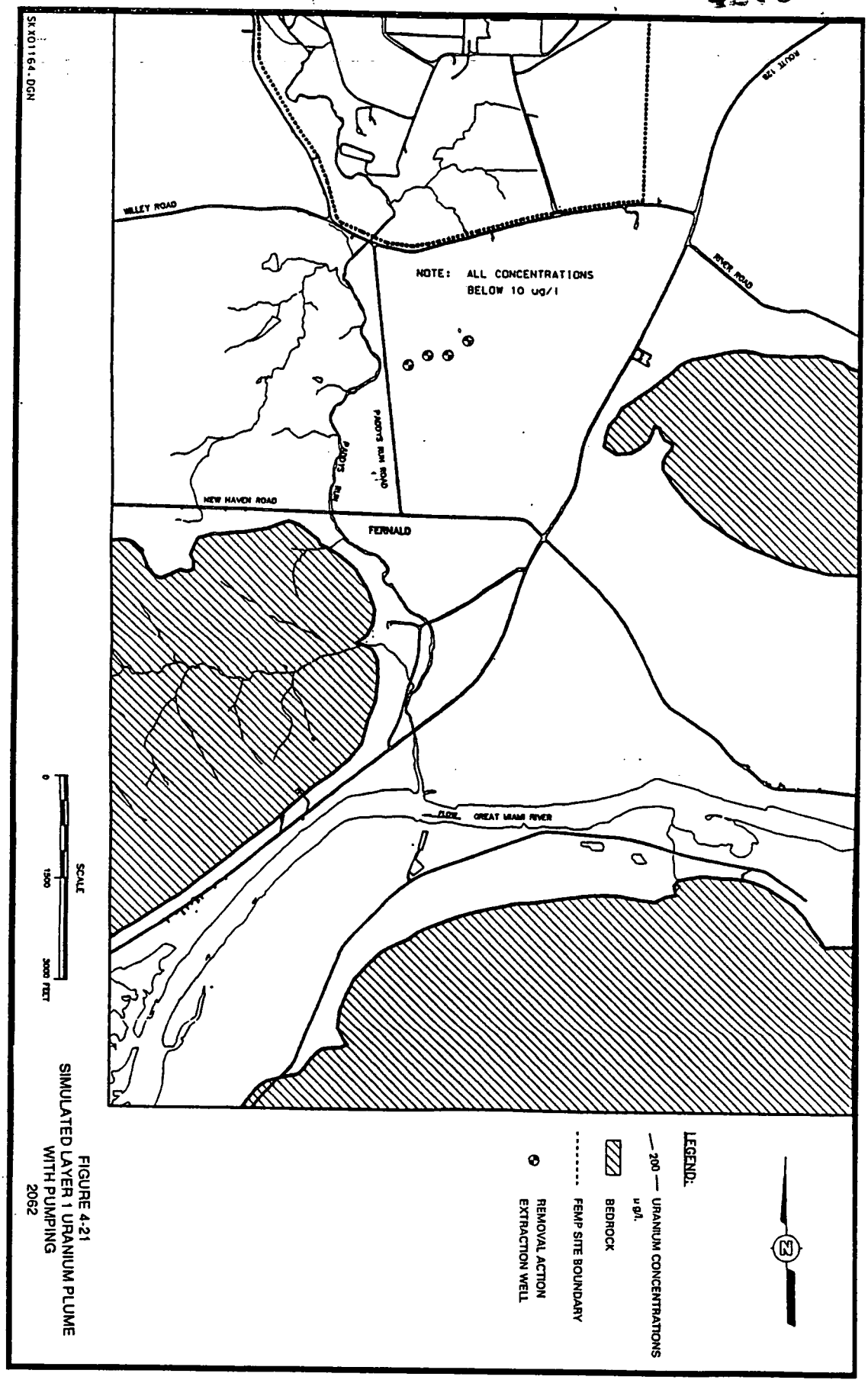


FIGURE 4-21
SIMULATED LAYER 1 URANIUM PLUME
WITH PUMPING
2062

Figure 4-21 - Simulated Layer 1 Uranium Plume With Pumping - 2062

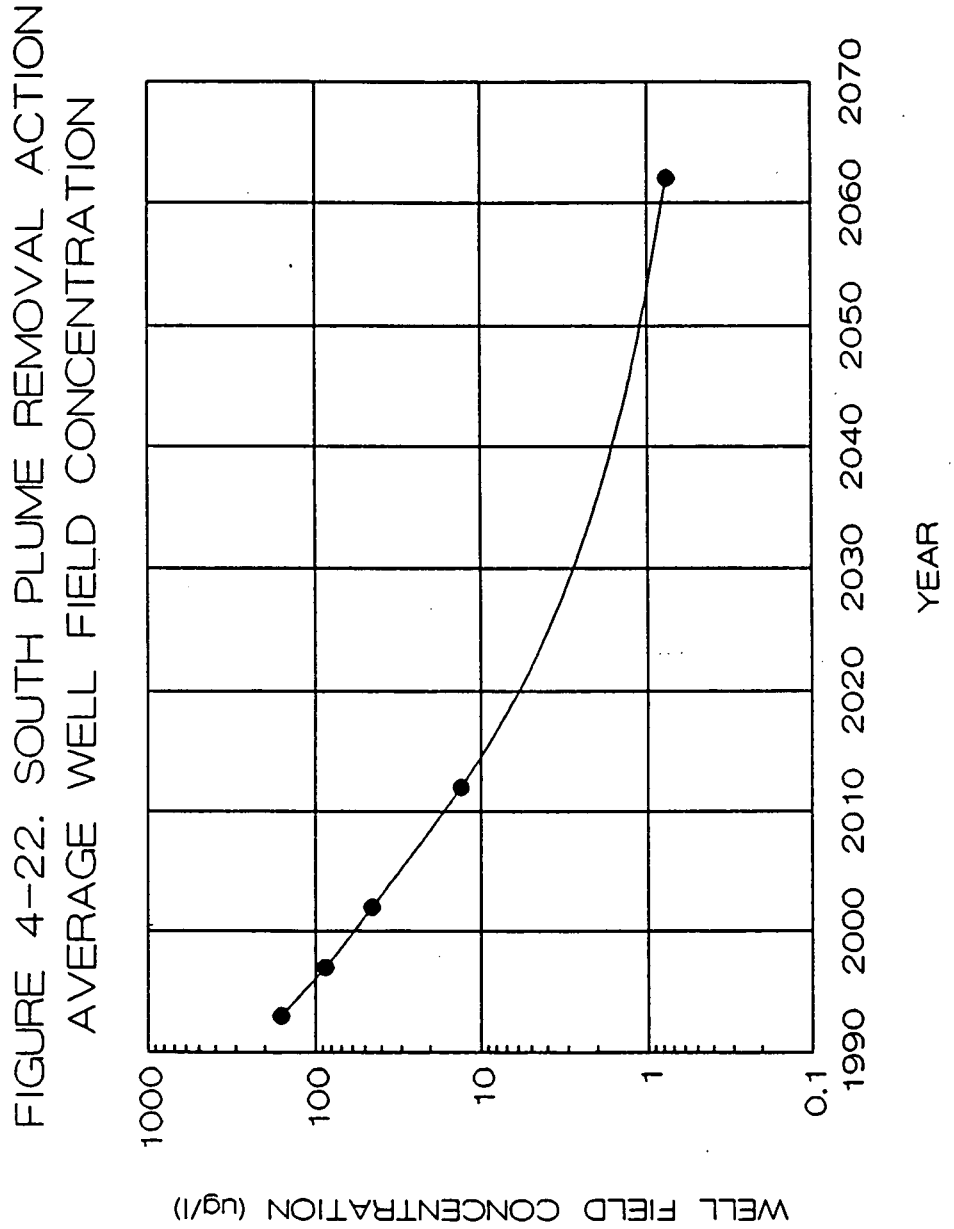


FIGURE 4-22
SOUTH PLUME REMOVAL ACTION
AVERAGE WELL FIELD
CONCENTRATION

Figure 4-22 - Average Well Field Concentration

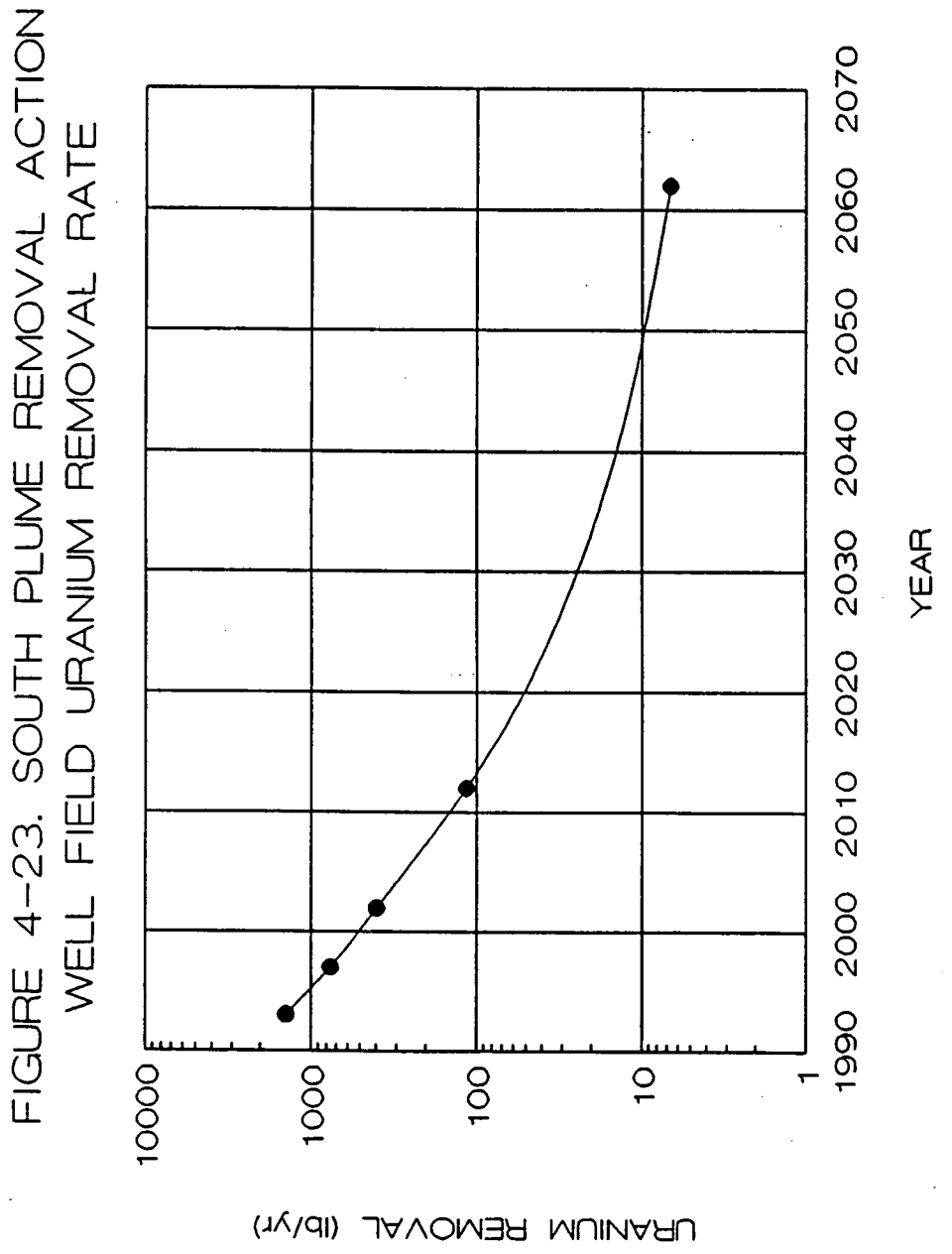


Figure 4-23 - Well Field Uranium Removal Rate

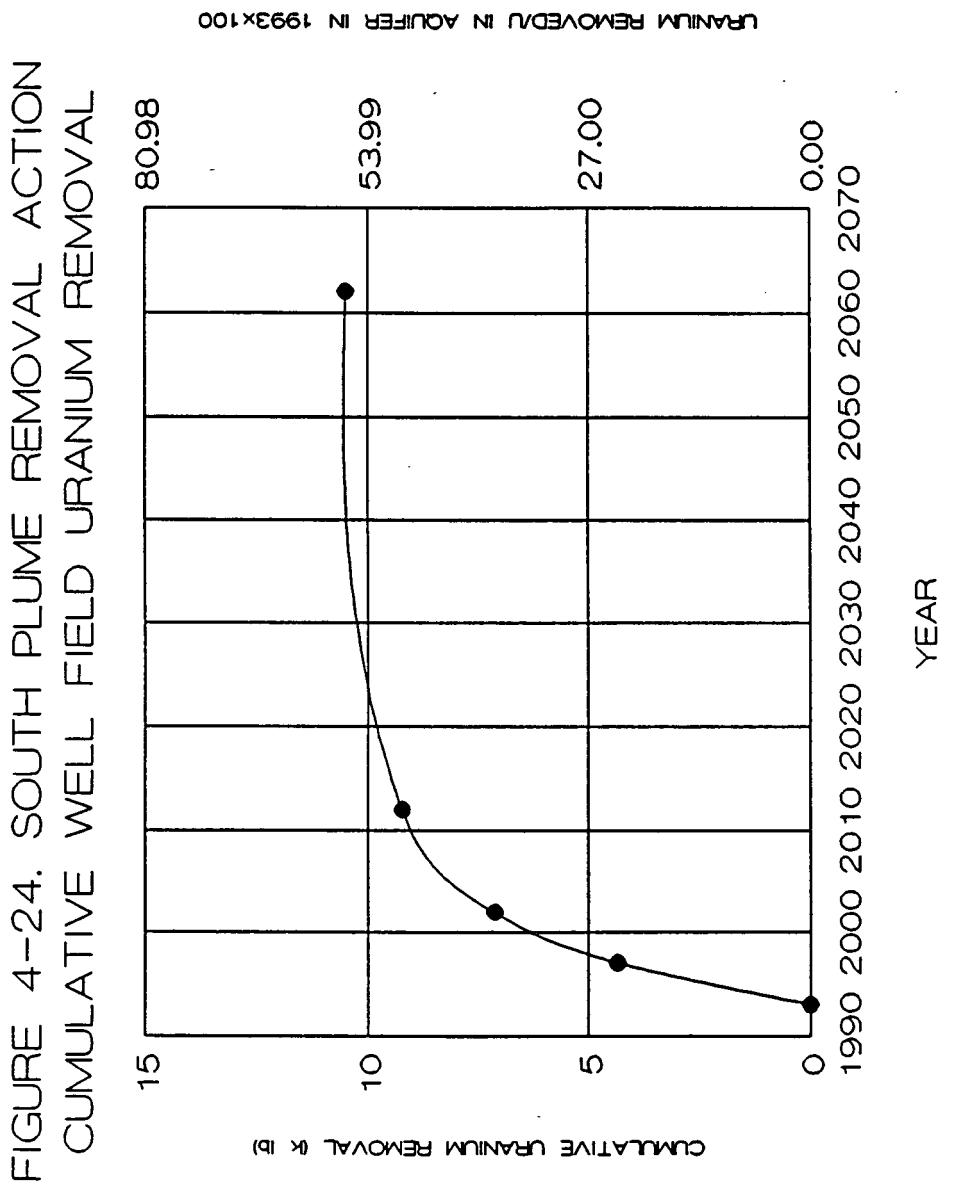


FIGURE 4-24
SOUTH PLUME REMOVAL ACTION
CUMULATIVE WELL FIELD
URANIUM REMOVAL

Figure 4-24 - Cumulative Well Field Uranium Removal

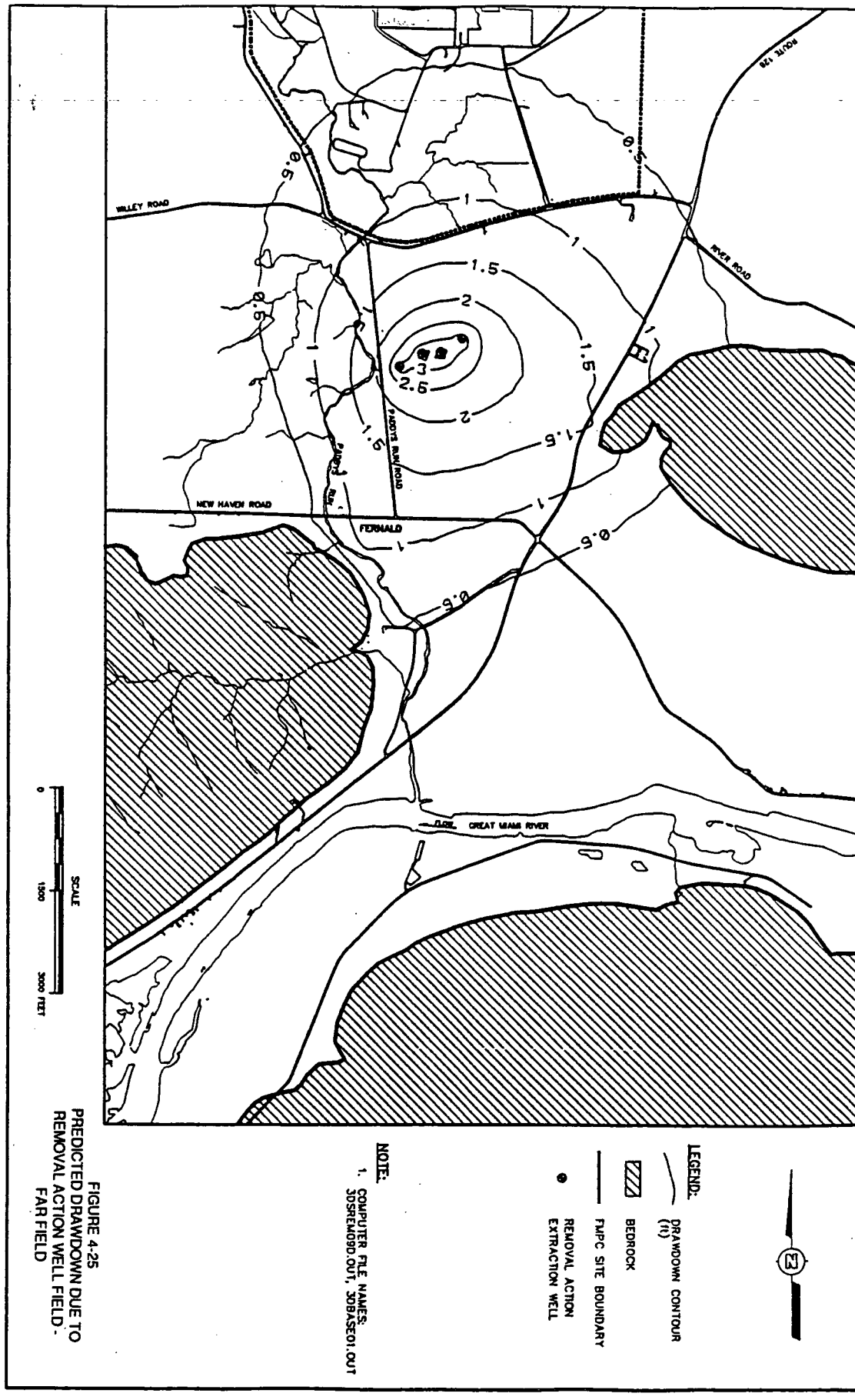


FIGURE 4-25
PREDICTED DRAWDOWN DUE TO REMOVAL ACTION WELL FIELD - FAR FIELD

Figure 4-25 - Predicted Drawdown Due to Removal Action Well Field - Far Field

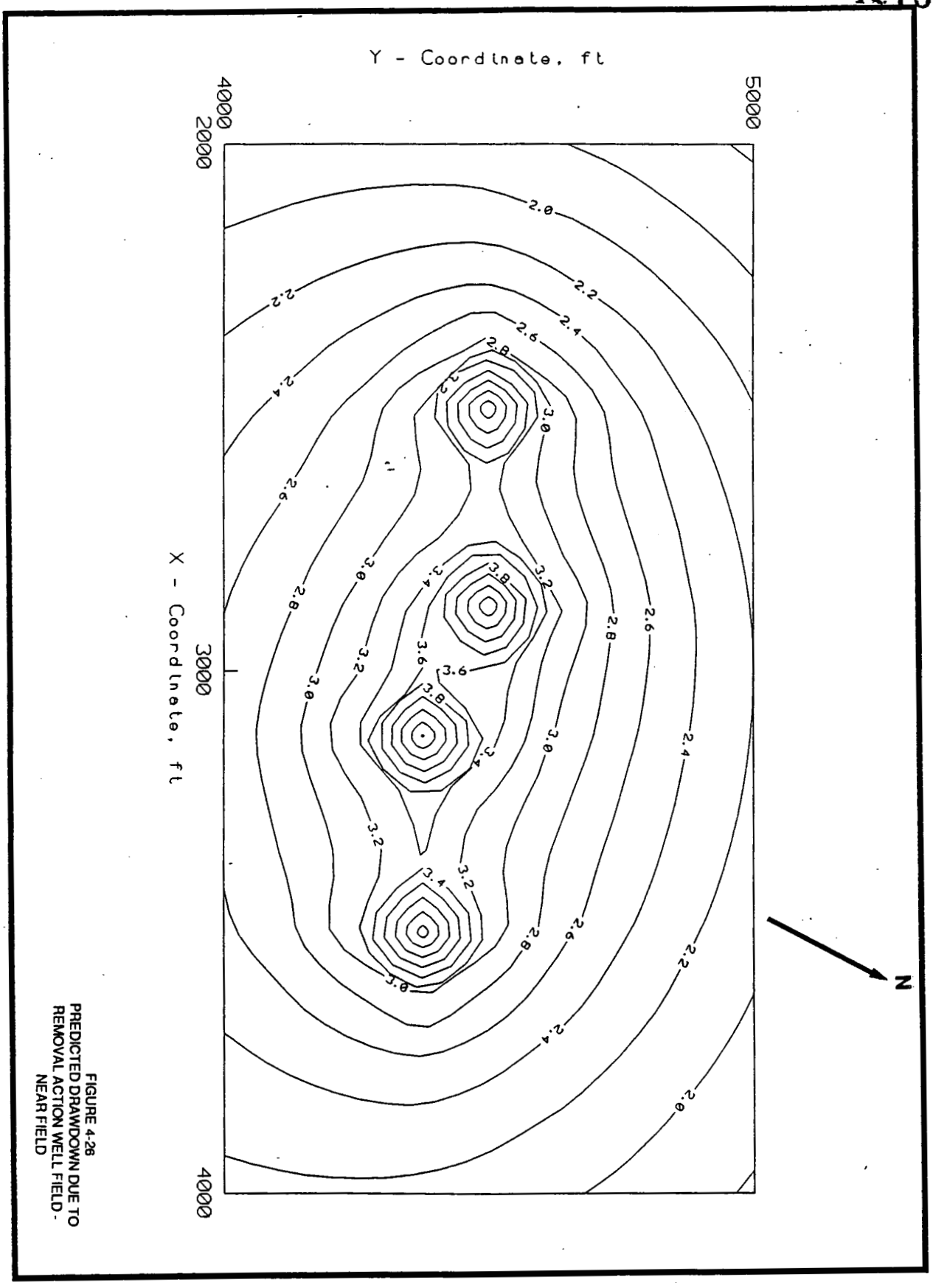


Figure 4-26 - Predicted Drawdown Due to Removal Action Well Field - Near Field

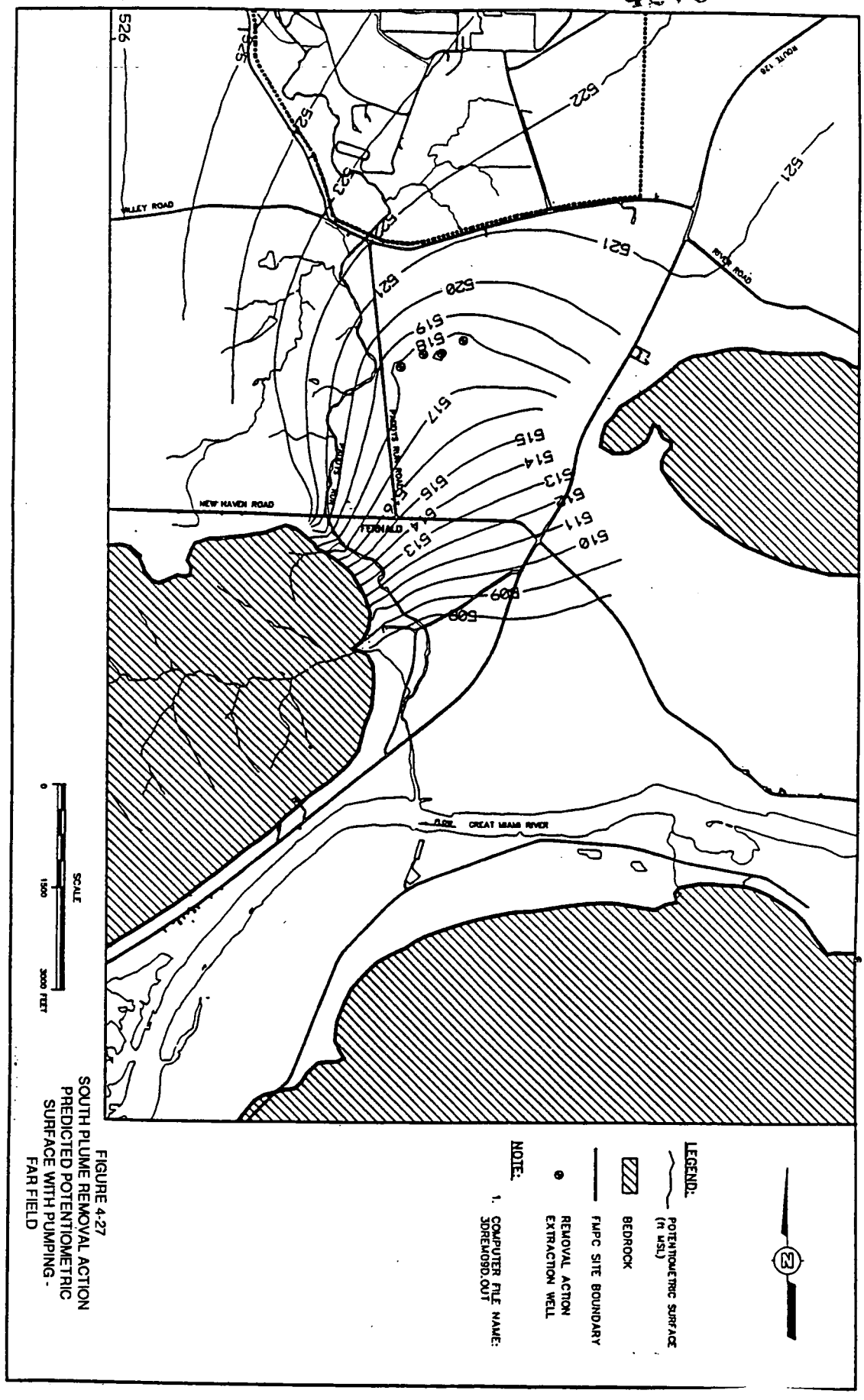


FIGURE 4-27
SOUTH PLUME REMOVAL ACTION
PREDICTED POTENTIOMETRIC
SURFACE WITH PUMPING -
FAR FIELD

Figure 4-27 - Predicted Potentiometric Surface With Pumping - Far Field

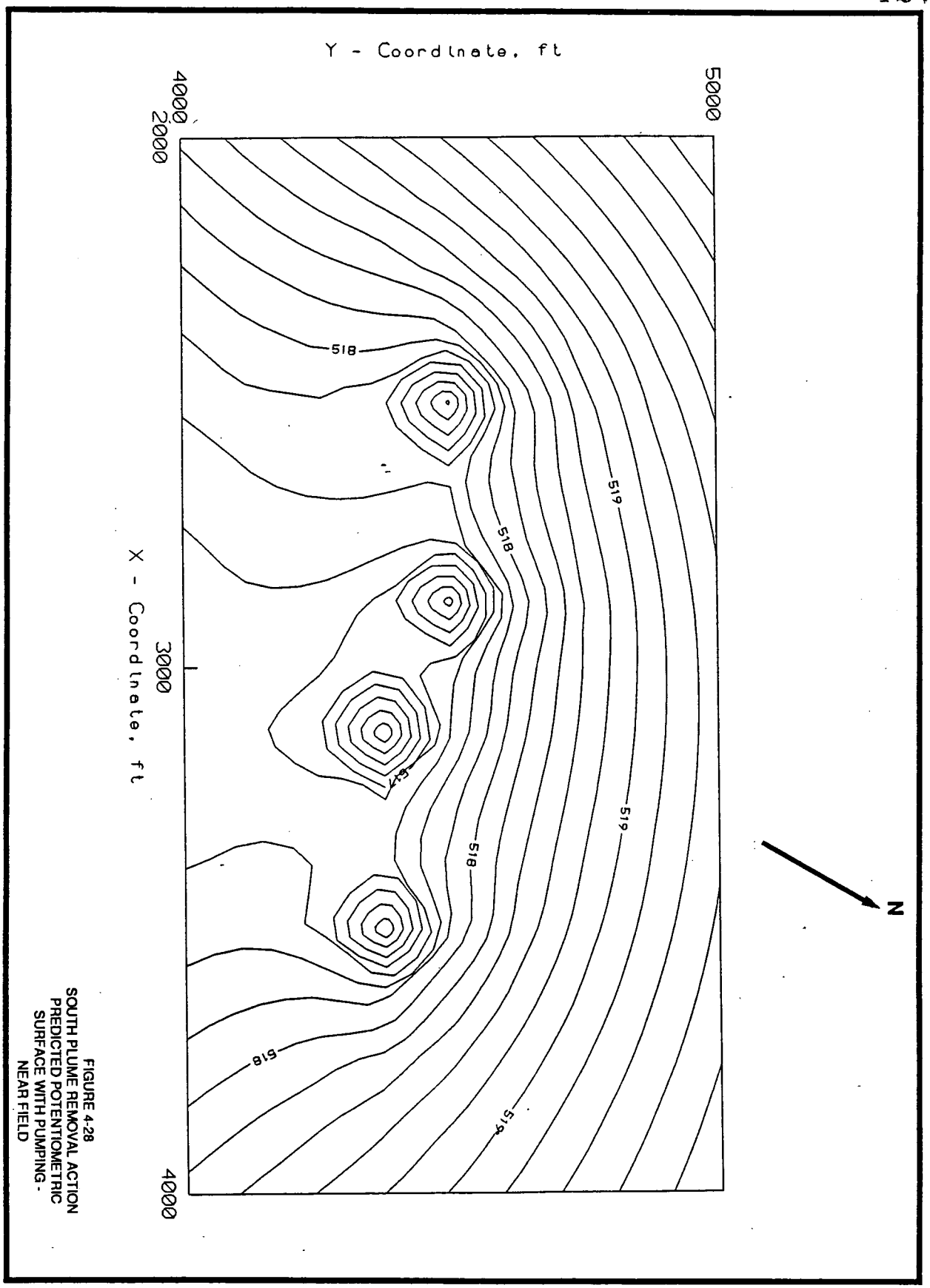


Figure 4-28 - Predicted Potentiometric Surface With Pumping - Near Field

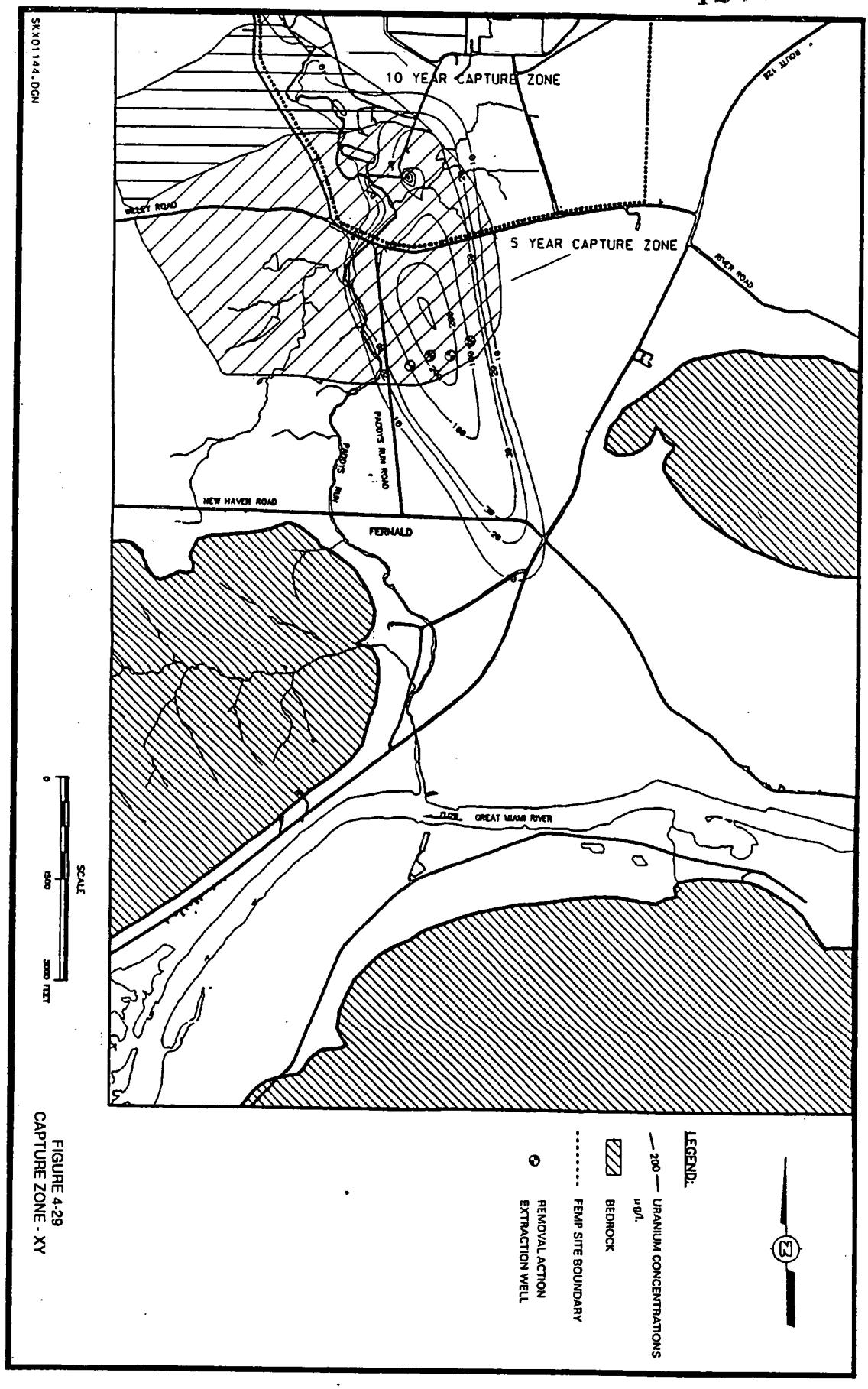


FIGURE 4-29
CAPTURE ZONE - XY

Figure 4-29 - Capture Zone - Superimposed on Model Layer 1 Plume

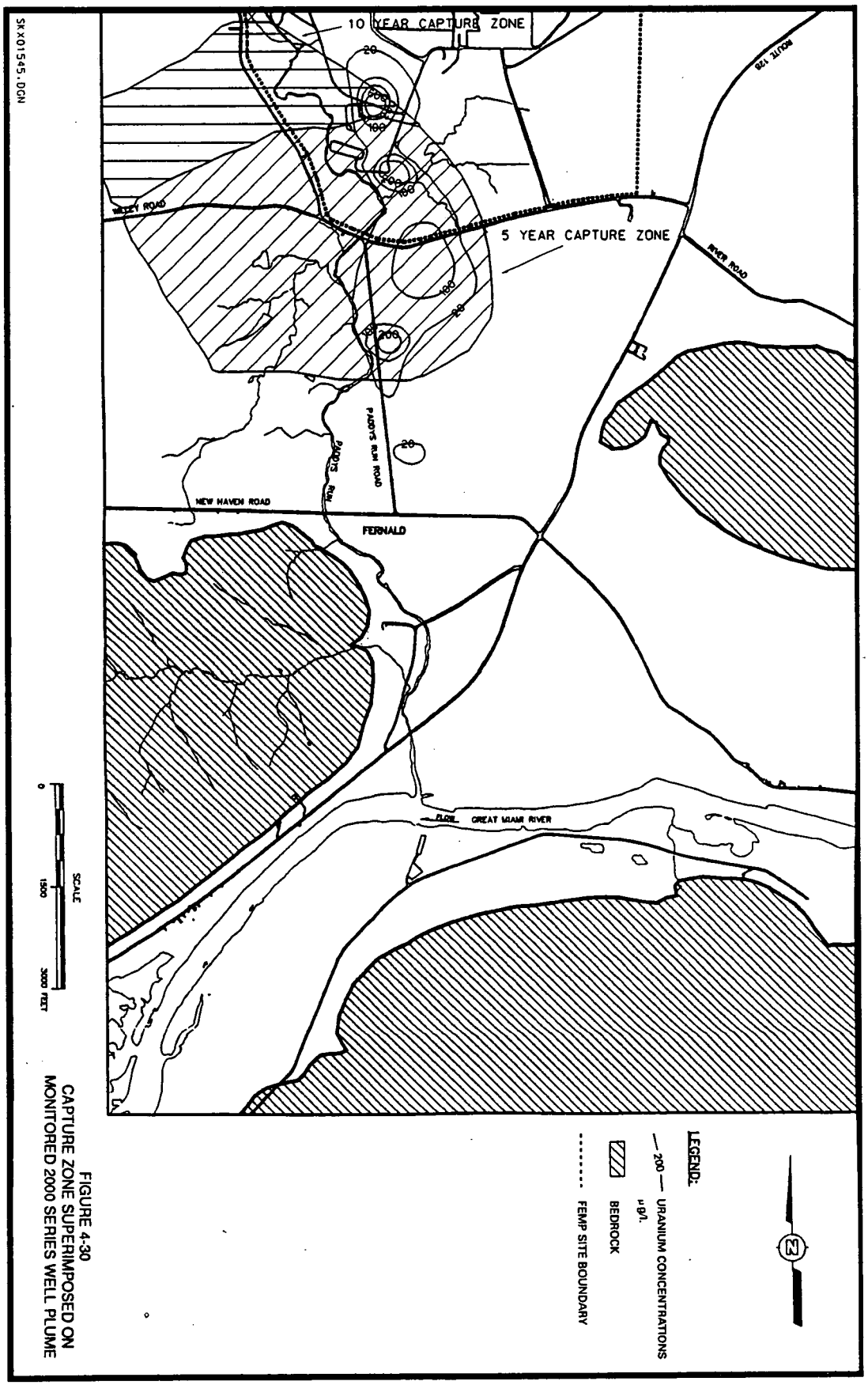


FIGURE 4-30
CAPTURE ZONE SUPERIMPOSED ON
MONITORED 2000 SERIES WELL PLUME

Figure 4-30 - Capture Zone - Superimposed on 2000 Monitoring Well Plume

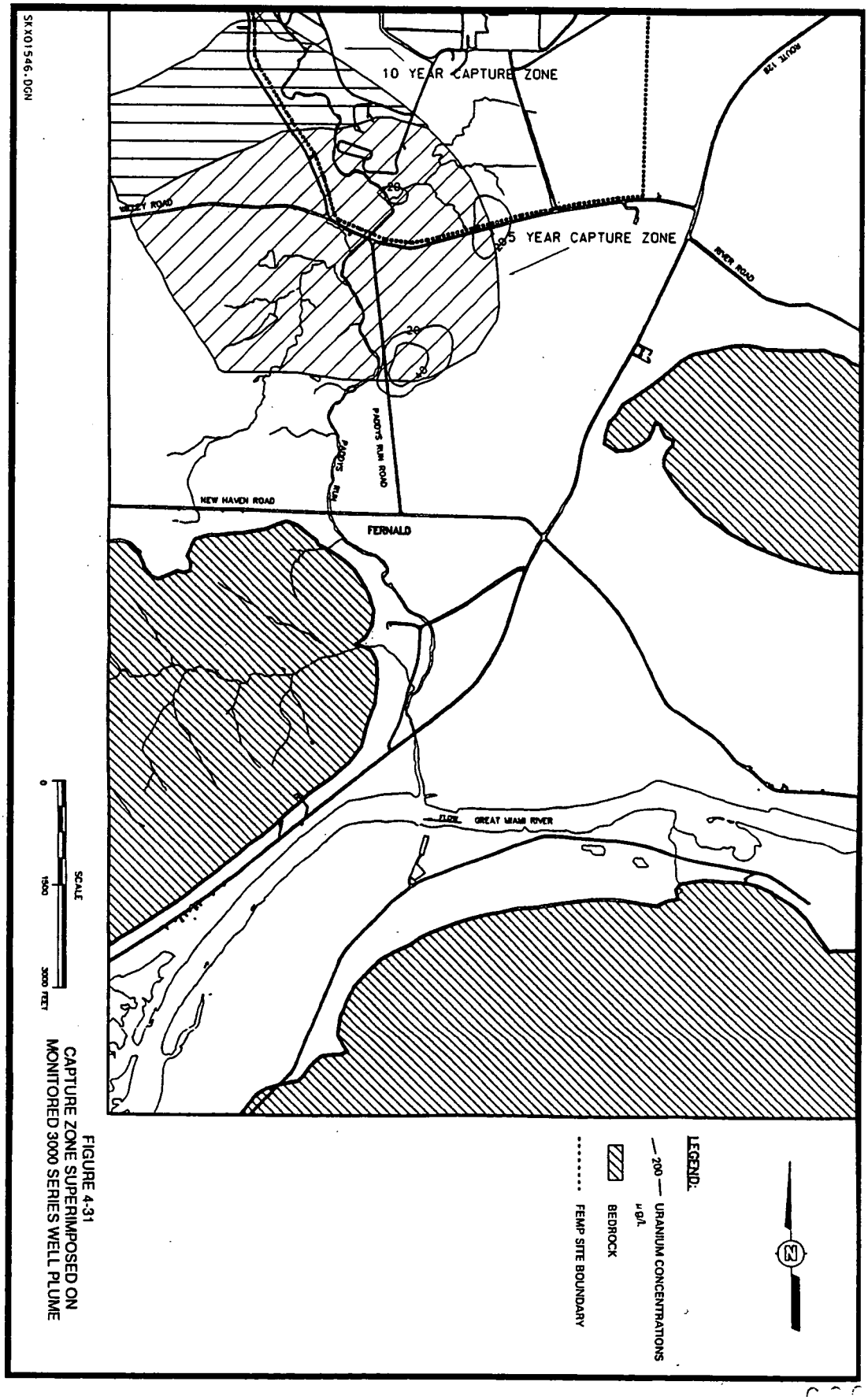


FIGURE 4-31
CAPTURE ZONE SUPERIMPOSED ON
MONITORED 3000 SERIES WELL PLUME

Figure 4-31 - Capture Zone - Superimposed on 3000 Monitoring Well Plume

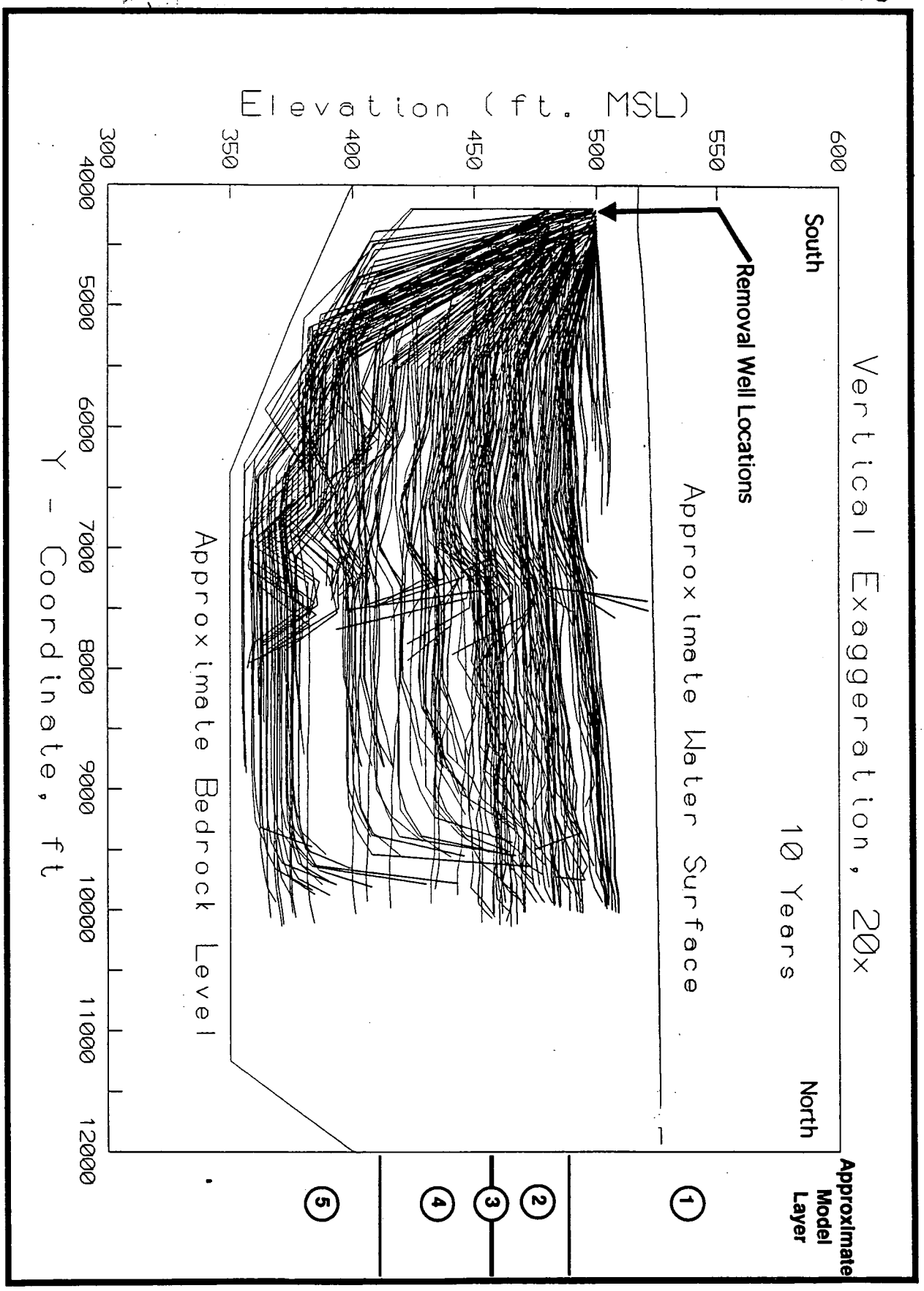


Figure 4-32 - Capture Zone - YZ

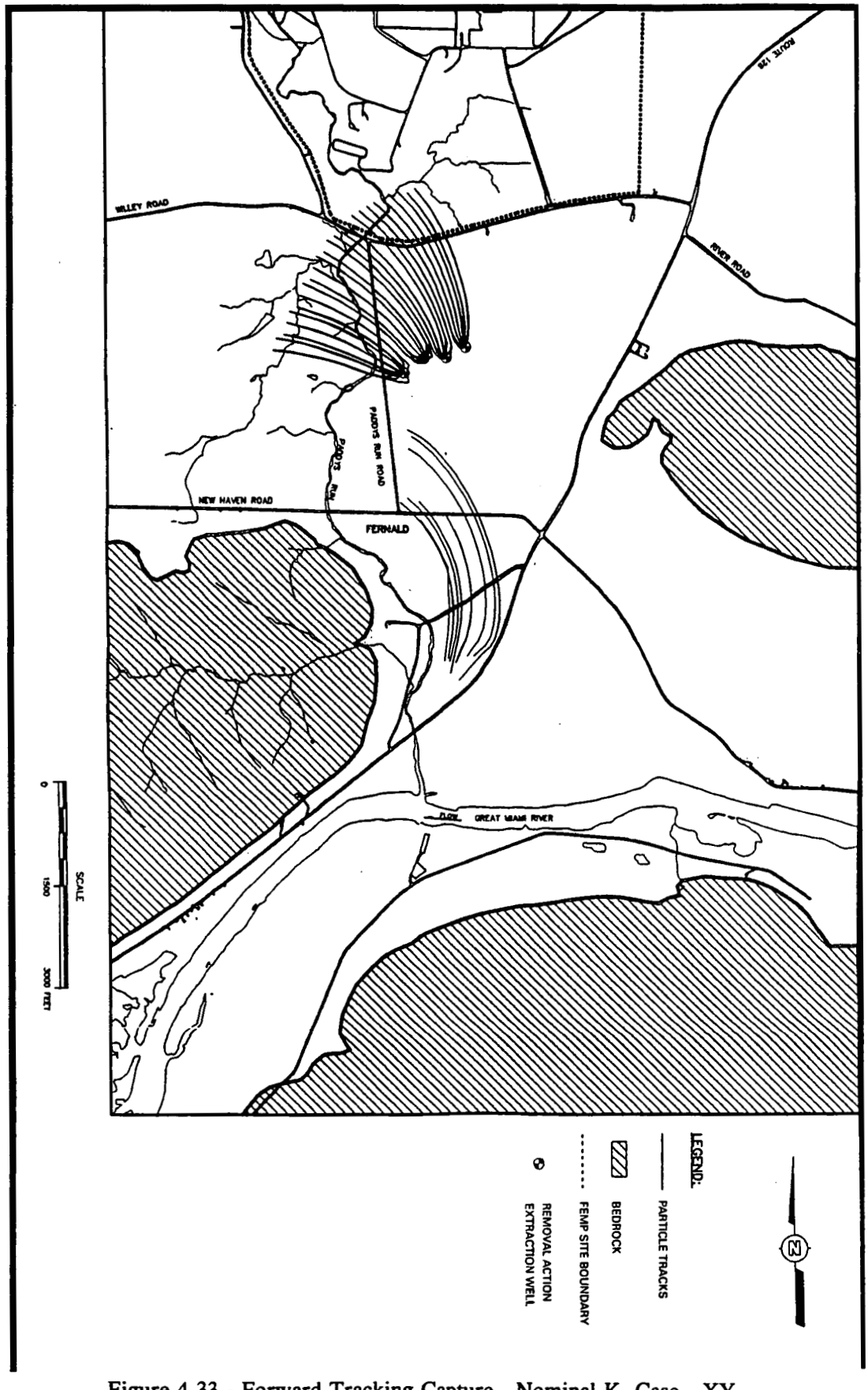


Figure 4-33 - Forward Tracking Capture - Nominal K_h Case - XY

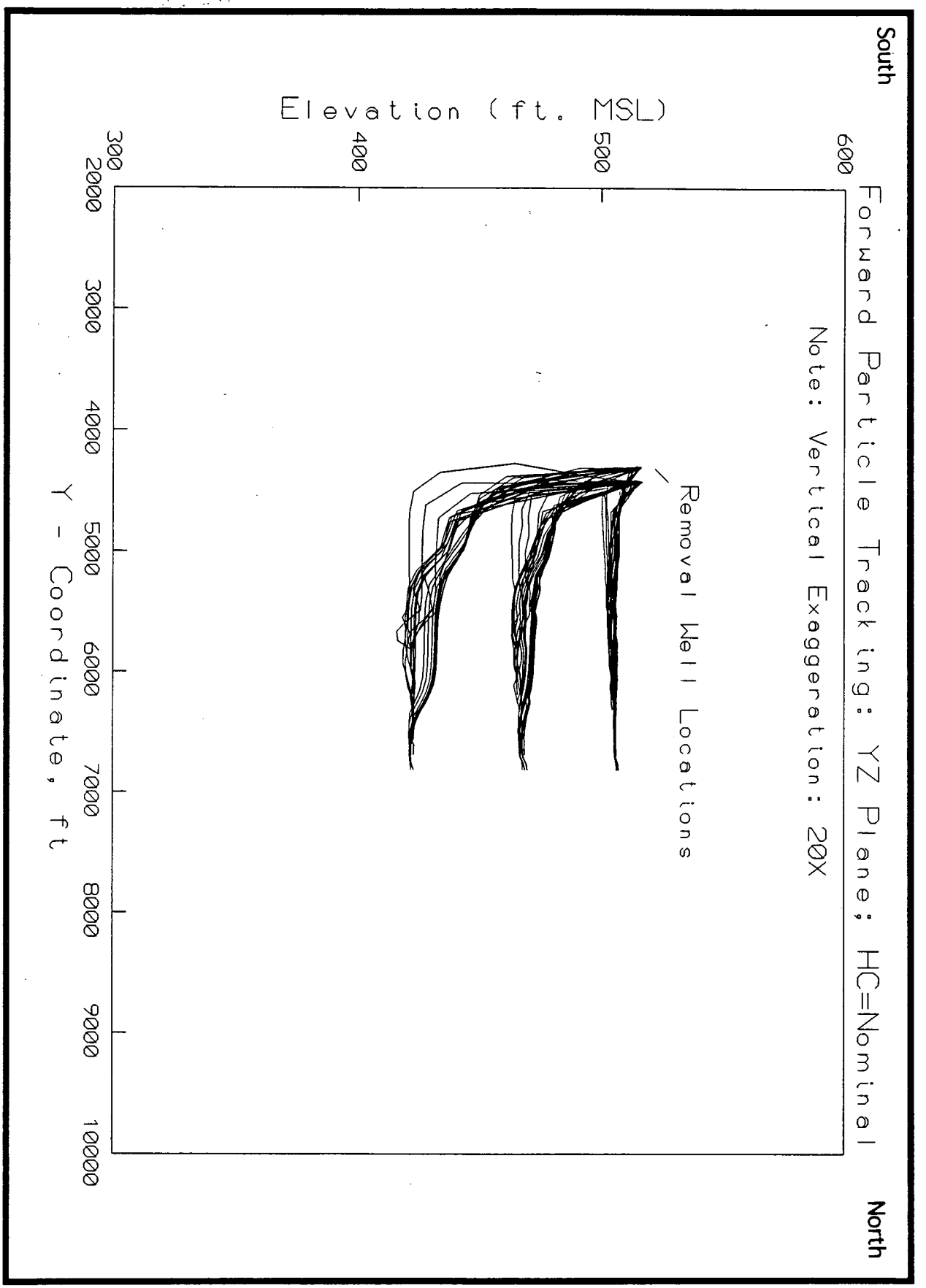


Figure 4-34 - Forward Tracking Capture - Nominal K_h Case - YZ

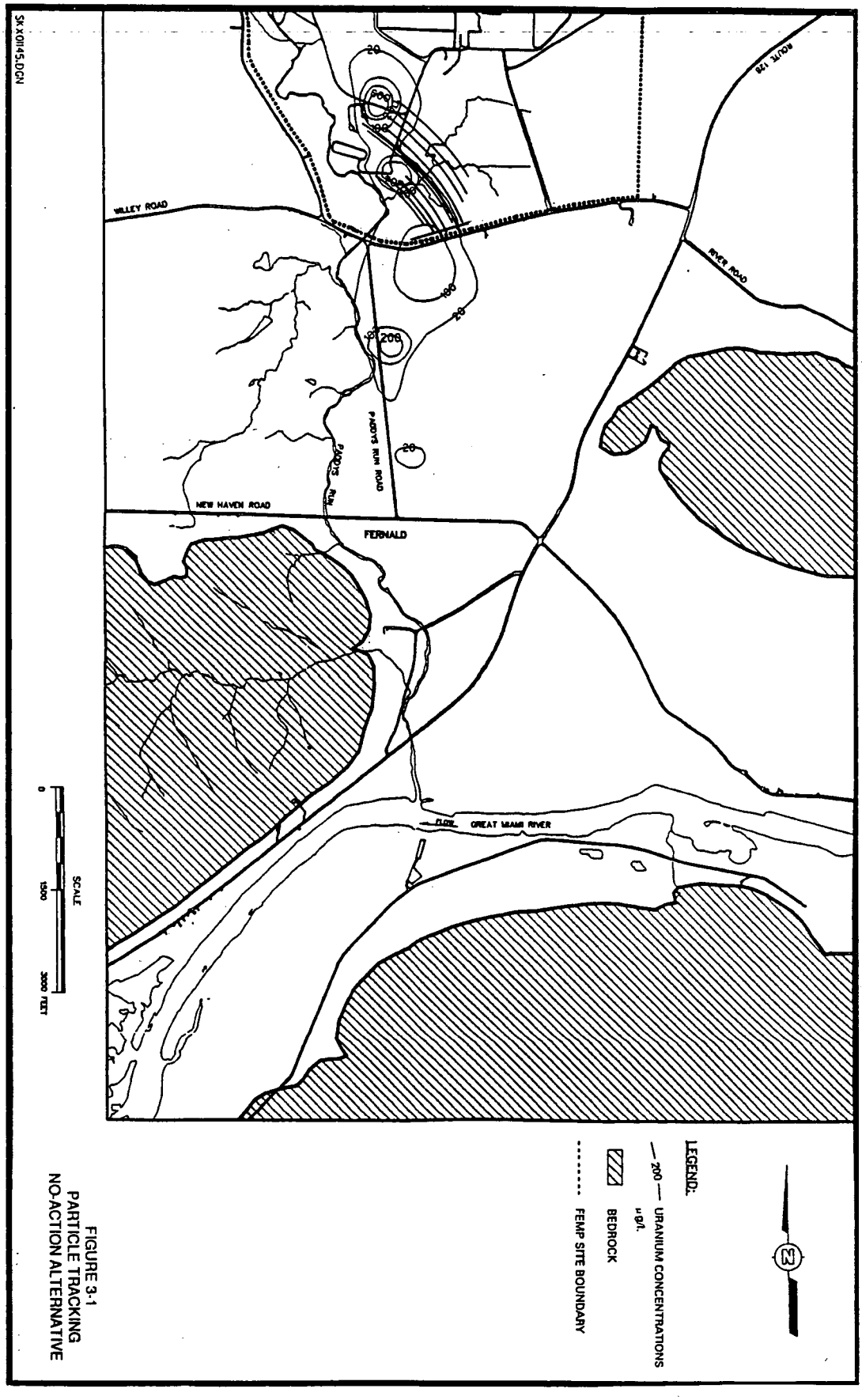


FIGURE 3-1
PARTICLE TRACKING
NO-ACTION ALTERNATIVE

Figure 4-35 - Forward Tracking - South Field Plume to Property Line

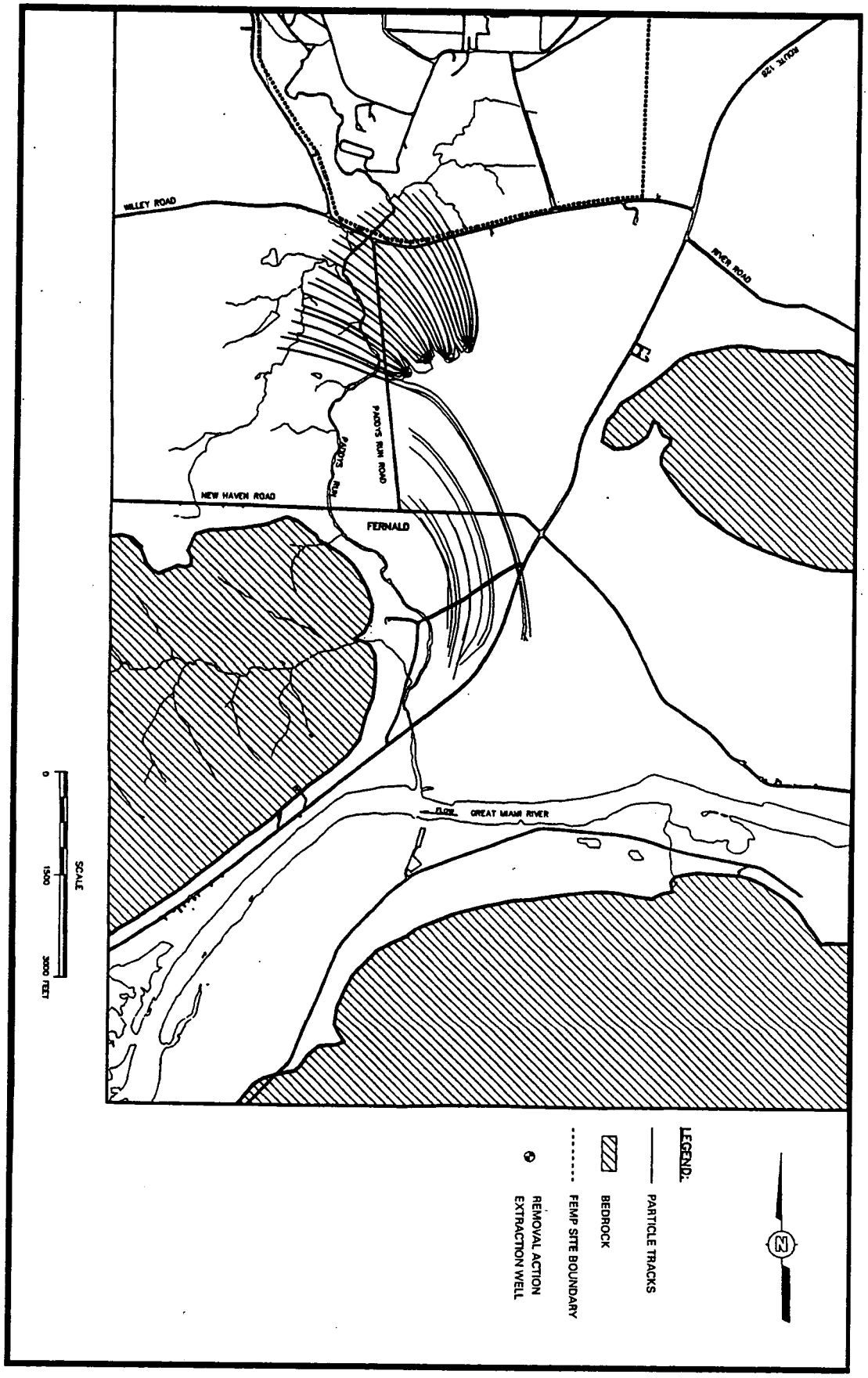


Figure 4-36 - Forward Tracking Capture - 1.5X Nominal K_h Case - XY

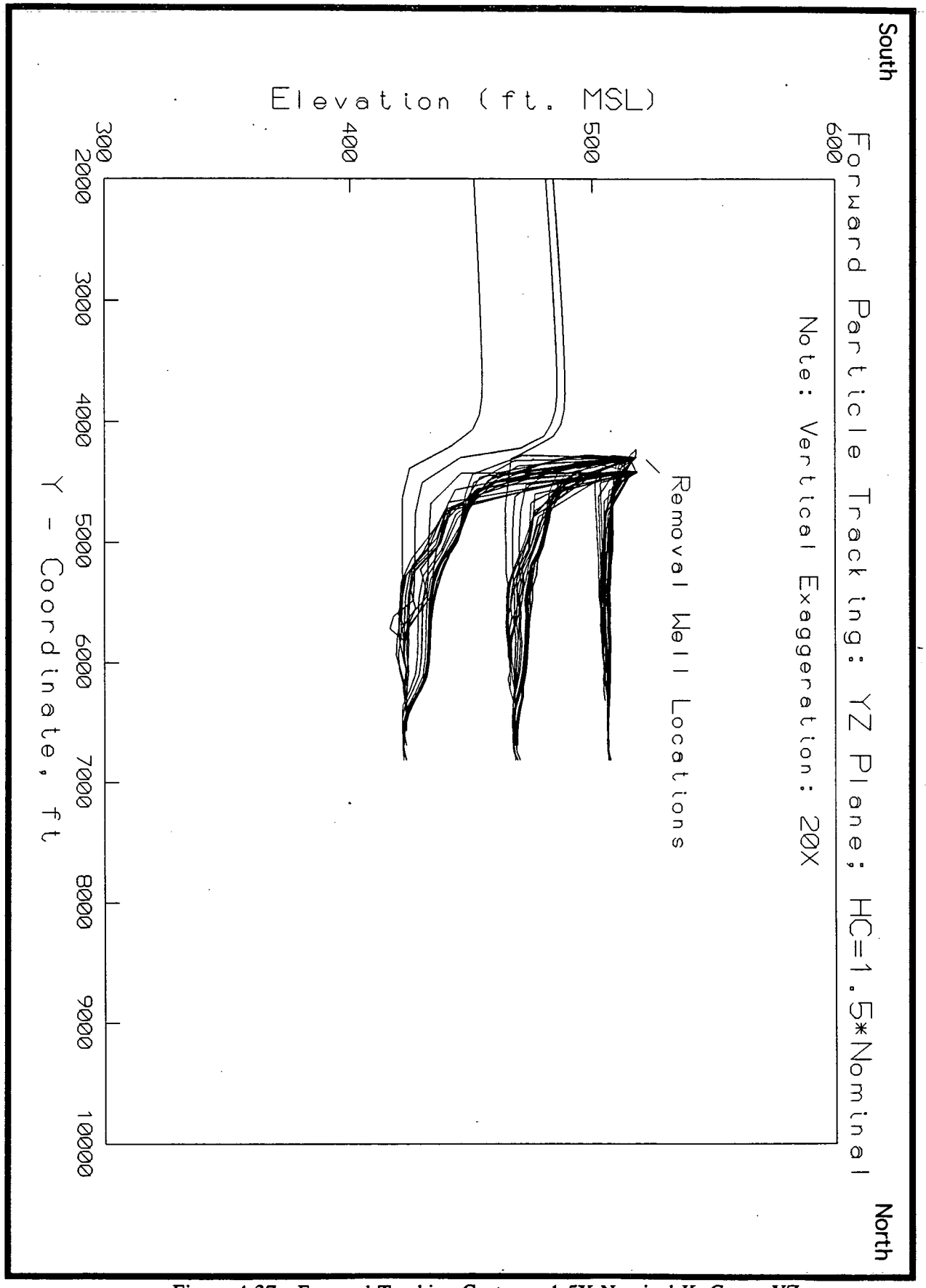


Figure 4-37 - Forward Tracking Capture - 1.5X Nominal K_h Case - YZ

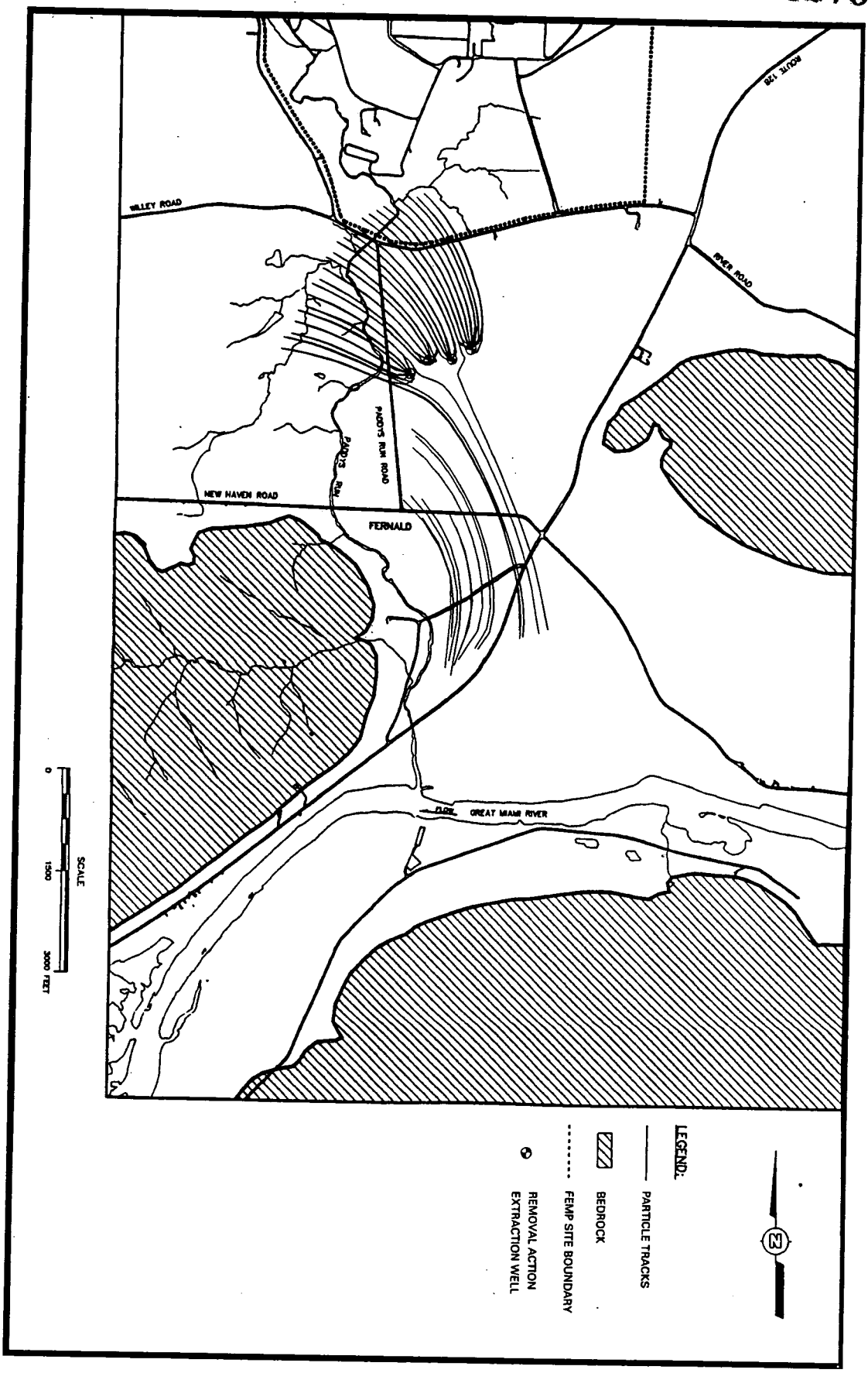


Figure 4-38 - Forward Tracking Capture - 1.75X Nominal K_h Case - XY

95

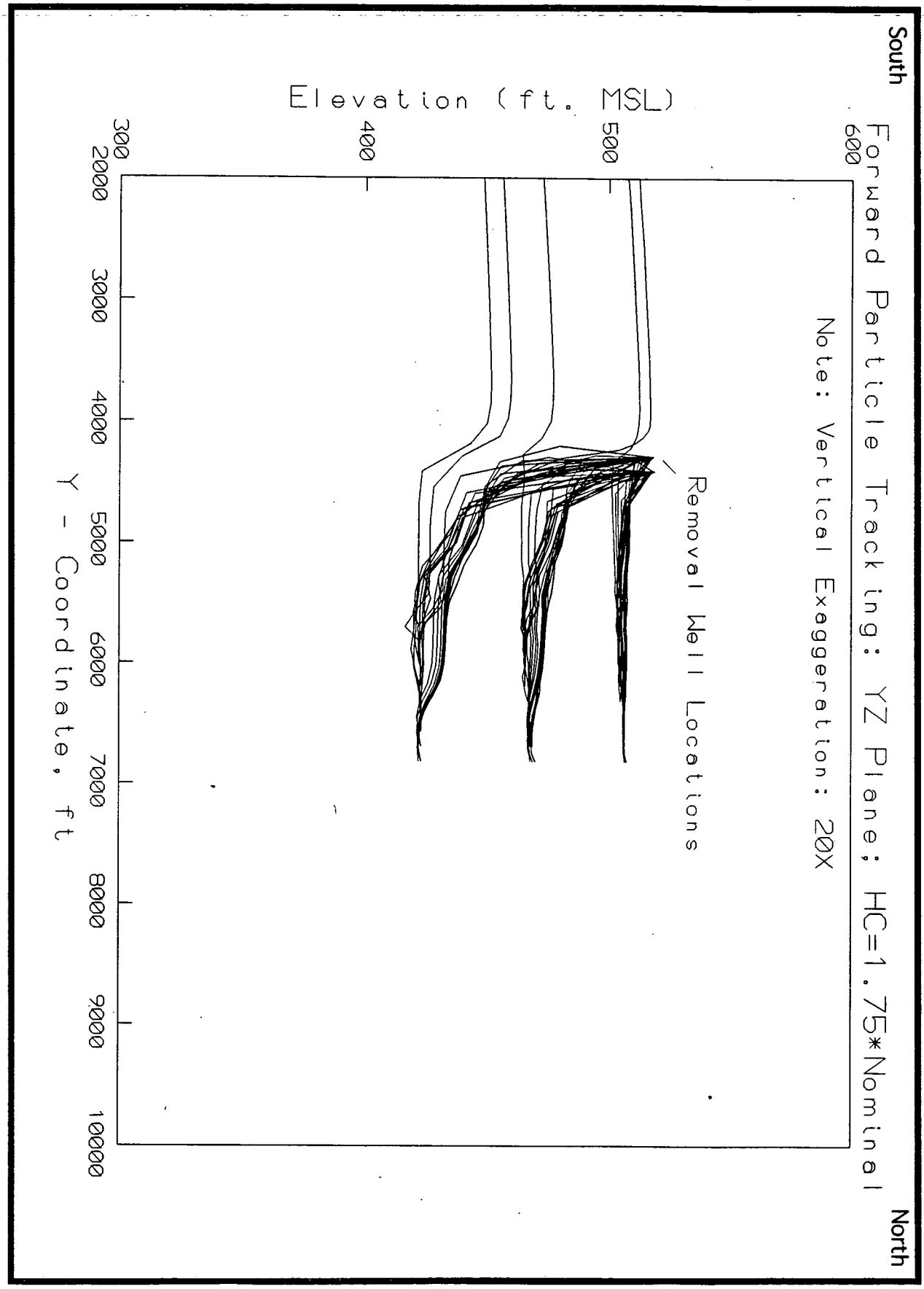


Figure 4-39 - Forward Tracking Capture - 1.75X Nominal K_h Case - YZ

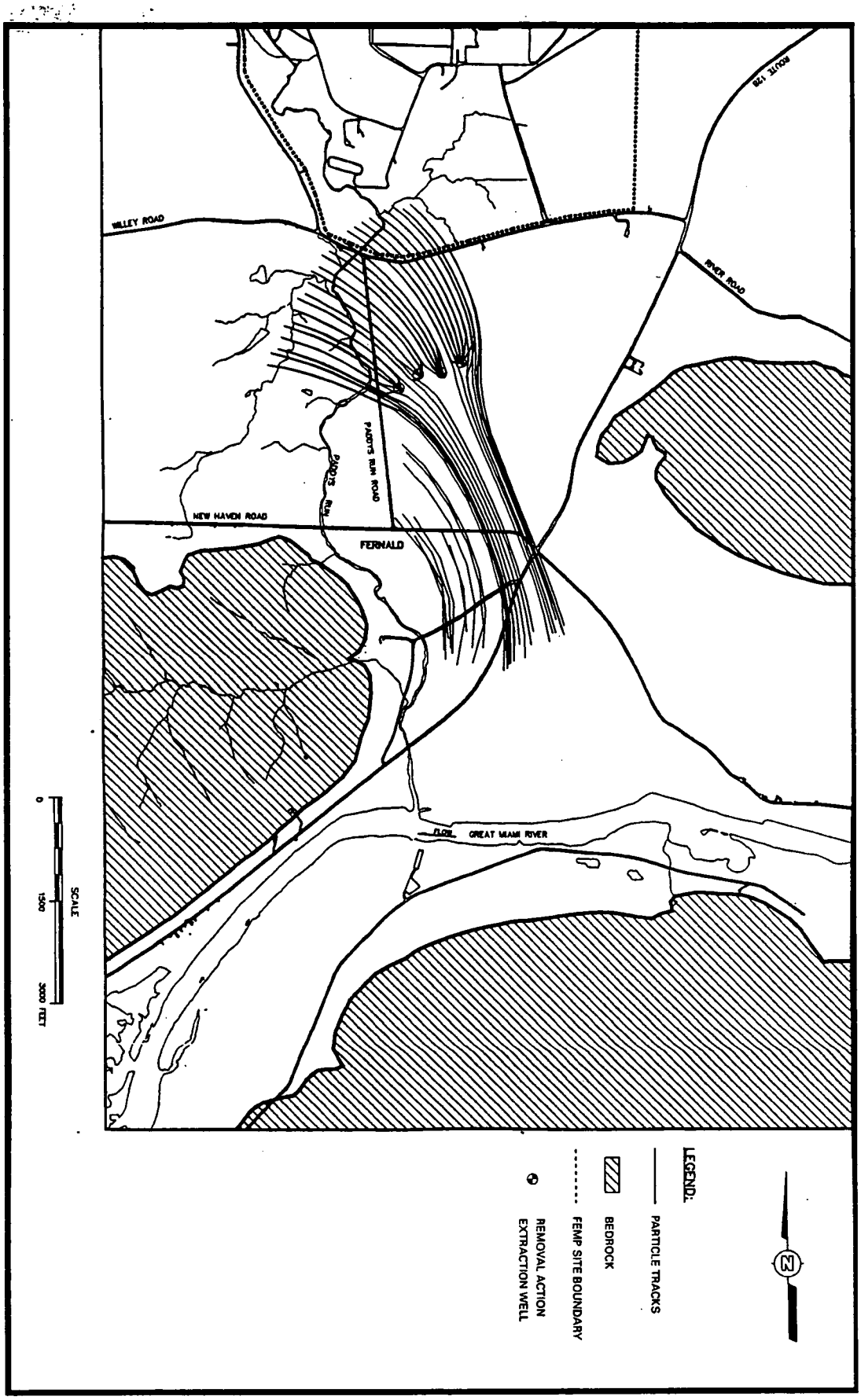


Figure 4-40 - Forward Tracking Capture - 3X Nominal K_h Case - XY

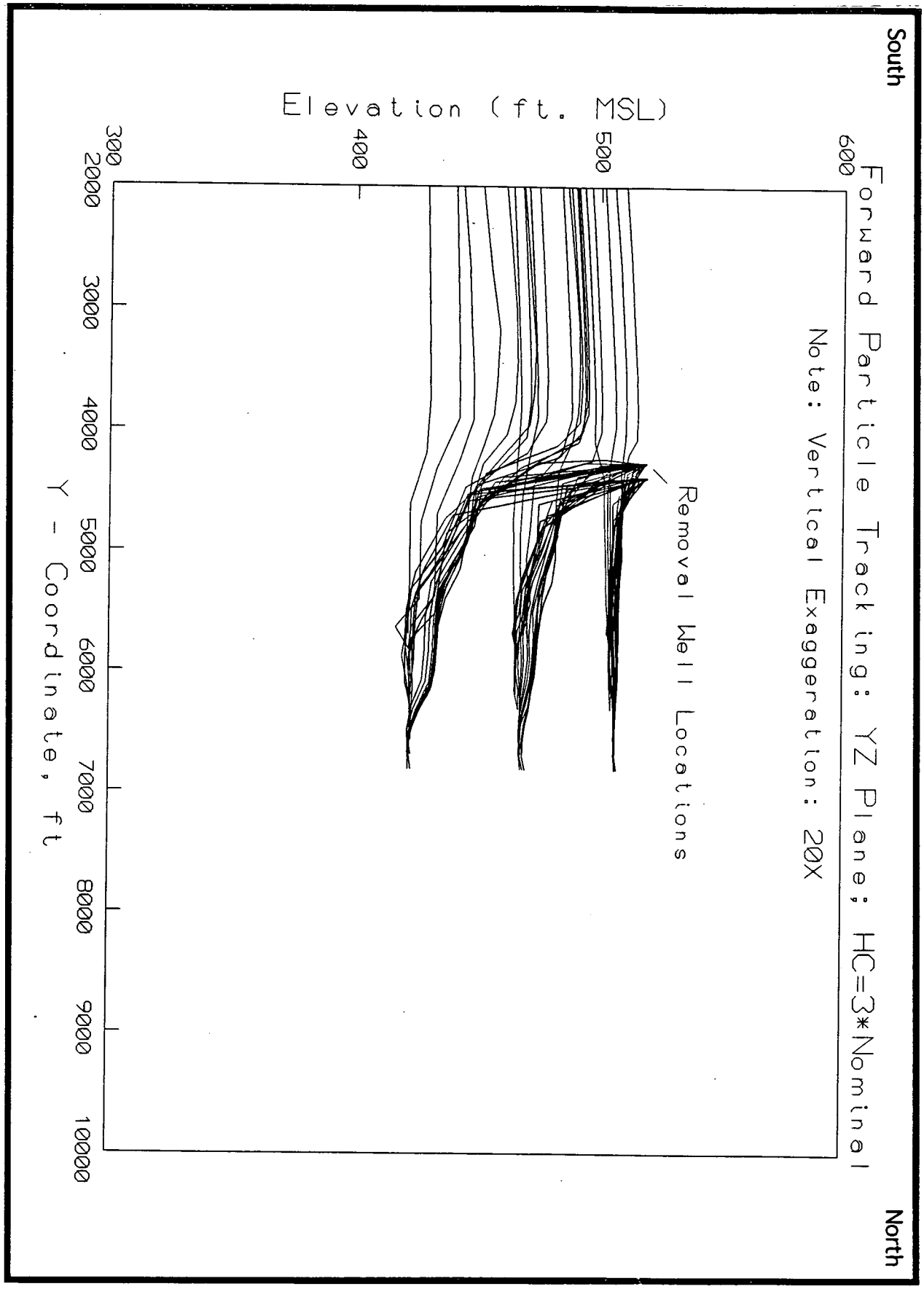


Figure 4-41 - Forward Tracking Capture - 3X Nominal K_h Case - YZ

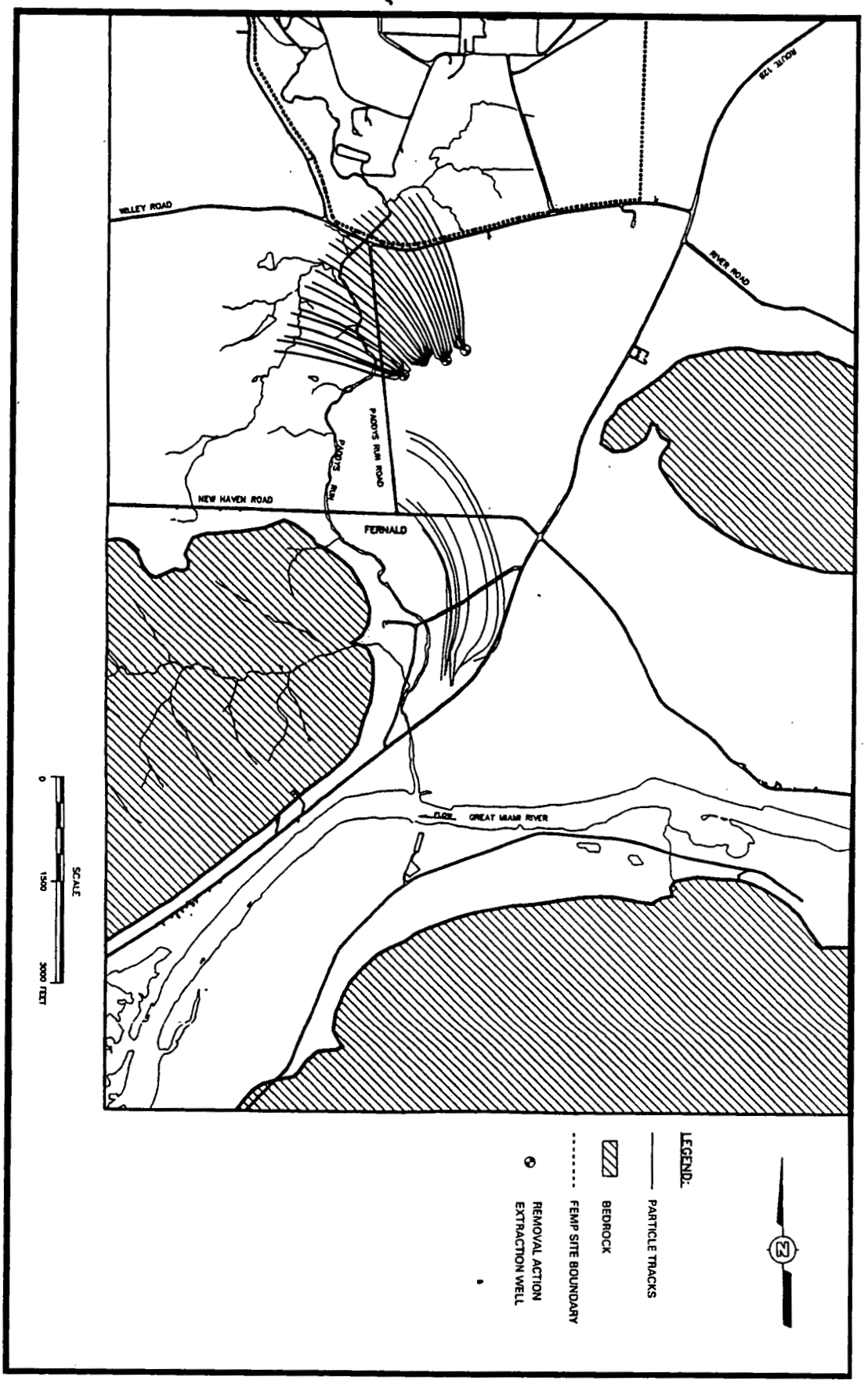


Figure 4-42 - Forward Tracking Capture - 0.7X Nominal K_h Case - XY

99

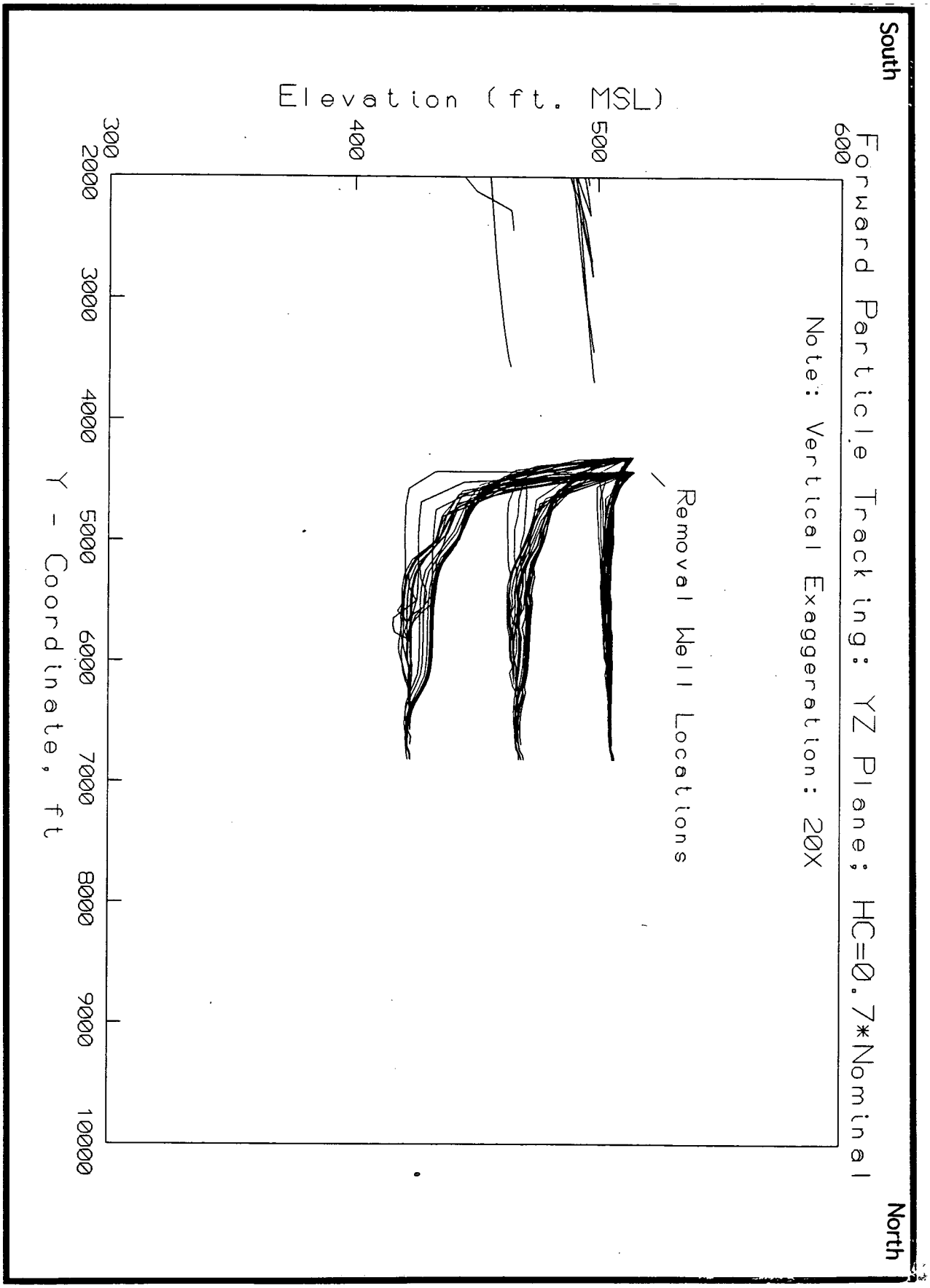


Figure 4-43 - Forward Tracking Capture - 0.7X Nominal K_h Case - YZ

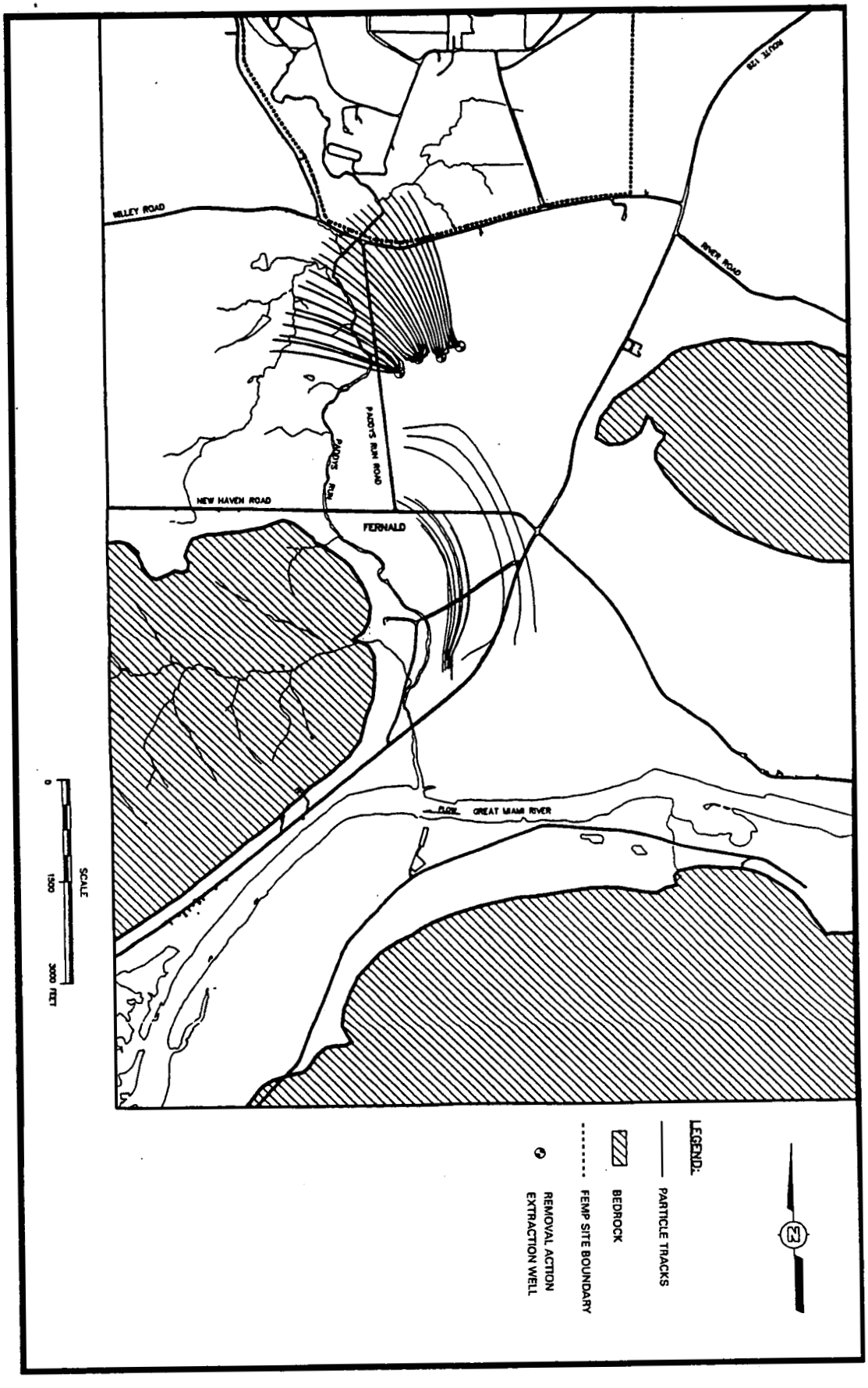


Figure 4-44 - Forward Tracking Capture - 0.4X Nominal K_h Case - XY

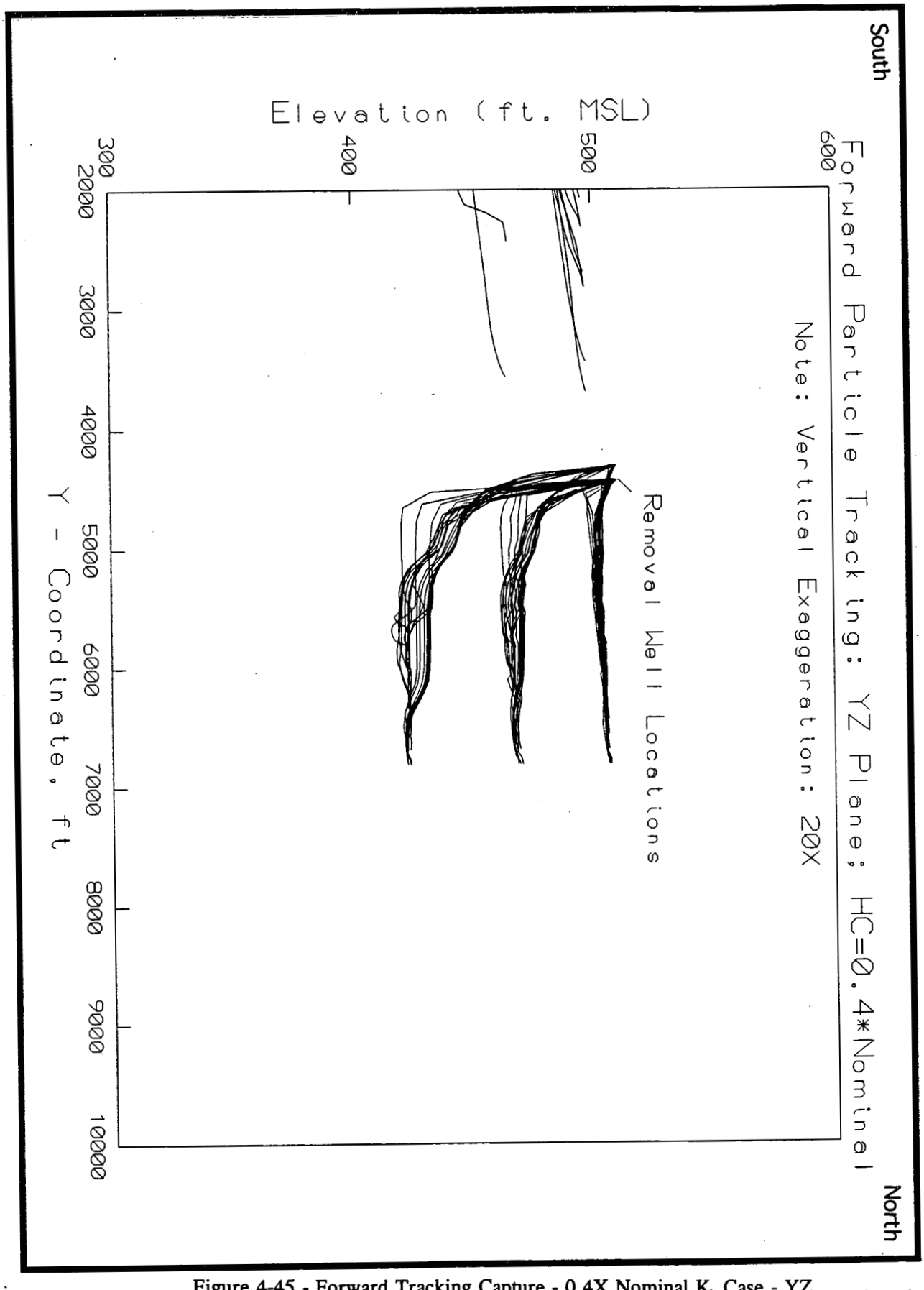


Figure 4-45 - Forward Tracking Capture - 0.4X Nominal K_h Case - YZ

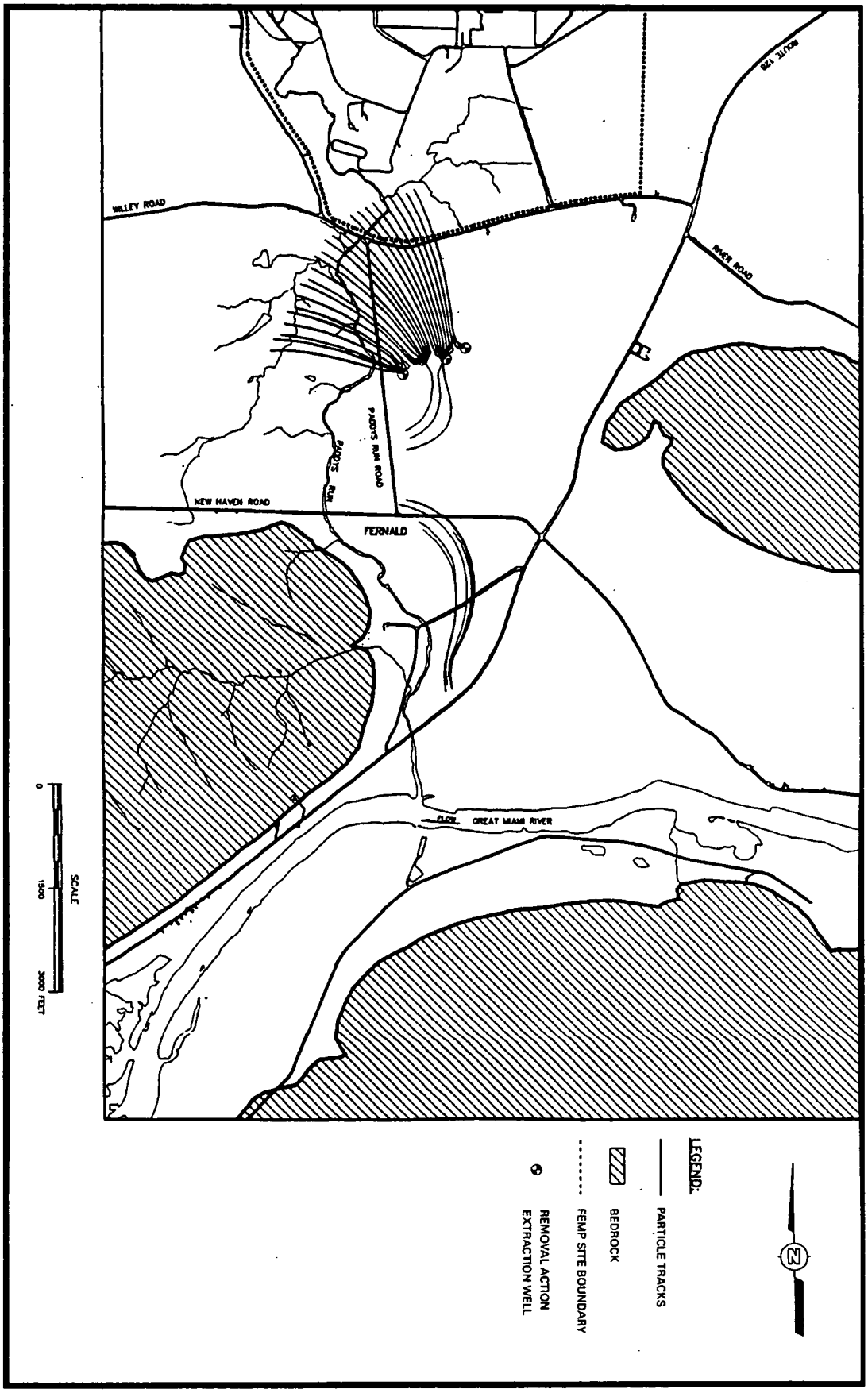


Figure 4-46 - Forward Tracking Capture - 0.25X Nominal K_h Case - XY

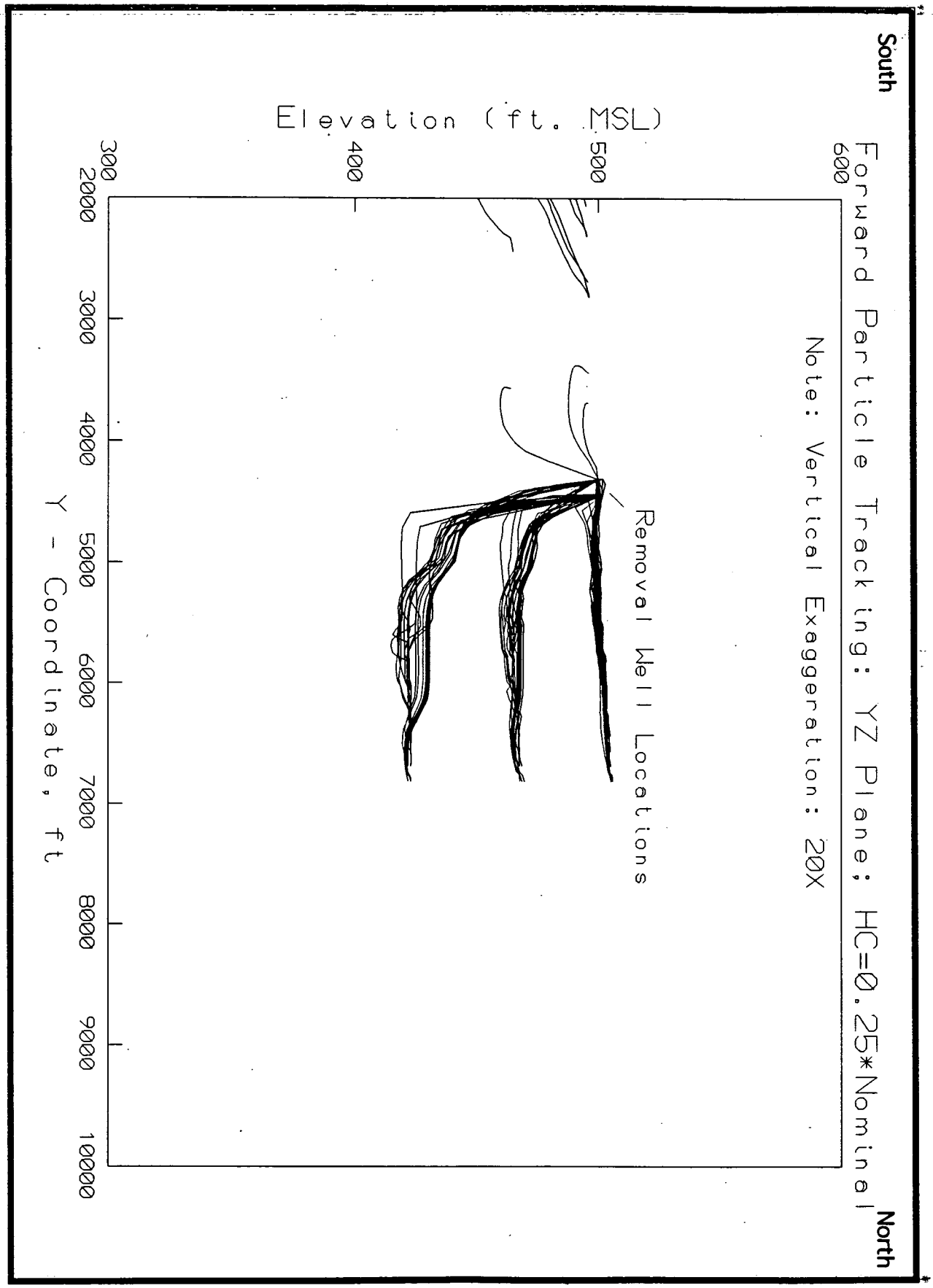


Figure 4-47 - Forward Tracking Capture - 0.25X Nominal K_h Case - YZ

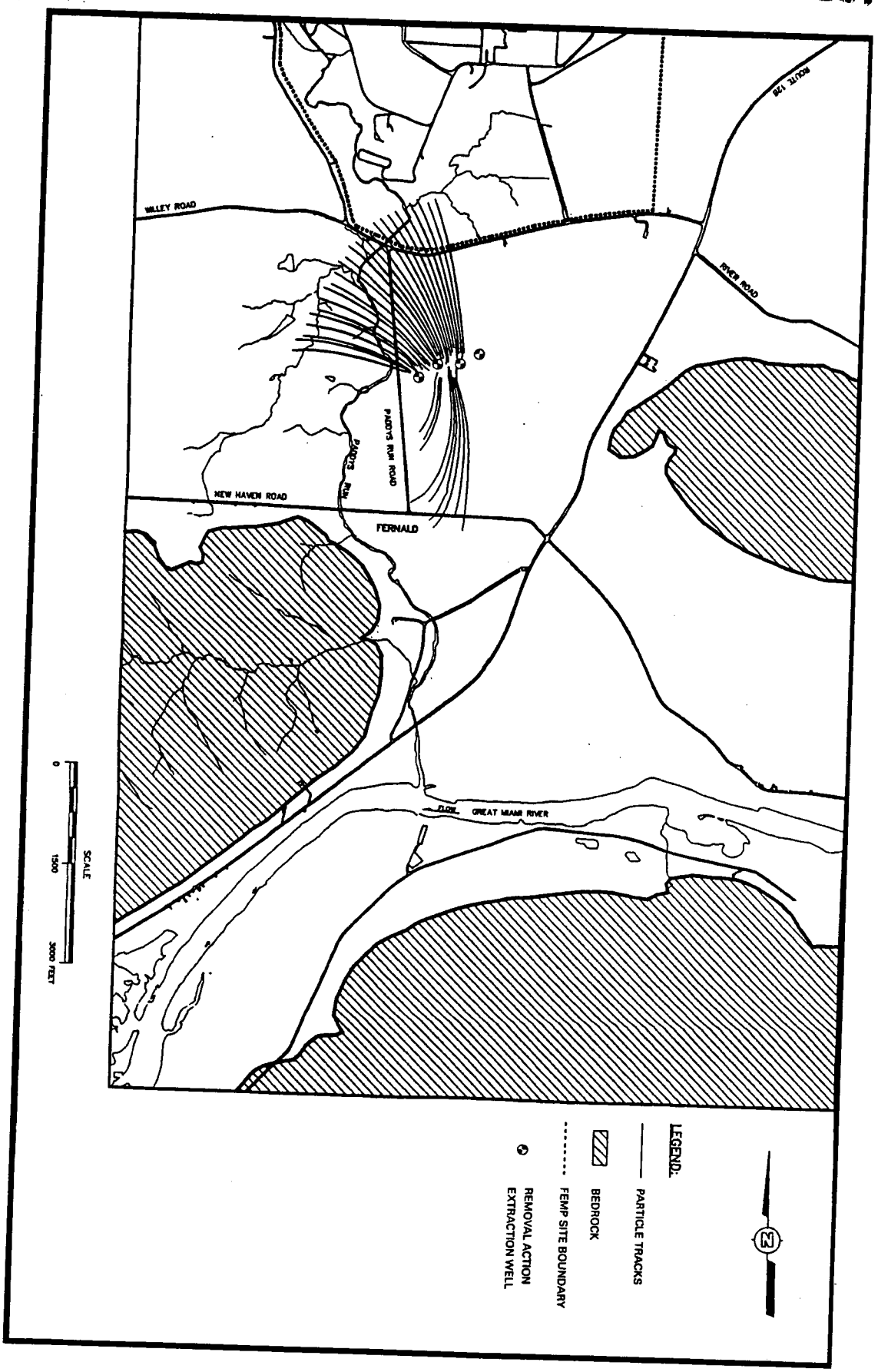


Figure 4-48 - Forward Tracking Capture - 0.1X Nominal K_h Case - XY

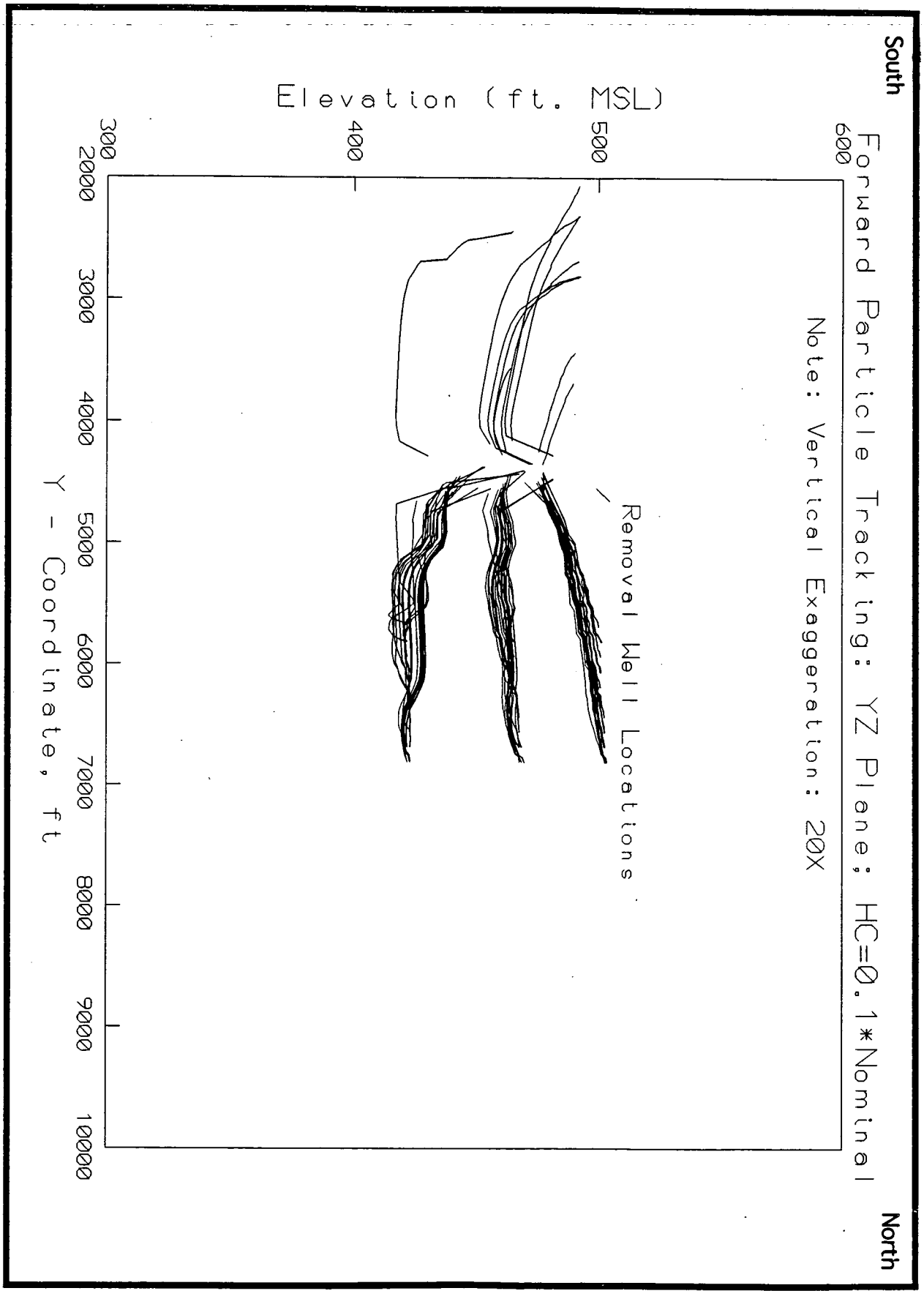


Figure 4-49 - Forward Tracking Capture - 0.1X Nominal K_h Case - YZ

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

Application of the FEMP groundwater model and analysis of field data were used for setting design parameters of a relocated groundwater recovery system that would achieve the revised goals of the Removal Action. Based on the results of the modeling simulations and field sampling data, a new location adjacent to Delta Steel was selected for the well field. At this location, the well field will be able to intercept the majority of the South Plume (based on both modeled and monitored data), while at the same time have minimal impact on the PRRS groundwater plume. Simulated pumping of the recovery wells at this location was successful in creating an effective hydraulic barrier. At a location near the approximate southern boundary of the FEMP a barrier was created over 3000 feet wide with complete particle capture in model layers 1, 2 and 4. Due to the proximity of the South Plume to the PRRS plumes, the modeling simulations predict that it is impossible to meet the goals of the Removal Action without having some influence on the PRRS plumes. However, the modeling simulations predict that the currently proposed well field will cause minimal deflection of the organic and inorganic plumes.

This well field only addresses the portion of the South Plume which is free of the PRRS plumes. Uranium contamination south of the wells will need to be addressed in a separate design.

5.1 Design Parameters

The basic parameters established by the groundwater modeling effort for the Removal Action well field include well placement, spacing, and pumping rates. Initial work was done to define the upper and lower bounds for these parameters, based on keeping the well field design as flexible as possible and to allow for uncertainties in monitoring data and modeling output.

The recommended design parameters for the Removal Action well field are specified in Table 5-1. These parameters are based on utilization of the 4-well, 2,000 gpm well field with the option of using a 3-well, 2,250 gpm well field in case of the failure of one of the wells. If two or more wells fail, the well field integrity will not be able to be maintained because of the large gaps in the hydraulic barrier which will arise. Some flexibility in the placement and spacings of the wells is shown to account for model discretization limits and the possible need to site wells away from buildings and other geographical features.

5.2 Model Limitations/ Implication to Removal Action

Weaknesses in the groundwater model have been identified during applications of the model over the last two years and a model improvement program has been developed to address these weaknesses. Nevertheless, the most effective tool to support the design of the recovery system is still the groundwater model. These model weaknesses can be overcome with a dual reliance on monitoring data as well as modeling results, with design conservatism, with an after-the-fact pump test, and with a better understanding of the sensitivity of plume capture to changes in the hydraulic conductivity. Selection of locations and design parameters for recovery wells and pumps are based both on monitoring data and flow model simulations including forward and reverse particle tracking. Solute transport simulations are only utilized to show gross type trends. Recommendations for ranges of parameters are included in the selection of design parameters.

Through sensitivity analysis on horizontal hydraulic conductivity (K_h), the effect of uncertainty of K_h is better understood and an acceptable range for K_h can be established. Raising and lowering the K_h have opposite effects on recovery system performance. Raising the K_h moves the system toward uranium break through, but decreases the tendency toward PRRS capture. Lowering the K_h increases the ability of the system to capture the uranium plume, however, the system will have a greater tendency toward PRRS capture. Either of these effects can be compensated for by raising or lowering the pumping rate of the recovery wells. K_h values of 787 feet/day and 315 feet/day have been determined to represent approximate upper and lower bounds for K_h at the design pumping rate of 4 wells at 500 gpm or 2000 gpm for the well field. Although break through did occur at 787 feet/day, it was primarily from layer 4. Greater PRRS deflection occurred at 315 feet/day, however 80 feet is a relatively minor impact.

The initial pumping rate should be 2000 gpm for the well field if the calculated Kh (from the pump test) falls within the acceptable range defined with the sensitivity analysis. If the calculated Kh falls outside of this acceptable range, engineering judgement should be used to modify the initial operating conditions. The process of changing operational conditions is described in the DMEPP.

5.3 Additional Remediation Considerations

Based on the analysis presented in Sections 3 and 4, the plumes in the South Field area need to be considered for possible remediation. Two situations are apparent. First of all, according to model simulations, a portion of the plume identified in the South Field is not captured by the proposed recovery wells. While it was never an objective to capture the plume in this area, nevertheless, this result is worth noting as a remediation concern. Secondly, the portion of these plumes that are captured by the proposed recovery wells will move slightly faster due to increased gradients caused by pumping. This will result in plume expansion and a shorter time of travel to the FEMP property line. Since the removal action needs to be consistent with the final remediation, this situation raises possible conflicts with this objective.

Work will continue to (1) identify potential sources in the South Field; (2) better define the extent of the plumes; and (3) confirm or deny model predictions about the ability of the recovery wells to capture these plumes.

The following two recommendations pertain to this finding:

1) Options for remediation at these locations should be evaluated. The predicted time of travel needs to be considered in the selection of the preferred option.

2) The groundwater model may be used to support the selection and design of remediation systems in the South Field area. The refined model should be used incorporating changes made with the model improvement plan (see Section 3) or with the latest data.

Table 5-1 - Removal Action Recovery Well Design Parameters

Number of Wells:	4
Pumping Rate:	500 gpm each maximum[a] 800 gpm each maximum[b]
Well Diameter:	12-inch I.D.
Screen Length:	40 feet
Screen Diameter:	12-inch I.D.
Screen Size:	0.020-Inch Slots (Approximate; Determine during drilling)
Screen Placement:	From surface of static water table to 40 feet below static water table

Well Locations	State Coordinates[c]	
Well:	East	North
1	1379841	474259
2	1380165	474448
3	1380444	474466
4	1380768	474654
Well Spacing	280 feet[d]	

[a] Based on well capture design.
[b] Based on well size.
[c] Coordinates of wells are ±50 feet any direction.
[d] Well spacing is ±25 feet.

SECTION 6

REFERENCES

(Anderson 1984) Anderson, M.P., 1984. "Movement of Contaminants in Groundwater: Groundwater Transport-Advection and Dispersion." In *Groundwater Contamination.* National Academy Press. pp. 37-45.

(Anderson 1989) -----, 1989. *Hydrogeologic Facies Models to Delineate Large-Scale Spatial Trends in Glacial and Glaciofluvial Sediments.* Geological Society of America Bulletin 101, pp. 501-511.

(Borg et al 1976) Borg, I.Y, H.B. Levy, L.D. Ramspott, 1976. *Information Pertinent to the Migration of Radionuclides in Groundwater at the Nevada Test Site, Part 1: Review and Analysis of Existing Information.* Lawrence Livermore Laboratory, Report UCRL-52078.

(Dames and Moore 1985) Dames and Moore, 1985. *Groundwater Table C Report.* Reston, VA: Dames and Moore.

(DOE 1989) United States Department of Energy, 1989. *Geochemical Program - Issues 3 and 5.* Feed Materials Production Center, Fernald, Ohio. Oak Ridge, TN: U.S. DOE.

(DOE 1990a) ----------, December 1990. *Groundwater Report, Feed Materials Production Center, Fernald Ohio, Remedial Investigation and Feasibility Study.* Oak Ridge, TN: U.S. DOE.

(DOE 1990b) ----------, 1990. *Engineering Evaluation/Cost Analyses - South Plume*, Oak Ridge, TN: U.S. DOE.

(DOE 1990c) ----------, December 1990. *Remedial Investigation Report for Operable Unit 5, Task 6 Report.* FMPC, Oak Ridge, TN: U.S. DOE.

(DOE 1991) ----------, 1991. *Work Plan for the South Groundwater Contamination Plume Removal Action - Part 5 Groundwater Modeling and Geochemical Investigation.* Oak Ridge, TN: U.S. DOE.

(DOE 1992) ----------, April 1992. *Sitewide Characterization Report.* RI/FS. FEMP, Oak Ridge, TN: U.S. DOE.

(DOE 1993) ----------, January 7, 1993. Presentation to the United States and the Ohio Environmental Protection Agency, Sheraton Hotel. Springdale, Ohio.

(Dove 1961) Dove, G.D., 1961. "A Hydrologic Study of the Valley-Fill Deposits in the Venice Area, Ohio," *Technical Report 4.* Ohio Department of Natural Resources, Division of Water.

(Driscoll 1986) Driscoll, F. G., 1986. *Groundwater and Wells* - 2nd Edition, Johnson Division. St. Paul, Minnesota.

(GeoTrans 1987) GeoTrans, 1987. *STLINE, Version 1.9 User's Manual.* Sterling, VA: Geotrans.

(IT 1990) IT Corporation, 1990. *Flow and Solute Transport Computer Code Verification.* Pittsburgh, PA: IT.

(Kazmann 1950) Kazmann, R.G., 1950. *Memorandum Report on Hydrogeological Survey for Southwestern Ohio Water Company.* Big Bend Area, Miami River, Hamilton County, Ohio.

(Klaer, et al. 1943) Klaer, F. and R.G. Kazmann, 1943. "A Qualitative Study of the Well Field of the Mill Creek Valley Water Supply Project," *U.S.G.S. Technical Report.* Butler County, OH.

(Klaer, et al. 1948) ----------, 1948. "Groundwater Resources of the Cincinnati Area," *U.S.G.S. Water Supply Paper.* Butler and Hamilton Counties, OH.

(Lewis 1968) Lewis, R.C., 1968. *An Investigation of the Potential Yield of the Big Bend Well Field*, (Unpublished), M.S. Thesis, University of Cincinnati, OH.

(Moody and Graybill 1963) Moody, M.M., and F.A. Graybill, 1963. *Introduction to the Theory of Graybill Statistics.* McGraw-Hill: New York, NY.

(NRC 1990) United States Nuclear Regulatory Commission, 1990. *Ground Water Models, Scientific and Regulatory Applications.* National Academy Press. Washington, D.C.

(PARSONS 1992) PARSONS, 1992a. *South Plume Removal Action - Design, Monitoring, and Evaluation Program Plan, Rev. No. 0.* Fairfield, OH: PARSONS.

(Smith 1968) Smith, R.C., 1962. *Groundwater Development Miami River Area*, Consultant Report to City of Cincinnati, Water Works Department (see GeoTrans, 1985).

(Spieker, et al. 1962) Spieker, A.M. and S.E. Norris, 1962. "Groundwater Movement and Contamination at the AEC Feed Materials Production Center Located Near Fernald, OH," *U.S. Geological Survey Technical Report for the U.S. Atomic Energy Commission.*

(Spieker 1968) Spieker, A.M., 1968. "Groundwater Hydrology and Geology of the Lower Great Miami River Valley Ohio," *U.S. Geological Survey Professional Paper 605-A.* U.S. Government Printing Office.

(Walton 1988) Walton, W.C., 1988. *Practical Aspects of Groundwater Modeling - 3rd Edition.* National Water Well Association: Worthington, Ohio.

(WMCO 1991) Westinghouse Materials Company of Ohio, April 1, 1991. Letter - Relocation of Parts 2 and 3 - Pumping and Discharge Recovery Well Field: South Groundwater Contamination Plume Removal Action.

APPENDIX A

REPRINT OF THE SOUTH PLUME EE/CA MODELING REPORT

APPENDIX A

EE/CA GROUNDWATER MODELING

TABLE OF CONTENTS

		Page
List of Figures		a-iii
List of Acronyms		a-iv
A.1.0	Purpose and Scope	A-1-1
A.2.0	Model Description	A-2-1
A.3.0	Model Calibration	A-3-1
A.4.0	Model Application	A-4-1
	A.4.1 Baseline Condition: No Action Alternative	A-4-1
	A.4.2 Alternative Water Supply Alternative	A-4-3
	A.4.3 Pumping Alternatives Plume Interception	A-4-6
	A.4.4 Plume Behavior	A-4-11
References		A-R-2

LIST OF FIGURES

Figure		Page
A-1	Groundwater Model Grid Boundary	A-2-2
A-2	3-Dimensional Solute Transport Model Recharge and Pumping Well Rates	A-2-5
A-3	Simulated Uranium Concentrations Present Conditions	A-4-2
A-4	Simulated Uranium Concentrations No-Action Conditions Five Years From Present	A-4-4
A-5	Particle Tracking Alternate Water Supply Alternative	A-4-5
A-6	Particle Tracking for Plume Interception Alternative	A-4-7
A-7	Drawdown Due to Groundwater Interceptor Wells	A-4-9
A-8	Particle Tracking for Central Plume Interception Alternative	A-4-10
A-9	Simulated Uranium Concentrations Five Years From Present With Interceptor Wells	A-4-12
A-10	Uranium Concentrations vs Time for Interceptor Wells	A-4-13
A-11	Cumulative Uranium Captured vs Time for Interceptor Wells	A-4-14

ACRONYM LIST

EE/CA	engineering evaluation/cost analysis
FMPC	Feed Materials Production Center
RI/FS	remedial investigation and feasibility study

A.1.0 PURPOSE AND SCOPE

The purpose of this groundwater modeling investigation was to support the engineering evaluation and cost analysis (EE/CA) of removal action alternatives for the south plume at the Feed Materials Production Center (FMPC) in Fernald, Ohio. The alternatives include no action, aquifer monitoring and institutional control, installation of an alternate water supply, groundwater pumping to control plume migration, and combinations thereof. The modeling study was necessary to supplement direct field observations so that the combined informational base would be sufficient to support: (1) the understanding of the current situation (i.e., the nature and extent of the contamination); (2) the public health and environmental risk assessment; and (3) the evaluation of the removal action alternatives.

Groundwater monitoring data provides insight into the nature and extent of contamination by establishing whether contamination is present at a specific location and to what level. The results of the modeling study utilize these same data as calibration points to approximate, through interpolation between and extrapolation beyond the field observations, the concentration distribution throughout the area of interest. This exercise can be used to establish the probable location and value of the absolute maximum concentration; estimate the total mass of a contaminant present in the aquifer; help explain the occurrence of the field observations; indicate whether or not any field observations should be considered as outliers; and determine the uncertainties for the planning of additional data collection efforts.

The public health risk assessment involves the evaluation of risk under both existing conditions and anticipated conditions (with and without an action). Direct field observations are often sufficient for the evaluation of current risk since groundwater at the specific locations of all known users can be monitored. On the other hand, model results can be used for the prediction of future conditions. Model predictions describe expected uranium distribution (and thus potential levels of exposure) in both space and time.

The evaluation of alternatives is only sparingly supported by direct field observations. This is due to

the limitation in utilizing current observations for the direct evaluation of future performance. The primary use of the field observations is to establish the present condition and to support the calibration of the model, which in turn is used to evaluate remedial action alternatives. In the case of the south plume, the model is intended to support the following:

- Projection of the likelihood that additional receptors would require an alternate water supply during the life of the action (Alternate Water Supply)
- Identification of the most susceptible receptor locations for additional "early warning" wells or control prioritization (Monitoring/Institutional Controls)
- Evaluation of the effects on plume migration if the industrial wells are shut down (Alternate Water Supply)
- Determination of the size and location of extraction wells to control plume migration (Pump and Treat)
- Evaluation of the effects of pumping on plume behavior at other locations (Pump and Treat)
- Estimation of the discharge rate, average concentration, and mass of uranium removed from extraction wells, support the evaluation of effects of the discharge on surface waters (Pump and Treat)
- Time required to reach the target level for cleanup (Pump and Treat)

The EE/CA, including the groundwater modeling study, was based on information available as of mid-1990. The available water level data from numerous monitoring wells was sufficient for a complete and successful calibration of the groundwater flow model. The results of all applications of the model that involved the groundwater flow component are, therefore, considered very reliable for their intended use.

On the other hand, the predictions of present and future uranium concentrations in the plume resulting from the application of the solute transport model should be viewed as approximations based on the best available data. The extent of the southern, leading edge of the plume remains uncertain due to a scarcity of field data in the area predicted (by the model) to contain the plume front. Results of

additional field investigations forthcoming from the Remedial Investigation/Feasibility Study (RI/FS) for the Environmental Media Operable Unit will improve the reliability of solute transport model predictions in this area.

Because uranium migration is influenced by geochemical factors, the anticipated results of the ongoing geochemical program will also increase the level of confidence in the predictions of future conditions from the solute transport model. Even though concentrations predicted in the present report may be revised as a result, the level of change is not expected to be significant enough to cause a change in the overall findings and conclusions of the EE/CA.

A.2.0 MODEL DESCRIPTION

The groundwater model used in support of the EE/CA for the south plume is a finite-difference computer model of groundwater flow and solute transport. The computer program is SWIFT III, Version 2.25. A detailed presentation of the model, its development, and the baseline input data will be issued as part of the overall modeling report being prepared under the RI/FS. Only the most pertinent information is provided here. A comprehensive verification study of the SWIFT III code has also been completed and a report will be forthcoming under separate cover.

Steps in the development of the model for application to the FMPC have included:

- Construction and calibration of a regional, two-dimensional, steady state, groundwater flow model
- Construction and calibration of a regional, three-dimensional, steady state, groundwater flow model
- Application of two-dimensional analytical solute transport models to help strategize the numerical solute transport model
- Construction of a local, two-dimensional, transient solute transport model
- Construction of a local, three-dimensional, transient solute transport model
- Calibration of the solute transport part of the local model with uranium concentration data from the monitoring wells

The local model covers a smaller area than the regional model (Figure A-1). The smaller area allowed the use of a refined grid with a small cell size, which is necessary for solute transport modeling. The smaller grid area was established to include the area of the existing uranium plume. The local model also covered the area for which uranium concentration data is available from monitoring wells. The interrelationship between the local and regional models is established by imposing the steady-state flow field predicted by the regional model on the solute transport model.

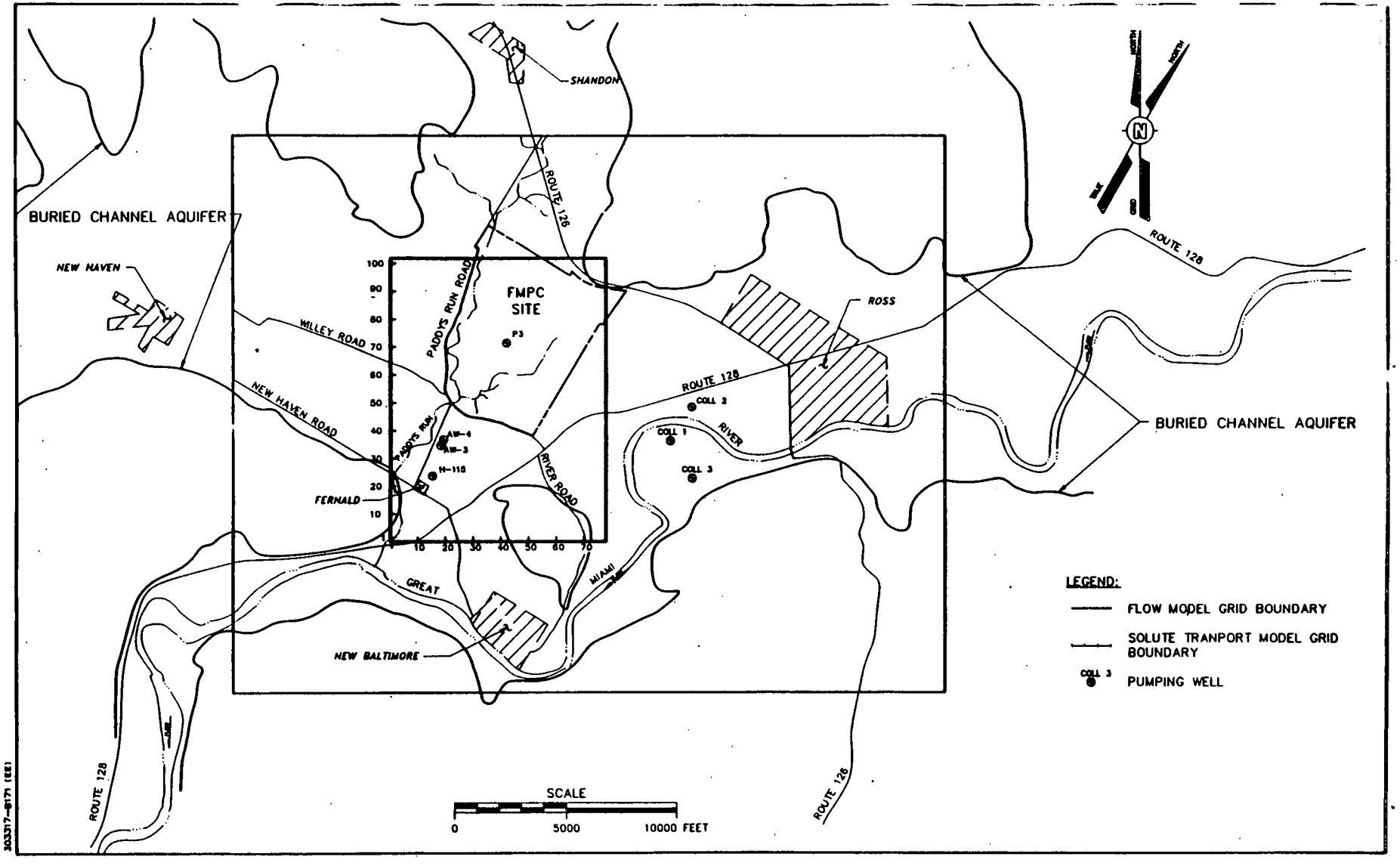


FIGURE A-1
GROUNDWATER MODEL GRID BOUNDARY

The model contains five layers. The uppermost two layers represent the upper and lower parts of the upper alluvial aquifer that underlies the area. The middle layer represents a clay bed that is present in the immediate vicinity of the FMPC site, and the lowermost two layers represent the upper and lower parts of the lower alluvial aquifer. The layers extend laterally into bedrock at the edges of a buried valley that contains the alluvium.

The model uses varying hydraulic conductivity values for the five layers, based on calibration results of the regional model using April, 1986 water level data. This period was used as it represents average groundwater conditions and water level elevations. From the calibration results of the regional three-dimensional flow model, the uppermost and middle layers were assigned a hydraulic conductivity value of 450 ft/day, and the lowermost layers used 600 ft/day. In addition, a portion of the middle layer which underlies the FMPC site was assigned 0.0003 ft/day as a hydraulic conductivity value to represent the area the clay interbed exists in (as shown by geologic borings). This simulated the presence of a low permeability clay and created semiconfining layer underneath part of the site and the surrounding area.

In addition to changing hydraulic conductivity values between layers, the number of aquifer cells presently in each layer was reduced the deeper the layer lies. This was done to simulate the downward narrowing U-shaped buried valley within which the Great Miami Aquifer lies and was accomplished using bedrock topography maps of the region.

Transmissivity values were not used as input for the model; instead, they were calculated by the model during its execution. As saturated thicknesses vary throughout the model, transmissivities vary as well and thus could not be calculated except on a cell-by-cell basis.

Recharge rates for the local model were also taken from the calibration results of the regional three dimensional flow model (Figure A-2). Recharge zones represent the varying soil types, with 6 inches/year representing sand and gravel aquifer overlain by glacial till, 14 inches/year representing sand and gravel aquifer overlain by nothing, and 32 inches/year representing the channel in which

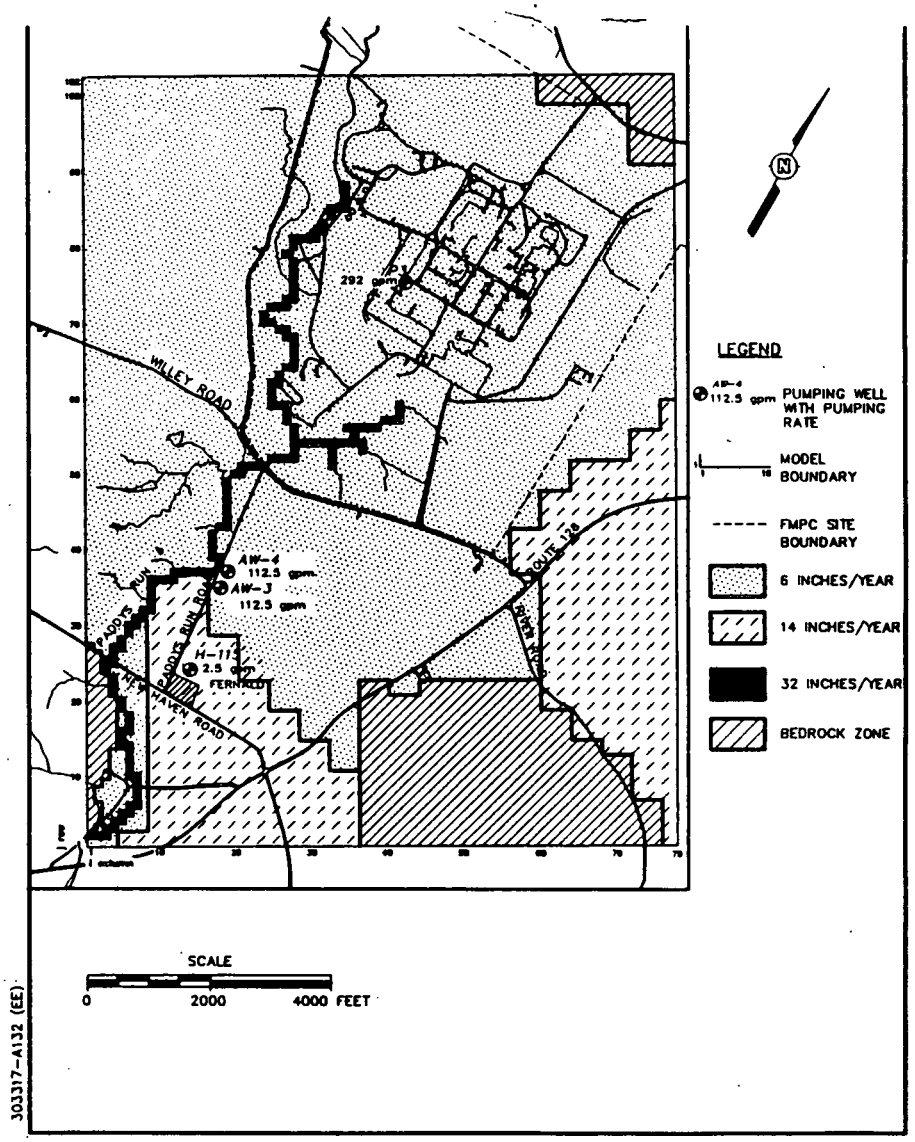


FIGURE A-2
3-DIMENSIONAL
SOLUTE TRANSPORT MODEL
RECHARGE AND PUMPING WELL RATES

Paddys Run flows. The divisions between the zones are based on surficial soil maps of Butler and Hamilton counties (Speiker 1968). Recharge values were derived initially from soil infiltration data and were modified during regional model calibration.

Pumping wells are located in the area spanned by the local model. These include an FMPC production well and three industrial wells located south of the FMPC site. Pumping from each of these wells was assigned to the proper cell and layer in the model. The three industrial wells are within the south plume study area (Figure A-2).

A.3.0 MODEL CALIBRATION

The calibration of the groundwater flow model was performed by comparing hydraulic heads calculated by the model against heads measured in numerous monitoring wells throughout the FMPC and surrounding areas.

This calibration was performed using the regional flow model. Reasonable estimates of hydraulic conductivity and recharge were initially input to the model and then varied within an acceptable range to adjust model-computed heads to agree with observed monitoring well heads. The monitoring well heads used for calibration were measured in 1986.

Both Paddys Run and the Great Miami River were included in the regional flow model and were modeled as being hydraulically linked with the groundwater system. As Paddys Run is basically a losing stream in the model area, it was modeled using a higher recharge rate than surrounding areas in regions where it flows over the alluvial aquifer. In areas where it flows over the glacial till deposits, it was assigned the same recharge rate as surrounding areas (Figure A-2).

The Great Miami River cannot be classified as either a totally gaining or losing river, as it does both within the model area. Where it flows by Collector Wells 1 and 2, (Figure A-1), it is a losing river, but upstream and downstream of this area it is a gaining river. To model this effect, a river leakage coefficient of 0.5 day^{-1} was set in all cells where the river was located. This river leakage coefficient represents the permeability of the river bed materials, and is approximately three orders of magnitude lower than the surrounding aquifer. The river cells also had river elevations set in them, based on river-gaging stations and predicted elevations from river profiles. By using both the river elevations and leakage coefficient, the model is able to calculate inflow/outflow to/from the river based on aquifer heads in the same cells. In this way, both gaining and losing conditions were simulated in the Great Miami River.

Groundwater flow conditions simulated by the model were successfully made to reproduce the observed flow conditions throughout the study area. Based on water levels from 55 wells, the mean residual (observed head minus calculated head at a monitoring well) for the calibrated flow model was 0.21 feet. The excellent fit portrayed by this residual value is realized when compared to a total change in hydraulic head of approximately 20 feet over the south plume area. The mean of the absolute values of the residuals was 1.08 feet. When the local model was constructed, a computer program was used to check, cell by cell, the correspondence of heads in the local model with heads in the regional model. The correspondence verified that the flow model calibration was preserved in the solute transport model.

The calibration of the solute transport model involved the following steps:

- Designating appropriate cells as source cells where uranium may enter the groundwater system, based on the current understanding of historic patterns of uranium release
- Dividing the model time into source loading periods corresponding to intervals during which source loading was probably significantly different from other periods
- Introducing reasonable initial estimates of uranium source loading for each source cell
- Establishing the best initial values of longitudinal and transverse dispersivity, as well as a distribution coefficient for uranium
- Adjusting source loading, source loading periods, dispersivities, and the distribution coefficient until concentrations calculated by the model are close to concentrations measured in the field

Source areas in the model were derived from site historic data which defined regions of contamination and pathways for contaminant transport. Based on this data, a number of regions, including Paddys Run, the storm sewer outfall ditch, the waste pits, the sewage treatment plant, and point sources within the FMPC production area, were all defined as potential source areas. Although all these areas were recognized as potential source areas, not all of them were used to load uranium contamination into the model. Rather, areas during calibration which caused concentrations to match those from field data were used primarily, while other areas were not used at all.

Initial loading rates and time periods were taken from literature reviews of the site's operation and estimates of the rates of contaminant escape. This data, for the most part, dealt with leakage rates from the waste pits and outflow events through the storm sewer outfall ditch. Comparison of leakage periods to each other showed four distinct time periods during which different source loading rates existed. These four periods represent the various operational times of the waste pits and in total encompass a 37-year period, extending from 1952 (when Waste Pit 1 was constructed) to 1989 (when the modeling study was ended).

Calibration of the model against measured site concentration data changed the active source areas and loading rates originally derived from the literature reviews. At no time were the loading periods or the potential source areas changed during the calibration; these were assumed to be fixed and unchangeable. Source rates and active source areas were allowed to be changed during calibration, as these were the variables that were used to match the site concentration data.

Modeling the south plume in this manner not only matched the present site groundwater data but also allowed the model to simulate the historical development of the groundwater plume. As predicted loading rates from the literature review were used as a basis for initial model-loading rates, the model was able to simulate the development of the plume from older source areas and not just as a large loading pulse from new sources. This allowed the formation of the general shape of the south plume by older periods, while newer source periods gave the plume more definition and finer detail. In this way the model derived the south plume, not as a large pulse of contaminant but rather as a long-term groundwater plume sourced by both older and newer source areas.

The distribution coefficient was set at 0.016 cubic feet per pound, which corresponds to a retardation factor of 9. After attempting calibrations with distribution coefficients corresponding to retardation factors of 1, 6, and 12, a retardation factor of 9 was selected as the most reasonable compromise between two competing goals. These goals were to keep the dispersivities as close to 100 feet as possible and to keep the distribution coefficient as low as possible. The preference for a dispersivity of 100 feet was based on information in the scientific literature. Walton (1985, Figure 2.16) presents a

graph of mean travel distance versus longitudinal dispersivity. Assuming a mean travel distance in the south plume of 2500 feet, Walton's graph yields a longitudinal dispersivity of a little over 100 feet. Walton also shows representative longitudinal dispersivities for areal models of alluvial sediments and glacial deposits to be between 39 and 200 feet. The desire to keep the distribution coefficient low was based on preliminary results of the geochemical investigation, which suggest that the uranium is in complexes which have neutral or negative charges. Such charges imply low retardation.

Because the plume is narrow and has high concentration gradients away from the center, the concentration patterns could be matched by having either a sufficiently high retardation factor or a sufficiently low dispersivity. Calibration with a retardation factor of 9 yielded a longitudinal dispersivity of 50 feet and a transverse dispersivity of 1 foot. The model uses transverse dispersivity for vertical dispersivity, so the calibrated transverse dispersivity tends to be low. Although the outcome of the geochemical investigation may result in a different retardation factor, the value of 9 is sufficiently realistic to allow for provisional application of the solute transport model in this study.

Statistics used to characterize the degree of calibration were based on monitoring data from wells that yielded detectable uranium in all samples. The object of the calibration was to produce a representative simulated plume. Calibration was performed by comparing calculated concentrations to the mean values of concentrations measured at the individual wells. Since the mean of observed concentrations at a well where only a few concentrations have been measured is not an accurate estimate of the most representative value for that well, such means were not matched more closely than their accuracy warranted. Instead, the model calibration emphasized (1) avoidance of excessive clumping of positive or negative residuals (observed mean concentration at a well minus the calculated concentration at the well), and (2) keeping the absolute values of the residuals reasonably low.

The first calibration criterion, clumping, was examined by calculating the unit normal deviate from a modification of Moran's I (IT Corporation 1987). A value greater than 1.645 indicates a nonrandom distribution of residuals at the 0.05 level of significance. The optimal value is zero. The value calculated for the calibrated run was 0.144.

The second calibration criterion, reasonably low absolute values of residuals, was examined by using a statistical procedure to determine whether the calculated concentration at an observation well differs from the mean concentration observed there by an improbable amount. The statistical testing procedure used for this purpose followed methods described by Grubbs (1969). This method of testing goodness of fit is more informative than simply measuring deviations from means because it includes uncertainty related to the representativeness of the observed concentrations (sample) at a given well. It allows less deviation from means of large samples and/or samples with little variation in values, but allows greater deviation from means based on only a few samples (only two samples had been collected at some wells) and/or means based on samples with much variation in values. The result of applying this procedure was that no calculated concentration within the plume defined by the 30 microgram per liter (µg/L) contour was significantly different from the observed mean for the well when tested at a level of significance of 2.5 percent. The calculated concentrations were judged to be sufficiently representative of the true mean concentrations in the plume.

Calibration of the solute transport model is provisional. As mentioned above, geochemical work which might supply a better estimate of the distribution coefficient is not complete. A different distribution coefficient would require compensating adjustments in the dispersivity value and the source loading rates to maintain the model calibration.

A.4.0 MODEL APPLICATION

A.4.1 BASELINE CONDITION: NO-ACTION ALTERNATIVE

The model results representing the current distribution of uranium in the south plume are shown in Figure A-3. Only the uranium values in the uppermost layer of the aquifer are shown since the highest observed values were from this layer. The maximum concentration in the plume is predicted to be approximately twice the maximum observed value and to lie northeast of the well with the highest observed level. The maximum concentration is also some distance downgradient from the source locations. This result indicates that the plume is affected by source loadings that were greater in the past than they are now. It is also important to note that a steep gradient of uranium concentrations is predicted to exist near several potential receptors and existing monitoring wells along Paddys Run Road.

For purposes of this study, the boundary of the plume has been defined to be the 30 µg/L isoconcentration contour, which is equivalent to the derived concentration limit for uranium in groundwater. It is also noted that the 30 µg/L uranium concentration limit represents elemental uranium, but uranium present in the Great Miami Aquifer is generally in the form of uranium complexes. Geochemical modeling indicates that uranium most commonly occurs as the complexes $UO_2(CO_3)_3^{-4}$ and $UO_2(CO_3)_2^{-2}$ in groundwaters from the aquifer. In some cases $UO_2(H_2PO_4)_3$ may form when inorganic phosphates are present, which they are through parts of the aquifer. All three of these complexes are fairly mobile, and thus can be expected to migrate in the present groundwater system. Thus, the presence of high concentrations of phosphorus around Paddys Run Road will not adversely impact the removal action of the interceptor wells. Rather, it is expected the phosphorus will simply change complexes to become $UO_2(H_2PO_4)_3$, which is expected to be slightly more mobile due to its neutral charge than the other species and thus will be extracted more efficiently. The boundary of the existing plume, as produced by the model, is shown in Figure A-3.

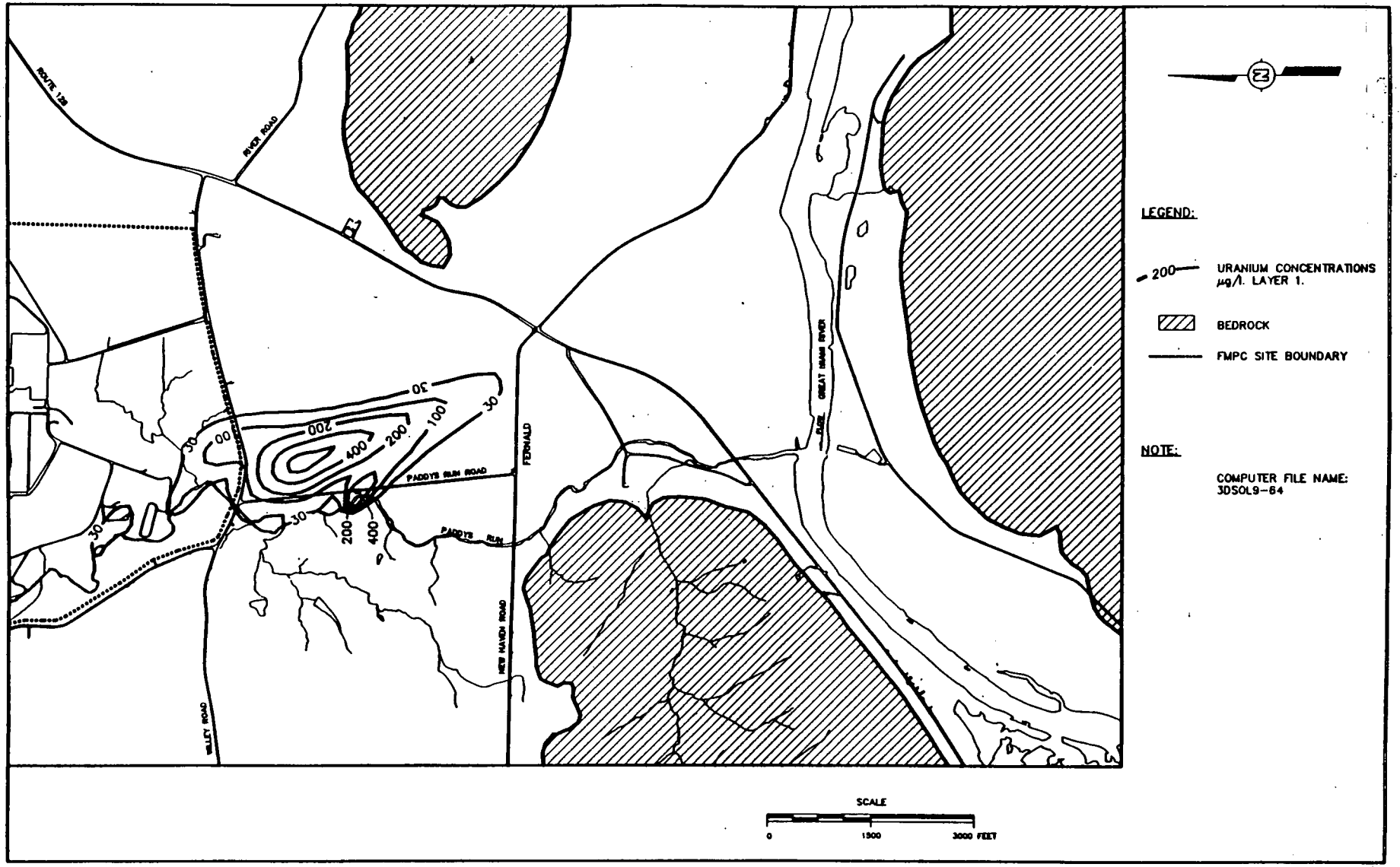


FIGURE A-3
SIMULATED URANIUM CONCENTRATIONS
PRESENT CONDITIONS

Modeling future concentrations under the no-action alternative was completed by extending the estimates of present source loadings five years into the future. This scenario results in the conditions shown in Figure A-4. The crest of the plume moves south about 1100 feet and the maximum concentration declines about 170 µg/L, or approximately 25 percent, due to plume dispersion.

The results presented in Figures A-3 and A-4 were generated by the solute transport model and are thus subject to the uncertainties discussed in previous sections. However, the presentation of existing conditions should not be greatly affected by such uncertainties since it represents the model run that was calibrated against field observations. The overall shape of the plume and the general magnitude of the values for both existing and future conditions are considered to be representative of field conditions.

A.4.2 ALTERNATE WATER SUPPLY ALTERNATIVE

The proposed source of the alternate water supply is a well located near Willey Road, 1750 feet west of the FMPC boundary. Particle tracking was used in conjunction with the groundwater flow model to investigate whether operation of this well at a 500 gpm flow rate would pull water from the plume. The results are presented in Figure A-5. These results show that the particle tracks in the plume are not distorted by the simulated production well; therefore, the well would not draw water from the plume. To verify this, these particle tracks were compared with the no-action scenario, again showing that the simulated production well has little effect on the particle tracks.

A.4.3 PUMPING ALTERNATIVES: PLUME INTERCEPTION

The location and pumping rates for interceptor wells that will produce a hydraulic control to the southward movement of contaminated water in the south plume were selected by introducing a line of wells with various spacings and pumping rates into the model. Particle tracking was used to determine whether water upgradient from the wells and within the lateral and vertical boundaries of the plume would be drawn into them.

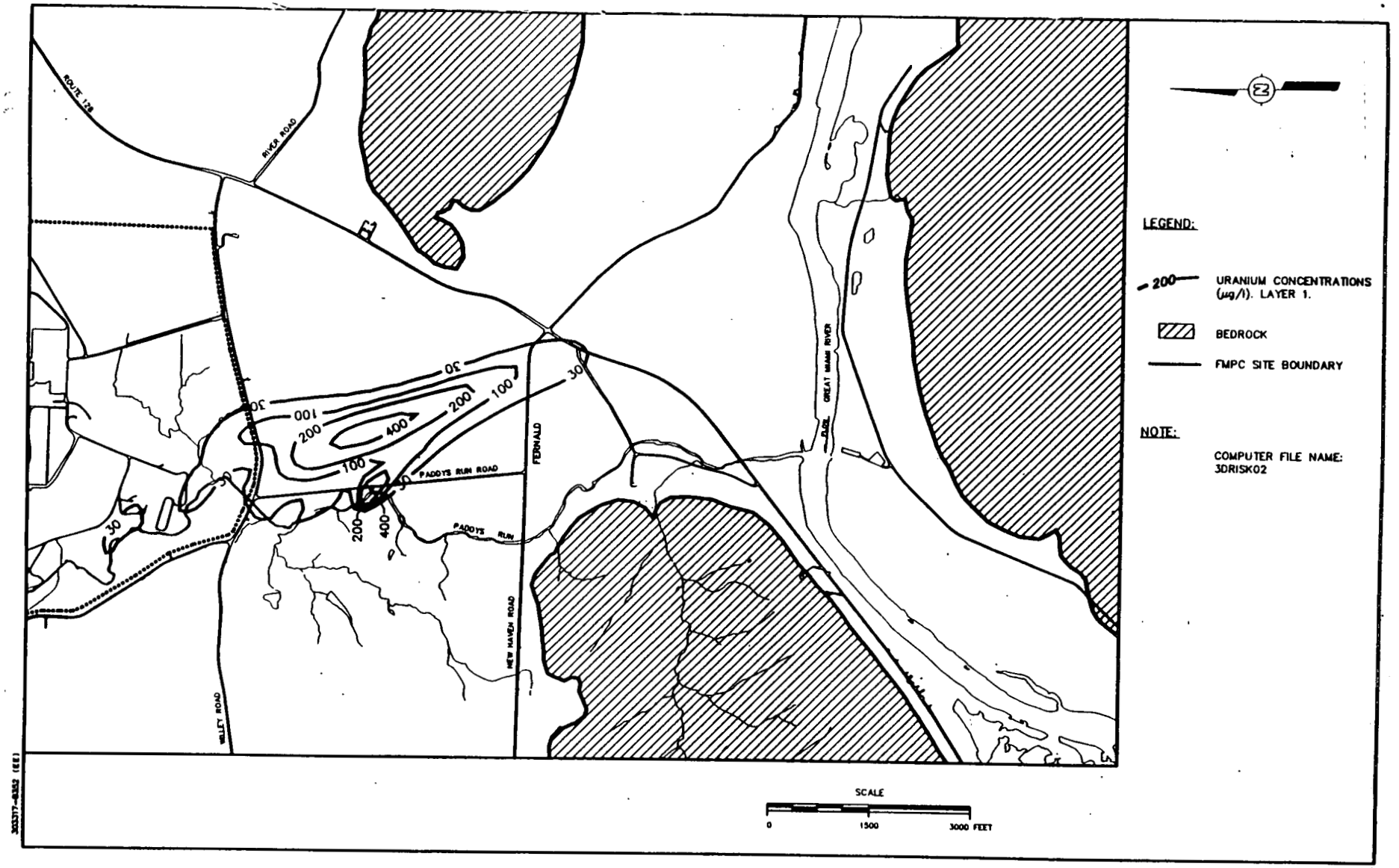


FIGURE A-4
SIMULATED URANIUM CONCENTRATIONS
NO - ACTION CONDITIONS
FIVE YEARS FROM PRESENT

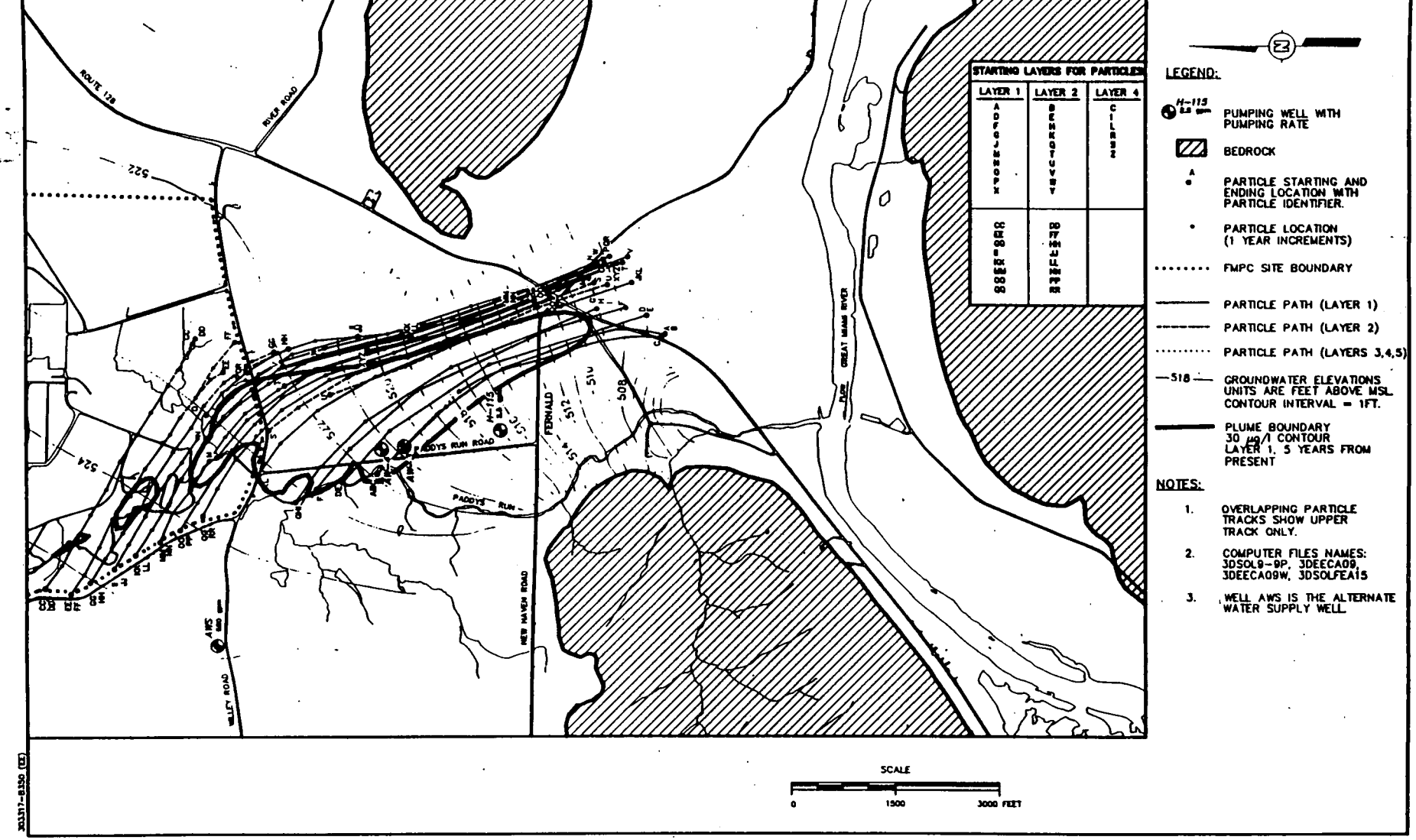


FIGURE A-5
PARTICLE TRACKING
ALTERNATE WATER SUPPLY
ALTERNATIVE

Particle tracking is a technique for determining and depicting the three-dimensional movement of groundwater in a finite-difference flow model. In the present investigation it involved processing output from the local SWIFT III model via a computer program named STLINE (GeoTrans 1987). STLINE computes the positions of particles moving in the direction of flow and at the average velocity of water in the porous material. The STLINE program accepts particle initial positions supplied by the user and computes the positions of the particles at the ends of specified time periods. The STLINE output describes the tracks of the particles as they move through the system.

Initial positions of particles were placed within the plume, along the lateral and vertical boundaries of the plume upgradient from the general location of future pumping, and along Paddys Run. Figure A-4 shows the particle tracking if no action is taken (i.e., no pumping). The plume is shown to migrate in a south-southeasterly direction. The focusing of flow lines from all along Paddys Run into the narrow trough of the aquifer is also demonstrated by the particle tracking.

The particles were then strategically placed in a sufficient number of locations to determine whether all water in the plume upgradient from any pumping wells would be intercepted. The results of the particle tracking for the recommended interceptor well system are shown in Figure A-6. The interceptor well system shown in Figure A-6 was selected after trying and rejecting several other possibilities. The rejected well systems included the following:

- Three wells spaced 560 feet apart and pumped at 500 gpm each did not capture all of the particles from the central part of the plume.
- Three wells near the center of the plume spaced 280 feet apart and pumped at 500 gpm each also did not intercept all particles from the eastern part of the plume.
- Five wells spaced 280 feet apart and pumped at 500 gpm each captured all particles from the plume, but involved pumping more water than the selected option described below.
- Three middle wells pumped at 500 gpm each and two end wells pumped at 250 gpm each, with all wells spaced 280 feet apart, failed to capture particles from lower layers in the eastern part of the plume.

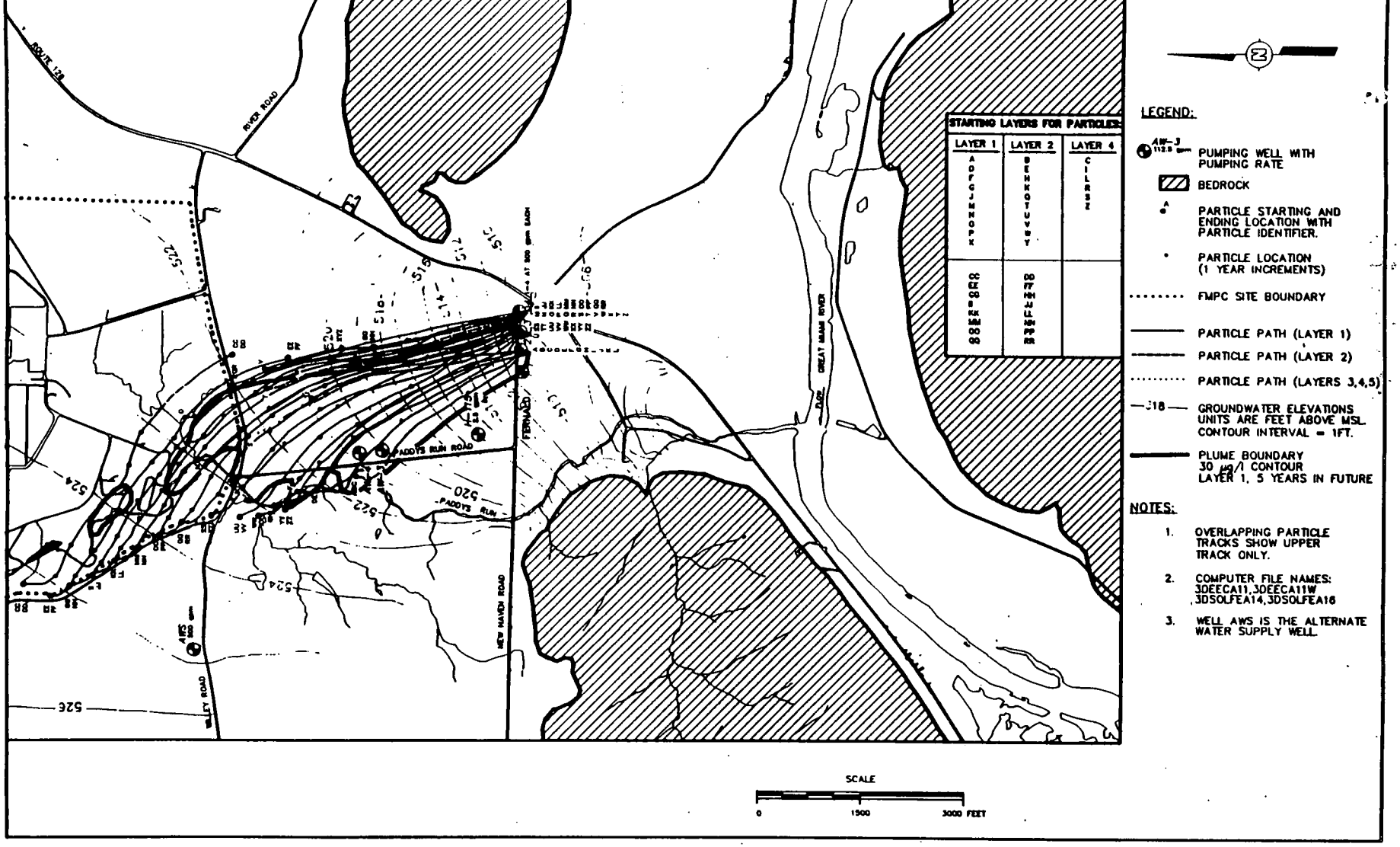


FIGURE A-6
PARTICLE TRACKING
FOR PLUME INTERCEPTION
ALTERNATIVE

The system selected used four wells spaced 280 feet apart with each well pumping at 500 gpm. This case was subjected to detailed particle-tracking analysis and captured all particles seeded in the plume north of the wells. Drawdown at the wells after five years of pumping was calculated at 8.1, 8.5, 8.5, and 8.2 feet from west to east. Well loss was not included in these calculations so the values represent drawdown in the aquifer. Contours of drawdown caused by the interceptor wells are shown in Figure A-7.

The alternately proposed scenario of four pumping wells located in the center of the south plume was also evaluated in the same manner. Four wells utilizing the same 280 foot spacing and 500 gpm pumping rate were located in a line near the center of the plume. Results of both the particle-tracking analyses and predicted plume shape are shown in Figure A-8. As can be seen, although the wells are able to effectively capture and remove all particles seeded north of themselves, they are unable to reverse gradients enough to affect the portion of the plume that has already moved past them. As the southern half of the plume is the portion which will reach potential receptors first, this scenario is deemed unacceptable as it is unable to affect or contain the critical portion of the plume. The analysis of the location and number of pumping wells utilized only the groundwater flow model, which has been thoroughly calibrated against a considerable database of field observations. Consequently, there exists a high level of confidence that the recommended system will be effective in capturing the plume north of the pumping wells.

A.4.4 PLUME BEHAVIOR

Simulated uranium concentrations in the plume corresponding to existing conditions were shown in Figure A-3. This distribution of uranium provided the initial condition for the evaluation of the effects of the pumping alternatives on plume behavior. (Note that no other alternative would have a significant effect on the future migration of the plume.) The simulated concentrations in the plume after five years with the selected well system in operation are shown in Figure A-9.

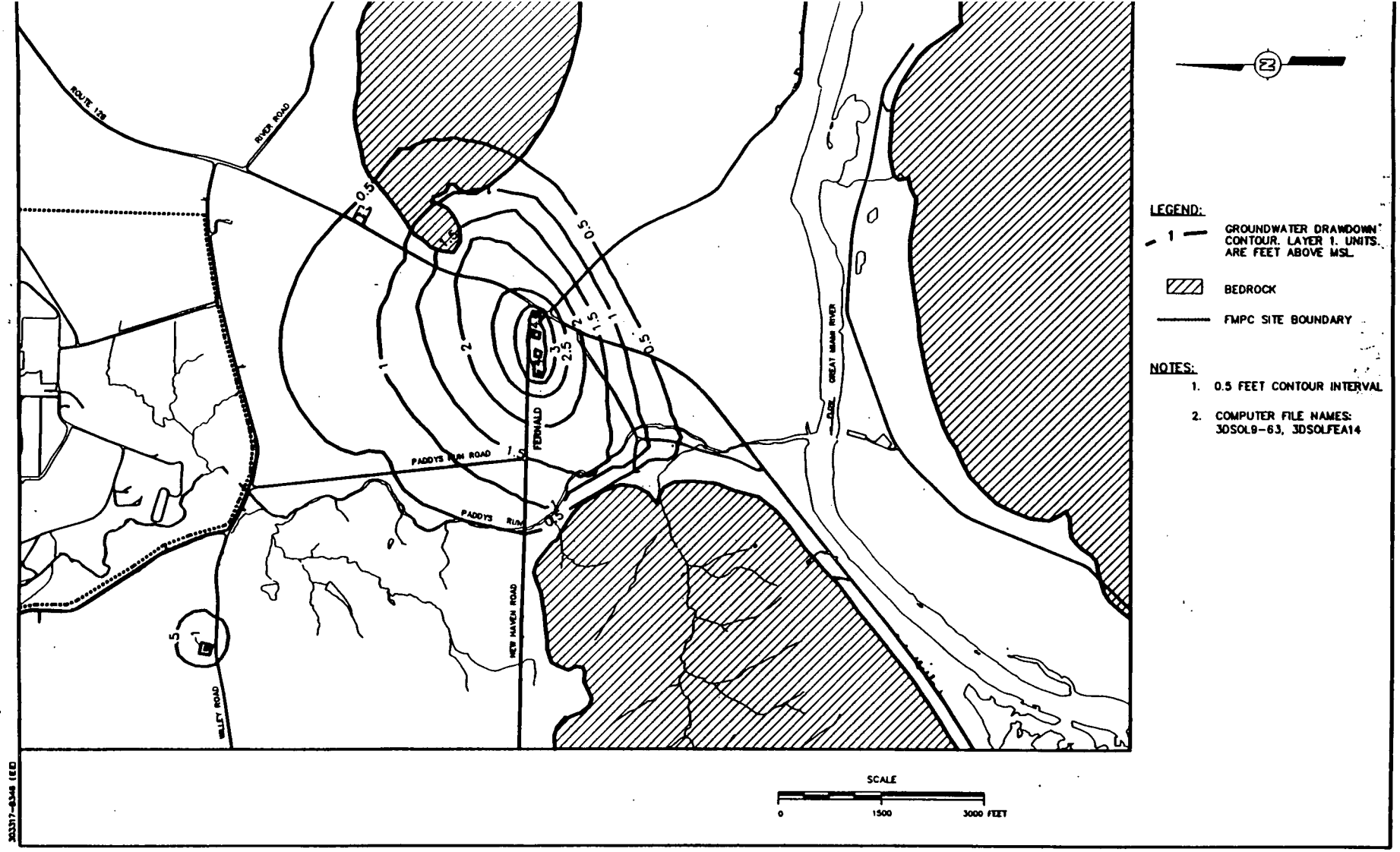


FIGURE A-7
DRAWDOWN DUE TO
GROUNDWATER INTERCEPTOR WELLS

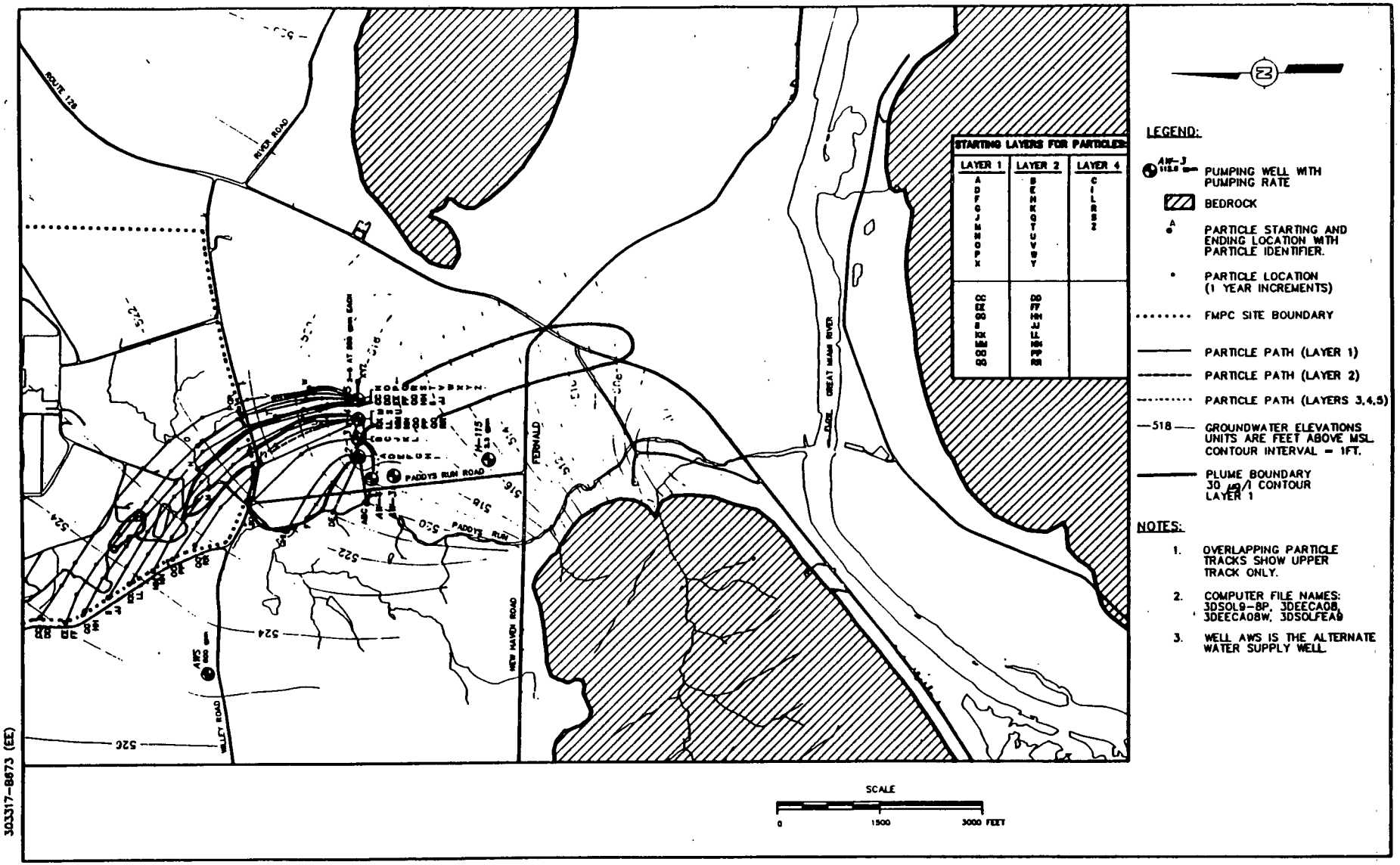


FIGURE A-8

PARTICLE TRACKING FOR CENTRAL PLUME INTERCEPTION ALTERNATIVE

303317-8673 (EE)

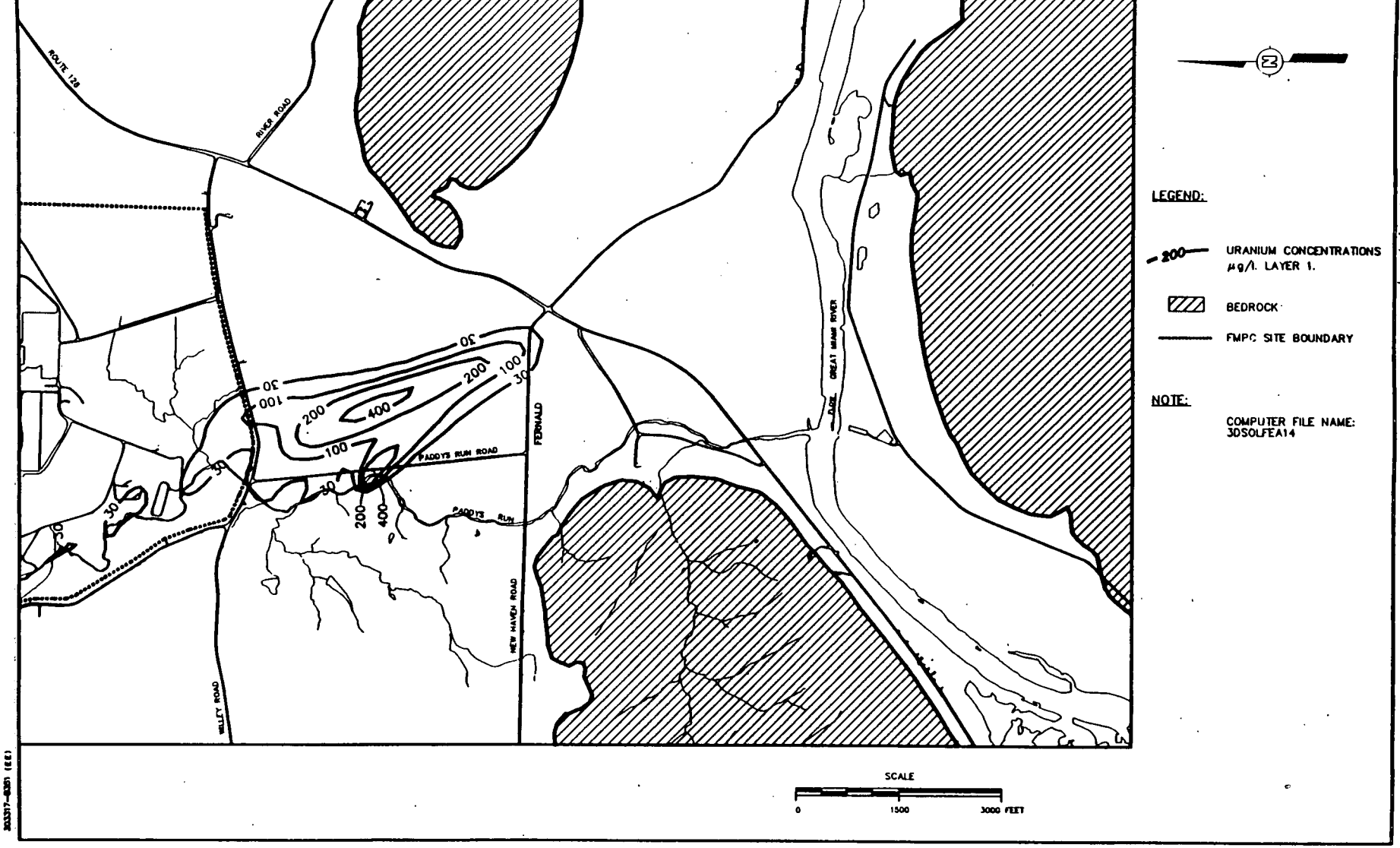


FIGURE A-9
SIMULATED URANIUM CONCENTRATIONS
FIVE YEARS FROM PRESENT WITH
INTERCEPTOR WELLS

The effect of the interception well system on the concentrations in the plume may be seen by comparing Figure A-9 with Figure A-3, which showed the predicted concentrations after the same time period under a no-action scenario. The plume is shown to be less dispersed as a result of the pumping action, which is important to the eventual selection of a final remedy to supplement the proposed removal action. The maximum concentration in the plume after five years of operation is predicted to be reduced from 509 µg/L for the case when interceptor wells are not operating (i.e., no action) to 490 µg/L when the wells are in operation. This minor reduction in the maximum concentration is due to the fact that the wells are placed at the leading edge of the plume and high concentrations of uranium are not removed by the wells within the first few years of operation. The placement of the wells near the southern leading edge of the plume was intended to protect groundwater users at downgradient locations.

The change in uranium concentration over time at the pumping wells is shown in Figure A-10. The calculated amount of uranium removed by the wells during five years of continuous operation is shown in Figure A-11. Although these results are approximations limited by the reliability of the solute transport model, the temporal patterns and the general magnitude of the mass removed are sufficiently accurate to draw two important conclusions. First, the amount of uranium removed increases with each year as the higher concentrations within the plume move southward toward the pumping wells. Second, it is likely that the goal of equivalent mass removal can be met during the later years of pumping when the removal amounts are at a maximum. Future refinement of the model results are not expected to change these general conclusions.

After the removal action has been selected and implemented, field validation of the solute transport model is recommended. Strategically placed monitoring wells could be used to track the response of the real system to the alternative selected, and appropriate action could be taken if the observed uranium concentrations deviate significantly from the expected values.

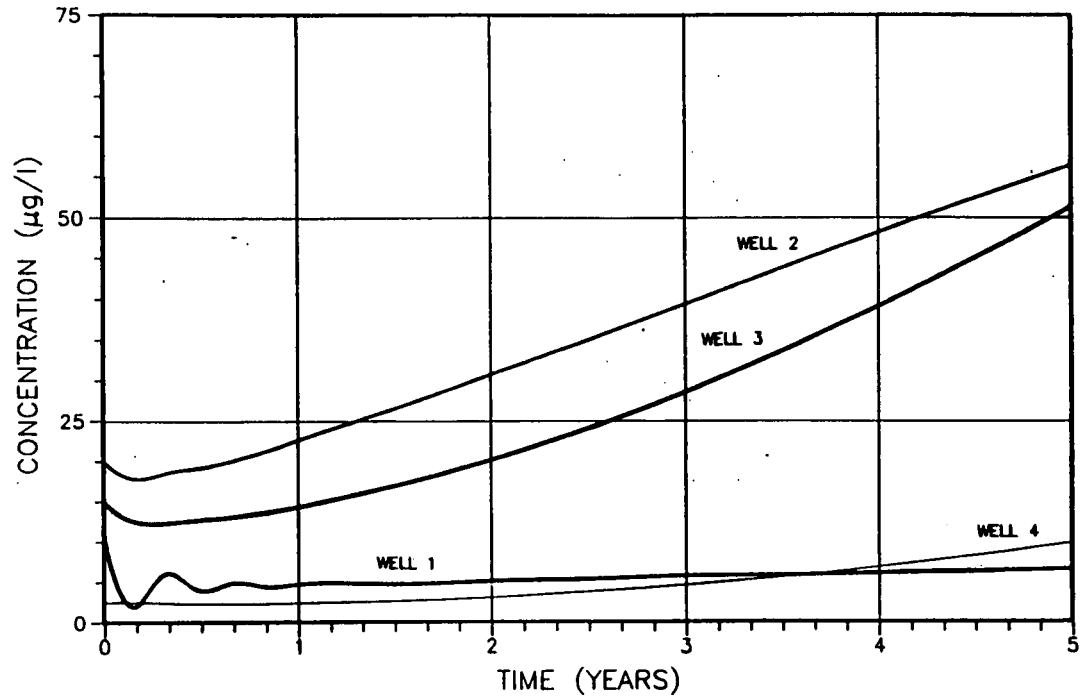


FIGURE A-10
URANIUM CONCENTRATION VS TIME
FOR INTERCEPTOR WELLS

303317-8178 (EE)

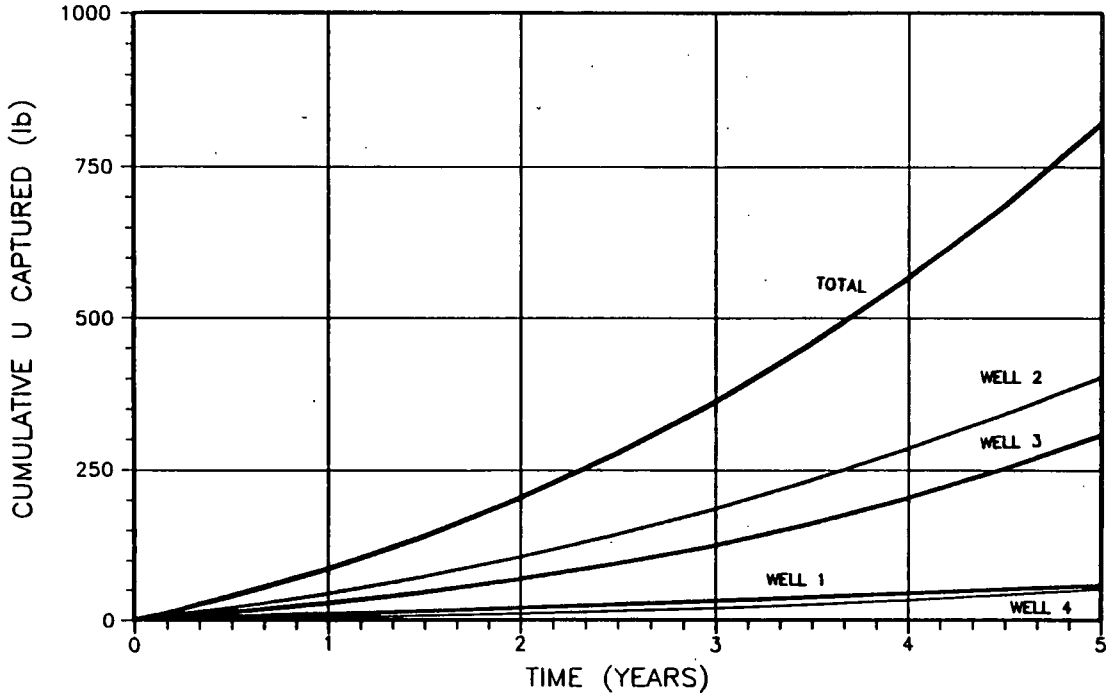


FIGURE A-11
CUMULATIVE URANIUM CAPTURED
VS TIME
FOR INTERCEPTOR WELLS

REFERENCES

REFERENCES

Geotrans, Inc., 1987, "STLINE, Version 1.9," User's Manual, Geotrans, Inc., Herndon, VA.

Grubbs, F. E., 1969, "Procedures for Detecting Outlying Observations in Samples," Technometrics, Vol. II, No. 1, pp. 1-21.

IT Corporation, 1987, "GEOSTAT, A Statistical Program for Examining the Goodness of Fit of Groundwater Modeling Data," Users Manual, IT Corp., Monroeville, PA.

Speiker, A.M., 1968, "Groundwater Hydrology and Geology of the Lower Great Miami River, Ohio", U.S. Geological Survey, Professional Paper 605-A, 37 pp., available from U.S. Government Printing Office, Washington, DC.

Walton, William C., 1985, "Practical Aspects of Groundwater Modeling," National Water Well Assn., Worthington, OH.

U.S. Department of Energy, August 1990, "Engineering Evaluation/Cost Analysis - Waste Pit Area Stormwater Runoff Control," DOE, Oak Ridge Operations Office, Oak Ridge, TN.

APPENDIX B

1990 TO 1992 URANIUM ANALYTICAL RESULTS

TABLE B-1

GREAT MIAMI AQUIFER WELLS

1ST QUARTER 1990 THROUGH 2ND QUARTER 1992

TOTAL URANIUM ANALYTICAL RESULTS (ug/l)

WELL	1st Qtr 90	2nd Qtr 90	3rd Qtr 90	4th Qtr 90	1st Qtr 91	2nd Qtr 91	3rd Qtr 91	4th Qtr 91	1st Qtr 92	2nd Qtr 92	MIN	MAX	AVG
2002		5.42	3.75	3.67			2.40			3.20	2.40	5.42	3.69
2004		9.38 *	13.90	6.94	7.25	9.00					6.94	13.90	9.29
2006	2.08	4.46		3.40				3.80	1.10	1.20	1.10	4.46	2.67
2007	4.28	2.75 *		1.63				1.00	1.20	0.60	0.60	4.28	1.91
2008		15.00	16.80	14.00	13.30	20.50			17.00	21.00	13.30	21.00	16.80
2009		13.60							19.30	17.00	13.60	19.30	16.63
2010	12.10	6.87	12.90		6.02	4.70	8.90	13.00	16.00	13.30	4.70	16.00	10.34
2011	<1.00	0.96 *	<1.00	<1.00	<0.57	0.20					0.20	1.00	0.79
2013	2.18	1.21	10.60		17.50	21.00	7.80	20.00	0.50		0.50	21.00	10.10
2014		19.30	12.90						14.80	11.00	11.00	19.30	14.50
2015	145.00	184.00	171.00		177.00 *		165.00	171.00	118.40	180.00	118.40	184.00	163.93
2016		14.00	15.50	10.10	14.00						10.10	15.50	13.40
2017		5.35	4.36	3.86			5.40	4.30	5.40	7.50	3.86	7.50	5.17
2018		2.59									2.59	2.59	2.59
2019	2.08	1.53	3.44	5.54	15.70	7.30	2.60	2.60	0.90	1.10	0.90	15.70	4.28
2020				1.22					1.70	0.40	0.40	1.70	1.11
2021	3.16	9.99	15.80	14.80	7.82	5.70	9.00	3.00	2.40	5.10	2.40	15.80	7.68
2022		3.18 *		35.10				3.80	2.50	2.80	2.50	35.10	9.48
2024	6.57	14.40	16.20		9.46	14.40 *	23.00	7.80	8.30	5.00	5.00	23.00	11.68
2027	10.00	10.50	8.50	7.21 *	5.83	1.30	2.10	5.10	16.00	13.70	1.30	16.00	8.48
2034		18.20									18.20	18.20	18.20
2037	6.28	8.40	7.30	6.59	8.84	8.00	10.00	13.00	4.40	4.80	4.40	13.00	7.60
2042		4.41	8.19		15.20			3.80	4.10	5.30	3.80	15.20	6.83
2043	1.20	2.64	15.50	0.74	0.95 *	0.40	0.80	0.60	0.30	1.60	0.30	15.50	2.47
2044		2.13	3.27					4.00	5.30	4.20	2.13	5.30	3.78
2045		329.00	305.00	282.00	260.00						260.00	329.00	294.00
2046		735.00	585.00	537.00	754.00						537.00	754.00	652.75
2047		8.77	6.81	8.22	6.67			16.00	14.80	14.90	6.67	16.00	10.88
2048		2.87	1.16	2.96							1.16	2.96	2.33
2049		22.10									22.10	22.10	22.10
2050							0.60	0.10	6.20	0.30	0.10	6.20	1.80
2051	2.70	2.28	1.97	1.89	1.04	0.90	1.60	0.90	1.00	0.50	0.50	2.70	1.48
2052	5.80	14.43 *	9.67		12.50	12.00 *	9.40	9.40	8.00	6.10	5.80	14.43	9.48
2053	2.96	4.93									2.96	4.93	3.95
2054	13.90	2.84		27.20	58.80						2.84	58.80	25.69
2055	2.55	5.45	3.72	4.31	5.70	1.30	3.90	3.70	3.20	1.30	1.30	5.70	3.28
2060	228.00	233.00		133.00							133.00	233.00	198.00
2061		287.00 *	302.00	303.00	231.00						231.00	303.00	280.75
2064		1.54 *		4.89				0.80	1.20	1.30	0.80	4.89	1.95
2065		10.20	14.50					9.10	9.30	9.00	9.00	14.50	10.42
2066	2.08 *	<1.00	<1.00	0.22	<0.40	0.60	0.50	0.20	0.10	0.20	0.10	2.08	0.63
2067	26.30	13.25 *	1.32	5.26			1.80	1.10	3.20	2.10	1.10	26.30	6.79
2068		2.33 *	<1.00	1.64	0.00			0.60	0.80	0.70	0.60	2.33	1.18
2069		14.20	7.34				3.60	11.00	6.80	8.50	3.60	14.20	8.57

TABLE B-1

GREAT MIAMI AQUIFER WELLS

1ST QUARTER 1990 THROUGH 2ND QUARTER 1992

TOTAL URANIUM ANALYTICAL RESULTS (ug/l)

WELL	1st Qtr 90	2nd Qtr 90	3rd Qtr 90	4th Qtr 90	1st Qtr 91	2nd Qtr 91	3rd Qtr 91	4th Qtr 91	1st Qtr 92	2nd Qtr 92	MIN	MAX	AVG
2070		1.75	2.78	4.86				1.70	0.95 *	0.73 *	0.73	4.86	2.13
2071				2.77							2.77	2.77	2.77
2084	20.30	30.40	20.30	26.90	19.50	14.00	12.00	15.00	20.00	20.60	12.00	30.40	19.90
2091	1.02						1.10	1.30	1.00	1.30	1.00	1.30	1.14
2092		1.16					0.90	0.70	1.00	0.80	0.70	1.16	0.91
2093		1.56									1.56	1.56	1.56
2094		<1.00									1.00	1.00	1.00
2095		70.90	52.30		93.50						52.30	93.50	72.23
2096								0.90	0.80	1.20	0.80	1.20	0.97
2097		2.42						0.50	0.30	1.30	0.30	2.42	1.13
2098		* 8.11			6.20 *	3.50		2.40	2.10	1.60	1.60	8.11	3.99
2104		1.94	1.02	0.43	0.61			0.80	0.70	0.80	0.43	1.94	0.90
2106		50.90	56.00					50.00	68.80	60.00	50.00	68.80	57.14
2107		4.18						12.00	10.30	12.00	4.18	12.00	9.62
2108		21.00		26.60							21.00	26.60	23.80
2109	12.10	12.40		10.50	12.30						10.50	12.40	11.83
2118	1.99	1.88		2.29				1.60	0.70	0.50	0.50	2.29	1.49
2120									11.50	9.40	9.40	11.50	10.45
2125		<1.30	59.40	59.90	52.70		4.20	40.00	46.15 *	2.80	1.30	59.90	33.31
2126		1.08	1.04	0.89	0.64		0.30	0.40		0.50	0.30	1.08	0.69
2127		7.59 *	10.64 *								7.59	10.64	9.11
2128		1.14	5.05	7.53	8.04		8.90	5.90	9.05 *	17.00	1.14	17.00	7.83
2129		2.25 *	4.16	5.25	0.61		1.20	1.20	6.50	1.60	0.61	6.50	2.85
2386								13.00	0.00	9.30	9.30	13.00	11.15
2391					1.91 *	1.23 *	1.35 *	0.97 *	0.90	0.90	0.90	1.91	1.21
2392								1.10	1.10	1.00	1.00	1.10	1.07
2393							0.30	0.10	0.10	0.20	0.10	0.30	0.18
2394						0.40	1.10	0.60	0.80	0.70	0.40	1.10	0.72
2396							0.90	1.10	1.20	1.20	0.90	1.20	1.10
2399									2.30	1.80	1.80	2.30	2.05
2541						6.70	1.00				1.00	6.70	3.85
2542						11.00	5.20				5.20	11.00	8.10
2543						20.00	3.40				3.40	20.00	11.70
2544							1.00				1.00	1.00	1.00
2545							43.00				43.00	43.00	43.00
2546							1.20				1.20	1.20	1.20
2547						0.70	1.00				0.70	1.00	0.85
2548						1.50	3.50				1.50	3.50	2.50
2549						0.20	0.50				0.20	0.50	0.35
2624							150.00				150.00	150.00	150.00
2625							1.20				1.20	1.20	1.20
2626						22.00	57.00				22.00	57.00	39.50
2627						9.70					9.70	9.70	9.70

TABLE B-1

GREAT MIAMI AQUIFER WELLS

1ST QUARTER 1990 THROUGH 2ND QUARTER 1992

TOTAL URANIUM ANALYTICAL RESULTS (ug/l)

WELL	1st Qtr 90	2nd Qtr 90	3rd Qtr 90	4th Qtr 90	1st Qtr 91	2nd Qtr 91	3rd Qtr 91	4th Qtr 91	1st Qtr 92	2nd Qtr 92	MIN	MAX	AVG
2631							1.70				1.70	1.70	1.70
2632							3.10				3.10	3.10	3.10
2633							0.60				0.60	0.60	0.60
2636						0.90	2.00				0.90	2.00	1.45
2643				15.40	10.20	8.80	8.90	14.00	7.60	5.10	5.10	15.40	10.00
2648				14.80	9.61		18.80	27.00	11.00	9.70	9.61	27.00	15.27
2649				8.78	6.69		9.30	8.50	8.00	7.30	6.69	9.30	8.10
3001	23.90	20.50	<1.00		<0.57	0.80	0.50	0.70	20.00	13.80	0.50	23.90	10.08
3003		3.40		3.49							3.40	3.49	3.45
3004		16.80 *									16.80	16.80	16.80
3005		1.91 *	1.90		1.29						1.29	1.91	1.70
3008	4.70	3.09 *	2.15		1.88	0.70	0.70	0.10	1.10	0.50	0.10	4.70	1.62
3009	7.61 *							9.10	8.60	15.00	7.61	15.00	10.08
3010	11.60	11.20	12.80	9.98	3.59	4.90	8.00	12.00	13.00	13.50	3.59	13.50	10.42
3011		<1.00	<1.00		3.80		4.20	1.40	0.10	0.10	0.10	4.20	1.66
3013	31.60	13.90	11.70	183.00	911.00	634.00	1150.00	1300.00	7.60		7.60	1300.00	471.42
3014		31.70	24.40						15.70	21.00	15.70	31.70	23.20
3015	1.58	3.74			3.26 *			1.30	1.30	1.80	1.30	3.74	2.16
3016		8.70	6.96	7.21	7.87						6.96	8.70	7.69
3017		4.10	1.19	1.47			0.70	0.70	1.20	0.80	0.70	4.10	1.45
3018	2.30		2.65	2.94	2.65			2.40	2.00	1.70	1.70	2.94	2.38
3019	2.63	89.90	93.50	1760.00	2520.00	1493.00	1420.00	1240.00	106.00	8.70	2.63	2520.00	873.37
3020	<0.86								1.00	0.70	0.70	1.00	0.85
3024	8.20	0.76 *	<1.00		3.39	0.20	2.60	2.50	0.20	<0.10	0.10	8.20	2.11
3032									11.10		11.10	11.10	11.10
3034	<0.54								0.50		0.50	0.54	0.52
3037	<1.00	1.69 *	1.62	3.06	0.00	5.45 *	1.00	1.00	0.60	1.30	0.60	5.45	1.77
3043	1.87 *	<1.00	5.70	1.35	0.86	0.20	0.10	0.10	0.10	0.10	0.10	5.70	1.14
3044		<0.42	1.32					1.60	1.40	1.50	0.42	1.60	1.25
3045								1.50	1.30	0.70	0.70	1.50	1.17
3046								1.50	2.00	1.40	1.40	2.00	1.63
3049		7.01									7.01	7.01	7.01
3051	<1.00										1.00	1.00	1.00
3053		1.66									1.66	1.66	1.66
3054	0.82			1.50							0.82	1.50	1.16
3055	<1.00	<1.00	2.43		2.63	0.90	0.90	0.50	0.30	0.10	0.10	2.63	1.00
3062		53.05 *	58.30		50.00				31.50	38.00	31.50	58.30	46.17
3064	<0.51							0.10	0.80	0.50	0.10	0.80	0.48
3065		1.18	3.50								1.18	3.50	2.34
3066	<1.00	1.62	1.16	2.78	2.87	0.90	1.00	1.00	0.60	0.10	0.10	2.87	1.30
3067	<0.98						0.50	0.40	0.50	0.30	0.30	0.98	0.54
3068								0.20	1.00	0.10	0.10	1.00	0.43
3069		2.01 *	3.62				31.00	41.00	35.00	20.00	2.01	41.00	22.10
3070	<0.73						0.80 *	0.50	0.30 *	1.03 *	0.30	1.03	0.67

TABLE B-1

GREAT MIAMI AQUIFER WELLS

1ST QUARTER 1990 THROUGH 2ND QUARTER 1992

TOTAL URANIUM ANALYTICAL RESULTS (ug/l)

WELL	1st Qtr 90	2nd Qtr 90	3rd Qtr 90	4th Qtr 90	1st Qtr 91	2nd Qtr 91	3rd Qtr 91	4th Qtr 91	1st Qtr 92	2nd Qtr 92	MIN	MAX	AVG
3084	110.00	30.00	103.00	16400.00	22500.00	250.00	10650.00	9180.00	150.00	470.00	30.00	22500.00	5984.30
3091	0.91							<0.10	<0.10	0.50	0.10	0.91	0.40
3092		<0.55						0.30	0.20	0.30	0.20	0.55	0.34
3093		<1.00							14.00	1.30	1.00	14.00	5.43
3094		<1.00									1.00	1.00	1.00
3095		3.35	7.78		6.64			4.20	4.70	4.40	3.35	7.78	5.18
3096								0.70	0.60	0.70	0.60	0.70	0.67
3097		1.29						1.30	1.30	1.80	1.29	1.80	1.42
3098		<1.00				0.70		0.90	0.80	0.60	0.60	1.00	0.80
3106		1.24	6.20					1.20	1.20	1.00	1.00	6.20	2.17
3107		2.25 *									2.25	2.25	2.25
3108		30.60									30.60	30.60	30.60
3120									0.30	<0.10	0.10	0.30	0.20
3125		39.90	34.20	19.30							19.30	39.90	31.13
3126		<1.00	1.25	1.83	4.50						1.00	4.50	2.15
3127		1.44 *	1.64 *								1.44	1.64	1.54
3128		<0.72	<1.00	0.60	1.18		1.20	0.70	1.40	0.40	0.40	1.40	0.90
3385								5.10	3.60	1.60	1.60	5.10	3.43
3387								3.80	3.30	3.90	3.30	3.90	3.67
3391					1.52 *	0.43 *	0.60 *	0.33 *	0.30	0.60	0.30	1.52	0.63
3396								0.70	0.70	0.40	0.40	0.70	0.60
3397									0.30	0.40	0.30	0.40	0.35
3636						0.70					0.70	0.70	0.70
4001	<1.00	<1.00	<1.00	1.99	<1.00	0.50	2.40	2.50	0.10	0.30	0.10	2.50	1.10
4008	4.00	<1.00	<1.00	0.97	<1.00	1.40	0.80	0.50	0.20	0.80	0.20	4.00	1.09
4010	1.01 *	1.48	<1.00	2.68	6.76	0.80	2.50	0.40	0.10	0.40	0.10	6.76	1.58
4011					2.67	0.10	2.30	5.30	1.90	0.90	0.10	5.30	2.20
4013	4.59	6.07 *	3.36		80.00	43.90	31.00	0.90	1.50	0.70	0.70	80.00	19.11
4014	<0.94	<0.69	3.36		2.99				0.30	0.10	0.10	3.36	1.40
4015	0.83 *	1.01	<1.00	0.18	<0.55			0.10	0.10	0.30	0.10	1.01	0.51
4016	<0.78	<0.66	1.22	4.74	4.92				0.00	0.00	0.66	4.92	2.46
4064	1.31								0.40	0.20	0.20	1.31	0.64
4067	<0.72						0.90	0.20	0.20	0.30	0.20	0.90	0.46
4091		<0.67						<0.10	<0.10	0.10	0.10	0.67	0.24
4096								0.60	0.60	0.70	0.60	0.70	0.63
4097		1.85						2.50	2.20	2.70	1.85	2.70	2.31
4101	0.68 *			1.30	0.26		0.10	0.10	<0.10	0.10	0.10	1.30	0.38
4102	<0.97			0.26	0.14		0.20	0.10	<0.10	0.10	0.10	0.97	0.27
4103	<0.67			0.26	<0.20		0.10	0.15 *	<0.10	<0.10	0.10	0.67	0.23

* Average for this quarter
< Below detection limit