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BASELINE REMEDIAL STRATEGY REPORT - REMEDIAL DESIGN FOR AQUIFER RESTORATION (TASK 1) - OCTOBER 1996 - (2505-RP-003, REV. B, DRAFT)

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BASELINE REMEDIAL STRATEGY REPORT

REMEDIAL DESIGN FOR AQUIFER RESTORATION (TASK 1)

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
FERNALD, OHIO

OCTOBER 1996

FOR INFORMATION ONLY

U.S. DEPARTMENT OF ENERGY
FERNALD AREA OFFICE

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Department of Energy

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SEP 30 1996

DOE-1424-96

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Dear Mr. Saric and Mr. Schneider:

Transmittal of the Baseline Remedial Strategy Report for the Aquifer Restoration

The purpose of this letter is to transmit, for your review and approval, the draft Baseline Remedial Strategy Report for the Aquifer Restoration. The purpose of the Baseline Remedial Strategy Report is to (1) provide the technical basis and results for the detailed design of the Department of Energy, Fernald Environmental Management Project's (DOE-FEMP) groundwater remedy, including enhancement modeling simulations used to support the basis of the detailed design, and (2) recommend a final restoration strategy to serve as the design basis for the full-scale program.

In summary, the enclosed Baseline Remedial Strategy Report recommends a 10-year baseline strategy for restoration of the Great Miami Aquifer at Fernald over the originally planned 27-year strategy outlined in the Operable Unit 5 (OU5) Feasibility Study and Proposed Plan. This significant reduction in the estimated cleanup time of the Great Miami Aquifer would result in cost savings of approximately 50 percent or $80 million from those estimated in the OU5 Feasibility Study. This aggressive groundwater restoration strategy is planned to be accomplished through the use of groundwater injection and additional on and off-property extraction wells. This proposed baseline remedial strategy for aquifer restoration joins the FEMP's recent commitment to a new, accelerated site cleanup plan designed to complete OU waste units and facility dismantlement and disposal activities by the year 2005. The DOE-FEMP is excited about this new facet of our program and we look forward to meeting with both of you to discuss and finalize this strategy.

This report also contains the most recent developments concerning the siting of wells in off-property locations. This is an ongoing issue that is currently being deliberated between DOE, EPA, and the respective landowner. In order to move forward with this 10-year strategy and the overall detailed remedial design process, the two off-property wells in question were placed on hold from the current design strategy until such time that the deliberations are completed and a resolution is achieved.

If you or your staff should have any questions, please contact Robert Janke at (513) 648-3124.

Sincerely

Johnny Reising

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Fernald Remedial Action
Project Manager

FEMP:R.J. Janke

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BASELINE REMEDIAL STRATEGY REPORT

REMEDIAL DESIGN FOR AQUIFER RESTORATION

(TASK 1)

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
FERNALD, OH

OCTOBER 1996

U.S. DEPARTMENT OF ENERGY
FERNALD AREA OFFICE

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LIST OF ACRONYMS

AWWT	advanced wastewater treatment [facility]
BSL	biodenitrification surge lagoon
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FEMP	Fernald Environmental Management Project
FRL	final remediation level
FS	feasibility study
IAWWT	interim advanced wastewater treatment
IEMP	Integrated Environmental Monitoring Plan
MCL	maximum contaminant level
O&M	operation and maintenance
OEPA	Ohio Environmental Protection Agency
OSDF	on-site disposal facility
PRRS	Paddys Run Road Site
RI	remedial investigation
ROD	record of decision
SSOD	storm sewer outfall ditch
TI	technical impracticability
SPIT	South Plume interim treatment
SWIFT	Sandia Waste Isolation Flow and Transport [model]
SWRB	storm water retention basin

1.0 INTRODUCTION

The Record of Decision (ROD) for Operable Unit 5 at the U.S. Department of Energy's (DOE's) Fernald Environmental Management Project (FEMP) was signed on January 31, 1996, setting in motion the remedial design (RD) process for the FEMP's Great Miami Aquifer groundwater restoration remedy (DOE 1996a). As the first formal deliverable required under the ROD, the U.S. Environmental Protection Agency (EPA) and Ohio Environmental Protection Agency (OEPA) approved the Operable Unit 5 RD Work Plan in July, 1996. The RD Work Plan outlines 11 design tasks and the associated design deliverables and schedule necessary to convey the design of the Great Miami Aquifer groundwater remedy for agency review and approval (DOE 1996b).

Task 1 of the approved RD Work Plan requires the DOE to prepare a Baseline Remedial Strategy Report that is intended to 1) serve as the technical basis for the detailed design of the FEMP's groundwater remedy and 2) summarize the results of the FEMP's ongoing enhancement modeling simulations that have been conducted following approval of the initial remedial strategy (termed the "base case" remedy) contained in the Operable Unit 5 Feasibility Study (FS) Report (DOE 1995a). This report fulfills the requirements for the Baseline Remedial Strategy Report as specified under Task 1 of the RD Work Plan.

1.1 ROLE OF THE FS "BASE CASE" REMEDY

The Operable Unit 5 FS Report and ROD outlined the site-wide remediation strategy for restoration of the aquifer, including the integration of existing actions into the final remedy. Under this overall strategy, restoration will be accomplished using a series of area-specific groundwater restoration modules and the centralized water treatment capabilities of the FEMP's advanced wastewater treatment (AWWT) facility. Each area-specific module will be brought on line as needed during the life of the remedy and independently withdrawn from service once remedial objectives within an area are achieved. The installation sequence and operation of the modules will follow a coordinated schedule that is based on the schedule and availability of access to the areas occupied by the source-control operable units (Operable Units 1 through 4) and the modeling projections of the duration and intensity of restoration actions necessary to achieve desired site-wide cleanup time frames and satisfy discharge requirements to the Great Miami River.

In order to demonstrate the feasibility of restoring the aquifer in a reasonable time frame, the Operable Unit 5 FS Report identified a "base-case" system consisting of 28 conventional extraction wells (packaged into four discrete modules) and system-wide pumping rates of approximately 4000 gpm, representing the hydraulic capacity of the aquifer beneath the FEMP beyond which undesirable drawdown conditions would be likely. Modeling simulations for the base case system indicated the aquifer could be restored in an estimated 27-year time frame at a total present worth cost of about $160 million (of which the majority of the costs are attributed to long-term operations and maintenance [O&M] costs accompanying groundwater treatment).

It was acknowledged in the FS Report and the ROD that the remedial design process would build upon the base case and evaluate additional scenarios that incorporated innovative enhancement technologies (such as groundwater injection) to further reduce remediation time, pumping-related hydraulic impacts, and cost. It was also acknowledged in the FS Report that the FEMP would implement EPA's "learn as you go and respond accordingly" improvement process for groundwater restoration that is contained in EPA's General Methods for Remedial Operation Performance Evaluations (EPA 1992). As envisioned by this guidance, once a base case remedy is selected for a site and documented in a ROD, ongoing efforts to improve system efficiency and respond to actual field conditions and performance results should be extended over the life of the remedy.

In the FS Report, DOE formally recognized the desire to incorporate this "learn as you go" philosophy into the modular, step-wise design and implementation strategy for the aquifer restoration program. Lastly, it was also acknowledged in the FS Report that the remedial design process would address EPA's desire to restore the off-property portion of the plume as the FEMP's highest groundwater priority.

1.2 ROLE OF THE BASELINE REMEDIAL STRATEGY REPORT

As the followup groundwater strategy document to the Operable Unit 5 FS and ROD, the role and intent of the Baseline Remedial Strategy Report is four-fold:

1) To report on the results of the enhancement modeling simulations that extend beyond the FS base-case system, including an evaluation of groundwater injection and the refinements necessary to enhance restoration of the off-property portion of the plume.

2) To recommend a final restoration strategy to serve as the design basis for the full-scale program.

3) To provide FEMP decision-makers with a perspective concerning the plausible range of estimated cleanup times and costs associated with the "in-the-field" performance of the final recommended strategy.

4) To assess the impact of recent landowner-imposed access constraints on the number and location of off-property extraction wells contemplated for restoring the off-property portion of the plume.

As of the October 1, 1996 submittal date of this report, the affected off-property landowner noted in Item 4 above has raised objections to two of the four off-property wells proposed in the preliminary baseline strategy identified in this report. To support ongoing discussions with the landowner and EPA and OEPA, a series of additional modeling simulations were performed to evaluate alternatives for addressing the landowner-imposed access constraints. These simulations are presented in Appendix E and are summarized in Section 5.0 of the report, along with a proposed path forward for addressing the landowner concerns.

The aquifer restoration program at the FEMP is a major activity that will take considerable time and resources to complete. As will be highlighted throughout this report, a number of factors cause uncertainty in the actual time and resources necessary to successfully complete the program. DOE, EPA, OEPA and other FEMP decision-makers need to fully understand the significance of the uncertainties in order to make well-informed decisions concerning how the program will be implemented both initially and at later stages of the cleanup.

The assessment of the performance of the recommended strategy contained in this report is intended to provide decision-makers with a perspective on: the hierarchy of issues and factors that drive uncertainty; the general likelihood of them happening; and the overall effect of the uncertainties on groundwater cleanup time and cost. This assessment has been provided so that decision-makers and affected stakeholders are aware of the sensitivity of the groundwater remedy to changes in the factors, and are prepared for future decisions should changes in the factors be experienced later during full-scale implementation. It is important to highlight that the recommended strategy conveyed in this report is intended to be an improvement over the FS base-case remedy. The evaluation of the uncertainties associated with the performance of this improved strategy is not intended as a retreat from any of the commitments for groundwater restoration contained in the Operable Unit 5 ROD.

One of the primary motivations for the final strategy contained in this Baseline Remedial Strategy Report is the FEMP's recent commitment to a new, accelerated cleanup plan designed to complete source-control actions and facility dismantlement and dispositioning (D&D) activities by the year 2005. This accelerated plan, designated as the FEMP's "Ten Year Plan", is focused on reducing long-term site operating and maintenance costs (and therefore total costs) by completing site restoration on a quicker, more aggressive schedule. These long-term costs are dubbed by DOE as "mortgage costs" and DOE has made a programmatic commitment to reducing such costs as the cornerstone of a recent ten-year goal to complete environmental restoration activities at DOE's facilities nationwide (Alm 1996).

At the time the Operable Unit 5 FS was prepared, completion estimates for the FEMP's source-area remediation and facility D&D activities were in the range of 25 to 30 years, based on funding profiles in existence at that time. These source-area completion estimates in turn controlled the pace of groundwater restoration because, as demonstrated in the FS, continued source loading from the source areas and physical access to the aquifer for direct groundwater extraction within the source areas were the key noted constraints that ultimately controlled the projections of cleanup time in the areas where the highest contaminant concentration levels are found.

Also at the time of the Operable Unit 5 FS, it was recognized that the FEMP's wastewater treatment infrastructure would need to be available over a 25 to 30 year period, to support the water treatment needs of the FEMP's other operable units. Incremental increases in long-term O&M costs, attributable to the treatment of groundwater over the estimated 27 year life of the FS base case remedy, were concluded to be relatively insignificant since the infrastructure supporting groundwater treatment would be in place to accommodate other needs that existed over this same duration.

Current funding profiles, however -- based on the new Ten Year Plan -- indicate that source-area remediation and facility D&D can be accomplished up to 15 or more years earlier than initial estimates. Although actual completion of the groundwater cleanup is not a formal element of the FEMP's Ten Year Plan, the strategy conveyed in this Baseline Remedial Strategy Report 1) recognizes the earlier access to the source-control areas that will be achievable with the FEMP's Ten Year Plan; and 2) intends to fulfill DOE's programmatic expectations to reduce long-term mortgage costs (consistent with the motivations of the Ten Year Plan) wherever possible by identifying cost-effective measures to achieve aquifer restoration sooner. As part of this intention, the strategy

recognizes that with the Ten Year Plan in place, the FEMP's long-term O&M costs associated with water treatment extending beyond the ten year end date would be solely attributable to the groundwater treatment needs of the FS base case remedy.

In accordance with these programmatic intentions, four new potential groundwater cleanup time targets were examined as part of the Baseline Strategy Report: 25, 15, 10, and 7.5 years. These targets were developed to first explore this fundamental question: "Is it possible to shorten groundwater restoration time to be more consistent with the Ten Year Vision that has been formulated for the FEMP?" If such shortening is within the realm of possibility (defined by the available geochemical and hydraulic data for the site), the targets would also facilitate the comparison of the cost implications of shortening the remediation schedule (thereby reducing long-term O&M costs) against the increased capital costs necessary to accommodate the additional infrastructure needed for a shorter remediation time.

Using best available existing (i.e., pre-implementation) data and cost projections, the overall objective of the report is to select a preferred strategy that balances up-front capital expenditures against the desired reduction in long-term mortgage costs in a manner consistent with DOE's programmatic goals and available funding profiles. Following the selection of the preferred strategy, an uncertainties analysis was conducted to provide an understanding of how cleanup time and cost for the preferred strategy are influenced by uncertainties in all of the major factors contributing to remedial performance.

It is acknowledged that the preferred strategy conveyed in this report will recommend an initial set of remedy components (numbers of wells, locations, operating parameters, and resultant estimated area-specific cleanup times) that may need to be re-evaluated or adjusted over the course of the restoration activity as post-implementation performance data become available and actual costs are realized.

1.3 KEY FACTORS AFFECTING CLEANUP PERFORMANCE

As mentioned in the preceding section, the baseline strategy evaluation is being conducted using best available existing (pre-implementation) information regarding aquifer physical properties and the expected costs associated with the remedial elements comprising the program. However, a number of factors cause uncertainty in the time and resources that will be necessary to successfully complete the program. This section summarizes the major factors that were evaluated in the report and those

which were specifically used to conduct the sensitivity analyses and quantitative uncertainty evaluations. The factors are listed under two categories: 1) those considered to be "human factors" (and which were evaluated qualitatively) and 2) those considered to be "natural factors" (which were evaluated quantitatively as part of the sensitivity analyses). Both types of factors are important and can have similar levels of impact on overall system performance (i.e., cleanup time and cost).

1.3.1 Human Factors

Human factors represent those factors affecting remedy performance that can be controlled by engineering design, funding commitments, or O&M procedures. They also include other man-made constraints associated with present or future activities conducted by other nearby parties (e.g., Southwest Ohio Water Company and the Paddys Run Road Site). The major human factors that can be influenced by DOE and which were considered for the baseline strategy report are:

- Well Design and Installation (as an example, the differences in installation risk between horizontal and vertical wells)
- Source-Area Remediation Schedule (which affects the duration of source-area loading to the aquifer and availability of access to the aquifer for direct groundwater extraction from "hot-spots" beneath source areas)
- Operation and Maintenance of the Restoration System (as an example, inefficient wells or treatment plant performance as a result of inadequate capacity maintenance could reduce the volume of water that can be extracted from the aquifer and therefore lead to longer cleanup times).
- Availability of Funding (unavailability of short-term funding can delay installation of system components, leading to longer cleanup times; unavailability of long-term funding can result in reduced level of operations and/or maintenance and corresponding longer cleanup times)

The uncertainties associated with these factors were generally evaluated qualitatively, as part of the initial selection process used to identify a preferred preliminary baseline scenario from among the four new scenarios evaluated. The effect of human factors are generally represented by simplifying assumptions (which can only be confirmed "after the fact)" rather than being subject to field testing as for the natural factors discussed below.

1.3.2 Natural Factors

Natural factors represent those factors affecting remedy performance that are intrinsic to the environmental media where the contaminants currently reside. Natural factors cannot be easily

modified by engineering measures and therefore represent constraints on the engineering approach and system design. Examples include climatological change, physical properties of the aquifer, and the ongoing geochemical interactions between the contaminants and the aquifer matrix.

Two major natural factors that affect cleanup time and cost for the aquifer were considered in the Baseline Remedial Strategy Report:

- The hydraulic characteristics and capacity of the aquifer, which limit total pumping rates based on the need to achieve desired aquifer drawdown profiles within the target cleanup zone and at neighboring off-property locations. Of prime concern is the need to minimize hydraulic impacts at the Paddys Run Road Site (where a second groundwater plume associated with that site is located) immediately south of the off-property portion of the FEMP's groundwater plume.

- The geochemical processes that occur within the aquifer, which control the amount of contaminant mass removal accompanying each pore volume exchange during restoration.

Although they cannot be easily changed, both of these natural factors are amenable to field testing to provide necessary design information (rather than relying solely on assumptions, as with the human factors).

The Great Miami Aquifer has been well characterized and evaluated during the course of 10 years of Remedial Investigation (RI) studies at the FEMP. Information has been obtained in sufficient detail to develop a preferred remedy and evaluate its anticipated performance. However, a degree of uncertainty remains for precise prediction of system performance and, at some point, it is necessary to implement the remedy and react to the results obtained before further insights into the aquifer conditions that affect cleanup time can be gained. This recognition is consistent with EPA remedy performance assessment guidance (EPA 1992).

The uncertainties associated with these two natural factors were used to conduct the uncertainties analyses regarding the range of performance (cleanup times and cost) anticipated for the preferred restoration scenario.

1.4 PROCESS FOR FUTURE REMEDIAL DECISIONS

Strategy presented in this Baseline Remedial Strategy Report provides a recommended course of action based on the best understanding of site conditions available at this time. It is important to

emphasize that the recommendation does not specify an exact enforceable reduction of restoration time frame that must be achieved at all costs. Rather, it identifies a preferred shorter restoration time frame based on the anticipated behavior of the aquifer and the expected performance and cost of additional remedial components, consistent with EPA groundwater guidance. The anticipated behavior of the aquifer (and the contamination) is based primarily on groundwater modeling predictions. It needs to be recognized that a groundwater model, by design, is a simplification of the natural system and cannot fully represent all of the localized conditions occurring in the aquifer such as preferential flowpaths and pockets of low permeability zones. These conditions may lead to localized differences between model predictions and actual conditions experienced. However, the initial remedial decisions regarding system design (i.e., remedial infrastructure and operational conditions) still need to be based on the best available modeling result.

At some point in the future, as actual operating conditions are experienced and performance results are obtained, the FEMP's primary decision-makers (DOE, EPA, OEPA, and affected stakeholders) may be confronted with a need to modify the operating strategy of the groundwater remedy from that recommended initially by this report. These modifications may be the consequence of imprecise assumptions or representations regarding the previously described key human and natural factors affecting remedy performance.

As a result of the uncertainty accompanying the key factors, the following operating situations (and accompanying remedial decisions) may develop as future performance information is compiled:

- Aquifer restoration is proceeding at or ahead of the desired target, and hydraulic impacts conform to expectations (Pending decision: no need to modify remedy)

- Aquifer restoration is proceeding at or ahead of the desired target, but hydraulic impacts are greater than desired (Pending decision: need to reduce net extraction rates, with a resulting potential increase in cleanup time)

- Aquifer restoration is proceeding behind the desired target, but hydraulic impacts are less than anticipated and additional extraction capacity is therefore available (Pending decision: need to evaluate best course of action from among several alternatives: increase net extraction rates with existing wells; add additional wells; or extend cleanup times)

- Aquifer restoration is proceeding behind the desired target, but hydraulic impacts are as desired and no additional capacity is available (Pending decision: may need to extend cleanup time as only viable option; if rates of progress become asymptotic, may need to pursue technical impracticability waiver to terminate operations)

These examples of conditions and situations that may be encountered in the future indicate that tradeoff evaluations could be necessary and that such tradeoffs will need to consider both the physical capabilities of the system and the most cost-effective path forward. The preferred course for some situations may result in adding additional infrastructure (resulting in increased capital cost) in order to preserve desired cleanup times and/or avoid additional long-term operational costs. In other cases, the preferred course may result in the need to extend cleanup time as the fiscally responsible decision. These decisions will need to be made on a case-by-case basis based on the physical and cost constraints imposed (recognizing DOE's programmatic objective to reduce site mortgage costs as tempered by available funding profiles), and under the collective agreement of DOE, EPA, OEPA, and affected stakeholders.

2.0 OVERVIEW OF THE BASELINE REMEDIAL STRATEGY REPORT

This section provides background information on the FEMP's current remedial design and implementation efforts; summarizes the objectives of the baseline groundwater remediation strategy; and outlines the contents of the remaining four sections and accompanying six appendices of the document.

2.1 BACKGROUND

As part of the approved FS and ROD, the FEMP's groundwater remediation levels, acceptable remediation time frames, and other regulatory constraints (e.g., outfall discharge concentration limits) have all been defined. The selected base case remedy contained in the FS and ROD identified the need for 28 extraction wells (see Figure 2-1), 4000 gpm groundwater extraction rates, 2000 gpm of dedicated effective groundwater treatment capacity, and almost 30 years to restore the aquifer. In concept, the base case remedial strategy demonstrated the feasibility of restoring the aquifer and attempted to employ the minimum number of conventional extraction wells necessary to achieve capture and cleanup of the FEMP's on- and off-property groundwater plumes within a reasonable time frame. However, such an approach is not necessarily the optimal strategy in terms of treatment requirements and durations (which have a profound effect on long-term O&M costs). The estimated present worth cost of the base case FS strategy is about $160 million, of which the most significant portion is attributed to the operation of the groundwater treatment facility. The estimated duration of groundwater treatment for the base case FS remedy is more than 20 years.

In order to gain an early start on groundwater restoration, five extraction wells were installed in 1993 at the leading edge of the off-property South Plume as part of the EPA-approved South Plume Removal Action. The original intention of the South Plume Removal Action was to prevent the further southward migration of the off-property portion of the groundwater plume, while the FEMP's ongoing RI/FS and remedy selection efforts were being finalized. The South Plume Removal Action system has been operating since the fall of 1993 and has removed over 1.9 billion gallons of water and more than 265 pounds of uranium from the South Plume to date.

In 1996, nine new on-property extraction wells comprising the South Field Extraction System module were installed in the vicinity of the South Field and the storm sewer outfall ditch (SSOD) features at the site, as part of an EPA-approved early start initiative ahead of the issuance of the Operable Unit 5

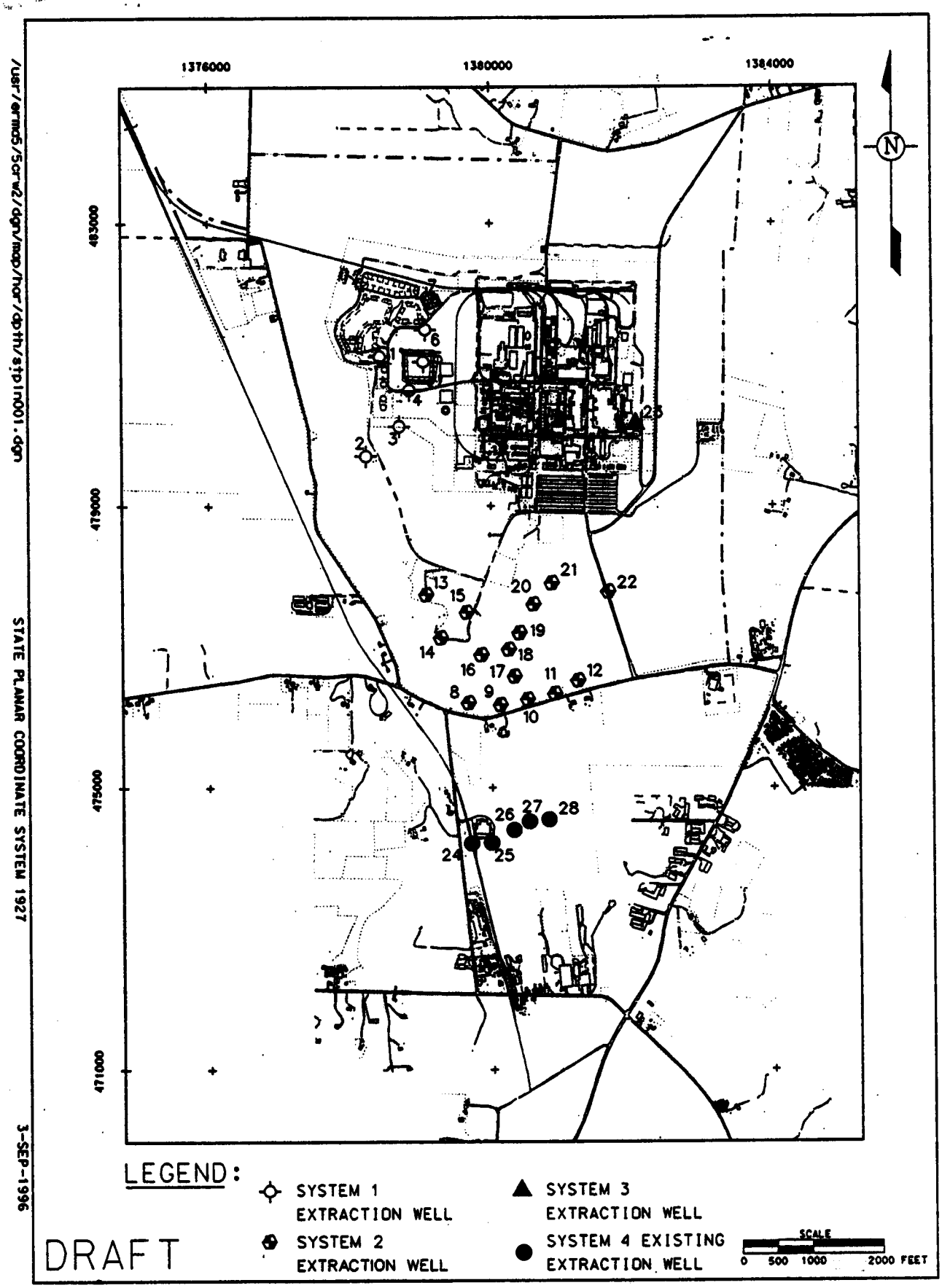

FIGURE 2-1. EXTRACTION WELL LOCATIONS - FS STRATEGY

ROD. The design of the piping network for the nine wells is currently being finalized and the network will be installed under the provisions of the Operable Unit 5 Remedial Action (RA) Work Plan. These nine wells are designed to aggressively remove groundwater contamination in an on-property area where uranium contamination levels in the aquifer are highest. The piping network designs for both the South Plume Removal Action and the South Field Extraction System include additional tie-in points that will facilitate future rounds of expansion as appropriate.

A number of enhancements to the Great Miami Aquifer groundwater remediation strategy proposed in the Operable Unit 5 FS have been evaluated following approval of the FS and incorporation of the base case remedy in the Operable Unit 5 ROD. These revisions were deemed necessary because of the shortened source-area remediation schedule accompanying the FEMP's Ten Year Plan, examination of additional supporting technologies (such as groundwater injection), and the DOE's ongoing commitment to further enhance the restoration of the off-property portion of the South Plume.

2.2 OBJECTIVES

One of the major objectives of this report is to summarize the predicted performance of a series of new groundwater remediation scenarios which have been developed and evaluated following completion of the Operable Unit 5 FS Report. Key technical approaches developed previously as part of the FS (such as the sequential/paused operation of the extraction system modules and the employment of maximum net extraction rates) were generally maintained in these new potential scenarios. However, the new scenarios also incorporate remedial technologies not previously evaluated in the FS such as groundwater injection and horizontal wells. The latest source-area remediation schedule (based on the FEMP's Ten Year Plan) and a more realistic approach for modeling the transition of aquifer geochemical conditions during remediation were also used to develop and evaluate the new scenarios.

In order to improve contaminant mass removal efficiency, several of the new scenarios include the placement of additional vertical extraction wells in groundwater "hot spots" beneath the FEMP's primary source areas, once source-area remediation activities are complete. One of the scenarios evaluates the use of horizontal wells to reach source-area hot spots prior to the completion of source-area remediation. This scenario also evaluates horizontal wells as an alternate means to remediate the off-property portion of the South Plume. In general, the new scenarios employ

additional measures to shorten restoration (and groundwater treatment) time frames and reduce the overall hydraulic impacts to the aquifer during the restoration activity.

The other primary objective of the Baseline Remedial Strategy Report is to document the selection of the preferred groundwater remediation scenario from among the new alternatives. Four cleanup time targets were included in the new scenarios: 25, 15, 10, and 7.5 years. These targets were used to compare the cost implications of shortening the remediation schedule (thereby reducing long-term O&M costs) against the increased capital costs necessary to accommodate the additional infrastructure needed for a shorter remediation time. The scenario-specific performance measures, relative costs, inherent risks/uncertainties, and operation and maintenance issues were all considered during the selection process. A leading strategy was selected based on the preliminary evaluations and carried forward for detailed evaluation and modification. During the detailed evaluation, necessary modifications to the selected strategy to accommodate off-property landowner constraints and the FEMP's current long-term funding profile were evaluated and incorporated into the selected strategy as appropriate.

Following selection of the recommended scenario, a sensitivity/uncertainty analysis was performed to bracket the range of estimated cleanup times and costs associated with the recommended scenario. Three additional simulations were conducted to provide an understanding of how cleanup time and cost are influenced by uncertainties in the major factors considered. The results of the evaluations are provided in Appendix F and summarized in Section 5.3.

Finally, operational considerations and guidelines regarding groundwater treatment decisions (and compliance with the ROD's Great Miami River discharge limits) were developed through the remedy performance evaluations. These guidelines will serve as the foundation for the operating procedures to be developed in the Operations and Maintenance Plan, which will be produced under Task 2 of the RD Work Plan.

2.3 REPORT ORGANIZATION

Figure 2-2 presents an overview of the Baseline Remedial Strategy Report and the process used to arrive at a final strategy. Sections 1.0 and 2.0 of the report present introductory information and provide an overview of the Baseline Remedial Strategy Report. Section 3.0 summarizes the commitments, constraints, and goals to be incorporated in the new groundwater remediation scenarios

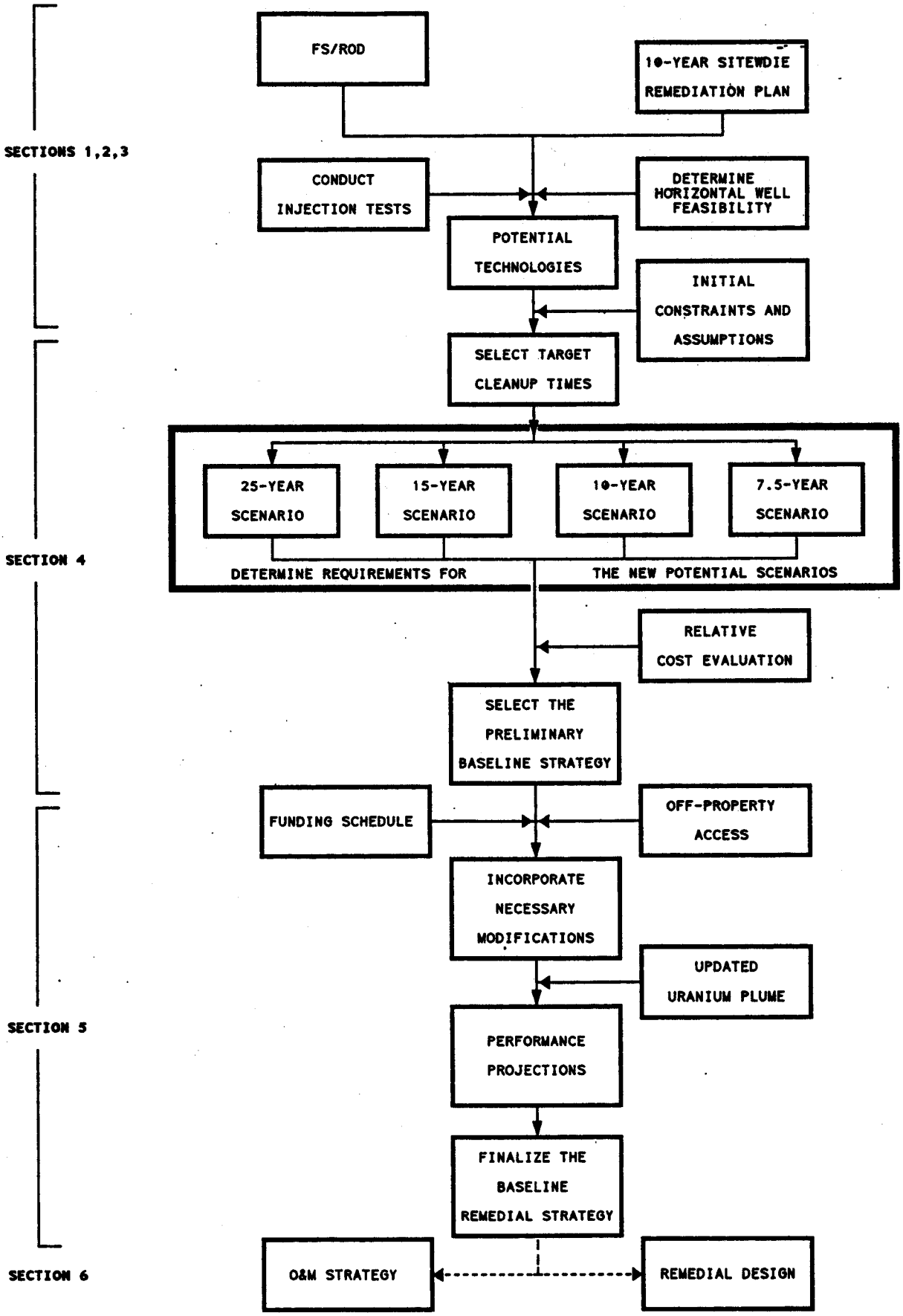

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FIGURE 2-2 FINALIZATION OF THE GROUNDWATER BASELINE REMEDIAL STRATEGY

along with the general assumptions used in their formulation. Section 4.0 presents the scenarios and provides an assessment of their predicted performance based on best estimates and assumptions for the major factors affecting remedy performance. The assessments provided in Section 4.0 also assume full funding and unimpeded off-property access for the implementation of the scenarios. A leading baseline strategy is selected from among the preliminary alternatives at the conclusion of Section 4.0. Section 5.0 finalizes the baseline remedial strategy through the evaluation of funding-based implementation constraints and off-property landowner access concerns. The remedy performance projections associated with the final baseline remedial strategy are also presented in Section 5.0, along with the results of a sensitivity analysis of the factors and uncertainties affecting cleanup time and cost. Section 6.0 then summarizes the conclusions and key operational considerations regarding the final baseline remedial strategy.

Five appendices are included at the end of the report to present additional details of the modeling approach (Appendix A), horizontal well applications (Appendix B), cost estimates (Appendix C), groundwater treatment systems (Appendix D), simulations conducted to address off-property landowner access concerns (Appendix E), and sensitivity analyses of the factors and uncertainties that affect cleanup time and cost for the recommended strategy (Appendix F).

3.0 COMMITMENTS, CONSTRAINTS, AND ASSUMPTIONS

An acceptable groundwater remediation strategy for the FEMP needs to satisfy the commitments and constraints that have previously been defined through regulatory agency interactions and review of earlier FEMP RI/FS documents. The existing commitments and constraints to be considered when developing the scenarios are summarized in this section. General assumptions regarding factors that can affect the feasibility and effectiveness of the potential remedial scenarios are also presented. Because uranium is the predominant groundwater contaminant at the FEMP, it has been used to define the major constraints as well as to evaluate the effectiveness of the groundwater remediation strategy. Therefore, most of the commitments, constraints, and assumptions are related to the distribution and behavior of uranium in the aquifer.

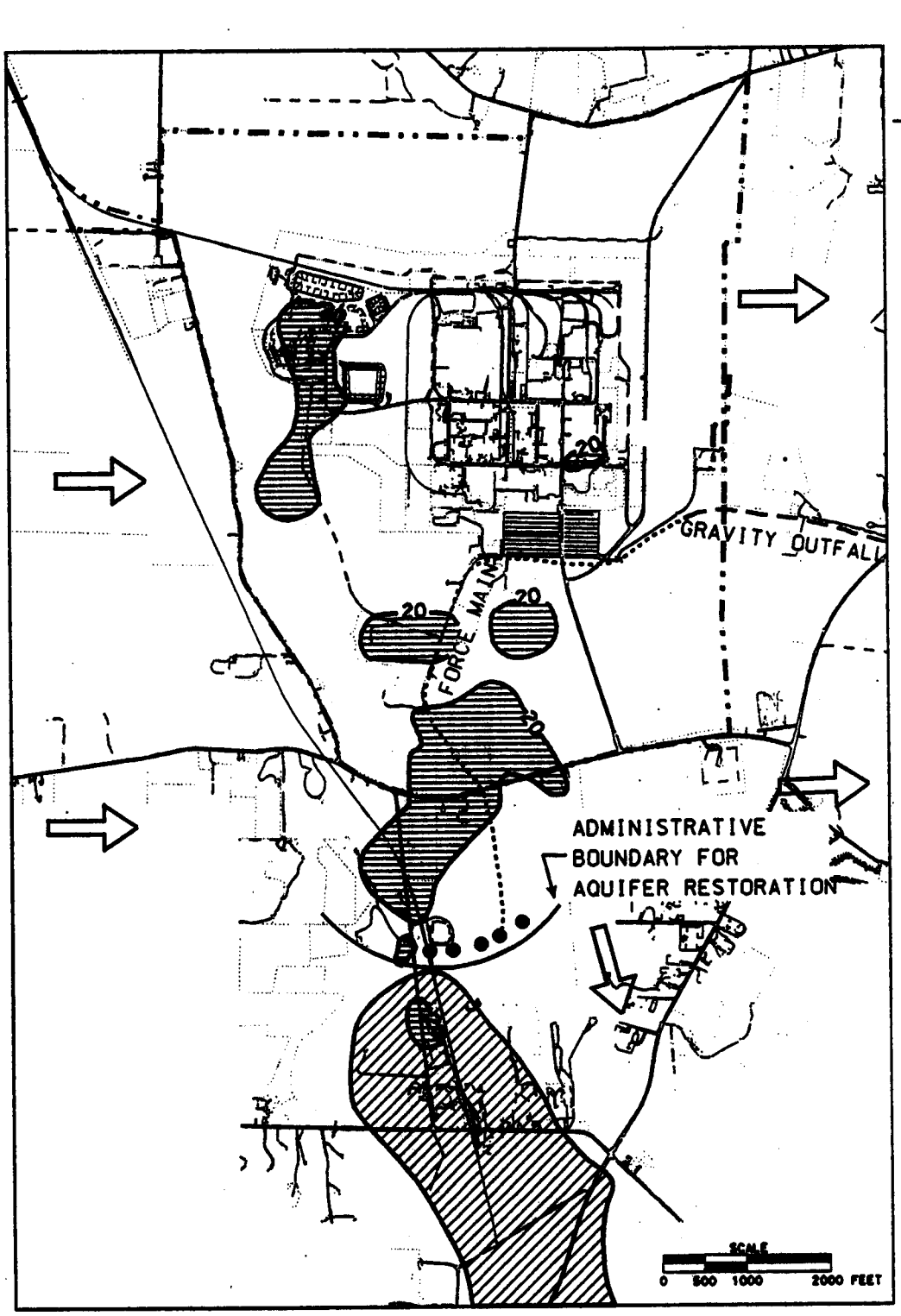
3.1 COMMITMENTS

The key aquifer restoration commitments which are formally recognized for development of the scenarios are discussed below. These specific commitments have their origin in the Operable Unit 5 ROD or in subsequent discussions with EPA and OEPA regarding the performance of the existing South Plume Removal Action system.

3.1.1 Aquifer Cleanup Levels

The FEMP's final remediation levels (FRLs) for groundwater were presented in the Operable Unit 5 FS Report and ROD. In general, the FRLs were based on maximum contaminant levels (MCLs) (or 10^{-5} incremental lifetime cancer risk or 0.2 hazard index when no MCL is available). For uranium, the predominant contaminant at the FEMP, the proposed MCL of 20 parts-per-billion (ppb) was selected as the FRL. As required by the Operable Unit 5 ROD, groundwater remediation is to take place until all constituent-specific groundwater concentrations in the aquifer are below the established FRLs or until a technical impracticability (TI) waiver can be justified.

Areas of the Great Miami Aquifer exceeding FRLs will be restored primarily through groundwater extraction methods. The areas of the aquifer requiring remediation are identified in Figure 3-1. As noted on Figure 3-1, the administrative boundary for aquifer restoration to be addressed is north of the Paddys Run Road Site plume. DOE's role and involvement in OEPA's ongoing assessment and/or cleanup of the Paddys Run Road Site plume, if any, would be defined separately as part of the Paddys Run Road Site response obligations and in accordance with the Paddys Run Road Site project



LEGEND:

- ● EXISTING EXTRACTION WELL
- FEMP BOUNDARY
- REGIONAL GROUNDWATER FLOW DIRECTION
- AREAS ABOVE URANIUM CLEANUP LEVEL
- PADDYS RUN ROAD SITE PLUME

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FIGURE 3-1. AREAS OF THE GREAT MIAMI AQUIFER REQUIRING REMEDIATION

schedule. Monitoring will continue south of the administrative boundary as identified in the Integrated Environmental Monitoring Plan (IEMP) (DOE 1996c), until such time as the need for action is established and implemented.

It is important to be clear that the FEMP's groundwater cleanup levels are concentration-based, rather than mass-based. Although mass-removal metrics provide a useful index for comparing alternative remedial strategies, the goal is to restore the aquifer to the concentration-based FRLs as the final measure of success. Those strategies that can achieve the FRLs uniformly (i.e. achieve uniform concentration levels throughout the plume footprint at completion) will generally be the most resource efficient, although they may not necessarily remove the most mass from the aquifer.

3.1.2 Discharge Outfall Limits

During site remediation, significant amounts of both treated and untreated water will be discharged to the Great Miami River. Treatment will be applied to storm water, wastewater and recovered groundwater to the extent necessary to limit the total mass of uranium discharged through the FEMP outfall to the Great Miami River to 600 pounds per year. This mass-based discharge limit became effective upon issuance of the ROD. Additionally, the necessary treatment will be applied to these streams to limit the concentration of total uranium in the blended effluent to the Great Miami River to 20 ppb. The 20 ppb discharge limit for uranium will be based on a monthly average and will become effective January 1, 1998. Beginning in 1998, up to 10 events per year are allowed for emergency by-pass due to storm events (i.e., such events will be accounted for in the annual mass-based discharge requirement but not in the monthly average concentration calculations).

Ongoing compliance with other NPDES requirements during the remediation is also a commitment recognized by the FEMP.

3.1.3 Treatment Capacity

A dedicated groundwater treatment capacity of at least 2000 gpm (including existing and new treatment capacities) will be made available for groundwater restoration. It is expected that this dedicated capacity can be achieved by adding new equipment within the confines of the existing AWWT facility. Additional treatment capacity beyond the 2000 gpm dedicated capacity may also be available during dry seasons or when the other remediation-related wastewater flows decrease. When

the treatment system is stabilized and additional AWWT improvements are incorporated, the anticipated uranium concentration in groundwater treatment effluent is expected to be around 5 ppb.

3.1.4 Groundwater Treatment Decision

Wherever possible, the piping networks that convey extracted groundwater will be designed to connect all the new extraction wells via double headers, with one connected to the main line to the treatment plant and the other to the main discharge line. The extracted groundwater can then be sent to either the treatment plant or directly to the discharge outfall. Through this arrangement, the treatment or discharge decision for each new well can be made on a well-by-well basis. The existing South Plume Removal Action wells will be handled as a unit, with the treatment decision made based on the combined concentration occurring in the existing South Plume force main. During remediation, only extracted groundwater with uranium concentrations higher than 20 ppb at individual wellheads will be treated, up to the available treatment capacity. When the extracted groundwater with concentrations higher than 20 ppb exceeds the treatment capacity, groundwater from wells which have relatively higher uranium concentrations will be treated preferentially. The remaining extracted groundwater will bypass treatment and be directly discharged under the regulatory constraints noted above.

3.1.5 Aquifer Cleanup Time

The 27-year projected aquifer restoration time frame associated with the base case FS remedy was deemed as a reasonable time frame for cleanup in the Operable Unit 5 ROD. However, shorter restoration time frames are preferred by EPA and OEPA, and the FS contained a commitment on the part of DOE to further evaluate measures to reduce cleanup time as a part of remedial design. Shortening the cleanup time can reduce the length of treatment plant operations which may result in significant total cost savings, although a higher up-front capital cost may be required. The scenarios developed for this report have been formulated to specifically address DOE's commitment to evaluate measures to shorten remediation time frames for both the on- and off-property areas of the FEMP.

3.1.6 South Plume Optimization Commitments

The term "South Plume Optimization" was coined during EPA's review of the April 1995 South Plume Removal Action report and signifies the desire of EPA, OEPA, and DOE to restore the off-property portion of the plume quickly and cost effectively. Because the original design of the existing South Plume Removal Action was for plume containment purposes rather than active restoration, a

review of measures to enhance the performance of the South Plume recovery well system has been specifically requested by EPA and OEPA. Additional off-property extraction wells in the South Plume and groundwater injection wells along the FEMP's southern property line are being evaluated in the baseline scenarios to increase mass removal efficiency and reduce the off-property cleanup time.

In the intervening period while such measures are under evaluation, containment of the South Plume will continue and potential hydraulic impacts to the adjacent Paddys Run Road Site will be kept to a minimum during operations.

3.2 PERFORMANCE GOALS

In addition to the regulatory-based commitments recognized above, the preliminary aquifer remediation scenarios will also strive to achieve the following specific performance goals:

Minimize Hydraulic Impacts

- Initiate groundwater remediation modules in sequence
- Minimize the net extraction rate
- Minimize the cumulative groundwater table drawdown
- Minimize the off-property cleanup time

Maximize the Mass Removal Efficiency

- Complete installation of additional extraction wells as soon as possible based on unconstrained funding and landowner access
- Install extraction wells directly in groundwater hot spots
- Extract directly from contaminated aquifer layer
- Focus the available pumping capacity in extraction wells with higher groundwater concentrations
- Adjust operational conditions with the progression of remediation

Minimize Impacts to Wastewater Treatment Operations

- Develop representative estimates of the extracted groundwater quality
- Develop representative estimates of groundwater treatment needs
- Minimize the potential for suspended solids in the extracted groundwater

Maximize the Usefulness of Monitoring Data

- Utilize current monitoring data to update the groundwater model
- Evaluate the monitoring data frequently to determine system effectiveness and potential problems
- Utilize modeling results to help specify future monitoring
- Update the monitoring program frequently with the progression of remediation

Minimize the System Downtime

- Incorporate preventive considerations into the system design
- Operate within the design envelope
- Establish effective preventive maintenance procedures
- Prepare for potential corrective maintenance needs (spare equipment)

Minimize the Overall Remediation Cost

- Shorten the cleanup time where cost effective
- Minimize required treatment capacity

3.3 OTHER CONSTRAINTS

There are additional constraints imposed on the groundwater remediation strategy due to factors such as aquifer characteristics, injection water sources, soil remediation schedules, and funding availability. These constraints also affect the implementability of any potential remedial strategy.

3.3.1 Extraction Rate

The net groundwater extraction rate should not exceed the recharge rate of the regional aquifer or cause excessive water table drawdown. Following technical evaluation, 4000 gpm was established as the limit for the net extraction rate for the aquifer in the Operable Unit 5 FS Report. The maximum pumping rate for each individual well should not exceed 500 gpm (again based on technical evaluations conducted for the FS) in order to prevent excessive local drawdown and improve uranium mass removal efficiencies. Hydraulic impacts to the groundwater contamination plume at the Paddys Run Road Site south of the existing South Plume recovery wells should also be kept to a minimum.

3.3.2 Injection Rate and Quality

Injection may be applied to reduce groundwater drawdown and to increase the groundwater flushing rate through the plume. Based on results of a field injectivity test, an injection rate as high as

450 gpm per well is achievable in the Great Miami Aquifer (DOE 1995d). However, due to areas of high iron concentrations in the Great Miami Aquifer and the existence of iron bacteria, the issue of geochemical compatibility between water types when injecting water into the aquifer needs to be considered in order to maintain long-term efficiency of groundwater injection in any well. The first short-term injection test conducted in October 1995, used untreated (not treated for iron) groundwater from the South Plume area and rapidly resulted in a significant well-plugging problem (DOE 1995d). Results of the second short-term injection test, conducted in March 1996, indicate that when treated (for iron) groundwater was used, plugging did not occur after 5 days of continuous injection at 200 gpm.

No water with a total uranium concentration greater than 20 ppb should be used for injection. Extracted groundwater (treated and untreated) is considered the only significant source of water available for injection. However, mixing the extracted groundwater from multiple wells in order to achieve a blended concentration less than 20 ppb for injection is not considered acceptable to the regulatory agencies. Therefore, the only acceptable source of injection water is the treated water produced by the AWWT facility.

3.3.3 Surface Access

Most of the groundwater plumes are located underneath contaminated soil and source-area waste materials. However, large-scale soil and source-material remediation will first be conducted north of the SSOD (i.e., in the Operable Unit 1, 2, and 3 areas). Due to these surface remediation activities, certain areas will not be directly accessible for installation and operation of groundwater wells until completion of these activities. A 20-year duration was assumed for soil remediation in the Operable Unit 5 FS Report. A shorter soil remediation schedule under the Ten Year Plan will allow an earlier start of groundwater extraction operations directly in the groundwater hot spots. It is assumed for the scenarios evaluated in this report that well installations within the Operable Unit 1, 2, and 3 areas can be initiated within seven years.

Access issues are also important with the off-property plume. Affected landowners must be willing to accommodate an array of remedial elements (wells, pipelines, electrical tie ins, monitoring and maintenance activities, safety and security measures, replacement/relocation actions, etc.) on their properties as part of the restoration program. The modeling simulations conducted for the initial selection of the preliminary baseline strategy (Section 4.0) do yet not consider any access constraints

or logistical issues that may ultimately be important to off-property landowners. The modifications to the selected baseline strategy (presented in Section 5.0) do consider such issues or constraints, where known.

3.3.4 Available Funding

With more vertical and/or horizontal extraction wells, certain groundwater remediation scenarios may be able to achieve shorter cleanup times and therefore lower total remediation cost. But it is also recognized that, due to uncertainty about available funds, remediation scenarios that will require higher up-front capital costs may not be implementable.

Ideally, a remedial strategy should be developed according to the most likely funding scenario, but estimation of a realistic funding scenario is difficult. Therefore, although the estimated up-front capital costs for certain remediation scenarios may be very high, the preliminary evaluation of potential strategies needs to be performed assuming sufficient funds will be available for each of the potential remediation scenarios (i.e., under an unconstrained funding situation). From the potential strategies, a preliminary remedial strategy would then be selected according to relative cost-effectiveness under the unconstrained case. Necessary modifications to the preliminary strategy would then be made based on the actual funding schedule (i.e., under a constrained funding case) when it becomes known. This was the process used to develop the final remedial strategy (presented in Section 5.0) from the preliminary remedial strategy selected in Section 4.0.

3.4 GENERAL ASSUMPTIONS

General assumptions incorporated in the groundwater transport modeling that have significant impacts on the predicted performance of the remediation scenarios are briefly summarized in this section.

3.4.1 Target Plumes

As in the Operable Unit 5 FS Report, the target plumes used in the model are conservatively based on the maximum uranium concentrations measured in each groundwater monitoring well. Although the current/actual uranium plume might be smaller, this approach ensures that all the evaluated remediation scenarios will be able to maintain full capture and to achieve the cleanup goals in time, with a potential trade-off of lower estimated mass removal efficiencies (i.e., the mass of uranium removed per unit volume of groundwater extracted) because of well placement. Uranium concentration contours of the targeted "maximum condition" plume are shown in Figure 3-2. After

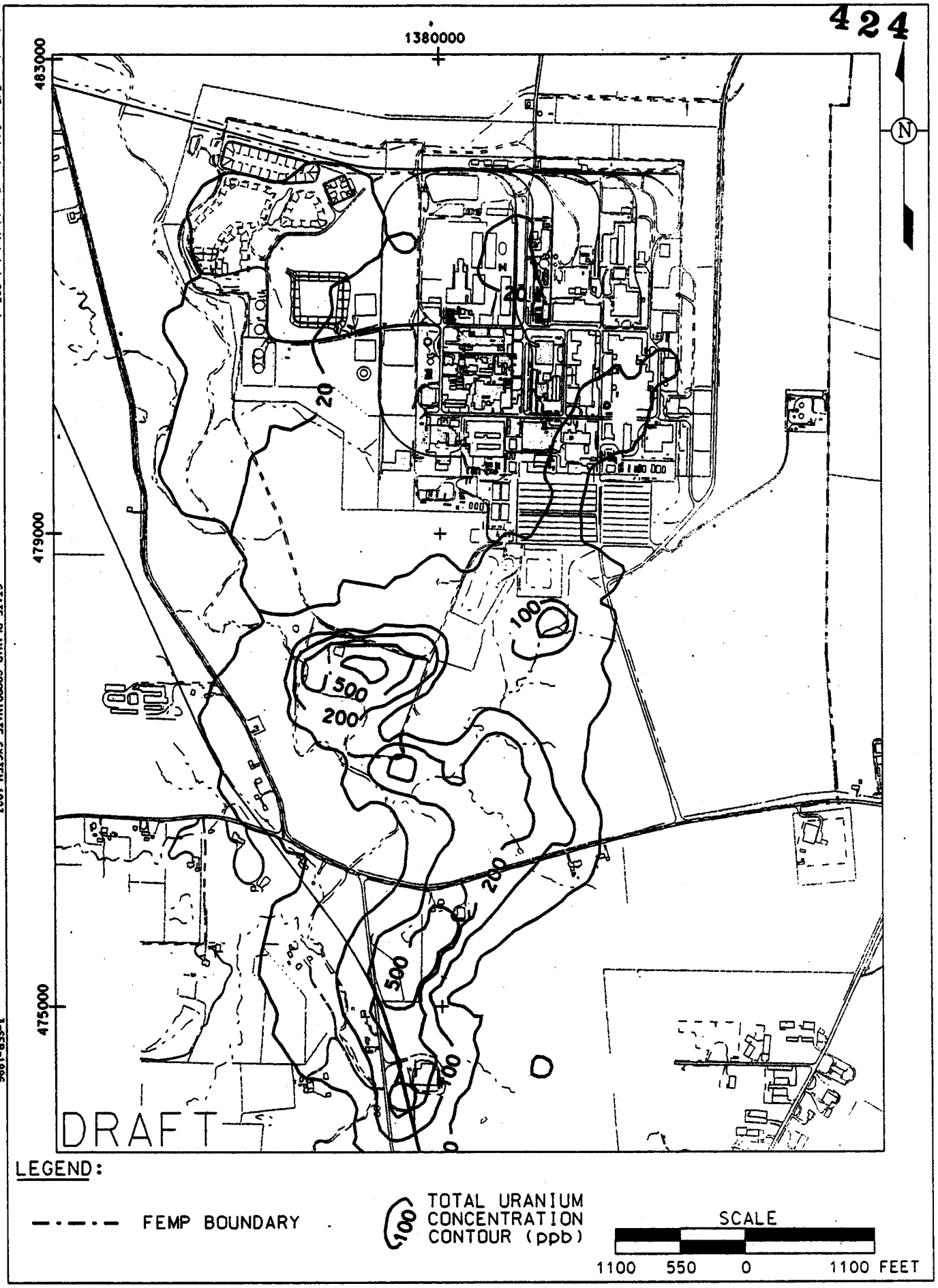

FIGURE 3-2. TARGETED URANIUM PLUME FOR PRELIMINARY EVALUATION

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the preliminary evaluation, the estimated cleanup time and groundwater treatment needed for the selected remedial strategy can be refined using the latest "current-condition" groundwater plume data.

3.4.2 Surface Remediation Schedule

The source operable unit remediation schedules accompanying the FEMP's new Ten Year Plan will be used to develop all of the new groundwater restoration scenarios. This assumption allows earlier initiation of vertical well installations and operations in areas where soil remediation will take place first. Contaminant source loadings due to vertical infiltration through the source areas as well as contaminated surface runoff during remediation will be terminated earlier. It is assumed that all of the area north of the SSOD will be accessible in about 7 years and all soil remediation will be completed in 10 years. The direct contaminant source loadings from Operable Units 1 and 2 will be terminated at the end of the 7th year (i.e., 2002) and surface runoff contaminant concentrations will be reduced to postremediation conditions at the end of the 10th year.

3.4.3 Treatment Capacity Schedule

The groundwater treatment capacities for the first and second years (i.e., 1996 and 1997) are assumed to be 400 and 850 gpm, respectively. The expanded total effective groundwater treatment capacity of 2000 gpm will be available starting from the third year (1998). If the initially predicted uranium concentrations exceed 20 ppb at the outfall line in a potential remediation scenario, the additional treatment capacity required to satisfy the concentration limit will also be estimated for scenario-specific cost estimation purposes. For any scenario in which additional treatment capacities are required, the cost of the additional capacity will be added to the scenario-specific overall cost by adding increments of 250 gpm treatment modules. It needs to be recognized that any scenarios that need such increments of treatment capacity will be requiring treatment that extends beyond the commitment for extended treatment capacity contained in the Operable Unit 5 ROD. The inclusion of the incremental treatment capacities for such scenarios are included for scenario comparison purposes only.

3.4.4 Geochemical Conditions

One key variable that will need to be assessed closely during the course of the remedial program is the mass of uranium and other contaminants of interest that are held in the aquifer solids and unavailable for desorption (i.e., the chemisorbed and precipitated uranium). As discussed in Appendix A, there is no standard way to represent this condition in simulation modeling using the

conventional distribution coefficient, K_d. (K_d represents a simple adsorption model where a linear adsorption isotherm holds). Several studies indicate that simple linear isotherm models do not fit observations of contaminant behavior in aquifers, as adsorption becomes less reversible as time increases (Lasaga 1981; Di Toro and Horzempa 1982, 1983; Voice and Weber 1983). When the contaminant mass available for desorption decreases with time, less contaminant is partitioned into fresh groundwater drawn over the aquifer matrix during the restoration process (see discussion provided in Appendix A). The lower contaminant concentration in groundwater may be interpreted as an increase in the K_d value and a decrease in the efficiency of the restoration process, when it is really a decrease in the mass of the contaminant available for desorption. This is not seen as a detrimental process, as the release of chemisorbed and precipitated contaminants to groundwater will stabilize at a concentration below the contaminant's designated clean-up level. However, assumptions are needed on the use of K_d to account for this behavior in the fate and transport model.

In general, the time dependent change in the mass of contaminant available for desorption is a primary factor in the decreasing contaminant recovery rates and long cleanup times that are often experienced with pump and treat groundwater systems. To model the time dependent change in the release of contaminants from the aquifer matrix several assumptions must be made to handle the mass of contaminant retained by the aquifer matrix and, most difficult, the time continuum over which the contaminant becomes fixed to the aquifer matrix.

Variation in the mass of the contaminant retained by the aquifer matrix can be approached by noting the difference in measured adsorption ratios versus desorption ratios (see Appendix A where these terms are defined). Over time, the desorption ratios increase relative to the adsorption ratio as contaminant is tied up in the aquifer matrix by chemisorption or precipitation. Therefore, the assumption is made that the K_d is represented by the adsorption and desorption ratios, and uncertainty in the cleanup cost and time associated with different adsorption and desorption ratios is evaluated by using these ratios to bracket the range in K_d values.

The range in adsorption and desorption ratios measured for uranium in the Great Miami Aquifer indicates that the ratios are different, with the desorption ratio generally higher in value. It is also important to emphasize that differences in adsorption and desorption ratios have been noted in short-term batch tests, although these tests are not considered definitive examples of the long-term geochemical processes that will occur over the full time of aquifer restoration. However, directly

measured adsorption and desorption ratios are used to set a potential range of K_d values that are used to evaluate uncertainty in projected cleanup time and costs. Appendix A provides additional information on assumptions behind the use of K_d in the evaluation of remedial strategies. Ultimately, the long-term impact of the selected K_d value on aquifer restoration needs to be assessed (and responded to) based on actual operating experience and sampling and analysis.

To account for the decrease in uranium available for desorption, and to bound estimates of cleanup time and treatment capacities, a range in the K_d values will be used to implement simulations of the remediation scenarios. The K_d values are assumed to reflect representative adsorption and desorption ratios of 1.78 and 17.8, respectively. Additional assumptions (e.g., timing of the K_d transition) behind the use of K_d in these simulations can be found in Appendix A.

One expected impact of using the desorption ratio (17.8 L/kg) to represent K_d is lower mobility of uranium in the aquifer (i.e., about 10 times slower under the same hydraulic gradient). Therefore, to minimize the distance of uranium transport, additional extraction wells may be placed in areas of former sources to recover uranium released from potentially abundant chemisorption and precipitation sites in these local areas. In areas where initial uranium contamination is not significant (i.e., less than 200 ppb), the presence of chemisorbed and precipitated uranium may result in shorter cleanup times, because less uranium will be released from an aquifer matrix containing these residual forms and the concentration-based uranium cleanup level can be met earlier.

Because the Sandia Waste Isolation Flow and Transport (SWIFT) model can only simulate one K_d value in each simulation, multiple model runs and superimposition of results are required to combine different timings of transitions among the recovery well systems. A more detailed description of this modeling procedure is provided in Appendix A.

As mentioned in Section 3.3.2, iron clogging of the injection wells and/or the aquifer matrix in close proximity to the wells, due to geochemical interactions between the aquifer and the injected water, is a potential site-specific obstacle that has been evaluated with several short-term single-well injectivity tests. It is assumed for the development of the baseline strategy that the potential iron clogging problem can be resolved and groundwater injection can be conducted with reliable long-term efficiency at the FEMP. However, it needs to be recognized that contingency actions may need to be developed and activated in the future (such as using reduced rates of groundwater injection) should

the geochemical interactions become a detrimental factor and unresolvable through further engineering measures. The aquifer restoration O&M Plan (to be developed under Task 2 of the RD Work Plan) will address monitoring, maintenance, and operating procedures needed to track and address this potential factor.

4.0 PRELIMINARY EVALUATION OF POTENTIAL STRATEGIES

4.1 TECHNICAL APPROACH AND ASSUMPTIONS

The preliminary evaluations were conducted to develop potential cost effective approaches for shortening the remediation time for the Great Miami Aquifer restoration program, to evaluate the effectiveness of groundwater enhancement technologies, and to acknowledge the benefits of the shorter remediation schedules for the FEMP's source control operable units under the accelerated (ten year) remedial plan.

4.1.1 Technical Approach

Four time-based remedial scenarios representing a range of aquifer cleanup times (7.5, 10, 15, and 25 years) were evaluated by conducting model simulations to determine the required number of extraction and injection wells and required groundwater treatment capacity necessary to satisfy the regulatory and technical commitments and constraints discussed in Section 3.0. The capital and O&M costs required for each strategy were estimated based on the Operable Unit 5 FS cost estimate tabulations and actual well installation and AWWT operational costs experienced to date with the FEMP's South Plume Removal Action. A cost-effectiveness comparison among the potential strategies was then performed to identify the most promising cost-effective strategy, in recognition of DOE's programmatic goals to reduce long-term site mortgage costs wherever possible. Following selection, the preferred scenario is then described and compared to the original base case FS remedy. The description includes an identification of the necessary groundwater extraction and injection modules and the implementation schedule which will be required to complete the aquifer restoration in the designated time frame.

The SWIFT GMA Model is used for simulating the three dimensional contaminant transport in the Great Miami Aquifer in this study. The SWIFT code is a fully coupled, transient, 3-dimensional finite difference model for groundwater flow through both porous and fractured media. The mass transport equations solved include terms for convection, dispersion, retardation by sorption, and decay or degradation of the contaminant. The SWIFT code, originally developed by Sandia National Laboratory in the late 1970s for the High Level Waste Program, has been revised several times to increase its capability and to change computer platforms. The site-specific SWIFT GMA model was originally calibrated in 1989 (DOE 1993a). The model was redesigned and recalibrated based on additional data including the South Plume pump test results (DOE 1993b and DOE 1994). The model

has been applied intensively to support all the RI/FS activities at the FEMP since the completion of model development. Based on results of the more recent hydraulic tests and operational data from the South Plume recovery well system in the past three years, the model generally can closely match the measured field hydraulic conditions (DOE 1995c, DOE 1995d, DOE 1996d). The specific procedures applied in the SWIFT model simulations conducted for this report are described in Appendix A.

4.1.2 Assumptions

In order to simplify the development of the potential remedial scenarios, the following assumptions were made for the preliminary evaluation:

- Target Plumes - The "maximum" uranium plume as shown in Figure 3-2 was used as the initial plume in the groundwater and contaminant fate and transport model, consistent with the simulation runs conducted for the Operable Unit 5 FS. The administrative boundary for aquifer restoration is shown in Figure 3-1. As noted on Figure 3-1, this boundary is north of the Paddys Run Road Site plume.

- Surface Remediation Schedule - All the area north of the SSOD will be accessible in about 7 years and all soil remediation will be completed in 10 years. The direct contaminant source loadings from Operable Units 1 and 2 will be terminated at the end of the 7th year (i.e., 2002) and surface runoff contaminant concentrations will be reduced to postremediation conditions at the end of the 10th year.

- Treatment Capacity Schedule - The groundwater treatment capacities for the first and second years (i.e., 1996 and 1997) are assumed to be 400 and 850 gpm, respectively. The baseline total effective groundwater treatment capacity of 2000 gpm will be available starting from the third year (1998). For those scenarios requiring additional groundwater treatment beyond the expanded capacity described in the Operable Unit 5 ROD, the additional capacity is assumed to be added by using increments of 250 gpm treatment modules. Treatment decisions will be made on a well-by-well basis except for the existing South Plume Recovery Well System, which will be made on a combined flow basis.

- Geochemical Conditions - An area-specific one-time transition in the uranium K_d from 1.78 L/kg to 17.8 L/kg was assumed to take place after source termination and the first few pore volumes of contaminated groundwater have been extracted from the area. This transition was implemented to reflect the continuing increase in K_d that occurs over time as chemisorption processes become predominant in later stages of remediation. It was further assumed that groundwater injection can be conducted with reliable long-term efficiency using treated groundwater and that no geochemical interferences would arise.

- Off-Property Access - Areal access for additional off-property wells for South Plume optimization purposes was assumed available without any landowner imposed constraints.

- Funding - For the preliminary evaluations, sufficient funds were assumed to be available to implement each of the potential remediation scenarios, and funding constraints are therefore not present.

4.2 DESCRIPTION OF THE POTENTIAL GROUNDWATER REMEDIATION SCENARIOS

Four additional potential groundwater remediation scenarios were developed for the preliminary evaluations based on the Operable Unit 5 FS base case strategy as well as the commitments, constraints, and assumptions previously discussed. Each scenario represents a remediation system that can achieve groundwater cleanup within a shorter time frame than was specified in the FS base case strategy. In order to cover a sufficiently wide range of capital and long-term O&M costs for analysis, the cleanup time frames targeted in the preliminary evaluations are for 25, 15, 10 and 7.5 years. During initial development, numerous adjustments to the numbers and locations of the extraction/injection wells and subsequent modeling runs were required to derive the final number of wells and locations. At the end all four remediation scenarios as presented in this section achieve the intended cleanup times and are in compliance with all the regulatory requirements and commitments.

The locations and depths of groundwater injection wells and off-property optimization wells included in these scenarios are generally based on results of previously conducted modeling studies furnished to EPA and OEPA. Results of the injection modeling study (along with a preferred approach) were presented to the EPA and OEPA in two technical information exchange meetings held in May and June of 1995. In general, the modeled groundwater injection water surface profiles (referred to as "mounds") match very well with the subsequent field injection test results conducted at the FEMP (DOE 1995d).

A synopsis of the FS strategy is first presented as the basis of all the new potential scenarios in the following subsections. Summaries of the developed specifications, predicted performances, and important design issues related to each of the four new potential remediation scenarios evaluated in this study are then provided. The groundwater model developed and applied for the RI/FS process was used to create these scenarios. A modified modeling approach, described in Appendix A, was followed to simulate the transition of uranium K_d values. Only the final modeling results for each scenario are presented.

4.2.1 Synopsis of The FS Strategy

Modeling conducted to support the Operable Unit 5 FS identified the need for at least 28 extraction wells distributed across the affected areas of the aquifer. These 28 wells are divided into four extraction well systems and are identified in Figure 2-1. The modeling conducted also demonstrated that a combined maximum pumping rate of 4000 gpm from the extraction well system will be required for up to 27 years to attain the final remediation levels. A portion of the extracted groundwater will be treated before being discharged to the Great Miami River to satisfy the outfall criteria. A dedicated groundwater treatment capacity of 2000 gpm will be required.

During the development of the FS strategy, it was assumed that site-wide soil and source-area remediation will take 20 years. Groundwater extraction by conventional vertical wells was the lead technology evaluated during the FS. It was further assumed in the FS that the vertical wells would not be installed through the contaminated source areas but rather along the downgradient edge of the groundwater contaminant plumes originating from the source areas. No additional off-property wells other than the existing South Plume Recovery Well System were employed in the FS scenario.

Assuming the uranium K_d value remains the same (i.e., 1.78 L/kg) throughout the duration of the FS strategy, it will take about 25 years and 27 years to reach a uranium remedial level of 20 ppb for the off-property and on-property areas, respectively. It is expected that with the K_d transition (employed in this Baseline study) the cleanup time for the FS strategy will exceed 30 years even under the shorter soil remediation schedule.

4.2.2 A Potential 25-Year Scenario

Two modifications (i.e., groundwater injection and South Plume optimization) to the Operable Unit 5 FS strategy are incorporated into this scenario. Groundwater injection operations using the five fence line wells (8, 9, 10, 11 and 12) in the original plan and five new wells (42, 43, 44, 49 and 51) north of the inactive flyash pile are included to reduce groundwater drawdown, prevent potential impacts to the Paddys Run Road Site plume, and increase groundwater flushing rates through the FEMP's contaminated zones. Four additional off-property extraction wells close to the center of South Plume (Wells 1, 2N, 3N and KN) are included to improve off-property mass removal rates from the South Plume. Among the four scenarios evaluated, this scenario makes the fewest changes to the base case FS strategy; these changes are:

- Move Well 2 from the waste pit area to the Plant 6 area
- Turn off Wells 26, 27 and 28 in the South Plume area after year 2.

4.2.2.1 Wellfield Pattern

The wellfield pattern of the 25-year scenario is shown in Figure 4-1; however, Well 22 was never used. All the extraction and injection wells are located outside of the areas where extensive soil excavations will take place. The only exception is the former production area where two extraction wells are required near Plant 6. Locations of the four new off-property extraction wells were selected considering the location of the groundwater plume as well as potential access and operational problems. In general, these off-property wells were assumed to be situated along the edge of fields and immediately away from residential dwellings.

4.2.2.2 Extraction/Injection Pumping Rate Schedule

The extraction/injection schedule used to achieve the 25-year cleanup time frame is presented in Table 4-1. The maximum extraction and injection pumping rates are 500 and 200 gpm, respectively. Because no wells will be installed inside the inactive flyash pile even after soil remediation, an earlier start of upgradient groundwater injection is necessary to increase flushing rates through the contaminated zone and ensure a reasonable cleanup time. Groundwater injection wells located along the fence line are used as a hydraulic barrier to prevent the plume from moving off property and to eliminate the effects of a groundwater stagnation zone in the South Plume area (which slows off-property cleanup time) that was identified in the FS strategy. Injection along the fence line is considered critical for achieving an earlier cleanup of the off-property groundwater south of the FEMP. Therefore, operation of the two groundwater injection systems starts at the earliest time possible, year 3 (1998).

4.2.2.3 Predicted Performance

System performance measures including years of groundwater treatment, extracted groundwater concentrations to and by-passing the treatment plant, blended outfall concentrations, and uranium mass removed are listed in Table 4-2. Because of the high injection rate used in the early stage, additional groundwater treatment capacity (beyond that described in the Operable Unit 5 ROD) is required under this scenario to maintain acceptable outfall concentrations. Groundwater treatment is required for 20 years. Due to the high initial concentrations in the South Field area and the transition

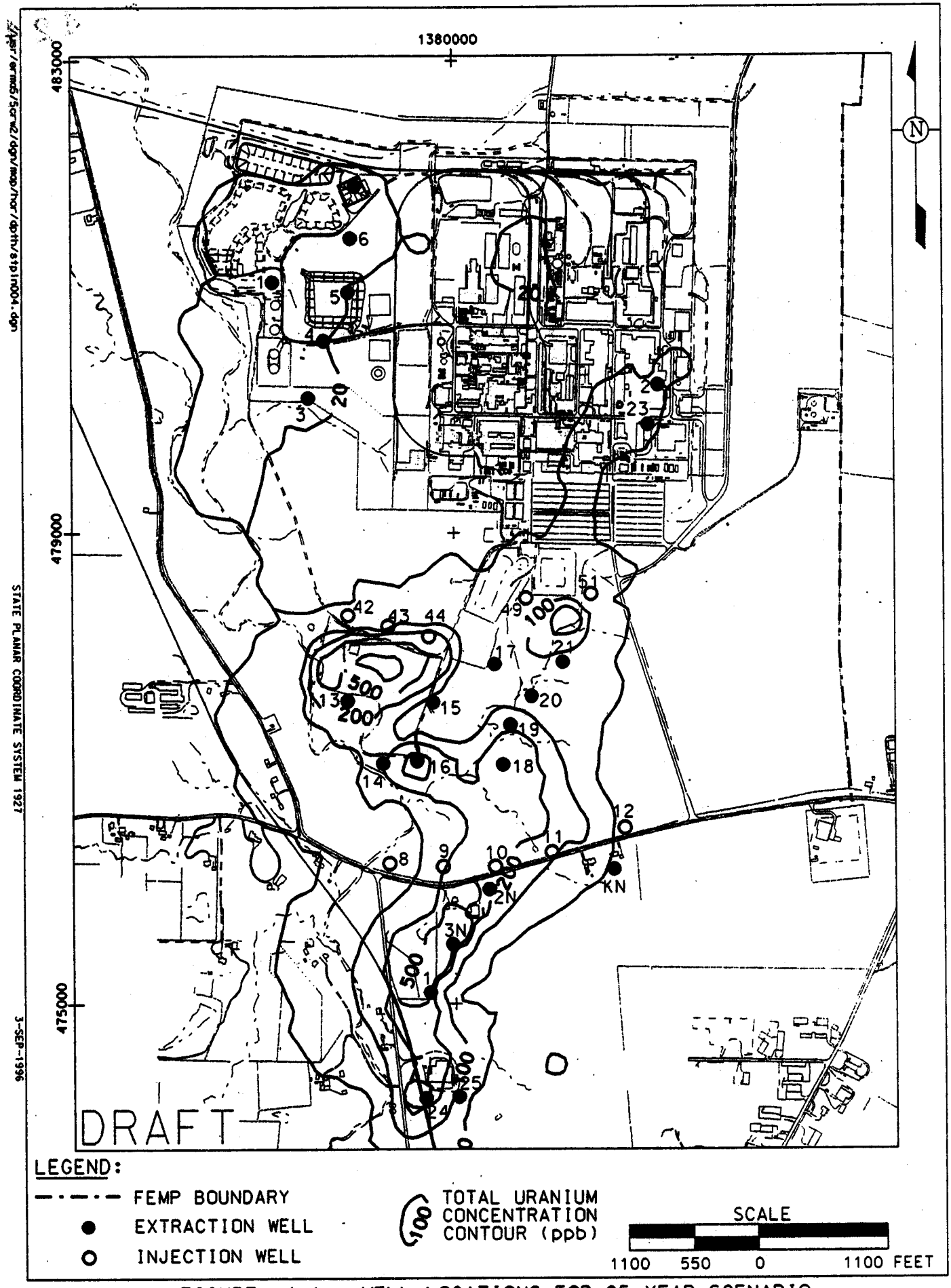

FIGURE 4-1. WELL LOCATIONS FOR 25-YEAR SCENARIO

TABLE 4-1

EXTRACTION/INJECTION SCHEDULE USED FOR 25-YEAR SCENARIO

		Pumping Rates (gpm) (+) = Pumped (-) = Injected				
Location	Well No.	Years 0 to 2	Years 3 to 7	Years 8 to 10	Years 11 to 10	Years 21 to 25
Waste pits	1	0	0	100	0	0
Waste pits	3	0	0	100	120	0
Waste pits	4	0	0	100	120	0
Waste pits	5	0	0	100	120	0
Waste pits	6	0	0	100	120	0
Waste pits	7	0	0	100	120	0
Totals		0	0	600	600	0
Plant 6	2	0	0	250	0	0
Plant 6	23	0	0	250	0	0
Totals		0	0	500	0	0
Fenceline injection wells	8	0	-200	-200	0	0
Fenceline injection wells	9	0	-200	-200	0	0
Fenceline injection wells	10	0	-200	-200	0	0
Fenceline injection wells	11	0	-200	-200	0	0
Fenceline injection wells	12	0	-200	-200	0	0
Totals		0	-1000	-1000	0	0
South Field	13	0	300	300	300	0
South Field	14	0	300	300	400	500
South Field	15	0	300	300	400	500
South Field	16	0	300	300	500	0
South Field	17	0	100	200	0	0
South Field	18	0	100	200	0	0
South Field	19	0	100	200	0	0
South Field	20	0	100	200	0	0
South Field	21	0	100	200	0	0
Totals		0	1700	2200	1600	1000
South Field injection wells	42	0	-200	-200	-200	-200
South Field injection wells	43	0	-200	-200	-200	-200
South Field injection wells	44	0	-200	-200	-200	0
South Field injection wells	49	0	-200	-200	0	0
South Field injection wells	51	0	-200	-200	0	0
Totals		0	-1000	-1000	-600	-400
South Plume	24	300	300	300	0	0
South Plume	25	300	300	300	0	0
South Plume	26	400	0	0	0	0
South Plume	27	400	0	0	0	0
South Plume optimization	1	0	250	250	0	0
South Plume optimization	2N	0	150	150	0	0
South Plume optimization	3N	0	350	350	0	0
South Plume optimization	KN	0	150	150	0	0
Totals		1400	1500	1500	0	0
Total pumping		1400	3200	4800	2200	1000
Total injecting		0	-2000	-2000	-600	-400
Net aquifer extraction		1400	1200	2800	1600	600

TABLE 4-2

SYSTEM PERFORMANCE MEASURES FOR 25-YEAR SCENARIO

Year	Total Water Pumped (gpm)	Treatment Capacity (gpm)	Water to Treatment (gpm)	Concentration to Treatment (ppb)	Water Not Treated (gpm)	Concentration Not Treated (ppb)	Uranium Extracted from Aquifer (lbs)	Injected Water (gpm)	Concentration of Injected Water (ppb)	Uranium Injected[a] (lbs)	Water Discharged (gpm)	Concentration of Discharge (ppb)	Uranium Discharged (lbs)	Uranium Removed from Aquifer (lbs)	Outfall Concentration with Additional Treatment Capacity[b]
1	1400	400	400	35.0	1000	35.0	214.5	0	N/A	0.0	1400	26.4	162.0	214.5	
2	1400	850	850	32.2	550	32.2	197.5	0	N/A	0.0	1400	15.7	96.2	197.5	
3	3200	2000	1950	127.3	1250	31.2	1256.8	2000	5.7	49.5	1200	31.2	163.9	1207.3	12.3
4	3200	2000	1950	117.7	1250	28.2	1159.1	2000	5.6	48.8	1200	28.2	148.3	1110.2	12.0
5	3200	2000	1950	104.5	1250	25.8	1033.1	2000	5.5	48.3	1200	25.8	135.4	984.8	11.8
6	3200	2000	1950	92.0	1250	23.7	915.1	2000	5.5	47.9	1200	23.7	124.6	867.3	11.6
7	3200	2000	1800	85.8	1400	21.8	809.4	2000	6.7	58.5	1200	21.8	114.5	750.9	12.4
8	4800	2000	450	39.3	4350	6.4	200.1	2000	6.1	53.5	2800	6.4	78.9	146.5	
9	4800	2000	550	44.1	4250	6.4	224.2	2000	6.0	52.3	2800	6.4	77.8	171.9	
10	4800	2000	550	49.1	4250	6.5	238.5	2000	6.1	53.1	2800	6.5	79.2	185.4	
11	2200	2000	480	42.4	1720	9.1	157.3	600	5.8	15.3	1600	9.1	63.6	142.0	
12	2200	2000	480	49.0	1720	9.1	171.5	600	5.8	15.3	1600	9.1	63.9	156.2	
13	2200	2000	480	53.1	1720	9.1	179.7	600	5.8	15.3	1600	9.1	63.4	164.4	
14	2200	2000	480	56.0	1720	8.9	184.9	600	5.8	15.2	1600	8.9	62.7	169.7	
15	2200	2000	480	58.1	1720	8.8	188.7	600	5.8	15.2	1600	8.8	62.0	173.5	
16	2200	2000	480	59.6	1720	8.7	190.5	600	5.7	15.1	1600	8.7	60.8	175.5	
17	2200	2000	480	60.7	1720	8.5	191.6	600	5.7	15.0	1600	8.5	59.7	176.6	
18	2200	2000	480	61.3	1720	8.3	191.4	600	5.7	14.9	1600	8.3	58.3	176.5	
19	2200	2000	480	61.6	1720	8.2	191.2	600	5.6	14.8	1600	8.2	57.4	176.4	
20	2200	2000	480	61.7	1720	8.0	190.0	600	5.6	14.7	1600	8.0	56.3	175.3	
21	1000	2000	0	0.0	1000	4.4	19.0	400	4.4	7.6	600	4.4	11.4	11.4	
22	1000	2000	0	0.0	1000	4.5	19.7	400	4.5	7.9	600	4.5	11.8	11.8	
23	1000	2000	0	0.0	1000	4.6	20.1	400	4.6	8.1	600	4.6	12.1	12.1	
24	1000	2000	0	0.0	1000	4.6	20.1	400	4.6	8.1	600	4.6	12.1	12.1	
25	1000	2000	0	0.0	1000	4.7	20.4	400	4.7	8.1	600	4.7	12.2	12.2	

Uranium Extracted from Great Miami Aquifer (lbs) 8184.6 Uranium Injected (lbs) 602.3 Uranium Removed from Great Miami Aquifer (lbs) 7582.3

[a]Calculated from residual uranium concentrations in injected water
[b]Assuming additional treatment capacity of 550 gpm to treat South Plume water

of the uranium K_d value used in the simulations, the overall cleanup time of this scenario (i.e., 25 years) is not significantly shorter than the 27 years estimated in the FS strategy. However, cleanup time for the off-property area is significantly shorter in this scenario and water table drawdown is reduced compared to the base case FS remedy.

4.2.2.4 Summary of Significant Design Issues

In order to implement the 25-year scenario, the following design issues need to be addressed:

- Piping network for the two groundwater injection systems
- Maintaining long-term efficiency of the groundwater injection wells
- Access for the four new off-property vertical extraction wells
- Need for additional treatment capacity beyond the capacity described in the Operable Unit 5 ROD.

4.2.3 A Potential 15-Year Scenario

In addition to the injection and South Plume optimization wells included in the 25-year scenario, four more vertical extraction wells at the inactive flyash pile (Wells 38, 41, 53 and 54) and four more vertical extraction wells in the waste pit area (Wells 55, 56, 57 and 58) are needed to reduce the cleanup time to 15 years. Well installation should immediately follow surface remediation in these areas. Three initial extraction wells around the inactive flyash pile (13, 14 and 16) are converted to injection wells after the new extraction wells are installed. Operation of these additional extraction/injection wells starts at the beginning of the 8th year (2002).

4.2.3.1 Wellfield Pattern

The wellfield pattern of the 15-year scenario is shown in Figure 4-2. Even with upgradient groundwater injection, extraction wells located at the center of the plume under the inactive flyash pile will still be much more efficient than wells located at the downgradient edge (i.e., those used in the 25-year scenario and the FS strategy). Therefore, after excavation and surface regrading in the South Field and waste pit areas, additional vertical extraction wells are installed to enhance remediation. Locations of these additional extraction wells can be seen in Figure 4-2.

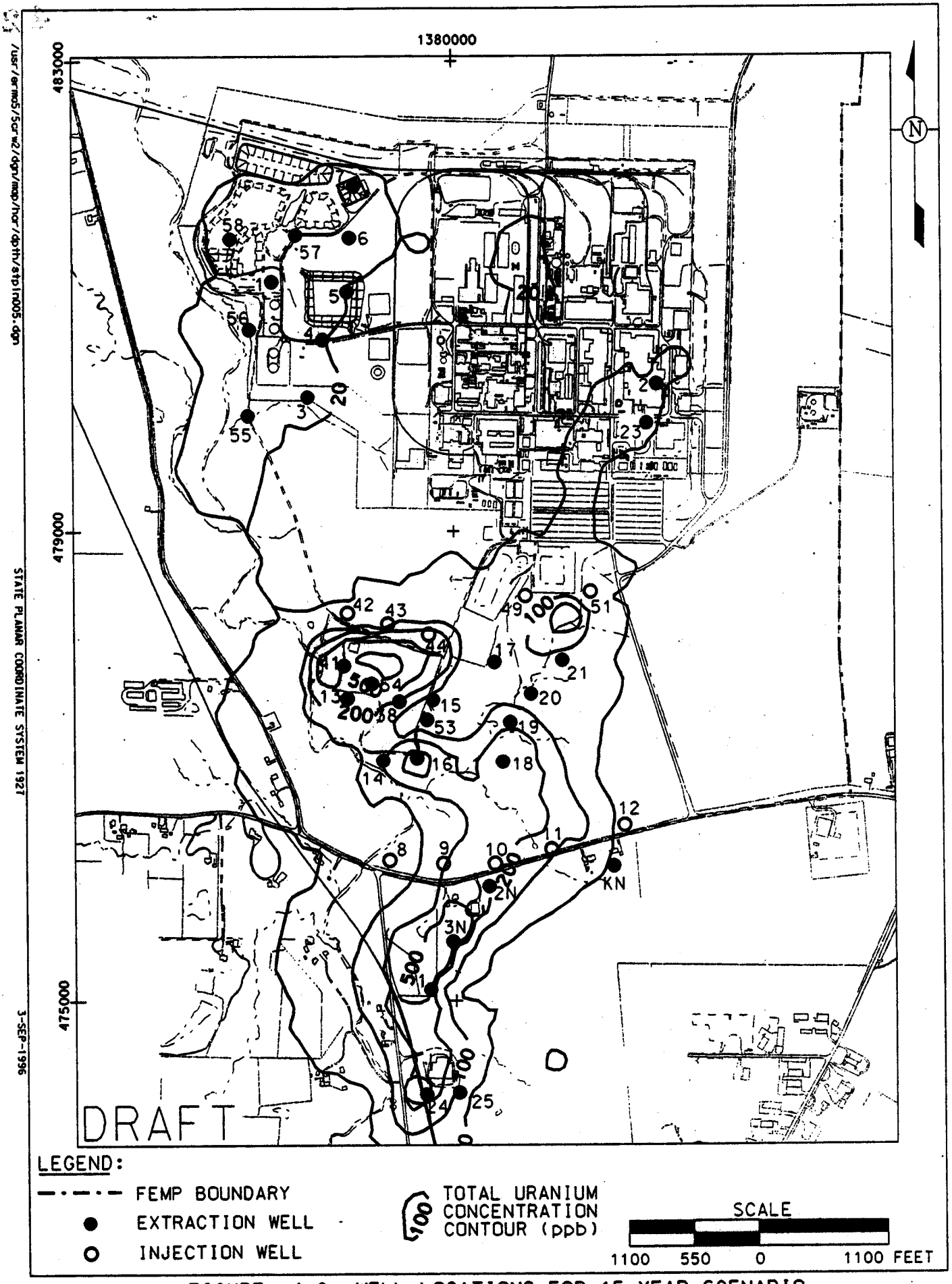

FIGURE 4-2. WELL LOCATIONS FOR 15-YEAR SCENARIO

4.2.3.2 Extraction/Injection Pumping Rate Schedule

The extraction/injection schedule used to achieve the 15-year cleanup is presented in Table 4-3. Because additional extraction wells will be installed in remaining groundwater hot spots, injection upgradient of the inactive flyash pile can start later. The additional extraction wells and the upgradient injection wells are assumed to start operating during the 8th year. The maximum extraction and injection rates are 400 and 300 gpm, respectively. After 10 years, all the extraction and injection wells other than those in the South Field can be removed.

4.2.3.3 Predicted Performance

System performance measures including years of groundwater treatment, extracted groundwater concentrations to and by-passing the treatment plant, blended outfall concentrations, and uranium mass removed are listed in Table 4-4. Groundwater treatment is required for 10 years and no additional treatment capacity above 2000 gpm is necessary. Because the 15-year scenario achieves groundwater cleanup in a much shorter time frame than the 25-year scenario, it actually removes less total uranium mass from the aquifer; however, the mass removal efficiency is higher and less uranium will be discharged to the Great Miami River.

4.2.3.4 Summary of Significant Design Issues

In order to implement the 15-year scenario, the following design issues need to be addressed:

- Increased complexities of the extraction piping networks due to a larger number of wells
- Piping network for the two groundwater injection systems
- Converting extraction wells to injection wells
- Maintaining long-term efficiency of the injection wells
- Access for the four new off-property vertical extraction wells
- Effects from potential delays in the soil remediation schedule.

4.2.4 A Potential 10-Year Scenario

Building on the previous scenario, it was determined that five more vertical extraction wells (59, 60, 61, 62 and 63, for a total of nine) are required in the South Field after surface remediation to further reduce groundwater cleanup time from 15 to 10 years.

4.2.4.1 Wellfield Pattern

The wellfield pattern of the 10-year scenario is shown in Figure 4-3. As described in the 15-year scenario, all the extraction and reinjection wells other than those in the South Field area can be

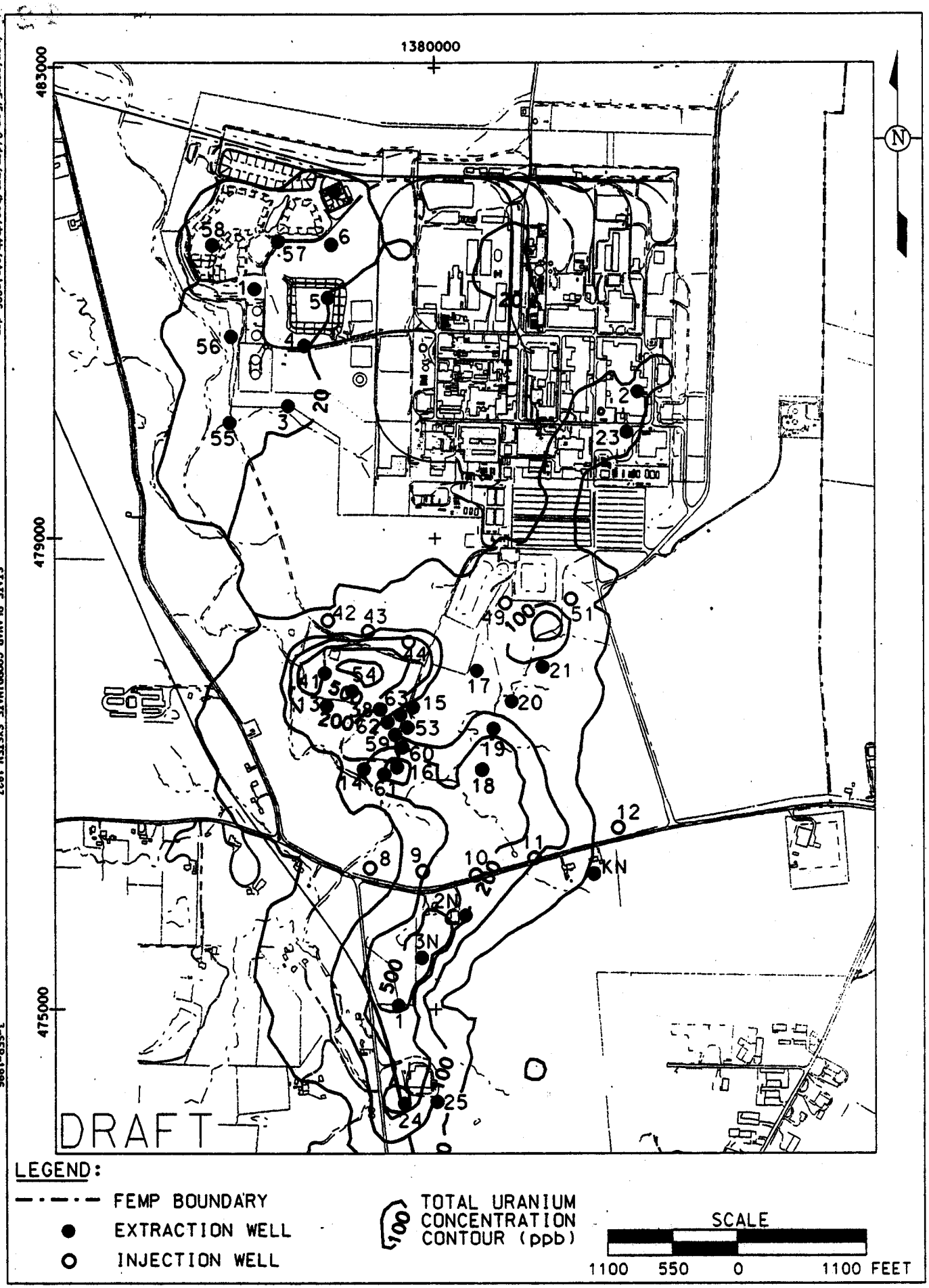

FIGURE 4-3. WELL LOCATIONS FOR 10-YEAR SCENARIO

TABLE 4-3
EXTRACTION/INJECTION SCHEDULE USED FOR 15-YEAR SCENARIO

		Pumping Rates (gpm) (+) = Pumped (-) = Injected			
Location	Well No.	Years 0 to 2	Years 3 to 7	Years 8 to 10	Years 11 to 15
Waste Pits	1	0	0	100	0
Waste Pits	3	0	0	100	0
Waste Pits	4	0	0	100	0
Waste Pits	5	0	0	100	0
Waste Pits	6	0	0	100	0
Waste Pits	7	0	0	100	0
Waste Pits	55	0	0	100	0
Waste Pits	56	0	0	100	0
Waste Pits	57	0	0	100	0
Waste Pits	58	0	0	100	0
Totals		0	0	1000	0
Plant 6	2	0	0	250	0
Plant 6	23	0	0	250	0
Totals		0	0	500	0
Fenceline injection wells	8	0	-200	-200	0
Fenceline injection wells	9	0	-200	-200	0
Fenceline injection wells	10	0	-200	-200	0
Fenceline injection wells	11	0	-200	-200	0
Fenceline injection wells	12	0	-200	-200	0
Totals		0	-1000	-1000	0
South Field	13	0	200	-200	-300
South Field	14	0	200	-200	-300
South Field	15	0	200	200	0
South Field	16	0	200	-200	0
South Field	17	0	100	200	0
South Field	18	0	100	0	0
South Field	19	0	100	200	0
South Field	20	0	100	200	0
South Field	21	0	100	200	0
South Field	38	0	0	300	400
South Field	41	0	0	400	400
South Field	53	0	0	300	400
South Field	54	0	0	400	400
Totals		0	1300	1800	1000
South Field injection wells	42	0	0	-200	-300
South Field injection wells	43	0	0	-200	-300
South Field injection wells	44	0	0	-200	0
South Field injection wells	49	0	0	-200	0
South Field injection wells	51	0	0	-200	0
Totals		0	0	-1000	-600
South Plume	24	300	300	300	0
South Plume	25	300	300	300	0
South Plume	26	400	0	0	0
South Plume	27	400	0	0	0
South Plume optimization	1	0	250	250	0
South Plume optimization	2N	0	150	150	0
South Plume optimization	3N	0	350	350	0
South Plume optimization	KN	0	150	150	0
Totals		1400	1500	1500	0
Total pumped		1400	2800	5400	1600
Total injected		0	-1000	-2600	-1200
Net Aquifer extraction		1400	1800	2800	400

TABLE 4-4

SYSTEM PERFORMANCE MEASURES FOR 15-YEAR SCENARIO

Year	Total Water Pumped (gpm)	Treatment Capacity (gpm)	Water to Treatment (gpm)	Concentration to Treatment (ppb)	Water Not Treated (gpm)	Concentration Not Treated (ppb)	Uranium Extracted from Aquifer (lbs)	Injected Water (gpm)	Concentration of Injected Water (ppb)	Uranium Injected[a] (lbs)	Water Discharged (gpm)	Concentration of Discharge (ppb)	Uranium Discharged (lbs)	Uranium Removed from Aquifer (lbs)
1	1400	400	400	35.0	1000	35.0	214.5	0	0.0	0.0	1400	26.4	162.0	214.5
2	1400	850	850	32.2	550	32.2	197.5	0	0.0	0.0	1400	15.7	96.2	197.5
3	2800	2000	1650	95.7	1150	29.2	838.0	1000	5.0	21.9	1800	20.5	161.4	816.1
4	2800	2000	1650	88.3	1150	25.6	766.6	1000	5.0	21.9	1800	18.2	143.1	744.7
5	2800	2000	1650	80.8	1150	22.8	698.4	1000	5.0	21.9	1800	16.4	128.9	676.5
6	2800	2000	1650	74.3	1150	20.4	639.5	1000	5.0	21.9	1800	14.9	117.1	617.6
7	2800	2000	1650	68.7	1150	18.4	588.7	1000	5.0	21.9	1800	13.6	106.8	566.8
8	5400	2000	450	41.6	4950	8.9	274.3	2600	8.2	93.4	2800	8.9	108.7	180.9
9	5400	2000	450	49.4	4950	8.4	280.0	2600	7.8	89.2	2800	8.4	103.4	190.8
10	5400	2000	550	47.9	4850	7.8	280.8	2600	7.2	82.0	2800	7.8	95.6	198.8
11	1600	2000	0	0.0	1600	12.1	84.6	1200	12.1	63.4	400	12.1	21.1	21.1
12	1600	2000	0	0.0	1600	11.2	78.6	1200	11.2	58.9	400	11.2	19.6	19.6
13	1600	2000	0	0.0	1600	10.5	73.2	1200	10.5	54.9	400	10.5	18.3	18.3
14	1600	2000	0	0.0	1600	9.8	68.3	1200	9.8	51.2	400	9.8	17.1	17.1
15	1600	2000	0	0.0	1600	9.2	64.2	1200	9.2	48.2	400	9.2	16.1	16.1
			Uranium extracted from Great Miami Aquifer (lbs)				5147.2	Uranium Injected (lbs)		650.6	Uranium Removed from Great Miami Aquifer (lbs)			4496.6

[a]Calculated from residual uranium concentrations in injected water.

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terminated after 10 years. Therefore, additional extraction wells were only added in the South Field area to achieve cleanup within 10 years. Through iterative model simulations, it was determined that nine vertical extraction wells need to be installed after the surface remediation to achieve groundwater cleanup in the South Field area within 10 years.

4.2.4.2 Extraction/Injection Pumping Rate Schedule

The extraction/injection schedule used to achieve the 10-year cleanup is presented in Table 4-5. As in the 15-year scenario, groundwater injection upgradient of the inactive flyash pile can start later. The maximum extraction and injection pumping rates are 300 and 200 gpm, respectively. These rates are lower than those used in scenarios with fewer extraction wells.

4.2.4.3 Predicted Performance

System performance measures including years of groundwater treatment, extracted groundwater concentrations to and by-passing the treatment plant, blended outfall concentrations, and uranium mass removed are listed in Table 4-6. Groundwater treatment is required for 9 years and no additional treatment capacity above 2000 gpm is necessary. Among the three scenarios described so far, the 10-year scenario has the highest mass removal efficiency and needs to remove the least amount of total uranium mass to achieve groundwater cleanup. Uranium mass discharged into the Great Miami River is about the same as in the 15-year scenario.

4.2.4.4 Summary of Significant Design Issues

Similar to the 15-year scenario, in order to implement the 10-year scenario, the following design issues need to be addressed:

- Increased complexities of the extraction piping networks due to a larger number of wells
- Piping network for the two groundwater injection systems
- Converting extraction wells to injection wells
- Maintaining long-term efficiency of the injection wells
- Access for the four new off-property vertical extraction wells
- Effects from potential delays in the soil remediation schedule.

4.2.5 A Potential 7.5-Year Scenario

The intended cleanup time of this scenario (i.e., 7.5 years) is shorter than the soil and source-area remediation time frame under the Ten Year Plan. Therefore, horizontal wells were evaluated as a

TABLE 4-5
EXTRACTION/INJECTION SCHEDULE USED FOR 10-YEAR SCENARIO

Location	Well No.	Pumping Rates (gpm) (+) = Pumped (-) = Injected		
		Years 0 to 2	Years 3 to 7	Years 8 to 10
Waste Pits	1	0	0	100
Waste Pits	3	0	0	100
Waste Pits	4	0	0	100
Waste Pits	5	0	0	100
Waste Pits	6	0	0	100
Waste Pits	7	0	0	100
Waste Pits	55	0	0	100
Waste Pits	56	0	0	100
Waste Pits	57	0	0	100
Waste Pits	58	0	0	100
Totals		0	0	1000
Plant 6	2	0	0	250
Plant 6	23	0	0	250
Totals		0	0	500
Fenceline injection wells	8	0	-200	-200
Fenceline injection wells	9	0	-200	-200
Fenceline injection wells	10	0	-200	-200
Fenceline injection wells	11	0	-200	-200
Fenceline injection wells	12	0	-200	-200
Totals		0	-1000	-1000
South Field	13	0	200	-200
South Field	14	0	200	-200
South Field	15	0	200	100
South Field	16	0	200	-200
South Field	17	0	100	100
South Field	18	0	100	0
South Field	19	0	100	200
South Field	20	0	100	200
South Field	21	0	100	200
South Field	38	0	0	300
South Field	41	0	0	300
South Field	53	0	0	300
South Field	54	0	0	300
South Field	59	0	0	300
South Field	60	0	0	300
South Field	61	0	0	200
South Field	62	0	0	200
South Field	63	0	0	300
Totals		0	1300	2700
South Field injection wells	42	0	0	-200
South Field injection wells	43	0	0	-200
South Field injection wells	44	0	0	-200
South Field injection wells	49	0	0	-200
South Field injection wells	51	0	0	-200
Totals		0	0	-1000
South Plume	24	300	300	300
South Plume	25	300	300	300
South Plume	26	400	0	0
South Plume	27	400	0	0
South Plume optimization	1	0	250	250
South Plume optimization	2N	0	150	150
South Plume optimization	3N	0	350	350
South Plume optimization	KN	0	150	150
Totals		1400	1500	1500
Total pumped		1400	2800	6300
Total injected		0	-1000	-2600
Net Aquifer extraction		1400	1800	3700

TABLE 4-6

SYSTEM PERFORMANCE MEASURES FOR 10-YEAR SCENARIO

Year	Total Water Pumped (gpm)	Treatment Capacity (gpm)	Water to Treatment (gpm)	Concentration to Treatment (ppb)	Water Not Treated (gpm)	Concentration Not Treated (ppb)	Uranium Extracted from Aquifer (lbs)	Injected Water (gpm)	Concentration of Injected Water (ppb)	Uranium Injected[a] (lbs)	Water Discharged (gpm)	Concentration of Discharge (ppb)	Uranium Discharged (lbs)	Uranium Removed from Aquifer (lbs)
1	1400	400	400	35.0	1000	35.0	214.5	0	N/A	0.0	1400	26.4	162.0	214.5
2	1400	850	850	32.2	550	32.2	197.5	0	N/A	0.0	1400	15.7	96.2	197.5
3	2800	2000	1650	95.7	1150	29.2	838.0	1000	5.0	21.9	1800	20.5	161.4	816.1
4	2800	2000	1650	88.3	1150	25.6	766.6	1000	5.0	21.9	1800	18.2	143.1	744.7
5	2800	2000	1650	80.8	1150	22.8	698.4	1000	5.0	21.9	1800	16.4	128.9	676.5
6	2800	2000	1650	74.3	1150	20.4	639.5	1000	5.0	21.9	1800	14.9	117.1	617.6
7	2800	2000	1650	68.7	1150	18.4	588.7	1000	5.0	21.9	1800	13.6	106.8	566.8
8	6300	2000	200	28.2	6100	9.9	288.2	2600	9.5	108.1	3700	9.9	159.9	180.1
9	6300	2000	200	33.4	6100	9.2	274.8	2600	8.9	101.0	3700	9.2	148.9	173.8
10	6300	2000	0	0.0	6300	7.3	201.4	2600	7.3	83.1	3700	7.3	118.3	118.3

Uranium Extracted from Great Miami Aquifer (lbs) 4707.6 Uranium Injected (lbs) 401.6 Uranium Removed from Great Miami Aquifer (lbs) 4306.0

[a]Calculated from residual uranium concentrations in injected water.

means to reach and pump directly from groundwater hot spots before the completion of surface remediation. Horizontal wells can be located outside a soil remediation area and then extend underground into targeted groundwater plumes beneath the remediation area. Because no horizontal wells have been used previously at the FEMP, their feasibility for groundwater remediation was evaluated. Major issues and the information collected during this evaluation are summarized in Appendix B. The general conclusion is that horizontal well technologies can be successful in certain applications at the FEMP as long as appropriate design, installation, and maintenance procedures are employed.

Under this scenario, horizontal wells are required in the inactive flyash pile, waste pit and former production areas to achieve the targeted cleanup time of 7.5 years. Horizontal wells along the fence line, instead of the off-property vertical extraction wells used in the previous three scenarios, are also incorporated in this scenario for the enhanced remediation of the off-property South Plume. This was considered in this scenario if off-property surface access becomes a problem and vertical wells cannot be used.

4.2.5.1 Wellfield Pattern

The wellfield pattern for the 7.5-year scenario is shown in Figure 4-4. Eight horizontal wells were used in both the excavated and off-property areas. Although not specifically modeled as horizontal wells, the discharges from the ten vertical wells in the waste pit area and two vertical wells in the Plant 6 area were combined for system performance calculations as if the discharges came from three separate horizontal wells, two in the waste pit area and one in the Plant 6 area (See Appendix A). These three horizontal wells were assumed to have the same performance as the vertical wells in these areas from the 10-year scenario except for the earlier start time for the horizontal wells. Vertical wells, other than the existing South Plume wells, are only used in the SSOD area for extraction; groundwater injection operations also still use vertical wells.

Length, locations, orientations, and extraction rates of these horizontal wells were determined using a multistep modeling approach. A pipe flow model (i.e., Fathom) was first used to determine the inflow rate distributions along various horizontal well-screen designs. Factors considered in this analysis included well diameter, length and depth, number of pumps, and aquifer response to pumping. Each of the estimated inflow rate distributions was then converted into a series of accumulated inflows in the SWIFT model grid blocks where the horizontal well was located. Iterative

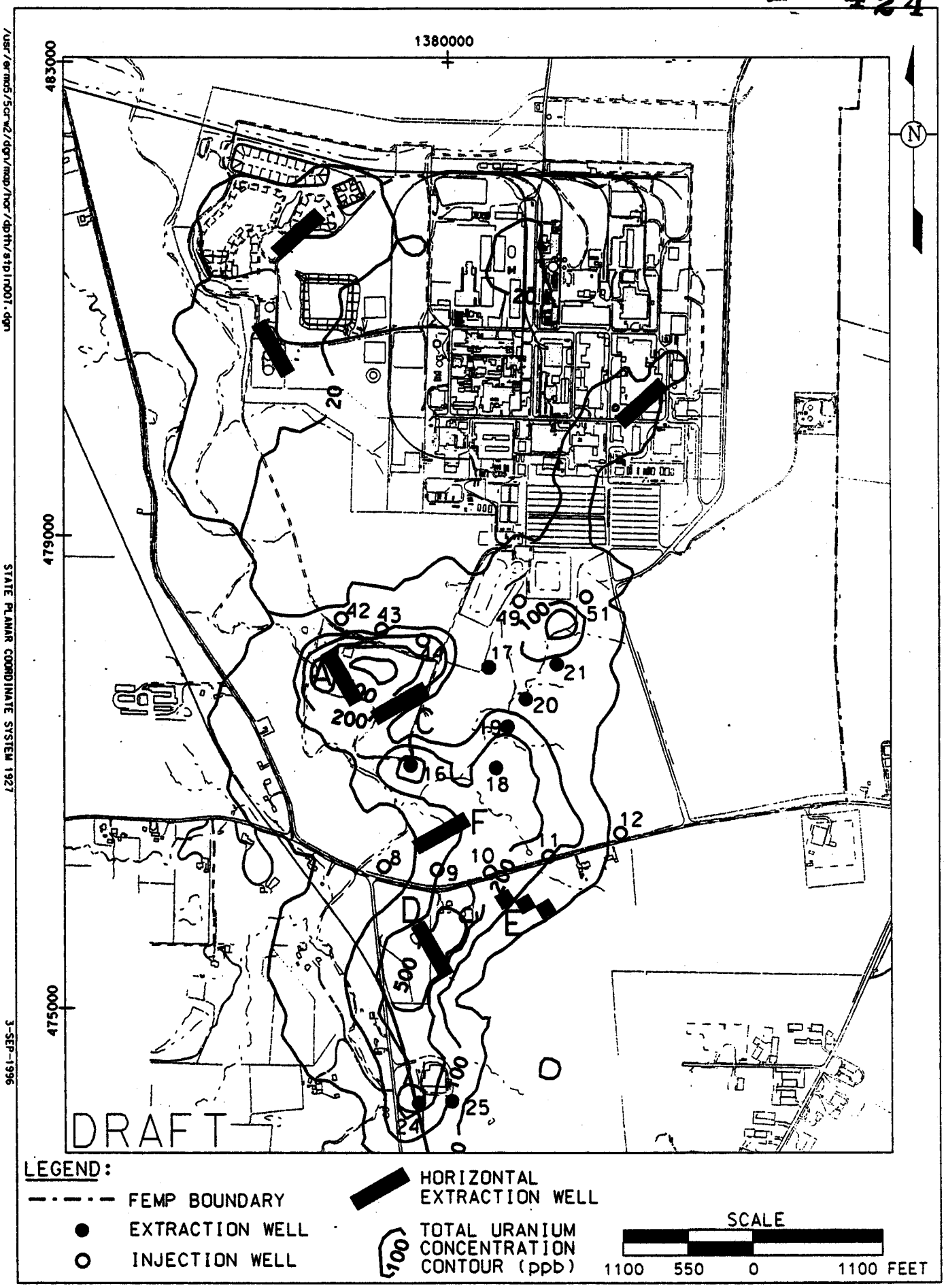

FIGURE 4-4. WELL LOCATIONS FOR 7.5-YEAR SCENARIO

SWIFT model simulations were then conducted to predict contaminant transport during the remediation and to finalize the conceptual layout of each horizontal well design. Because a horizontal well can be installed by either horizontal directional drilling or Ranney technology, the advantages and disadvantages of these two approaches were evaluated to select the appropriate installation method.

The major advantages of using horizontal directional drilling include the capability to install much longer wells (i.e., with more than a 350-foot-long horizontal section) and continuous wells (i.e., wells with both ends open to the ground surface). The expected cost of directional drilling is lower than the Ranney approach. However, in order to facilitate the desired high pumping capacity (i.e., 300- to 900 gpm), larger well diameters will need to be installed than is typically done in directional drilling applications. Another potential problem associated with the directional drilling is that it is often difficult to properly develop the well (i.e., to remove fine materials from the formation and the residual drilling mud used during the drilling process). There is also no assurance that, even with adequate well-screen diameters, effective well maintenance can be performed due to the curvature of the well which may preclude the use of appropriate well-cleaning devices.

Ranney collector wells have a better chance to obtain the high pumping capacities because no drilling mud is required during installation and larger or multiple pumps can be installed in the 9- to 16-foot caisson. Ranney wells can also have multiple lateral drains in a single caisson. In a Ranney well, access to the well-screens is easily made in the caisson so that proper well-cleaning equipment can be used to rehabilitate the well-screens, if required. However, significant amounts of soil need to be excavated and disposed of during installation. The required length of the horizontal well specified in Figure 4-4 is much longer than is typically done in Ranney well applications (i.e., up to 350 feet). Installation of the large caisson and associated health and safety requirements will result in much higher costs for Ranney wells than for wells installed by directional drilling.

Based on the advantages, disadvantages, and limitations of the two horizontal well installation technologies, the suitable installation technology for each horizontal well was selected. Directional drilling was selected to install the five continuous horizontal wells (i.e., can pump from the both ends) in the South Field, waste pit, and Plant 6 areas. The main reason for this selection was the contaminated soil in these areas which will preclude the Ranney approach. Due to the potentially lower achievable pumping rate in each well, additional horizontal wells can be installed in these areas

to ensure the desired overall extraction rates, if deemed necessary. The Ranney approach was selected for installing the three horizontal wells in the South Plume area, because the overburden is considered clean and higher pumping rates are required in this area. Although these selections do not affect the estimated performance measures, they will be reflected in the estimated cost of this scenario.

4.2.5.2 Extraction/Injection Pumping Rate Schedule

The extraction/injection schedule used to achieve the 7.5-year cleanup is presented in Table 4-7. In general, the extraction rate of a horizontal well is equivalent to the total extraction rate of a group of vertical wells used in the previous scenarios. However, the horizontal wells can be operated before completion of soil remediation. The use of horizontal wells also enables a longer section of well-screen to be installed (for the same overall extraction rate) to lower the entrance velocities through the well-screen and reduce the head losses, which results in a lower plugging rate and lower maintenance requirements.

4.2.5.3 Predicted Performance

System performance measures including years of groundwater treatment, extracted groundwater concentrations to and by-passing the treatment plant, blended outfall concentrations, and uranium mass removed are listed in Table 4-8. Due to the higher extraction rate directly from groundwater hot spots and operation of both injection systems, significantly more groundwater treatment capacity (i.e., an additional 1000 gpm) will be required for this scenario.

4.2.5.4 Summary of Significant Design Issues

In order to implement the 7.5-year scenario using horizontal wells, the following design issues need to be addressed:

- Piping network for the two groundwater injection systems
- Maintaining long-term efficiency of the injection wells
- Difficulties associated with horizontal well installation
- Additional treatment capacity needed.

4.3 COMPARISONS AND SELECTION

Based on the specifications of the evaluated scenarios and predicted performance measures summarized in Section 3.0, this section compares the cost-effectiveness and potential risk/uncertainty

TABLE 4-7

EXTRACTION/INJECTION SCHEDULE USED FOR 7.5-YEAR SCENARIO

		Pumping Rates (gpm) (+) = Pumped (-) = Injected		
Location	Well No.	Years 0 to 2	Years 3 to 5	Years 6 to 7.5
Waste pits	B1	0	500	0
Waste pits	B2	0	500	0
Totals		0	1000	0
Plant 6	G1	0	500	0
Totals		0	500	0
Fenceline injection wells	8	0	-200	-200
Fenceline injection wells	9	0	-200	-200
Fenceline injection wells	10	0	-200	-200
Fenceline injection wells	11	0	-200	-200
Fenceline injection wells	12	0	-200	-200
Totals		0	-1000	-1000
South Field	13	0	0	0
South Field	14	0	0	0
South Field	15	0	0	0
South Field	16	0	200	200
South Field	17	0	0	0
South Field	18	0	100	200
South Field	19	0	100	200
South Field	20	0	100	200
South Field	21	0	100	200
Totals		0	600	600
South Field injection wells	42	0	-200	-200
South Field injection wells	43	0	-200	-200
South Field injection wells	44	0	-200	-200
South Field injection wells	49	0	-200	-200
South Field injection wells	51	0	-200	-200
Totals		0	-1000	-1000
South Plume	24	300	300	300
South Plume	25	300	300	300
South Plume	26	400	0	0
South Plume	27	400	0	0
South Plume optimization	1	0	0	0
South Plume optimization	2N	0	0	0
South Plume optimization	3N	0	0	0
South Plume optimization	KN	0	0	0
Totals		1400	600	600
South Field horizontal	A1	0	150	150
South Field horizontal	A2	0	100	100
South Field horizontal	A3	0	100	100
South Field horizontal	A4	0	150	150
Totals		0	500	500
South Field horizontal	F1	0	160	160
South Field horizontal	F2	0	100	100
South Field horizontal	F3	0	80	80
South Field horizontal	F4	0	60	60
Totals		0	400	400

TABLE 4-7
(Continued)

Location	Well No.	Pumping Rates (gpm) (+) = Pumped (-) = Injected Years 0 to 2	Years 3 to 5	Years 6 to 7.5
South Plume horizontal	D1	0	360	360
South Plume horizontal	D2	0	225	225
South Plume horizontal	D3	0	180	180
South Plume horizontal	D4	0	135	135
Totals		0	900	900
South Plume horizontal	E1	0	150	150
South Plume horizontal	E2	0	90	90
South Plume horizontal	E3	0	60	60
Totals		0	300	300
Total pumping		1400	5300	3800
Total injecting		0	-2000	-2000
Net aquifer extraction		1400	3300	1800

TABLE 4-8

SYSTEM PERFORMANCE MEASURES FOR 7.5-YEAR SCENARIO

Year	Total Water Pumped (gpm)	Treatment Capacity (gpm)	Water to Treatment (gpm)	Concentration to Treatment (ppb)	Water Not Treated (gpm)	Concentration Not Treated (ppb)	Uranium Extracted from Aquifer (lbs)	Injected Water (gpm)	Concentration of Injected Water (ppb)	Uranium Injected[a] (lbs)	Water Discharged (gpm)	Concentration of Discharge (ppb)	Uranium Discharged (lbs)	Uranium Removed from Aquifer (lbs)
1	1400	400	400	35.0	1000	35.0	214.5	0	N/A	0.0	1400	26.4	162.0	214.5
2	1400	850	850	32.2	550	32.2	197.5	0	N/A	0.0	1400	15.7	96.2	197.5
3	5300	2000	1800	121.7	3500	35.8	1506.7	2000	8.1	70.7	3300	35.8	516.4	1436.0
4	5300	2000	1800	89.7	3500	31.6	1190.4	2000	7.7	67.0	3300	31.6	455.8	1123.4
5	5300	2000	1800	69.7	3500	28.3	983.1	2000	7.3	64.2	3300	28.3	409.3	918.9
6	3800	2000	1800	57.4	2000	28.8	703.5	2000	7.4	64.6	1800	28.8	226.5	638.9
7	3800	2000	1800	49.5	2000	25.2	610.7	2000	7.0	61.5	1800	25.2	198.7	549.2
8	3800	2000	0	0.0	3800	3.6	59.5	2000	3.6	31.3	1800	3.6	28.2	28.2
								Total U						
			Uranium Extracted from Great Miami Aquifer (lbs)				5465.8	Uranium Injected (lbs)		359.2	Uranium Removed from Great Miami Aquifer (lbs)			5106.6

[a]Calculated from residual uranium concentrations in injected water.

for implementing the evaluated remediation scenarios. Based on the comparisons, recommendations for the new baseline groundwater remediation strategy at the FEMP are provided.

4.3.1 Relative Cost Estimation

All four groundwater remediation scenarios developed in this study can satisfy all the commitments and constraints when sufficient groundwater treatment capacity is available. A ranking based on relative overall costs of all the evaluated remediation scenarios is required in order to determine the optimal cost-effectiveness. The costs for additional treatment capacity over 2000 gpm are also included for two of the scenarios (i.e., the 25-year and 7.5-year scenarios). It needs to be noted that for both of these scenarios, the additional capacity is greater than the expanded capacity commitment contained in the Operable Unit 5 ROD.

4.3.1.1 Estimated Relative Component Costs

Relative costs of major system components such as different types of wells, well O&M, groundwater treatment module, groundwater treatment operation, and groundwater monitoring activities are listed in Table 4-9. The relative costs are presented as ratios to the cost for design and construction of a typical on-property vertical extraction well and associated pump and piping (i.e., about $500,000). These relative costs were estimated based on costs of existing systems and design packages at the FEMP, EPA documents, and information from vendors and represent DOE's best estimate of the cost of each of the major system components. The component-specific sources of information for unit cost estimation and the associated uncertainty are summarized in Table C-1 of Appendix C. Uncertainties associated with the estimated unit costs are presented in three categories (i.e., low, moderate, and high).

Due to higher uncertainties associated with directional drilling and Ranney well installations, the potential ranges of relative costs for these wells were estimated. During groundwater remediation relative unit costs for noncapital components are expected to increase with time. The reasons for the increases include older equipment and a heavier share of administration costs assigned to the Aquifer Restoration Project when the number of other ongoing remediation projects at the FEMP gradually decreases. Therefore, the relative unit costs for four components (i.e., O&M costs for extraction and injection wells, groundwater treatment, and groundwater monitoring) are estimated separately for the first 10 years and beyond.

TABLE 4-9

ESTIMATED RELATIVE UNIT COSTS OF MAJOR COMPONENTS

Components	Relative Costs
1 On-property vertical extraction well (including pump and piping)	1 ($500,000)[a]
1 Off-property vertical extraction well (including condemnation, pump and piping)	2
1 Vertical injection well (including piping)	0.75
1 Horizontal extraction well (by directional drilling, including pump and piping)	4.5 - 6
1 Ranney well (including pump and piping)	7.5 - 10
1 Additional horizonal section from a Ranney well (including pump and piping)	4 - 6
O&M per extraction well per year (Years 0-10/11-)	0.07/0.1
O&M per injection well per year (Years 0-10/11-)	0.035/0.05
Expansion of groundwater treatment capacity to 2000 gpm	7.5
1 250-gpm mobile groundwater treatment module	3
Groundwater treatment per year (Years 0-10/11-)	6/8
General groundwater monitoring and reporting per year (Years 0-10/11-)	2/3

[a] Estimating unit

4.3.1.2 Scenario-Specific Relative Cost

Using the relative unit costs listed in Table 4-9 as well as component specifications, cleanup times, and required groundwater treatment capacities summarized in Section 3.0, the scenario-specific relative overall costs (without inflation) are listed in Table 4-10 (in units of $500,000). To simplify the cost estimation process, the effects of installation timing, escalation, and potential interest savings are not considered. The potential impacts from these simplifying assumptions on the relative cost are considered small given the shorter durations of the groundwater remediation scenarios. Such simplifying assumptions are also consistent with DOE's programmatic evaluations of the long-term cost savings that may accompany implementation of the Ten Year Vision. As shown in Table 4-10, the annual groundwater treatment cost is assumed to be independent of treatment flow rates. More details of the cost calculations are included in Appendix C. Although all the simplifications are considered reasonable, these cost estimates are only intended for ranking and strategy selection purposes instead of detailed budgeting purposes.

TABLE 4-10

SUMMARY OF THE ESTIMATED SCENARIO-SPECIFIC RELATIVE COSTS[a]

Cost	Remediation Scenario			
	25-Year	15-Year	10-Year	7.5-Year
Capital				
Well, pump, piping	35	40	45	53
Treatment	15	9	7	20
Well operation & maintenance	25	17	14	7
Treatment operation & maintenance	140	60	54	45
Monitoring/Reporting	65	35	20	15
Total	280	160	140	140 - 150

[a]Estimating unit is $500,000

The number of significant digits used in the cost calculations presented in Appendix C may be misleading regarding the expected accuracy of the overall cost estimates. Due to the inherent uncertainty of the relative unit costs (see Table C-1 of Appendix C), the scenario-specific overall costs may be rounded to 280, 160, 140, and 140-150 units for the 25-Year, 15-Year, 10-Year, and 7.5-Year Scenarios, respectively. These rounded relative overall costs only reflect the uncertainty associated with the unit costs. Potential uncertainty of the overall remediation cost due to uncertainty of the actual cleanup time achievable by the selected baseline remedial strategy is evaluated in Section 5.3.2 and Appendix F.

Figure 4-5 shows the relationship between cleanup time and relative costs for the four evaluated scenarios. Capital and O&M costs (including well O&M, treatment O&M and monitoring/reporting) are plotted separately. An average capital cost for well, pump, and piping in the 7.5-year scenario (i.e., 57.5) is used in the figure. The cost trend for scenarios with cleanup times less than 7.5 years is shown by the dashed lines from 5 years to the first data point at 7.5 years. As shown in the figure, a longer cleanup time means lower capital but higher O&M costs; a shorter cleanup time means higher capital but lower O&M costs; and a cleanup time around 10 years results in the optimal overall remediation cost. In the optimal-cost scenario, the capital and O&M portions of the overall remediation costs are about 40 and 60 percent, respectively. When the O&M or the capital cost

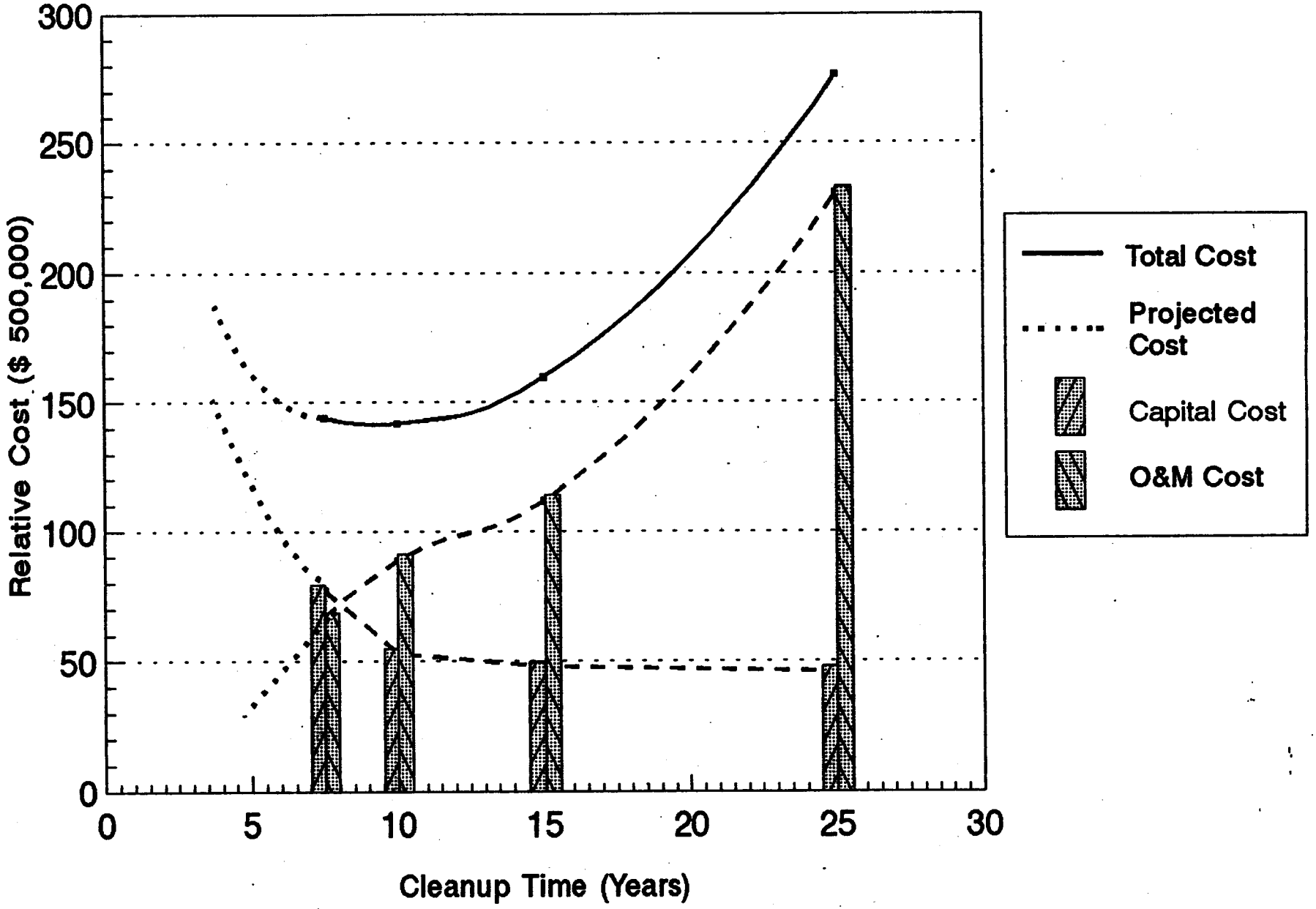

FIGURE 4-5. CONCEPTUAL COST COMPARISON

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exceeds 40 percent, the overall remediation cost becomes higher than the optimal cost. It is important to note that the cost increases are more significant in scenarios with longer cleanup times.

4.3.2 Implementation Risk and Uncertainty

In addition to the cost, other factors that may affect the implementability of a groundwater remediation scenario need to be understood when selecting the final remedial strategy. Minimizing the selected strategy's unavoidable implementation risks and uncertainties should be emphasized during the design process. When the selected strategy cannot be implemented due to unforeseen reasons, an alternative should be readily available for implementation. In general, the four remediation scenarios evaluated provide a sufficient range of potentially implementable alternatives that satisfy all the commitments.

4.3.2.1 Source-Area Remediation Schedule

Because the 10-year site-wide remediation plan is very aggressive, the possibility of significant delays in the schedule is considered moderate (i.e., 50/50). Under this situation the scenarios which rely on additional vertical extraction wells inside the excavated zones (i.e., the 15-year and 10-year scenarios) may not achieve the predicted cleanup times and become impractical. Implementabilities and performances of the 25-year and 7.5-year scenarios are less sensitive to the soil remediation schedule because no wells need to be installed in the excavation zones.

4.3.2.2 Treatment Capacity and Efficiency

Sufficient groundwater treatment capacity needs to be available before certain proposed groundwater extraction and/or injection rates can be implemented. This is especially important during the first few years when large volumes of contaminated groundwater with higher concentrations will be extracted. The treated groundwater concentrations also need to be sufficiently low (as assumed in the modeling) so the projected treatment capacity is sufficient for maintaining acceptable outfall concentrations and for supplying source water for injection wells.

During groundwater remediation, if the treatment capacity and/or efficiency are significantly lower than currently expected, the extraction/injection pumping rate schedules may need to be reduced in order to maintain low outfall concentrations. These modifications will result in longer cleanup and treatment times than originally predicted.

The possibility of a significant schedule delay for bringing the expanded AWWT capacity of 1800 gpm on-line is low. With the expansion of the AWWT facility on-line, the total effective capacity for treating groundwater will be assumed to be 2000 gpm. However, the chance of getting any additional capacity by adding mobile treatment modules is also very low. A potential compromise is to use capacity freed up from surface water treatment for groundwater treatment during drier seasons. However, this will require schedule changes and lower extraction and/or injection rates for remediation scenarios which require higher treatment capacities. The possibility of lower treatment efficiency, resulting in higher treated groundwater concentrations (> 5 ppb), is currently considered moderate.

4.3.2.3 Well Design and Installation

The overall performance of any groundwater remediation system is highly dependent on the proper design, installation and operation of all the required extraction and injection wells. Risk and uncertainty related to design and installation of the three types of wells evaluated in this study are summarized below. In general, other than the vertical extraction wells, there are many lessons and issues which need to be learned and resolved for the injection wells and the horizontal extraction wells.

- Vertical Extraction Well - Sufficient experience with vertical extraction well design and installation exists at the FEMP. Hydrogeological conditions at proposed well locations that may affect installation have been properly characterized. However, uncertainties in groundwater contaminant concentrations and plume thicknesses at these locations still remain and may not be confirmed until the wells are installed. Installation schedules for wells in areas requiring soil remediation will depend on the actual completion date of the remediation.

- Injection Well - Design and maintenance procedures for an injection well with a long-term efficiency have not been completed. Injection-specific hydraulic conditions as well as plugging need to be considered during the design process. The currently assumed groundwater injection rates may not be achievable if the injection well is not properly designed and maintained.

- Horizonal Extraction Well - Although the potential benefits of horizontal wells are very significant, the costs and risks associated with them are also very high. Design and installation of a horizontal well is considerably more complicated than a vertical well. In order to achieve high pumping capacity and long operational life, more detailed analysis of the geological conditions and even pilot-scale field tests may be required to properly design the horizontal wells based on the site-specific conditions. A much higher chance of installation problems with a horizontal well can also be expected. An insufficient capacity and/or a short operational life may result from improper installation procedures.

4.3.2.4 Operation and Maintenance

A perfectly designed and installed hardware system does not automatically result in successful groundwater remediation. Proper O&M of the system are as important as the hardware system. The role and contents of an Operations and Maintenance Plan for the aquifer restoration system are being defined (as Task 2 of the Operable Unit 5 RD Work Plan). This plan will address all the important issues considered and resolutions obtained during the design and installation processes which may affect the system's performance. System operation, monitoring, adjustment, and maintenance needs to be closely integrated. In order to ensure the success of aquifer restoration, guidelines for the key activities listed below need to be defined.

- System Performance Monitoring - Aquifer, wellhead, and outfall contaminant concentrations as well as the injection and treatment efficiencies need to be monitored. All the decisions to be made during groundwater remediation will rely on these monitoring results. Frequency, locations, and parameters for performance monitoring need to be properly selected.

- Treatment Decision - Because treatment capacity is limited, extracted groundwater from the right wells needs to be treated in order to maintain the acceptable outfall concentrations; wells showing higher concentrations should obviously have priority for treatment. Available capacity freed up from surface or other remediation- generated water treatments should also be used to treat groundwater when possible.

- Groundwater Injection - Only treated groundwater and extracted groundwater with wellhead concentrations less than 20 ppb can be injected. Full benefits of groundwater injection can only be achieved by obtaining a sufficient amount of acceptable water and maintaining high hydraulic efficiency of the injection wells. In order to operate within the maximum allowable net extraction rate, groundwater extraction needs to be throttled down when the actual injection rate is lower than currently assumed.

- System Adjustment - The well pattern and extraction/injection pumping rate schedule specified in the remedial strategy are developed by conducting groundwater model simulations. Although groundwater models are the only tool available for developing the remedial strategy, it is important to note that all groundwater models have limitations when simulating the real world conditions. Assumptions and simplifications regarding the modeled physical and chemical processes may lead to inaccurate model predictions. Therefore, operation of the remediation system should have sufficient flexibility in order to handle unexpected conditions. Frequent adjustments of the extraction/injection pumping rate schedule, monitoring of performance, frequency, locations and treatment decisions may be necessary to maintain the desired system performance.

- System Maintenance and Rehabilitation - All hardware components in the groundwater remediation system will require routine maintenance in order to prevent their deterioration. Extraction and injection wells may need periodic rehabilitation in order to recover their efficiency.

4.3.2.5 Geochemical Conditions

On average the assumed uranium K_d values during groundwater remediation are considered realistic. Potentially the uranium K_d value may further increase above 17.8 L/kg resulting in lower uranium mobility. However, the estimated groundwater cleanup time will not change significantly due to lower groundwater concentrations because less uranium mass will be desorbed under higher K_d values. Timing of the transition from lower K_d value to higher K_d values should be closely monitored by evaluating mass removal efficiencies in the extraction wells. This timing is important for determining when to start groundwater injection north of the South Field in the 15- and 10-year scenarios.

As a critical component in all the groundwater remediation scenarios evaluated in this report, the feasibility of groundwater injection remains to be confirmed. Although water can be injected into the aquifer without much initial resistance, the problem of iron precipitation and subsequent plugging of the well-screen as described in the draft South Field Injection Test Report (DOE 1995d) needs to be resolved. An O&M procedure that can ensure long-term efficiency and injectivity of the injection wells is necessary. This procedure may include additional pretreatment for injection water and/or periodic rehabilitation of the injection wells. The second short-term injection test which used treated groundwater showed promising results.

4.3.3 Selected Preliminary Baseline Strategy

Based on the overall relative costs listed in Table 4-10 and risk/uncertainty information discussed in Section 4.3.2, the 10-year scenario is selected as the baseline groundwater remediation strategy for the remedial design process. The main reasons for this selection include:

- Overall relative cost is lower
- Capital cost for well installation is distributed over 7 years
- Piping network complexities due to the additional extraction wells are considered manageable
- No additional treatment capacity beyond the planned AWWT facility expansion is necessary
- The only higher risk and uncertainty associated with this scenario when compared to the other three scenarios is the soil remediation schedule.

The 7.5-year scenario was not recommended due to the significantly higher up-front capital cost (i.e., 70 to 84 cost units) and high risks associated with horizontal well installation. However, if current

funding projections or technical constraints were to indicate that the source-area remediation will be delayed for more than 5 years and sufficient groundwater funding is available, then the 7.5-year scenario could potentially be justified. As shown in Table 4-10, the estimated higher end of the overall cost of the 7.5-year scenario is slightly lower than that of the 15-year scenario. This indicates that when the groundwater cleanup time exceeds 15 years when using only vertical extraction wells, using horizontal wells to reduce the cleanup time becomes a much more competitive alternative. It is important to note that the window of opportunity for initiating the horizontal well alternative is within the next 2 years in order to realize any significant reductions of groundwater cleanup time and overall cost.

4.3.3.1 Modifications to The FS Strategy

When compared to the remedial strategy presented in the Operable Unit 5 FS Report, the following modifications have been included in the selected preliminary baseline strategy:

- Groundwater injection along the fence line and north of the South Field will be used to improve hydraulic performance of the remediation system. The fence line system (converted from Wells 8 through 12 in the FS Strategy) will start operation within 3 years while the upgradient system (5 new injection wells) will start at the end of the 7th year.
- Well 17 in the FS Strategy is moved to a new location north of the SSOD.
- Well 22 in the FS Strategy is reserved as a contingent well and its location will be selected during remediation if determined necessary.
- Four additional off-property extraction wells and two of the existing South Plume wells will be used to optimize the South Plume Recovery Well System.
- Nine more vertical extraction wells in the inactive flyash pile, four more vertical extraction wells in the waste pit area, and one more vertical extraction well in the Plant 6 area will be installed and operated immediately following completion of local surface remediation.
- Three of the initial extraction wells around the inactive flyash pile will be converted into injection wells after the new extraction wells are installed.

Overall 46 wells (i.e., excluding Well 22) are included in the selected preliminary baseline strategy. The number of wells is 18 more than the number in the FS Strategy.

4.3.3.2 Groundwater Treatment Capacity

No groundwater treatment capacity above the planned 2000 gpm is necessary in the new baseline strategy. Appendix D describes the existing and currently planned treatment modules in the overall

FEMP wastewater treatment system. The bulk of the dedicated groundwater treatment capacity will come from the AWWT facility expansion with its downrated capacity of 1500 gpm. Fifty percent of the downrated AWWT - Phase I capacity of 600 gpm (i.e., 300 gpm) will be dedicated to groundwater treatment. The interim AWWT (IAWWT) units will provide 350 gpm of dedicated groundwater treatment capacity annually. The South Plume interim treatment system is predicted to continue its good performance at 200 gpm for groundwater treatment. However, certain upgrades and/or modifications to the AWWT - Phase I and the IAWWT will be necessary. In summary, according to the current plan, over 2000 gpm of dedicated groundwater treatment capacity with an average effluent uranium concentration of 5 ppb will be available by the end of 1997.

4.3.3.3 Predicted Hydraulic Impacts and Uranium Plumes

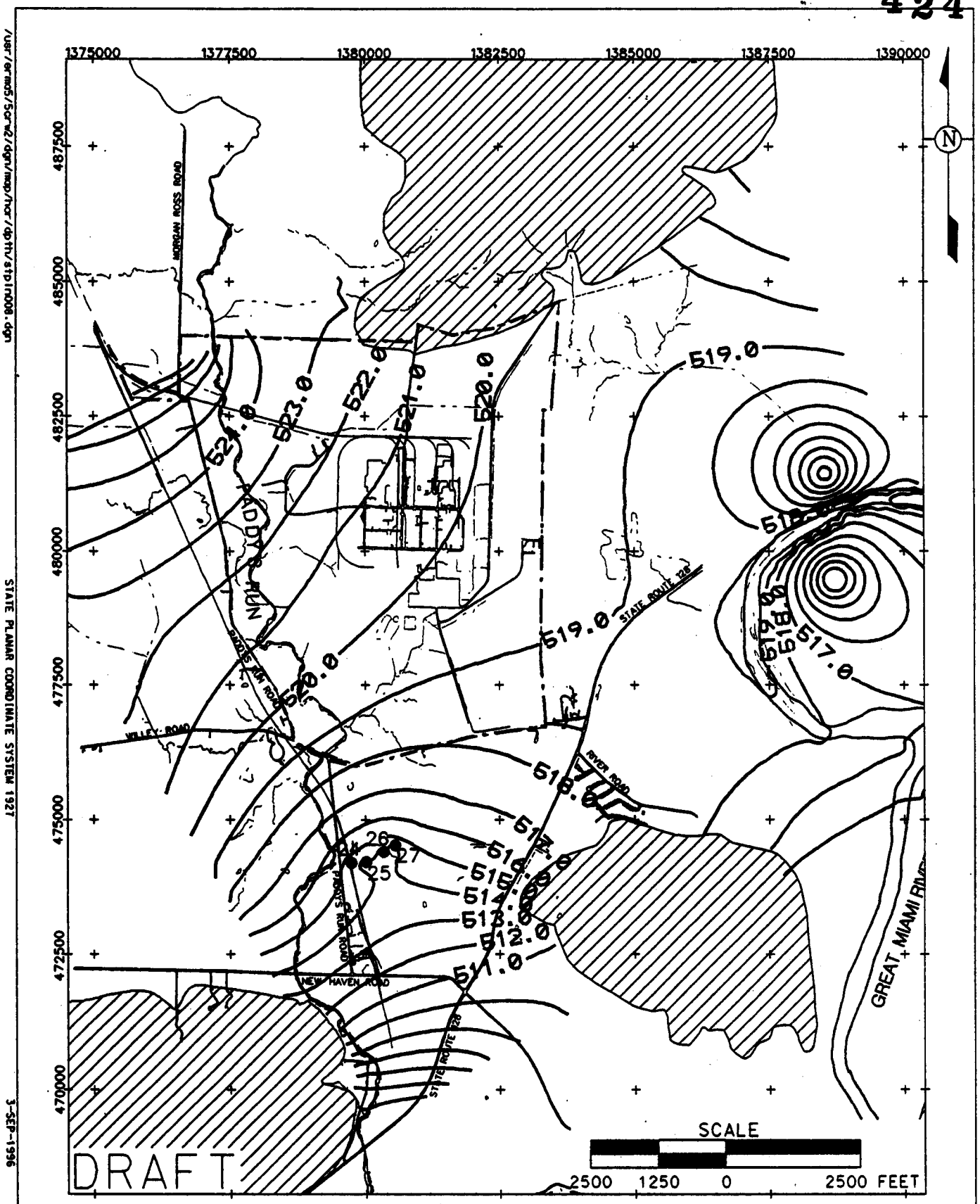
Figures 4-6 through 4-8 show the modeled groundwater flow patterns under the selected preliminary groundwater remediation strategy. Corresponding groundwater drawdown contours are shown in Figures 4-9 through 4-11. Groundwater and uranium capture zones with and without retardation resulting from this remedial strategy are presented in Figures 4-12 and 4-13. The projected uranium concentration contours are shown in Figures 4-14 through 4-16.

4.3.3.4 Aquifer Restoration Modules

In the preliminary baseline remedial strategy, the aquifer remediation would be accomplished through the six aquifer restoration modules shown on Figure 4-17. Each module consists of from 2 to 22 extraction and/or injection wells.

The existing South Plume extraction wells were installed and began operation in 1993 as part of a removal action to stop the further southward migration of the off property portion of the uranium plume. The module currently operates with four wells pumping at a combined rate of 1400 gallons per minute.

The South Plume Optimization Module consisting of 4 proposed extraction wells will be installed off property south of the FEMP to restore the off-property portion of the uranium plume quickly and cost effectively. The location and final number of wells will be finalized upon completion of negotiations with the affected landowner.



LEGEND:

— · — · — FEMP BOUNDARY

● EXTRACTION WELL

511.0 GROUNDWATER ELEVATION CONTOURS (FEET ABOVE msl)

FIGURE 4-6. GROUNDWATER ELEVATIONS FOR 10-YEAR SCENARIO, YEARS 0 - 2

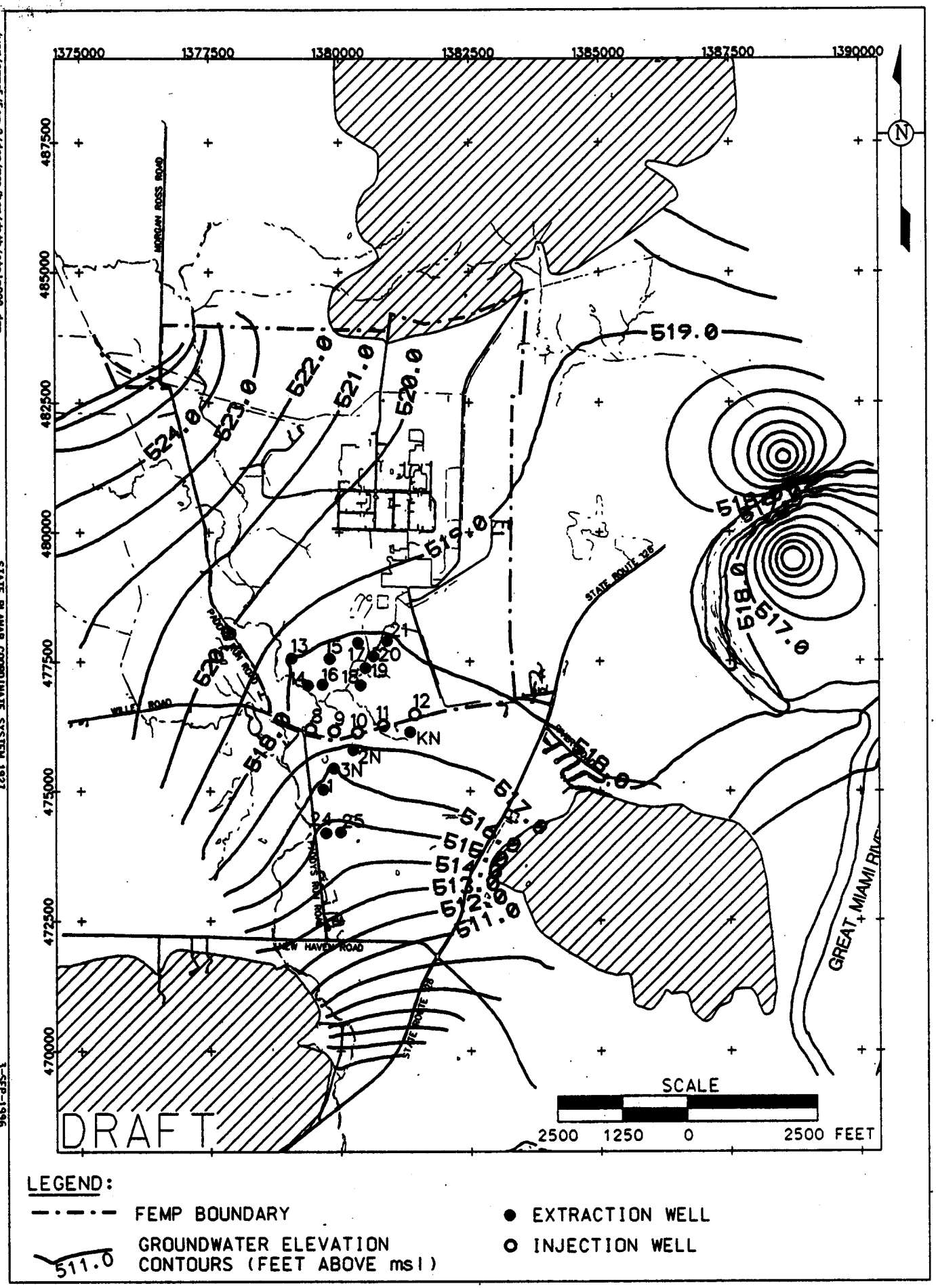
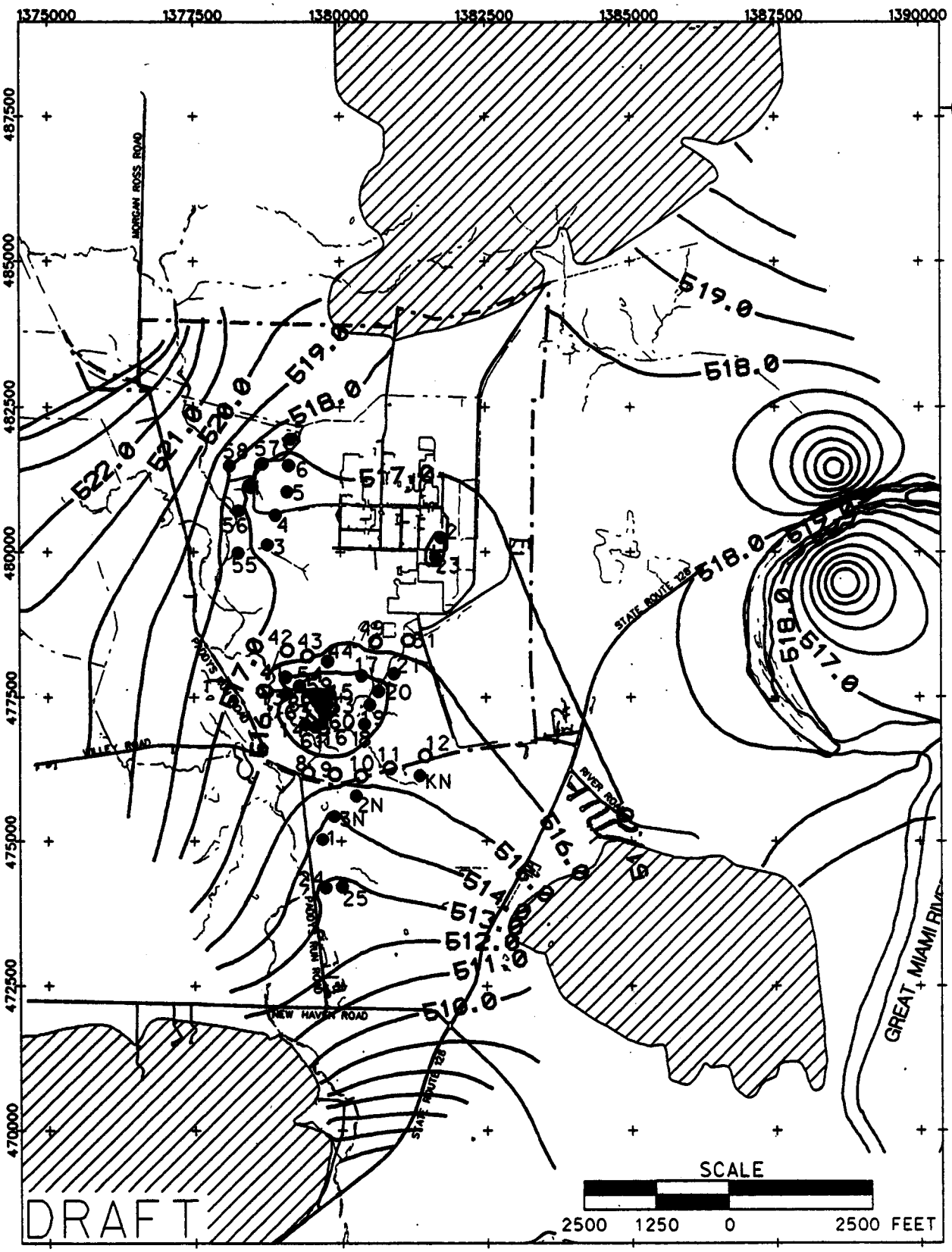


FIGURE 4-7. GROUNDWATER ELEVATIONS FOR 10-YEAR SCENARIO. YEARS 3 - 7

/usr/ermo5/5cr.w2/dgn/map/hor/dpthv/stp1n009.dgn
STATE PLANAR COORDINATE SYSTEM 1927
3-SEP-1996



LEGEND:

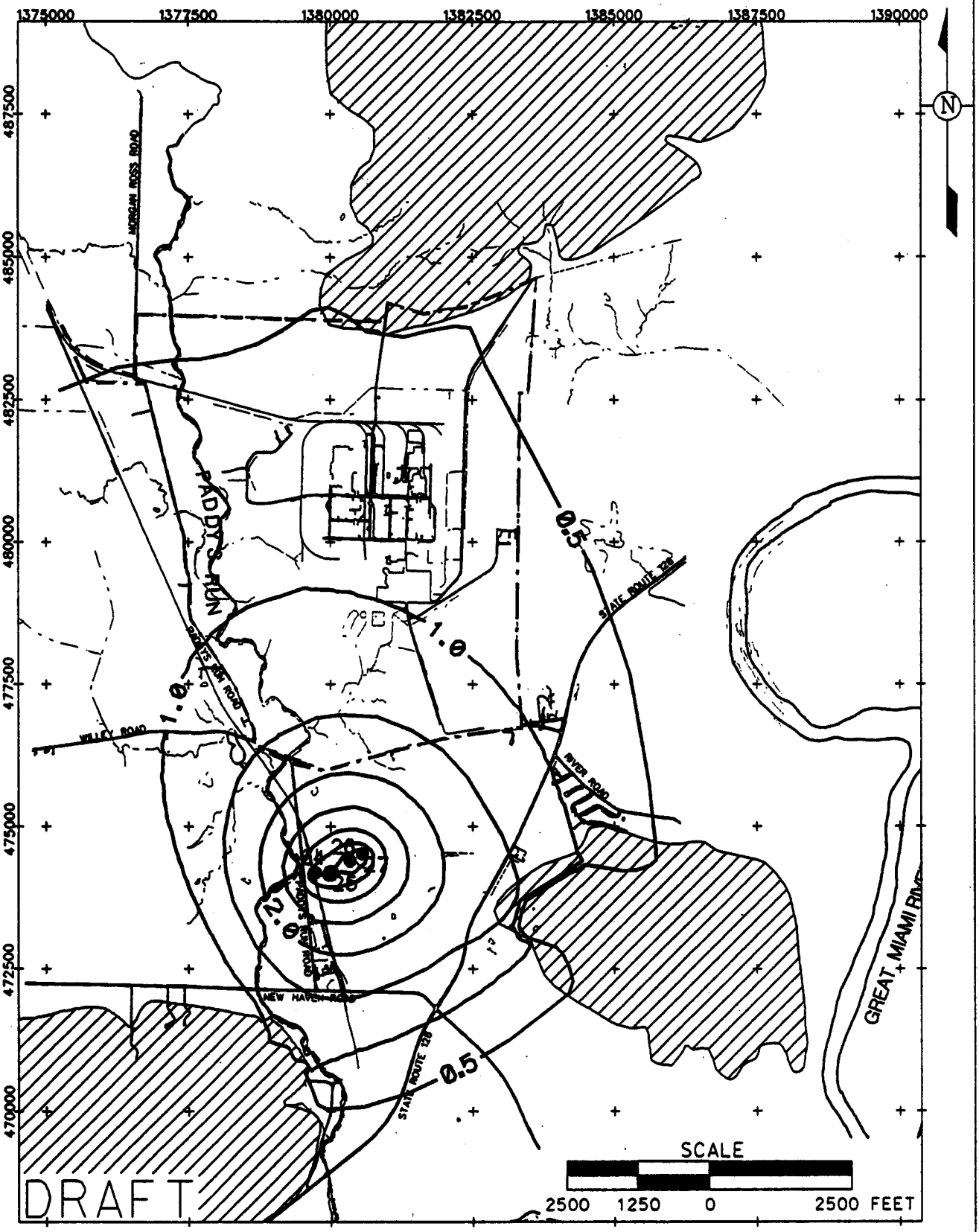
- FEMP BOUNDARY
- GROUNDWATER ELEVATION CONTOURS (FEET ABOVE msl) — 511.0
- ● EXTRACTION WELL
- ○ INJECTION WELL

FIGURE 4-8. GROUNDWATER ELEVATIONS FOR 10-YEAR SCENARIO. YEARS 8 - 10

/usr/armd5/Scr42/dgn/map/hor/dpitv/stpln010.dgn

STATE PLANAR COORDINATE SYSTEM 1927

3-SEP-1996



LEGEND:

FEMP BOUNDARY

DRAWDOWN IN GROUNDWATER ELEVATION (FT.)

● EXTRACTION WELL

FIGURE 4-9. DRAWDOWN CONTOURS, 10-YEAR SCENARIO, YEARS 0 - 2

/usr/armd5/scr02/dgn/map/hor/dpth/stp1n011.dgn
STATE PLANAR COORDINATE SYSTEM 1927
3-SEP-1996

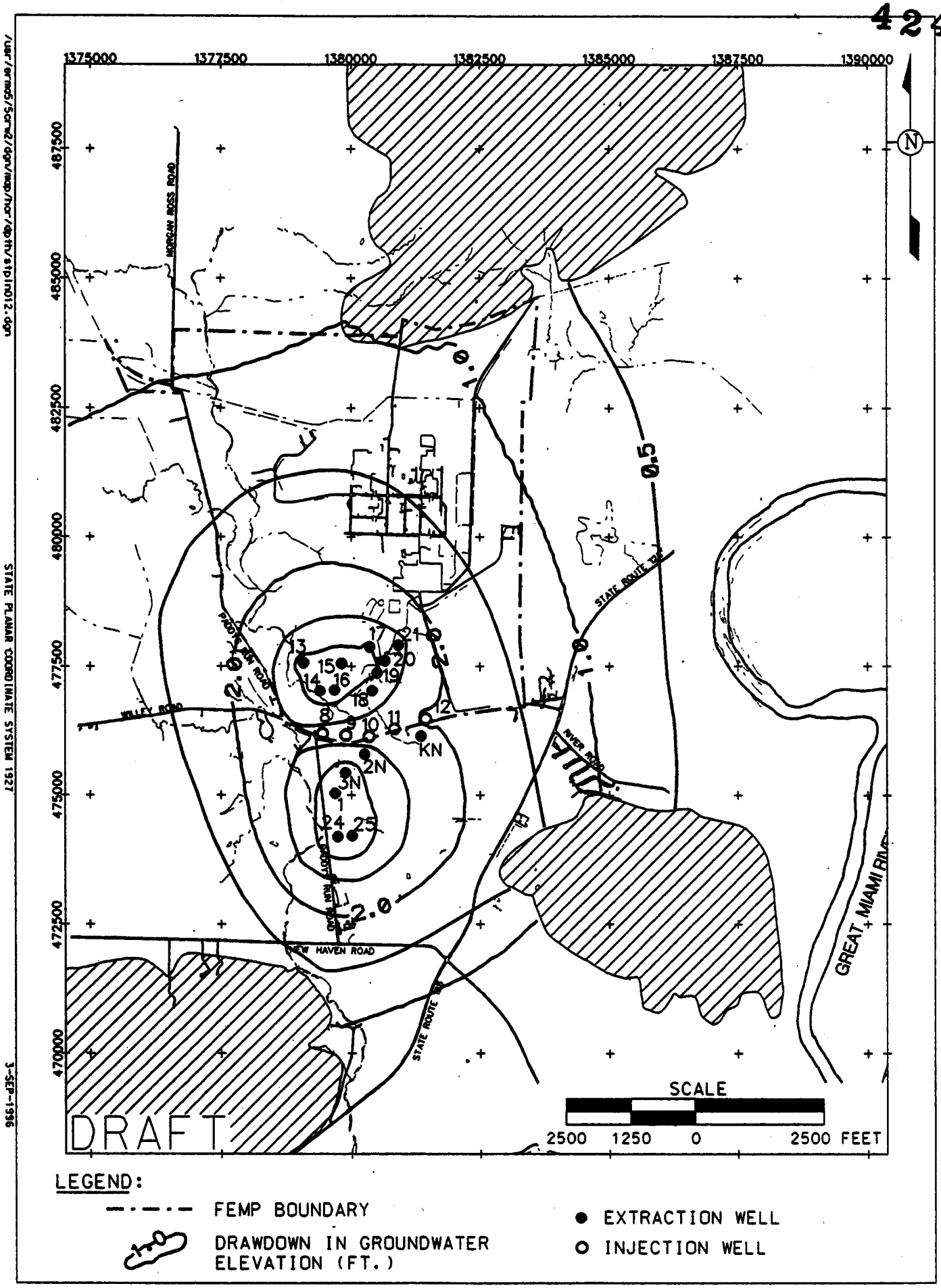


FIGURE 4-10. DRAWDOWN CONTOURS. 10-YEAR SCENARIO. YEARS 3 - 7

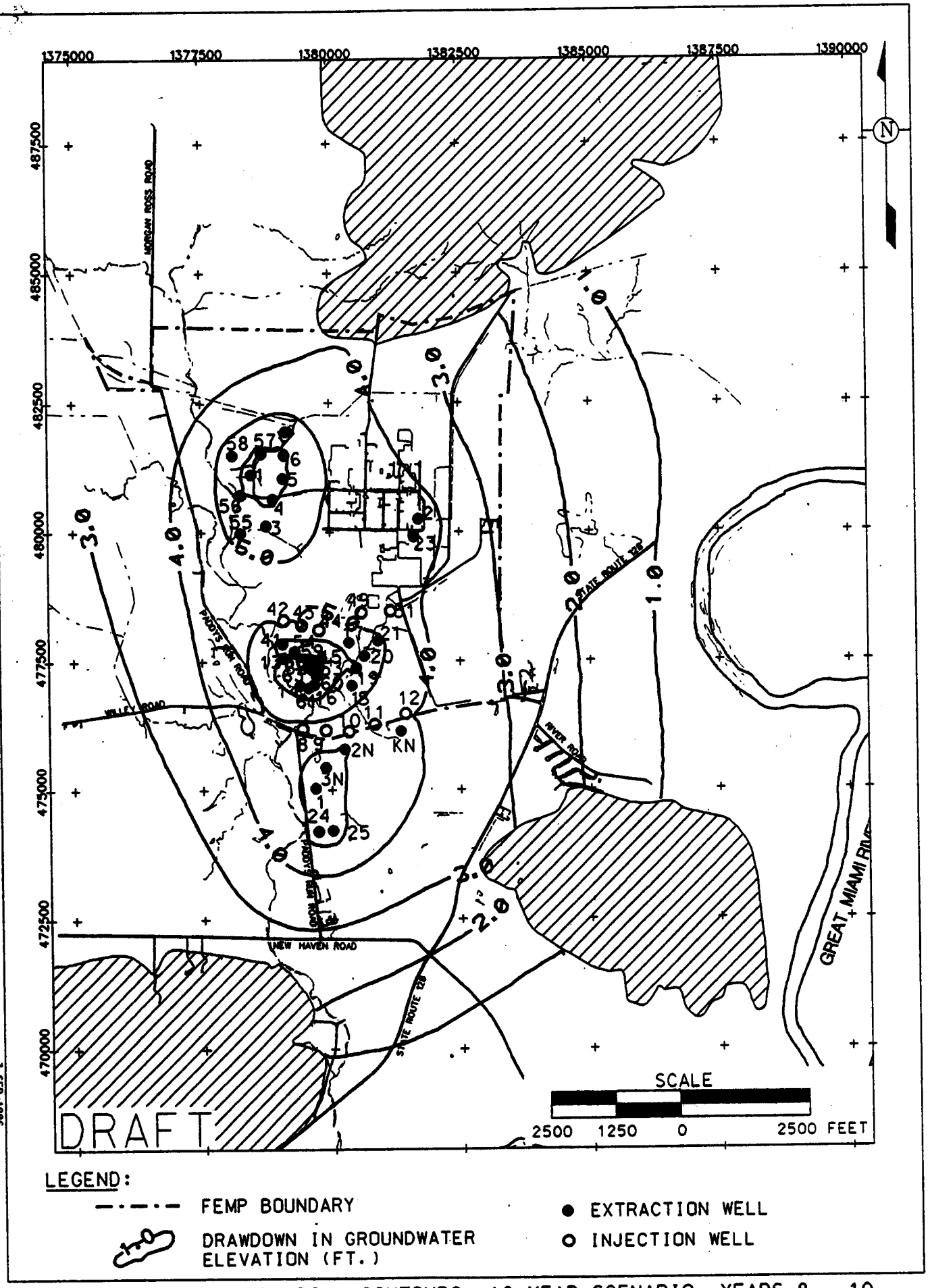


FIGURE 4-11. DRAWDOWN CONTOURS, 10-YEAR SCENARIO, YEARS 8 - 10

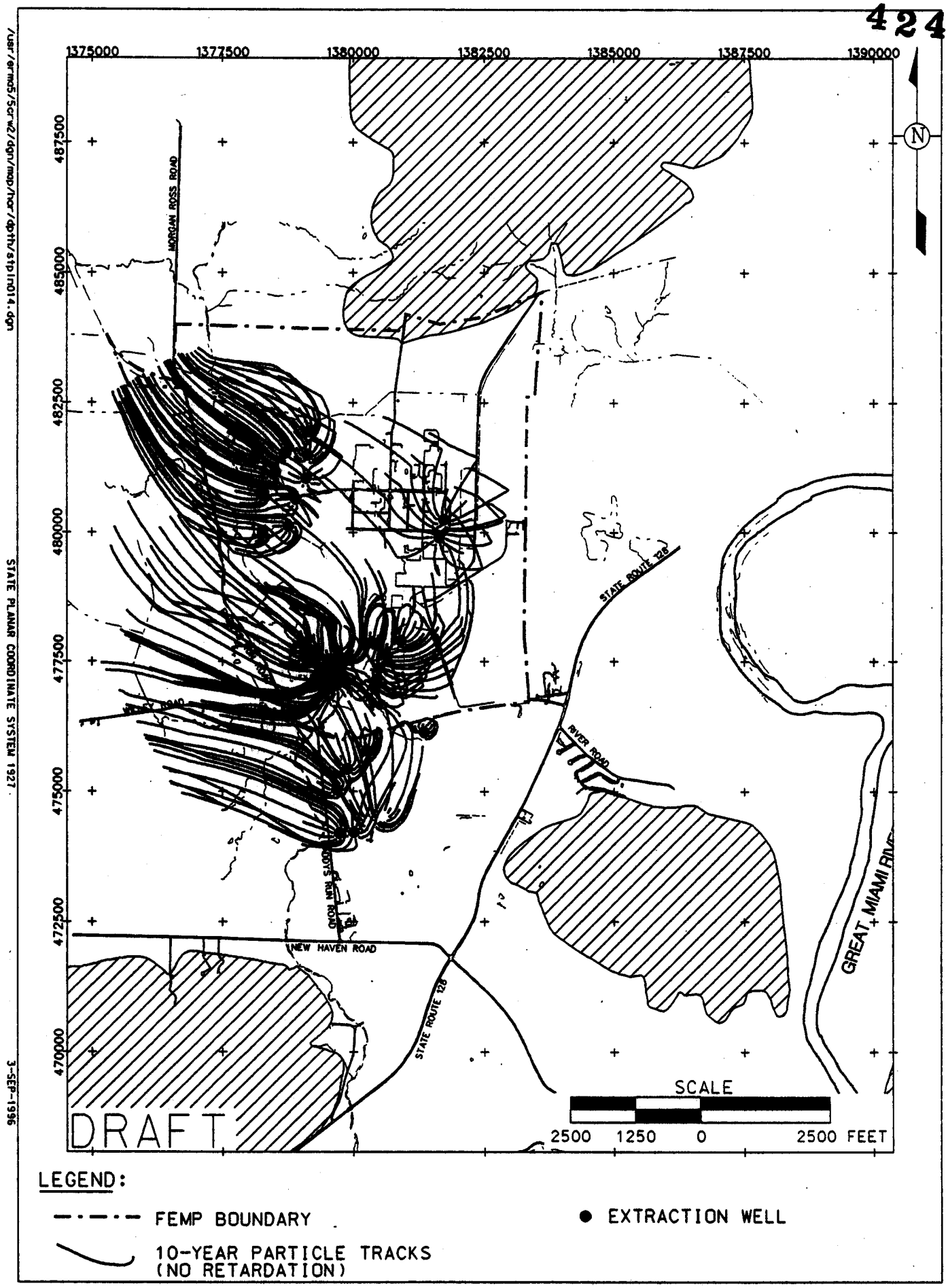


FIGURE 4-12. CAPTURE ZONE, 10-YEAR SCENARIO, NO RETARDATION

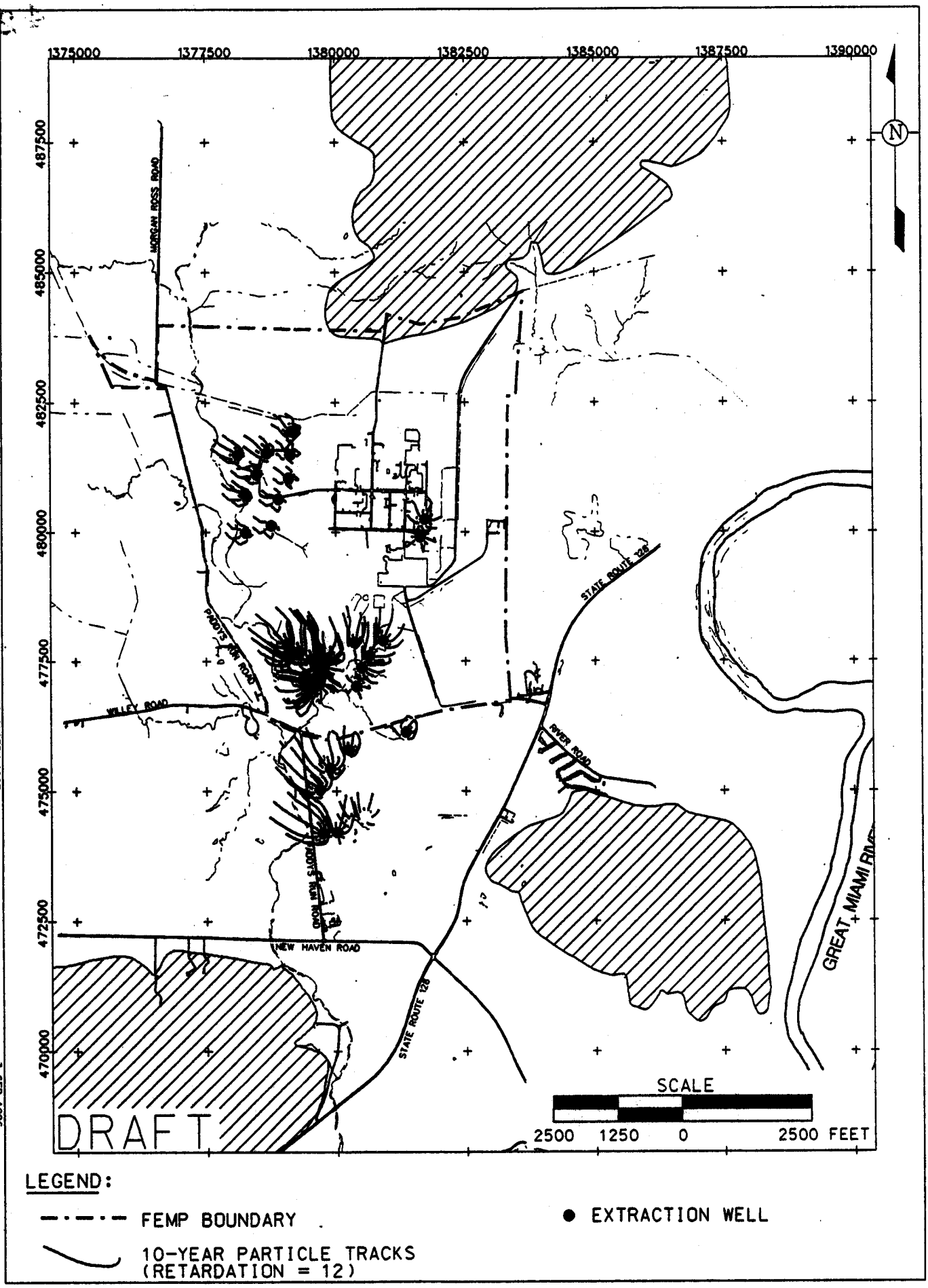


FIGURE 4-13. CAPTURE ZONE, 10-YEAR SCENARIO, RETARDATION=12

/usr/ermd5/scrn2/dgn/map/hor/dpftv/stplrn015.dgn

STATE PLANAR COORDINATE SYSTEM 1927

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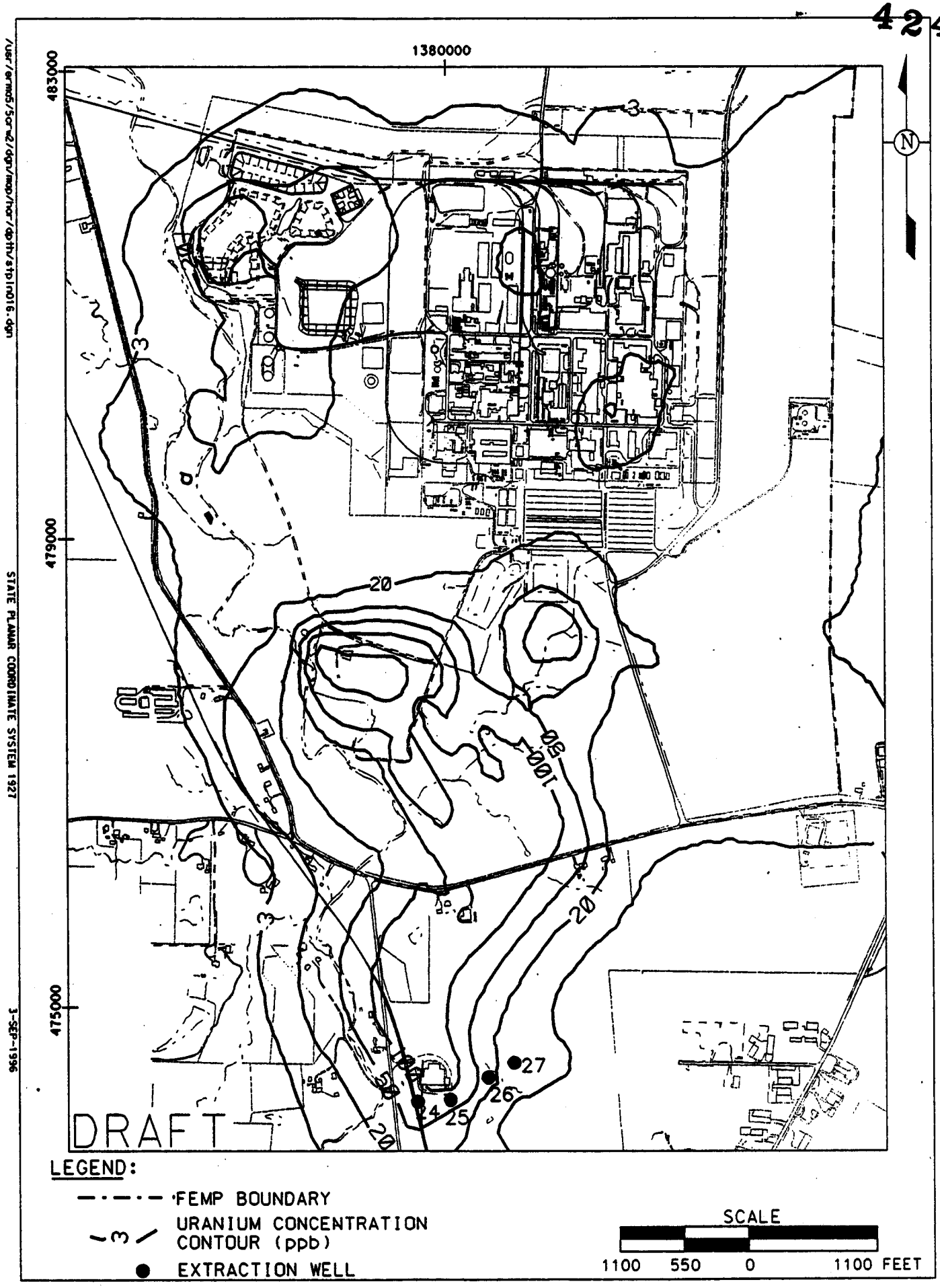


FIGURE 4-14. URANIUM CONCENTRATIONS AND PUMPING WELLS FOR 10-YEAR SCENARIO, YEAR 2

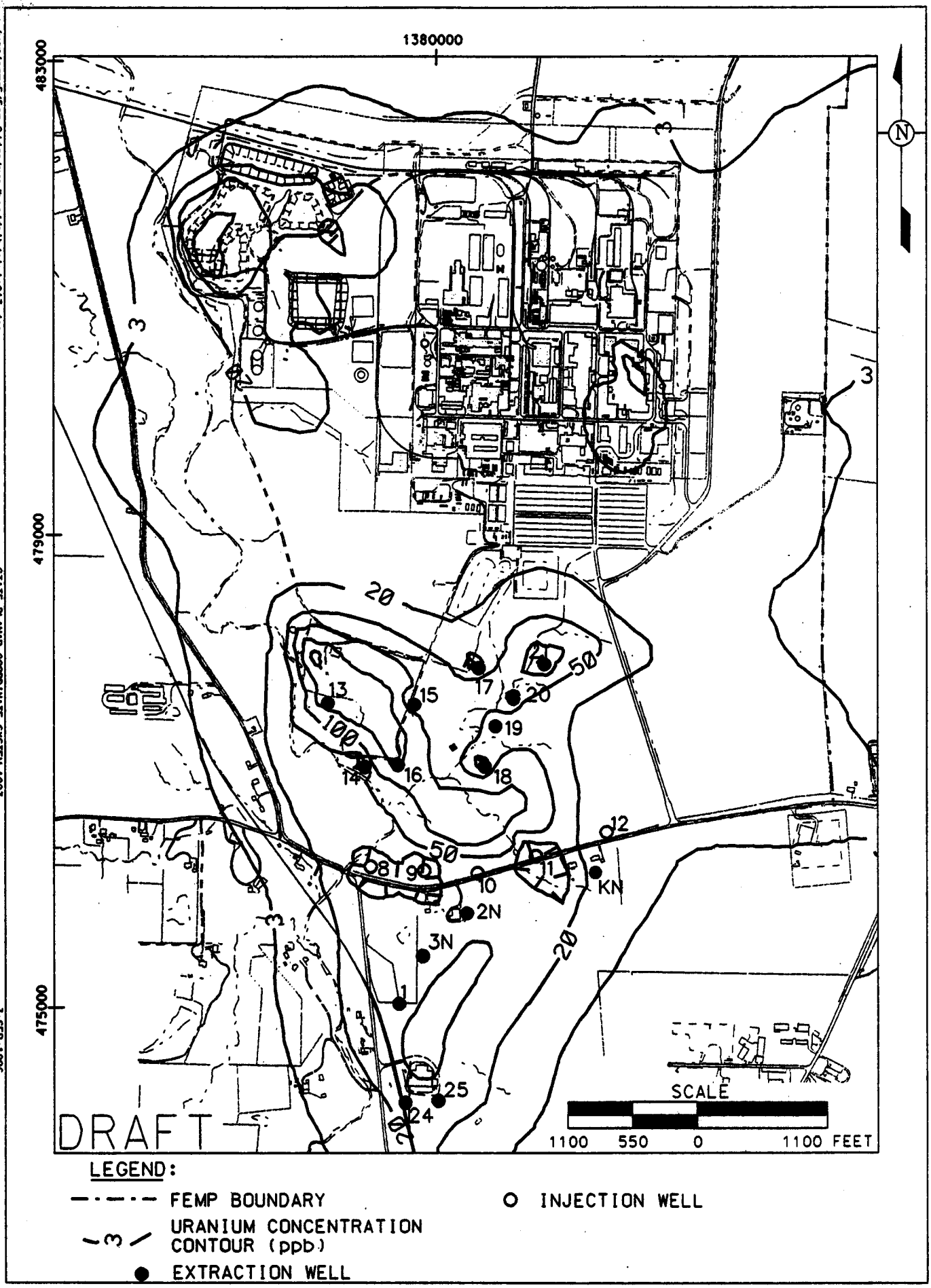


FIGURE 4-15. URANIUM CONCENTRATIONS AND PUMPING/INJECTION WELLS FOR 10-YEAR SCENARIO, YEAR 7

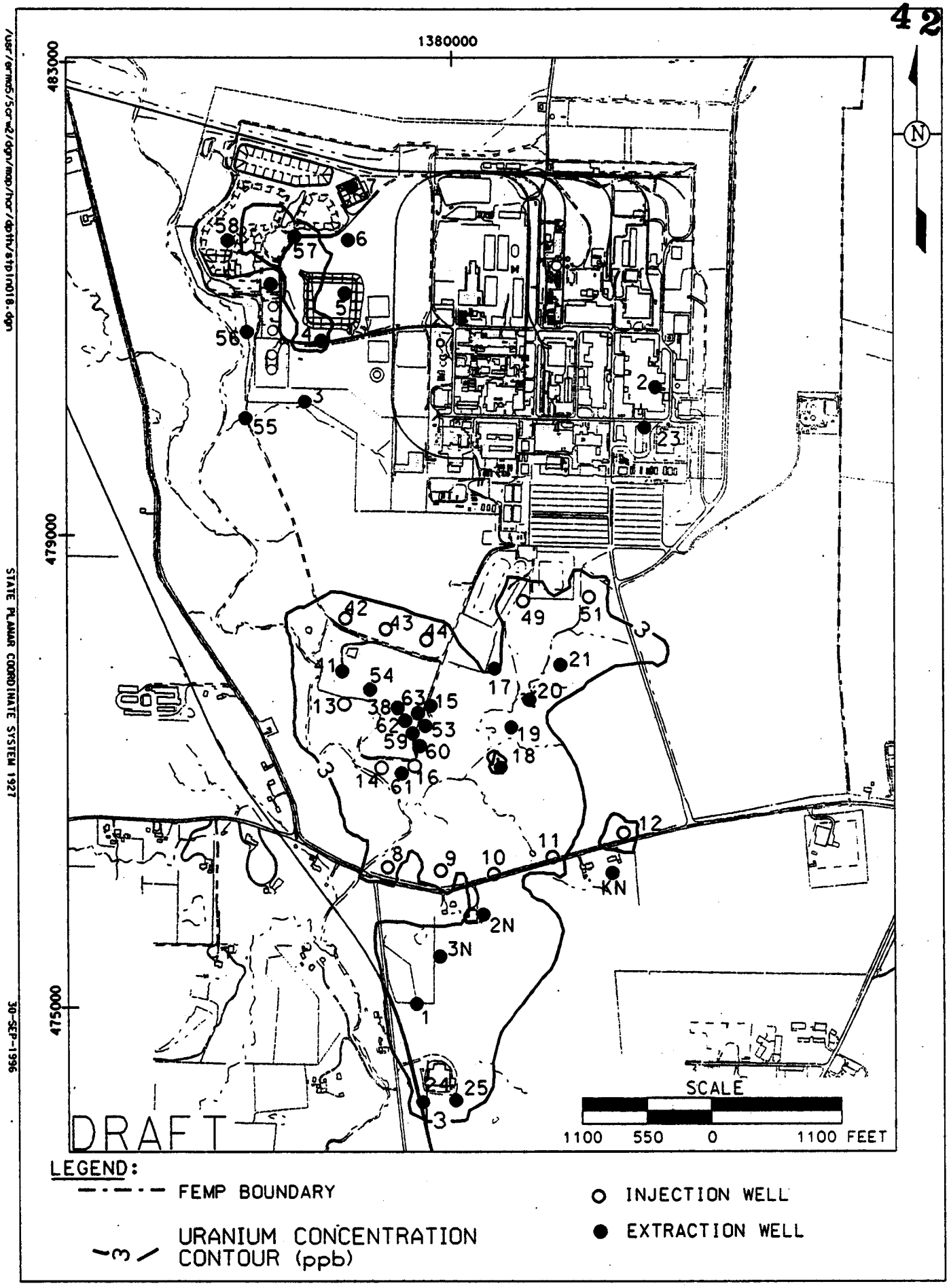


FIGURE 4-16. URANIUM CONCENTRATIONS AND PUMPING/INJECTION WELLS FOR 10-YEAR SCENARIO, YEAR 10

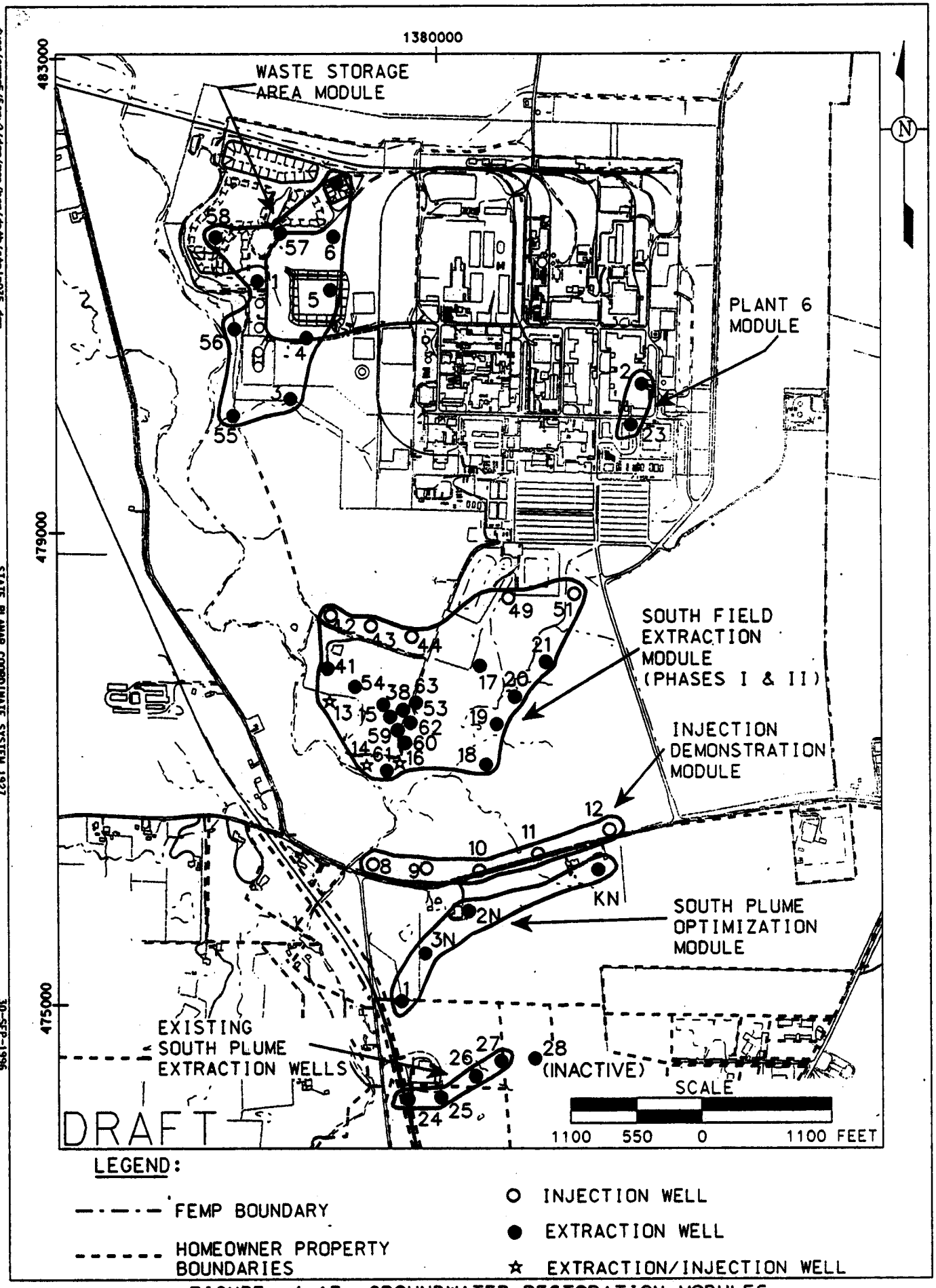


FIGURE 4-17. GROUNDWATER RESTORATION MODULES

The Injection Demonstration Module along the southern fenceline of the FEMP consists of five on property injection wells which will help to speed the off property clean up of the uranium plume and help to block further off property plume movement through the establishment of a hydraulic barrier. Treated groundwater will be re-injected into the aquifer at 200 gpm per well for a total injection rate of 1000 gpm in this module.

The South Field Module (Phase I) consists of 9 on property extraction wells which are currently installed but which will not begin pumping until associated piping is completed. After surface excavations in the South Field area are completed in 2003, an additional eight extraction wells and five up gradient injection wells (Phase II) are scheduled to be installed to speed the aquifer restoration in this area. The South Field Module (Phases I and II) will pump the majority of the groundwater to be extracted from the aquifer because this area has the highest uranium concentrations on site.

The Waste Storage Area Module consists of ten extraction wells which will become operational in 2004 after surface excavations are complete. These wells will pump contaminated groundwater from beneath what were the waste pits for the production operations at the FEMP.

Finally, the Plant 6 Area Module consists of two extraction wells which will become operational in 2004 after Plant 6 has been removed. These two wells will pump uranium contaminated groundwater from beneath this area.

4.4 SUMMARY OF OTHER IMPORTANT FINDINGS IN THE PRELIMINARY EVALUATIONS

Other important findings not specifically discussed in the previous sections are presented in this section. These findings will also be considered when finalizing the baseline remedial strategy.

4.4.1 Optimal Extraction Well Location

Mass removal efficiency of the groundwater extraction well can be greatly improved when installed in the hot spots instead of along the edge of groundwater plume. However, due to the soil remediation activities in the source areas, installation of extraction wells in the hot spots can not be initiated until completion of the soil remediation.

The total mass required to be recovered from the aquifer in order to achieve the concentration-based cleanup goal is lower when more extraction wells are located directly in the hot spots. Consequently,

a shorter cleanup time, a less extracted groundwater volume, and less contaminant mass discharged to the Great Miami River can be achieved.

In order to maximize the recovery efficiency, certain off-property extraction wells may need to be located close to private houses or farming facilities. These preferred locations may not be obtainable because of landowner constraints, and secondary locations may be required.

4.4.2 Effects of Groundwater Injection

Groundwater injection along the southern property line can effectively stop further migration of the on-property portion of contaminant plume into the off-property area. The stagnation zone in the off-property area which exists in the FS strategy can be effectively eliminated by injection along the southern fence line. Groundwater injection can also permit higher groundwater extraction rates while not exceeding the net extraction rate limit of 4000 gpm. Therefore, the groundwater flushing rate through the contaminated zone can be increased.

Modeled plume expansions in both the horizonal and vertical directions due to groundwater injection are not significant. However, proper coordination between extraction and injection operations should be maintained to prevent any significant expansion during remediation. Additional deeper monitoring wells around the injection wells may also need to be installed.

4.4.3 Groundwater Treatment Decision

Under the groundwater treatment decision hierarchy described in Section 3.1.4, the combined flow from the existing South Plume Recovery Well System will usually be the only untreated groundwater that has uranium concentrations above 20 ppb. Because the remaining treatment capacity can not treat the entire South Plume flow and it was assumed in the evaluation that the combined South Plume flow cannot be divided further for partial treatment, the baseline 2000 gpm treatment capacity cannot always be fully utilized in the scenarios, as indicated in Tables 3-2, 3-4, 3-6, and 3-8. Although the discharge limits are achieved in the evaluations, in order to further reduce mass loading to the Great Miami River (as a good management practice), it may be desirable during remedial design to examine methods to permit the splitting of the South Plume flow for partial treatment so that the available treatment capacity can always be utilized.

5.0 FINALIZATION OF THE BASELINE STRATEGY

As presented in Section 4.0, the preliminary baseline strategy was developed based on assumptions of unconstrained funding and unrestricted off-property access. These assumptions were made to simplify the overall cost-benefit evaluation process. However, before the engineering design can be initiated, the actual funding profiles and current off-property access constraints need to be considered. Also, in order to provide representative comparisons with the FS base case remedy, the "maximum" plume configuration employed in the FS Report (representing the maximum reported plume concentrations throughout the FEMP's historical period of record) was used to conduct all of the modeling simulations for the preliminary evaluations and ultimately to identify the preferred scenario. For detailed design purposes, the FEMP is planning to use the most recent "current condition" plume configuration (based on actual recent monitoring data) so that well locations are situated as accurately as possible.

This section presents the process of finalizing the preliminary baseline strategy by considering these three major implementation issues (funding profiles, off-property access constraints, and current condition plume configuration). The finalized baseline remedial strategy developed in this section will then be the basis for the remedial design.

5.1 SUMMARY OF THE IMPLEMENTATION ISSUES

5.1.1 Current Uranium Plume

The initial uranium plume in all the model simulations conducted during the preliminary evaluation process was based on the maximum concentrations measured in the FEMP's monitoring wells prior to 1994. The development procedures for this plume were presented in Appendix F.7 of the Operable Unit 5 FS. This synthetic "maximum" plume is a very conservative representation of the actual uranium plume in terms of size and concentration levels. It was used in the FS to ensure that the selected groundwater remediation system will maintain a sufficiently large hydraulic capture zone and that the broad response actions evaluated in the FS (no action, containment, and active restoration) were compared fairly. However, use of this plume during the detailed design process could inadvertently lead to the selection of extraction well locations outside of the actual plume and result in lower mass recovery efficiency. Therefore, it is necessary to consider a more realistic plume delineation based on the most recent data when finalizing the remedial system design. The realistic

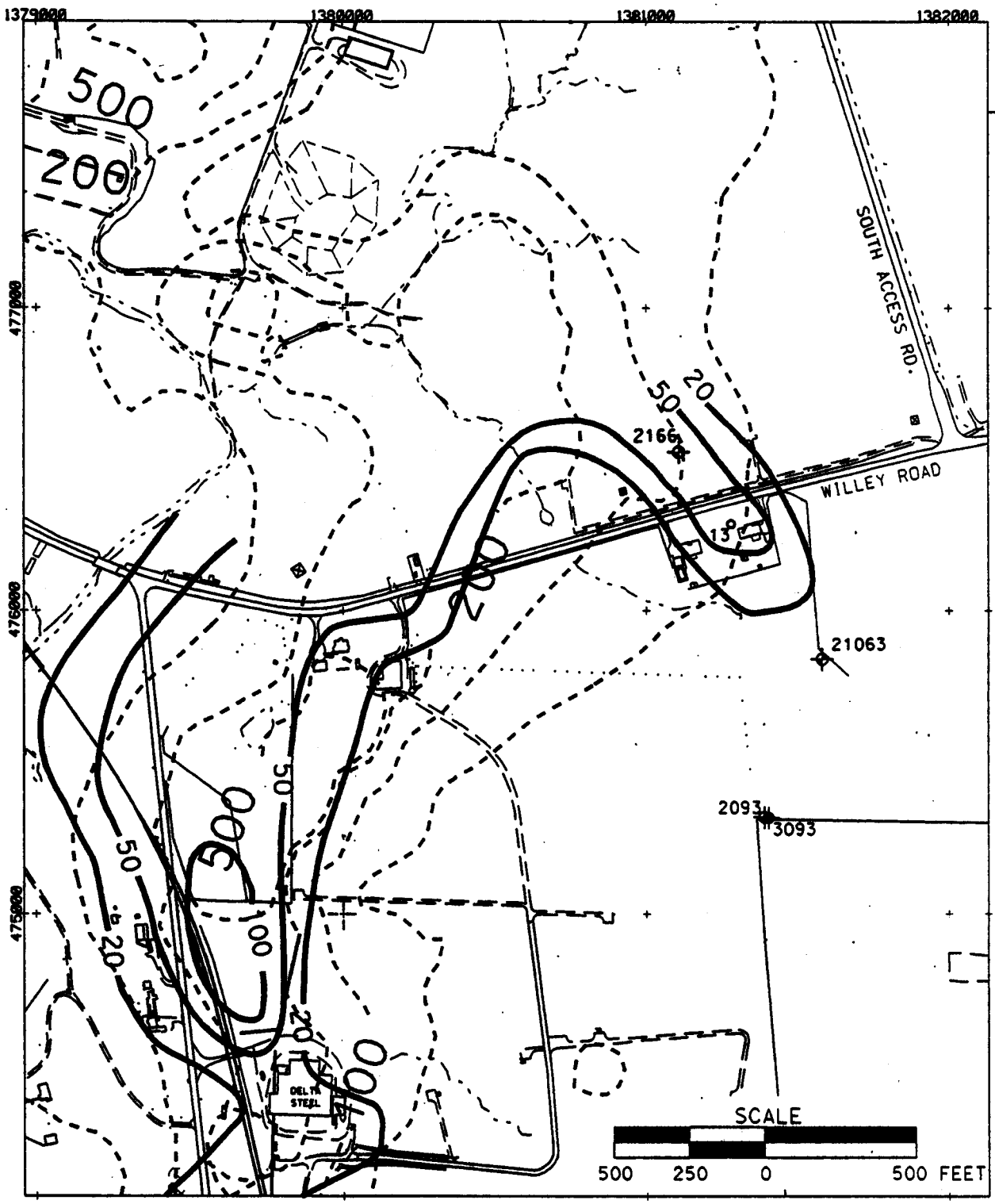
plume may be used to fine tune the well locations and projections of the system performance measures.

Groundwater data collected through the South Plume Design, Monitoring, and Evaluation Program Plan (DMEPP) in the past three years provides a more up to date delineation of the off-property portion of the uranium plume. Significant differences between the synthetic "maximum" plume and the currently measured off-property plume can be seen in Figure 5-1. These differences can be attributed to operation of the South Plume Recovery Well System in the last 3 years as well as reduction of contaminated surface runoff discharged into Paddys Run. Conversely, there are few new data points that have been collected from the on-property area in the vicinity of the source areas since 1993, and no remedial activities have yet taken place in this area. Therefore, it was decided to update only the off-property portion of the plume to current conditions (where most of the changes have occurred) for the purpose of finalizing the baseline strategy. Figure 5-2 shows the modified portion of the uranium plume. To be reasonably conservative, the new target plume was set to be slightly larger than the plume presented in the DMEPP. This updated plume was then used as the new initial condition in model simulations to finalize the off-property well locations and performance projections of the baseline remedial strategy. When the updated plume was used in model simulations, the time zero in the model was set at the beginning of FY97.

5.1.2 Off-Property Access Considerations

The preliminary baseline remedial strategy selected at the conclusion of Section 4.0 contains four new proposed off-property extraction wells to enhance the overall restoration of the off-property plume. These four new wells are identified as Wells 1, 3N, 2N, and KN on Figure 5-3.

All four of the wells are situated on private property owned by Knollman Farms, Inc. The locations of the four wells were identified through modeling simulations and are designed to accommodate the desire of EPA, OEPA and DOE to shorten overall off-property remediation time, improve mass removal efficiency, and minimize the further expansion of the off-property plume. With these four new extraction wells in place, only the western two existing South Plume recovery wells (shown as Wells 24 and 25 on Figure 5-3) are necessary for maintaining full hydraulic capture of the off-property plume.



LEGEND:

DMEPP PLUME (DECEMBER, 1995)

MAXIMUM PLUME

FEMP BOUNDARY

HOMEOWNER WELL

EXISTING MONITORING WELL

DRAFT

FIGURE 5-1. COMPARISON BETWEEN THE MAXIMUM AND CURRENT URANIUM PLUMES

/usr/erwd5/crw2/dgn/map/hor/dpttv/stplnd33.dgn

STATE PLANAR COORDINATE SYSTEM 1927

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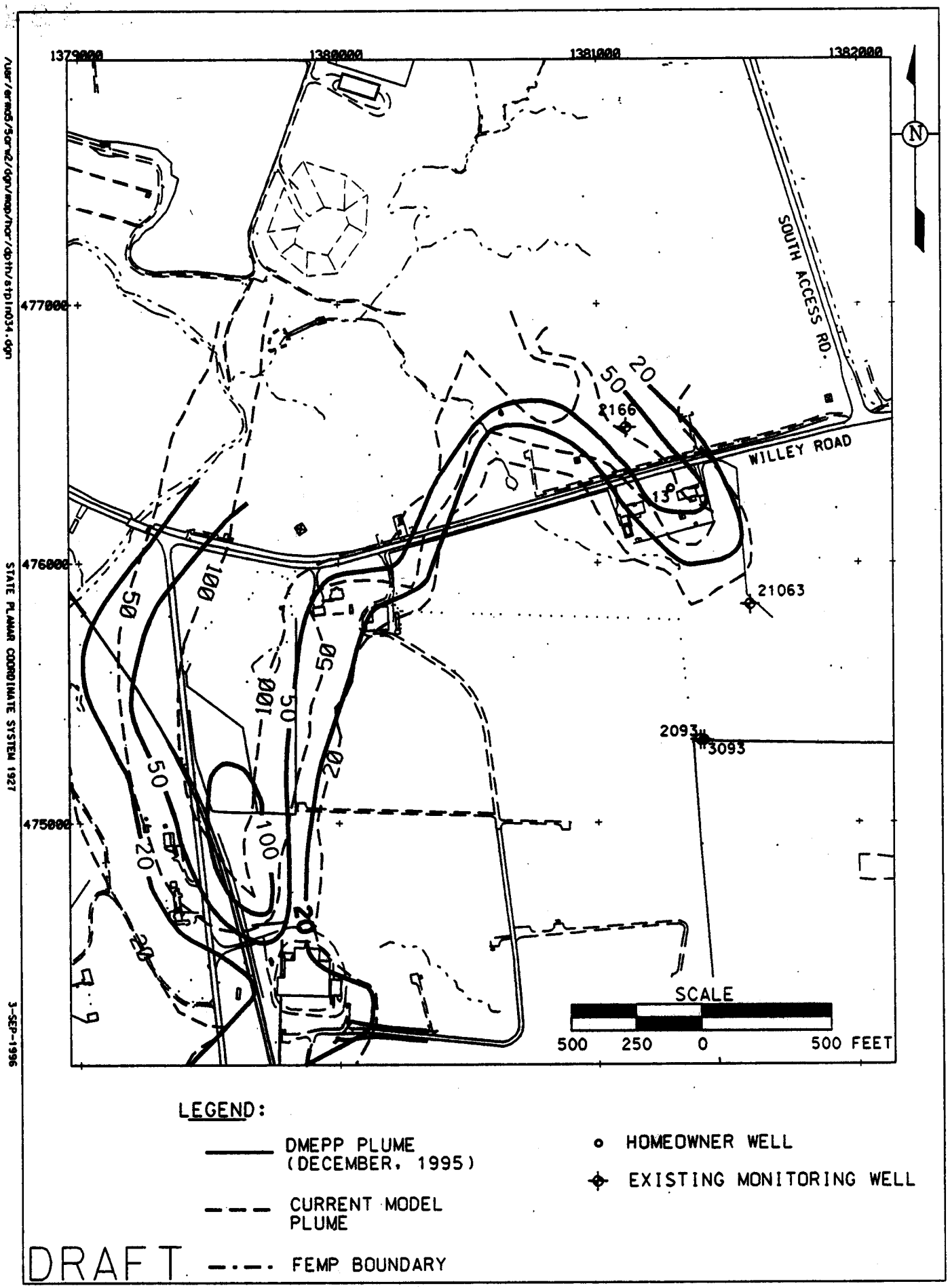


FIGURE 5-2. MODIFIED PORTION OF THE URANIUM PLUME FOR MODEL SIMULATION

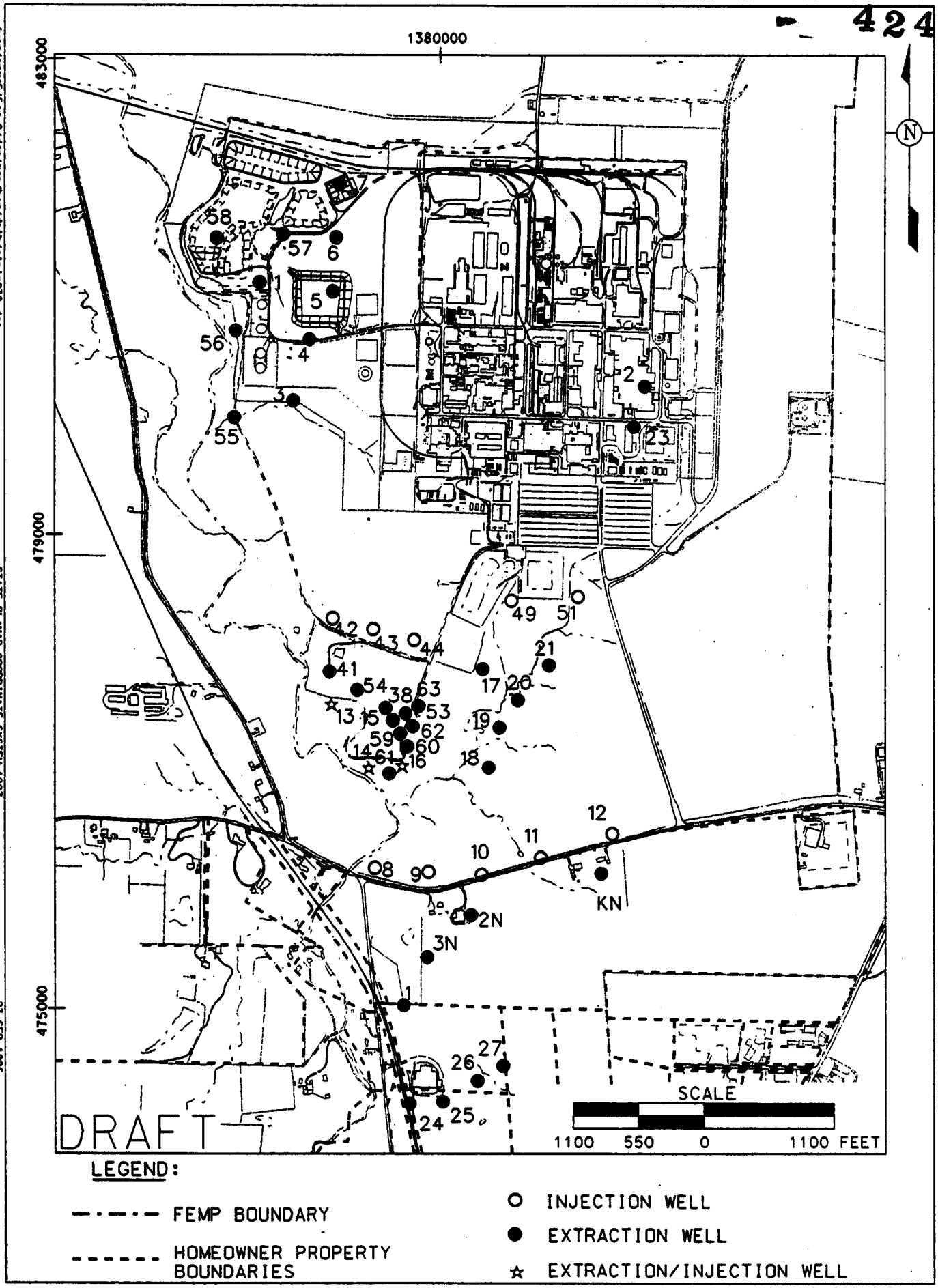


FIGURE 5-3. WELL LOCATIONS FOR THE BASELINE GROUNDWATER REMEDIAL STRATEGY

The locations for the four wells shown on Figure 5-3 are idealized locations used to perform the modeling simulations. They do not necessarily consider property owner access considerations and localized land use constraints. It was recognized in the development of the modeling simulations that final locations would need to be adjusted as appropriate to accommodate actual property owner constraints and desires, once successfully negotiated as part of the ongoing remedial design process.

Recently, several meetings were held between DOE, EPA, OEPA, and the property owner to discuss property access issues of concern to the property owner. As part of the discussions, the nature of the benefits to be provided by the four new wells, in terms of off-property aquifer restoration time and further plume expansion, were reviewed. It was acknowledged during the discussions that two of the new wells (1 and 3N), which are to be placed along the main axis of the off-property plume, are key to shortening off-property cleanup time because they address the area where the highest off-property groundwater concentrations are exhibited (this area was shown by the modeling simulations to be the off-property rate-limiting area). The remaining two wells (2N and KN) function primarily to halt the further expansion of the plume and to increase overall mass removal efficiency from that achievable by using the existing South Plume recovery wells alone. These two wells do not, however, contribute meaningfully to the shortening of the overall off-property cleanup time since, by function, they do not reside in the rate-limiting area where contaminant concentrations are highest. It was also acknowledged that in the absence of Wells 2N and KN, the plume would continue to expand but within the geographic confines of the hydraulic capture zone created by the South Plume recovery wells.

As of the October 1, 1996 submittal date of this report, the property owner has expressed specific concerns to DOE, EPA, and OEPA with Wells 2N and KN, indicating that the long-term activities associated with the operation of these two wells may cause unacceptable levels of disruption and disturbance (considering the proximity of the wells to the landowner's residential dwellings and cattle

breeding operations). The property owner is more agreeable to the installation of Wells 1 and 3N, considering their role in addressing the core of the off-property groundwater plume and their proposed location along the edge of a farm field away from dwellings and barns. DOE is working to resolve the property owner's concerns and continues to evaluate the technical merits of Wells 2N and KN in light of the landowner's concerns.

To support the past and ongoing deliberations regarding the landowner's concerns with Wells 2N and KN, a series of five new modeling simulations were conducted to further evaluate the performance of the wells and the merits of moving the wells to alternate on- and off-property locations. The results of these simulations are summarized in Section 5.2.1, and the details are provided in Appendix E. Further discussion will also be provided in Section 5.2.1 regarding the proposed path forward for accommodating the ongoing negotiations regarding the landowner's expressed concerns.

It needs to be recognized that without the property owner's concurrence, it will require a lengthy condemnation process in order to obtain access for Wells 2N and KN. Currently, DOE does not plan to proceed with the condemnation process if these wells are not critical to the completion of aquifer restoration.

5.1.3 Funding Constraints for Fiscal Years 1997 and 1998

In order to implement the preliminary baseline remedial strategy, it will require close to 10 million dollars from the FEMP's FY97 budget to complete the South Field Extraction Phase I System (remaining piping network), the South Plume Optimization Module (four new wells and piping network), the AWWT Facility Expansion, and the fenceline Groundwater Injection Demonstration Module (which is funded separately through a DOE Headquarters technology demonstration grant). However, under the current funding schedule, the annual funding available for these projects in FY97 and FY98 will be about 3 and 7 million dollars, respectively. Therefore, the components assumed to be completed in FY97 under the unconstrained preliminary baseline strategy case will need to be constructed sequentially over the years FY97 and FY98. Currently, there is no foreseen out-year funding problem for installing the remaining modules of the system -- South Field Phase II, Waste Storage Area, and the Plant 6 Area modules -- in accordance with the desired schedule defined in the preliminary baseline strategy.

Among all the system performance measures of the Aquifer Restoration and Wastewater Treatment Projects, compliance with the outfall criteria will be given the highest priority during remediation. Sufficient wastewater treatment capacity is critical for maintaining the outfall compliance when all the FEMP remediation projects are in operation, and for producing needed water for the Injection Demonstration Module. Therefore, the AWWT Facility Expansion is selected as the lead project to be funded in FY97. Following construction, the expanded groundwater treatment capacity will be available in February 1998 as assumed in the unconstrained funding case.

The other two components assumed in the preliminary strategy to be initiated in FY97 under the unconstrained funding case (South Plume Optimization Module and South Field Phase I System) will be delayed until FY98 and, following construction, brought on line in FY99.

5.2 MODIFICATIONS TO THE PRELIMINARY BASELINE STRATEGY

The necessary modifications to the preliminary baseline strategy to accommodate the off-property access considerations and funding constraints for FY97 and FY98 are identified in this subsection.

5.2.1 Path Forward for the South Plume Optimization Module

Appendix E contains the results of the modeling simulations conducted to support the past and ongoing deliberations regarding the off-property landowner's concerns with Wells 2N and KN of the South Plume Optimization Module. Five specific scenarios involving wells 2N and KN were evaluated in the simulations:

- Scenario I -- Wells 2N and KN are located further to the south from their original locations specified in the preliminary baseline strategy shown in Figure 4-3. The new locations reflect the position of the leading edge of the plume at the time when these wells begin operation (assumed in the simulations to be FY99) based on current funding scenarios for FY97 and 98.

- Scenario II -- Wells 2N and KN are inoperative in this scenario, representing the condition that landowner preferences result in agreement not to install the wells.

- Scenario III -- Wells 2N and KN are positioned on the FEMP's property north of Willey Rd., and groundwater injection is delayed for a number of years to accommodate the operation of the extraction wells. This scenario was included to examine the effectiveness of Wells 2N and KN if they were installed at the FEMP's fenceline and not on the landowner's property.

- Scenario IV -- Wells 2N and KN are positioned on the FEMP's property north of Willey Rd., along with two additional extraction wells. This scenario was included to evaluate the option of using extraction wells instead of injection wells to create a full hydraulic barrier along the fenceline, and the resulting impacts to off-property cleanup success.

- Scenario V -- In this scenario, Well KN is eliminated and Well 2N is positioned at its original location for the preliminary baseline strategy shown on Figure 4-3. This scenario was included to examine the merits of installing one of the two wells at a location that attempts to minimize overall disturbance to the property owner's cattle operations. In this situation, no wells are located near the property owner's residential dwellings.

The alternate well locations are shown for all of these scenarios on the maps provided in Appendix E, along with the extraction and injection rate operating schedules employed.

5.2.1.1 Summary of the Simulation Results

The results of the simulations, presented in detail on the maps provided in Appendix E, reveal the following principal conclusions:

- All of the scenarios result in approximately the same degree of off-property plume expansion, as indicated by the position of the 20 ppb total uranium FRL concentration contour.

- In all cases, the area of expansion resides within the capture zone of the South Plume recovery wells (provided South Plume recovery wells 24, 25, 26, and 27 shown on Figure 5-3 remain in operation).

- Off-property cleanup times for Scenarios I, II, and V are nearly identical, although Scenarios II and V remove less contaminant mass compared to Scenario I, owing to the dissipation of the plume as it migrates southward (at concentrations less than the uranium FRL) en-route to the South Plume recovery well field.

- Scenarios III and IV are not nearly as effective in restoring the off-property portion of the plume (as evidenced by longer cleanup time), because these scenarios do not fully benefit from groundwater injection. The expansion of the plume is about the same as the other scenarios, however it takes significantly longer to clean up and regional drawdown impacts are much more pronounced.

These summary results were shared in detail with the landowner and EPA and OEPA at a meeting held on September 17, 1996. All of the maps that were presented at the meeting are provided in Appendix E.

5.2.1.2 Path Forward to Accommodate Ongoing Deliberations Concerning Off-Property Access

Pending the outcome of the ongoing deliberations regarding the affected landowner's concerns, the FEMP is proceeding with remedial design activities assuming that the conditions evaluated in Scenario II (i.e., interim discontinuance of wells 2N and KN, until further notice) are in play. This is necessary to meet the enforceable remedial design schedules and document delivery dates contained in the Operable Unit 5 RD Work Plan. The preliminary and prefinal design packages for the South

Plume Optimization Module will therefore include Wells 1 and 3N along with the accompanying piping and infrastructure.

As part of the deliberations, the landowner is also considering the final acceptable right-of-way for the pipeline servicing Wells 1 and 3N. To meet the October 1, 1996 document submittal date for the South Plume Optimization Module preliminary design package, it has been assumed that Wells 1 and 3N will follow a new northward right-of-way access back to the FEMP property where on-property tie ins to the South Field treatment and bypass headers can be accommodated. The landowner, however, has not yet agreed to this right-of-way access. Alternately, if the northward right-of-way is not agreeable to the landowner, Wells 1 and 3N will be tied in to the existing South Plume Removal Action pipeline (subject to approval by EPA) following an existing eastward right-of-way previously negotiated with the landowner. It is anticipated that the right-of-way access issue will be resolved by the landowner for the prefinal design package which is due to be submitted to EPA on January 15, 1997.

If the ongoing technical and logistical deliberations regarding Wells 2N and KN result in one or more of these wells being required, then an additional restoration module ("South Plume Optimization II") will be included in the FEMP's restoration program to accommodate this outcome of the deliberations. Design of this module would then be conducted under a new schedule and task description (to be developed for EPA approval following the conclusion of the deliberations) and which will be included as formal addendum to the RD Work Plan.

In the interim, in order to maintain full capture of the off-property plume, existing South Plume Recovery Wells 1, 2, 3, and 4 (shown as Wells 24, 25, 26 and 27 on earlier figures) will continue to be operated while the need for the South Plume Optimization II module is under collective evaluation by the concerned parties.

5.2.1.3 Regulatory Considerations Associated With Off-Property Plume Expansion

As discussed in the previous section, the FEMP is proceeding with detailed remedial design by assuming, for the interim, that Wells 2N and KN may not be installed. This assumption will be utilized until the deliberations concerning landowner access constraints result in a definitive path forward regarding final well locations and/or the need for the wells as part of the restoration program. This section reviews the regulatory considerations associated with expansion of the leading

edge of the plume (within the confines of capture zone created by the South Plume recovery wells) if Wells 2N and KN are not installed (as shown in Figure E-10 of Appendix E).

Regulatory acceptance of this controlled expansion can be supported by the following points:

- The affected property owner has not granted approval for placing Wells 2N and KN on his property and there are no feasible alternate locations for these wells to stop the expansion of the plume
- The plume will be contained in the overall hydraulic capture zone created by other extraction wells
- The off-property cleanup time will not be extended as a result of the action
- The uranium concentrations in the expansion area are projected to remain relatively low over the duration of the action (greater than 20 ppb, but less than 50 ppb)
- The impacted area currently has an alternate water supply available through the new public water supply
- Groundwater will not be used for irrigation or other purposes during remediation
- Groundwater conditions in the impacted area will be closely monitored as part of the Integrated Environmental Monitoring Plan (DOE 1996c).

The above listed reasons provide sufficient justification under the guidance contained in EPA's OSWER Directive No. 9283.1-2 for approval of a limited or no action response for all or part of a contaminated groundwater zone at a CERCLA site (EPA 1998). It needs to be recognized that the modified baseline strategy does provide a limited response for this affected portion of the plume, as it is expected to attenuate within the capture zone created by the other off-property wells, and is therefore under the hydraulic control of the overall system.

Similarly, State of Ohio groundwater antidegration requirements can be satisfied by this action because the projected plume migration does not constitute a "discharge"; the plume will not migrate to portions of the aquifer used for drinking; and the overall contaminant levels are low, meeting the tests provided in EPA's July, 1990 Guidance for Complying with State Groundwater Antidegradation Requirements at CERCLA Sites (EPA 1990).

RCRA regulations provide similar approval authorities for controlled attenuation of off-property groundwater zones at 40 CFR part 264.525 which states that "If the owner/operator is unable to

obtain the necessary permission to undertake corrective action beyond the facility boundary, and can demonstrate to the satisfaction of the Regional Administrator that despite the owner/operator's best efforts, he/she is as a result unable to achieve media cleanup standards or levels beyond the facility boundary, then media cleanup standards or levels must be achieved to the extent practicable, as specified by the Regional Administrator."

5.2.2 Funding-Based Implementation Schedule

The implementation schedule for the Groundwater Injection Demonstration, South Field Phase I System, and the South Plume Optimization Module(s) will need to be coordinated with the funding schedule. The AWWT Expansion will be completed in early 1998 as originally scheduled. Because the treated groundwater is needed for injection, the Groundwater Injection Demonstration along the southern fence line will be initiated at the same time when the AWWT Expansion is completed. The necessary piping network for the injection operation is expected to be completed with the technology demonstration grant funding in FY97. The South Field Phase I System and the initial South Plume Optimization Module (Wells 1 and 3N) will be brought on line by early 1999. Implementation schedules for the South Field Extraction System Module Phase II, Waste Storage Area Module, and Plant 6 Module remain the same as in the preliminary baseline strategy.

5.2.3 Extraction/Injection Rate Schedule

Table 5-1 summarizes the modified extraction/injection rate schedule for the baseline groundwater remedial strategy. Differences in the rate schedules between the preliminary and finalized baseline strategies (see Tables 4-5 and 5-1) include necessary modifications due to modifications in the South Plume Optimization Module (pending the outcome of ongoing deliberations with the affected landowner) and the funding-based implementation schedule. Due to the low off-property residual concentrations, all the off-property wells and the Southern Fence Line Injection System are also turned off in the 8th year in the modified rate schedule.

5.3 PERFORMANCE PROJECTIONS

The projected performance indicators for the finalized baseline strategy are summarized in this subsection.

TABLE 5-1
EXTRACTION/INJECTION SCHEDULE FOR THE BASELINE REMEDIAL STRATEGY

		Pumping Rates (gpm) (+) = Pumped (-) = Injected			
Location	Well No.	Year 1997	Year 1998	Years 1999-2003	Years 2004-2006
Waste Pits	1	0	0	0	100
Waste Pits	3	0	0	0	100
Waste Pits	4	0	0	0	100
Waste Pits	5	0	0	0	100
Waste Pits	6	0	0	0	100
Waste Pits	7	0	0	0	100
Waste Pits	55	0	0	0	100
Waste Pits	56	0	0	0	100
Waste Pits	57	0	0	0	100
Waste Pits	58	0	0	0	100
Totals		0	0	0	1000
Plant 6	2	0	0	0	250
Plant 6	23	0	0	0	250
Totals		0	0	0	500
Fenceline injection wells	8	0	-200	-200	0
Fenceline injection wells	9	0	-200	-200	0
Fenceline injection wells	10	0	-200	-200	0
Fenceline injection wells	11	0	-200	-200	0
Fenceline injection wells	12	0	-200	-200	0
Totals		0	-1000	-1000	0
South Field - Phase I	13	0	0	200	-200
South Field - Phase I	14	0	0	200	-200
South Field - Phase I	15	0	0	200	100
South Field - Phase I	16	0	0	200	-200
South Field - Phase I	17	0	0	100	0
South Field - Phase I	18	0	0	100	0
South Field - Phase I	19	0	0	100	200
South Field - Phase I	20	0	0	100	200
South Field - Phase I	21	0	0	100	200
Totals		0	0	1300	100
South Field - Phase II	38	0	0	0	300
South Field - Phase II	41	0	0	0	300
South Field - Phase II	53	0	0	0	300
South Field - Phase II	54	0	0	0	300
South Field - Phase II	59	0	0	0	300
South Field - Phase II	60	0	0	0	300
South Field - Phase II	61	0	0	0	200
South Field - Phase II	62	0	0	0	200
South Field - Phase II	63	0	0	0	300
Totals		0	0	0	2500
South Field injection wells	42	0	0	0	-200
South Field injection wells	43	0	0	0	-200
South Field injection wells	44	0	0	0	-200
South Field injection wells	49	0	0	0	-200
South Field injection wells	51	0	0	0	-200
Totals		0	0	0	-1000
South Plume	24	300	300	300	0
South Plume	25	300	300	300	0
South Plume	26	400	400	400	0
South Plume	27	400	400	400	0
South Plume optimization	1	0	0	250	0
South Plume optimization	2N	0	0	0	0
South Plume optimization	3N	0	0	350	0
South Plume optimization	KN	0	0	0	0
Totals		1400	1400	2000	0
Total pumped		1400	1400	3300	4800
Total injected		0	-1000	-1000	-1600
Net Aquifer extraction		1400	400	2300	3100

5.3.1 Basic Performance Measures

After incorporating the necessary modifications described in Section 5.2, performance measures of the baseline remedial strategy are projected by model simulation using the updated uranium plume in the off-property area. As mentioned earlier, the first model year corresponds to FY97 in this simulation. Table 5-2 summarizes the important performance measures. Differences between performance measures of the preliminary and finalized baseline strategies (see Tables 4-6 and 5-2) are due to elimination of wells (i.e., Wells 2N and KN), modified implementation schedule, and the updated off-property plume. In general the aquifer is projected to be restored in about 10 years as in the preliminary baseline strategy. As shown in Table 5-2, groundwater treatment capacity will be almost fully utilized throughout the remediation period even between years 8 to 10. This is necessary because the groundwater will need to be treated for iron before it can be injected regardless of the uranium concentration. This constraint was not imposed during the preliminary evaluation. Figures 5-4 through 5-7 show the modeled groundwater flow patterns under the finalized baseline groundwater remedial strategy. Corresponding groundwater drawdown contours are shown in Figures 5-8 through 5-11. The projected uranium concentration contours are shown in Figures 5-12 through 5-16.

In the absence of Wells 2N and KN, the baseline strategy will, in effect, be relying on a controlled natural attenuation approach to address the expanding portion of the plume. The maximum extent of the off-property 20 ppb contour interval is depicted in Figure 5-17. This extent was determined through the modeling simulations and represents a composite picture of the individual time steps of plume advance provided in Figures 5-12 through 5-16. This composite maximum expansion, however, will still reside within (and therefore be controlled by) the hydraulic capture zone created by the existing South Plume recovery wells. This capture zone is also indicated in Figure 5-17. No new off-property owners are affected by this degree of plume expansion.

5.3.2 Uncertainty Analysis

As described in Section 1.3, a number of factors cause uncertainty in the actual time and resources necessary to successfully complete aquifer restoration. DOE, EPA, OEPA and other FEMP decision-makers need to fully understand the significance of the uncertainties in order to make well-informed decisions concerning how the program will be implemented both initially and at later stages of the cleanup.

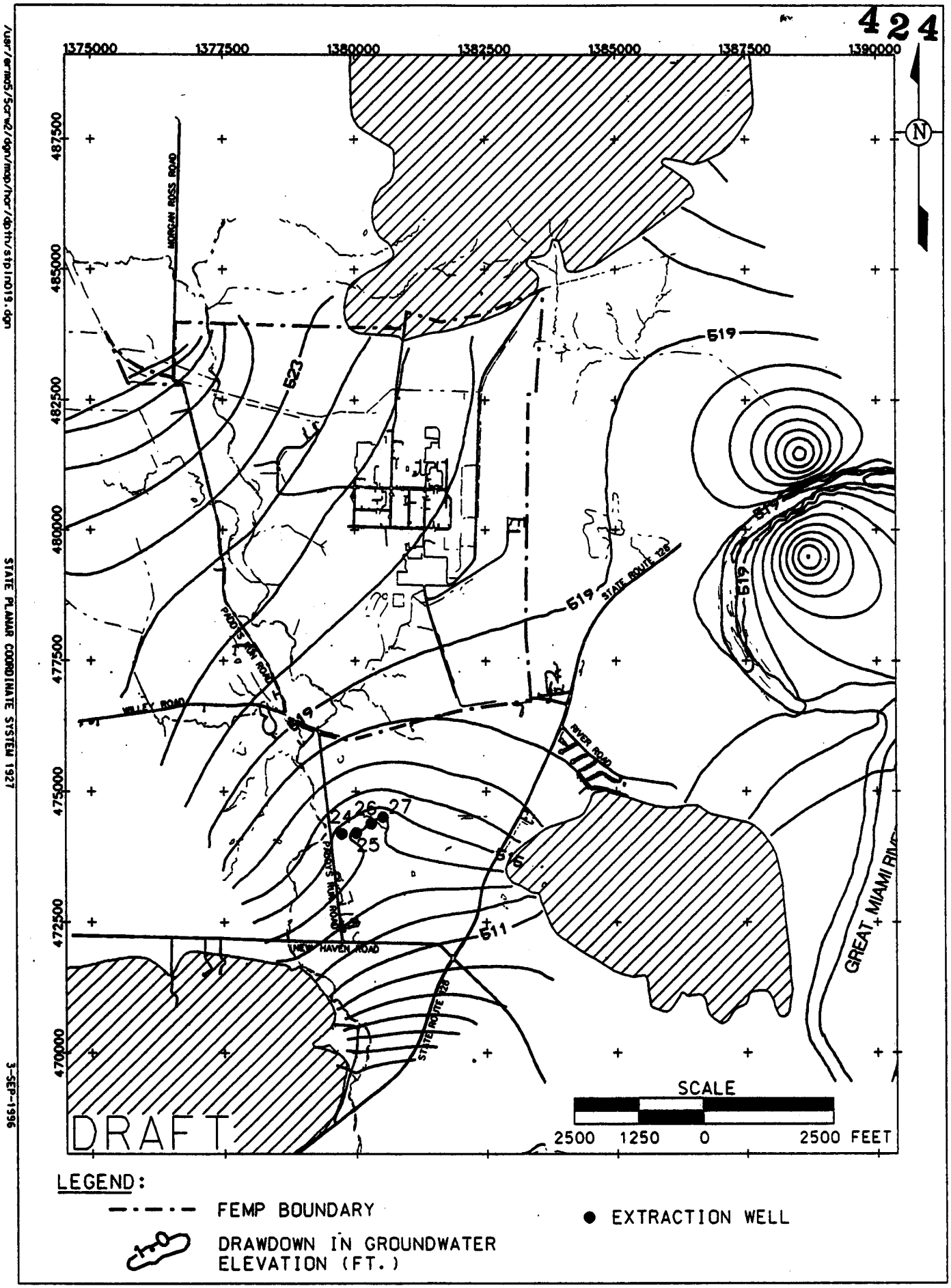


FIGURE 5-4. GROUNDWATER ELEVATION FOR THE BASELINE STRATEGY, YEAR 1

/usr/ermo5/5cr02/dgn/map/hor/dbthr/stplnd19.dgn

STATE PLANAR COORDINATE SYSTEM 1927

3-SEP-1996

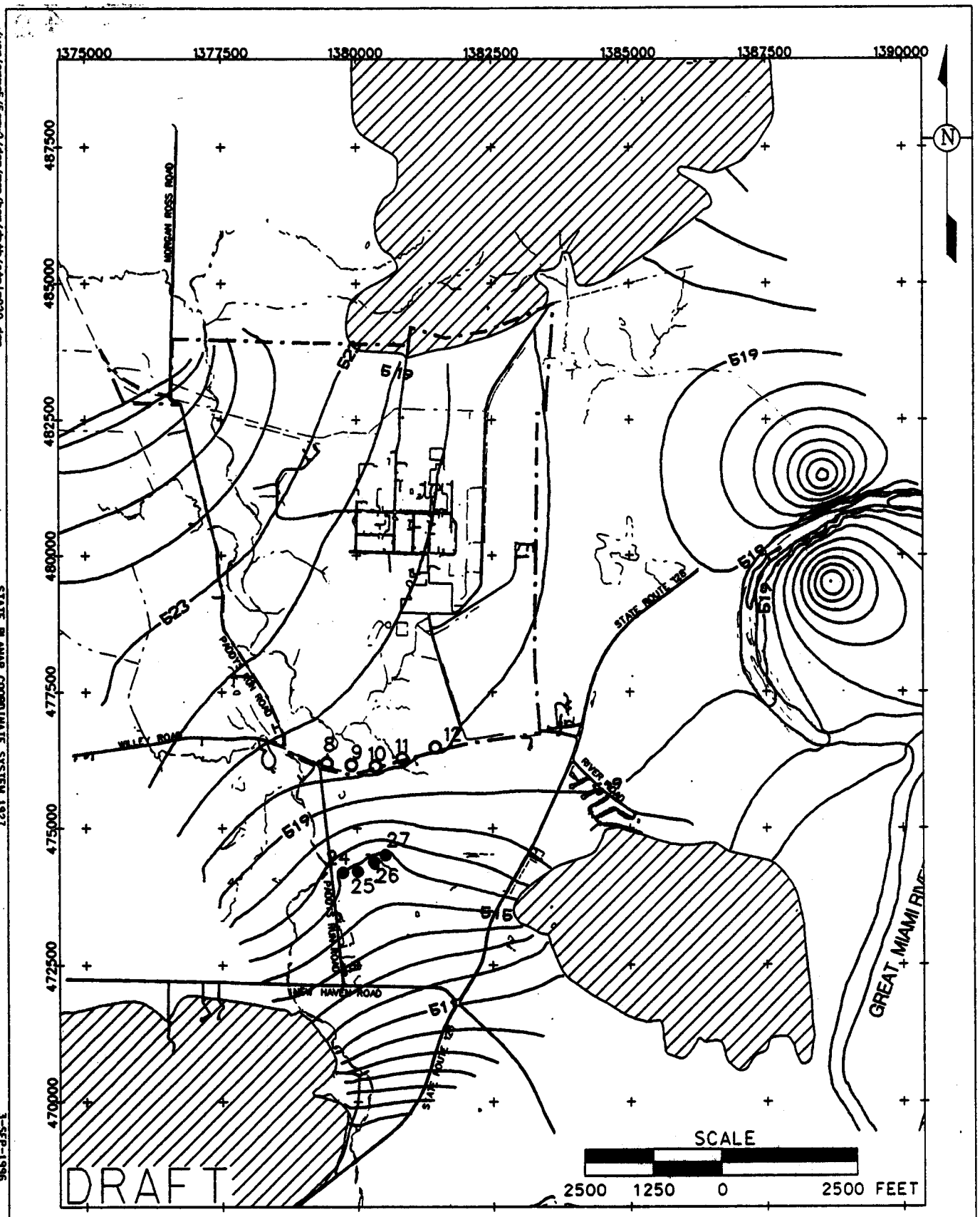


FIGURE 5-5. GROUNDWATER ELEVATION FOR THE BASELINE STRATEGY, YEAR 2

/usr/ermo5/5crw2/dgn/map/hor/dpth/stpln020.dgn
STATE PLANAR COORDINATE SYSTEM 1927
3-SEP-1996

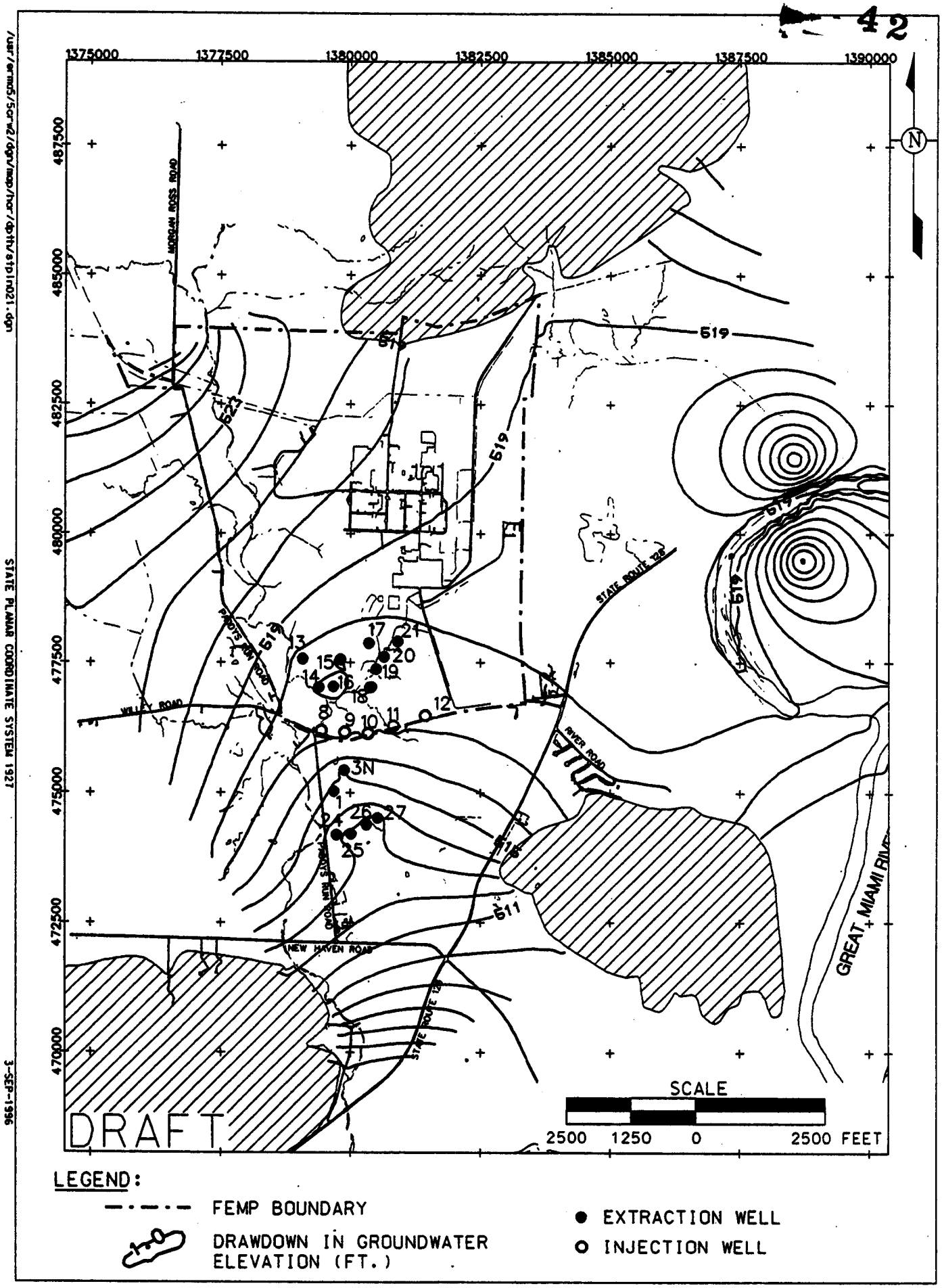
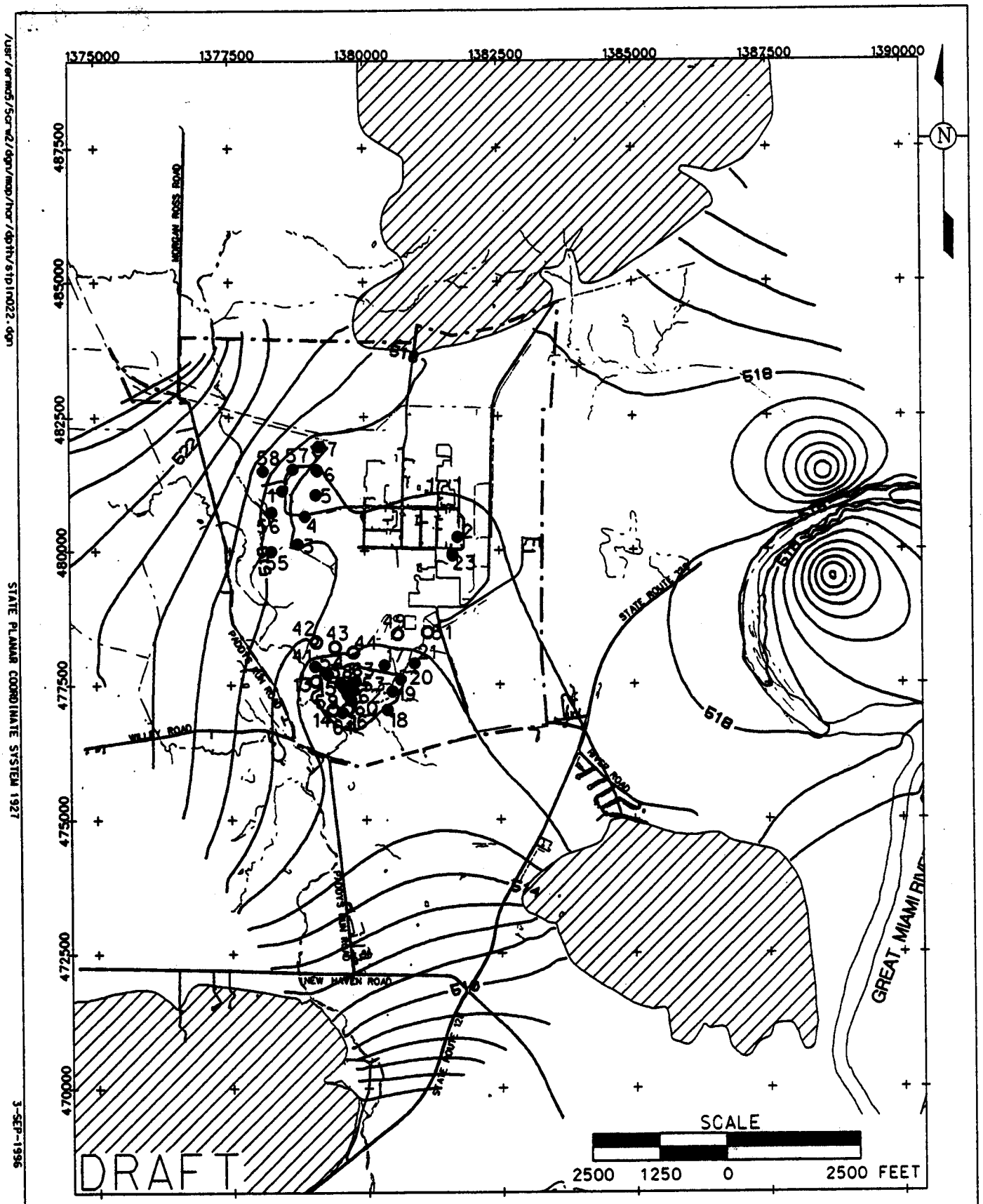


FIGURE 5-6. GROUNDWATER ELEVATION FOR THE BASELINE STRATEGY, YEARS 3-7



LEGEND:

- FEMP BOUNDARY
- DRAWDOWN IN GROUNDWATER ELEVATION (FT.)
- ● EXTRACTION WELL
- ○ INJECTION WELL

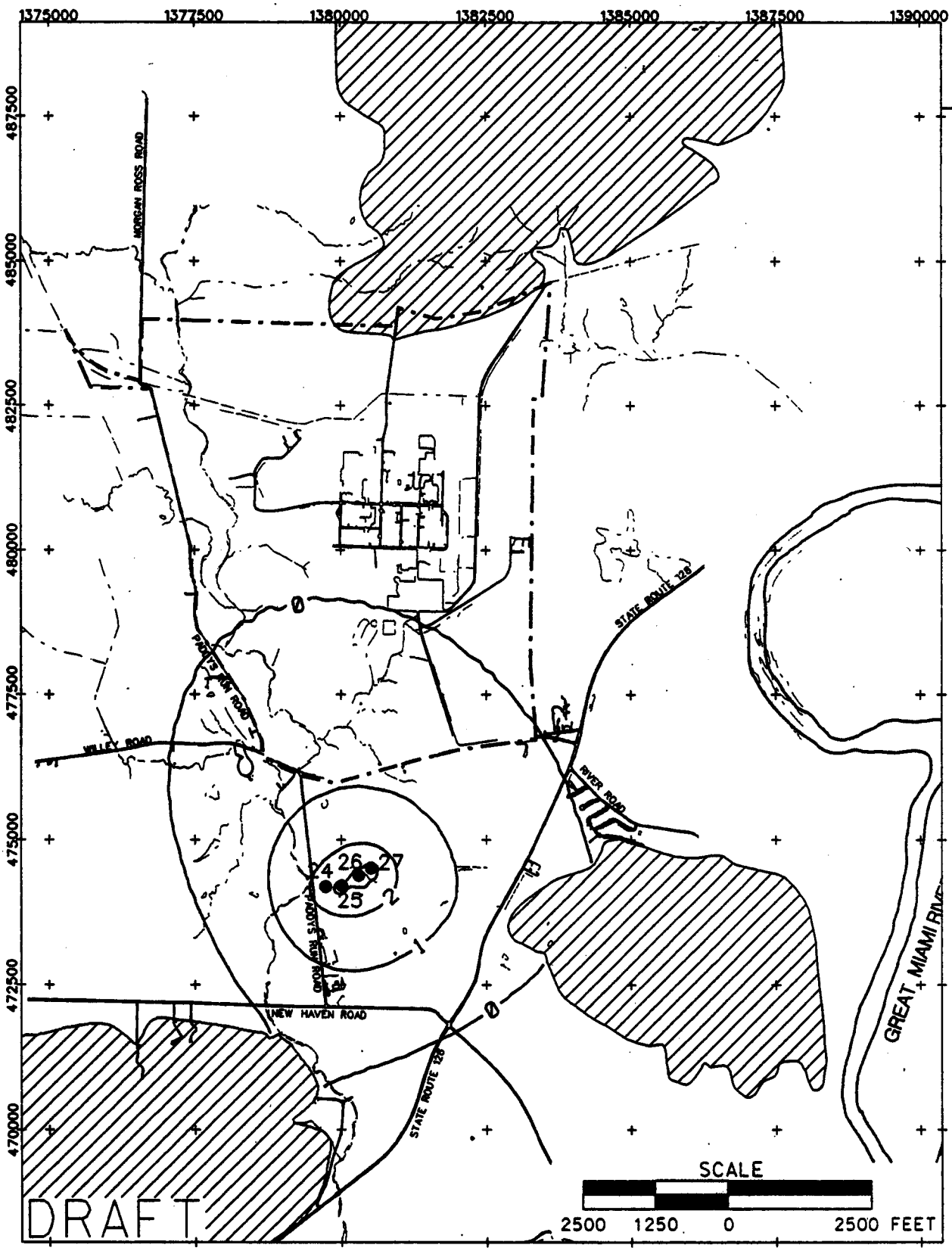
FIGURE 5-7. GROUNDWATER ELEVATION FOR THE BASELINE STRATEGY, YEARS 8-10

/usr/armd5/5cr42/dgn/map/hor/depth/stp1n022.dgn

STATE PLANAR COORDINATE SYSTEM 1927

3-SEP-1996

000104



LEGEND:

FEMP BOUNDARY

DRAWDOWN IN GROUNDWATER ELEVATION (FT.)

EXTRACTION WELL

FIGURE 5-8. DRAWDOWN CONTOURS FOR THE BASELINE STRATEGY, YEAR 1

/usr/ermo5/5cr42/dgn/map/hor/dp1hr/stp1n023.dgn

STATE PLANAR COORDINATE SYSTEM 1927

3-SEP-1996

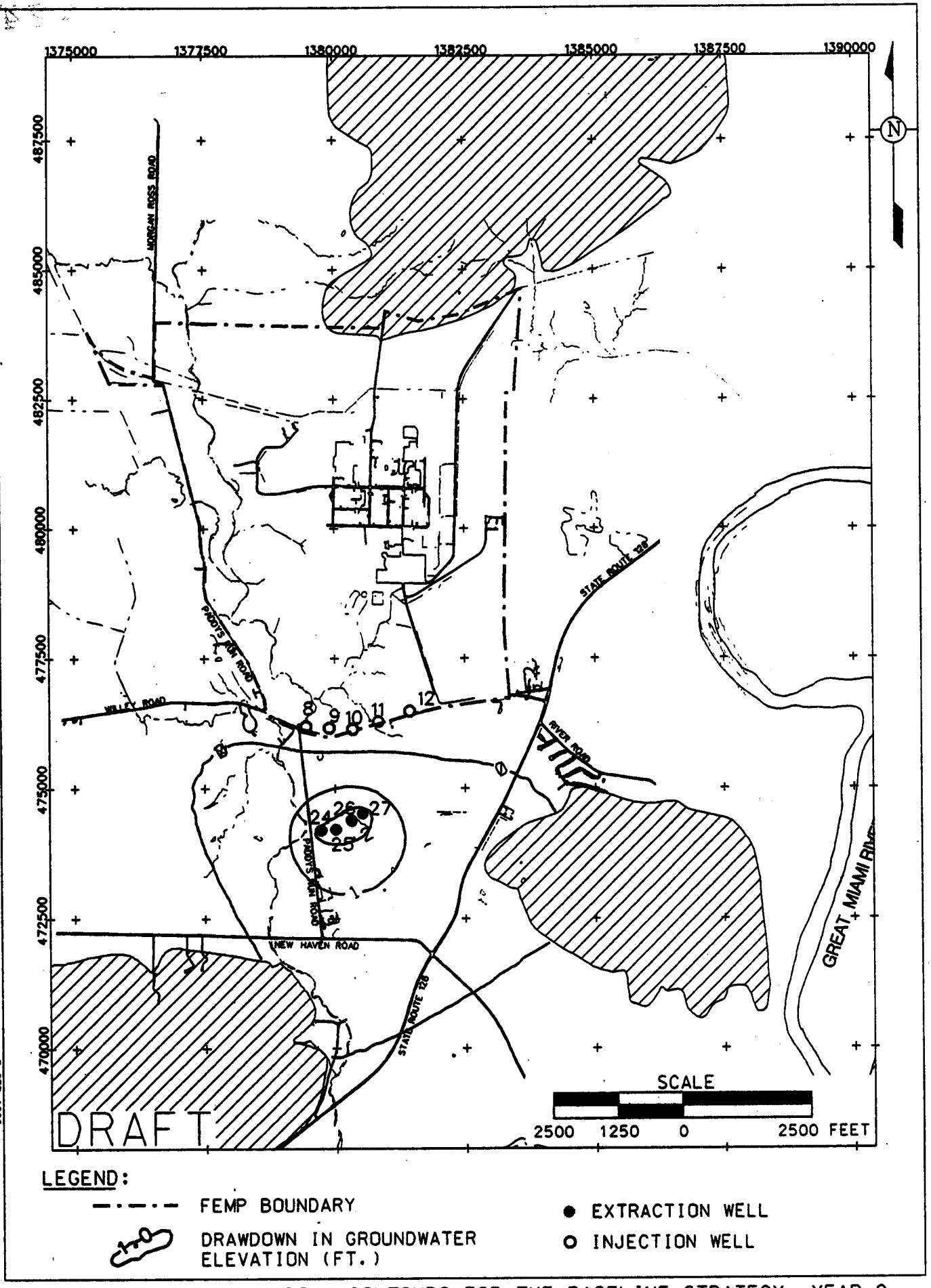


FIGURE 5-9. DRAWDOWN CONTOURS FOR THE BASELINE STRATEGY, YEAR 2

/usr/ermo5/5cr42/dgn/map/hor/dpitv/stpln024.dgn

STATE PLANAR COORDINATE SYSTEM 1927

3-SEP-1996

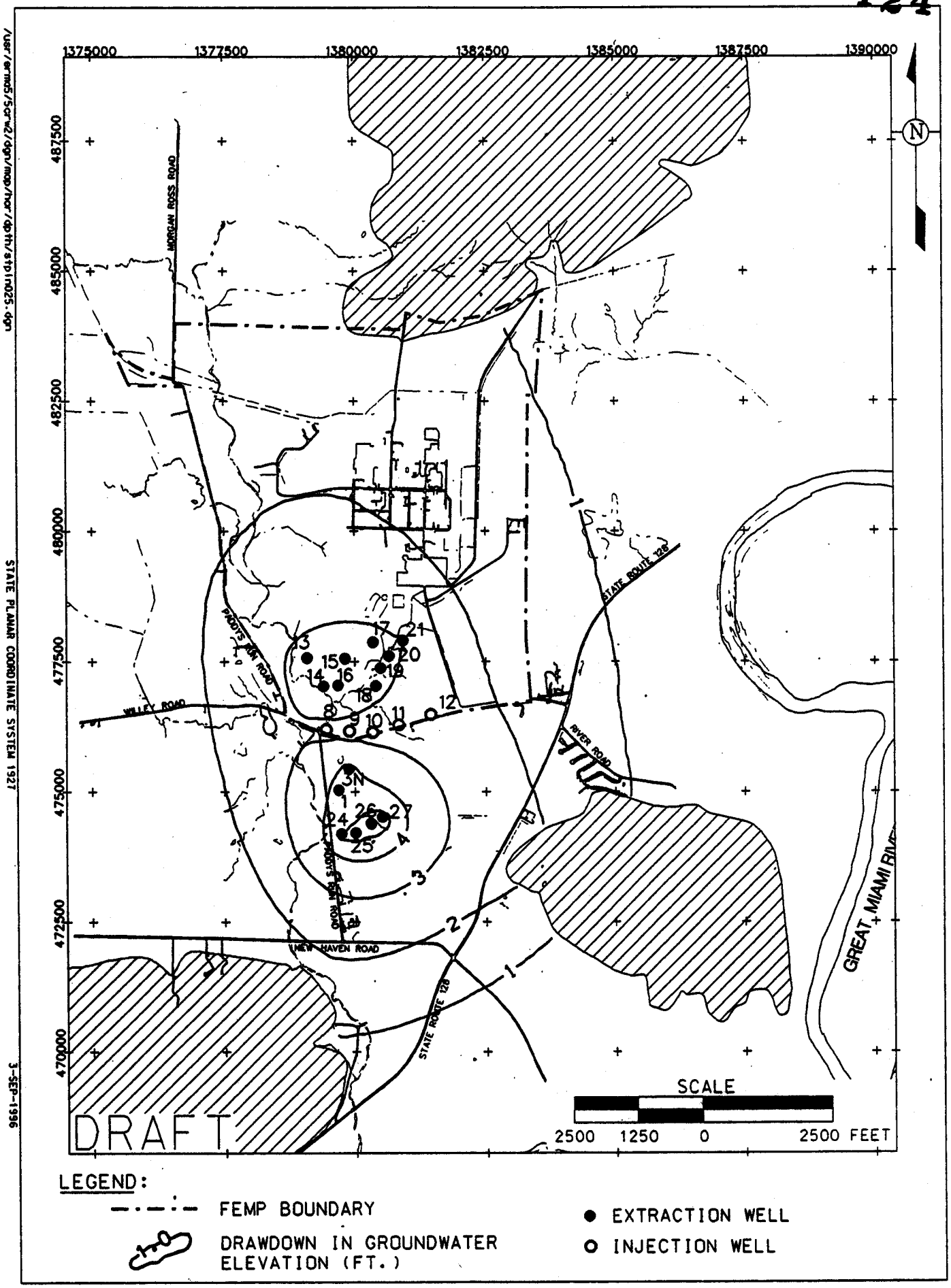


FIGURE 5-10. DRAWDOWN CONTOURS FOR THE BASELINE STRATEGY, YEARS 3-7

/usr/ermd5/5crw2/dgn/map/hor/dpfh/stpln025.dgn

STATE PLANAR COORDINATE SYSTEM 1927

3-SEP-1996

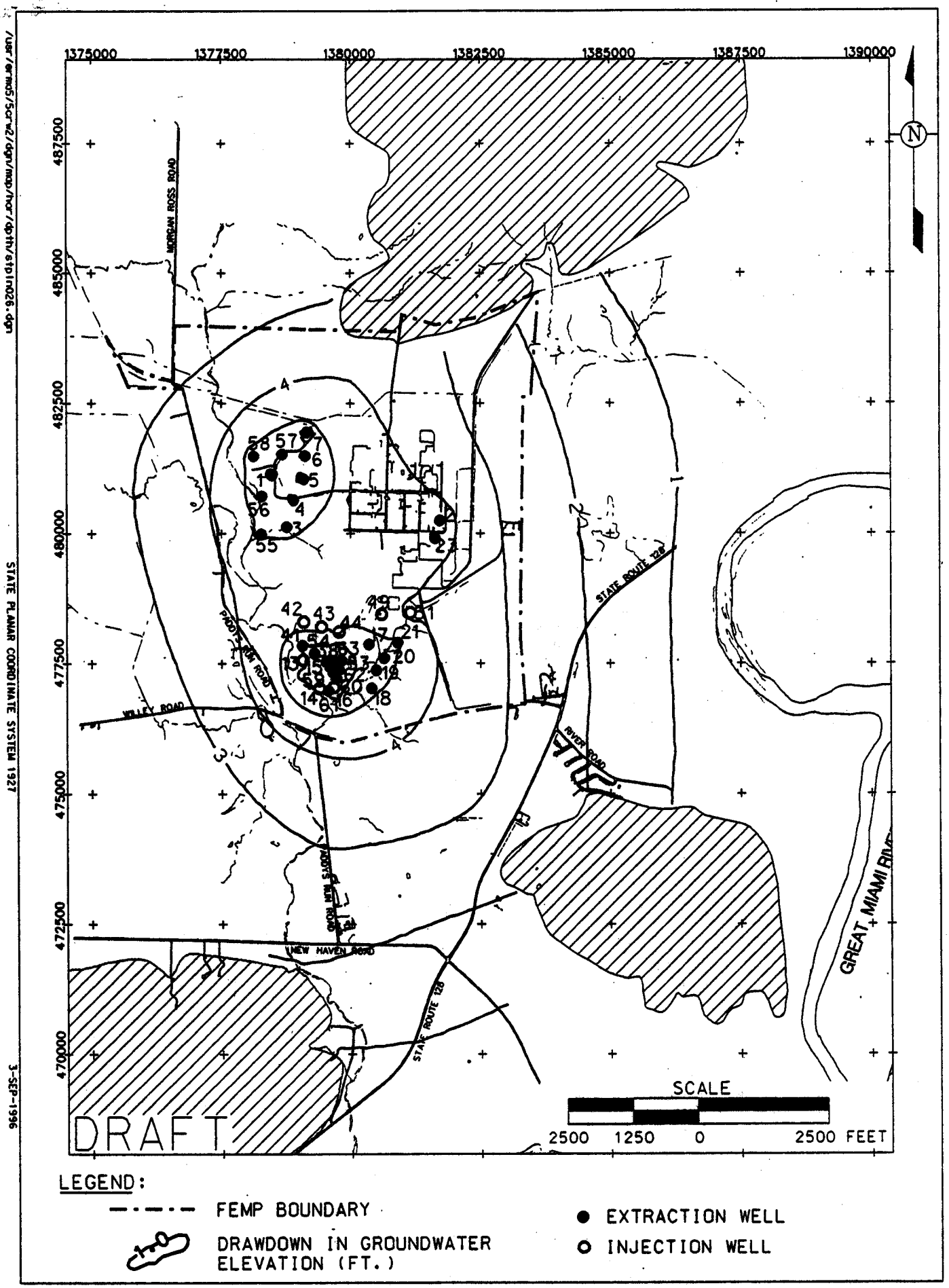


FIGURE 5-11. DRAWDOWN CONTOURS FOR THE BASELINE STRATEGY, YEARS 8-10

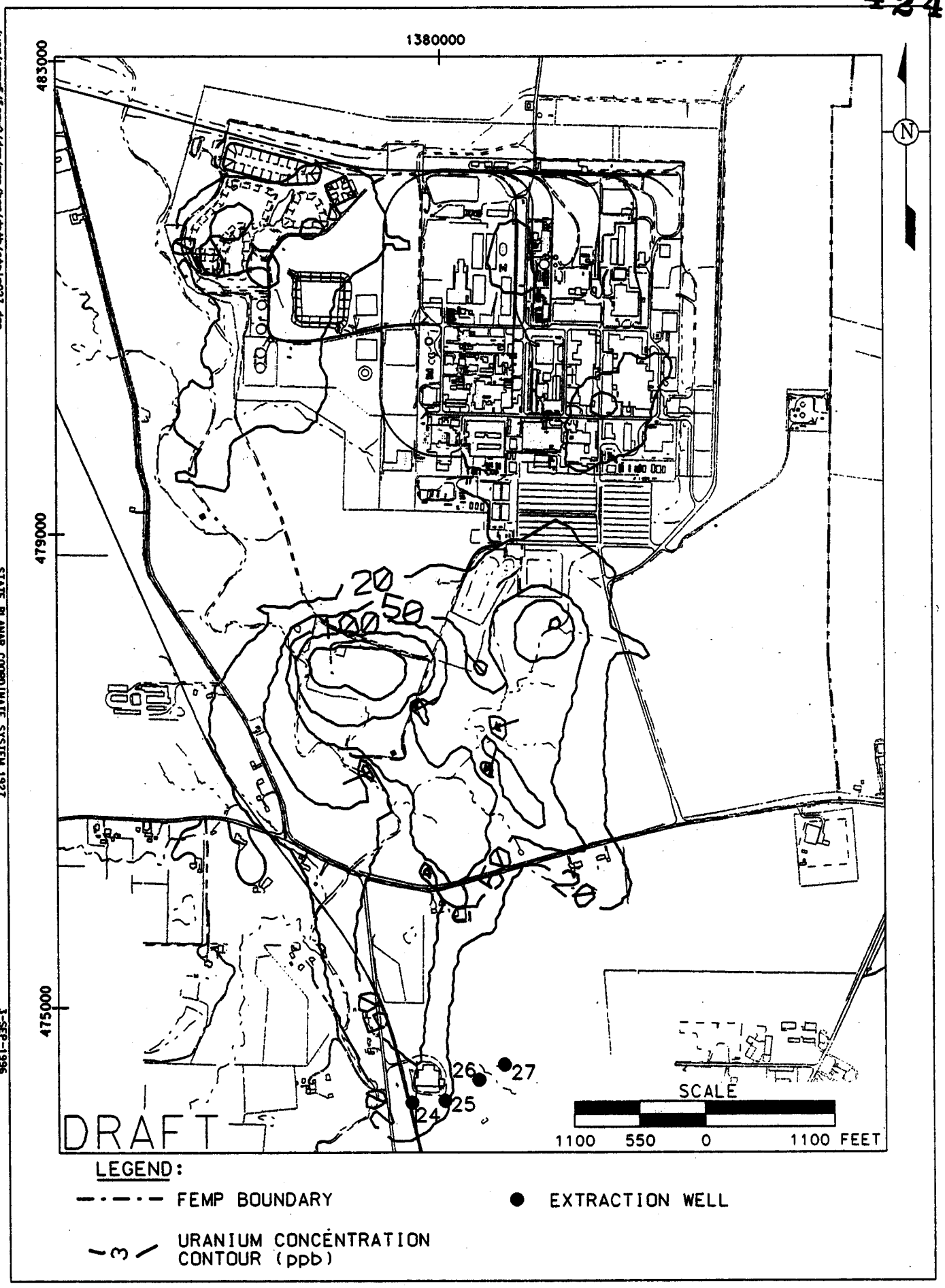


FIGURE 5-12. URANIUM CONCENTRATIONS AND PUMPING WELLS FOR THE BASELINE STRATEGY, YEAR 1

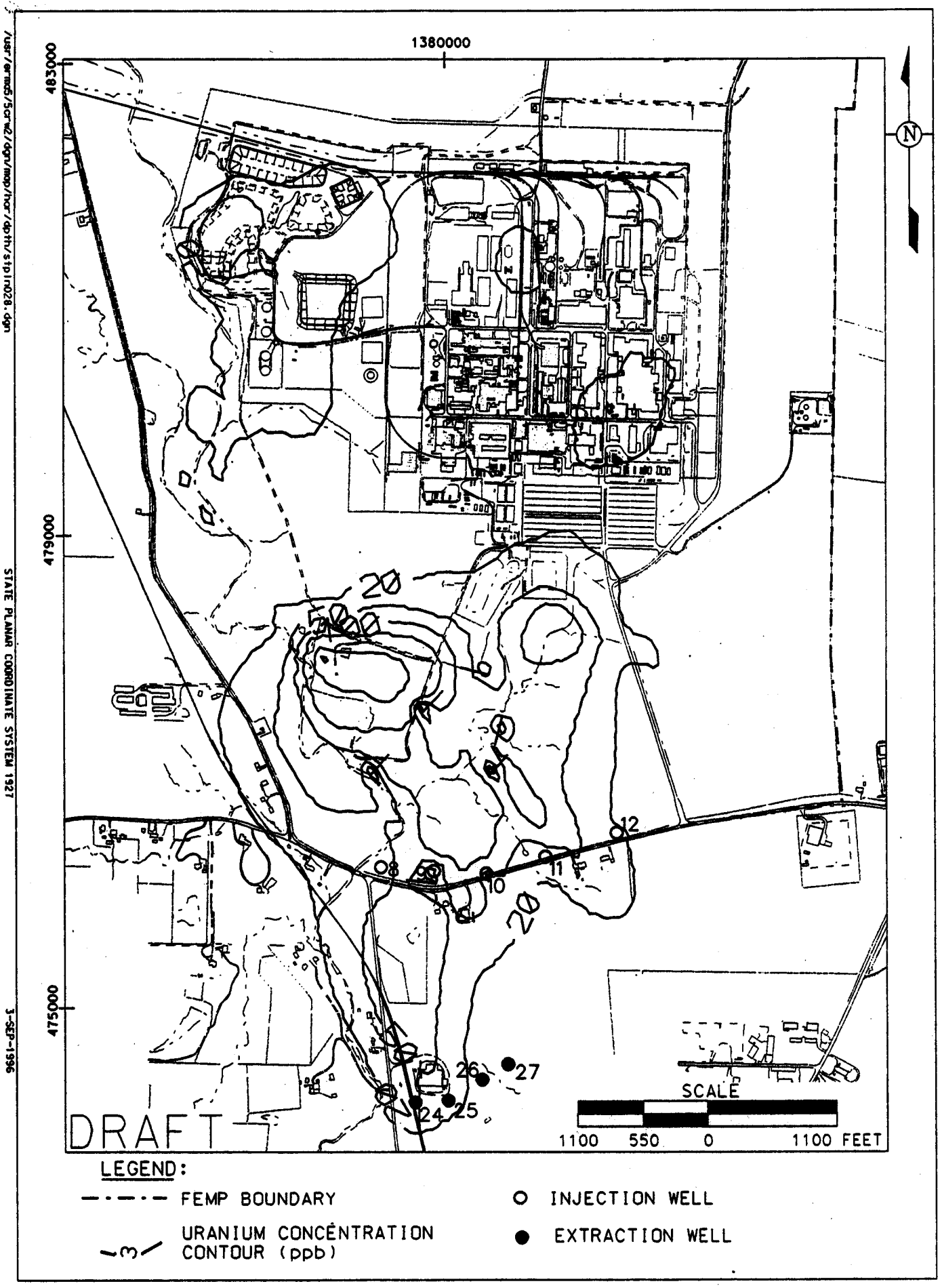


FIGURE 5-13. URANIUM CONCENTRATIONS AND PUMPING/INJECTION WELLS FOR THE BASELINE STRATEGY, YEAR 2

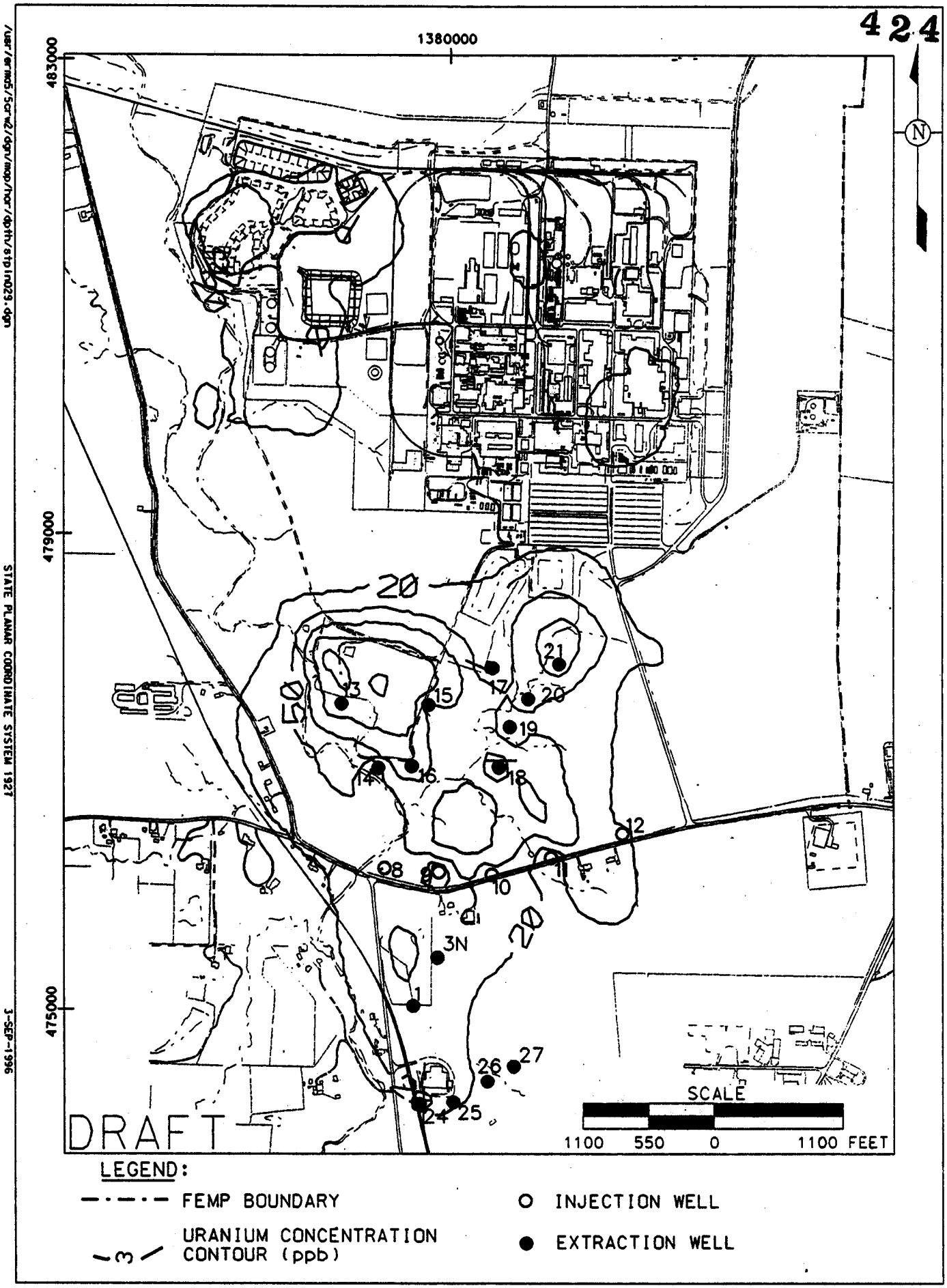


FIGURE 5-14. URANIUM CONCENTRATIONS AND PUMPING/INJECTION WELLS FOR THE BASELINE STRATEGY, YEAR 3

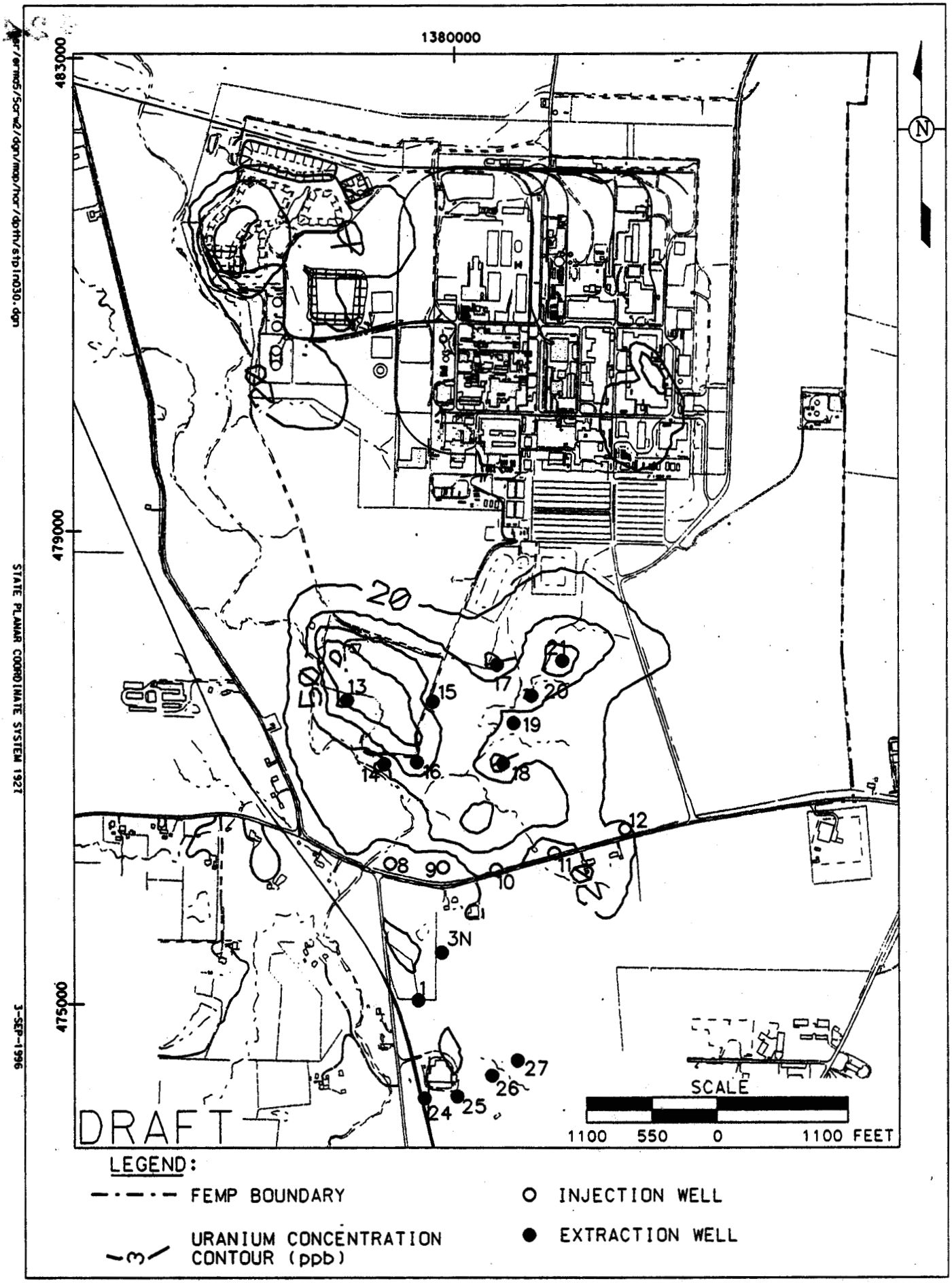


FIGURE 5-15. URANIUM CONCENTRATIONS AND PUMPING/INJECTION WELLS FOR THE BASELINE STRATEGY, YEAR 7

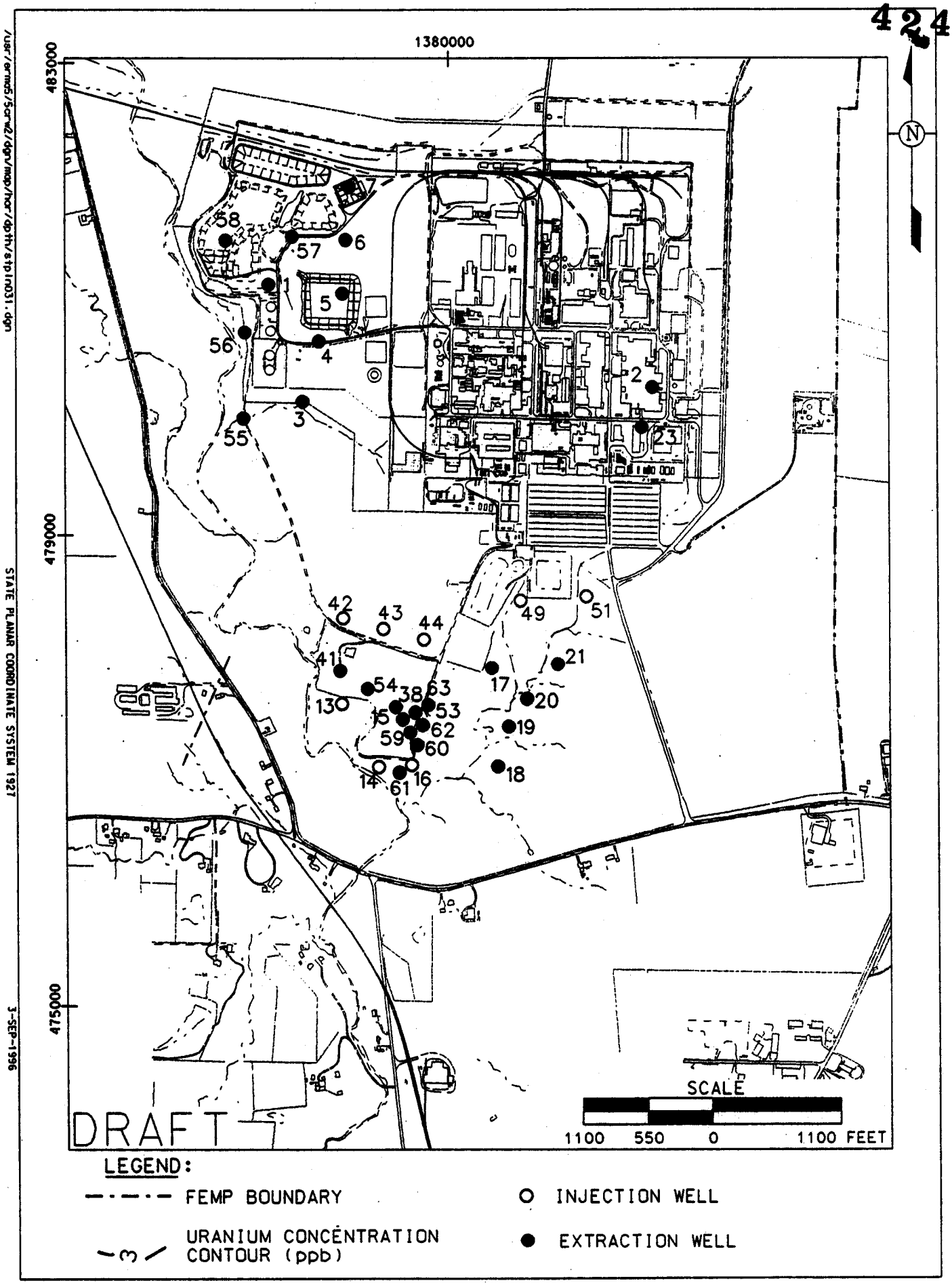
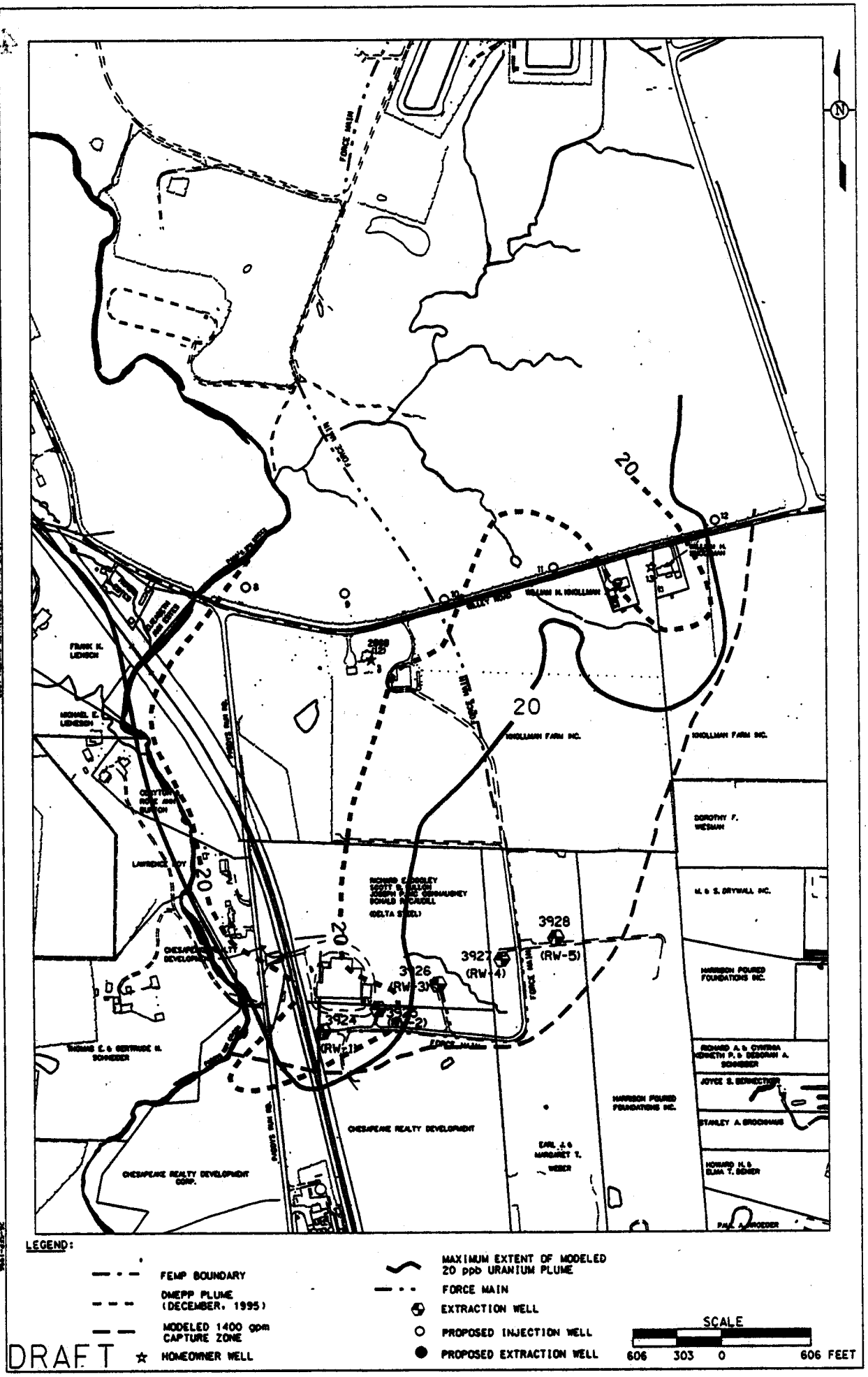


FIGURE 5-16. URANIUM CONCENTRATIONS AND PUMPING/INJECTION WELLS FOR THE BASELINE STRATEGY, YEAR 10



000114 FIGURE 5-17. CAPTURE ZONE AND MAXIMUM PLUME EXTENT

TABLE 5-2

SYSTEM PERFORMANCE MEASURES FOR THE BASELINE REMEDIAL STRATEGY

Year	Total Water Pumped (gpm)	Treatment Capacity (gpm)	Water to Treatment (gpm)	Concentration to Treatment (ppb)	Water Not Treated (gpm)	Concentration Not Treated (ppb)	Uranium Extracted from Aquifer (lbs)	Injected Water (gpm)	Concentration of Injected Water (ppb)	Uranium Injected[a] (lbs)	Water Discharged (gpm)	Concentration of Discharge (ppb)	Uranium Discharged (lbs)	Uranium Removed from Aquifer (lbs)	Outfall Concentration with Additional Treatment Capacity[b]
1	1400	850	850	12.9	550	12.9	79.1	0	N/A	0.0	1400	8.1	49.7	79.1	
2	1400	2000	1450	12.2	0	N/A	74.5	1000	5.0	21.9	400	5.0	8.8	52.6	
3	3300	2000	1500	75.2	1800	10.9	579.5	1000	5.0	21.9	2300	9.6	97.0	557.7	12.3
4	3300	2000	1500	73.2	1800	10.3	561.8	1000	5.0	21.9	2300	9.1	92.1	539.9	12.0
5	3300	2000	1500	69.5	1800	9.8	533.1	1000	5.0	21.9	2300	8.7	87.8	511.3	11.8
6	3300	2000	1500	80.4	2150	10.5	503.5	1000	5.0	21.9	2300	10.2	102.3	481.7	11.6
7	3300	2000	1150	76.4	2150	9.7	475.8	1000	5.0	21.9	2300	9.4	94.5	453.9	12.4
8	4800	2000	1700	19.1	3100	9.0	263.3	1600	5.0	35.0	3200	9.0	125.4	228.3	
9	4800	2000	1700	18.6	3100	7.9	245.4	1600	5.0	35.0	3200	7.9	110.3	210.3	
10	4800	2000	1700	14.3	3100	4.0	160.8	1600	5.0	35.0	3200	4.0	56.4	125.8	

Uranium Extracted from Great Miami Aquifer (lbs) 3476.8 Uranium Injected (lbs) 236.3 Uranium Removed from Great Miami Aquifer (lbs) 3240.5

[a]Calculated from residual uranium concentrations in injected water
[b]Assuming additional treatment capacity of 550 gpm to treat South Plume water

The human factors (see Section 1.3.1) which can not be directly addressed in a quantitative uncertainty analysis were evaluated qualitatively when selecting the preliminary baseline strategy as discussed in Section 4.3.2. Impacts of the two major natural factors (i.e., hydraulic characteristics of the aquifer and geochemical conditions as described by the K_d parameter in the SWIFT model) on the recommended baseline remedial strategy as described in Section 5.2 were further evaluated in an uncertainty analysis which is summarized in Appendix F.

As described in Appendix F, the sensitivity of the projected system performance to aquifer hydraulic characteristics and geochemical conditions was first evaluated. The purpose of the sensitivity evaluation was to identify the critical parameters used in modeling to characterize these two factors. Critical parameters were identified based on parameter-specific uncertainties and expected impact to the modeling results within the parameter-specific uncertainty ranges. The critical parameters were then evaluated in the uncertainty analysis to quantify the ranges of potential cleanup time and cost. During the uncertainty analysis, three bounding scenarios were defined to bracket the plausible range of potential geochemical conditions.

Results of the uncertainty analysis indicate that the range of the overall groundwater cleanup time using the recommended baseline remedial strategy should be between 10 to 20 years. Using the relative unit costs presented in Table 4-9, the overall cost of the aquifer remediation will be between 140 to 250 relative cost units (each unit is $500,000) based on the range of uncertainty in cleanup time. The difference between the lower and upper bounds primarily includes 10 years of groundwater treatment operation and monitoring and reporting activities after all the other FEMP source remedial activities are completed.

Based on the best available information, the projected performance of the recommended baseline remedial strategy as presented in Section 5.3.1 is considered the most likely path in which the groundwater remediation at the FEMP will progress. Strategies for dealing with the less likely conditions (such as those evaluated in the uncertainty analysis), should they manifest themselves during the remedial operation, are discussed in Section 5.4.5.

5.4 GENERAL OPERATIONAL STRATEGY

In addition to the properly designed extraction/injection well systems, success of the Aquifer Restoration Project as part of the overall FEMP remediation will also rely on a realistic operational

strategy which considers other major remediation activities at the FEMP. This subsection provides the critical operating guidelines during aquifer restoration.

5.4.1 General Principles

Requirements for achieving the performance goals of different FEMP remedial actions may compete for the same resources or may occasionally lead to conflicting operating decisions during remediation. Therefore, it is important to develop a general operating priority. The main potential conflict among aquifer restoration, storm water/waste water management, and wastewater treatment will be the treatment decision between storm water runoff and extracted groundwater. The general principles that will be followed to resolve these conflicts are the following:

- Compliance with the outfall criteria (NPDES and ROD commitments) will be the dominant regulatory requirement during the FEMP remediation
- Minimizing potential spreading of contaminants in the surface pathways (i.e., air, surface water, and sediment) caused by remediation activities is also one of the most important requirements for each of the FEMP remediation projects (so supporting the surface source control efforts is important)
- Allow duration of surface remediation involving open excavation, construction, or storage activities to be minimized (so supporting the on-going surface remediation activities is important)
- Uncontrolled storm water runoff concentrations should not be worse than the current conditions
- Available treatment capacity should be fully utilized.

5.4.2 Baseline Treatment Priorities

Due to the limited storm water retention basin (SWRB) capacity (for a 10-year, 24-hour storm event over the production and parking lot areas), collection of storm water runoff from areas with potentially higher contaminant concentrations in runoff (based on soil contaminant concentrations) should be given higher priority. This may involve adjustments of the storm water control area with the progression of the soil remediation and construction projects. Currently the storm water control system covers both the production and waste pit/silo areas where runoff contaminant concentrations are consistently higher than the remaining FEMP property.

Due to the higher contaminant concentrations expected in remediation wastewater and storm water runoff from source areas, treating remediation wastewater and storm water runoff will be given

higher priority than treating the extracted groundwater. Therefore, the total groundwater extraction rate will be throttled down when the available treatment capacity can not handle all three types of inflows and satisfy the outfall criteria. When groundwater extraction rate needs to be throttled down, remediation of the off-property groundwater plume should have higher priority.

Currently, the combined uranium concentration in the extracted South Plume groundwater is less than 20 ppb. This extracted groundwater flow does not require treatment to satisfy the outfall criteria. Therefore, the baseline priority does not impact the current operation of the groundwater remediation. However, when the South Field Extraction System starts operation in FY99, extracted groundwater from this module will require treatment. Groundwater extraction rate and treatment decisions will be affected during the wet seasons when storm water runoff volume is significant.

5.4.3 Groundwater Extraction And Injection Rate Determination

Table 5-2 summarizes the groundwater extraction/injection rate schedule based on assumptions regarding available groundwater treatment capacity. During the remediation, available groundwater treatment capacity will be determined using actual treatment capacity, and after storm water runoff and remediation wastewater treatment needs are met. Computer modeling will then be conducted to determine the optimal groundwater extraction rate for the extraction wells still within the uranium plume by maximizing the flow rate up to the originally planned rate and uranium mass that can be handled by the available treatment capacity and still satisfy the outfall criteria. Uranium concentrations of the extracted groundwater and the combined outfall will be projected in the modeling process. The model simulations will include groundwater injection when the injection wells are on-line. After the outfall criteria are satisfied, remaining available treated groundwater will be quantified and used in the injection operation. The projected capture zone and other hydraulic impacts will also be determined and documented.

In order to support the extraction/injection rate determination, validity of the Great Miami Aquifer groundwater model developed through the RI/FS process will be periodically evaluated and updated using the groundwater monitoring data collected during the remediation.

5.4.4 Modes Of Operation

Depending on the actual treatment capacity/performance and climatological conditions, there will be three major modes of operation of the groundwater remediation and wastewater treatment systems

during the FEMP remediation. Operating procedures for these three modes will be developed separately during the remedial design process. This subsection describes the general approaches of operation under these three modes.

5.4.4.1 Normal Mode

The expected normal operational mode is when the treatment capacity and the storm water/wastewater generation rate are close to the projected long-term average levels, respectively. Under the normal mode, groundwater remediation systems can be operated as planned and the outfall criteria can be satisfied. The normal operational mode represents a realistically achievable operational condition and will be maintained as much as possible throughout the life of the FEMP remediation.

5.4.4.2 Emergency Bypass Mode

During abnormal storm events, a portion of the collected storm water runoff may need to bypass treatment and be directly discharged to the Great Miami River to prevent overflow of the SWRB into the SSOD. The current outfall criteria allow 10 days (240 hours) in each year for emergency discharge of high storm water runoff. Groundwater extraction rates will be throttled down when the IAWWT treatment capacities need to be used for treating remaining storm water in the SWRB until the threat of overflow is eased. Because of the higher uranium concentrations, extraction rate of the on-property groundwater remediation modules will be lowered first to reduce the demand for treatment capacity. This will also allow the off-property groundwater remediation schedule to be maintained.

5.4.4.3 Insufficient Treatment Performance Mode

When the treatment capacity or efficiency (measured by uranium concentration in the treated water) drops significantly below the planned capacity due to technical problems for more than two weeks (i.e., 50 percent of the monthly evaluation period), groundwater extraction rates will need to be throttled down to ensure compliance with the monthly outfall criteria. The optimal lower extraction rates will be determined by model simulation. The technical problems will need to be corrected as soon as possible.

5.4.5 Continuous Performance Assessment and System Improvement

Based on the best available information and the most reasonable assumptions regarding site-specific hydrogeological, geochemical, and groundwater contamination, the selected remedial strategy presents

the "optimal" starting point of the detailed engineering design process and the full-scale groundwater remediation at the FEMP. However, due to the complex nature of groundwater contaminant fate and transport processes, a continuous improvement process based on EPA's "learn as you go" guidance (EPA 1992) will also be applied during the long-term operation of the remedial system. The Integrated Environmental Monitoring Plan (defined as Task 9 in the Operable Unit 5 RD Work Plan) will incorporate data collection and evaluation procedures necessary for continuous performance assessment and system improvement.

As described in Appendix F, although the bounding geochemical conditions simulated in the uncertainty analysis are significantly different from the baseline scenario, in order to simplify the uncertainty analysis only minor modifications to the original extraction/remediation rate schedule (see Table 5-1) using the wells included in the recommended baseline strategy and one additional contingent well were considered. Given the uncertainty of system performance, the operating situations (and accompanying remedial decisions) as described in Section 1.4 may develop. At some point in the future, as actual operating conditions are experienced and performance results are obtained, the FEMP's primary decision-makers (DOE, EPA, OEPA, and affected stakeholders) may be confronted with a need to modify the operating strategy of the groundwater remedy from that recommended initially by this report.

As stated in Section 1.4, tradeoff evaluations could be necessary during groundwater remediation and such tradeoffs will need to consider both the physical capabilities of the system and the most cost-effective path forward. The preferred course for some situations may result in adding additional infrastructure (resulting in increased capital cost) in order to preserve desired cleanup times and/or avoid additional long-term operational costs. In other cases, the preferred course may result in the need to extend cleanup time as the fiscally responsible decision. These decisions will need to be made on a case-by-case basis based on the physical and cost constraints imposed (recognizing DOE's programmatic objective to reduce site mortgage costs as tempered by available funding profiles), and under the collective agreement of DOE, EPA, OEPA, and affected stakeholders.

6.0 CONCLUSIONS

6.1 SUMMARY OF THE RECOMMENDED BASELINE REMEDIAL STRATEGY

The baseline groundwater remedial strategy to be used as the basis of the remedial design process has been developed. The development process started with a preliminary evaluation focusing on cost-effectiveness of a range of potential improvements to the FS strategy with simplified assumptions regarding funding and off-property access. A preliminary 10-year baseline strategy was selected at the end of the preliminary evaluation. The baseline strategy was finalized by incorporating necessary modifications after considering the actual funding schedule and off-property access limitations imposed by the landowner.

6.1.1 System Configuration

When compared to the remedial strategy presented in the Operable Unit 5 FS Report (DOE 1995a), the following modifications have been included in the selected preliminary baseline strategy:

- Groundwater injection along the fence line and north of the South Field will be used to improve hydraulic performance of the remediation system. The fence line system (converted from Wells 8 through 12 in the FS Strategy) will start operation in FY98 while the upgradient system (5 new injection wells) will start before FY04.
- Well 17 in the FS Strategy is moved to a new location north of the SSOD.
- Well 22 in the FS Strategy is reserved as a contingent well and its location will be selected during remediation if determined necessary.
- Two additional off-property extraction wells (pending the outcome of land access negotiations with the affected property owner) and four of the existing South Plume wells will be used to optimize the South Plume Recovery Well System.
- Nine more vertical extraction wells in the Inactive Flyash Pile, four more vertical extraction wells in the Waste Pit area, and one more vertical extraction well in the Plant 6 area will be installed and operated immediately following completion of local surface remediation or by FY04.
- Three of the initial extraction wells around the Inactive Flyash Pile will be converted into injection wells after the South Field Phase II System wells are installed.

Overall 44 wells (i.e., excluding Well 22) are included in the selected preliminary baseline strategy. The number of wells is 16 more than the number in the FS Strategy.

To meet groundwater injection requirements and satisfy outfall discharge criteria, a groundwater treatment capacity of 2000 gpm will be required. This capacity will be available in early 1998 following the completion of the AWWT expansion, which has been selected as the lead project for implementation under FY97 funding constraints.

6.1.2 Projected Performance

The recommended baseline strategy, the modified 10-year scenario, incorporates groundwater injection and additional off-property extraction wells. Shorter remediation schedules for other operable units under the 10-year site-wide remediation plan allow earlier starts of groundwater extraction operations directly in the groundwater hot spots with additional vertical extraction wells. It is expected that the recommended baseline strategy can shorten aquifer restoration time by seven to 17 years, considering geochemical uncertainties (see Appendix F for an analysis of the uncertainties associated with this restoration time). This is a significant reduction from the estimated 27 years presented in the Operable Unit 5 FS Report. As a result the overall cost of aquifer restoration may be reduced by approximately 50 percent from that estimated in the Operable Unit 5 FS, primarily due to the shorter remediation time. This reduction is partially due to a more realistic transition of the K_d values used in the groundwater model to evaluate system performance. In general, higher mass removal efficiency will be achieved with more direct groundwater extractions at the hot spots. The stress on the aquifer and potential impacts to the Paddys Run Road Site will be reduced by using groundwater injection. Also, less uranium mass will be discharged to the Great Miami River due to the higher removal efficiency and the lower overall volume of groundwater needing to be extracted. In summary, all the regulatory requirements and previous commitments are satisfied in the recommended baseline strategy.

6.1.3 System Implementation Flexibilities

It is important to highlight that the 10-year, 15-year, and 25-year scenarios do not differ in terms of remedial infrastructure until year seven, which is the year that source-area remediation is assumed to be complete. The scenarios begin to differ at that point in terms of the number and location of followup wells and operating schedules. This consideration is important because all three scenarios start with the same initial remedial hardware, and followup decisions regarding out-year infrastructure do not need to be made until some point in the future. This preserves an additional element of implementation flexibility, as decision-makers are not really eliminating other options with the decision to implement the 10-year strategy as the starting baseline system.

On the other hand, the 7.5-year scenario eliminates such flexibility because it requires a commitment to totally different infrastructure at initial implementation. The 7.5-year scenario represents a bounding case to demonstrate the technical difficulties of going to a less than 10-year cleanup.

6.2 PATH FORWARD

6.2.1 Remedial Design and Remedial Action

Six fundamental objectives have been formulated for the Great Miami Aquifer remedial design process:

- Accommodate the need for sequential restoration modules, each independently designed, installed, and operated using "learn as you go" principles over the life of the remedy
- Build into the remedy the necessary enhancements and improvements (i.e., injection) that were envisioned by the Operable Unit 5 FS and ROD Reports
- Develop a sound remedial approach that will accomplish remedial action objectives within the aggressive time frames contained in the FEMP's current funding baseline
- Accommodate the transition of the existing infrastructure and early start actions into a coordinated site-wide final remedy
- Satisfy discharge limits for the release of groundwater, storm water, and remedial wastewater to the Great Miami River
- Restore the off-property portion of the Great Miami Aquifer groundwater plume as the FEMP's highest groundwater priority.

In order to fulfill these objectives, a remedial design process that extends over the life of the remedy is required. The remedial design scope of work reflects the need to prepare stand-alone design packages for each of the area-specific restoration modules that will ultimately be brought on line.

The delivery dates for each of the design packages have been estimated based on groundwater modeling projections of the behavior of the system over the entire life of the remedy. These projected dates represent the DOE's best technical estimates for when design submittals will be necessary. It is important to be clear, however, that the "in-the-ground" performance of the system, once the various modules come on line, will dictate the actual dates for when the out-year design packages will be necessary.

The Amended Consent Agreement requires preparation of a remedial action work plan to cover

construction activities and the establishment of an enforceable RA schedule. Initially an "umbrella" RA Work Plan will be submitted to provide all information required by the Consent Agreement and to convey the enforceable construction schedule for the first module to be brought on line. Then an abbreviated addendum to the RA Work Plan will be submitted for each successive module as a means of providing the enforceable construction schedule for that module. The RA Work Plan addenda will be furnished as part of the prefinal design package for each future module and will be tailored to address module-specific implementation issues and needs.

6.2.2 Operations and Maintenance Plan

Under Task 2 of the RD Work Plan, A master Operations and Maintenance Plan will be developed as a means to coordinate the extraction, collection, conveyance, treatment, and discharge of all groundwater, storm water, and remediation wastewater generated on a site-wide basis over the life of the FEMP's cleanup mission. The general operational strategy for aquifer restoration discussed in Section 4.4 will be incorporated in this plan. Preventative and corrective maintenance requirements for the extraction/injection well systems specified in the baseline strategy will be presented in the plan.

The plan will also serve as the focal point for coordinating and scheduling remedial wastewater conveyance and treatment needs with other projects throughout the duration of the FEMP's cleanup mission. The plan will delineate the operating schedule, allowable direct discharge and treated water flow rates, system-by-system sequencing, and other operating constraints required to balance site-wide water management needs so that the FEMP's discharge limits are achieved. The plan will be modified as necessary over the life of the remedy to accommodate expansions to the system or the retiring of individual restoration modules from service once area-specific cleanup levels are achieved. The plan will thus serve as a living guidance document to instruct operations staff in implementing required adjustments to the system over time.

6.2.3 Process for Future Remedial Performance Decisions

As outlined in Section 1.4, the recommended strategy presented in this Baseline Remedial Strategy Report provides a recommended course of action based on the best understanding of site conditions available at this time. It is important to emphasize that the recommendation does not specify an enforceable restoration time frame that must be achieved at all costs. Rather, it identifies a preferred restoration time frame based on the anticipated behavior of the aquifer and the expected performance

and cost of the remedial components, consistent with EPA groundwater guidance.

At some point in the future, as actual operating conditions are experienced and performance results are obtained, the FEMP's primary decision-makers (DOE, EPA, OEPA, and affected stakeholders) may be confronted with a need to modify the operating strategy from that recommended initially by this report. The type of modifications, administrative actions, and/or hardware decisions will need to be assessed on a case-by-case basis based on the unique physical and cost constraints imposed. A cost/benefit analysis (similar to the one provided in this report) can be used to help establish an appropriate technical or administrative path forward. That path forward may involve an extension of restoration time, the addition of more wells to maintain restoration time, or the ultimate granting of a TI waiver based on the conditions experienced.

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APPENDIX A

MODELING APPROACH WITH K_d TRANSITION

A.1.0 PURPOSE

Mobility of uranium in the Great Miami Aquifer (GMA) is tied to the interplay of several physicochemical processes: precipitation, dissolution, adsorption, desorption, and ion exchange. Uranium may be removed from groundwater by precipitation, ion exchange, and adsorption, or returned to groundwater by dissolution, ion exchange, or desorption. The affinity for one process to occur over another will vary within the aquifer as groundwater composition, redox potential, particle composition, and particle surface area vary. Therefore, propagation of a uranium plume through an aquifer is a dynamic event where all these processes may occur simultaneously.

Commonly used fate and transport models are inherently simplistic when dealing with the spectrum of geochemical processes involved in the fate and transport of contaminants. The majority of fate and transport codes use the distribution coefficient (K_d) to account for the "retardation" of a contaminant as it travels with the groundwater. In a strict geochemical sense, the K_d establishes the equilibrium partitioning of a contaminant between the aquifer solid and groundwater for the special case of fast and reversible adsorption (i.e., a linear isotherm). However, this is not the conceptual model that fits the dynamic geochemical system outlined above, and assumptions must be made when applying the K_d concept to the fate and transport modeling of aquifer systems.

In the remainder of this appendix, each geochemical process is discussed and assumptions are formulated to tie these processes to the K_d value in the fate and transport model. The appendix is concluded by summarizing how the technical considerations and assumptions are implemented in the modeling procedures.

A.2.0 GEOCHEMICAL PROCESSES

Precipitation of a solute from groundwater requires that the activity product of ions in the precipitated phase exceed the solubility product for the phase (i.e., there is a thermodynamic affinity for the phase to form). Additionally, kinetics play a role in formation of the nucleation site and diffusion of ions to the nucleated phase. For the case of uranium in GMA groundwater, two secondary uranium phases have been identified in Fernald soil: meta autunite ($Ca(UO_2)_2(PO_4)_2 \bullet 4H_2O$) and soddyite ($((OU_2)_2SiO_4 \bullet 2H_2O$) (Buck et al. 1994). The extent of these uranium phases within the GMA has not been established, but their presence in Fernald soils indicates their ability to nucleate and precipitate under ambient conditions over the lifetime of the facility.

Dissolution of identified uranium phases by groundwater requires that the activity product of the ions comprising the precipitated phase is less than the solubility product of the phase. From a kinetic viewpoint, the surface area of the solid phase is the most important factor affecting the dissolution under ambient temperature and pressure. Additionally, uranium phases formed under ambient conditions are expected to have a greater affinity to dissolve in groundwater as compared to uranium oxides formed at high temperature (e.g., UO_2), as indicated by solubility studies conducted on contaminated Fernald soils (Lee et al. 1993).

Adsorption refers to two distinct processes: physical adsorption and chemisorption (Lasaga 1981). Physical adsorption results from the intermolecular or Van der Waal's forces acting between the particle surface and ion. This is the initial step in removing the ion from solution. Chemisorption involves the formation of chemical or ionic bonds between the surface atoms and the adsorbed species. Although physical adsorption occurs rapidly, chemisorption is slow and requires that the physically adsorbed specie "age" on the site to allow time for the bonding reaction to take place. Once chemisorption has occurred, additional energy is required to remove the specie from the solid. Therefore, adsorption/desorption reactions tend to become irreversible with time (i.e., only a fraction of what is initially adsorbed to the solid can be removed or extracted by desorption), which is in contrast to the fully reversible assumption invoked in fate and transport models by the use of K_d.

Ion exchange is physical adsorption that is accompanied by desorption of a different specie. The exchangeability of an adsorbed ion depends on how it is attached to the soil particle; that is, physical adsorption versus chemisorption. Species physically adsorbed to the soil particle surface are readily exchanged, while chemisorbed particles are more commonly exchanged only when they are on the corners or edges of particle fragments (Lasaga 1981).

A.3.0 REPRESENTATION OF GEOCHEMICAL PROCESSES IN FATE AND TRANSPORT MODELS

The state of the art in many areas of geochemical research is embryonic (EPA 1990). For example, activity coefficients of ions in strongly mixed electrolytes, the thermodynamic properties of clays, and the thermodynamics of adsorption have yet to be accurately determined. Thermodynamic data for many minerals and organic aqueous species are unavailable. Therefore, much preparatory research must be done before suitable simulations of geochemical processes can be conducted. Although, a substantial number of computer codes are available to evaluate the distribution of chemical species in

solutions, computer codes that model mass transfer or mass transport with simultaneous chemical reactions are currently limited in availability and/or scope.

A.3.1 COMPLEX MODELS

Four general types of computer codes are used to model aqueous geochemistry: thermodynamic codes (e.g., SUPCRT and PHAS20), distribution-of species codes (e.g., SOLMNEQ), reaction-progress codes (EQ3/6, PHREEQE, PHREEQEP, and ECES), and combined transport codes. Among these four types of computer codes, only the combined transport codes can directly simulate groundwater remediation operations.

Combined transport codes model chemical transport by combining aqueous-geochemistry codes with physical-transport codes. Two major approaches have been used: integrated codes simultaneously solve all mass, momentum, and energy-transfer equations, including those in which chemical reactions participate, for each time step in the evolution of the system; two-step models first solve mass momentum and energy balances for each time step and then re-equilibrate the chemistry using a distribution-of-species code. The CHMTRN, THCC, and CHMTRNS developed in late 80s are examples of integrated transport models. CHMTRN includes dispersion/diffusion, advection, adsorption of ions and complexes, aqueous complex formation, and dissociation of water. THCC is a variant that simulates uranium transport with variable temperature and oxidation potential. The latest version, called CHMTRNS (Noorishad et al. 1987), can simulate in one dimension both homogeneous aqueous phase and heterogenous temperature-dependent reaction kinetics. It has been applied to a number of simple problems involving reversible and irreversible dissolution, and oxidation-reduction reactions. It has not been tested with complex multicomponent systems. DYNAMIX (Liu and Narashimhan 1989 and 1989b) is an example of two-step transport model. It combines the transport code TRUMP with distribution-of-species code PHREEQE. The most recent version handles the thermodynamics of hydrolysis aqueous complexation, redox reactions and precipitation-dissolution.

Due to their complexities, intensive input data requirements, and difficulties of field verifications, combined transport models which also simulate complex chemical reactions, such as CHMTRNS and DYNAMIX, are still not widely used in typical contaminant fate and transport modeling projects. Capabilities and major deficiencies of these complex transport codes are summarized in a EPA report (EPA 1990). The sampling and analysis required to develop a site-specific complex transport model using these codes just to fine tune remedial system designs is prohibitive with respect to cost and

schedule. Therefore, it is not considered feasible or cost-effective to apply these codes to the development of remedial alternatives at the FEMP.

A.3.2 SIMPLIFIED MODELS

As an alternative to the complex combined transport models discussed in the previous section, most of the commonly applied groundwater contaminant fate and transport models only incorporate simple partitioning equations (Travis 1981) in a two-step approach. Well-known examples of these types of models include MODFLOW/MT3D, MOC, FEMWATER/FEMWASTE, and SWIFT. The models first solve mass, momentum and energy balances for each time step and then re-equilibrate the chemistry using the simple partitioning equations. These simple partitioning equations usually include parameters such as K_d to quantify the combined results of all relevant geochemical processes. These simpler models are used to provide estimates of the representative or conservative geochemical conditions in the study area. They usually can not simulate the actual time-dependent geochemical processes.

In common fate and transport models, K_d is used in a generic sense to include all geochemical processes in the continuum of precipitation, dissolution, physical adsorption, chemisorption, desorption, and ion exchange; albeit many users of fate and transport models do not state this assumption explicitly. K_d in the SWIFT model employed for Operable Unit 5 RI/FS and Baseline Remedial Strategy Report is used in this generic sense, and the implications of this assumption are highlighted below.

From a purely geochemical perspective, K_d implies equilibrium partitioning of a contaminant between soil and groundwater, where at any time interval the amount of contaminant removed by adsorption is equal to the amount released by desorption (i.e., adsorption and desorption ratios are equal). However, the release of adsorbed ions is a function of time (Lasaga 1981), and as the resident time of the absorbed ion increases there is a greater probability that the ion will chemisorb to ions in the structure of the solid phase. Once chemisorption takes place, it takes a greater amount of energy to remove the chemisorbed ion from the solid (i.e., desorb), and there is some diminishing return on the removal of the adsorbed contaminant from the solid.

The chemisorption process may manifest itself in measured "apparent" K_d values presented for desorption batch tests reported in Attachment F.8.IV, Appendix F of the Operable Unit 5 FS Report

(DOE 1995a). In these batch tests, the assumption was made that uranium in excess of background was adsorbed uranium, and an increase in the "apparent" K_d is an artifact of the removal of some portion of the contaminant from the adsorption/desorption process. To illustrate, consider a soil with adsorbed uranium of 2 mg/kg in equilibrium with groundwater having a uranium concentration of 1 mg/L, with the K_d being equal to 2 L/kg. The groundwater is removed from the soil during remediation and the next volume of groundwater equilibrates at a uranium concentration of 0.1 mg/L with soil having a uranium concentration of 1.8 mg/kg. The "apparent" K_d would be measured as 18 L/kg. However, if the true K_d remains at 2 (0.2 mg/kg ÷ 0.1 gm/L), the implication is that 1.6 mg of uranium is chemisorbed on a kg of solid. Alternatively, the assumption that uranium in excess of background is adsorbed may be incorrect if chemisorbed or precipitated uranium is present. This situation in FEMP surface soil has been verified and evaluated in a laboratory multi-phase desorption batch test study in which 30 soil samples were analyzed (DOE 1995c).

A.4.0 SITE-SPECIFIC CONSIDERATIONS

The rate of uranium adsorption/desorption processes will control potential mobility of uranium as well as aqueous-phase concentrations in the GMA. Therefore, estimates of the groundwater cleanup time and the treatment requirements during groundwater remediation are highly dependent on modeling assumptions regarding the uranium adsorption/desorption processes. Because, the SWIFT model can only use one K_d value in a model simulation, the previous modeling approach (e.g., FS modeling [DOE 1995a]) used constant uranium K_d values throughout the duration of groundwater remediation. The uranium K_d value used in a specific model simulation either represented the adsorption or the desorption condition. However, as described in Attachment F.3.I, Appendix F of the Operable Unit 5 RI Report (DOE 1995b), adsorption and desorption processes are not fully reversible and may have significantly different "apparent" solid/liquid equilibrium ratios.

Due to the termination of source loading and removal of initial dissolved mass, it is expected that the geochemical conditions will change during groundwater remediation. The adsorption dominant process in the early stage of remediation will become a more desorption dominant process in the later stage. Because, even under the same groundwater flushing rate, the apparent releasing rate of residual mass during the desorption process is much slower than the original adsorption process, the uranium "apparent" K_d value is expected to increase during groundwater remediation. It is important to note that the instantaneous equilibrium assumption is still required for using the "apparent" K_d

concept in a model during the desorption dominant process. Only the equilibrium ratio is changed in the transport model.

To handle the mass of chemisorbed or precipitation uranium on the aquifer solids, adjustments can be made to the mass balance calculation or "apparent" K_d value. A negative mass loading may be used to account for the uranium mass that is unavailable for desorption, or a larger "apparent" K_d value can be used to retain the uranium mass on the aquifer solids. For either case, additional uncertainty presents itself at the point selected to begin the negative loading or increase the "apparent" K_d, and this is addressed in Section A.4.6. As a matter of continuity with previous fate and transport work at Fernald, the "apparent" K_d value was changed from a lower adsorption value to a higher desorption value to account for uncertainty in the uranium mass retained by chemisorption or precipitation. The assumptions invoked for this analysis are that the higher "apparent" K_d value will:

- Account for chemisorbed or precipitated uranium that may persist for some time in the aquifer and
- Mimic the anticipated retention of some uranium by chemisorbed and precipitation forms after initial extraction of present groundwater.

Key technical considerations for the new modeling approach are described in this section. These considerations identify the factors and issues that need to be quantified or resolved in the modeling approach. In order to incorporate the transition of uranium K_d value into the modeling approach, several important factors need to be properly characterized.

A.4.1 "APPARENT" URANIUM K_d DURING ADSORPTION

A uranium K_d value of 1.78 L/kg is representative of the adsorption dominant conditions. This value was determined through the transport model calibration process which simulated the uranium loading (primarily through surface water infiltration) in the past 40 years (DOE 1993 and 1994) to match the current groundwater plume. During this period, a significant amount of uranium contaminated surface runoff infiltrated through Paddys Run and the SSOD into the Great Miami Aquifer. The resulting groundwater plume then migrated south and southeast from the losing sections of these two surface water bodies. Due to this continuous loading of uranium mass, the dominant process in the aquifer during the past 40 years was adsorption of uranium onto aquifer soil. During the early stage of groundwater remediation before the source loading is terminated and initial dissolved uranium is extracted, the dominant geochemical process will still be adsorption.

A.4.2 "APPARENT" URANIUM K_d DURING DESORPTION

During groundwater remediation, after the source loading is terminated and initial dissolved uranium is extracted, the dominant geochemical process will begin to shift to desorption. Residual uranium mass adsorbed on soil will start to dissolve when groundwater concentrations are significantly reduced by extraction. A uranium K_d value of 17.8 L/kg is considered representative of the desorption dominant conditions. As presented in Attachment F.8.IV, Appendix F of the Operable Unit 5 FS Report (DOE 1995a), this value was determined through regression analysis of results from desorption batch tests of contaminated aquifer soil samples.

The numerical difference between 1.78 and 17.8 L/kg may not seem to be significant considering uncertainty usually associated with inorganic K_d values. However, the amount of uranium currently in the GMA will be 10 times higher if an initial K_d value of 17.8 L/kg is used directly instead of the 1.78 L/kg value. The resultant uranium mass will significantly exceed all the independent estimates of mass that may be present in the aquifer (Boback et al. 1987). Therefore, from a mass-balance point of view the 1.78 and 17.8 L/kg K_d values are significantly different for determining the starting mass of uranium in the GMA and should present two very different geochemical conditions.

A.4.3 TIMING OF THE TRANSITION

In reality, the transition between adsorption and desorption conditions will be a gradual and continuous process. However, the SWIFT model cannot simulate a continuous transition process. In order to use the SWIFT model, it is necessary to simplify the continuous process into a two-stage process. The first stage will simulate the adsorption dominant period while the second stage simulates the desorption dominant period. Conceptually, a significant variation of the uranium geochemical condition may occur immediately after the source loading is terminated and the initial dissolved mass is extracted. Therefore, the "apparent" K_d transition can be assumed to happen right after both conditions (i.e., source termination and extraction of initial dissolved mass) are satisfied.

A.4.4 MASS BALANCE

The mass of uranium in the aquifer before and after transition of the K_d value should remain the same in the model. Only the distribution of overall mass between the aqueous and solid phases is changed at the time of K_d transition. Predicted groundwater concentrations and uranium adsorption K_d of 1.78 L/kg should be used to determine the overall mass at the time of transition. The "apparent"

uranium desorption K_d value of 17.8 L/kg should then be used to redistribute the uranium mass between the two phases.

A.4.5 REMEDIATION SCHEDULE

Due to the soil remediation schedule and the need for sequential starts of groundwater extraction systems in different areas, transition of the "apparent" K_d value in different portions of the aquifer may occur at different times. Therefore, groundwater plumes in different areas may need to be simulated separately. In general, multiple model runs and superposition of results will be required to combine different timings of transitions among the recovery well systems. However, a consistent groundwater flow model that simulates the site-wide extraction/injection rate schedule needs to be used as the common basis for all the separate transport model runs. Only the targeted plumes and the uranium geochemical conditions will be varied among simulation runs for which the results are to be superimposed.

A.5.0 GENERAL MODELING PROCEDURES

Based on the previous discussions, an alternative modeling approach using the existing SWIFT model was developed and used to more realistically simulate the uranium adsorption/desorption process during groundwater remediation. A transition of the "apparent" uranium K_d value from an adsorption dominant condition to a desorption dominant condition during remediation was implemented in this approach. This section describes the approach as it was applied to select the new baseline groundwater remedial strategy.

Technical considerations described in the previous sections are implemented in the following modeling procedures:

Step 1 Specify the extraction/injection rate schedule and complete the flow model simulation

The site-wide groundwater flow conditions under the specified extraction/injection operation will not be affected by the modifications in the contaminant fate and transport simulations.

Step 2 Separate the initial overall groundwater plume into multiple plumes

Based on the local soil remediation schedule and the extraction/injection rate schedule, the transition of the geochemical condition may occur at different times for different portions of the overall plume.

Therefore, it is necessary to divide the overall groundwater plume into multiple plumes according to the remediation schedule. These plumes will then be modeled separately, as in Steps 3-7.

Step 3 Determine the time required to extract initially dissolved mass in each individual plume

The time-dependent hydraulic capture zone of the recovery well system operated in each individual plume needs to be determined using particle tracking in order to estimate the time required to extract the initially dissolved contaminant mass. Another approach is to run the fate and transport model to determine the local cleanup time assuming no adsorption/desorption (i.e., K_d = 0 L/kg) and no additional loading.

Step 4 Determine appropriate transition time of K_d for each individual plume

The one-step transition is assumed to happen right after the source termination and extraction of initial dissolved mass. Therefore, between the time required to complete source remediation and the time required to extract initially dissolved mass, select the longer time frame as the approximated transition time of geochemical conditions.

Step 5 Complete the Stage I fate and transport simulation for each subarea

Use a K_d value of 1.78 L/kg to simulate the adsorption dominant period (i.e., from the current time up to the transition time).

Step 6 Assign initial concentrations for Stage II in each subarea

Redistribute the total residual mass in each model block at the end of Stage I between the aqueous and solid phases using a K_d value of 17.8 L/kg.

Step 7 Complete the Stage II fate and transport simulation for each subarea

Use a K_d value of 17.8 L/kg to simulate the desorption dominant period (i.e., from the transition time until site-wide cleanup is achieved).

Step 8 Overlay the fate and transport modeling results of each subarea

Superimpose the subarea-specific modeling results obtained in Steps 5 and 7 at select time points throughout the groundwater remediation.

Step 9 Postprocess the final results

Time-specific site-wide groundwater plume contours, treatment capacity requirements, outfall concentrations, and other performance measures can be obtained from the combined groundwater concentrations.

A.6.0 UNCERTAINTY ANALYSIS

Modeling results need to be evaluated considering the uncertainties associated with the above important factors. Among the important factors, uncertainty regarding timing of "apparent" K_d transition is considered the highest because currently it is not based on any laboratory studies or model calibration. Therefore, model simulations with delayed transitions (i.e., assuming the "apparent" K_d transition will not occur immediately after the source termination and extraction of one additional pore volume) have been conducted to quantify the impact on the groundwater remediation time. A no-transition scenario (i.e., using a constant adsorption K_d value throughout the simulation as in the FS modeling) should provide an upper bounding estimate of the cleanup time estimate of a specific system design. On the other hand, a no-K_d scenario which assumes all the currently adsorbed mass will not dissolve during remediation should provide a lower bounding estimate of the cleanup time estimate. Therefore, three sensitivity runs (i.e., no-K_d, delayed-transition, and no-transition) in addition to the baseline approach (described in Section 5.0) were conducted to bracket the cleanup time for a given remedial system design.

Appendix F summarizes the model simulations conducted for the uncertainty analysis of the Baseline Remedial Strategy Report, and also reviews the previous sensitivity analyses conducted during the Operable Unit 5 RI/FS.

A.7.0 SUMMARY

Existing groundwater contaminant fate and transport modeling technologies still cannot efficiently simulate the dynamic, nonuniform, irreversible adsorption/desorption process in the real world. The modeling approach described in this appendix uses the existing SWIFT model, multiple intermediate model runs for subareas with different geochemical conditions, and superimposition of these results to allow a simulation of the transition of geochemical conditions. Therefore, a more realistic prediction of the groundwater remediation process can be achieved. Although this approach is still a simplification to a very complex adsorption/desorption process, the estimated scenario-specific treatment capacity requirement, treatment time, cleanup time, amount of uranium recovered, and

impact to the Great Miami River are considered more accurate. Based on results from this modeling approach, the remedial strategy can be selected more appropriately.

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APPENDIX B

FEASIBILITY OF USING HORIZONTAL WELLS FOR GROUNDWATER REMEDIATION

B.1.0 INTRODUCTION

The feasibility of using horizontal wells for groundwater remediation at the FEMP was evaluated as a part of the process to finalize the groundwater strategy for remedial design purposes. Literature reviews, vendors' recommendations, and results of model simulations was gathered for determining the feasibility and relative cost of applying horizontal wells to groundwater remediation. Appendix B briefly presents the process and important findings of this feasibility evaluation task.

B.2.0 OVERVIEW

Specific objectives, general procedures, and deliverables of this evaluation are listed in the following sections.

B.2.1 OBJECTIVES

The following objectives were first identified:

- Evaluate the feasibility of using horizontal recovery wells for groundwater remediation at the FEMP
- Determine cost and benefits
- Incorporate the collected information into the selection process for the new baseline groundwater remedial strategy.

As indicated by these objectives, the two key questions to be answered by this task are about the feasibility and cost effectiveness of horizontal wells.

B.2.2 EVALUATION PROCEDURES

A series of evaluation procedures were followed in order to cover all the important sources of information regarding the feasibility, cost, and performance of horizontal wells. Both qualitative and quantitative evaluations were conducted based on relevant general and site-specific conditions. The evaluation procedures can be summarized by the following:

- Identify potential installation techniques
  - Directional drilling (blind well and continuous well)
  - Vertical caisson with radial collector wells (Ranney well)

- Select target areas at the FEMP for applying horizontal wells
- Review area-specific hydrogeological and contamination data
- Conduct literature search
- Identify and consult internal and external experts
- Estimate achievable inflow distributions and optimal well layouts by modeling
- Compare the available and normally applied installation techniques
  - List major well-design considerations
  - Identify potential risks and logistical problems during installation
  - Determine the most effective design and installation approach
- Define the maintenance requirements
- Estimate the relative cost of horizontal wells versus vertical wells.

B.2.3 DELIVERABLES

Specific deliverables of this evaluation included:

- Summary of the feasibility
- Conceptual presentation of the most effective horizontal well design
- Cost information.

After completion of this task, information presented in these deliverables was then incorporated in the development of a potential groundwater remediation scenario using horizontal wells. This potential scenario was evaluated during the selection process of the new baseline remedial strategy.

B.3.0 IMPORTANT FINDINGS

Important findings of this evaluation task, which will directly impact the remedial strategy selection at the FEMP, are described in this section. Other more general descriptions regarding horizontal well design, installation, and application can be found in an EPA manual (EPA 1994).

B.3.1 PATTERNS OF THE INFLOW DISTRIBUTIONS

Due to the long screen length, a uniform or a transmissivity-weighted inflow pattern usually assumed for a relatively shorter vertical well screen is not appropriate for a horizontal extraction well. Therefore, a pipe flow model (i.e., Fathom) was first used to determine the inflow rate distributions

along various horizontal well-screen designs. Factors considered in this analysis included well diameter, length, depth, number of pumps, and the aquifer's response to pumping.

In this pipe model the aquifer was simulated as a series of reservoirs 25 feet (i.e., a typical vertical well-screen length) apart along the pipe with constant water elevation equal to the average water table elevation before pumping. Elevation of the horizontal pipe is set at about 20 feet below the water table. The aquifer step drawdown test results (i.e., the pumping rate versus the drawdown curve) were then embedded in a series of conceptual energy-loss components between each reservoir and the horizontal pipe. Therefore, when a specific inflow occurred between a conceptual reservoir and the horizonal pipe, the component linking the reservoir to the pipe caused a head loss equivalent to the drawdown due to pumping at the same rate. In order to approximate the accumulated drawdown due to adjacent inflows, the drawdown curve was increased by a factor of two, except for the two reservoirs at each end of the well-screen. Various pumping rates from one end or both ends of the pipe were then simulated. The simulated inflow rates within each of the four quarter sections of the horizontal pipe were then calculated. Finally, the four sectional inflow rates were then converted into percents of the total inflow (i.e., normalized against the total flow).

The following three types of horizontal well-screen designs were simulated using the pipe model:

- Type A - Blind well with a fixed diameter
- Type B - Blind well with variable (i.e., telescoped) diameters
- Type C - Continuous well (i.e., pumps at the both ends) with a fixed diameter.

The estimated sectional inflow rate distribution along the length of the above three well-screen designs are summarized below:

- Type A - 55, 20, 10, and 15 percent (starting from the pumping end)
- Type B - 40, 25, 20, and 15 percent (starting from the pumping end)
- Type C - 30, 20, 20, and 30 percent (pumping from both ends).

B.3.2 OPTIMAL LAYOUT OF HORIZONTAL WELLS

After the potential inflow rate distribution patterns were determined, SWIFT model simulations were conducted to predict uranium transport using various horizontal well layouts (i.e., specific types, lengths, locations, orientations, and extraction rates) for groundwater remediation. The specific extraction rate of a horizontal well was simulated by assigning extraction rates in multiple model grid blocks where the horizontal well is located. The estimated inflow distribution pattern for the type of well simulated was used to determine these extraction rates.

Figure B-1 shows the most effective horizontal well layout evaluated for the South Field/SSOD and South Plume areas. Five horizontal wells were used in this scenario including:

- Two Type C horizontal wells with 500-foot screens and pumping at 500 gpm each (a total of 1000 gpm) in the South Field
- One Type B horizontal well between the SSOD and Willey Road with a 500-foot screen and pumping at 400 gpm
- One Type B horizontal well with a 500-foot variable diameter screen pumping at 900 gpm
- One Type B horizontal well with a 375-foot variable diameter screen pumping at 300 gpm.

Geological cross sections along each of these five well axes were prepared and evaluated to verify that the well type specified can be installed. Type B horizontal wells were used along the fence line primarily to avoid the need for off-property surface access. Although not specifically simulated, it was assumed that two Type C horizontal wells and one Type B well can also be used in the waste pit and Plant 6 areas, respectively. In a horizontal well remediation scenario, these three horizontal wells can be used to replace all the vertical extraction wells specified in the remedial strategy presented in the Operable Unit 5 FS Report (DOE 1995) for these two areas.

B.3.3 WELL INSTALLATION

Because a horizontal well can be installed by either horizontal directional drilling or Ranney technology, the advantages and disadvantages of these two approaches were evaluated to select the appropriate installation method in the optimal layout determined through model simulations. Other major design considerations regarding the horizontal wellbore specifications include: trajectory, diameter, casing/screen materials and filter pack.

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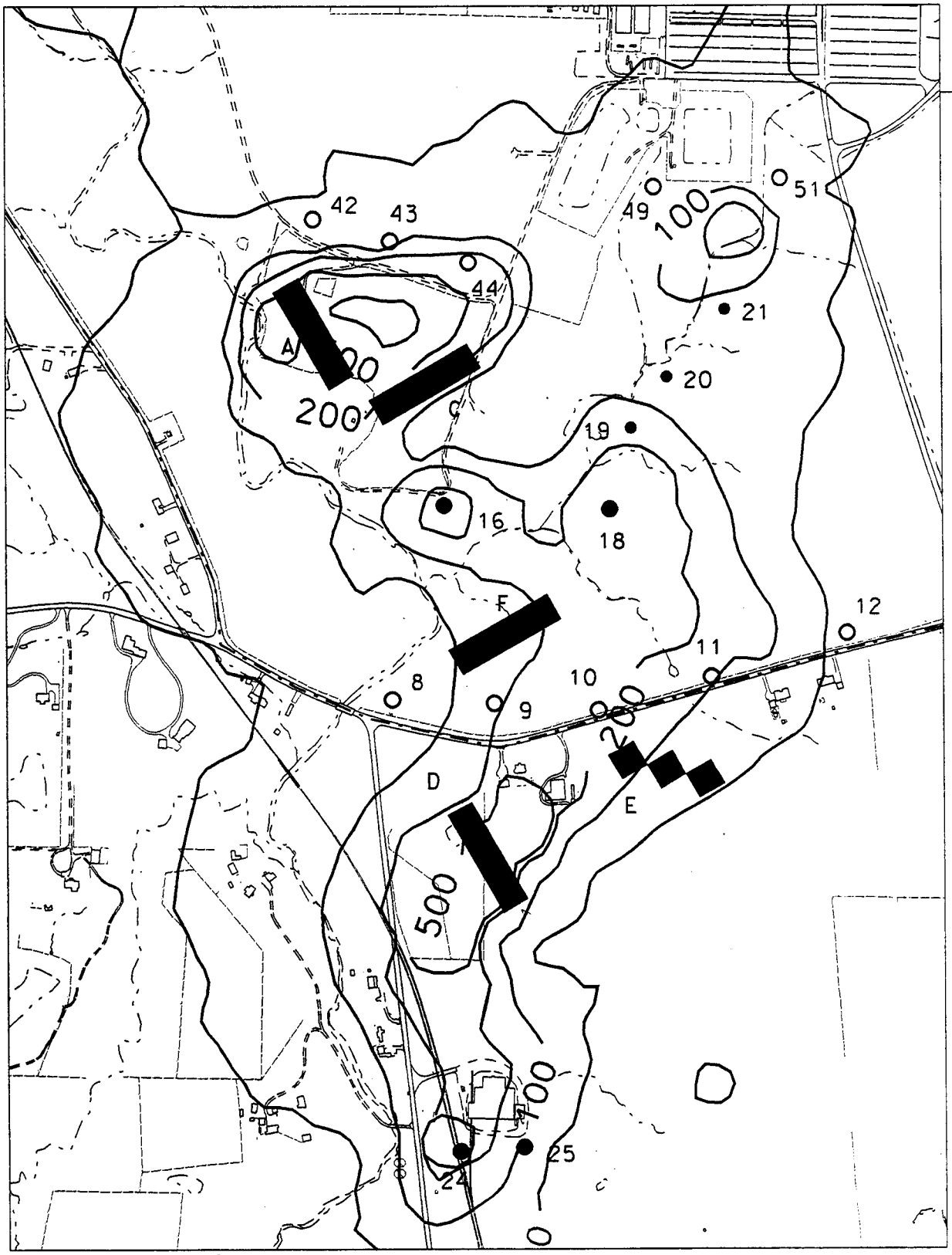

FIGURE B-1. HORIZONTAL WELL LAYOUT EVALUATED FOR THE SOUTH FIELD/SSOD AND SOUTH PLUME AREAS

The major advantages of using horizontal directional drilling include the capability to install much longer wells (i.e., with a more than 350-foot long horizontal section) and continuous wells (i.e., wells with both ends open to the ground surface). The expected cost of directional drilling is also lower than the Ranney approach. However, in order to facilitate the desired high pumping capacity (i.e., 300 to 900 gpm), well diameters that are larger than is typically done in directional drilling applications will need to be installed. Another potential problem associated with the directional drilling is that it is often difficult to properly redevelop the well-screen area to remove fine materials and residual drilling mud used during the drilling process from the formation. Even with adequate well-screen diameters, there is no assurance that effective well-maintenance cleaning can be performed if needed, due to the curvature of the well precluding the use of appropriate cleaning devices.

Ranney wells have a better chance to obtain the high pumping capacities because no drilling mud is required during installation and larger or multiple pumps can be installed in the 9- to 16-foot caisson. Ranney wells can also have multiple lateral drains in a single caisson. In a Ranney well, access to the well-screens is easily made in the caisson so that proper well-cleaning equipment can be used to rehabilitate the well-screens, if required. However, a significant amount of soil needs to be excavated and disposed of during installation and the required length of the horizontal well is much longer (i.e., up to 350 feet) than is typically done in Ranney well applications. Installation of the large caisson and associated health and safety requirements will result in much higher costs for Ranney wells than wells installed by directional drilling.

Based on the advantages, disadvantages and limitations of the two installation technologies, a suitable technology was selected for each horizontal well. Directional drilling was selected for installing the five continuous horizontal wells (i.e., pumped from both ends) in the South Field, waste pit, and Plant 6 areas because contaminated soil in these areas which will preclude the Ranney approach. Additional horizontal wells can be installed in these areas to ensure the desired overall extraction rates, if deemed necessary by the potentially lower achievable pumping rate in each well. Stainless steel casing and prepacked screens are preferred for these wells. The Ranney approach was selected for installing the three horizontal wells in the South Plume area because the overburden is considered clean and higher pumping rates are required. Although these selections do not affect the estimated performance measures, they will be reflected in the cost estimates.

B.3.4 RISKS AND RELATIVE COST

Installation

The typical cost of a horizontal well installation using directional drilling technology is about 5 to 10 times higher than a vertical well. Following are some of the reasons for the higher installation cost for a horizontal well:

- Mobilization of special equipment
- Larger amount of contaminated cuttings
- Need for an effective guidance system
- Longer casing and screen
- Difficulty of filter pack installation
- Decontamination of special equipment (e.g., rig, guidance system and mud system).

The installation cost of a Ranney well will be higher than a directionally drilled horizontal well due to the following factors:

- Very few contractors have Ranney well experience or capability
- Need for a large reinforced concrete caisson
- Additional soil excavation and disposal
- Health and safety requirements for the deep and confined working space.

A major cost component of horizontal well installation will be for covering the risk of potential failure during installation and the subsequent need for rework. Contractors usually use larger safety factors (sometimes adding up to 200 percent to the real cost of the horizontal well installation) when bidding on horizontal well installation projects. Potential problems during horizontal well installation at the FEMP may include:

- Access to a large laydown and entrance area
- Difficulty of steering the drilling bit in unconsolidated sand and gravel
- Higher risk of wellbore collapsing in unconsolidated sand and gravel
- Side effects of the drilling fluid
- Unexpected hard materials such as rock or concrete debris along the designed path
- Potential difficulties during well completion and development.

Currently some experts in the horizontal directional drilling industry are promoting a well design and installation technique for horizontal wells that is standardized, low risk, and familiar to the contractors. Details of these proposed approaches are described in a recent paper (Wilson 1996).

Operation and Maintenance

Cost savings from using horizontal wells will be realized primarily during operation from the following factors:

- Smaller number of pumps
- Less complex piping network and operational procedure
- Shorter cleanup and treatment time frame.

There are several concerns during operation of the horizontal wells:

- Need for a higher groundwater treatment capacity
- Questionable long-term performance of pumps in inclined or horizontal positions
- Curvature of the well may preclude use of appropriate well-cleaning devices
- Difficulty targeting specific smaller zone of residual contamination along the well screen.

Relative Cost

Estimated ranges of the relative costs of horizontal well installations when compared to a typical vertical extraction well are listed below:

Types of Wells	Relative Costs
One on-property vertical extraction well	1
One horizontal extraction well	4.5 - 6
One Ranney well	7.5 - 10
One additional horizonal section from a Ranney well	4 - 6

The fully burdened cost (i.e., well design/installation/development, pump and piping) of a vertical extraction well at the FEMP is about $500,000. The above-listed relative costs also include the piping and pump associated with the well.

B.4.0 CONCLUSION

The general conclusion of this investigation is that horizontal well technologies can be successfully applied at the FEMP as long as appropriate design, installation, and maintenance procedures are employed. However, the higher up-front capital costs of horizontal wells need to be justified by significantly shorter groundwater cleanup and treatment times when compared with vertical wells.

Improvements of installation technologies which may reduce cost and risk associated with environmental horizontal well installation are continuously being developed by the industry. Progress in the industry and on-going application projects should be closely followed if horizonal well technologies are selected to be used at the FEMP.

It is important to highlight that horizontal wells have been discussed with the affected off-property landowner who has expressed concern that it is not reasonable to employ horizontal wells anywhere near residential dwellings.

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APPENDIX C

RESULTS OF OVERALL RELATIVE COST COMPARISONS

TABLE C-1

SUMMARY OF THE SITE-SPECIFIC PROJECT EXPERIENCES FOR ESTIMATING RELATIVE UNIT COSTS OF MAJOR COMPONENTS

Summary

On-property vertical extraction well (including pump and piping): Installation of the nine Phase I South Field extraction wells. Considered to have low uncertainty.

Off-property vertical extraction well (including condemnation, pump and piping): Installation of the five South Plume recovery wells. Considered to have moderate uncertainty.

Vertical injection well: Installation of the nine Phase I South Field extraction wells without the pump (based on preliminary conceptual design injection operation will not require pumps). Considered to have low uncertainty.

Horizontal extraction well (by directional drilling, including pump and piping): No site-specific experience. Will be based on literature information. Considered to have high uncertainty.

Ranney well (including pump and piping): No site-specific experience. Will be based on literature and vendor information. Considered to have high uncertainty.

Additional horizontal section from a Ranney well (including pump and piping) No site-specific experience. Will be based on literature and vendor information. Considered to have high uncertainty.

O&M per extraction well per year: Three years of operational data collected from the South Plume Recovery Well System. Considered to have low uncertainty in the first 10 years and moderate uncertainty thereafter.

O&M per injection well per year: No site-specific experience. Will be based on vender information. Considered to have high uncertainty.

Expansion of groundwater treatment capacity to 2000 gpm: Installation of the AWWT and SPIT Systems. Considered to have low uncertainty.

250-gpm mobile groundwater treatment module: Installation of the IAWWT System. Considered to have low uncertainty.

Groundwater treatment per year: Over 2 years of operational data from the SPIT System. Considered to have moderate uncertainty in the first 10 years and high uncertainty thereafter.

General groundwater monitoring and reporting per year: Over a decade of groundwater sampling at the FEMP. Considered to have low uncertainty in the first 10 years and moderate uncertainty thereafter.

Notes: Low uncertainty - 10% or less
Moderate uncertainty - 10% to 30%
High uncertainty - 30% or more

TABLE C-2

SCENARIO-SPECIFIC RELATIVE CAPITAL COSTS

Components	Relative Unit Cost	25-Year Case		15-Year Case		10-Year Case		7.5-Year Case	
		Units	Cost	Units	Cost	Units	Cost	Units	Cost
Well/Pump/Piping									
On-Property Vertical Extraction Well	1	17	17	25	25	30	30	5	5
Off-Property Vertical Extraction Well	2	4	8	4	8	4	8	0	0
Vertical Injection Well	0.75	10	7.5	10	7.5	10	7.5	10	7.5
Directionally Drilled Horizontal Extraction Well	4.5 - 6[a]	0	0	0	0	0	0	5	22.5/30
Ranney Well	7.5 - 10[a]	0	0	0	0	0	0	1	7.5/10
Additional Horizontal Section from a Ranney Well	4 - 6[a]	0	0	0	0	0	0	2	8/12
Subtotal			32.5		40.5		45.5		50.5/64.5
Groundwater Treatment									
Expansion of Groundwater Treatment Capacity to 2000 gpm	7.5	1	7.5	1	7.5	1	7.5	1	7.5
250 gpm Mobile Groundwater Treatment Module	3	2	6	0	0	0	0	4	12
Subtotal			13.5		7.5		7.5		19.5
Total Capital Cost			46		48		53		70/84

[a]Estimated range of relative unit cost.

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TABLE C-3

SCENARIO-SPECIFIC RELATIVE OPERATION AND MAINTENANCE COSTS

Tasks	Relative Unit Cost	25-Year Case		15-Year Case		10-Year Case		7.5-Year Case	
		Units	Cost	Units	Cost	Units	Cost	Units	Cost
Well O&M in the First 10 Years									
Per Extraction Well Per Year	0.07	152	10.64	164	11.48	179	12.53	72	5.04
Per Injection Well Per Year	0.035	80	2.8	64	2.24	64	2.24	55	1.93
Subtotal			13.44		13.72		14.77		6.97
Well O&M after the First 10 Years									
Per Extraction Well Per Year	0.1	100	10.0	20	2.0	0	0	0	0
Per Injection Well Per Year	0.05	40	2.0	20	1.0	0	0	0	0
Subtotal			12.0		3.0		0		0
Groundwater Treatment O&M									
Per Year In The First 10 Years	6	10	60	10	60	9	54	7.5	45
Per Year After The First 10 Years	8	10	80	0	0	0	0	0	0
Subtotal			140		60		54		45
Monitoring/Reporting									
Per Year In The First 10 Years	2	10	20	10	20	10	20	7.5	15
Per Year After The First 10 Years	3	15	45	5	15	0	0	0	0
Subtotal			65		35		20		15
Total O&M Cost			230.44		111.72		88.77		66.97

TABLE C-4

SUMMARY OF THE ESTIMATED RELATIVE OVERALL GROUNDWATER REMEDIATION COSTS

Cost Components	25-Year Scenario	15-Year Scenario	10-Year Scenario	7.5-Year Scenario
Capital				
Well/Pump/Piping	32.5	40.5	45.5	50.5 - 64.5
Treatment	13.5	7.5	7.5	19.5
Well O&M	25.44	16.72	14.77	6.97
Treatment O&M	140	60	54	45
Monitoring/Reporting	65	35	20	15
Total	276.44	159.72	141.77	136.97 - 150.97

APPENDIX D

FEMP WASTEWATER TREATMENT SYSTEM DESCRIPTIONS

D.1.0 INTRODUCTION

D.1.0 INTRODUCTION

During the FEMP remediation, the wastewater treatment systems will include the AWWT system - Phases I and II, the IAWWT system, the SPIT, and the currently planned AWWT expansion. The effluents from these systems along with Sewage Treatment Plant effluent, uncontaminated wastewater (e.g., boiler plant blowdown), and bypassed (untreated) groundwater will combine at Manhole 176B to form the FEMP site's regulated discharge of uranium to the Great Miami River.

D.2.0 DESCRIPTION OF THE MAJOR TREATMENT SYSTEMS

Figure D-1 shows the treatment modules and simplified general wastewater flows in the overall FEMP centralized wastewater treatment system during remediation. The following sections describe the capacity, sources of wastewater, effluent quality, and current status of each of the existing and planned wastewater treatment systems.

D.2.1 AWWT - PHASE I

This system is intended to be used primarily for the treatment of uranium-contaminated storm water runoff from the former production area; however, when no storm water is available this system will be used to treat the less contaminated groundwater from aquifer remediation efforts. This system was designed as a 700-gpm throughput system; and the treatment capacity of this system is 600 gpm on an annual average basis. This system capacity rating takes into account downtime for major maintenance activities and unplanned system shutdowns.

It is estimated that approximately 50 percent of system capacity will be dedicated to treatment of storm water and 50 percent to treatment of groundwater (i.e., 300 gpm each on an estimated annual average flow rate). At the present time, this system is only capable of a sustained throughput of approximately 400 gpm. Replacement of the existing tubular filtration system with multimedia filtration in the fall of 1996 will allow this system to achieve the nominal 600-gpm flow.

As mentioned above, the sources to this system are contaminated storm water runoff and extracted groundwater. The storm water discharges to the SWRB contain approximately 500 ppb uranium while the South Plume groundwater currently being pumped contains somewhat less than 20 ppb. This differential in concentration illustrates the need for a treatment philosophy of preferentially

treating storm water over groundwater. However, if future groundwater remediation concentrations exceed that of storm water runoff, the priority would be reversed.

Based on initial system operational experience, it is estimated that this treatment system will be capable of maintaining a system effluent at approximately 10 ppb of uranium for wastewater and may be lower for groundwater.

It should be noted that during periods of exceptionally high rainfall, the AWWT Phase I may not be able to keep up with the inflow to the SWRB. Therefore, in order to prevent an overflow of storm water to Paddys Run, storm water will be by-passed directly to the Great Miami River. This emergency bypass will be regulated under the Operable Unit 5 ROD commitments.

D.2.2 AWWT - PHASE II

This system is intended to treat the existing FEMP process wastewater and future remediation wastewater flows. The existing flows include all wastewater requiring uranium removal that are currently directed to the BSL, including waste pit area storm water runoff and contaminated General Sump flows. Future remediation flows except the extracted groundwater are intended to be directed to the BSL in order to take advantage of the lagoon's 8-million-gallon flow and concentration equalization capability. The Phase II system was designed as a 400-gpm throughput system. The expected throughput on an annual average basis is approximately 300 gpm. Of this 300 gpm available capacity approximately 100 gpm is expected to be consumed by existing process and future remediation wastewater average annual flows.

The remaining 200 gpm is available for the treatment of remediation flows. However, in periods of low flow, extracted groundwater can be directed to this system for treatment. Treatment projections do not assume any groundwater treatment by the Phase II system. At the present time, this system is only capable of a sustained throughput of approximately 200 gpm. Replacement of the existing tubular filtration system in the fall of 1996 will allow this system to achieve the nominal 300-gpm flow.

Current flows from the BSL have a uranium concentration of approximately 1000 ppb and it is assumed that future additions of remediation wastewater will not alter this concentration significantly.

Based on initial system operational experience, it is estimated that the AWWT - Phase II system will be capable of maintaining a system effluent of approximately 10 ppb of uranium.

D.2.3 IAWWT

This treatment system was designed as a 300-gpm treatment system to treat uranium contaminated storm water before the installation of the AWWT - Phase I system. As originally planned, this system was to be decommissioned once full treatment of storm water was achieved by the AWWT - Phase I; however, current plans use this system for groundwater treatment. In its new role as a groundwater treatment system, the IAWWT throughput will be increased to approximately 400 gpm. However, the annual average flow rate is expected to be closer to 350 gpm dedicated to treatment of groundwater. Operational experience has shown that this system can achieve an effluent uranium concentration of 5 ppb.

This system is currently still needed for treatment of storm water runoff as the AWWT - Phase I system is not up to full capacity; this treatment is expected to be needed until the AWWT Multi-Media Filters Project is completed in the fall of 1996. At present, the flow through this system is limited to approximately 250 gpm due to excessive pressure drop across the ion exchange vessels; however, this resin is scheduled to be changed out and the vessel strainers overhauled. It is anticipated that this maintenance work will return this system to its full flow capacity.

D.2.4 SPIT

The SPIT system is a 200-gpm treatment system dedicated to treatment of extracted groundwater only. This system currently has a throughput of approximately 150 gpm due to excessive differential pressure across the ion exchange vessels; however, this system will have the strainers overhauled and the resin changed out in order to achieve full capacity.

The SPIT system will continue to be dedicated to treatment of extracted groundwater at 200 gpm and has shown that an effluent concentration of 5 ppb of uranium can be expected.

D.2.5 AWWT SYSTEM EXPANSION

This treatment system is currently in the design phase. The current design is for a treatment system dedicated to extracted groundwater and a throughput of 1800 gpm. It is anticipated that this treatment system will be able to process approximately 1500 gpm on an annual average basis. This planned

reduction from full capacity takes into account downtimes for scheduled maintenance and unplanned interruptions of flow. As this new system is very similar in design to the SPIT system, it is expected to perform similarly. Therefore, an effluent uranium concentration of 5 ppb can be expected.

D.3.0 PROJECTED GROUNDWATER TREATMENT CAPACITY

The bulk of the dedicated groundwater treatment capacity will come from the AWWT system expansion with its treatment capacity of 1500 gpm. Fifty percent of the downrated (i.e., anticipated average capacity accounting downtimes) AWWT - Phase I capacity of 600 gpm (i.e., 300 gpm) will be dedicated to groundwater treatment. The IAWWT units will provide 350 gpm of dedicated groundwater treatment capacity annually. The SPIT system is predicted to continue its good performance at 200 gpm for groundwater treatment. Therefore, with the tubular filtration upgrades to the AWWT - Phase I and resin change out and strainer replacement to the IAWWT, over 2000 gpm of dedicated groundwater treatment capacity will be available during aquifer restoration.

Based on the current progress of the design and construction processes, the projected operational schedule of the combined groundwater treatment capacity is summarized in Figure D-2. A conservatively estimated effective groundwater treatment capacity of 2000 gpm with an effluent uranium concentration of 5 ppb, available by January 1998, will be incorporated as a part of the baseline groundwater remediation strategy.

D.4.0 OPERATION AND MAINTENANCE STRATEGY

A master Operations and Maintenance Plan (O&MP, defined as Task 2 in the Operable Unit 5 Remedial Design Work Plan [DOE 1996]) will be developed to guide and coordinate the extraction, collection, conveyance, treatment, and discharge of all groundwater, storm water, and remediation wastewater generated site-wide over the life of the FEMP's cleanup mission. The plan will delineate the commitments, performance goals, operating schedule, direct discharge and treated water flow rates, system-by-system sequencing, and other operating constraints and priority required to balance site-wide water management needs so that compliance with the FEMP's discharge limits is maintained. The plan will serve to inform FEMP management, DOE, and the regulatory agencies of the planned operational approaches and strategies that are intended to meet the regulatory agreements made during the Operable Unit 5 RI/FS process. The plan will also serve as the focal point for coordinating and scheduling remedial wastewater conveyance and treatment needs with other site projects throughout the duration of the FEMP's cleanup mission.

Specifically, the plan will address the following:

- Definition and prioritization of the flow routing decisions associated with aquifer restoration and site-wide wastewater treatment
- Operating philosophy for groundwater extraction and injection well systems, other remediation wastewater collection systems, and groundwater and wastewater treatment systems
- System and component maintenance requirements
- FEMP operating organization and protocols
- Notifications and reporting.

This plan is not intended to provide specific operating instructions to operations or maintenance personnel; however, it is to be used as a reference and site policy to ensure that planned modes of operation are consistent with regulatory requirements and FEMP commitments. Therefore, this plan will also provide the FEMP operating and maintenance organizations with the basis for development of more detailed documents (e.g., Standard Operating Procedures and Standing Orders). These existing documents will be updated (revised, combined, or eliminated) to reflect the general strategies and guidelines defined in this O&MP.

All environmental monitoring activities conducted in support of operations and maintenance decisions will be conducted and reported through the Integrated Environmental Monitoring Plan (Task 9 in the Operable Unit 5 Remedial Design Work Plan [DOE 1996]). The O&MP will be modified as necessary over the life of the remedy to accommodate expansions to the system or the retiring of individual restoration modules from service once area-specific cleanup levels are achieved. The plan will also be amended as needed to address future agreements with the regulatory agencies or to reflect the experience gained from actual operations. These amendments will be formally issued on an annual basis and the plan will be revised and re-issued every 2 years. The O&MP will thus serve as a living guidance document to guide operations staff in implementing required adjustments to the system over time.

The first edition of the O&MP will cover specific components of the existing FEMP groundwater recovery well system, storm water management, and wastewater treatment system as of August 1996. Future additions or expansions of these systems as currently defined in the Operable Unit 5 Remedial Work Plan (DOE 1996) and this Baseline Remedial Strategy Report will also be listed for general scheduling purposes. The O&MP is scheduled to be submitted to the regulatory agencies in July 1997.

REFERENCES

U.S. Dept. of Energy, 1996, "Remedial Design Work Plan for Remedial Actions at Operable Unit 5," Draft Final, Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

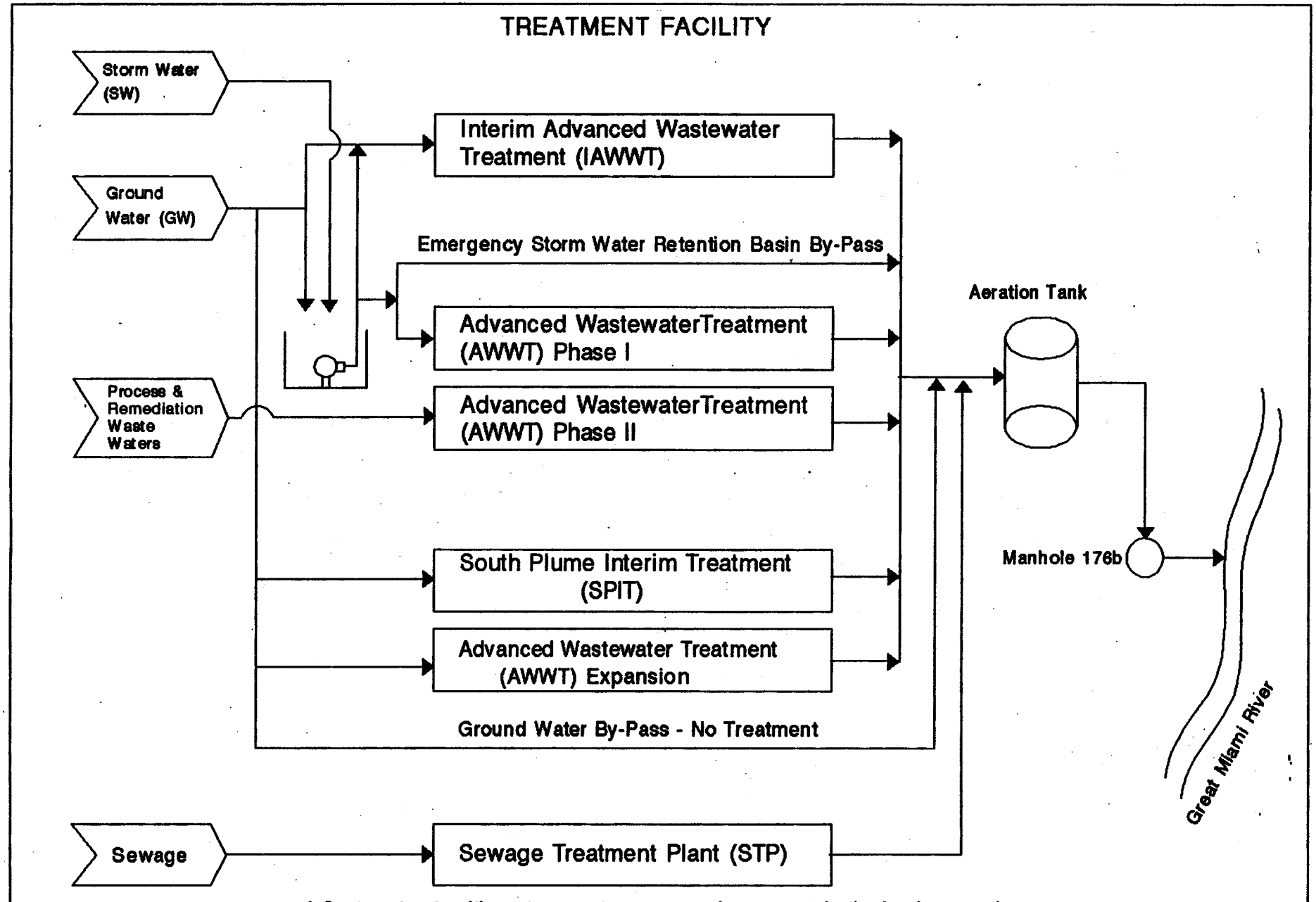

FIGURE D1. PROJECTED EFFLUENT FLOW DIAGRAM

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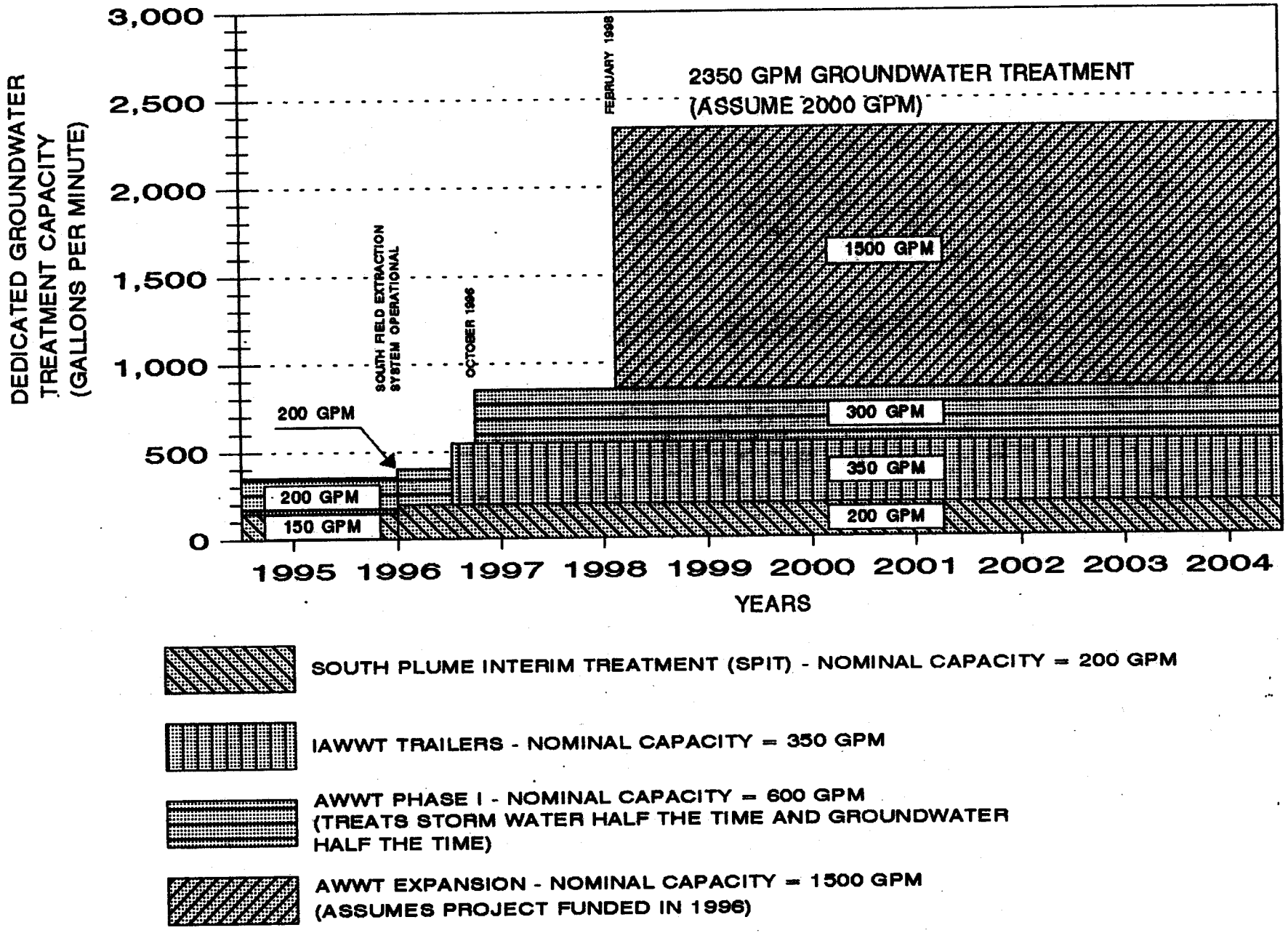

FIGURE D2. OPERATIONAL SCHEDULE OF COMBINED GROUNDWATER TREATMENT CAPACITY

APPENDIX E

ADDITIONAL MODELING SIMULATIONS TO SUPPORT REVIEW OF OFF-PROPERTY LANDOWNER ACCESS CONCERNS

E.1.0 PURPOSE

The preliminary baseline strategy described in Section 4.0 includes four new off-property wells (i.e., 1, 3N, 2N, and KN). These four wells are located on areas owned by the same private property owner. As discussed in Section 5.1.2, the property owner has concerns regarding these wells. This appendix summarizes additional modeling results which were generated and presented to the private property owner during a consultation process to explain the system design options and purposes of each well for the South Plume Optimization Module. These modeling results also provide more information for the decision-makers regarding the system design issues such as funding schedule, piping layout, and area access for routine well maintenance.

E.2.0 DEFINITIONS OF SCENARIOS

The well locations and operational schedules for five additional scenarios are defined to address specific concerns. The operational schedules also consider the actual funding situation in FYs 97 through 99 as described in Section 5.2.2. The main focus of each scenario is also explained in the following subsections. Well 64 shown in Figures E-1 through E-5 indicates a contingent extraction well which may be used to improve the on-property cleanup time and is not currently simulated in all the modeling runs.

E.2.1 SCENARIO I

Figure E-1 shows the well locations of Scenario I. Wells 2N and KN are located further to the south from their original locations as specified in the preliminary baseline strategy shown in Figure 4-3. These new locations reflect the leading edge of the 20 ppb plume when these wells start operation in 1999. These wells are located at the leading edge so they can intercept the complete plume. The off-property and fenceline extraction/injection rate schedule for this scenario between 1997 and 2006 is listed in Table E-1.

E.2.2 SCENARIO II

Figure E-2 shows the well locations of Scenario II. Wells 2N and KN are eliminated in this scenario assuming that they can not be installed. Four existing South Plume wells will therefore need to be continuously operated to maintain hydraulic capture of the off-property plume. The off-property and fenceline extraction/injection rate schedule for this scenario between 1997 and 2006 is listed in Table E-2.

E.2.3 SCENARIO III

Figure E-3 shows the well locations of Scenario III. Wells 2N and KN are relocated to just north of Willey Road. This scenario is developed to evaluate the option of first using extraction wells to reduce the off-property plume. The injection operation (wells 8 through 12) will be delayed to allow Wells 2N and KN to recover some off-property uranium mass from the on-property area until the projected recovery efficiency diminishes. Four existing South Plume wells will also need to be continuously operated to maintain hydraulic capture of the off-property plume. The off-property and fenceline extraction/injection rate schedule for this scenario between 1997 and 2006 is listed in Table E-3.

E.2.4 SCENARIO IV

Figure E-4 shows the well locations of Scenario IV. Wells 2N and KN are relocated to just north of Willey Road with Wells 8 and 10 also used for extraction. This scenario is developed to evaluate the option of using extraction wells instead of injection wells to create a hydraulic barrier along the fenceline and recover the eastern portion of the off-property plume. Injection wells 9 and 11 are eliminated. The off-property and fenceline extraction/injection rate schedule for this scenario between 1997 and 2006 is listed in Table E-4.

E.2.5 SCENARIO V

Figure E-5 shows the well locations of Scenario V. Well KN is eliminated in this scenario assuming that it can not be installed, and 2N is positioned at its original location for the preliminary baseline strategy. It is also assumed that Wells 2N, 1 and 3N will still start operation in 1999. Four existing South Plume wells will need to be continuously operated to maintain hydraulic capture zone of the off-property plume. The off-property and fenceline extraction/injection rate schedule for this scenario between 1997 and 2006 is listed in Table E-5.

E.3.0 MODELING RESULTS

Simulated groundwater table drawdown contours at 1999, maximum extent of the off-property plume, and uranium plume at year 2003 for each of the five scenarios are presented in this subsection. Year 1999 is when the maximum off-property drawdown is expected for each of these scenarios. Year 2003 is right before the "apparent" K_d transition in the South Field and South Plume areas (see Appendix A) will take place in the model simulations. After the K_d transition is implemented, differences between scenarios in the off-property area become insignificant. These modeling results

demonstrate the performance of each of the scenarios in terms of hydraulic impact, plume expansion, and potential range of cleanup time. Figures E-6 through E-20 present the modeling results of the five scenarios. There are three contiguous figures for each of the five scenarios.

As can be seen in Figures E-6, E-9, E-12, E-15, and E-18; Scenario IV has the maximum drawdown in the immediate off-property area; Scenario V has the maximum drawdown around the existing South Plume wells; while Scenario I has the minimum overall off-property drawdown. The maximum extents of the off-property plume presented in Figures E-7, E-10, E-13, E-16, and E-19 indicate that the five scenarios result in similar degrees of expansion, overall. Comparatively, Scenario IV has less overall expansion compared to the others, while Scenario III shows the greatest amount of expansion. The differences in plume expansion between Scenarios I and II are relatively insignificant as shown in Figures E-7 and E-10. Particle tracking from the fenceline extraction wells are also shown in Figures E-13 and E-16. As can be seen in these two figures, capture zones of the fenceline extraction wells do not extend significantly to the off-property area and can not cover the entire off-property plume. Particle tracks from all the off-property wells in Scenario V are presented in Figure E-19.

Simulated off-property plumes at year 2003 for the five scenarios are shown in Figures E-8, E-11, E-14, E-17, and E-20. Scenario II has the minimum off-property plume while Scenario III has the maximum. Locations of the off-property plumes in Scenarios III and IV are different from the other three scenarios. In scenarios with pumping operation along the fenceline, the plumes will tend to linger along the fenceline due to competing upgradient and downgradient hydraulic forces.

TABLE E-1

SCENARIO I PUMPING SCHEDULE BY AREA

	1997	1998	1999-2001	2002-2003	2004-2006
Off Property	1400	1400	1500	1500	0
Fenceline	0	-1000	-1000	-1000	0
On Property	0	0	1300	1300	4800
Northern Injectors (including 13, 14, and 16)	0	0	0	0	-1600

Notes: + = pumping
- = injecting

TABLE E-2

SCENARIO II PUMPING SCHEDULE BY AREA

	1997	1998	1999-2001	2002-2003	2004-2006
Off Property	1400	1400	2000	2000	0
Fenceline	0	-1000	-1000	-1000	0
On Property	0	0	1300	1300	4800
Northern Injectors (including 13, 14, and 16)	0	0	0	0	-1600

Notes: + = pumping
- = injecting

TABLE E-3

SCENARIO III PUMPING SCHEDULE BY AREA

	1997	1998	1999-2001	2002-2003	2004-2006
Off Property	1400	1400	2000	2000	0
Fenceline	0	0	0	-1000	0
On Property	0	0	1600	1300	4800
Northern Injectors (including 13, 14, and 16)	0	0	0	0	-1600

Notes: + = pumping
- = injecting

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TABLE E-4

SCENARIO IV PUMPING SCHEDULE BY AREA

	1997	1998	1999-2001	2002-2003	2004-2006
Off Property	1400	1400	1200	1200	600
Fenceline	0	0	800	800	800
On Property	0	0	1300	1300	4200
Northern Injectors (including 13, 14, and 16)	0	0	0	0	-1600

Notes: + = pumping
- = injecting

TABLE E-5

SCENARIO V PUMPING SCHEDULE BY AREA

	1997	1998	1999-2001	2002-2003	2004-2006
Off Property	1400	1400	2200	2200	0
Fenceline	0	-1000	-1000	-1000	0
On Property	0	0	1300	1300	4800
Northern Injectors (including 13, 14, and 16)	0	0	0	0	-1600

Notes: + = pumping
- = injecting

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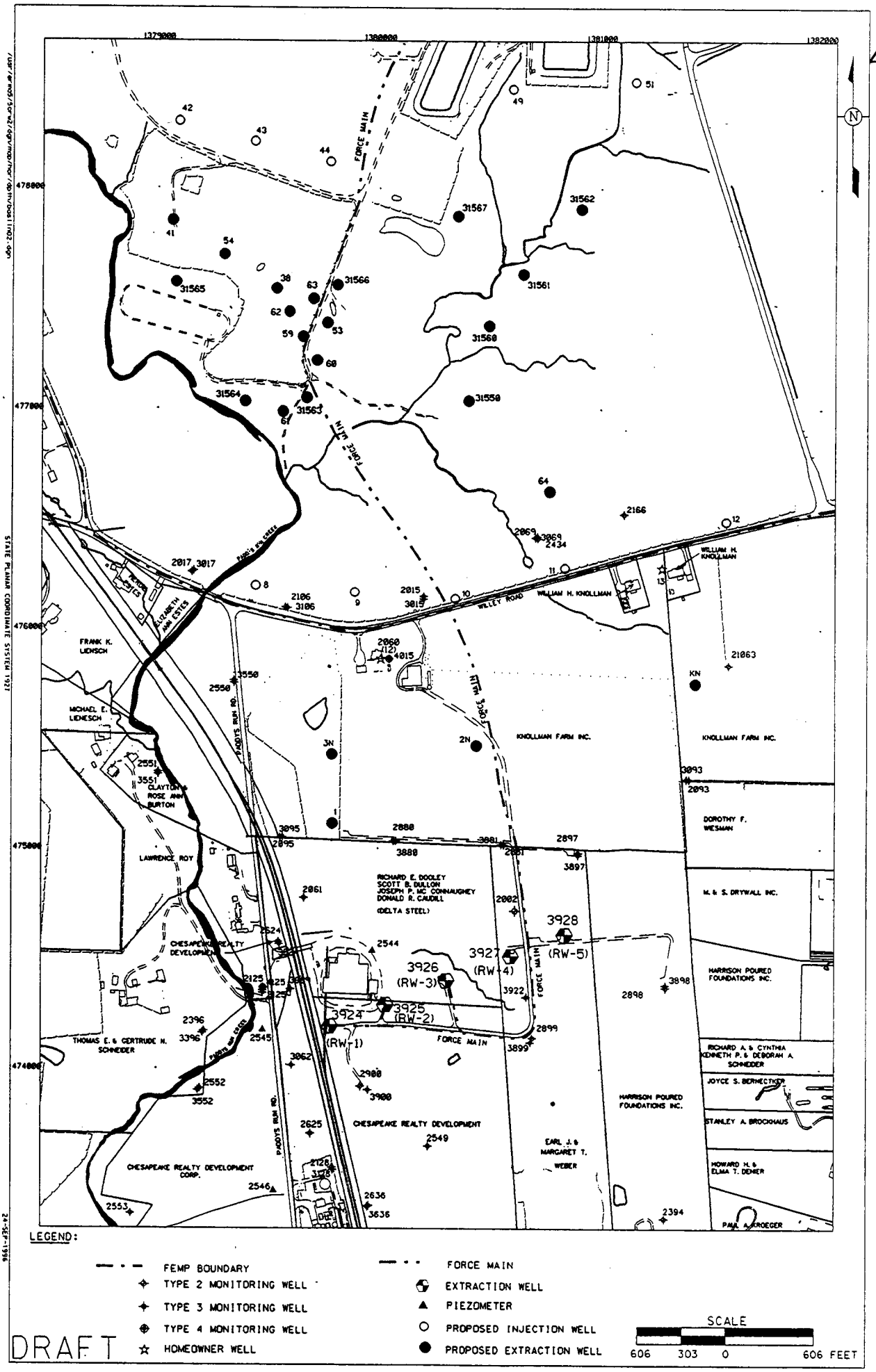
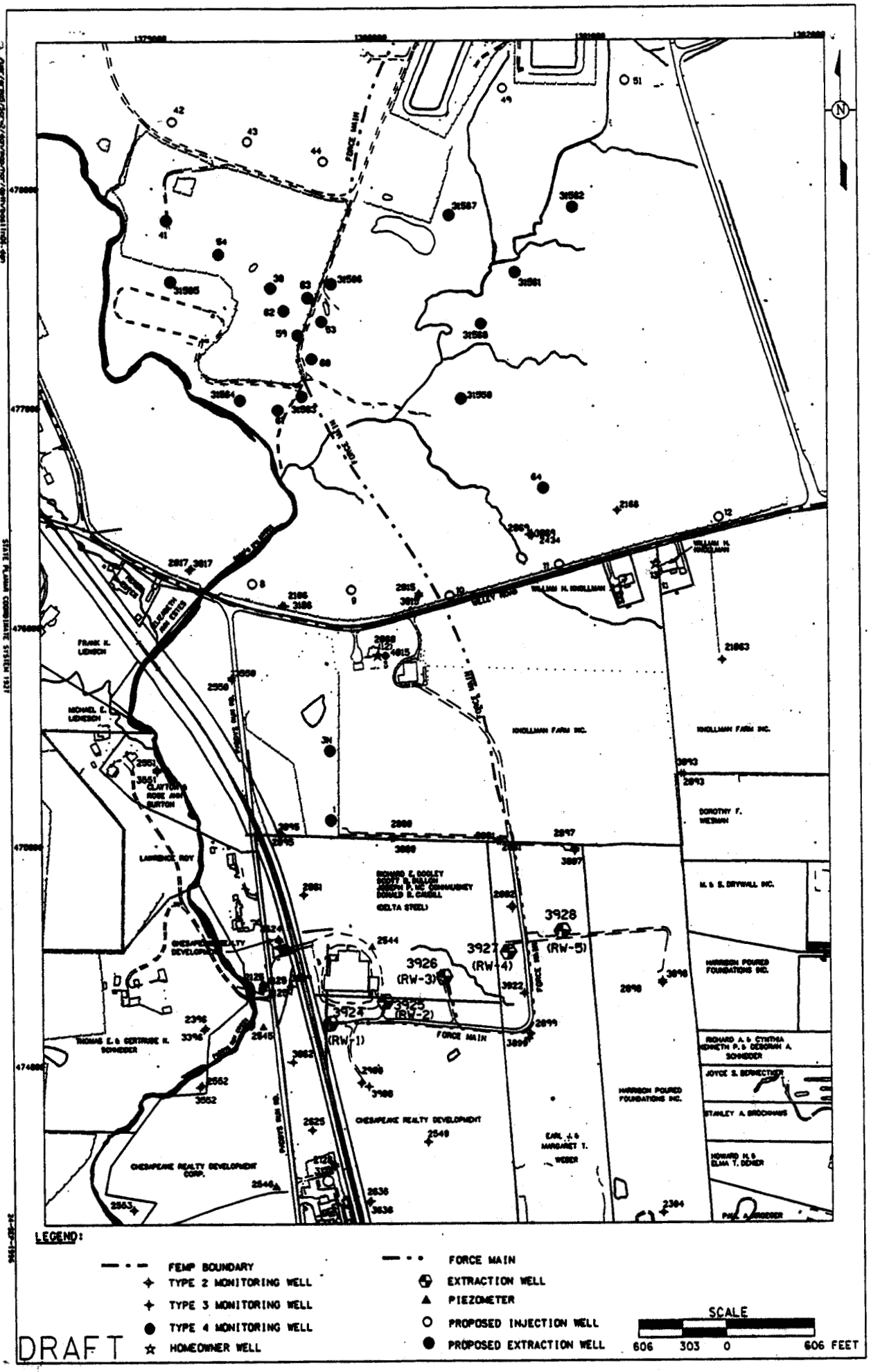


FIGURE E-1. WELL LOCATIONS FOR SCENARIO I



000177 FIGURE E-2. WELL LOCATIONS FOR SCENARIO II

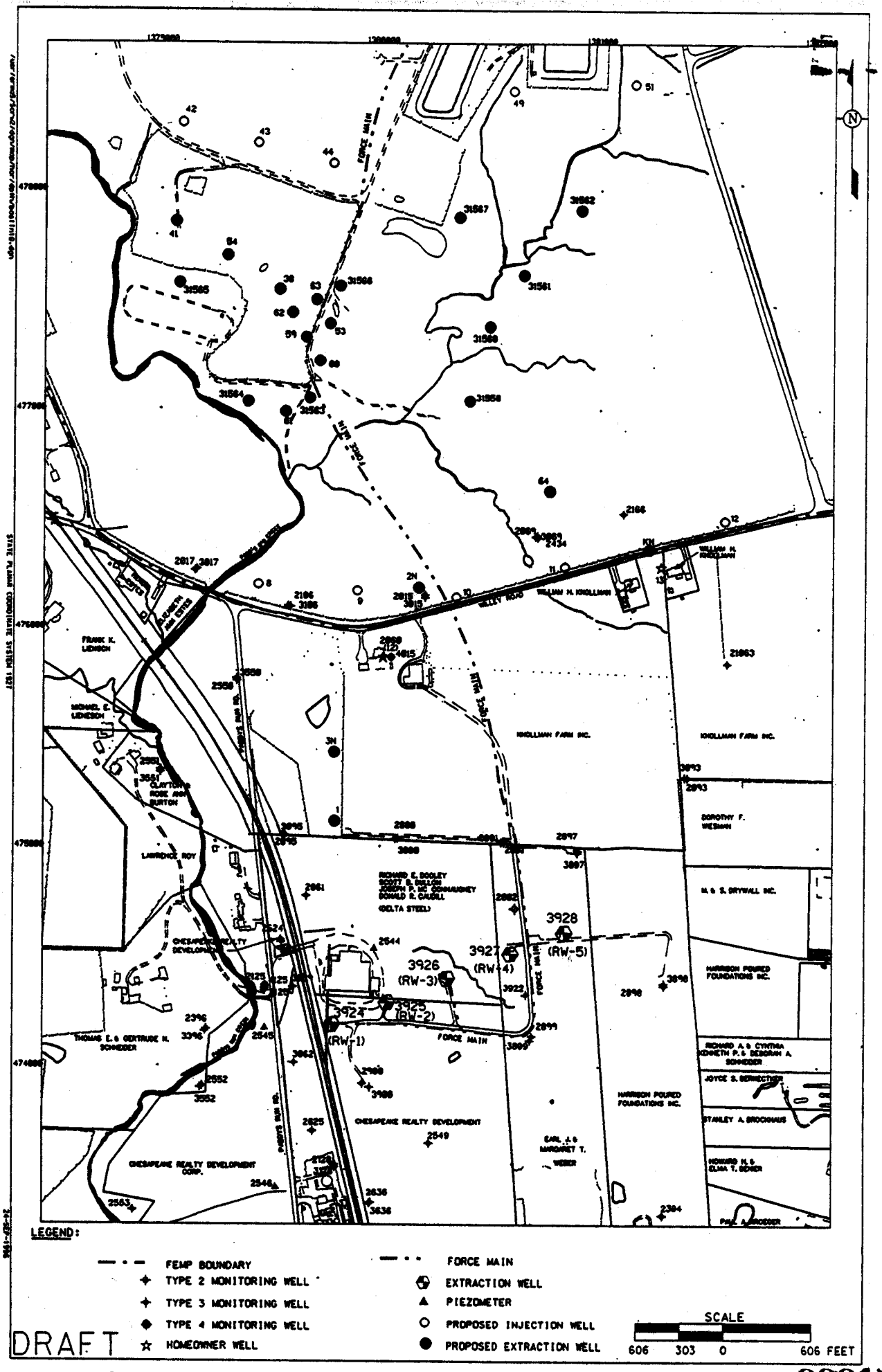


FIGURE E-3. WELL LOCATIONS FOR SCENARIO III

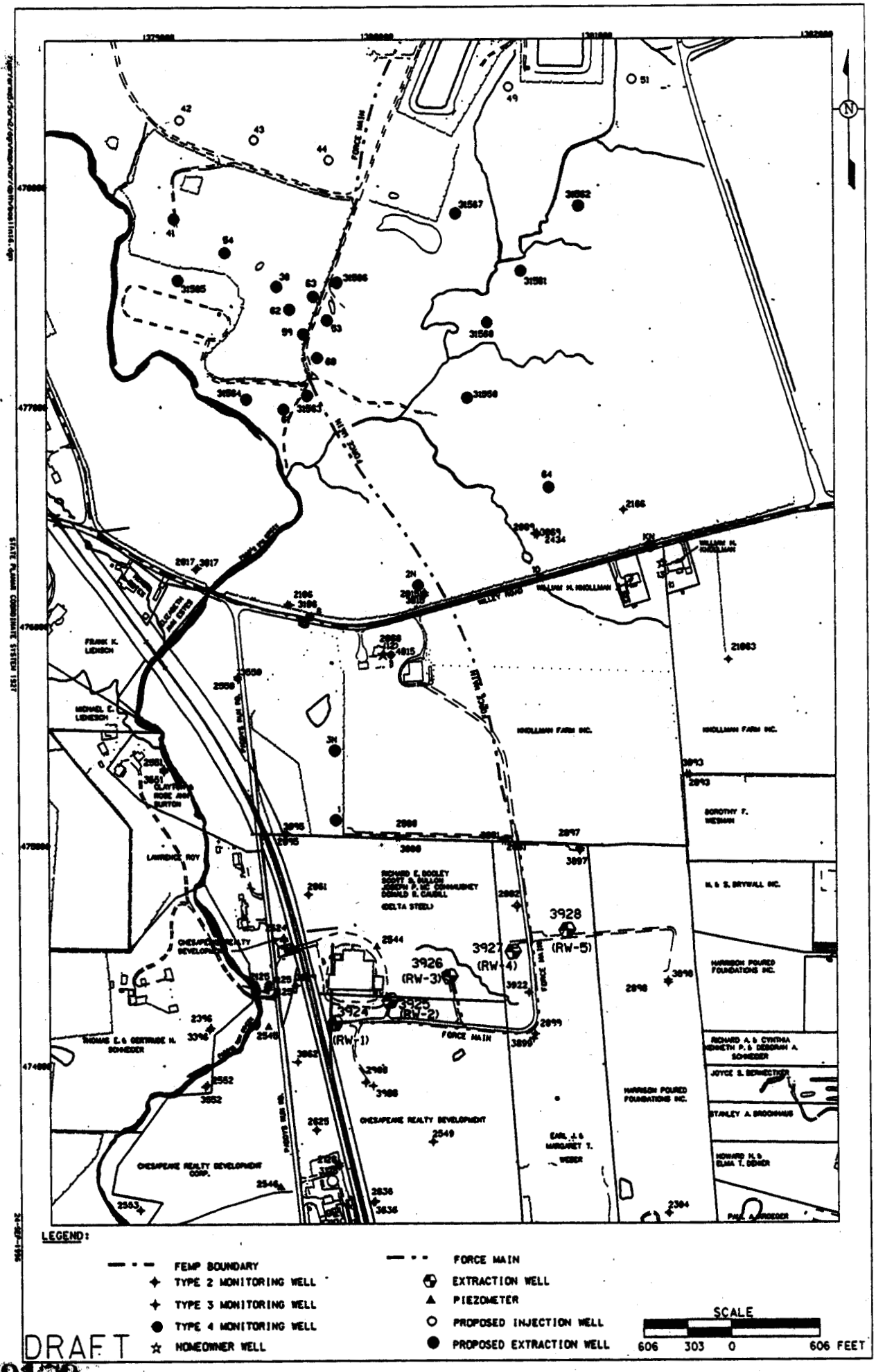


FIGURE E-4. WELL LOCATIONS FOR SCENARIO IV

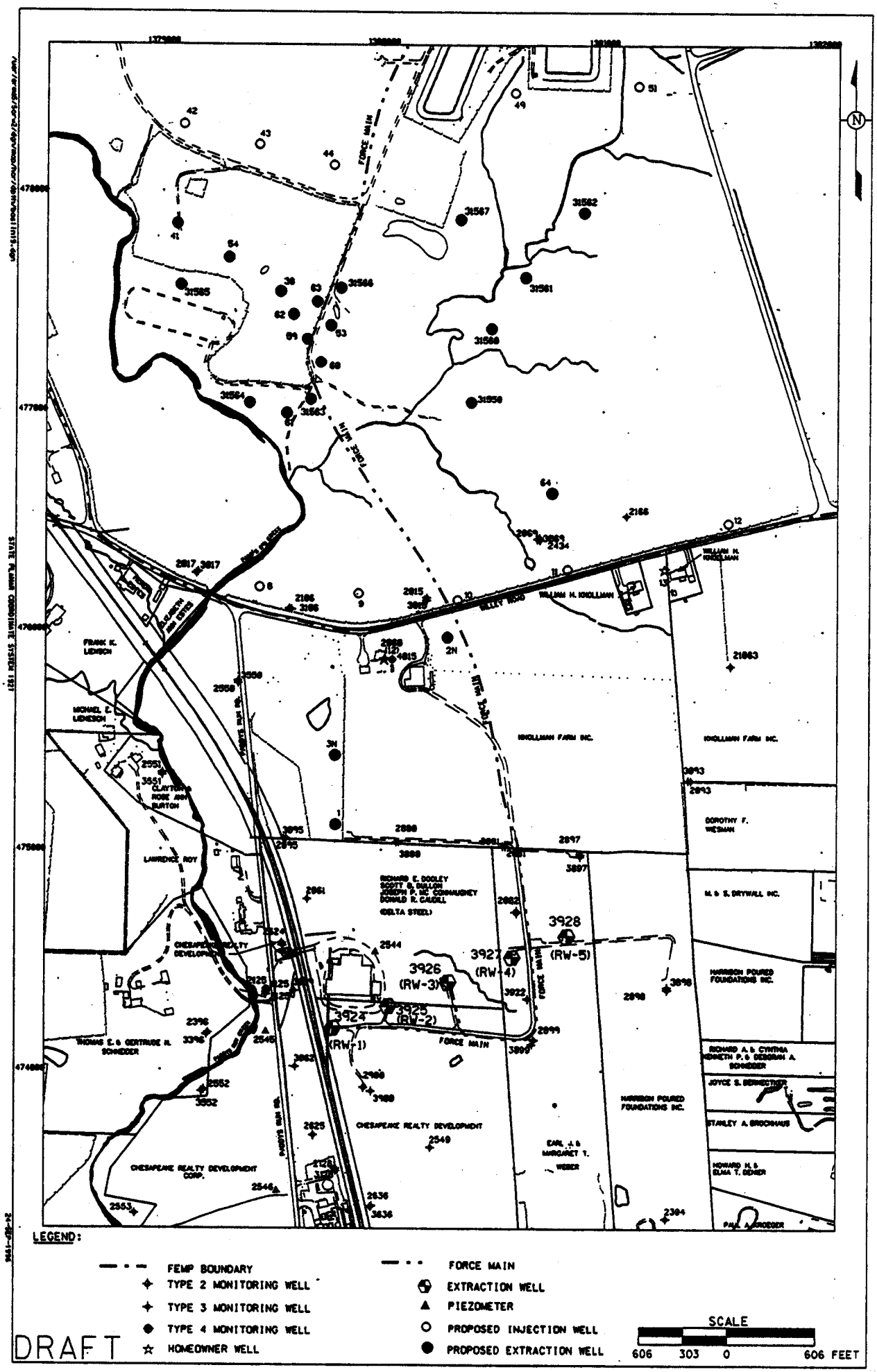


FIGURE E-5. WELL LOCATIONS FOR SCENARIO V

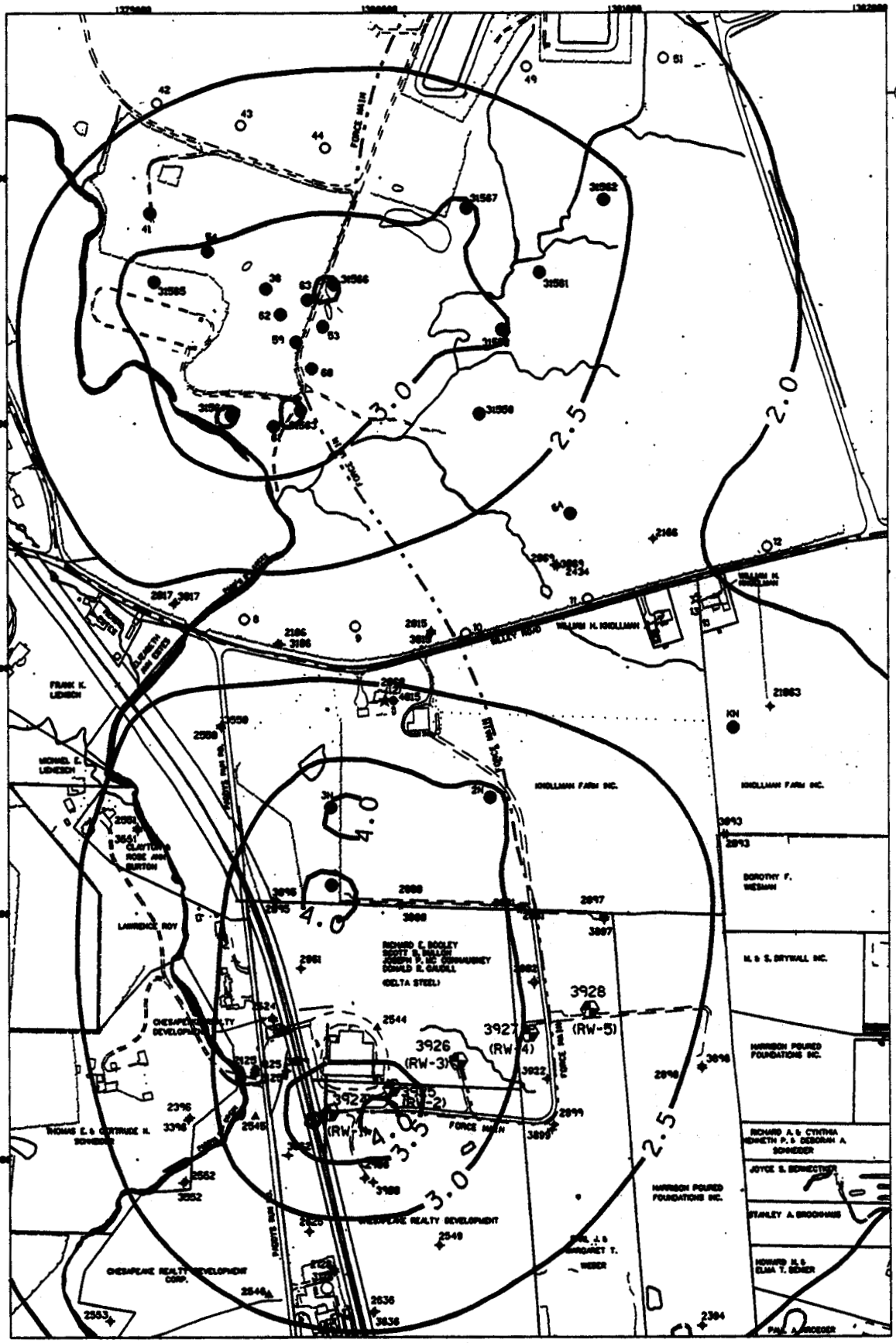


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FIGURE E-6. DRAWDOWN AT 1999 - SCENARIO I

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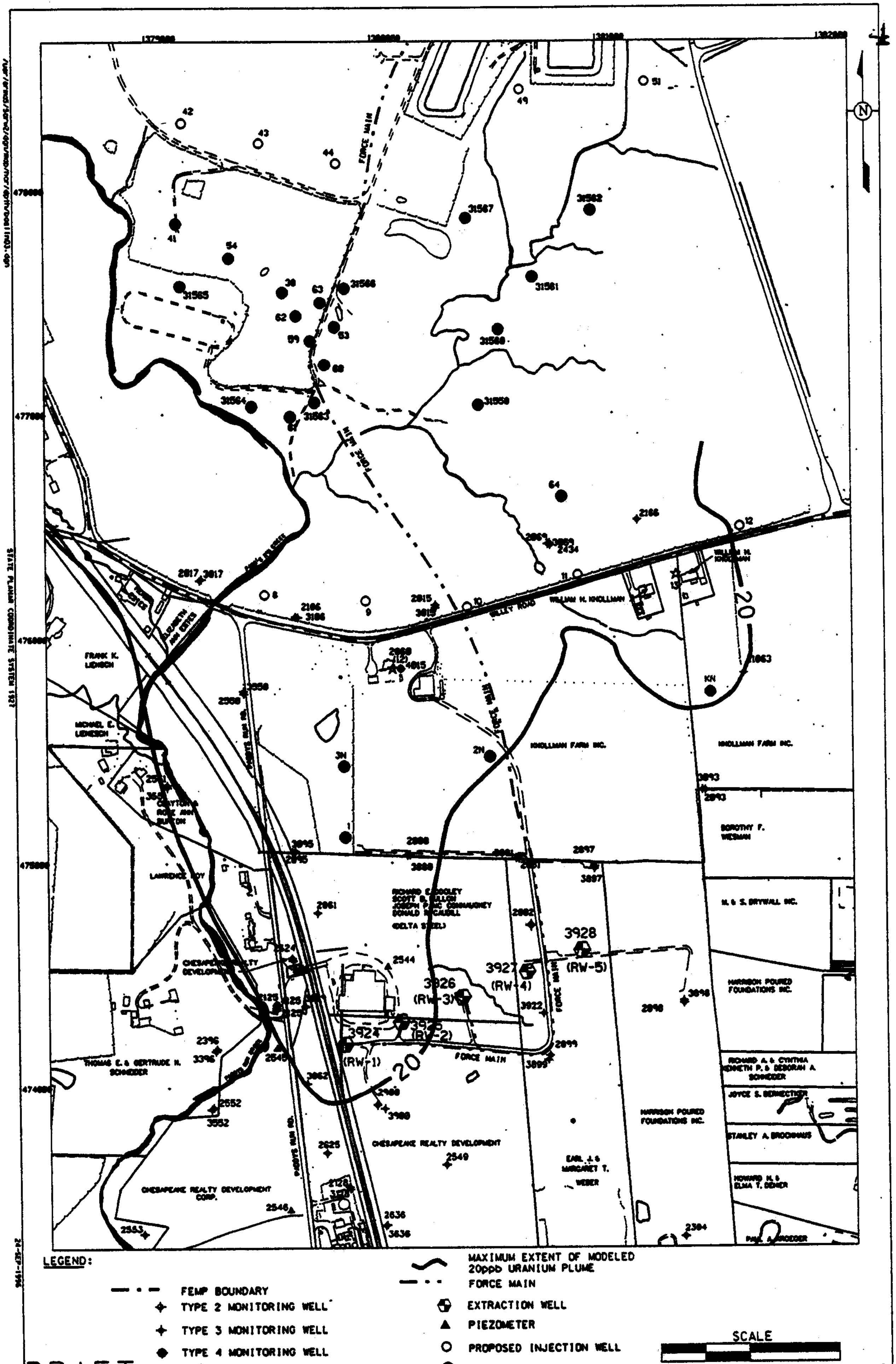

FIGURE E-7. MAXIMUM EXTENT OF THE OFF-PROPERTY PLUME - SCENARIO I

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FIGURE E-8. URANIUM PLUME AT 2003 - SCENARIO I

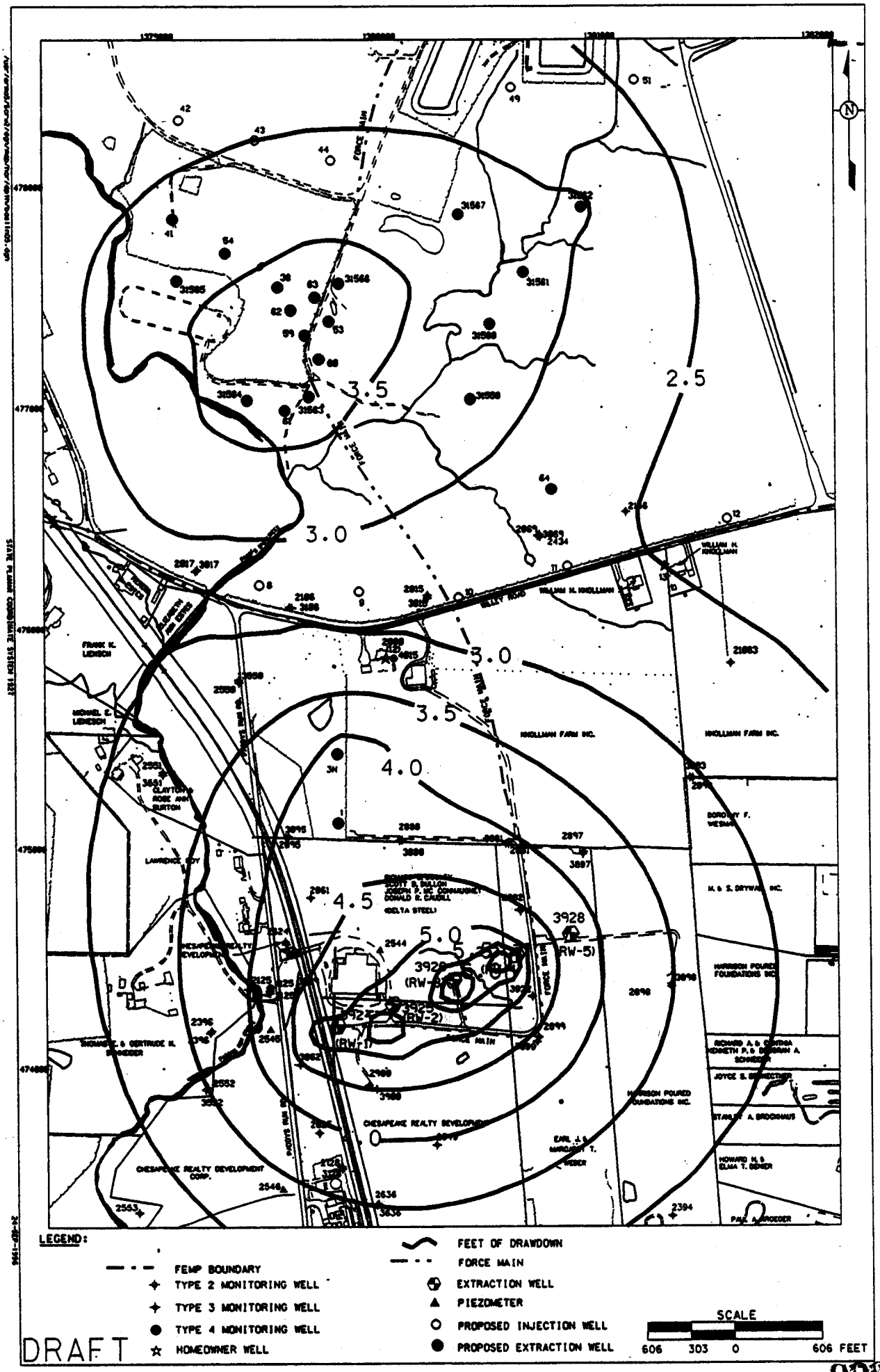

FIGURE E-9. DRAWDOWN AT 1999 - SCENARIO II

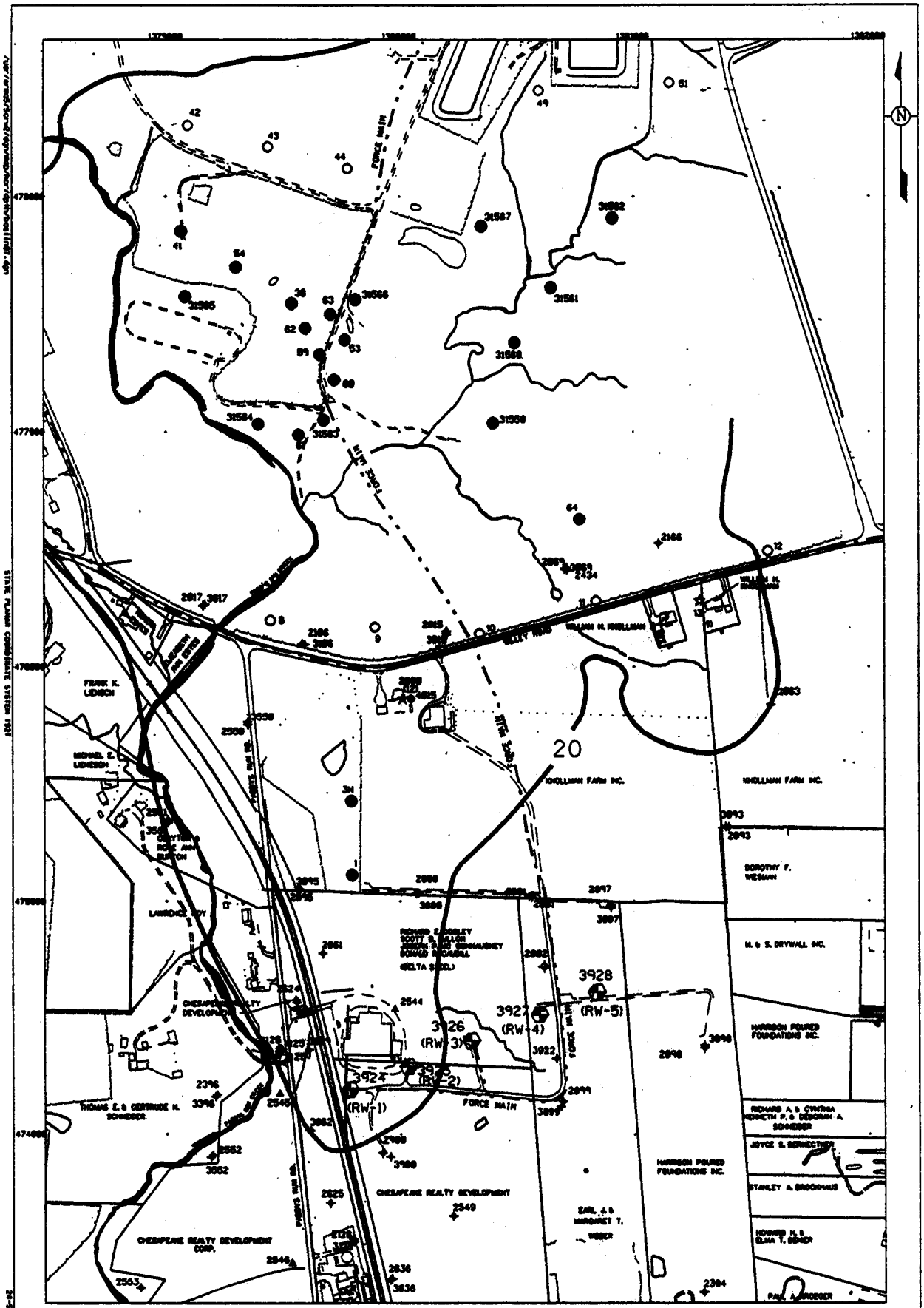

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FIGURE E-10. MAXIMUM EXTENT OF THE OFF-PROPERTY PLUME - SCENARIO II

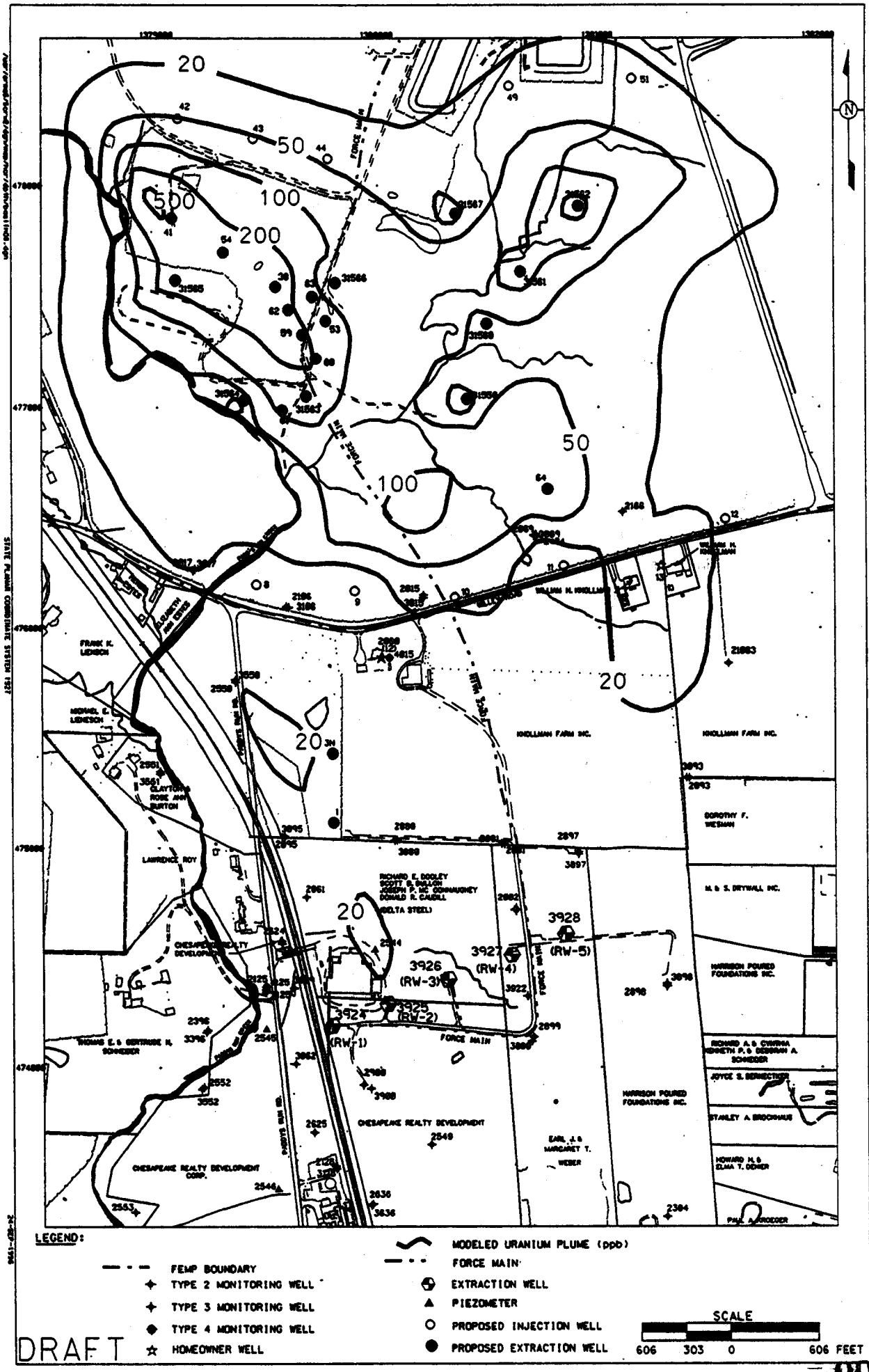

FIGURE E-11. URANIUM PLUME AT 2003 - SCENARIO II

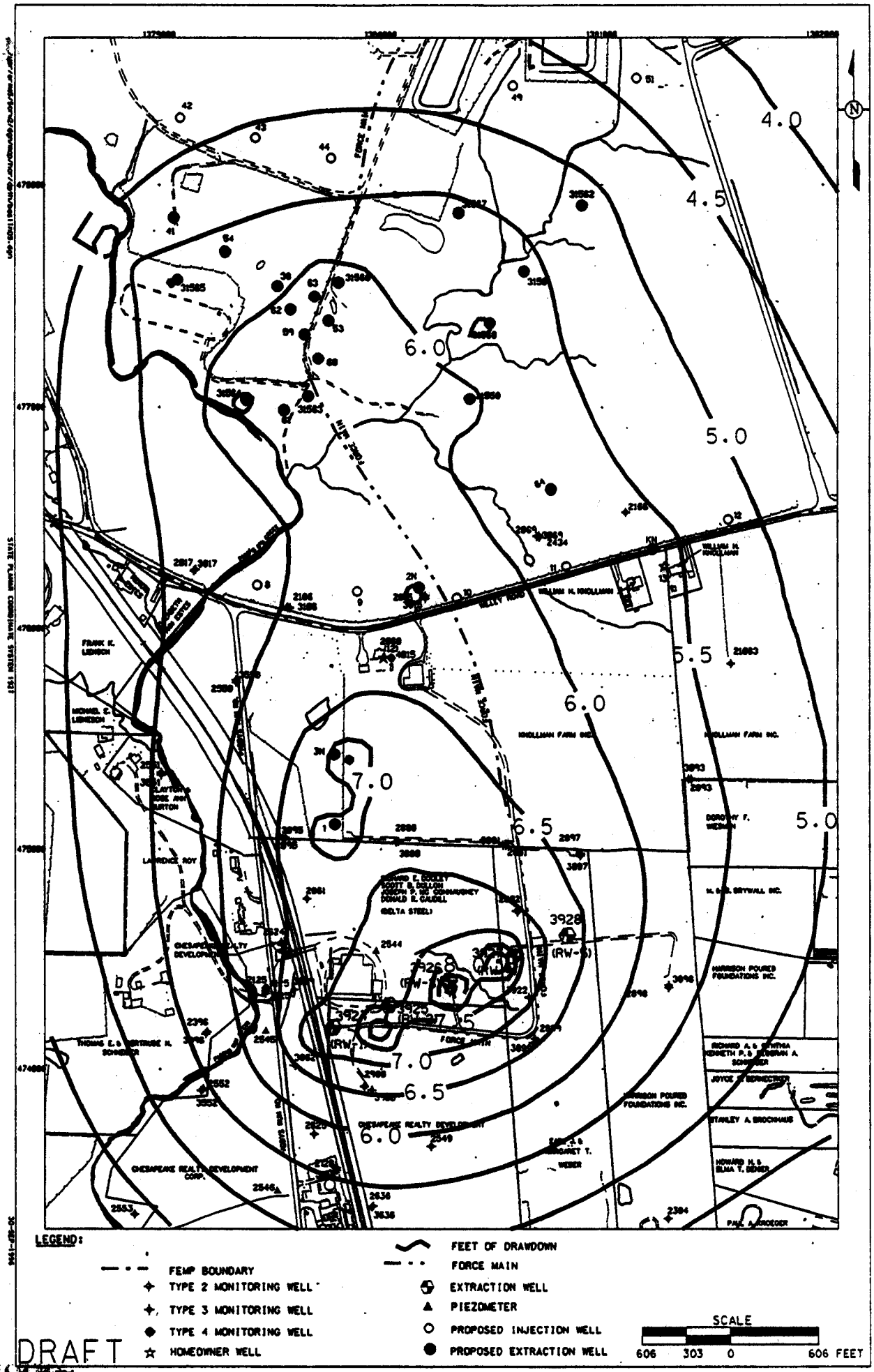

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FIGURE E-12. DRAWDOWN AT 1999 - SCENARIO III

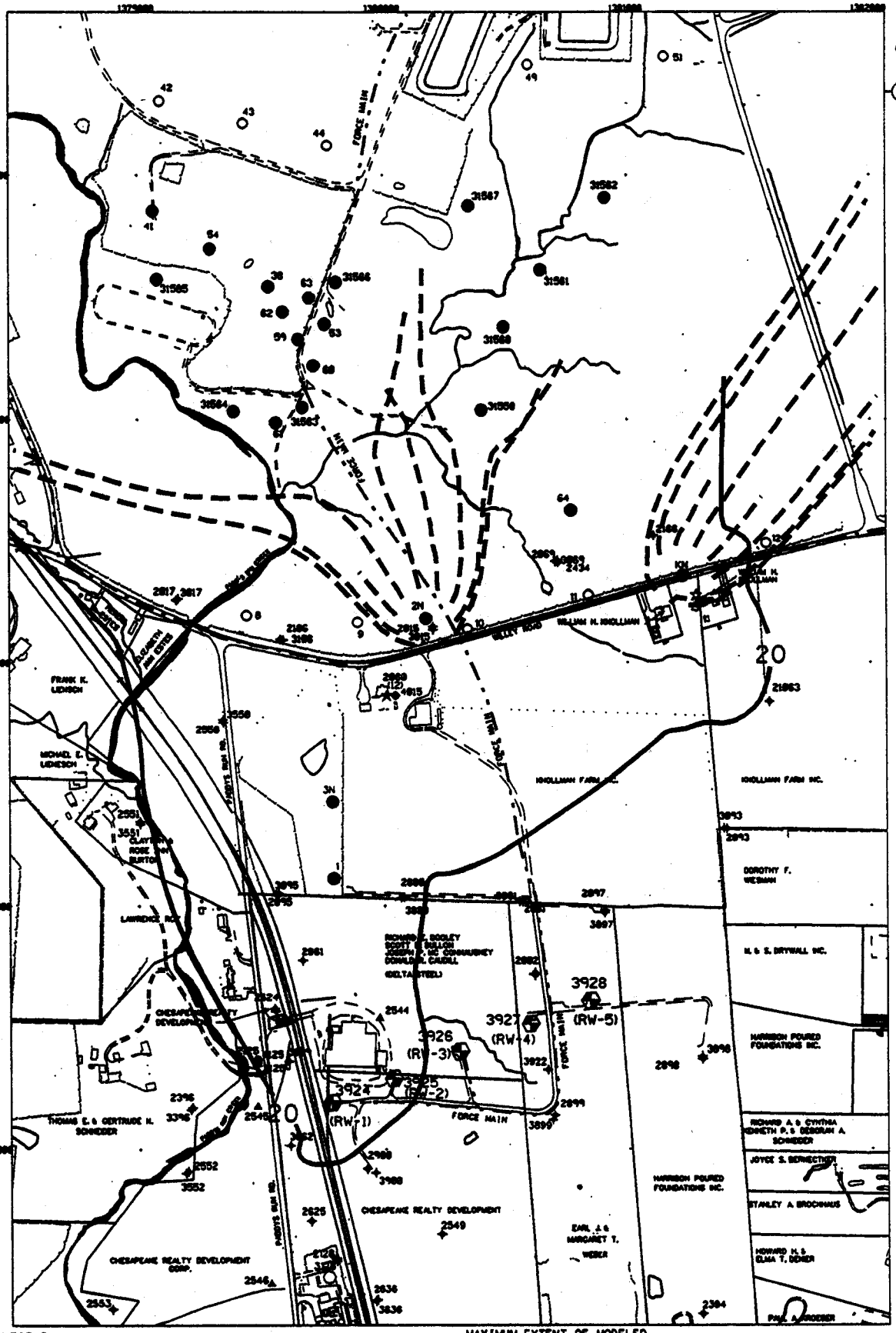

FIGURE E-13. MAXIMUM EXTENT OF THE OFF-PROPERTY PLUME - SCENARIO III

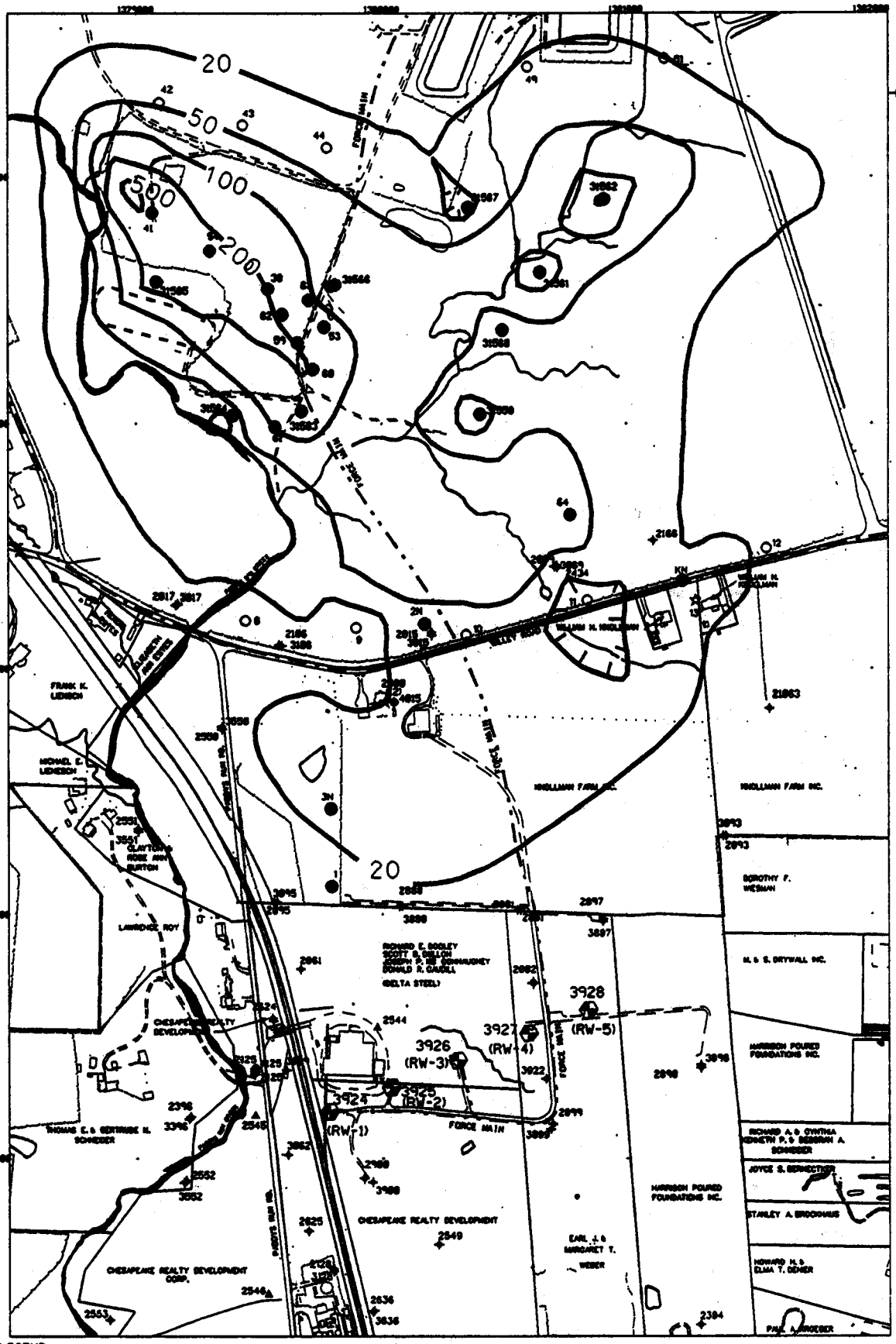

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FIGURE E-14. URANIUM PLUME AT 2003 - SCENARIO III

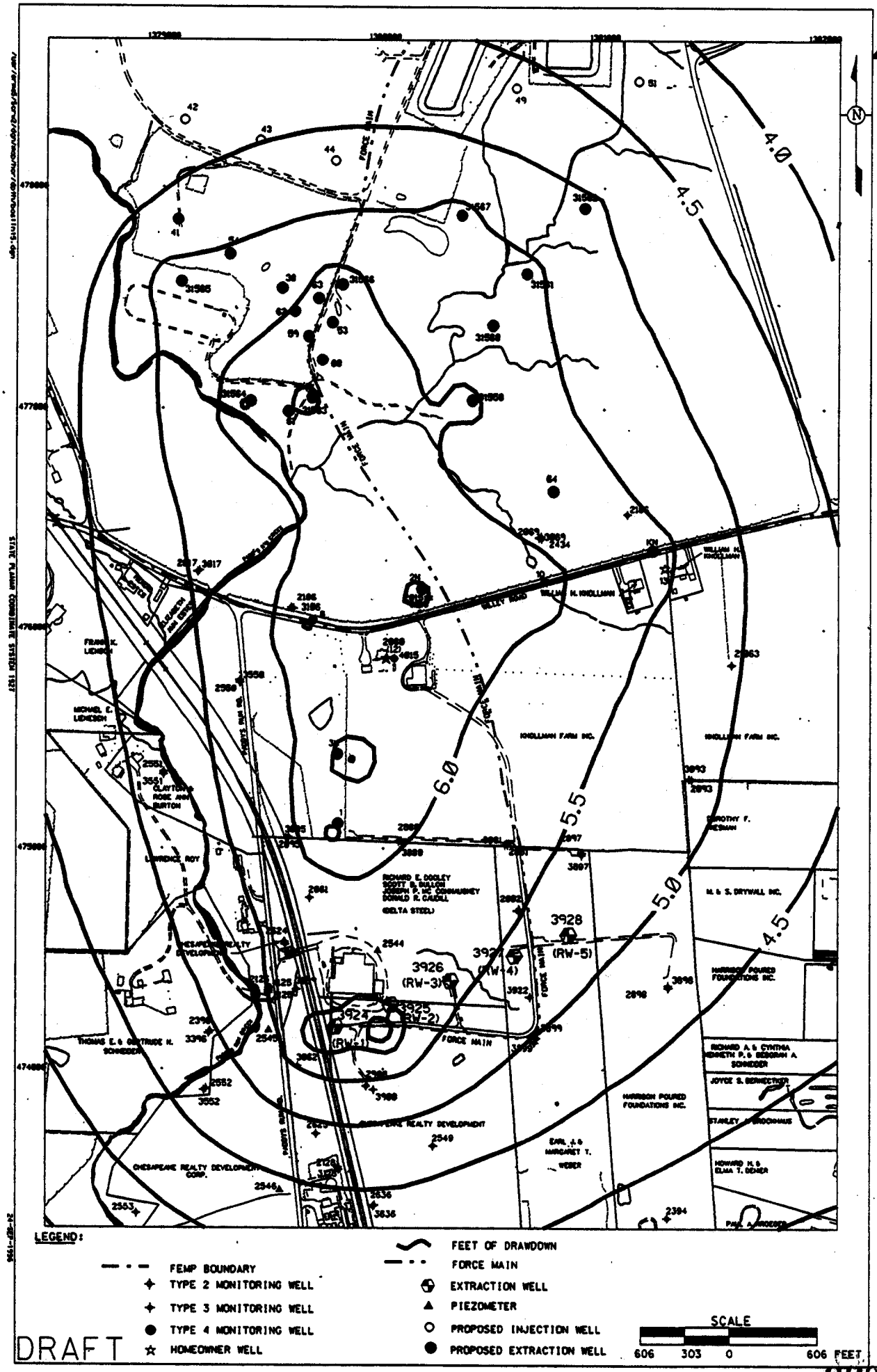

FIGURE E-15. DRAWDOWN AT 2003 - SCENARIO IV

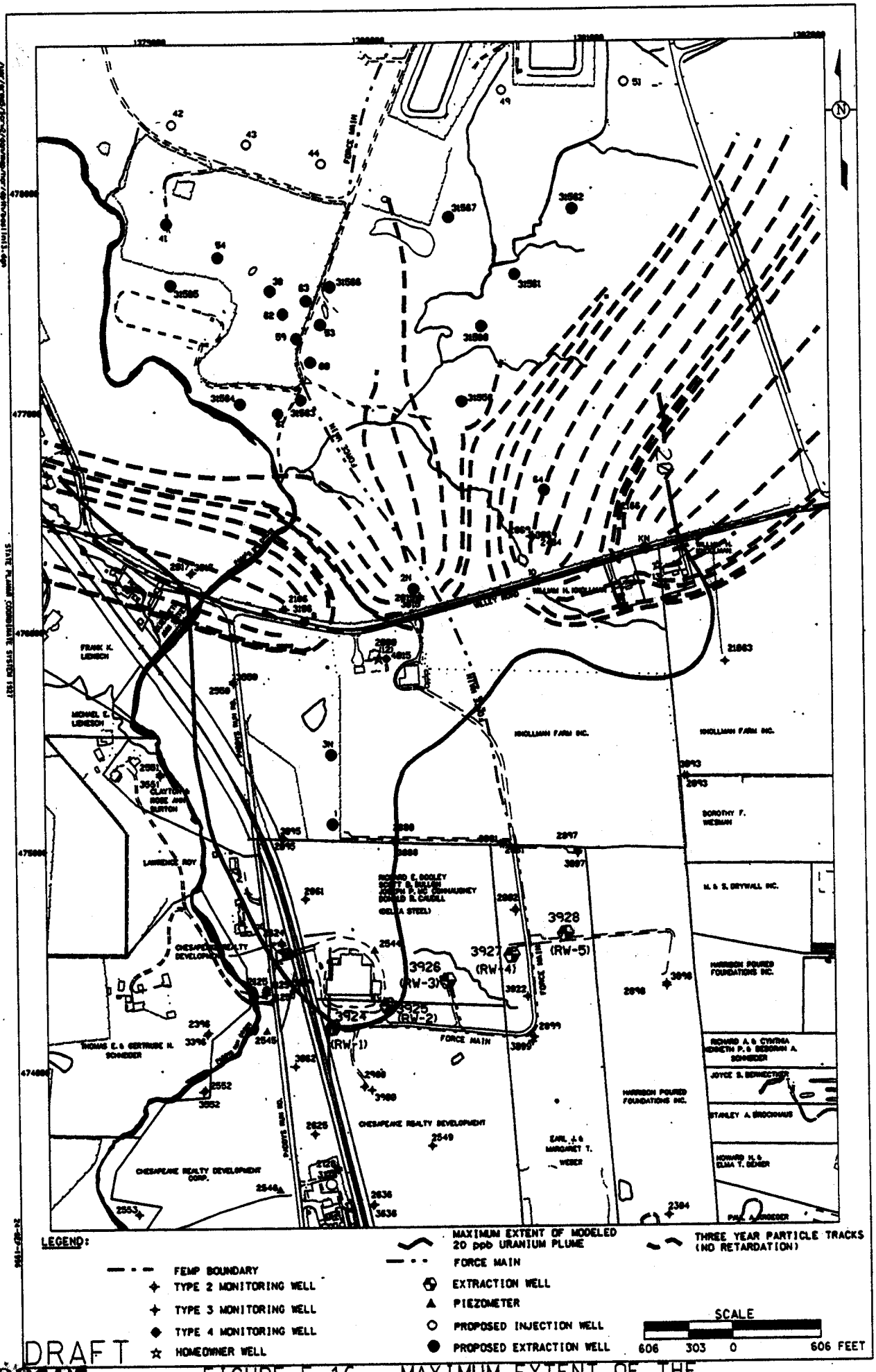

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FIGURE E-16. MAXIMUM EXTENT OF THE OFF-PROPERTY PLUME - SCENARIO IV

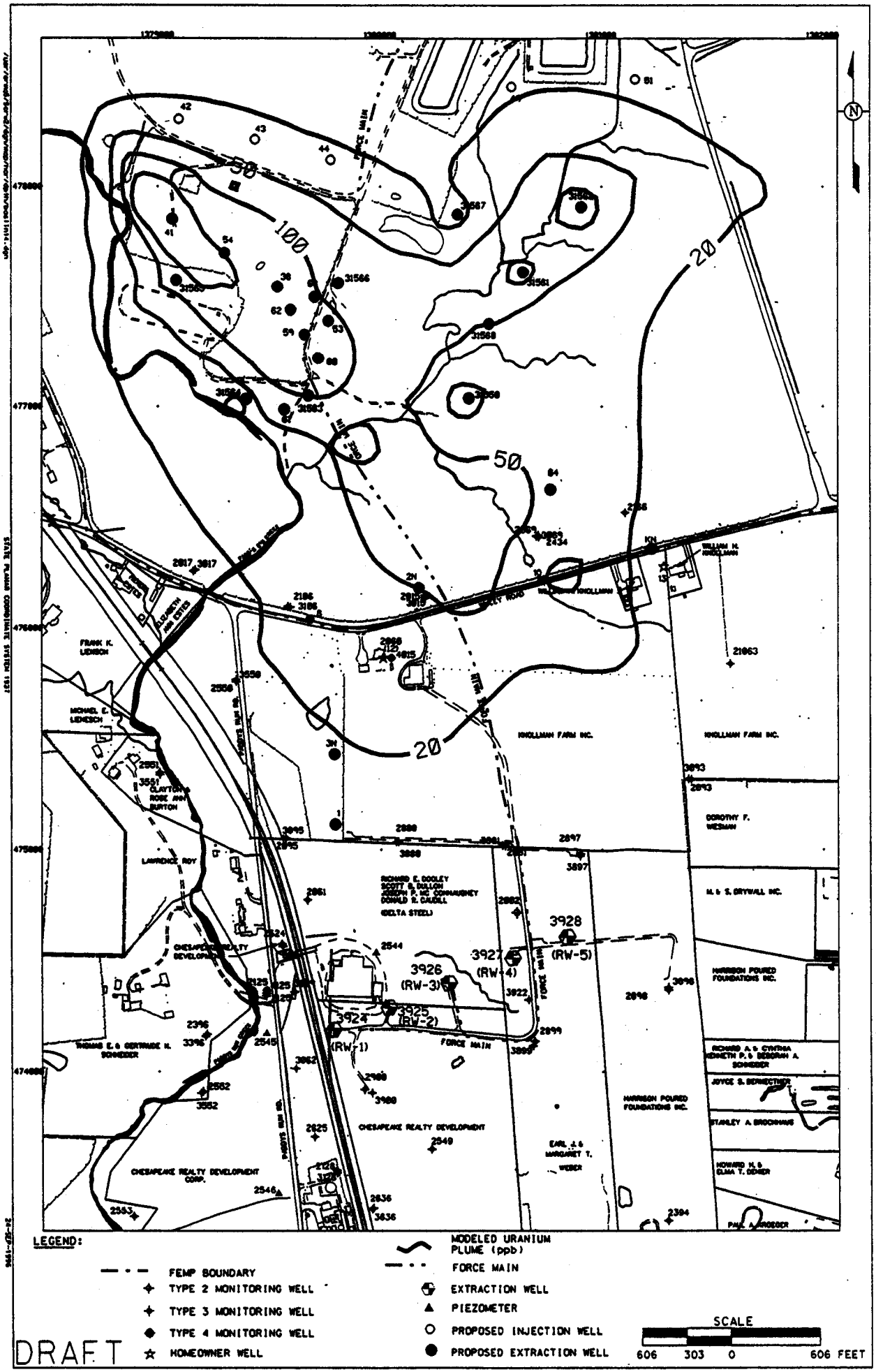
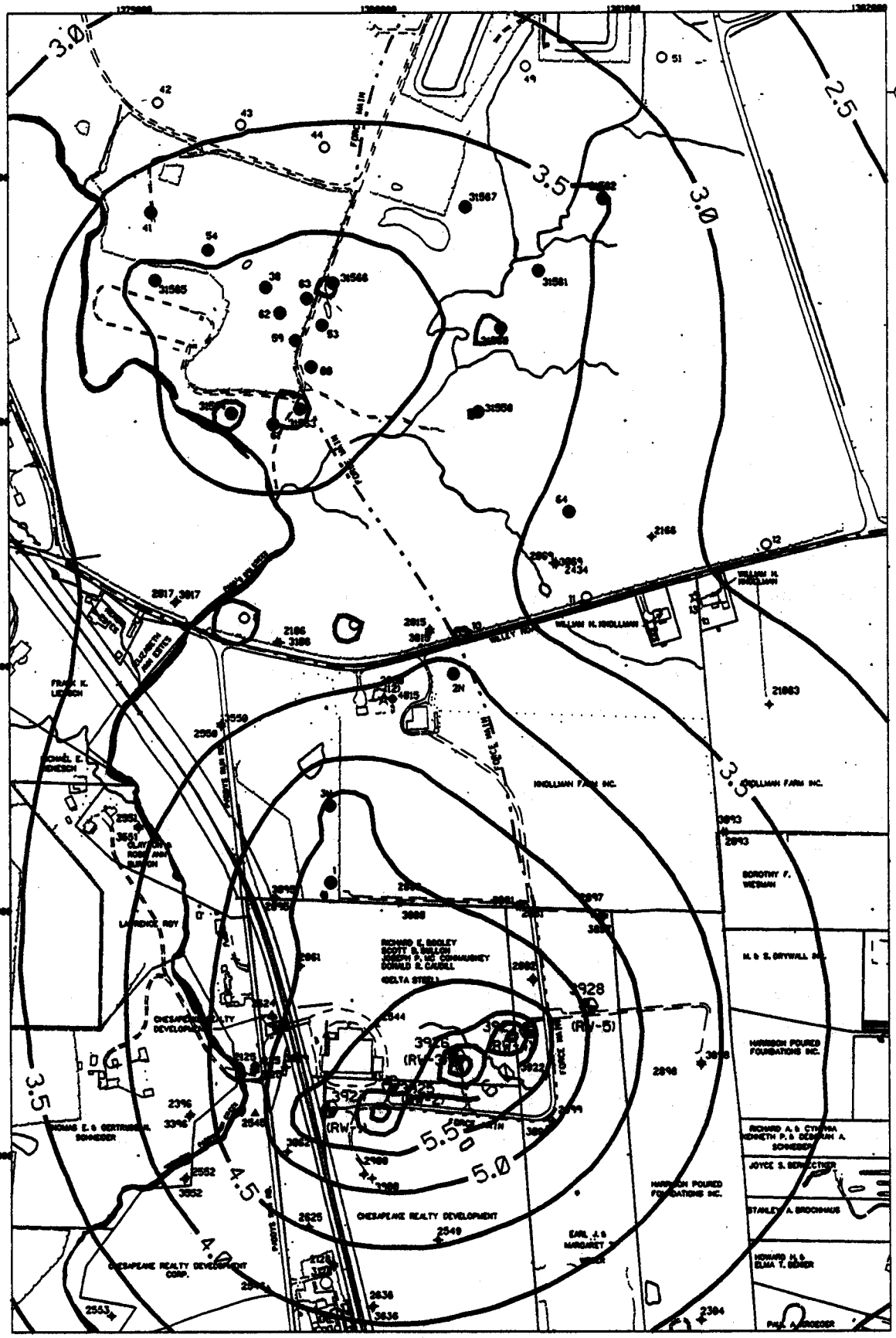


FIGURE E-17. URANIUM PLUME AT 2003 - SCENARIO IV



LEGEND:

- FEMP BOUNDARY
- TYPE 2 MONITORING WELL
- TYPE 3 MONITORING WELL
- TYPE 4 MONITORING WELL
- HOMEOWNER WELL
- FEET OF DRAWDOWN
- FORCE MAIN
- EXTRACTION WELL
- PIEZOMETER
- PROPOSED INJECTION WELL
- PROPOSED EXTRACTION WELL

SCALE: 606 303 0 606 FEET

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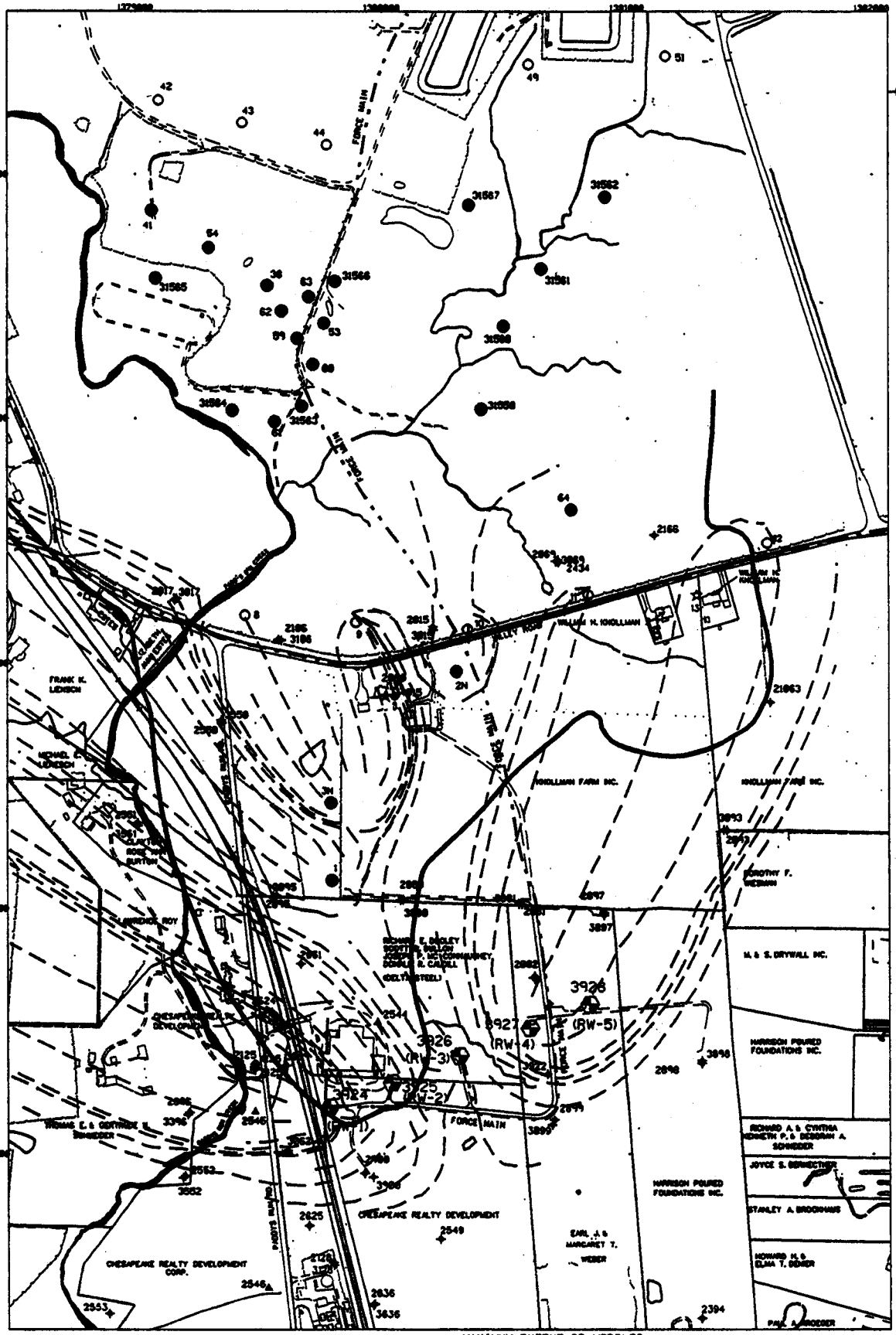
FIGURE E-18. DRAWDOWN AT 2003 - SCENARIO V



LEGEND:

- FEMP BOUNDARY
- TYPE 2 MONITORING WELL
- TYPE 3 MONITORING WELL
- TYPE 4 MONITORING WELL
- HOMEOWNER WELL
- MAXIMUM EXTENT OF MODELED 20 ppb URANIUM PLUME
- FORCE MAIN
- EXTRACTION WELL
- PIEZOMETER
- PROPOSED INJECTION WELL
- PROPOSED EXTRACTION WELL
- THREE YEAR PARTICLE TRACKS (NO RETARDATION)

SCALE: 606 303 0 606 FEET

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FIGURE E-19. MAXIMUM EXTENT OF THE OFF-PROPERTY PLUME - SCENARIO V

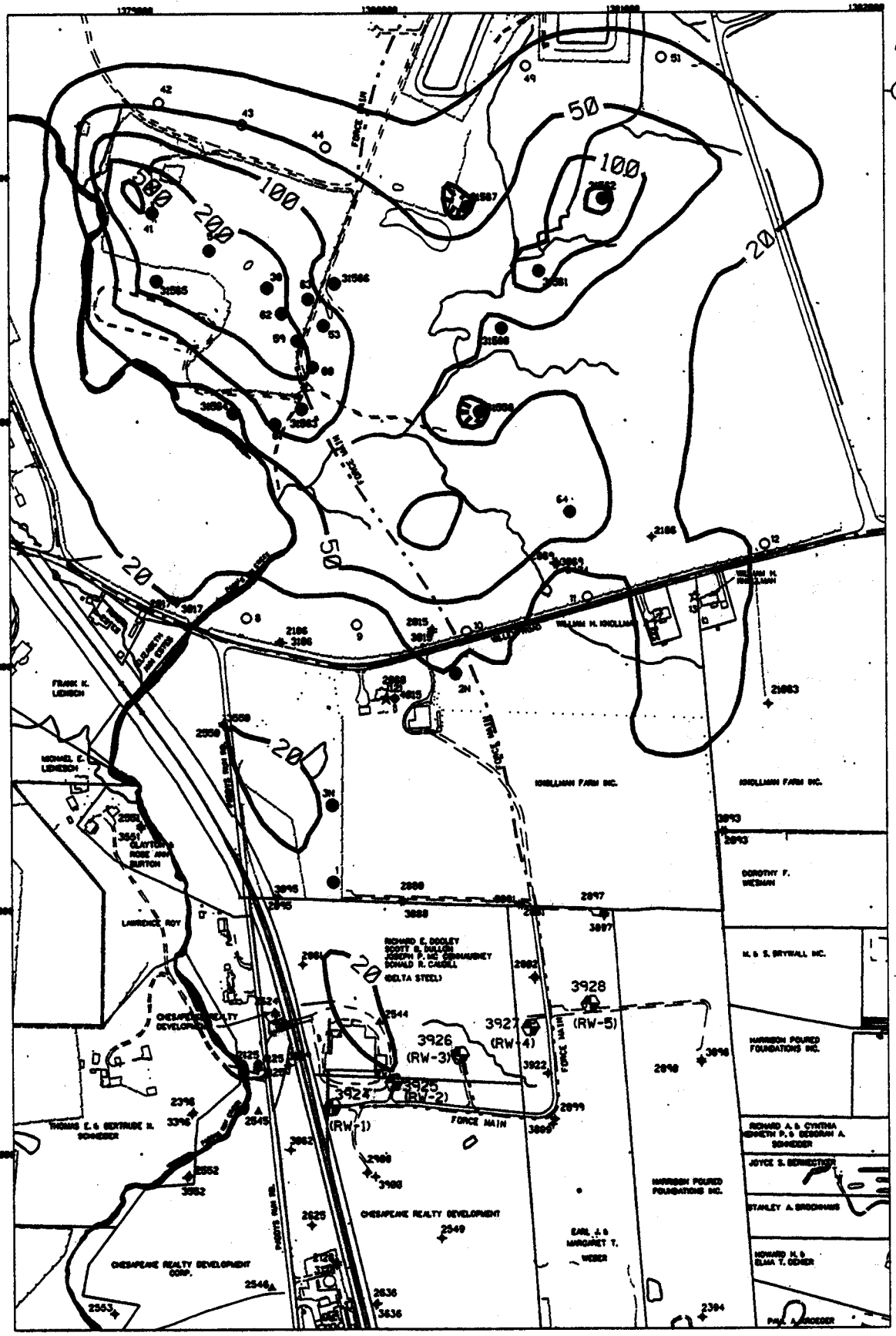

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FIGURE E-20. URANIUM PLUME AT 2003 - SCENARIO V

APPENDIX F

SUMMARY OF UNCERTAINTY ANALYSIS

F.1.0 INTRODUCTION

As described in Section 1.3 of this report, a number of factors cause uncertainty in the actual time and resources necessary to successfully complete the Great Miami Aquifer (GMA) restoration program at the FEMP. DOE, EPA, OEPA and other FEMP decision-makers need to fully understand the significance of the uncertainties in order to make well-informed decisions concerning how the program will be implemented both initially and at later stages of the cleanup.

The human factors (see Section 1.3.1) which can not be directly addressed in a quantitative uncertainty analysis were evaluated qualitatively when selecting the preliminary baseline strategy as discussed in Section 4.3.2. Following the selection of the preferred strategy using best available existing (i.e., pre-implementation) data and cost projections, uncertainty of the projected cleanup time of the selected baseline strategy was further analyzed. Impacts of the two major natural factors (i.e., hydraulic characteristics of the aquifer and geochemical conditions as described by the K_d parameter in the SWIFT model) were evaluated. The sensitivity of the projected system performance to aquifer hydraulic characteristics and geochemical conditions was first evaluated. The purpose of the sensitivity evaluation was to identify the critical parameters used in modeling to characterize these two factors. Critical parameters were identified based on parameter-specific uncertainties and expected impact to the modeling results within the parameter-specific uncertainty ranges. The critical parameters were then evaluated in the uncertainty analysis to quantify the ranges of potential cleanup time and cost. The overall approach for conducting the uncertainty analysis is presented in Figure F-1.

This appendix summarizes the sensitivity analysis using information from previous studies and provides a new quantitative uncertainty analysis. Model simulations of the recommended remedial system with bounding scenarios regarding the potential geochemical conditions were conducted in the uncertainty analysis.

F.2.0 EVALUATION OF PARAMETER SENSITIVITY

Various sensitivity and uncertainty analyses on the site-specific groundwater flow and contaminant fate and transport model parameters have been historically conducted during the groundwater model development and the Operable Unit 5 RI/FS processes. Information available from these analyses was

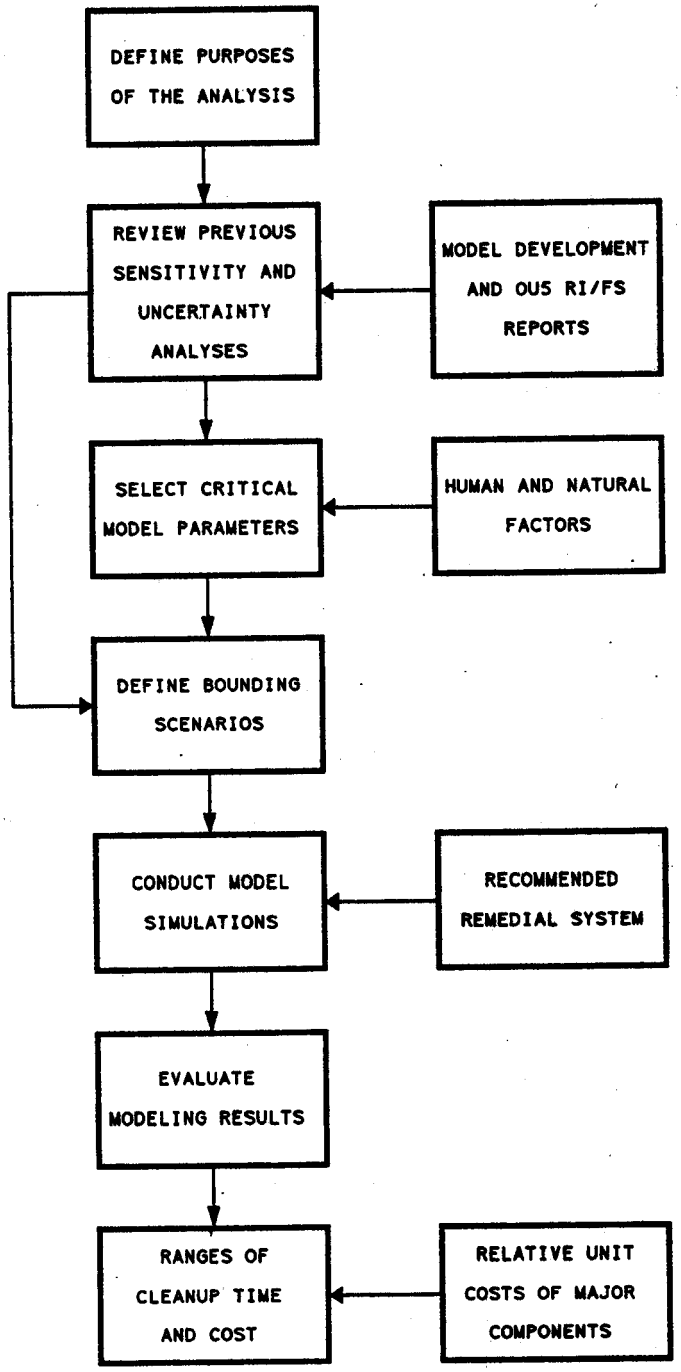

FIGURE F-1 OVERVIEW OF THE APPROACH

reviewed first to identify critical parameters so the new uncertainty analysis on the recommended baseline remedial strategy can be focused on these critical parameters.

F.2.1 REVIEW OF PREVIOUS SENSITIVITY AND UNCERTAINTY ANALYSES

F.2.1.1 Model Development Process

During the model development process the following hydraulic and geochemical parameters were evaluated in an uncertainty analysis (DOE 1994):

- Horizontal hydraulic conductivity
- Horizontal/vertical hydraulic conductivity ratio
- Effective porosity
- Longitudinal dispersivity
- Hydraulic gradient
- Mixing depth
- Infiltration rate
- K_d value

The ECTran model (DOE 1993) was used to perform Monte Carlo simulation as a part of the sensitivity analysis of the model performance measure (i.e., exposure point concentrations) on these parameters. Results of these simulations supplement the simple-band SWIFT model sensitivity analysis by presenting the complete range of potential combinations of parameter values and corresponding exposure point concentrations using a probabilistic approach. The ECTran model simulations provide a general understanding of the sensitivity of the GMA model predictions to these tested parameters. In general, the analysis indicated that the predicted exposure point concentrations were more sensitive to K_d values than to all the hydraulic parameters.

A total of 17 sensitivity runs were subsequently performed using the SWIFT model in a simple-band sensitivity analysis. The purpose of these simulations was to assess each parameter individually in the SWIFT model. The general conclusions of the analysis indicated that uncertainty of the groundwater flow portion of the model (i.e., groundwater elevation, flow rate, and direction) is lower than the transport portion of the model (i.e., contaminant concentrations). The analysis of model uncertainty showed that defining key variables at extreme values impacts risk assessment performance measures (maximum concentration anywhere in the aquifer, and maximum concentration at the property line) in general, less than an order of magnitude. The ratio of potential actual value to the current best estimate was defined as the uncertainty factor for quantifying the uncertainty. Estimated range of the uncertainty factor for the maximum groundwater concentration was between 0.22 to 2.2 (Table 5.4-2,

DOE 1994). The range of the uncertainty factor for the maximum fenceline groundwater concentration was between 0.28 to 1.43 (Table 5.4-2, DOE 1994).

F.2.1.2 Operable Unit 5 FS

A sensitivity analysis of aquifer cleanup time to geochemical conditions using the analytical model was presented in Attachment F.8.III, Appendix F of the Operable Unit 5 FS (DOE 1995a). The relationship between the "apparent" desorption K_d value and residual plume size after extracting the initial dissolved contaminant mass was first discussed. Impacts of "apparent" desorption K_d value, residual plume size, and groundwater flushing rate on aquifer cleanup time were then evaluated using an analytical model.

The analysis indicated that although higher desorption K_d values may potentially prolong the aquifer restoration time due to lower desorption rates, they can reduce the size of plume that will require long-term operation of the groundwater extraction system. Therefore, after terminating all the source loading and recovering the initial dissolved mass, the total pumping rate of the aquifer extraction system can be reduced and only focused on the smaller remaining plume which still has significantly high adsorbed-phase concentrations. To estimate additional time of extraction required after the initial dissolved-phase uranium mass has been recovered, the second part of the sensitivity analysis consisted of analytical model simulations to determine the relation between groundwater flushing rate and the required time to reach the groundwater cleanup level. Given an initial adsorbed-phase concentration of 5 mg/kg and a constant size of contaminated aquifer volume (i.e., 500 feet by 500 feet by 40 feet) used in the analysis, the additional extraction time required increased with increasing K_d value up to a point where further increases in K_d value began to reduce the time required. This phenomenon occurs because at some threshold value the portion of contaminant mass that is available to distribute into the dissolved-phase is insufficient to exceed the concentration-based groundwater cleanup level. For the assumed source condition, the maximum cleanup time resulted from a threshold K_d value around 100 L/kg. As expected, the cleanup time decreased with higher groundwater flushing rates. The maximum additional time required was about 15 years with a groundwater flushing rate of 1500 gpm for K_d values between 0 and 250 L/kg.

The SWIFT modeling approach using a K_d transition was first explored in Section F.7.7.4 of the Operable Unit 5 FS. However, correlation between timing of the K_d transition and termination of the surface source loading terms was not well defined in the preliminary modeling approach. No

conclusive information was presented in the FS from these earlier model simulations. The lessons learned during the FS regarding simulating the K_d transition have been incorporated into the updated modeling approach presented in Appendix A of this report.

Sections F.7.7 and F.8.6 in Appendix F of the Operable Unit 5 FS (DOE 1995a) present sensitivity and uncertainty analyses conducted during the FS process. Geochemical conditions, hydraulic effects, and model limitations were all evaluated in detail. The following recommendation was presented in Section F.8.7.2.3:

> "The actual contaminant desorption characteristics will affect the optimal aquifer remediation approach. The baseline geochemical conditions in the optimization study assumed a uniform uranium K_d value of 1.78 L/kg and fully reversible adsorption/desorption processes. These assumptions allow the maximum extent of the aquifer that may require continuous pumping, the maximum amount of uranium mass that needs to be recovered, and the potentially longest aquifer restoration time (due to the larger extent and mass need to be remediated with a limited extraction capacity) to be determined. Therefore, a conservative overall cost of aquifer restoration can be estimated for planning purposes.
>
> However, the adsorption process is partially irreversible and the desorption process is usually slower as shown by the desorption batch tests for the South Field area aquifer soil samples. Based on results of the geochemical sensitivity analysis, higher K_d values (i.e., slower desorption) will require higher groundwater flushing rates in some localized areas which have significant solid-phase contaminant concentrations, in order to achieve cleanup in a reasonable time frame. When a K_d significantly higher than 1.78 L/kg is encountered, the extraction strategy will need to be adjusted during aquifer remediation. Because of the smaller residual plumes that will remain after extraction of the initial pore volume of the contaminated aquifer due to higher K_d value, available extraction capacity can then be concentrated in smaller areas to achieve higher groundwater flushing rates and achieve the same cleanup time frame (as demonstrated in the sensitivity analysis). Reinjection and pulsed pumping will also be considered to improve the mass removal efficiency. Therefore, the overall cost and remediation time frame for aquifer restoration will not be significantly affected when properly managed."

Although the Operable Unit 5 FS used a longer site-wide remediation schedule and did not include injection and additional off-property wells, the general conclusions of the sensitivity analyses conducted regarding important factors which will affect groundwater cleanup time and cost remain valid. Uncertainty of the original 27-year cleanup time frame due to the natural factors evaluated will not be significant when the extraction rate schedule can be properly adjusted according to the actual conditions encountered during the remediation.

F.2.2 IDENTIFICATION OF THE CRITICAL FACTORS

Given the FEMP's new 10-Year Site-Wide remediation schedule, the Baseline Remedial Strategy Report identifies a potentially shorter groundwater cleanup time frame using additional extraction wells and groundwater injection as part of the recommended baseline remedial strategy. Based on the best available information, the groundwater cleanup time as indicated by modeling simulations may be reduced to 10 years. However, the uncertainty of the achievable reduction of groundwater cleanup time and cost may be more significant than the uncertainty associated with the original overall cleanup time frame of 27 years. As mentioned earlier, although the potential cleanup time frame reduction will be very sensitive to the human factors (see Section 1.3.1), uncertainties associated with these factors can not be easily quantified. Therefore, the new quantitative uncertainty analysis only focuses on the natural factors.

Based on results of additional hydraulic tests conducted since the completion of the SWIFT GMA model development (DOE 1995c and DOE 1995d), the groundwater flow portion of the model usually matches the measured field conditions very closely. Because the recommended baseline remedial strategy does not increase hydraulic impacts to the GMA even when more extraction wells are included, the cleanup time frame will not be affected significantly by the uncertainties associated with the hydraulic parameters as concluded by the previous sensitivity analyses conducted during the RI/FS processes and the subsequent flow model validation results. The most critical natural factors which may affect the estimated cleanup time reduction are the geochemical parameters such as the K_d value and timing of the "apparent" K_d transition as defined in Appendix A. Although not evaluated in previous sensitivity analyses, timing of the "apparent" K_d transition is expected to have significant impacts on the cleanup time. Therefore, these two geochemical parameters were selected for further evaluation in the new quantitative uncertainty analysis.

F.3.0 BOUNDING SCENARIOS OF THE UNCERTAINTY ANALYSIS

For this uncertainty analysis the K_d values and timing of K_d transition described in Appendix A for all the model simulations presented in this report except the uncertainty analysis was termed the baseline scenario. In the baseline scenario, the "apparent" adsorption and desorption K_d values were 1.78 and 17.8 L/kg, respectively. Local transition between these two K_d values was assumed to occur after termination of the localized source loading terms (based on the new 10-Year Site-Wide Remediation Plan) and extraction of one additional pore volume from each local contaminated portion of aquifer. Under the baseline remedial strategy, it will only take a few months to extract one pore volume from the contaminated portion of aquifer covered by a remedial system module.

Bounding scenarios which have different combinations of K_d values and timing of K_d transition than the baseline scenario were defined to bracket the plausible range of potential conditions. Based on information obtained from the previous uncertainty analyses, the following three bounding scenarios were developed:

- No-Transition Scenario - Assuming that the initial "apparent" desorption K_d value of 1.78 L/kg throughout the remediation.
- No-K_d Scenario - Assuming no adsorption/desorption process and all the initially adsorbed mass will not dissolve during remediation.
- Delayed Transition Scenario - Assuming that the K_d transition will not occur immediately after the source termination and extraction of one additional pore volume.

The No-Transition Scenario should provide an upper bounding estimate of the cleanup time estimate and the No-K_d Scenario should provide a lower bounding estimate of the cleanup time estimate. Together with the baseline scenario, cleanup time frames under these scenarios should provide sufficient information regarding cleanup time uncertainty of a remedial system.

The recommended baseline remedial strategy, as presented in Section 5.2, was then simulated with each of these bounding scenarios in the quantitative uncertainty analysis of the cleanup time frame. In order to simplify the analysis, only minor modifications to the original extraction/remediation schedule using the wells included in the recommended baseline strategy and Well 64 (as shown in Figures E-1 through E-5 in Appendix E) were considered in these simulations. However, during actual operation further improvements of the system performance by further adjusting the extraction/injection rate schedule will be possible.

F.4.0 MODELING RESULTS

F.4.1 CLEANUP TIME RANGE

In order to estimate the uncertainty due to geochemical conditions alone, the model simulations only focused on the South Field and South Plume areas. The modeling results for each scenario revealed the following:

- The simulated cleanup time for the No-Transition Scenario is about 20 years.
- The simulated cleanup time for the No-K_d Scenario is within one year after the local surface source remediation was assumed to be completed. For example, if South Field surface source-area remediation takes 7 years, the groundwater cleanup time will be within 8 years.
- The simulated cleanup time of the Delayed-Transition Scenario is within one year after the K_d transition, if the transition occurs more than one year after termination of the local source-area loading. For example, because the South Field surface source remediation is scheduled to be completed in 7 years under the 10-Year Site-Wide Remediation Plan, if the "apparent" K_d transition occurs at the end of 8th year, the groundwater cleanup time will be within 9 years.

The estimated range of groundwater cleanup time in the South Field and South Plume areas due to uncertainty regarding geochemical conditions alone is between 8 to 20 years.

Although not specifically evaluated, the last two conclusions should also apply to the Waste Pit and production area portion of the plume. Under the No-Transition Scenario the cleanup times for the Waste Pit and production area should be less than 20 years, because of the lower initial concentrations and smaller plume than the South Field and South Plume areas. It was assumed that the source remediation in the Waste Pit and the production areas will be completed within 10 years under the 10-Year Site-Wide Remediation Plan it will take a few more months to extract one additional pore volume from the contaminated portion of the aquifer. Therefore, based on all the findings, the range of the overall Great Miami Aquifer groundwater cleanup time using the recommended baseline remedial strategy, considering uncertainty, should be between 10 to 20 years.

F.4.2 COST RANGE

Using the relative unit costs presented in Table 4-9, the overall cost of the aquifer remediation will be between 140 to 250 relative cost units (each unit is $500,000). The difference between the lower and upper bounds primarily includes 10 years of groundwater treatment operation and monitoring and reporting activities after all the other FEMP source remedial activities are completed.

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