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WORK PLAN GROUND WATER FLOW/SOLUTE TRANSPORT MODELING REMEDIAL INVESTIGATION - FEED MATERIALS PRODUCTION CENTER JUNE 1988

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WORK PLAN
GROUND WATER FLOW/SOLUTE TRANSPORT MODELING
REMEDIAL INVESTIGATION
FEED MATERIALS PRODUCTION CENTER

PREPARED FOR:

U.S. DEPARTMENT OF ENERGY
OAK RIDGE OPERATIONS

PREPARED BY:

IT CORPORATION
MONROEVILLE, PENNSYLVANIA

JUNE 1988
PROJECT NO. 303317

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1.0 INTRODUCTION

Ground water flow and solute transport modeling will be performed for the U.S. Department of Energy's (DOE) Feed Materials Production Center (FMPC) in Fernald, Ohio to support the ongoing, sitewide Remedial Investigation and Feasibility Study (RI/FS). The overall model development process and use in the RI/FS is shown in Figure 1-1. As indicated, a preliminary flow model was first developed from historical data available from the site and surrounding area as well as from information gained from modeling studies conducted in the past. This preliminary modeling effort has been previously completed as part of a special study of the effects of discharges from the main effluent line on the Great Miami River and nearby production wells (Zone of Influence Study).

The focus of this work plan is a refined flow model and a solute transport model that will be progressively developed, calibrated, and applied using newly collected data from the RI. A model verification study, which is also addressed in this work plan, and a companion geochemical analysis and modeling effort will contribute to the final flow and solute transport models. The application of the resultant models for the evaluation of alternatives in the FS is discussed only in general terms in this work plan since the range of applications will develop parallel to the FS work. More information on the application of the model for purposes of the FS will be included in the FS work plan currently being prepared. A separate work plan for the FS modeling component may be required at a later date.

1.1 MODELING OBJECTIVES

The objectives of the computer simulation of ground water flow and solute transport for the FMPC RI/FS are summarized in Figure 1-1. A key objective of any modeling study is to contribute to the understanding of the physical system being modeled. For the case of the FMPC, the following hydrologic, hydrogeologic, and geochemical issues will be evaluated:

- Ground water flow rates and directions relative to the FMPC waste storage areas, waste discharge areas, and areas of postulated releases (e.g., storm sewer outfall ditch, main effluent line, and Production Area)

- Recharge (further define and quantify) to the regional aquifer (i.e., surface water and ground water) through till, alluvial, bedrock, and stream areas

- Recently collected and historical water quality data relative to the identified potential chemical and radiological constituent sources
- The relative importance of the identified sources in terms of chemical and radiological constituent loading rates to the aquifer
- The effects of geochemical variability in the aquifer system as it relates to radionuclide mobility

By gaining a refined understanding of the current situation through the modeling study, it is possible that critical physiochemical processes or site locations will be identified that have not been sufficiently investigated. A secondary objective of the model is, therefore, to evaluate the need for additional monitoring and to aid in the scoping of any related field investigations.

For purposes of the RI, a principal use of the model will be to support the evaluation of potential public health and environmental risks. In particular, the evaluation of the no-action alternative requires the prediction of future conditions for both on-site and off-site receptors. Since past and current field observations cannot yield such predictions, the results of a verified and calibrated model become a critical input to the no-action risk assessment.

A similar application of the ground water flow and solute transport models will be made in support of the FS. In this case, however, the short- and long-term effects of various remedial action alternatives on the rates of contaminant release and migration are the focus. The temporal and spatial variations of concentration resulting from the different remedial actions will also be predicted. The ground water flow model can also be used as a tool for the conceptual design phase of the FS. For example, the number, location, and spacing of interceptor wells for a ground water pumping and treatment option can be optimized through the application of the model.

1.2 PROJECT SETTING AND MODEL DESIGN

The hydrogeologic setting in the model study area (Figure 1-2) is composed of a buried channel aquifer which is deeply incised into bedrock. The buried channel varies in width from about one-half mile to over two miles and has a U-shaped cross section with a broad, relatively flat bottom and steep valley

walls (Figure 1-3). Bedrock is predominately flat-lying shales with thin interbedded layers of limestone. Thick deposits (exceeding 200 feet) of glacial outwash material composed of coarse sands and gravels with interbeds of silts and clays fill the buried channel. Overlying the aquifer in places are variable thicknesses of glacial till (Figure 1-3).

Details of the project area hydrogeologic setting are described in previous reports (IT, 1987). Site conditions considered in the decision to construct and use a three-dimensional ground water flow and solute transport model for the RI/FS process are:

- Presence of several potential source areas with different strengths and periods of release as well as several types of potential receptors
- Location of the site over a large, irregularly shaped buried channel aquifer
- Thick, highly permeable aquifer with complex variations in horizontal and vertical hydraulic conductivities
- Location of major pumping centers in the model study area which influence the aquifer potentiometric head over large areas
- Pumping at depth (partially penetrating wells) within the sand and gravel aquifer
- Large changes in horizontal hydraulic gradients across the study area
- The presence of vertical hydraulic gradients within the study area, possibly induced by local pumping
- Complex river and aquifer interactions
- Uncertainties of areal recharge through varying hydrogeologic zones composed of till, floodplain, and alluvial deposits

Chemical and radiological contaminants associated with the FMPC site most likely would have been introduced to the aquifer from one or more of the following:

- Leaky waste pits in the waste storage area
- Discharges to and leakage from Paddys Run
- Discharges to and leakage from the storm water outfall ditch

- Leakage from the main effluent line
- Waste or product spills in the Production Area as well as "suspect" waste disposal areas within the FMPC site
- Any facility in the Production Area used for the storage, containment, or transfer of radiological or chemical materials

Figure 1-4 shows the FMPC site and the possible source areas for solute introduction to the regional aquifers.

Based on previous published work as well as a knowledge of the site, a conceptual design for the ground water model has been developed. The ground water flow model will simulate the relationships between the Great Miami River, the aquifers in the region, and the local pumping withdrawals. The solute transport model will be capable of simulating contaminant transport away from source locations. For these reasons, the flow model area was chosen to cover the entire area of possible ground water influence by the Southwestern Ohio Water Company (SOWC) pumping wells (Figure 1-2), or an area of about 20 square miles. A smaller model area will be used for solute transport simulation.

1.3 MODEL USE

The development of the RI/FS work plan for the FMPC was highly influenced by the source-pathway-receptor framework of a CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act of 1980) study. Within this context and with reference to Figure 1-5, the source, pathway, and receptor components can be correlated with the geochemistry, ground water modeling, and endangerment assessment portions of the RI/FS, respectively.

Source Analysis

A geochemical work plan that involves field, laboratory, and modeling studies has been prepared toward the objective of substantiating whether a release of radionuclides or chemicals has occurred, is occurring, or could potentially occur from various waste sources at the FMPC. The geochemical program is intended to evaluate the potential for migration and release throughout the glacial till zone, thereby providing a consistency with the ground water model that is limited to the underlying sand and gravel aquifer. Where possible,

the time frame, rate, and/or total mass of contaminant release from each principal source into the sand and gravel aquifer will be quantified as part of the geochemical program for input into the ground water flow/solute transport models. *

Receptor Analysis

A separate work plan is also being prepared for the endangerment assessment. In this case, the results of the ground water model will be used to support the associated risk assessment in terms of the magnitude, extent, and duration of off-site contamination at critical receptor locations.

Pathway Analysis

The critical link between the sources and receptors is the transport pathways; in this case, ground water flow. The key application of the ground water model, therefore, will be to substantiate whether a pathway exists between various sources and receptors and if so to confirm or predict conditions at the receptor locations.

The preferred application of a ground water flow and solute transport model is to predict, with a high degree of confidence, the time-varying concentrations of multiple contaminants at various receptor locations resulting from several sources. To claim this capability, however, a full calibration of the model against known source terms and actual, observed concentrations at the receptor is required. Conditions at the FMPC are such that this objective is not expected to be fully satisfied. In particular, too little is known about the rate of release, duration of release, and total mass of release from the sources to be able to strictly and quantitatively calibrate the results of the solute transport model against observed concentrations. It is expected, however, that a full calibration of the ground water flow model will be achieved. How? The goal of the pathway analysis will be to make maximum use of both the ground water flow and solute transport models but to emphasize the ground water flow component due to the higher level of confidence in flow model calibration.

Figure 1-6 has been prepared to summarize the application of the ground water flow and solute transport models for pathway analysis. The procedure will be

What time period & organic small & labors

applied for each combination of source, pathway, and receptor. With reference to Figure 1-6, the geochemical program will initially establish whether a past, current, and/or future release of contaminants through the till can be expected from a given source. The rate and total mass of each release will be quantified to the extent practical. If a significant release from a given source has not occurred and is not expected to occur even under the no-action alternative, as would be the case if insoluble forms are present or if the contaminant is strongly bound to the soil matrix within the till, there would be no need to pursue a pathway analysis for that source. Otherwise, a pathway analysis will proceed with the application of the ground water model.

The initial application of the ground water flow model is to determine, through the analysis of the calibrated ground water directional flow vectors, whether a receptor of interest is hydraulically connected to a given source via the ground water pathway. If this is not the case, then the critical link between the source and receptor is nonexistent and no additional pathway analysis is warranted regardless of the magnitude and duration of the release. Note that it may also be necessary to evaluate the directional flow vectors under various pumping scenarios and hydrologic conditions to simulate conditions associated with historic releases.

? * Human or Eco RIC

If both a release and a hydraulic connection are substantiated by the model results, the next step in the pathway analysis becomes dependent on the type of release. Future releases cannot be associated with any contamination already observed at receptor locations; consequently, any case involving only a future release must be treated as an expected future condition. The application of the model in such a case will proceed directly to the prediction of future impacts at receptor locations under the no-action condition.

For any sources that are associated with past and/or current releases, the question that next arises is whether the released contaminants would have yet reached (or even bypassed) the receptor location. There are two components to the corresponding analysis of travel time. The first involves the application of the ground water flow model and the analysis of the resultant velocity vectors. In this case, the travel time of ground water between the source and the receptor, as predicted by the model, will be compared to the time elapsed

since the earliest date of release from the source. If the travel time is greater than the elapsed time, then any potential impacts can be considered as a future condition and the analysis can proceed directly to the evaluation of the no-action alternative. An exception would be if a contaminant "front" precedes the average movement of flow due to solute dispersion. A simplified analytical model will be used to check for this condition.

If, on the other hand, it is found that ground water underlying the source could have reached the receptor location within the elapsed time, it must still be determined whether a contaminant subject to retardation processes would also have reached the receptor location in the same elapsed period. This determination of contaminant retardation and effective travel time will be made using the solute transport model. The overall extent of any contaminant plume can also be approximated from the results of this analysis of travel times.

The remaining two steps of the pathway analysis can be used to: (1) confirm the hypothesized pathways, (2) evaluate the relative contributions from multiple sources, or (3) indicate the possible need for additional model calibration. These two steps (Figure 1-6) involve a comparison of actual field observations with the conditions that would be expected due to a release from a particular source. The solute transport model provides an important analytical tool in this regard although a detailed analysis of field data will also be critical. A more detailed presentation of these steps is provided in Section 5.5.

Upon completion of the pathway analysis, three general types of model applications will proceed in support of the risk assessment, including: (1) an evaluation of the current situation, in which case the model will be used to interpolate between and extrapolate beyond the point locations of field observations; (2) the prediction of expected future conditions under a no-action scenario; and (3) the prediction of expected future conditions under various remedial action alternatives. The first two applications will be performed as part of the RI; the evaluation of remedial action alternatives will be accomplished in the FS.

2.0 BACKGROUND

Investigations of the surface and ground water resources and the overall hydrogeologic environment of the FMPC study area have been conducted by many state and federal agencies and private firms. A partial listing of pertinent references is provided with this work plan and will be used to form the historical data base for the modeling study.

2.1 PREVIOUS STUDIES

Rather than attempting to provide a summary of each of the aforementioned references, which would exceed the intent and needs of this work plan, only those studies that represent direct predecessors to the current modeling study will be considered in this section. Note that each of the studies to be presented below made appropriate use of the available reference material; therefore, the references can be considered to be indirectly accounted for.

2.1.1 IT Litigation Support

National Lead of Ohio, Inc. (NLO), provided a scope of work to IT Corporation (IT) dated January 10, 1986, wherein NLO set forth anticipated tasks required with respect to the Fernald litigation case. The primary objective of the hydrogeologic scope of work subsequently developed by IT was to establish the geographic boundaries of off-site impacts, if any, from the FMPC. A preliminary report concerning the extent of impact was based on information available as of April 12, 1986.

The study area encompassed the region within a five-mile radius of the FMPC. The data review and data collection programs were designed to assist in evaluation of the effects of waterborne emissions from the plant production and waste storage areas. During the study, existing hydrologic, hydrogeologic, and geochemical data were reviewed. Additionally, ground water elevation and water quality data were collected by IT (prior to April 12, 1986) and reviewed. From this data base, IT performed a preliminary evaluation of ground and surface water flow directions, ground water flow rates, and chemical migration beyond the boundaries of the FMPC that supported the planning of the RI ground water program.

2.1.2 Zone of Influence Study

The Zone of Influence Study was conducted in accordance with Order 14B of the State of Ohio's Director's Orders and Findings. The study objectives were to determine if the discharge from the FMPC effluent pipeline is located within the zone of influence of the production well field operated by the SOWC or any other major production field and, if so, to qualitatively and quantitatively determine any associated adverse environmental impact.

The scope of work for this study centered on analytical and numerical modeling studies of the surface water and ground water environments. Models were used to establish the approximate boundaries of the zone of influence of the SOWC wells and to quantify the effects of three mixing processes on the impacts caused by the FMPC discharge. These processes included the mixing of the effluent discharge with background water in the Great Miami River, the mixing of induced infiltration from reaches of the river upstream from the FMPC discharge with that from impacted reaches downstream from the discharge, and the mixing of the ground water flow component originating from the river with the regional aquifer flow and other sources of recharge prior to reaching the SOWC wells.

An extensive review of available data and a limited field program provided both the input data base for the models and the calibration data used to test model performance. A sensitivity analysis was also completed to test the sensitivity of the model results and study conclusions with respect to assumed site conditions and parameter values. The results of the data review and modeling studies allowed the following two general conclusions to be made:

- The discharge from the FMPC effluent pipeline likely occurs within a reach of the Great Miami River that contributes flow, via induced infiltration, to the SOWC collector wells. The relative contribution of flow to the SOWC wells from the river downstream from the discharge is, however, a small fraction of the flow contributed from upstream reaches of the river. The sensitivity testing of the model indicates that the FMPC discharge could actually be outside of the capture zone of the SOWC wells if the river infiltration rate is greater than assumed.

- Even if the FMPC discharge is within the zone of influence of the SOWC wells, the incremental impact of the effluent on the water quality of the pumped water lies within the range of variability of previous observations and is below analytical detection limits under

average conditions. Therefore, no observable improvements in water quality would result in the SOWC wells from eliminating the effluent effects (e.g., by relocating the pipeline).

Based on the results of this study and the conclusions drawn therefrom, no further studies specifically addressing the impact of the FMPC discharge on the SOWC collector wells were recommended.

The SOWC collector wells, the river, and the regional ground water flow system assessed in this preliminary study are of utmost importance to the overall issues being addressed in the sitewide RI/FS and other related studies. The results of the preliminary modeling studies were of value in expanding the current understanding of sitewide and regional issues. Additional investigations to address the remaining uncertainties are being performed as part of the sitewide RI/FS, including the modeling study being addressed in this work plan.

2.1.3 Previous Ground Water Modeling Studies

Three previous ground water modeling projects have been completed in the vicinity of the FMPC. The U.S. Geological Survey (USGS, 1968) published the results of their analog model study. The purpose of this study was to predict the effects of increased pumping on the buried channel aquifer in the Fairfield-New Baltimore area. GEOTRANS, Inc. (GEOTRANS, 1985), completed a limited three-dimensional modeling study of the buried channel aquifer to assess the general ground water flow directions and speculate on rates of contaminant transport away from the FMPC. IT (1987) performed a two-dimensional numerical modeling study of the buried channel aquifer to assess the impacts of the FMPC discharges on the SOWC and other well fields. This study provided the preliminary ground water flow model to be used in the RI/FS. Results of these studies will be incorporated in the present modeling task.

2.2 MODEL CODE SELECTION AND VERIFICATION HISTORY

For purposes of the RI/FS modeling study, four minimum requirements for the model code were established (IT, 1987), including the following:

- Only codes that had three-dimensional or quasi-three-dimensional modeling capabilities were considered. This is necessary to account for vertical flow through varying types of geologic strata and to

simulate the effects of vertical hydraulic gradients caused by regional pumping at depth.

- The capacity to quantitatively predict contaminant concentration at receptor locations is considered necessary to fully satisfy the requirements of the RI/FS. Therefore, only codes with options to model solute transport and associated attenuation/retardation processes were considered.

- Only models that have been adequately verified and previously applied under similar project settings were considered. This criterion was necessary due to the sensitive nature of the FMPC work and the magnitude of future decisions that could be based on model predictions.

- The immediate availability of the modeling code and accompanying documentation was necessary to satisfy near-term deliverables.

Available modeling codes were evaluated against these four criteria to establish a "short list" of codes for additional evaluation. Four codes were found to satisfy these criteria, including SWIFT II/III, GEOFLOW, SWENT, and the Princeton Transport Code (PTC) (IT, 1987).

Numerous other selection criteria were applied to these four model codes to refine the selection process with respect to the specific site conditions and study requirements, including:

- The capacity to model unconfined flow regimes in case unsaturated flow beneath the river or waste storage units is eventually found to be a critical process.

- The capacity to model decay chains. Although the radionuclides of most concern do not require the consideration of daughter products, this would become a consideration if other radionuclides are found to be important.

- The ability to accurately represent attenuation/retardation (e.g., adsorption) and decay processes so as to provide flexibility in the range of constituents that can be modeled.

- The capacity to handle a wide variety of boundary conditions so as not to limit the available options for best representing actual site conditions.

- The option to consider density variations and temperature or concentration effects on fluid viscosity. Although not considered necessary at this time, this option could be beneficial to best simulate certain critical processes (e.g., leakage through the riverbed).

- The convenience of model application based on features such as pre- and postprocessing capabilities, user documentation, mesh generation, solution method, restart capability, applicability to available computer systems, and user familiarity.

Following a critical evaluation of the relative benefits and deficiencies of the respective codes, SWIFT III was determined to most comprehensively satisfy the full set of selection criteria. Therefore, a decision was made to select SWIFT III as the primary code for use in the hydrogeologic investigation of the FMPC sitewide RI/FS (IT, 1987).

SWIFT III Overview

The SWIFT model code was originally developed by Sandia National Laboratories (SNL) for the Nuclear Regulatory Commission (NRC) for use in the high-level nuclear waste isolation program. The first extension of the SWIFT code was made by GeoTrans and was given the title SWIFT II.

Comparisons of results from the SWIFT II model code and analytical solutions appear in many documents. In addition, code verification of the SWIFT codes has appeared in several journals and poster sessions. Results of the SWIFT model applications have also been compared with data collected in numerous field studies. The comparisons provide evidence that the equations solved in the model properly simulate observed hydrogeologic behavior. Applications of the code to actual sites have also appeared in several reports, the most noteworthy are those appearing in Ward, et al. (1984 and 1988), which are summaries of the model verification process and field comparisons.

Modifications to the SWIFT II code were made by GeoTrans in 1987. A primary modification consisted of changing the code from FORTRAN IV to FORTRAN 77 to create a more computer-general model. Modifications were also made for data input and output simplification. The resultant model was termed the SWIFT III code.

Pursuant to the modifications, GeoTrans and IT conducted verification work that tested the validity of several features of the SWIFT III code. The results of GeoTrans' most recent model code verification work are presented in SWIFT III Quality Assurance Benchmark Problem Execution (Ward, 1988). The

results of the IT verification program will be presented with the results of the RI/FS modeling study. Additional details of these previous and additional proposed verification efforts are provided in Chapter 3.0.

3.0 MODEL CODE VERIFICATION

3.1 INTRODUCTION

The SWIFT III computer model code was selected to evaluate ground water flow and solute transport for both the hydrogeologic study of the FMPC discharge to the Great Miami River and the overall, sitewide RI/FS. At the time of model selection and application to the hydrogeologic study of FMPC discharges to the Great Miami River, no verification of the SWIFT III code had been documented. Therefore, a work plan for a comprehensive model verification study was prepared and submitted by IT on November 4, 1987. The purpose of the verification study was to validate the accuracy of the computational algorithms used to solve the governing equations and to ensure that the computer code is fully operational in the host computer. Specifically, the objectives of the computer model code verification study were to:

- Determine if SWIFT III functions in a manner similar to well-established ground water flow/solute transport model codes and analytical solutions
- Verify the capability of the model code to solve complex, large-scale problems, i.e., matrix solutions and parameter calculations
- Establish a high level of confidence for the code capabilities
- Document the procedures and findings of the verification process

The overall objective of the program was to show that the SWIFT III model code accurately performs the operations specified during the ground water flow/solute transport modeling process. Upon approval of the work plan, this verification work was initiated by IT and is proceeding.

Typically, a code is checked for correct coding of theoretical principles and for major programming errors by executing selected problems for which an analytical solution exists. Analytical problems typically incorporate the code's main program and most of its subroutines, including all of the frequently called ones, in the testing. However, testing numerical computer codes by comparing results for simplified situations for which an analytical solution exists does not guarantee a fully debugged code. The comparison of correctness and computational efficiency of one code against another is also necessary, particularly for problems for which analytical solutions do not exist.

Such comparisons can demonstrate the influence of model domain heterogeneity and hydrogeologic stratification and the effects of partially penetrating wells, etc., on the computational algorithms. Consequently, the verification study includes comparisons with the results of other well-verified and widely accepted ground water model codes such as the USGS Modular Ground Water Flow Code (McDonald & Harbaugh Code [McD-H]), IT's proprietary ground water flow and solute transport model GEOFLOW, and the PTC developed by Princeton University.

Several analytical verification tests have been completed to date and several others were in progress until put on hold pending resolution of a potential redundancy with the recent efforts of GeoTrans. In late March 1988, IT was notified of concurrent SWIFT III model verification work being performed by GeoTrans. The results of GeoTrans' work have been published and made available to IT. In response, a decision was made to reevaluate IT's verification program in relation to the work completed by GeoTrans. The purpose of this section is to summarize what has been accomplished to date and what remains to be done to satisfy the original objectives of IT's verification program. The conclusions reached during this reevaluation and proposed additional verification needs are shown in Tables 3.1 and 3.2. The following sections describe what verification work has been completed, what future work needs to be completed, and the approach to completing the verification.

3.2 VERIFICATION WORK PERFORMED BY IT AND GEOTRANS

Verification work has been completed to date by both GeoTrans and IT (Tables 3.1 and 3.2). This verification involved creating problem sets which could be applied to both the SWIFT III code and other numerical codes and analytical solutions.

The flow portion of the code has been checked using two-dimensional problem sets, which included:

- Analytical solutions for fully penetrating pumping wells in both homogeneous, isotropic and homogeneous, anisotropic confined aquifers
- Numerical comparisons with GEOFLOW and the McD-H codes for an irregularly shaped water table aquifer

- Comparisons of the model results to an actual field case involving an anisotropic aquifer with aquitards and injection pumping

No three-dimensional comparisons for flow have been documented.

The solute transport portion of the code has been checked using one- and two-dimensional problem sets. The one-dimensional problems have included analytical solutions for transport in homogeneous, isotropic aquifers with chain decay using both equal and unequal retardation. The two-dimensional problems have included:

- A field case which compared actual and computed contaminant concentrations in an aquifer downgradient of a landfill
- Comparisons of computed concentrations using the SWIFT III and GEOFLOW codes

No three-dimensional comparisons for solute transport have been documented.

3.3 ADDITIONAL VERIFICATION NEEDS

Additional SWIFT III model code verifications will focus on evaluating the following:

- Three-dimensional flow using analytical comparisons
- Three-dimensional flow using numerical comparisons
- Two-dimensional solute transport using analytical comparisons
- Two-dimensional solute transport using numerical comparisons
- Three-dimensional solute transport using numerical comparisons

The verification of three-dimensional flow and solute transport using field comparisons will be accomplished during the final stages of the RI/FS model construction and calibration by making comparisons between recorded site conditions and computer output.

Specific features of the code to be tested include:

- The flow portion of the code; specifically, the river recharge subroutines, well pumping subroutines, and the simulation of water table conditions
- Solute transport with a refined grid system using a small hypothetical problem set

The verification process will test the code for accuracy in simulating flow and solute transport in a layered, unconfined, anisotropic aquifer system with partially penetrating pumping wells and river aquifer interaction.

3.4 APPROACH TO COMPLETE VERIFICATION

The approach to completing the model code verification is shown in Figure 3-1. The three-dimensional flow portion of the code will be evaluated using a problem set which includes several model layers, pumping at depth, river aquifer interaction, and water table conditions. To complete the model code checks, the chosen problem set will be simulated using the SWIFT III and McD-H programs. Upon completion of the verification checks on flow, draft documentation will be completed describing the results.

Code verification for solute transport will be completed by making comparisons to simplified two-dimensional and three-dimensional problem sets. For two-dimensional transport, comparisons will be made between SWIFT III output and analytical solutions using STRIP1 and/or STRIP1B (analytical programs developed and verified by IT) and numerical solutions using GEOFLOW.

Three-dimensional transport will be evaluated by simulating a simplified test problem on both SWIFT III and PTC. Findings and conclusions of the solute transport code verification will be documented and combined with the flow verification documentation to complete the final verification report.

As specified in the IT Quality Assurance Manual, the content of the SWIFT III model code verification documentation will include:

- Verification Master Log - This is a record of a program's revisions and of its verification status. (Items which will be included are persons performing verification or reverification [if necessary], date of verification, content of verification program, person logging the information, and date of log entry.)

- Description and Explanation of What Was Done to Verify the Program - This identifies what independent options of the program were verified and should include error message options and default options as well as regular program options.

- Verification Comparison Material - These are the actual documents which show the results that are being compared to the program being verified. Included are hand calculations, computer runs, test program results, and/or textbook and journal references.

- Computer Program Verification Runs for the Options Being Verified - These will be the original runs, giving results which will be compared to the documents listed immediately above.

Verification material will be filed by program name, with material from all revisions retained in the Fernald RI/FS files.

The format of the SWIFT III model code verification report will be as follows:

- An introduction explaining the overall verification process, the purpose and the specific objectives of the program, and the types of problem sets selected
- The objectives of each problem set and justification for selection
- A description of each problem
- Assumptions made for each problem
- Analytical and numerical solutions
- Model code input specifications
- Model code output specifications
- Results of each problem set comparisons
- Summary and conclusions of the overall ground water flow/solute transport verification process

The anticipated report format will be similar to Ward, et al. (1984).

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4.0 MODEL DATA BASE

The data base for the RI/FS modeling study will be assembled from reports and data files available from the public record and from information obtained during the RI process and assembled in the project Data Base Management System (DBMS). Data required for construction of the model will be recorded in the RI computer data base and in tables and figures with available references cited.

4.1 AVAILABLE DATA BASE

The FMPC ground water model project area has been studied by numerous individuals, federal and state agencies, and private firms. The extent of the historical data base is shown in the list of references included at the end of this work plan. Regional and site data required to meet the objectives of the modeling study exist for the following areas:

- Geology
- Hydrogeology
- Soil types
- Meteorology/climatology
- Bedrock elevations
- Till thicknesses
- Ground water elevations
- Aquifer transmissivities
- Streamflow and river hydraulics
- Surface water quality
- Ground water quality
- Ground water pumping
- Domestic, agricultural, and industrial well locations
- Water and land use
- Stream/aquifer interrelationships

Records and publications of the USGS, the Miami River Conservancy District, the Ohio Department of Health, the Ohio Environmental Protection Agency (OEPA), and the Ohio Department of Natural Resources (DNR) are available for information about ground and surface water flows and quality. The U.S. Soil Conservation Service (SCS) records are available for information about the physical and chemical properties of the area soils. Other important sources of information regarding the site and the surrounding area include documents issued by the DOE and its predecessor agencies. Data gathered during previous site investigations and site inspections by the U.S. Energy Research and Development Administration (ERDA) and DOE contractors are available.

In addition to the historical data base, site-specific data collected during the RI process will be used for model construction. This RI/FS data base will include information on:

- Ground water quality
- Surface water quality
- Subsurface soil properties
- Ground water elevations
- Till horizontal hydraulic conductivity
- Contaminant source types and locations

Site-specific RI data will be incorporated into the DBMS developed for the project. Where appropriate, study area data will be compiled into computer files for incorporation into the model. This information may include:

- Ground water elevations
- Ground water chemical and radiological parameters
- Top-of-aquifer elevations
- Locations of interbeds

From the historical and RI data base and literature reviews, the following model input parameters will be estimated:

- Contaminant loadings to the aquifers
- Contaminant retardation factors based on geochemical studies and modeling
- Aquifer recharge

Additional data required for developing model input parameters will be assembled into tables and figures and become part of the project data base files.

4.2 MODEL INPUT PARAMETERS

Specific model input parameters required for flow and transport simulations are discussed below.

Hydrogeologic Parameters

Hydrogeologic parameters required for model construction include:

- Subsurface Stratigraphy - Which includes top-of-aquifer elevations, thickness of aquifer materials, location and thickness of interbeds, bedrock elevations, and geologic material properties

- Aquifer and Interbed Hydraulic Conductivities - Which may be varied by layers and zones within the model area

- Storage Coefficient - For transient flow simulations

- Regional Recharge Rates - Through the till, bedrock, floodplain, and alluvial areas

- River Hydraulic Parameters - Including flow, stage, and flood frequency return periods and riverbed hydrologic properties

- Water Supply Well Pumping Rates - From agricultural, domestic, and industrial users

- Water Supply Well Intake Elevations - For partially penetrating wells

- Aquifer Potentiometric Levels - From the historical and RI data bases

This information is required to construct the ground water flow portion of the model.

Solute Transport Parameters

Model input parameters required for solute transport simulations include:

- Solute Source Types - Required to properly assign solute retardation coefficients for different chemical and radiological constituents (more data exist for uranium than for any other chemical constituent)

- Source Locations - To properly model contaminant dispersion and extent of migration, proper starting points within the aquifer need to be assigned (Figure 1-4)

- Source Loading - To properly model the extent of contaminant migration and dilution, initial input loading rates must be approximated (this information will be acquired from the geochemical assessment)

- Porosity/Effective Porosity - Required for ground water pore velocity calculations

- Retardation Factors - Various retardation factors for the different chemical and radiological parameters must be estimated to predict the concentrations of the contaminants downgradient of the source areas (this information will be acquired from the geochemical assessment) LIT.?

- Aquifer Dispersivity - This parameter will be selected from literature to predict the vertical and horizontal spreading of contaminants migrating through the aquifer — EIS PROBLEM W. LIT. #

- Radioisotope Decay Constants - An evaluation of the half-life of the various radionuclide constituents will be completed to determine if radioactive decay is an important attenuation process to be accounted for in the model study

- Chemical and Radiological Constituent Concentrations - Water quality parameters obtained from the RI field program will be evaluated and concentration maps prepared when appropriate

Input parameters for contaminant transport modeling will be acquired from the RI data base, literature reviews, and geochemical modeling and testing.

4.3 DATA BASE PREPARATION

Field data obtained during the investigation will be compiled and evaluated throughout the course of the RI. The quality and completeness of the data base resulting from the RI will be examined for adequacy, for determination of model input parameters, and for comparison to modeling results.

As part of the model data base, statistical techniques will be used to evaluate data from the sampling programs. For example, geostatistical analysis will support different mappings of the magnitude and extent of site contamination and determine the level of data reliability. Kriging?

Project area data incorporated in the DBMS will pass through one or more of the following three successively more detailed levels of processing before use in the modeling:

- Level I - This is output derived directly from the DBMS and for any data types which may occur in three format categories:

  - Report-style tabular output on hard copy

  - Records formatted for graphics processing

  - Records formatted for programs which extrapolate input data for the model grid — Kriging

- Level II - This level consists of processed data represented by output from the graphics subsystems consisting of SURF II, Autocad, and SAS-Graph

- Level III - This level represents new hydrogeologic tables and figures, based upon Level I and II output, generated to document interpretations and computations

The programming required for automating grid assignments and information searches within the model system will be developed to effectively examine and edit model input data. The display of modeling output consists of developing

the necessary computer codes to the requirements of the SAS-Graph, Autocad, or SURF II postprocessors. Storage and retrieval of input/output data sets for individual model runs will be performed by transferring data electronically between host microcomputers at the project offices or at the particular laboratories where they reside. A list of data types which support the modeling effort and also some estimates of corresponding record lengths and record number will be developed for model input. In addition, graphic and tabular displays required for each data type will be identified.

Presentation formats typical of geologic, hydrogeologic, and environmental studies to be utilized for purposes of data summarization include:

- Location and character of areas containing waste or waste-generated chemicals outlined on the site topographic map. Sampling locations and approximate concentrations for one or more indicator chemicals will also be depicted on the map.

- Site hydrogeology depicted on a series of hydrogeologic cross sections that transect the most pertinent waste and/or environmentally affected areas of the site, including the location and thickness of clay and sand and gravel interbeds within the till and the regional configuration of the buried valley aquifer.

- Contour maps to show ground water flow direction and gradients and potentiometric contours superimposed on a topographic map for both the till and the sand and gravel aquifers. Monitoring well locations will also be shown on the topographic map.

- Base maps to present results of the hydrogeologic data analysis. This information will include, for example, the location(s) of water-bearing strata and other subsurface features, the degree of vertical connection between the till and sand and gravel aquifers, ground water/surface water interrelationships, and chemical concentrations.

- Regional RI/FS site maps to identify potential receptors of contaminants released from the site as well as any other sources of wastes in the regional area that could be contributing contaminants to the wells being monitored.

Use of these data summaries for model construction is discussed in Chapter 5.0. The data base and data evaluation program output will be formulated around the RI/FS ground water model.

5.0 MODEL DEVELOPMENT

5.1 OVERVIEW

Proper evaluation of ground water flow and solute migration under and surrounding the FMPC area requires the development and use of a relatively complex three-dimensional computer model. The complexities of the hydrogeologic environment, the magnitude of on-site and off-site pumping, and the type, rate, and timing of multiple releases of contaminants from the site all create a situation which cannot be properly evaluated by intuitive and analytical methods alone or by the use of even a two-dimensional numerical model.

The process by which three-dimensional ground water flow and solute transport models are developed, calibrated, and applied is fostered, however, by the systematic use of one- and two-dimensional numerical and analytical models as "building blocks" (Figure 5-1). These latter models provide for cost-effectiveness when numerous runs are required either to pinpoint critical processes and parameters or to bound the conditions to be evaluated through the use of the more complex and resource-intensive three-dimensional models. In short, the relative simplicity afforded by one- and two-dimensional models can be used to advantage when analyzing interim results as model development proceeds.

The baseline process illustrated in Figure 5-1 will be utilized in the development of the three-dimensional solute transport model for the FMPC. A preliminary two-dimensional flow model previously developed in support of the Zone of Influence Study will initially be refined to account for the most recent RI data as well as to better represent conditions underlying the FMPC that were not the focus of the earlier study. Once the two-dimensional flow field has been adequately characterized and calibrated, parallel efforts will proceed toward the development of both a three-dimensional ground water flow model and a two-dimensional solute transport model. As indicated in the figure, analytical solute transport models will be utilized in support of the corresponding numerical model. The calibrated three-dimensional flow and two-dimensional solute transport models will then be merged to create the final three-dimensional solute transport model.

The simplified process for model development shown in Figure 5-1 must also be accompanied by a series of companion efforts, including:

- Review of pertinent literature and previous studies
- Model verification
- Critical review of previously available and newly collected RI data (including statistical interpretation)
- Geochemical analysis and modeling

Figure 5-2 has been prepared to show the contribution and interaction of each of these activities with the underlying model development process. In this chapter, a detailed technical approach to carry out the comprehensive process shown in Figure 5-2 will be described. Details on the verification steps were previously presented in Chapter 3.0 and will not be repeated in this chapter.

5.2 REFINED TWO-DIMENSIONAL FLOW MODEL

A preliminary two-dimensional flow model for the FMPC was developed, calibrated, and applied to the study of the zone of influence and associated effects of the effluent discharge from the FMPC to the Great Miami River. An interim report on this study was issued on October 1, 1987. This report described the various steps in the modeling process in detail, including the justification for the key technical decisions. Since neither external nor internal peer reviews of this report have generated any significant criticism of the modeling approach, it is not expected that changes will be made in the major conceptual features of the preliminary model as the model refinement step proceeds. However, since issuance of the October report, new RI data have been compiled. These data will be used in the development and testing of the refined two-dimensional model.

The following sections will highlight and review those features of the preliminary two-dimensional flow model that will be retained. Any expected changes to refine the earlier model will be noted. The various steps necessary to achieve a calibrated two-dimensional flow model will also be reviewed as will the use of the model for parameter sensitivity analysis.

5.2.1 Model Grid and Boundary Conditions

The major influences on ground water flow beneath and within the general area of the FMPC are the following:

- Channeling of the regional flow system through several bedrock troughs surrounding the FMPC, which causes relatively steep flow gradients and localized variations in flow direction
- Presence of the Great Miami River within a mile of the FMPC to the east and the associated ground water recharge and discharge conditions
- Location of major pumping centers in the vicinity of the FMPC, including, in particular, the SOWC wells near the river at its point of closest proximity to the FMPC

To incorporate each of these principal influences, and for purposes of establishing appropriate model boundary conditions, the modeling grid was established to cover an aquifer area of approximately 20 square miles (Figure 5-3). In the grid east-west direction, the grid extends from about two miles west of the FMPC to approximately one-half mile east of Ross. In the grid north-south direction, it extends from about three-quarters of a mile south of Shandon to about one-half mile south of New Baltimore. The model grid north will be oriented 30 degrees west of true north to orient the bedrock trough approximately west to east across the grid (Figure 5-3).

With reference to Figure 5-3, one apparent feature of the grid is the use of a gradually finer grid mesh in both the east-west and north-south directions in the vicinity of the SOWC wells. This feature was originally incorporated into the model due to the focus of the earlier Zone of Influence Study on this area. It will be retained in the refined model due to the dominant influence of the SOWC wells and the associated need to avoid excessive gradients over individual cells that would otherwise occur near these wells.

The alignment of the grid also provides convenience in establishing representative boundary conditions. The grid boundaries are essentially perpendicular to each of the four principal bedrock troughs, which indicates that the flow vectors will also be perpendicular to the grid boundaries. A constant head boundary is used to represent such a condition. Any cell associated with the bedrock "walls" will be assigned as no-flow boundaries. Cells lying totally

within bedrock area will be considered as inactive zones of the aquifer and will be excluded in the numerical flow computations.

It is important to note that each of the two-dimensional and three-dimensional models being developed will be limited to the principal sand and gravel aquifer. The glacial till overlying this aquifer across much of the site is highly variable and supports only localized flow systems resulting from sand and gravel lenses and local recharge sources. Floodplain and alluvial areas are more permeable than the till but generally serve only as a vertical connection to the principal underlying aquifer. Any effects of the till and alluvium will be accounted for in the model by adjusting the values of recharge to the sand and gravel aquifer in a systematic manner. The bedrock underlying the regional aquifer does not represent a significant flow zone when compared to the sands and gravels and will be treated as a no-flow boundary in the vertical direction.

5.2.2 Input Data

Table 5.1 has been prepared as a summary of the input data required for the ground water flow model. The primary and secondary data sources for each parameter are also indicated in the table.

Information on the physical setting of the model area, referred to as stratigraphic data, has been developed almost entirely from the reported results of previous subsurface investigations at the FMPC and in the regional area. The associated model input was prepared as part of the preliminary modeling study but will be refined as the boring logs from the new RI wells are compiled and analyzed. The emphasis will be on the area comprising the FMPC, which is the focus of the RI data collection efforts. A bedrock elevation map, which is not expected to change to any degree, has been prepared.

The hydrologic properties of the aquifer are represented by the hydraulic conductivities and the storage coefficient or specific yield. For purposes of initiating the refined flow model, the parameter values developed in the preliminary modeling study will be used. These values are reported in Table 5.2 as are representative ranges of the values. Nevertheless, since these parameters represent principal "fitting" parameters in the model, changes in the

values reported in Table 5.2 may occur through the model calibration process to achieve the most representative set of values. A map showing the principal hydrogeologic environment zones of variation in hydraulic conductivity values, as referenced in Table 5.2, will be provided in the model study report.

Three types of information that highly influence model results, but which are not direct properties of the aquifer being modeled, are the recharge (or discharge) through the overlying and underlying units, the hydraulic properties of the river, and the features of the major pumping wells. Typical values for these parameters are given in Table 5.2. The necessary information on pumping wells is fully satisfied by available documents and will not require further calibration. Recharge rates, on the other hand, are highly variable across the study area due to changes in the composition and thickness of the overlying units. As with the hydrologic properties of the aquifer, the recharge rates may be varied as a result of the model calibration process. The river properties are generally available through published data. The most important river parameter, the rate of seepage from the river, has been measured in the vicinity of the site and was found to be locally variable. As such, this parameter will require "fine tuning" in the calibration process and site-specific field measurements may be required.

Potentiometric heads are important both as an initial condition and as a comparative reference for model calibration. A potentiometric contour map was developed from an April 1986 regional ground water elevation survey. This potentiometric map was utilized in the preliminary modeling study. The refined model will be based on updated ground water level data from May 1988. The corresponding data base will consist of measurements from over 100 new and existing wells being monitored in the RI as well as concurrent measurements taken by the Miami Conservancy District from scores of other wells in the area surrounding the FMPC.

5.2.3 Model Calibration

Calibration of the refined two-dimensional ground water flow model will be achieved prior to any attempts to calibrate either the three-dimensional flow model or the two-dimensional solute transport model. The initial calibration step will verify the representativeness of both the input parameters and the conceptual assumptions.

The procedure to be utilized for calibrating the refined model will be similar to that used in the preliminary modeling study. An iterative procedure will be used to calibrate the system model by matching computed ground water levels with observed data. The model results from each computer run will be compared to observed field data from the May 1988 survey and the differences between actual and computed ground water level contours examined and explained. Each succeeding simulation run will include revised input parameters. Results will again be examined, the variances explained, and the necessary parameters once again adjusted. This process will be repeated until results that closely match the field data are obtained. It is expected that the principal parameters to be adjusted in the calibration process will include the hydraulic conductivity, the recharge from overlying till and alluvium, and the seepage rate through the river bottom.

The criteria to be utilized in judging the acceptability of a calibration run are given in Table 5.3. The absolute differences between computed and observed ground water levels, as well as the standard deviation of the differences, will be evaluated as measures of model performance. It will also be necessary that the value for each parameter in the calibrated model lies within an acceptable range based on field measurements and previously published data.

Two other tests of model performance will also be considered. The first will be to evaluate the model results in the immediate vicinity of the major pumping wells. Of particular importance are the levels of drawdown at the wells, the steep gradients within the zone of drawdown, and the possible overlapping of the zones of influence. A second test of model performance will be a consistency of flow rates and directions throughout the model area in comparison with observed and/or postulated conditions. This is particularly important in the case of the FMPC due to the complications introduced by the bedrock troughs, the river, and the extensive pumping. A water balance between the major elements of recharge (surface precipitation recharge, river recharge, and flow across upgradient boundaries) and discharge (pumping wells, river discharge, and flow across downgradient boundaries) will be utilized in evaluating the representativeness of the model results.

A steady-state simulation will be used for all flow calibration runs. This is considered adequate since the response time of any significant changes in the dominant processes (e.g., removal or addition of a major pumping center) will be sufficiently short over the spatial scale of the principal zones of influence. Short-term fluctuations in pumping rates, recharge, etc., should not have a significant influence on the potentiometric surface of the regional sand and gravel aquifer.

5.2.4 Sensitivity Analysis

The predicted flow patterns and parameter relationships are not expected to change significantly as one proceeds from a two-dimensional to a three-dimensional ground water flow model. Consequently, it is efficient to utilize a two-dimensional model for much of the testing of model sensitivity to changes in model assumptions and parameter values. The two-dimensional sensitivity analysis will be carried out as a series of model runs, each representing a variation of the calibrated flow model resulting from a change in either a single parameter or a simplified combination of parameters.

Such a sensitivity analysis will serve to bound the model results (i.e., the flow conditions) with respect to the following:

- Those changes due to the expected temporal variability in the parameters representing natural or induced conditions
- Those changes attributable to uncertainties in the value of hydraulic parameters that would otherwise be relatively constant with time

The types of natural or induced variations will include, for example, seasonal or extreme hydrologic conditions and changes in pumping patterns. The former will be represented by changes in the recharge rates and the river stage while the latter will be accounted for by varying the pumping rates. The hydrologic parameters that will be evaluated based on uncertainties in the estimates include hydraulic conductivities of the various stratigraphic units and the rate of leakage from the river. Typical ranges for these parameters to be used in the sensitivity analysis are given in Table 5.2.

An important feature of the sensitivity analysis is an evaluation of the degree of change in model results for each sequential change in parameter

value. Uncertainties in the value of some parameters may be shown not to be important if the model results are found to be insensitive to changes in these parameter values. On the other hand, if the model results are shown to be highly sensitive to those parameters with a high degree of uncertainty, it may be necessary to perform additional field studies to increase the level of confidence in the parameter values.

5.3 THREE-DIMENSIONAL FLOW MODEL

5.3.1 Model Framework

The development of a three-dimensional flow model will further refine the modeling process by directly accounting for the variability of vertical properties of the hydrogeologic units. In particular, the model will account for the vertical gradients induced by pumping, the vertical variability of important hydraulic properties or stratigraphic units (e.g., the blue clay), and the effects of the partially penetrating wells that pump from depth.

The model framework in two horizontal dimensions, including the grid orientation, mesh size, and boundaries, will remain as shown in Figure 5-3. In the vertical direction, between four and six "layers" will be used to represent the vertical stratigraphy for modeling purposes (Figure 5-4). The layers will be used to accurately simulate the:

- Great Miami River environment
- Upper sand and gravel aquifer
- Blue clay interbed
- Lower sand and gravel aquifer
- Pumping zone for the SOWC collector wells and the FMPC wells

Layer thickness will vary across the model area due to changes in bedrock elevation, the changes in thickness or absence of the blue clay, and the degree of penetration of the river into the sand and gravel aquifer.

5.3.2 Input Data

The types of input data identified in Tables 5.1 and 5.2 also apply to a three-dimensional model. The key difference is that appropriate parameter values must now be assigned to each of the vertical layers. The following data are necessary for each layer:

- Thickness - The thickness of the vertical layers will be computed by dividing the full depth of each cell into four or six sections in accordance with the local stratigraphy and the prescribed sectioning layer. Thicknesses will vary both vertically within a cell (Figure 5-4) and horizontally across adjacent cells (e.g., because of the varying thickness of the blue clay).

- Hydraulic Conductivity - Horizontal hydraulic conductivities for layers within the sand and gravel aquifer will be generally the same as those used in the two-dimensional model. An exception would be if the deeper layers would be better represented by higher values due to the presence of coarser sands, gravel, and boulders. The blue clay layer will be represented by a much smaller conductivity value while the lower sand and gravel aquifer underlying the blue clay may or may not be assigned the same value as the upper aquifer. Vertical hydraulic conductivities will be assigned as a fraction of the horizontal values (e.g., $K_V = K_H/3$ in Table 5.2) with a check for consistency against any laboratory data or published information.

- River Characteristics - Values for those parameters describing the river interaction with the aquifer will be the same as those used in the two-dimensional model. In this case, however, the values will be assigned to only the topmost one or two layers depending on the degree of river penetration into the underlying aquifer.

- Pumping Rates - Pumping rates and associated cells will be the same as those used in the preliminary model; however, all pumping withdrawal will be done from the single vertical layer set up to represent the partially penetrating wells.

- Recharge - The precipitation recharge from surface infiltration and the recharge from (or discharge to) the underlying bedrock will be assigned the values from the calibrated two-dimensional flow model. The values will be assigned only to the topmost and bottommost layers, respectively.

- Boundary Conditions - The constant head and no-flow boundary conditions will be appropriately assigned to each vertical layer to maintain a consistency with both the two-dimensional conditions and the values at adjacent cells and layers. It is noteworthy that the sloping sides of the bedrock troughs could shift the boundary condition to different cells as deeper layers are considered.

- Potentiometric Heads - The vertical changes in potentiometric head are an important consideration since vertical gradients control vertical flow rates. Much of the informational base will come from the May 1988 ground water level survey at numerous well clusters completed as part of the RI. Some data from off-site wells completed in the lower zones of the sand and gravel aquifer will also be available.

5.3.3 Model Calibration

The calibration of the three-dimensional flow model will be analogous to the two-dimensional case described in Section 5.2.3; that is, the aquifer and river hydraulic properties will be systematically varied until a "best fit" between computed and observed potentiometric heads is achieved within acceptable criteria. On the one hand, the calibration of the three-dimensional model should be aided by the three-dimensional simulation of the actual physical setting and the earlier calibration work completed using the two-dimensional model. On the other hand, both the number of parameters that can be varied and the number of comparative data sets are greater in the three-dimensional case due to the vertical segregation of layers. For example, potentiometric heads observed in both the 200-Series wells (top of upper sand and gravel aquifer) and the 300-Series wells (bottom of upper sand and gravel aquifer) must be separately compared to the model results from two different layers.

In the case of the three-dimensional calibration process, another important comparison is the computed vertical gradient and the observed head differential in the 200-, 300-, and 400-Series (bottom of lower sand and gravel aquifer) well clusters. The capability of the model to reproduce observed drawdown characteristics in the immediate vicinity of the pumping wells will also be evaluated.

All runs for purposes of the three-dimensional ground water flow model calibration will be made at steady-state conditions. However, two or three transient runs will be made to ascertain the representativeness of the steady-state model and to further the understanding of the transient behavior of the flow system at the FMPC.

5.3.4 Sensitivity Analysis

Section 5.2.4 describes a relatively comprehensive program of sensitivity testing using the two-dimensional ground water flow model. The underlying premise was that the use of the two-dimensional model would be able to achieve the overall objectives of the sensitivity analysis program more cost-effectively than by using the three-dimensional model. Consequently, only a limited sensitivity analysis will be performed using the three-dimensional

model. In applying the three-dimensional model, only the hydraulic conductivity in the principal aquifer layers, the river leakage rate, and the pumping rate of the SOWC wells will be varied.

The overall application of the three-dimensional flow model to the RI/FS will, in and of itself, serve to document the range of flow conditions resulting from changes in the input parameters; that is, a form of sensitivity analysis will be completed in a later task. This is addressed in more detail in Chapter 6.0.

5.4 ANALYTICAL SOLUTE TRANSPORT MODEL

With reference to Figures 5-1 and 5-2, the development of the numerical solute transport model will be preceded by the application of an analytical solute transport model. The principal reason for introducing this transition step is that the analytical model provides an efficient tool for a preliminary evaluation of the critical source-pathway-receptor relationships and the controlling physiochemical processes. In particular, a one- or two-dimensional analytical solute transport model will be used to study the effect of various hydrological and geochemical parameters on the rate of migration and dispersion of radionuclides and chemicals away from various sources. The results of this preliminary analysis will considerably limit the range of conditions that will require consideration using the more complex and resource intensive numerical models.

5.4.1 Model Framework

The principal objective of the analytical solute transport model is to evaluate the effects of flow rate, retardation, and dispersion on contaminant migration. For purposes of this evaluation, the most convenient approach will be to align the horizontal model coordinate system with the primary direction of ground water flow. The problem then reduces to a one-dimensional model application with convective transport along the principal axis (i.e., the direction of flow) and dispersion of any plume occurring along the perpendicular and longitudinal axes. Plume attenuation and retardation will be accounted for in all directions. On a one-dimensional model, a uniform velocity distribution is assumed to occur across either the horizontal or vertical plane.

The principal direction of flow, as well as the average convective flow velocities, will be determined from the results of the two-dimensional ground water flow model.

The progressive analysis of the model results could indicate that it may be necessary to extend the analytical solution to the two-dimensional case for the evaluation of some source-pathway-receptor combinations. The model framework will then consist of convective transport away from the source in both the principal horizontal flow direction and vertically. Dispersion and retardation will be considered in three dimensions. Flow direction and average horizontal and vertical velocities will be taken from the initial runs of the three-dimensional flow model concurrently being developed.

As discussed in a previous section, the numerical flow models will be run under the assumption of steady-state flow conditions. The corresponding flow direction and average velocities input to the analytical solute transport model will, therefore, be kept constant with time. This assumed condition reflects the relatively fast hydrodynamic response time of the aquifer when compared to the multiyear time frame of interest. The steady-state assumption cannot be applied to solute transport, however, since the time-variant movement of individual contaminant particles (i.e., the plume) is the critical issue rather than the characteristics of the overall flow field. The temporal changes in plume location, as well as changes in concentration due to dilution and dispersion as migration occurs, must be considered. Solute transport will, therefore, be analytically modeled as a transient process within a steady-state flow condition.

At this point in time, it is anticipated that only two representative chemical and radiological constituents will be considered in the solute transport model. The first will be uranium, which is the principal constituent of interest for the following reasons:

- Uranium is the predominant radiological or chemical species associated with the FMPC
- The available data base on uranium in all media at the FMPC, including ground water, greatly exceeds that available for other radiological or chemical species

- Uranium is the only radionuclide or chemical that has been consistently observed at off-site ground water monitoring locations
- The geochemical behavior and associated parameters are better understood for uranium than for other radionuclides
- Both the radiological and toxicological properties of uranium may be important to the evaluation of risk at receptor locations

The second constituent will be a selected tracer and will be assumed to be totally soluble with no attenuation in ground water. A consideration of such a constituent will establish a "worst-case" bound on the most mobile radionuclide or chemical being transported through the ground water pathway. Tc_{99}

Estimates of the rate of migration and receptor concentrations of any other indicator radionuclides or chemicals identified in the risk assessment will be accomplished by interpolating or extrapolating the model results from the uranium and tracer cases. The analytical model developed for uranium could also be run with different sets of source terms and geochemical parameters representative of any other constituent, if known. No attempt will be made, however, to refine the model calibration for any other constituents unless they are found to be as critical as (or more critical than) uranium as to the risk posed to off-site receptors or the simulated solute transport for uranium (or the tracer) would not be able to adequately predict the concentrations of the constituent of concern. Sufficient field data must also exist before calibrating the model to other constituents.

The analytical model to be applied will likely be selected from a series of models developed by IT staff and published in international scientific journals (Batu, 1982 and 1983; IT, 1987). The model developed by Oak Ridge National Laboratory (ORNL) for purposes of the FMPC Environmental Impact Statement (EIS) will also be considered. At a minimum, the "lessons learned" by ORNL personnel throughout their model development and calibration efforts, including the resultant bounds on model conditions, will be used by the modeling team.

5.4.2 Input Data

Table 5.4 presents the types of information required for input to the analytical solute transport model for each constituent of interest. The solute source types, or constituents to be modeled, will be established in the risk assessment based on the prevalence, concentration, and radiological/toxicological properties of each constituent measured in ground water. Only uranium and a soluble tracer are being considered in this work plan for detailed modeling analysis although other constituents may be found to require a similar analysis based on the progressive study findings.

The location and loading rates of each source will be established, to the extent practical, in the companion geochemical program. The total mass of release, the time period of the release, and the associated rate of release are all important to a transient solute transport model. The principal uncertainty in the modeling of solute transport at the FMPC is expected to revolve around the source terms due to the multiple locations and types of potential releases and the lack of historical documentation. It is likely that only ranges of values will be established for source terms and that a compositing and simplification of the actual conditions will be necessary (e.g., considering multiple sources as a single point or line source). As indicated in Table 5.4, the model itself could be used to support the quantification of the most critical source terms through the calibration process.

Some input parameters identified in Table 5.4, including the effective porosity and the longitudinal and transverse dispersion coefficients, are related more to the aquifer properties than to the geochemical properties of a given solute. Representative values for these parameters will be taken from published literature for similar hydrogeologic settings and aquifer materials although each will be varied during the model calibration phase to attain a "best fit" to the characteristics of the plume.

Problem w. EIS model

Decay constants for uranium and any other isotopes of interest are well documented and will be assigned values from the literature. The other important geochemical parameter is the retardation factor, which is dependent on the properties of the aquifer materials, the individual radionuclide or chemical, and the geochemical state of the ground water (e.g., pH, Eh). The retardation

factors, or the related distribution coefficients, will be initially established through a combination of field, laboratory, and geochemical modeling studies. Reference is made to the work plan for the geochemical program for the technical approach to the estimation of retardation factors. These same factors will also be the principal "fitting" parameters for model calibration, within the constraint that all final values must lie within an acceptable range established in the geochemical program.

It must be noted that only the retardation factor for the sand and gravel aquifer and not the blue clay interbed (Table 5.4) will be necessary for the analytical solute transport model. The factor(s) for the till will be incorporated into the geochemical program and will already be accounted for in the source term. Consideration of any retardation associated with the blue clay or interbeds will eventually be required in the two-dimensional analytical model or the three-dimensional numerical solute transport model.

Table 5.2 provides a listing of preliminary values for the principal parameters to be used in the solute transport model for uranium. These initial values are based on a review of available literature and could change as the geochemical and analytical modeling efforts proceed. A key objective of the analytical model is to refine this range of parameter values prior to the application of the numerical solute transport models.

5.4.3 Trend Analysis

The goal of the trend analysis process for the analytical model is to achieve a reasonable fit to observed uranium concentrations at critical receptor locations by adjusting source strengths, velocity vectors, retardation coefficients, and dispersion coefficients within acceptable ranges of values. Since it is expected that the ground water flow field will be well defined by the numerical flow models, the degree to which the trend analysis goal will be achieved will be highly dependent on the success of the geochemical program in quantifying the location, time, and rate of uranium release from the sources. The level of confidence in the analytical model results must be based on the relative use of documented source terms versus the degree to which the source term is used as a fitting parameter; that is, model results using independent, supportable source terms will be more easily accepted as representing actual

conditions than if the model results are forced to fit the observed data only by adjusting the source terms.

5.5 TWO-DIMENSIONAL SOLUTE TRANSPORT MODEL

The findings of the analytical modeling study will be used to better focus the development and application of a two-dimensional numerical solute transport model. The transition to the more complex, resource-intensive numerical model is proposed for purposes of both system representation and eventual model application. The analytical model only views solute transport under average conditions along and symmetric to a preestablished pathway between a source and a receptor. On the other hand, the numerical model allows a two-dimensional, gridwide analysis of multiple sources using grid-specific flow and velocity vectors. This capacity is particularly valuable to the identification of critical locations away from the points of direct field observation, under both present conditions and future projections.

A second key advantage of the numerical model is the flexibility in the types of remedial actions that can be evaluated. Not only can source control options be better simulated, but pathway modifications resulting from localized ground water flow controls can be evaluated at the point of implementation rather than averaged across the modeled system as required by analytical models.

5.5.1 Model Framework

The initial steps in developing a two-dimensional solute transport model are the selection of an appropriate grid system and the assignment of meaningful boundary conditions. Since the two-dimensional flow field will be independently determined and made available to the solute transport model through the refined flow model (Section 5.2), there is no requirement to use the same grid for both models if the flow model grid was extended only to account for flow boundaries. The solute transport model grid need only span the principal sources and receptor as long as appropriate boundary conditions can be set.

For purposes of resource efficiency, therefore, a much smaller grid will be established for the numerical solute transport model (Figure 5-5). However, this grid will be subdivided in comparison to the flow grid to allow for

better resolution in the principal area of interest and for improved numerical stability. The area enclosed within the identified grid includes all known sources and all off-site locations where elevated levels of uranium in ground water have been detected. An analytical solute transport model will be used to extend any analysis beyond the grid boundary. A numerical grid extension will be considered only if uranium migration beyond the boundary is found to be either a critical risk determinant or a key factor in remedial action decisions. Further changes in grid or cell size may also be found to be necessary to achieve numerical stability, in accordance with an analysis of the Peclet number.

Based on current information, the dimensions of the solute transport grid are sufficiently large to assign a constant concentration equal to the background value at each of the boundary nodes. A zero flux condition may also be found to be appropriate at selected nodes based on an analysis of the geologic setting or the flow field. The bottom boundary (i.e., the bedrock boundary) will be approximated as a no-flux boundary.

As with the analytical model, solute transport will be modeled as a transient process using steady-state flow conditions. A time step between one and six months will be used. Only uranium and a tracer (totally soluble, nonattenuated) constituent will be modeled using the numerical solute transport model unless study findings dictate otherwise, as previously discussed.

5.5.2 Input Data

The input parameters for the two-dimensional numerical model are generally the same as those reported in Tables 5.2 and 5.4. A detailed discussion of the data requirements for solute transport modeling was presented in Section 5.4.2 and need not be repeated here. Three differences in input data between the analytical and numerical cases are the following:

- In the numerical model, parameter values are required at each node and could vary across the grid due to changes in hydrogeologic or ground water geochemical properties
- The parameter values available to the numerical model will already have been refined by the application of the analytical model

- Sources of uranium will have to be distributed as vertical line or plane sources in the numerical model to achieve consistency with the two dimensionality of the system representation

Whereas the vertical concentration profile at a point location was the key target for the analytical model trend analysis, the two-dimensional model will focus on horizontal distribution patterns. Isoconcentration maps for uranium in ground water will be developed based on the May 1988 sampling program to fill this data need. Similar maps will also be prepared for other radionuclides or chemicals for which solute transport modeling is performed.

5.5.3 Model Calibration

The two-dimensional numerical solute transport model is a transitional "building block" that is not expected to be directly applied for purposes of final data evaluation in the RI/FS. Consequently, the primary value of the two-dimensional model will be for model calibration and sensitivity analysis. In particular, by calibrating the dominant parameters within the range specified by the geochemical program and analytical model, the following types of important information can be gained for use in the three-dimensional model: (1) approximate times of transport between critical sources and receptors, (2) the potential extent of current and future contamination, (3) refinement in the range of parameter values, and (4) the necessary expansion or contraction of the solute transport grid.

With reference back to Figure 1-6, the calibration process will be initiated by the application of the two-dimensional solute transport model to predict the concentration pattern resulting from a hypothetical release of a unit mass of material from a given source. The release could be instantaneous or continuous, a point source or a dispersed source, depending on the nature of the actual release being simulated. The predicted concentration at key monitoring points resulting from the source of unit mass will be compared to observed concentrations at the same locations to estimate the actual mass that would have had to be released to cause the observed condition. In practice, a range of model parameters will be used (based on the previous sensitivity analysis) to establish a probable range of source conditions rather than a single value. This range of source conditions will then be compared to the actual mass of the release, as estimated from the geochemistry program, to evaluate the source-pathway-receptor relationship.

If the estimated actual release is within the predicted range, the level of confidence in the relationship is greatly increased. If the estimated release is below the predicted range, it can be conjectured that that particular source cannot be the only source of contaminants to the monitored location. The degree to which a source is less than the lower bound on the predictions is a measure of the relative importance of that source to the observed condition at the monitoring points. An estimated source that greatly exceeds the upper bound on the predicted range would indicate an analytical inconsistency. The subsequent resolution could require a reevaluation of the actual source strength or further calibration of the solute transport model.

The previous step focused on concentration at a point and its relationship to an estimated release. A corollary step involves the comparison of the predicted concentration pattern from a unit source with statistically generated plots of observed concentrations in ground water. A similarity of patterns would support a single source-pathway-receptor scenario while major anomalies would indicate either the presence and possible domination of other sources and/or pathways or greatly varied hydrogeologic or geochemical parameters.

It is likely that a range of source locations and source strengths has produced the current patterns of uranium in the sand and gravel aquifer in the vicinity of the FMPC. Considerable uncertainty remains in the quantification of source terms in both space and time, each of which is critically important to a transient solute transport model. The effects of this uncertainty on model calibration cannot be resolved at this time--only the continuing efforts in document review, field and laboratory observations, geochemical analysis, and analytical and numerical modeling will eventually provide the degree of confidence in the model results.

5.5.4 Sensitivity Analysis

Since it is expected that the three-dimensional solute transport model will eventually be used to set final bounds on contaminant migration pathways and concentrations, the two-dimensional sensitivity analysis will be limited to the key parameters, including the longitudinal and transverse dispersion coefficients, the retardation factor(s), and the source strength. The range

of values produced from the analytical model will be input to the best-calibrated solute transport model. Any meaningless results will be evaluated to modify or further limit the range of acceptable parameter values for eventual use in the three-dimensional model.

5.6 THREE-DIMENSIONAL SOLUTE TRANSPORT MODEL

The need to eventually focus all modeling efforts into a comprehensive, three-dimensional numerical solute transport model is largely dictated by the physical setting of the site. Among the factors requiring a three-dimensional approach are: (1) the vertical pathways connecting sources at the upper boundary of the aquifer to wells pumping from depth (i.e., the receptor), (2) the presence of vertical gradients, most likely induced by the major pumping centers and the associated partially penetrating wells, (3) complex river and aquifer interactions that predominate only in the upper zone of the aquifer, and (4) the presence of large variations in vertical hydraulic conductivities (e.g., the blue clay layer).

5.6.1 Model Framework

The results of the two-dimensional solute transport model and the three-dimensional flow model will initially be reviewed to determine the applicability of the model grid shown in Figure 5-5. If modifications to the grid were made during the course of the two-dimensional solute transport modeling task, the modified grid will be evaluated rather than that shown in the figure. Any changes in the grid or cell size resulting from this review will be incorporated and justified.

The vertical layers to be used in the three-dimensional solute transport model will be identical to those used in the corresponding flow model (Figure 5-4). Boundary conditions along vertical boundaries will be the same as those used in the two-dimensional model, with appropriate adjustment to account for the vertical layering. Source terms from the till will be assigned to the upper layers rather than distributed vertically.

The three-dimensional solute transport model will be run as a transient case using steady-state flow conditions. The latter will be provided from the three-dimensional flow model.

5.6.2 Input Data

The input data to the three-dimensional solute transport model will be essentially the same as those used for the two-dimensional model, including the best-fit parameter values established in the model calibration process. However, distinct parameter values will have to be assigned to vertically layered cells, thereby requiring a consideration of vertical variability when transferring the two-dimensional values. Some vertical layers will use the same parameter values as adjacent layers; others, such as the blue clay layer, will be assigned very different hydrodynamic and geochemical properties than the two-dimensional counterpart.

An additional coefficient must be introduced into the three-dimensional model to account for vertical dispersion. The initial value for vertical dispersivity will be based on literature values for similar stratigraphic units as refined by the calibration of vertical dispersion in the analytical solute transport model.

The transposition of isoconcentration maps to three dimensions will likely take the form of vertical concentration profiles at selected locations. These will include locations near the source(s), near receptor wells or other critical wells, and at intermediate monitoring points.

5.6.3 Model Calibration

The calibration of the three-dimensional solute transport model will rely heavily on the results of the two-dimensional model calibration. One additional criterion for acceptance will be the degree to which the model results reproduce observed vertical concentration profiles in addition to the horizontal concentration patterns.

The principal fitting parameters will be the vertical dispersivity and the geochemical properties of any interbeds. These parameters are important to the predicted vertical concentration profile and were not among those previously fitted in the two-dimensional solute transport model calibration. Some adjustment of those parameters fitted in the two-dimensional model calibration may also be required due to the effects on model results of changing to a three-dimensional flow field and redistributing the vertical boundary flux

terms to individual vertical layers. Changes to the flow parameters are not expected in this calibration step, however, since the three-dimensional flow field will have been previously calibrated and is not affected by low concentration solute transport.

5.6.4 Sensitivity Analysis

The primary purpose of a sensitivity analysis is to bound the model results in terms of the uncertainty of the important parameter values. The effect of parameter uncertainty will have been the principal target of the sensitivity analyses being proposed for each of the previously described transitional flow and solute transport models. Consequently, those parameters to which model predictions of flow and solute transport are most sensitive will have already been identified prior to the sensitivity analysis using the three-dimensional solute transport model. An exception will be those parameters just introduced into the list of required input as, for example, the vertical dispersivity and the interbed properties. The latter parameters will, therefore, be the focus of the sensitivity analysis using the three-dimensional solute transport model.

A final check will also be made on other key parameters to determine if the transition to a three-dimensional approach had altered any previous conclusions regarding parameter sensitivity. The source terms and the interaction between the river and the aquifer are key elements that may influence the model results differently under two-dimensional and three-dimensional modeling scenarios.

6.0 MODEL APPLICATION

Chapter 1.0 discussed the principal objectives of the ground water modeling study. One of these objectives--the refinement of the current understanding of site conditions--represents an important application of the model in the RI. This objective will be implicitly addressed throughout the model development and calibration phases described in Chapter 5.0. In addition, a direct application of both the ground water flow and solute transport models toward this objective will be performed, as discussed in Section 6.1.

A second objective of the modeling study is to provide a predictive tool to support the risk assessment in both the RI and the FS. The application of the model for the evaluation of the no-action alternative will be considered an RI activity. Subsequent applications in support of remedial action assessments will be performed as part of the FS. Each application is described in Section 6.2.

6.1 EVALUATION OF CURRENT SITUATION

6.1.1 Flow Modeling

The calibrated two- and three-dimensional flow models will be used to develop statistically based ground water elevation contours for the vertical layers of interest over the model area. From these plots, general horizontal and vertical flow patterns can be established, including typical velocities and flow rates across the site. Flow characteristics at a point will also be established from the model results and will be graphically summarized using plots of the velocity vectors at each grid cell. The orientation of each vector will delineate the local flow direction while the length of the vector will be proportional to the local scalar velocity. Steady-state flow paths from critical source locations will be identified using the plotted velocity vectors, including any vertical components of flow.

In addition to this characterization of the flow field, several key issues at the FMPC will be evaluated using the model results, including:

- Rate and Direction of Flow - Flow directions and gradients relative to various waste storage, discharge, and disposal areas will be established. This information will be used in evaluating and predicting the rate and direction of solute movement away from these areas.

- Water Balances at Major Pumping Wells - A water balance will be established for the SOWC wells to the east of the FMPC, the Albright-Wilson well to the south, and the FMPC production well within the site. The flow components to be quantified and balanced against the pumping rate are the contributions from the river, ground water flow originating from beneath the FMPC, ground water flow from other upgradient areas, and recharge from vertical infiltration through the overlying till.

- Interaction with Great Miami River - It is expected that the Great Miami River serves both as a ground water discharge zone and as a source of recharge to the sand and gravel aquifer depending on location along the river and seasonal fluctuations. Zones of ground water discharge will be studied using a water balance approach similar to that just described for the pumping wells. The percentage of discharge coming from beneath the FMPC is a principal quantity of interest. The amount of river recharge to the aquifer will be computed for use in the preceding water balances at the pumping wells. The amount of recharge is also important to the analysis of the effects of background concentrations in the river on observed ground water quality at nearby wells.

- Area of Influence of Production Well - The flow field near the production well on the FMPC will be evaluated to determine if any significant interconnection exists between the upper sand and gravel aquifer and the pumping zone beneath the blue clay. The percentage of flow contribution from the overlying aquifer will be determined as will the area of influence within the upper sand and gravel aquifer.

Field tests.

Since the results of each of these evaluation scenarios are highly dependent on both the ambient hydrologic system and any induced forcing functions, it will be necessary to repeat the above model runs and evaluations using a range of input parameters. The following variations in model input parameters will be made, with the associated model runs summarized in Table 6.1:

- Vary pumping rates
  - SOWC wells
  - Albright-Wilson well
  - FMPC production well

- Vary river elevation (and thus the rate of leakage)
  - Low flow condition
  - Mean annual flow condition
  - Flood condition (appropriate return period to be determined)

- Vary recharge
  - Paddys Run only
  - Entire model area

From the results of these multiple runs, critical hydrologic patterns will be identified. These would include, for example, reversals in potentiometric gradient (and thus flow direction) and major shifts in recharge/discharge patterns along the Great Miami River. Pertinent tables and plots will be prepared relating the effects of critical dependent parameter(s) on the issues considered.

6.1.2 Solute Transport Modeling

One- and two-dimensional analytical solute transport modeling along with two- and three-dimensional numerical solute transport modeling will be used to study the rate of migration and dispersion of radionuclides and chemicals away from the various sources.

Since the parameter directly produced by the solute transport models (i.e., concentration) is also the key parameter of interest to the other parts of the RI/FS, any subsequent manipulation of the solute transport model results will be limited. Some types of postmodeling analysis that could extend the utility of the model results are: (1) computation of the relative mass loadings associated with each flow component of the aforementioned water balances at the wells and river, (2) calculation of the cumulative mass loadings at each critical location over time, including future years, and (3) quantification of the total mass of uranium or other constituent leaving the FMPC boundary in a given time frame.

Based on the model results, isoconcentration profiles for selected times will be developed for the various vertical layers being monitored at the FMPC (200-, 300-, and 400-Series well elevations). Plots of concentration versus time at selected locations will also be produced.

The same combinations of input parameters as shown in Table 6.1 will be used in the solute transport model runs. Any case for which the change in input parameters did not affect the flow field, as determined in the previous application of the flow model, will not be repeated for the solute transport model.

6.2 SUPPORT TO RISK ASSESSMENT

6.2.1 Current Situation

Three general types of model applications will be used to support the risk assessment. In the first, significant pathways associated with past and current releases will be evaluated to refine the assessment of current risk posed by contaminated ground water. A key application of the model will be to augment the existing data base by "filling in the gaps" between the single-point observations. Locations of maximum concentration, possibly resulting from the integration of the contributions from multiple sources, as well as the approximate extent of any contaminant plume, represent the types of information that can be most effectively generated via the application of a model. It is these same types of information that are critical to the evaluation of current risk.

6.2.2 No-Action Alternative

An evaluation of the no-action alternative requires the prediction of future conditions and associated risks if all sources and pathways are unaltered from their current status. In particular, the ground water flow and solute transport model will be used to predict whether concentrations in ground water at critical receptors will increase and whether additional receptors will be impacted to a significant extent.

The initial condition for the no-action model will be equated to the model output in the previous evaluation of current conditions. By so doing, the effects of any past releases will be accounted for by existing concentrations in the ground water. Current releases will be quantified as sources to the extent possible. Any anticipated future releases, as determined from the geochemistry program, will be introduced as additional sources unless the release can be shown to be insignificant.

6.2.3 Remedial Action Alternatives

The application of the model in the FS will be of two principal types. The ground water flow model will be used to evaluate the technical feasibility of remedial actions. For example, the model can be used to test the effectiveness of an impermeable subsurface barrier, to size and locate pumping wells, and to determine the zone of influence for any potable water replacement

wells. Such applications are straightforward and generally require only a modification of input parameters to simulate the remedial actions.

A second application will involve the full solute transport model and will be similar to the evaluation of the no-action alternative. In this case, the objective will be to predict future conditions when various remedial action alternatives are accounted for. Most actions will likely take the form of source control measures and are typically simulated by eliminating the respective current or future releases from the model input. In practice, however, full source control is rarely realized. Therefore, the model will be used to assess the effects of an incomplete source control and to evaluate various source reduction measures to determine the most cost-effective program. The modification of a pathway, e.g., the local depression of the piezometric surface to control ground water flow, will be accounted for in the ground water flow model. The resultant flow field will, however, influence contaminant transport patterns, and thus impacts at receptor locations, in the solute transport algorithms.

7.0 REPORT PREPARATION

The report generated for the ground water flow/solute transport model will be included as an appendix to the FMPC RI/FS reports. Conclusions and recommendations about pathways, receptors, and chemical loading rates and concentrations along with the uncertainties in model input parameters will be summarized and included within the text of the report. The model code verification process and conclusions will be included within the RI ground water modeling report.

7.1 PRESENTATION OF RESULTS

During the course of model development and application, a report outline will be developed. Included within the ground water flow/solute transport report will be a summarization of the:

- Model Code Verification - Including work done by GeoTrans and IT
- Model Data Base - Including historical and RI data
- Flow Model Development and Calibration - Including a description of the model framework, model construction, and calibration
- Geochemical Modeling - Including documentation of the selection of solute transport parameters
- Model Sensitivity Analyses - Including a detailed discussion of the model response to varying input parameters
- Solute Transport Model Development - Including the use of analytical and numerical techniques
- Analysis of Modeling Results - For both the flow and solute transport portions of the study

Analysis of modeling results will include documenting conclusions about ground water flow rates and directions, contaminant concentrations, receptors of contamination, and the analysis of remedial alternatives. Included in the documentation will be tables of:

- Monitoring well locations with coordinates, elevations, monitoring zones, and rationale for selection
- Ground water elevations and dates of measurements
- Great Miami River hydrologic parameters

- Geochemical data used in the modeling
- Model hydrogeologic input parameters
- Model output summaries
  - Quality and quantity of water reaching potential receptors (e.g., SOWC wells, Paddys Run, etc.)
  - Variations in rates of migration and quantities of solute reaching receptors based on variations in model input parameters
- Summary of model sensitivity analyses
- Water balance for the model study area
- Model conclusions

Figures to be included for documentation are:

- Model study area
- Hydrogeologic cross sections
- Well location map
- Top of bedrock map
- Hydrogeologic environment map with recharge and aquifer hydraulic conductivity variations
- Potentiometric contour map(s)
- Area of influence of production wells
- Selected river and aquifer hydrographs
- Ground water quality map(s)
- Idealized schematic of two- and three-dimensional model construction with layers, boundaries, and hydrogeologic zones
- Schematic drawings of analytical model flow field and boundary conditions
- Model output showing ground water elevation contours and flow vectors for selected layers and chemical concentration profiles and plots both vertically and horizontally away from various source areas

The intent of the model study report is to fully document the rationale and procedures for the ground water flow/solute transport model development, calibration, and use. Applications and conclusions pertinent to the RI/FS reports will be presented and the analysis described in detail.

8.0 SCHEDULE

The schedule for the ground water flow/solute transport model development is shown in Figure 8-1. The tasks to be completed include:

- Ground water flow model development, including data input preparation, two- and three-dimensional model construction and calibration, and input parameter sensitivity analysis
- Solute transport model development, including input data preparation, two- and three-dimensional model construction and calibration, analytical modeling, and input parameter sensitivity analysis
- Verification studies
- Model development reports
- Final model report
- Application to the RI

Schedules for application of the model to the FS tasks will be provided with this project management documentation.

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TABLES

TABLE 3.1

SWIFT III CODE GROUND WATER FLOW VERIFICATION

	GEOTRANS			IT		
COMPARISON WITH	ANALYTICAL	NUMERICAL	FIELD	ANALYTICAL	NUMERICAL	FIELD
TWO DIMENSIONAL PROBLEMS	• FULLY PENETRATING WELL CONSTANT DISCHARGE HOMOGENEOUS ISOTROPIC AQUIFER, CONFINED CARTESIAN COORDINATES RADIAL COORDINATES • FULLY PENETRATING WELL CONSTANT DRAWDOWN HOMOGENEOUS, ISOTROPIC AQUIFER CONFINED RADIAL COORDINATES • FULLY PENETRATING WELL, HORIZONTAL ANISOTROPIC AQUIFER, CONFINED CARTESIAN COORDINATES • FULLY PENETRATING WELL, LEAKY AQUIFER, CONFINED, HOMOGENEOUS ISOTROPIC RADIAL COORDINATES	NOT DOCUMENTED IN THE AVAILABLE USERS MANUALS OR VERIFICATION REPORT	• HYDRAULIC TESTING FOR THERMAL ENERGY. STORAGE IN AN AQUIFER TO TEST CODE FOR, – PRESSURE SOLUTIONS – ANISOTROPIC AQUIFER CHARACTERISTICS – INJECTION AND OBSERVATION WELL RESPONSES – FLOW FROM AQUITARDS – EFFECTS OF AQUIFER BOUNDARIES	• FULLY PENETRATING WELL CONSTANT DISCHARGE HOMOGENEOUS ISOTROPIC AQUIFER, CONFINED CARTESIAN COORDINATES • FULLY PENETRATING WELL CONSTANT, DISCHARGE ANISOTROPIC AQUIFER CONFINED CARTESIAN COORDINATES • DUPUIT–FORCHEIMER STEADY STATE PROBLEM – TO SIMULATE FLOW FROM A FREE–WATER SURFACE NOTE: SWIFT III DATA INPUT GUIDE RELEASE 2.25 WITH VERIFICATION PROBLEM SET RECEIVED APRIL 1988	• COMPARISON OF ACTUAL SITE DATA WITH GEOFLOW AND McDONALD AND HARBAUGH CODES FOR FLOW IN A WATER TABLE AQUIFER WITH IRREGULAR BOUNDARIES AND STEADY–STATE FLOW	NOT NECESSARY (WILL DO 3–D)
THREE DIMENSIONAL PROBLEMS	NOT DOCUMENTED IN THE AVAILABLE USERS MANUALS OR VERIFICATION REPORT	NOT DOCUMENTED IN THE AVAILABLE USERS MANUALS OR VERIFICATION REPORT	NOT DOCUMENTED IN THE AVAILABLE USERS MANUALS OR VERIFICATION REPORT	IMPRACTICAL	NECESSARY	NECESSARY

TABLE 5.2

SWIFT III CODE SOLUTE TRANSPORT VERIFICATION

COMPARISON WITH	GEOTRANS			IT		
	ANALYTICAL	NUMERICAL	FIELD	ANALYTICAL	NUMERICAL	FIELD
ONE DIMENSIONAL PROBLEMS	• TRANSPORT WITH CHAIN DECAY AND EQUAL RETARDATION, ISOTROPIC HOMOGENOUS AQUIFER CARTESIAN COORDINATES • TRANSPORT WITH CHAIN DECAY AND UNEQUAL RETARDATION, ISOTROPIC HOMOGENOUS AQUIFER CARTESIAN COORDINATES	NOT DOCUMENTED IN THE AVAILABLE USERS MANUALS OR VERIFICATION REPORT	NOT DOCUMENTED IN THE AVAILABLE USERS MANUALS OR VERIFICATION REPORT	• TRANSPORT WITH CHAIN DECAY AND EQUAL RETARDATION, ISOTROPIC HOMOGENOUS AQUIFER CARTESIAN COORDINATES NOTE: SWIFT III DATA INPUT GUIDE RELEASE 2.25 WITH VERIFICATION PROBLEM SET RECEIVED APRIL 1988	NOT NECESSARY	NOT NECESSARY
TWO DIMENSIONAL PROBLEMS	NOT DOCUMENTED IN THE AVAILABLE USERS MANUALS OR VERIFICATION REPORT	NOT DOCUMENTED IN THE AVAILABLE USERS MANUALS OR VERIFICATION REPORT	• CONTAMINANT MIGRATION FROM A LANDFILL TO TEST CODE FOR; – CONTAMINANT CONVECTION AND HYDRODYNAMIC DESPERSION – STEADY STATE VELOCITY – TIME AND SPACE DEPENDENT CONTAMINANT SOURCE TERMS – AQUIFER INFLUENCE FUNCTIONS	NECESSARY	• COMPARISON WITH GEOFLOW FOR WATER TABLE AQUIFER WITH IRREGULAR BOUNDARIES AND STEADY–STATE FLOW	NECESSARY
THREE DIMENSIONAL PROBLEMS	NOT DOCUMENTED IN THE AVAILABLE USERS MANUALS OR VERIFICATION REPORT	NOT DOCUMENTED IN THE AVAILABLE USERS MANUALS OR VERIFICATION REPORT	NOT DOCUMENTED IN THE AVAILABLE USERS MANUALS OR VERIFICATION REPORT	NOT NECESSARY	NECESSARY	NECESSARY

TABLE 5.1

FLOW MODEL INPUT DATA

PARAMETERS	DATA SOURCE: PROJECT HISTORICAL DATA	LITERATURE REVIEW	RI FIELD DATA	RI LABORATORY DATA	RI DERIVED DATA	PARAMETER ESTIMATION	UNITS
STRATIGRAPHY							
–TOP OF AQUIFER ELEVATION	●		●				FEET
–AQUIFER THICKNESS	●		◒				FEET
–INTERBEDS (LOCATION AND THICKNESS)	●		●				FEET (ABMSL)
–BEDROCK ELEVATIONS	●		○				FEET (ABMSL)
–GEOLOGIC MATERIAL PROPERTIES	◒		●				
HYDRAULIC CONDUCTIVITY							CM/SEC (FEET/DAY)
HORIZONTAL							
–AQUIFER	●	○				◒	
–INTERBEDS		◒				●	
VERTICAL							
–TILL	○	◒		◒		●	
–AQUIFER		◒				●	
–INTERBEDS						●	
STORAGE COEFFICIENT/SPECIFIC YIELD							DIMENSIONLESS
–AQUIFER	●					◒	
–INTERBEDS		◒				●	
PRECIPITATION RECHARGE							INCHES (FEET)
–TILL	◒					●	
–BEDROCK	○					●	
–FLOOD PLAIN AND ALLUVIAL AREAS	◒	○				●	
RIVER HYDRAULIC PARAMETERS							
–STAGE	●						FEET (ABMSL)
–RIVER BOTTOM ELEVATION	●						FEET (ABMSL)
–SEEPAGE	◒					●	1/FOOT
PUMPING WELL INFORMATION							
–PUMPING RATES	●						GPM (FEET/DAY)
–WELL CONSTRUCTION	●						
–WATER LEVELS	●						FEET
POTENTIOMETRIC HEADS							
–TILL	○		●				FEET (ABMSL)
–AQUIFER	◒		●				FEET (ABMSL)

LEGEND

● PRIMARY

◒ SECONDARY

○ LIMITED

TABLE 5.2

LIST OF MODEL INPUT PARAMETERS - INITIAL AND RANGE OF VALUES CONSIDERED FOR SENSITIVITY ANALYSIS

	MODEL ZONE 1 HYDROGEOLOGIC ENVIRONMENT I		MODEL ZONE 3 HYDROGEOLOGIC ENVIRONMENT III		
	RANGE OF VALUES FOR SENSITIVITY ANALYSIS	INITIAL VALUES	RANGE OF VALUES FOR SENSITIVITY ANALYSIS	INITIAL VALUES	NOTES AND REFERENCES
Aquifer Values					
Effective Porosity	0.2 - 0.3	0.25	0.2 - 0.3	0.25	Estimated from geologic logs and site experience
Storage coefficient	N/A(a)	0.2	N/A	0.2/.05(b)	Mean of various sources
Horizontal hydraulic conductivity K_h (feet/day)	100 - 800	400	100 - 800	400	Statistically derived from various sources
Vertical hydraulic conductivity K_v (feet/day)	$K_h/100 - K_h$	$K_h/3$	$K_h/300 - K_h$	$K_h/10$	Estimated from site experience
Aquifer thickness (feet)	N/A	Variable	N/A	Variable	From contour plots of bedrock and top of aquifer
Precipitation recharge (inches/year)	8 - 20	14	3 - 12	6	
Daily pumping (feet^3/day):					
- FMPC wells	N/A	N/A	N/A	64,000	
- Southwestern Ohio Water Company wells					
(Collector 1)	N/A	1,600,000	N/A	N/A	Estimated
(Collector 2)	N/A	800,000	N/A	N/A	Estimated
- Albright and Wilson well	N/A	N/A	N/A	19,000	Information obtained by IT for 1986
EDS Delta Steel? Rulgen Niece ?				10,000 ?	

See footnotes at end of table.

Compare w. EIS

TABLE 5.2
(Continued)

		MODEL ZONE 1 HYDROGEOLOGIC ENVIRONMENT I		MODEL ZONE 3 HYDROGEOLOGIC ENVIRONMENT III		
		RANGE OF VALUES FOR SENSITIVITY ANALYSIS	INITIAL VALUES	RANGE OF VALUES FOR SENSITIVITY ANALYSIS	INITIAL VALUES	NOTES AND REFERENCES
Solute Transport						
Longitudinal Dispersivity (Sand and Gravel) (feet)	D_L	10 - 300	100	10 - 300	100	U.S. Environmental Protection Agency, 1985
Ratio of Transverse to Longitudinal Dispersivity (Sand and Gravel)	$\frac{Dt}{DL}$	1/10 - 1/2	1/10 feet	1/10 - 1/2	1/10	Frind, Emil O. and Diane Germain, 1986 Gelhar, L. W. and C. L. Axness, 1983 Gelhar, L. W., et al., 1985
Ratio of Vertical to Longitudinal Dispersivity (Sand and Gravel)	$\frac{Dv}{DL}$	1/30 - 1/800	1/100	1/30 - 1/800	1/100	Reeves, Mark, David S. Ward, Norman D. Johns, and Robert M. Cranwell, 1986 Ward, David S., David R. Buss, James W. Mercer, and Shereen S. Hughes, 1987
Retardation Factor		To be obtained from the geochemical studies LITERATURE DATA? (see EIS)				

(a)N/A = Not applicable.

(b)0.2/0.05 - The first value refers to the upper aquifer and the second value refers to the lower aquifer.

TABLE 5.2
(Continued)

	MODEL ZONE 1 HYDROGEOLOGIC ENVIRONMENT I		MODEL ZONE 3 HYDROGEOLOGIC ENVIRONMENT III		
	RANGE OF VALUES FOR SENSITIVITY ANALYSIS	INITIAL VALUES	RANGE OF VALUES FOR SENSITIVITY ANALYSIS	INITIAL VALUES	NOTES AND REFERENCES
Aquifer Values (Cont.)					
River stage (feet MSL)	520.5 - 528.6	524 at Ross Bridge	N/A	N/A	
River leakage factors (1/day)	0.18 - 3.5	0.35	N/A	N/A	
River water temperature (°F)	N/A	60	N/A	N/A	
Ground water temperature (°F)	N/A	54	N/A	54	
Interbed Values					
Clay vertical hydraulic conductivity (feet/day)	N/A	N/A	$3 \times 10^{-5} - 3 \times 10^{-2}$	3×10^{-3}	Estimated
Thickness of interbed (feet)	N/A	N/A	10 - 25	20	
Effective porosity	N/A	N/A	0.05 - 0.1	0.05	Assumed
Bedrock Values					
Horizontal hydraulic conductivity (feet/day)	$3 \times 10^{-5} - 3 \times 10^{-1}$	3×10^{-3}	$3 \times 10^{-5} - 3 \times 10^{-1}$	3×10^{-3}	Estimated

See footnotes at end of table.

TABLE 5.3

CRITERIA FOR FLOW MODEL CALIBRATION

HYDRAULIC HEAD

Statistical tests for goodness of fit between an observed and computed set of heads.

- Mean residual (i.e., the difference between computed and observed head) ±0.5 feet
- Mean of the absolute residuals within ±2 feet
- Standard deviation of differences within 3 feet
- Regression coefficient between measured and computed values of 0.95
- Nearest neighbor autocorrelation (computed using a revised version of Moran's I); achieve a unit normal deviate of <1.90

WATER BALANCE

- Simulations producing a model water balance within 20 percent of computed water balance for study area using known hydraulic parameters

TABLE 5.4

SOLUTE TRANSPORT MODEL INPUT DATA

PARAMETERS	DATA SOURCE: PROJECT HISTORICAL DATA	LITERATURE REVIEW	RI FIELD DATA	RI LABORATORY DATA	RI DERIVED DATA	PARAMETER ESTIMATION	UNITS
SOLUTE SOURCE TYPES							
—CHEMICAL			◒	●			
—RADIOLOGICAL	○		◒	●			
SOURCE LOCATIONS	○		◒	◒			
SOURCE LOADING			◒		◒	○	pCi/l OR mg/l
EFFECTIVE POROSITY		●				◒	DIMENSIONLESS
RETARDATION FACTORS							DIMENSIONLESS
—TILL		?			●	◒	
—AQUIFER					●	◒	
—INTERBEDS					●	◒	
DISPERSION COEFFICIENT		●				◒	CM (FEET)
RADIOISOTOPE DECAY CONSTANTS		●					1/YEAR
CHEMICAL AND RADIOLOGICAL CONSTITUENT CONCENTRATIONS			◒	●			pCi/l OR mg/l

LEGEND

● PRIMARY

◒ SECONDARY

○ LIMITED

TABLE 6.1

THREE–DIMENTIONAL FLOW MODEL APPLICATION

	RUN NUMBER											
	1	2	3	4	5	6	7	8	9	10	11	12
PUMPING RATE												
SOWC WELLS	↓●↑								●			●
ALBRIGHT–WILSON WELL		●↑										
ON–SITE FMPC WELL			↓●↑							●	●	
RIVER ELEVATION (LEAKAGE)												
LOW FLOW				●					●	●		
MEAN ANNUAL FLOW					●							
FLOOD FLOW						●					●	●
PRECIPITATION RECHARGE												
PADDYS RUN						●						
OVER ENTIRE MODEL AREA							↓●↑					

LEGEND:

● INDICATES PARAMETERS TO BE VARIED, WHILE OTHER PARAMETERS REMAIN CONSTANT

↑ INCREASE

↓ DECREASE

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FIGURES

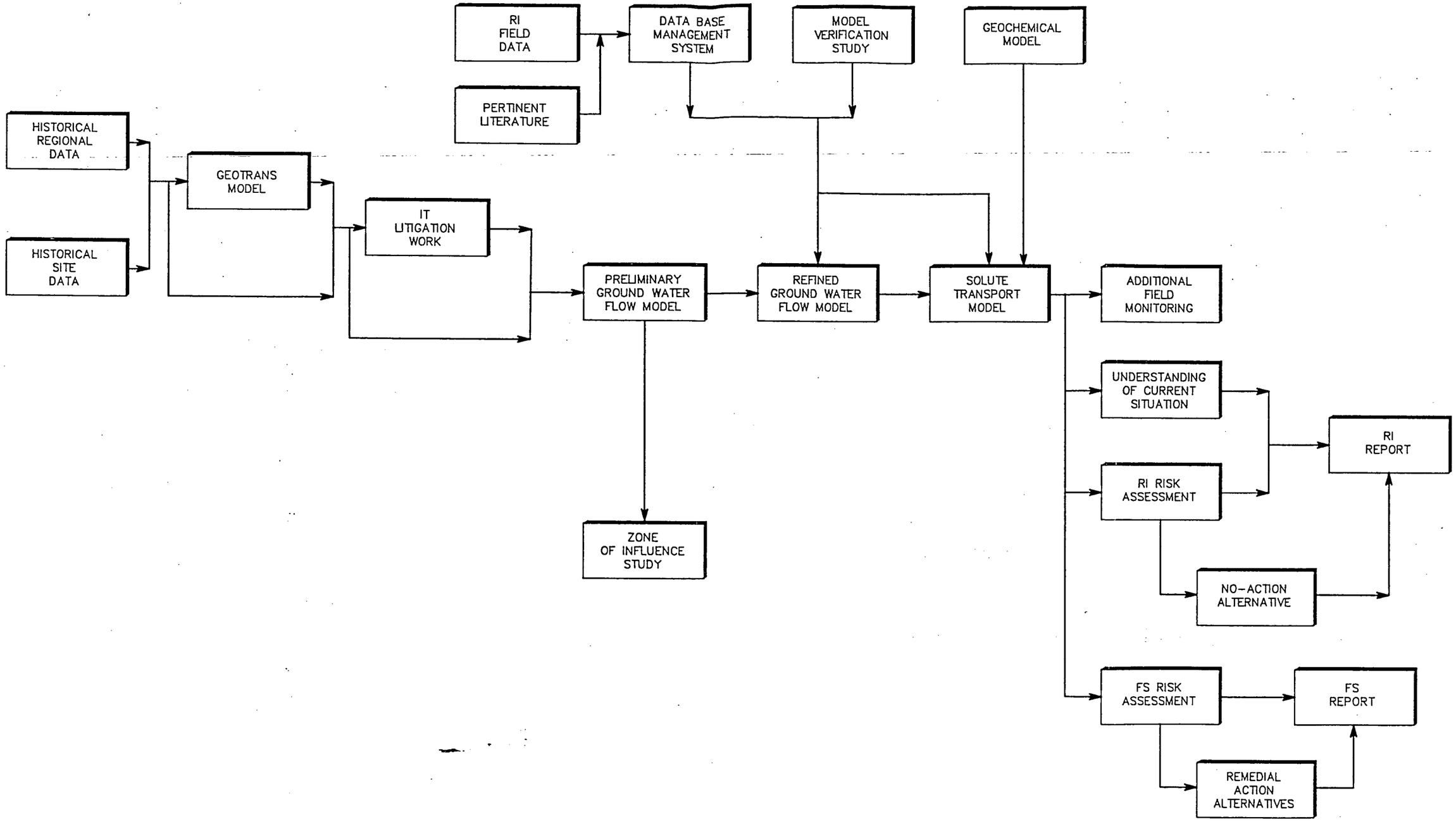

FIGURE 1–1

MODEL DEVELOPMENT AND USE IN FMPC RI/FS

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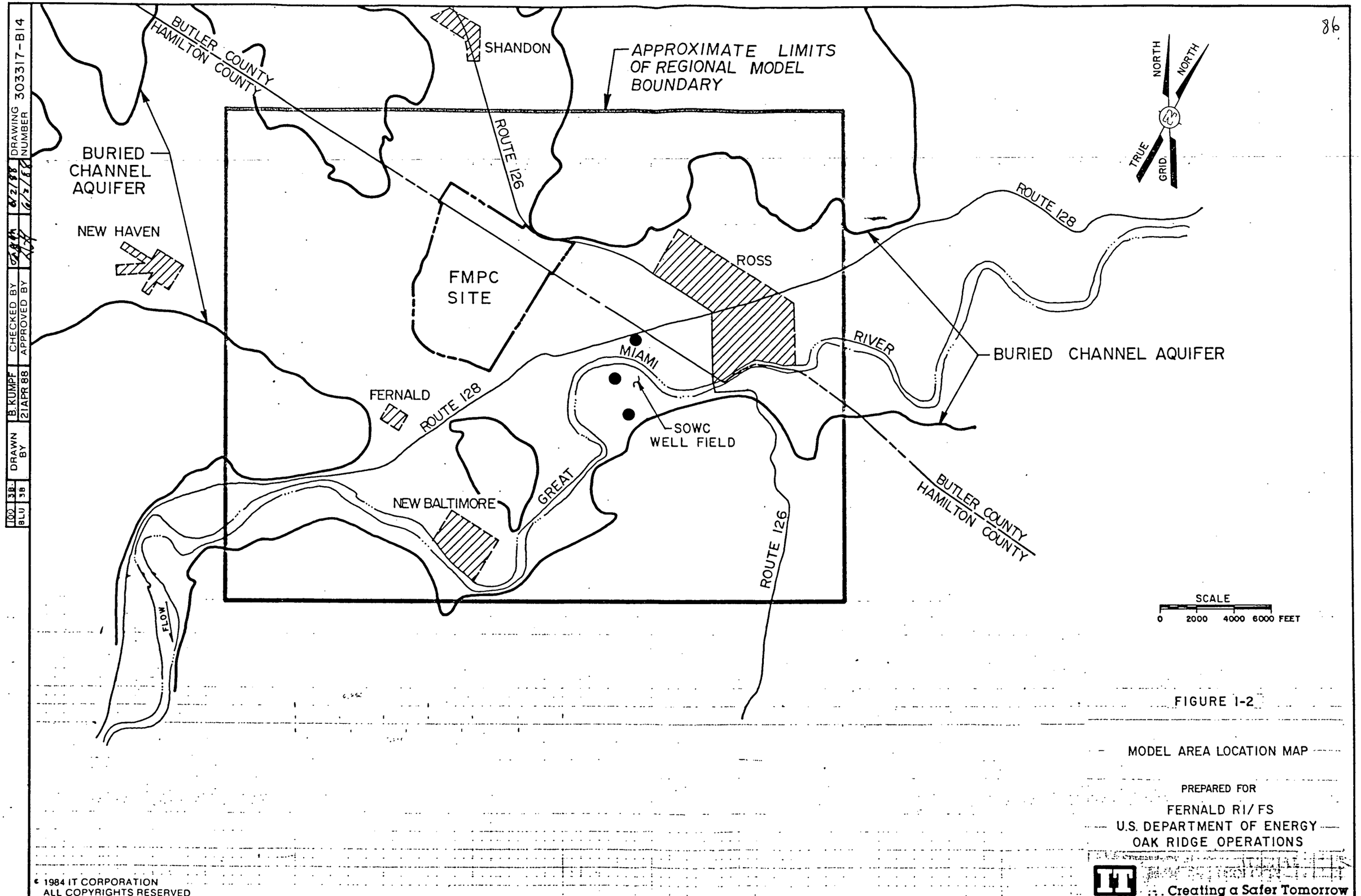

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FIGURE 1-2

MODEL AREA LOCATION MAP

PREPARED FOR

FERNALD RI/FS
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OAK RIDGE OPERATIONS

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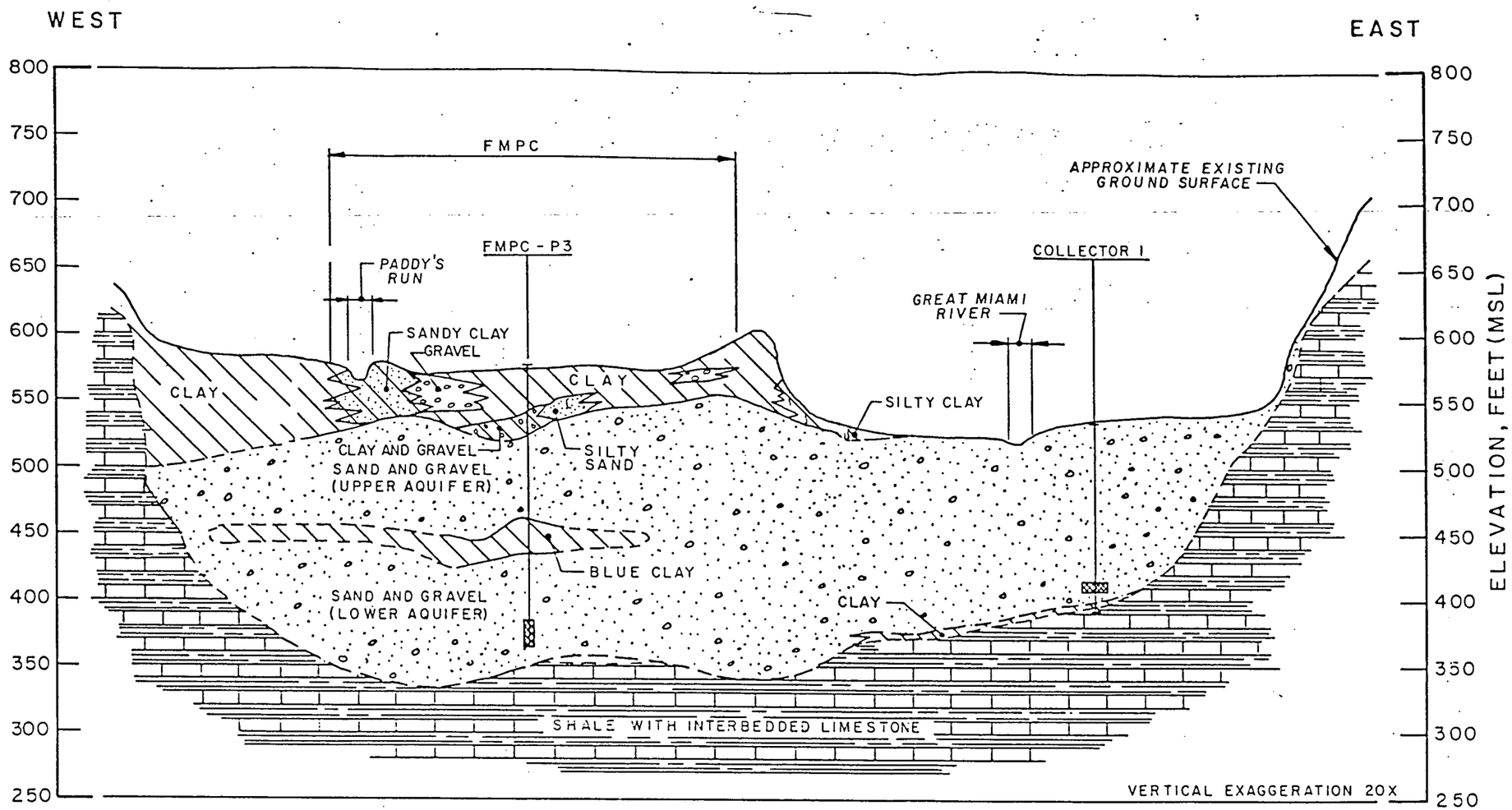

GENERALIZED CROSS-SECTION
BURIED CHANNEL AQUIFER

(LOOKING NORTH)

VERTICAL SCALE

0 100 200 FEET

HORIZONTAL SCALE

0 2000 4000 FEET

REFERENCE:

MODIFIED FROM U.S.G.S. PROFESSIONAL PAPER 605-A USING AVAILABLE OHIO STATE WATER WELL RECORDS, SOWC WATER WELL DATA, DAMES & MOORE FEED MATERIALS PRODUCTION CENTER GROUNDWATER STUDY TASK A & C REPORTS AND IT BORING LOGS

FIGURE 1-3

GENERALIZED HYDROGEOLOGIC CROSS SECTION OF THE BURIED CHANNEL AQUIFER

PREPARED FOR

FERNALD RI/FS
U.S. DEPARTMENT OF ENERGY
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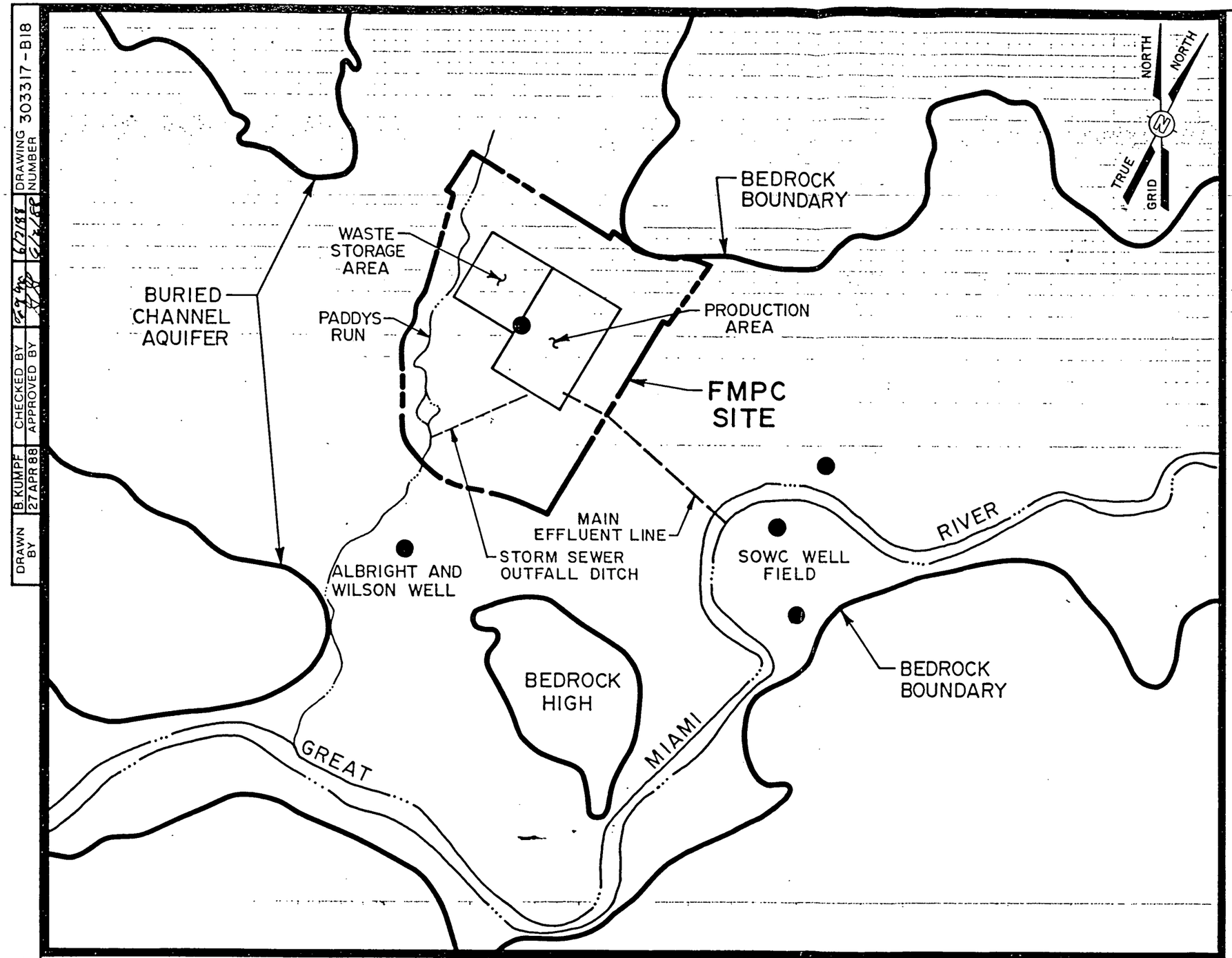

LEGEND:

● MAJOR GROUND WATER PUMPING CENTERS

FIGURE 1-4

MODEL INPUT FEATURES

PREPARED FOR

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U.S. DEPARTMENT OF ENERGY
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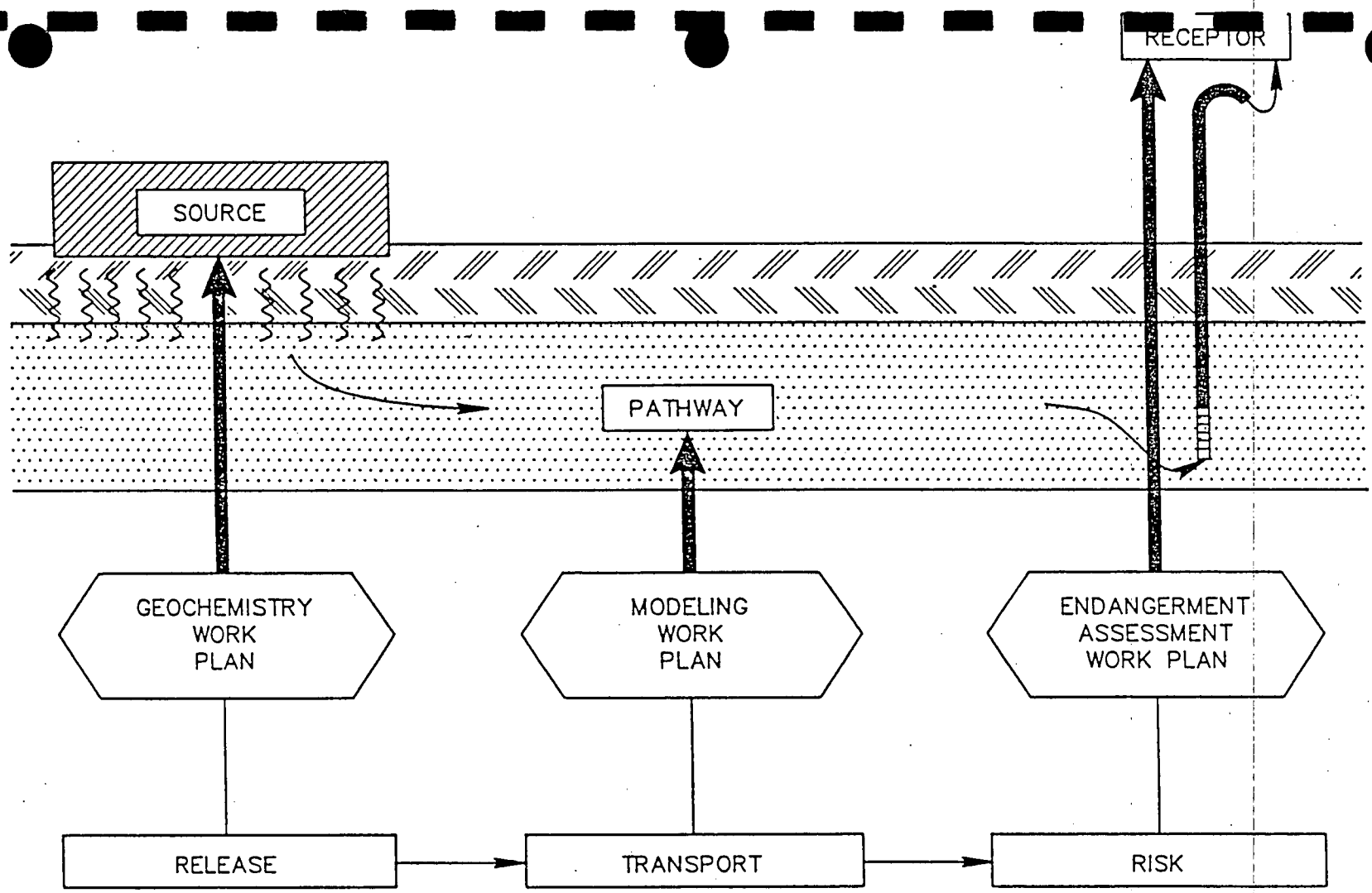

LEGEND

- WASTE
- GLACIAL TILL
- SAND & GRAVEL

FIGURE 1–5

OVERVIEW OF MODEL APPLICATION

INTERNATIONAL TECHNOLOGY CORPORATION

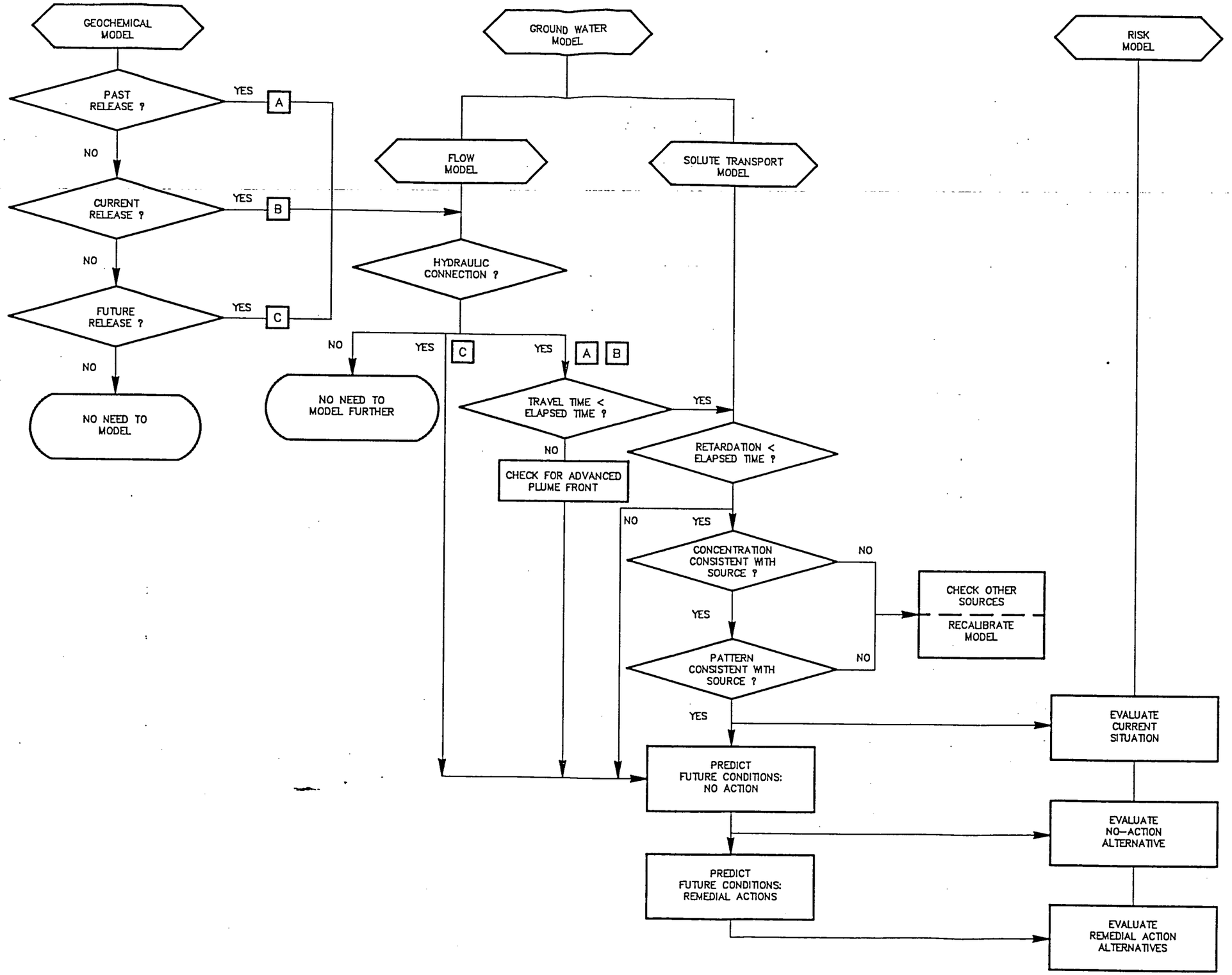

FIGURE 1–6

MODEL APPLICATION FOR PATHWAY ANALYSIS

SOURCE	POTENTIAL REMEDIAL ACTIONS: NON-REMOVAL WITH IN-PLACE STABILIZATION	NON-REMOVAL WITH INFILTRATION CONTROL	NON-REMOVAL WITH SUBSURFACE FLOW CONTROL	NON-REMOVAL WITH SUBSURFACE WATER DIVERSION	REMOVAL WITH ONSITE COMPLIANCE DISPOSAL	REMOVAL WITH ONSITE TREATMENT (& DISPOSAL)	REMOVAL WITH OFFSITE DISPOSAL	NON-REMOVAL WITH RADON EMISSIONS CONTROL		ASSESSMENT INFORMATIONAL NEEDS	INVESTIGATIVE TASKS: RADIATION MEASUREMENT	WASTE SAMPLING	SURFACE SOIL SAMPLING	SEDIMENT SAMPLING	SURFACE WATER SAMPLING	AIR SAMPLING	GROUNDWATER WELLS / MONITORING	GEOPHYSICS	DEEP BOREHOLES	FLORA SAMPLING	TERRESTRIAL / AQUATIC ORGANISM SAMPLING	DRUM SAMPLING	WASTE STREAM SAMPLING	FACILITIES TESTING PLAN	GROUNDWATER MODEL	AIR MODEL	PUBLIC HEALTH / ENVIRONMENTAL RISK ASSESSMENT
WASTE PITS	●	●	●		●	●	●			NATURE OF WASTES STORED	●	●			●	●											
	●				●	●	●			VOLUME AND DEPTH OF WASTES		●															
	●	●	●							LEAKAGE POTENTIAL (LINER ?)		●			●												
			●		●	●				LOCAL HYDROGEOLOGIC SETTING									●								
		●								POTENTIAL FOR FLOODING																	
	●	●	●		●	●	●			CURRENT VS. RESIDUAL RISKS	●	●			●	●									●	●	●
	●				●	●	●			RISKS DURING IMPLEMENTATION	●	●			●	●									●	●	●
	●	●	●		●	●	●			REGULATORY CONSTRAINTS		●															
BURN PIT	●	●	●		●	●	●			NATURE OF WASTES PRESENT	●	●	●			●			●								
	●				●	●	●			VOLUME AND DEPTH OF WASTES		●	●					●	●								
		●								POTENTIAL FOR FLOODING																	
	●	●	●							LEAKAGE POTENTIAL		●					●								●		
			●		●	●				LOCAL HYDROGEOLOGIC SETTING							●	●	●						●		
		●								SURFACE WATER RUNOFF PATTERNS																	
	●	●	●		●	●	●			CURRENT VS. RESIDUAL RISKS	●	●				●									●		●
	●				●	●	●			RISKS DURING IMPEMENTATION	●	●	●			●									●		●
LIME SLUDGE PONDS																											
										(SEE WASTE PITS)																	

FIGURE 3.1
INVESTIGATIVE FRAMEWORK (EXAMPLE)

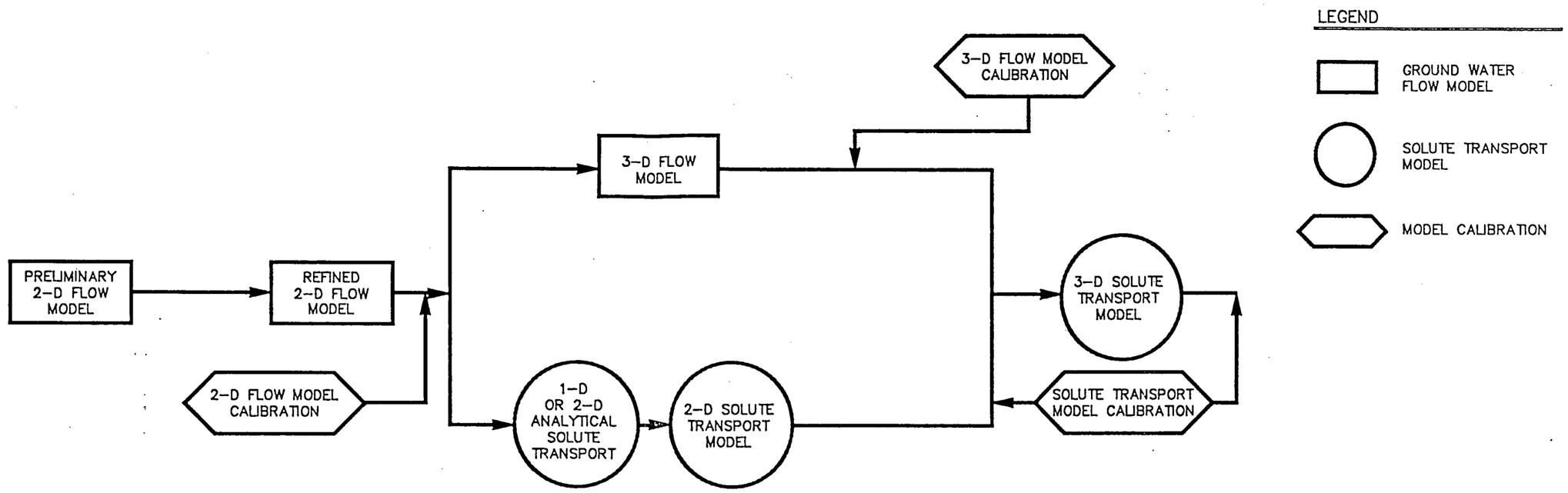

FIGURE 5-1

OVERVIEW OF MODEL DEVELOPMENT

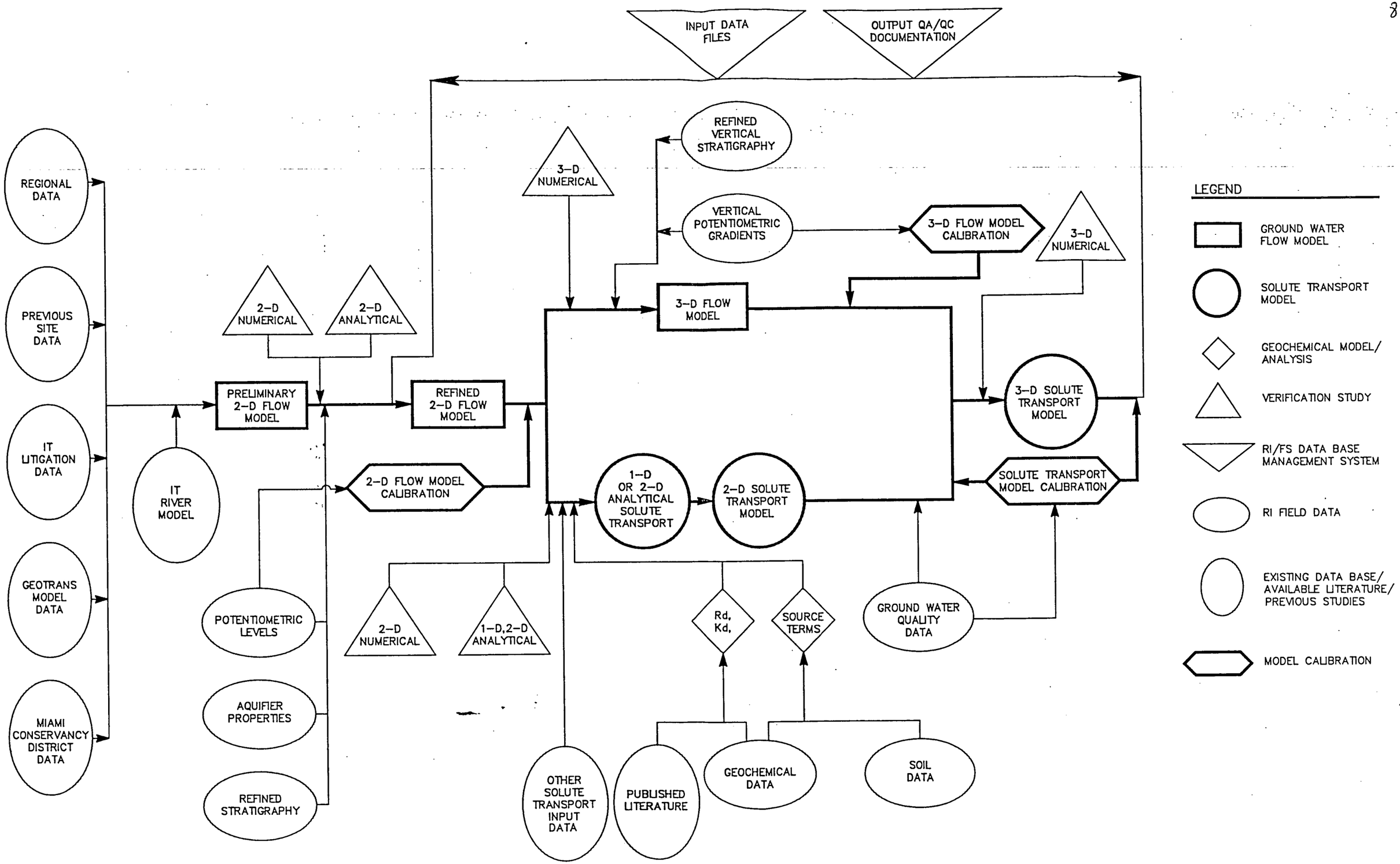

FIGURE 5-2

GROUND WATER FLOW / SOLUTE TRANSPORT MODEL DEVELOPMENT

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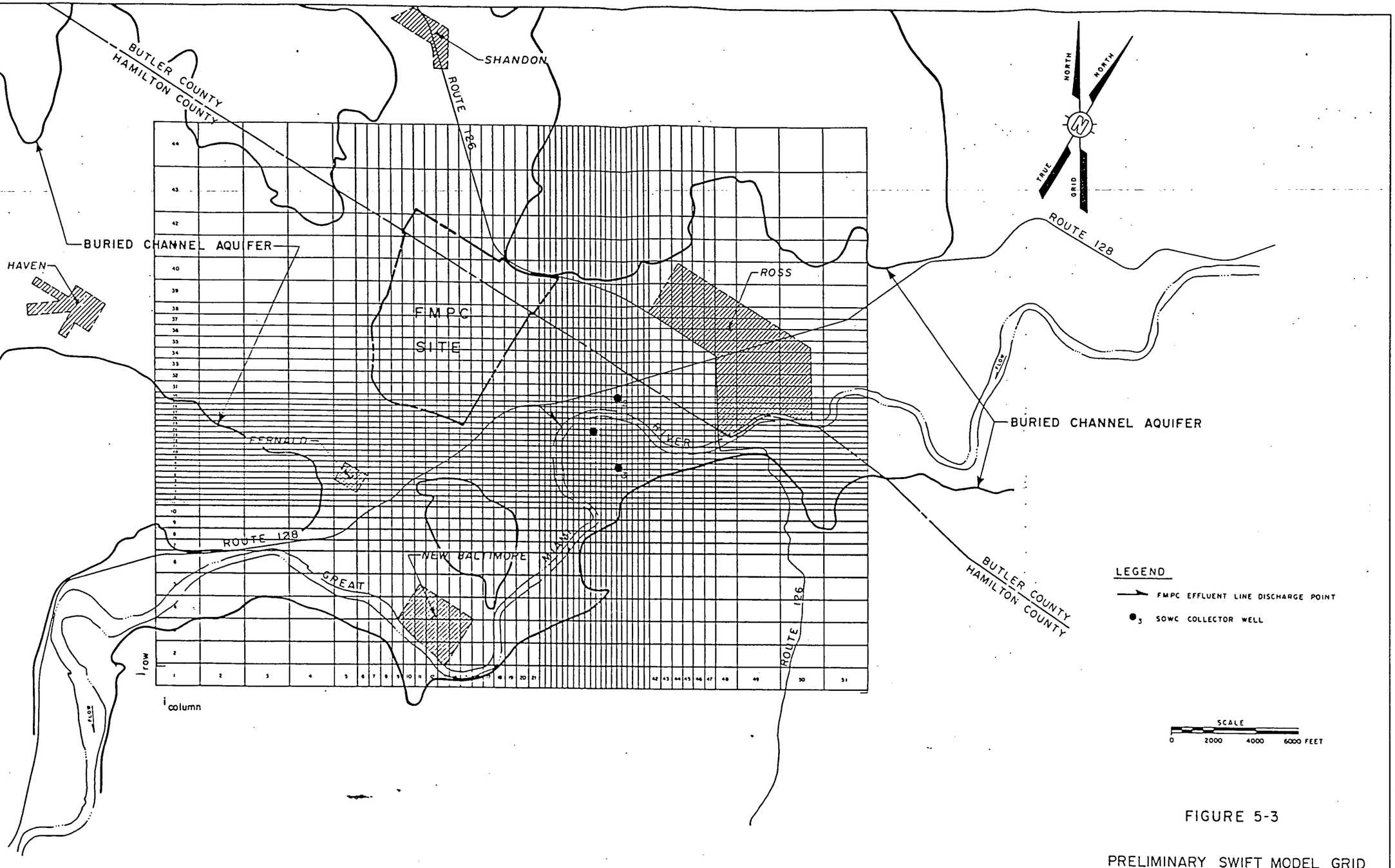

LEGEND

FMPC EFFLUENT LINE DISCHARGE POINT

$\bullet_3$ SOWC COLLECTOR WELL

SCALE

0 2000 4000 6000 FEET

FIGURE 5-3

PRELIMINARY SWIFT MODEL GRID
FOR RI/FS MODEL AREA

PREPARED FOR

FERNALD RI/FS
U.S. DEPARTMENT OF ENERGY
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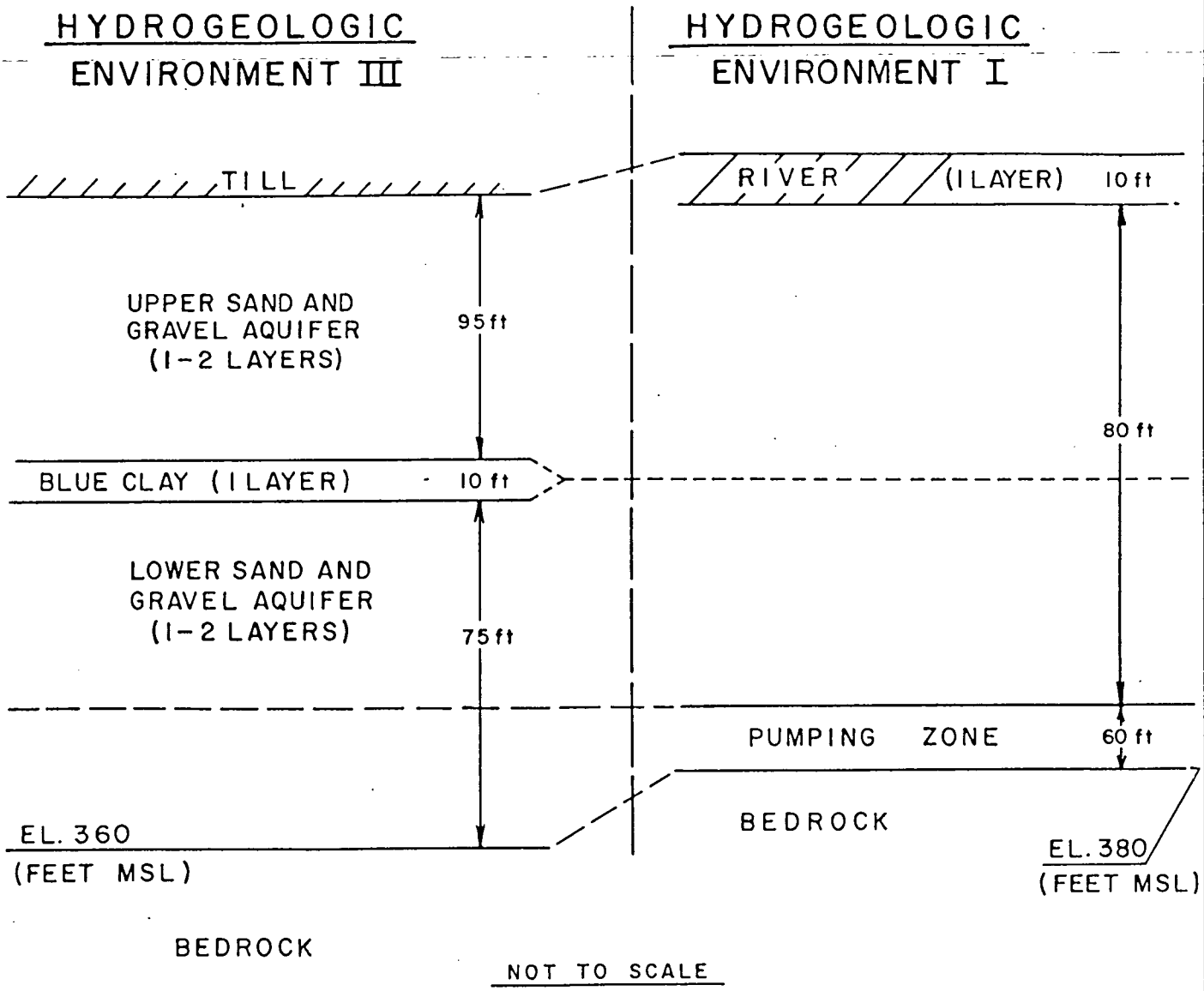

FIGURE 5-4

CONCEPTUAL DESIGN FOR MODEL LAYERING

PREPARED FOR

FERNALD RI/FS
U.S. DEPARTMENT OF ENERGY
OAK RIDGE OPERATIONS

INTERNATIONAL TECHNOLOGY CORPORATION

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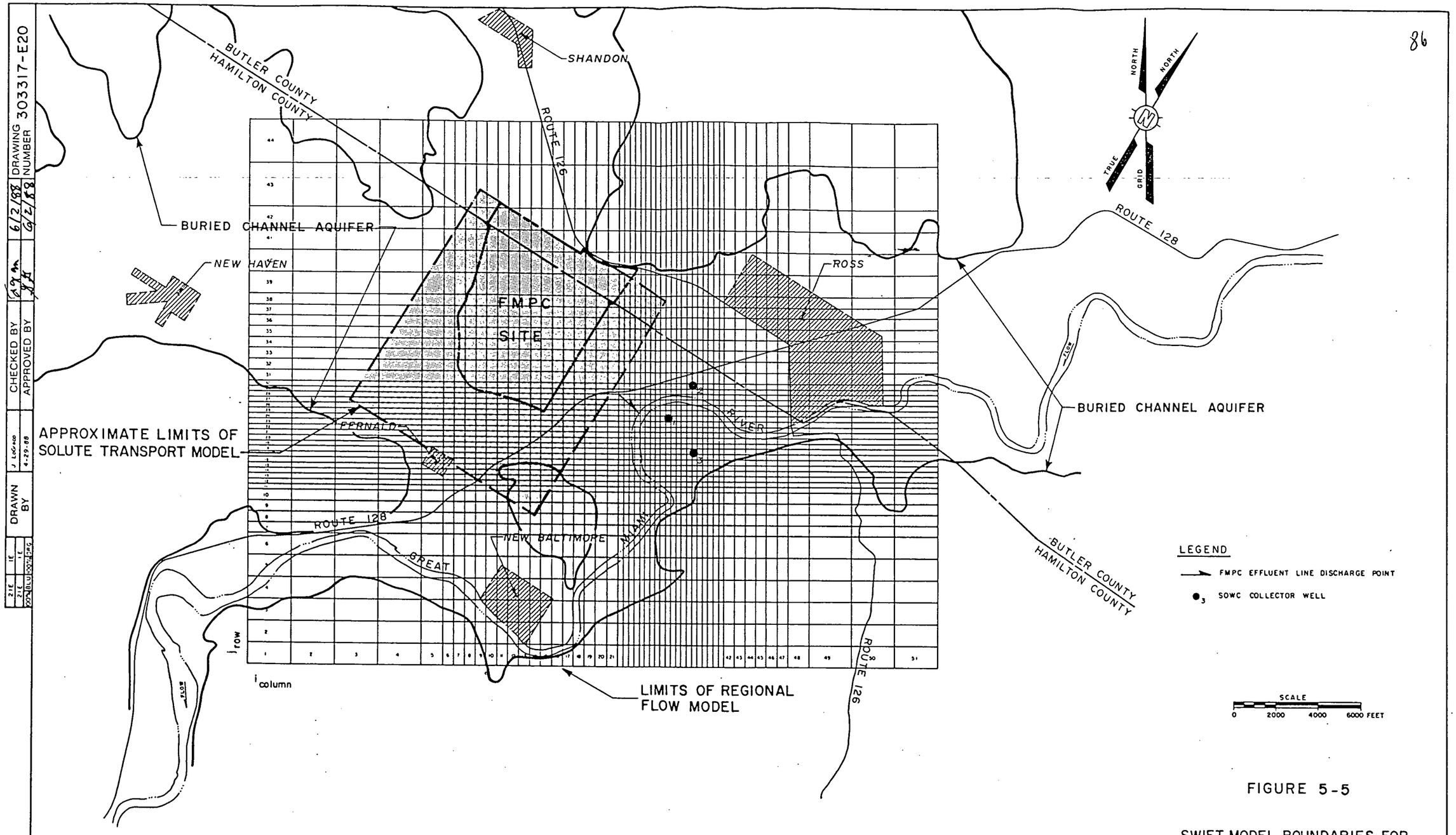

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FIGURE 5-5

SWIFT MODEL BOUNDARIES FOR
RI/FS GROUNDWATER FLOW
AND SOLUTE MODELS

PREPARED FOR

FERNALD RI/FS
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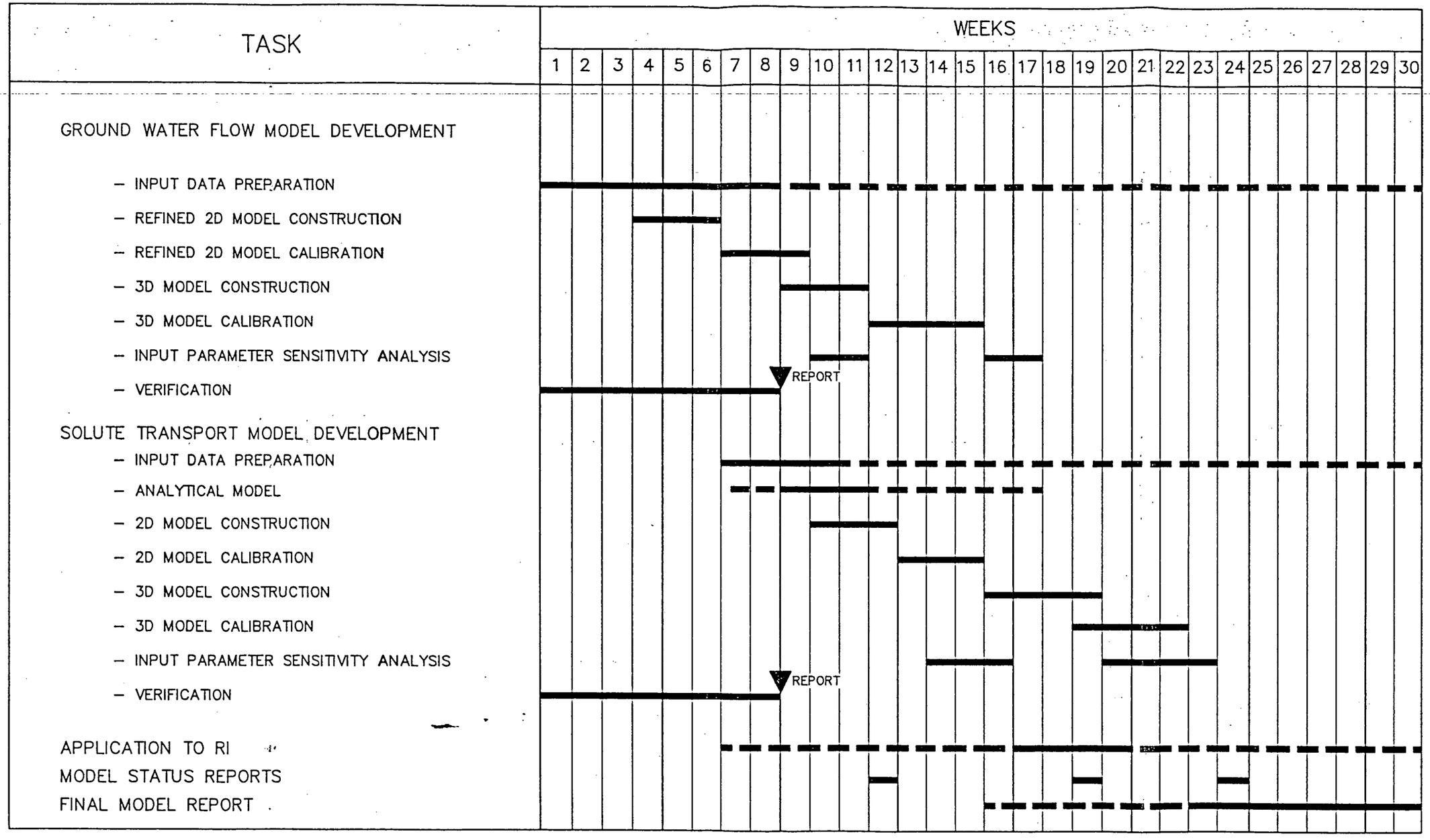

FIGURE 8–1

SCHEDULE
GROUND WATER FLOW / SOLUTE TRANSPORT MODELING

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