Environmental Programs

OVERVIEW OF CAMP EDWARDS MODELING ACTIVITIES

Jay Clausen, AMEC

Presented to NGB, USEPA, MADEP, USGS, WES, and Jacobs Engineering on April 5, 2001 at Camp Edwards (IAGWSPO Contact Dave Hill 508-968-5621).

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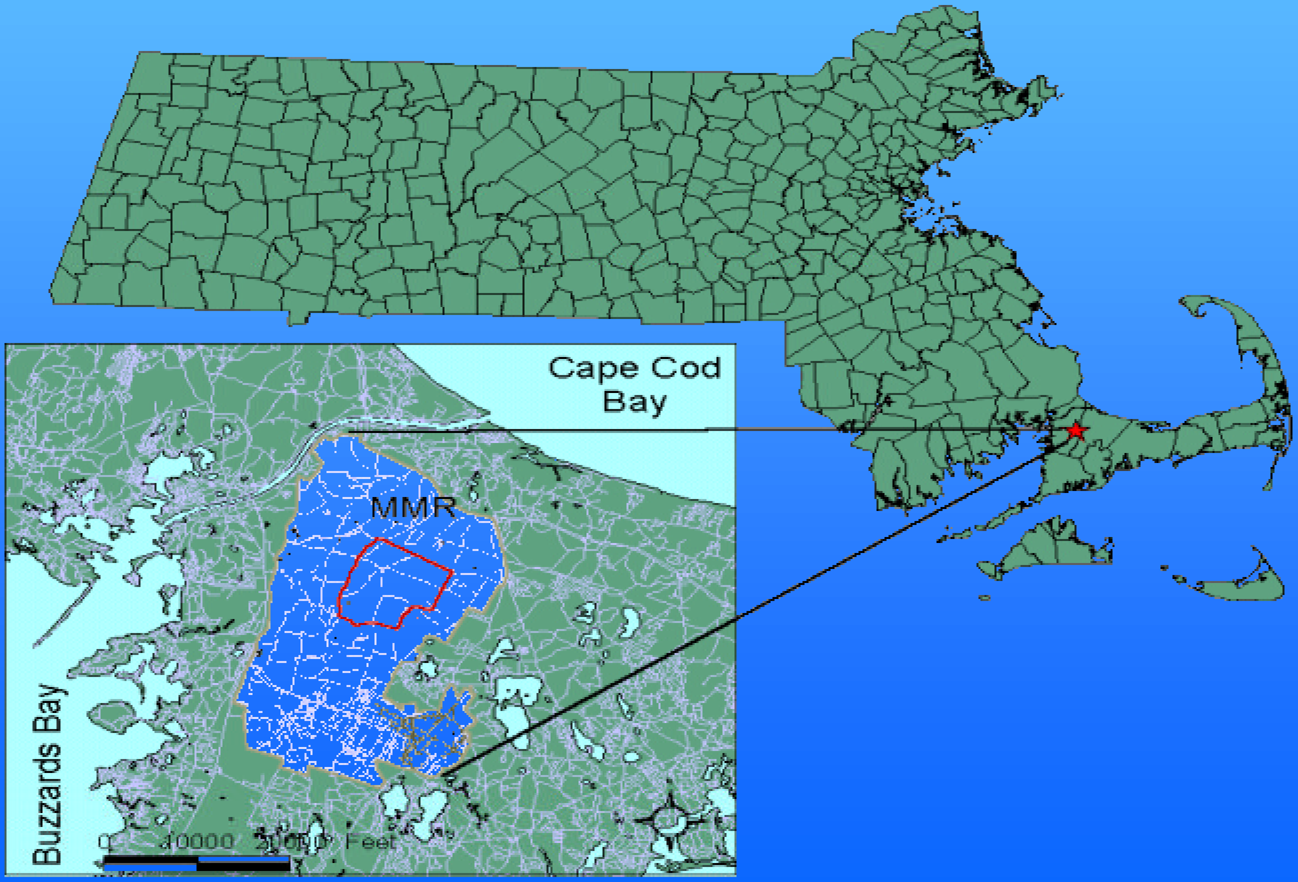
LOCATION



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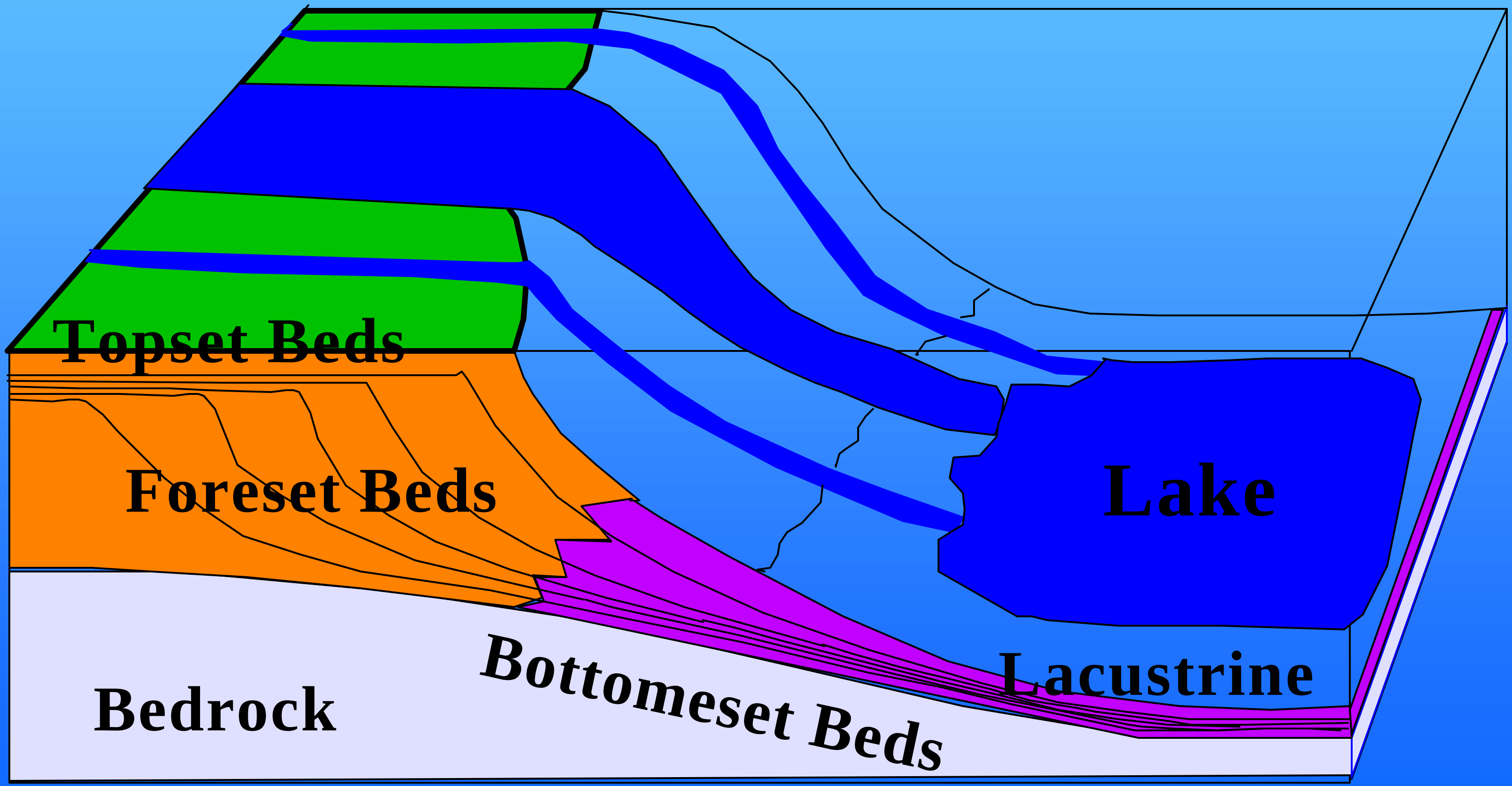
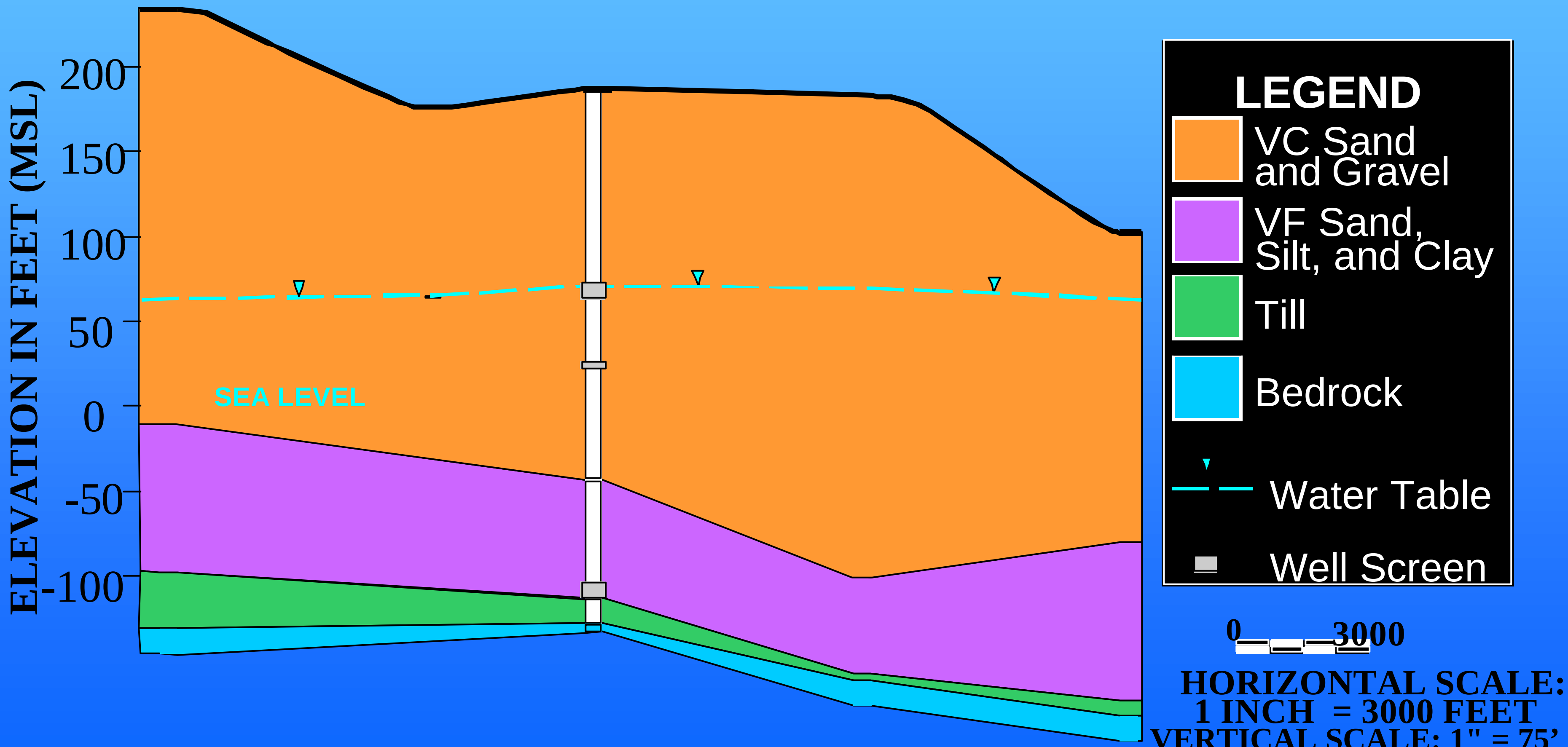
GEOLOGIC CONCEPTUAL MODEL



Modified from Smith and Ashley, 1985

GENERALIZED LITHOLOGIC CROSS-SECTION



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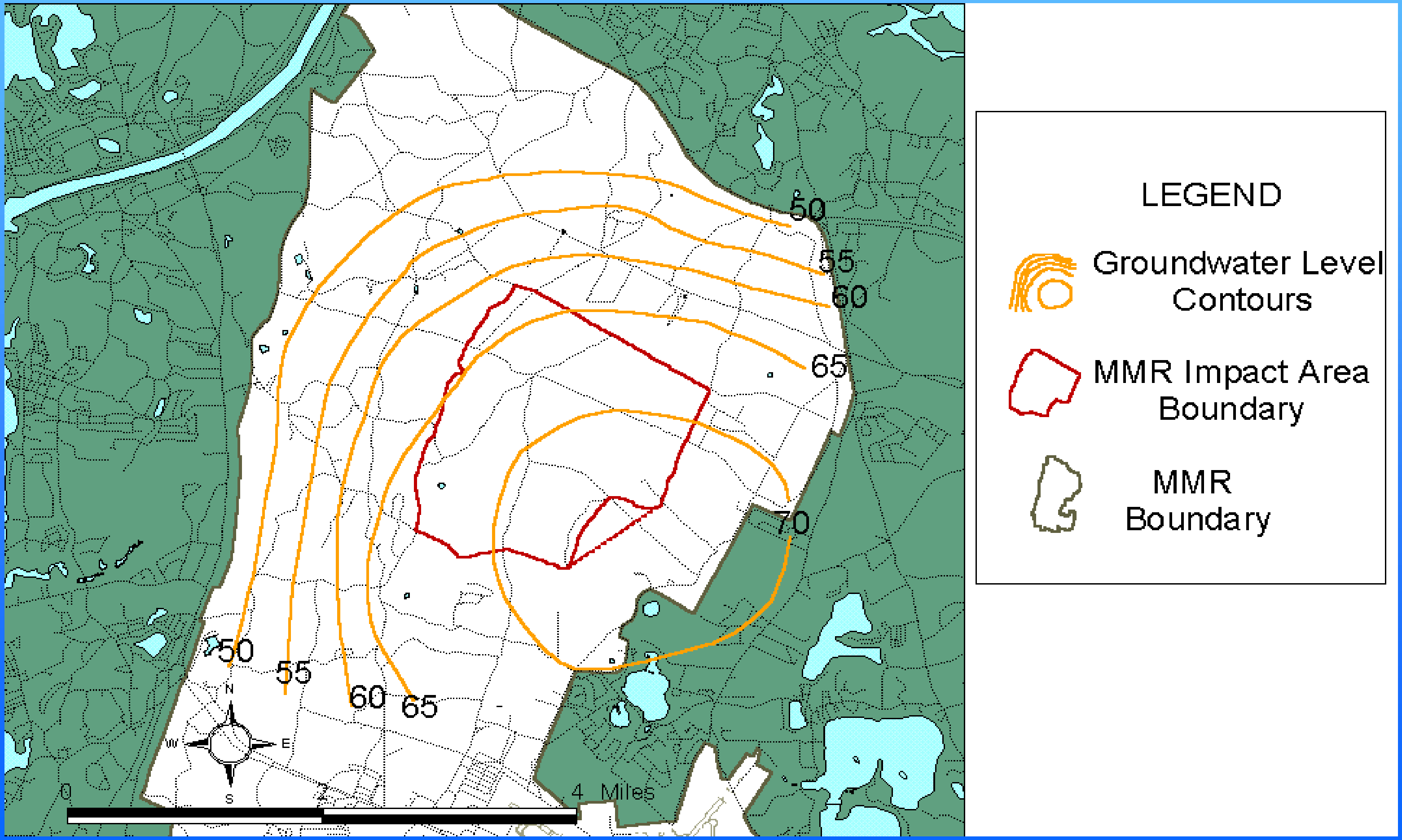
GROUNDWATER FLOW



MAJOR SOURCES OF INFORMATION

- USGS Regional Model and Reports
- AMEC/OGDEN Reports
- Jacobs Engineering Group Inc. Reports
- Technical Papers and Articles

PRESENTATIONS

- Unsaturated Zone Modeling Results for Demo 1 (Jay Clausen, AMEC)
- Unsaturated Zone Modeling Results for the Gun and Mortar Positions (Jay Clausen, AMEC)
- Preliminary Saturated Zone F&T Modeling Results for Demo 1 (Tod Monks, AMEC)
- Discussion of Saturated Zone F&T Modeling Approach for J Ranges (Jacob Zaidel, AMEC)
- Discussion of Saturated Zone F&T Modeling Approach for Central Impact Area (Jay Clausen, AMEC)

MODELING OBJECTIVES

- Assist in the identification of COCs by conducting unsaturated zone modeling of the G&M Positions, Demo 1, CIA, J Ranges, and Phase IIB
- Develop soil cleanup standards, based on unsaturated zone modeling, to ensure COCs leaching to groundwater are below regulatory guidelines
- Develop subregional saturated zone fate-and-transport models for Demo 1, CIA, and J Ranges
- Analyze remedial options for the COCs in the saturated zone at Demo 1, CIA, and J Ranges

MODEL CODES

- SESOIL (Unsaturated)
- MODFLOW/MT3D (Saturated)

UNSATURATED ZONE OBJECTIVES

- Assist in the Identification of COCs for the Site Through a Leaching Potential Analysis using SESOIL

SATURATED ZONE MODELING OBJECTIVES

- Develop a Subregional Groundwater Flow and Contaminant Transport Model to Simulate Fate and Transport of COCs
- Conduct a Sensitivity Analysis to Quantify the Uncertainty in the Calibrated Model Caused by the Uncertainty in the Estimates of Aquifer Parameters
- Document the Modeling Activities in a Report or in a Subsection of Another Report

DELIVERABLES AND SCHEDULE

Marc Grant, AMEC

DELIVERABLES AND SCHEDULE

- Demo 1: Unsaturated Zone Modeling in Demo 1 COC Soil Report — 03/16/01
- Demo 1: Saturated Zone F&T Modeling in Demo1 GW PSI Workplan — 05/13/01
- G&M: Unsaturated Zone Modeling in G&M COC Soil Report — 04/10/01
- Central Impact Area: Unsaturated Zone Modeling in Central Impact Area Soil Report — 07/17/01
- Central Impact Area: Saturated Zone F&T Modeling in Central Impact Area Groundwater FS Screening Report — 06/14/01

DELIVERABLES AND SCHEDULE

- J2 Range: Unsaturated Zone Modeling in J2 Range Additional Report — 09/27/01
- J2 Range: Saturated Zone F&T Modeling in SE Corner FS Screening Report — 05/20/02
- J1, J3, L Range: Unsaturated Zone Modeling in J1, J3, L Range Report — 09/05/01
- J1, J3, L Range: Saturated Zone F&T Modeling in Report SE Corner FS Screening — 05/20/02

DELIVERABLES AND SCHEDULE

- UXO: Unsaturated Zone Modeling in UXO FS Screening Report — TBD
- UXO: Saturated Zone F&T Modeling in FS Report — TBD
- Phase IIB: Unsaturated Zone Modeling in Phase IIB Report — 07/24/01
- Phase IIB: Saturated Zone F&T Modeling in Phase IIB FS Report — 07/24/01
- Small Arms: Unsaturated Zone Modeling in Small Arms FS Soil Report — TBD
- Small Arms: Saturated Zone F&T Modeling in Small Arms FS GW Report — TBD

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DEMO 1 UNSATURATED ZONE MODELING RESULTS

Jay Clausen, AMEC

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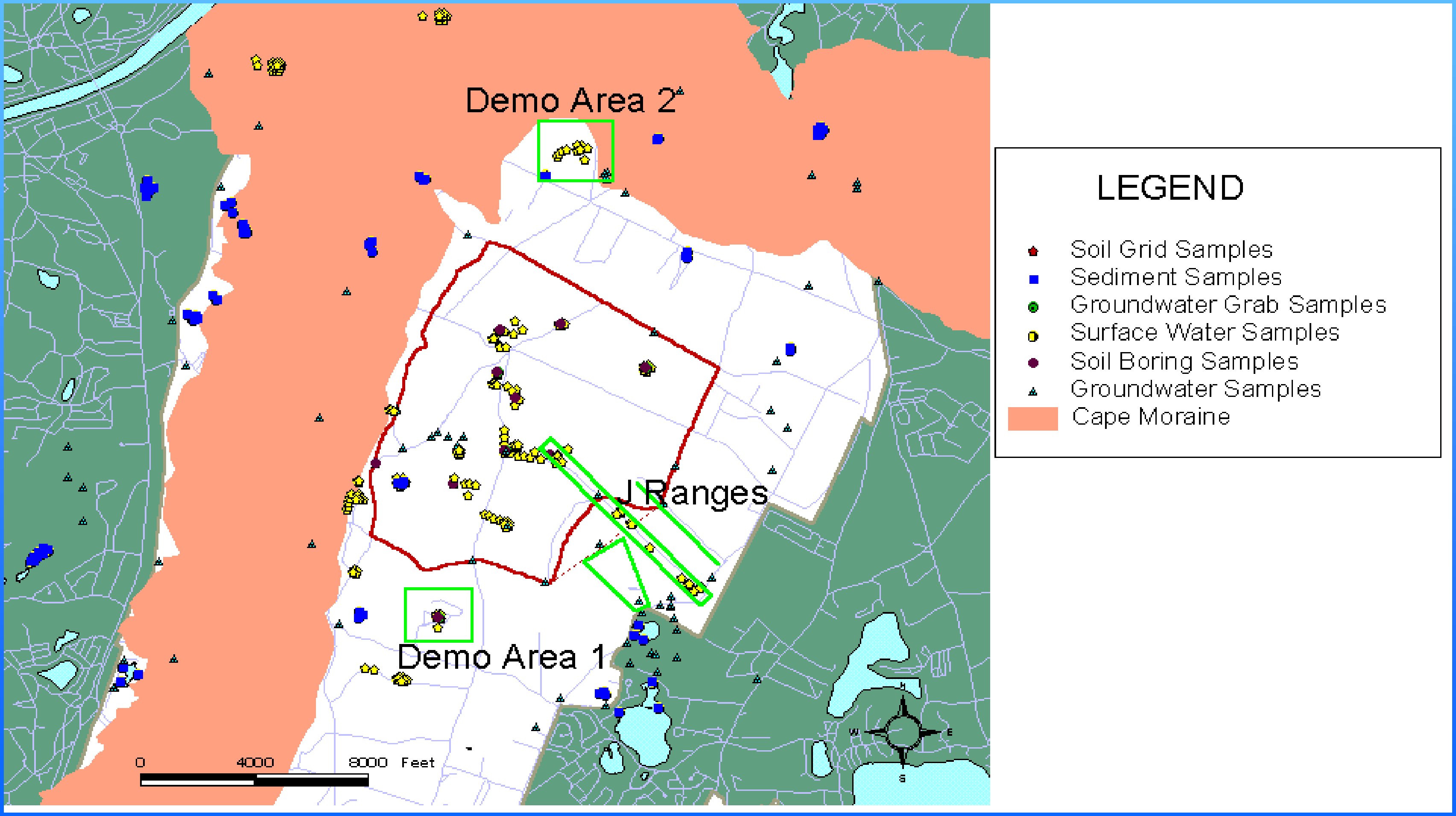
LOCATION



GENERAL MODEL CONSTRUCTION

- Depth of Soil Contamination = 0 to 1 ft
- Area of Soil Contamination = 4 acres
- Depth to the Water Table = 44 ft
- Maximum Contaminant Level for Demo 1 was Used

SPECIFIC MODEL PARAMETERS

- Bulk Density = 1.434 g/mL
- Effective Porosity = 0.454
- Organic Carbon Content = 1.84 percent
- Number of Soil Layers = 4
- Number of Soil Sublayers = 10

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MODEL CALIBRATION VARIABLES

- Effective Porosity = 0.25 to 0.45
- Disconnectedness Index = 3.7 to 4.0
- Intrinsic Permeability = 1.0E-08 to 2.0E-09 cm^2

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MODEL CALIBRATION TARGETS

- Average Soil Moisture Content = 11.3 to 13.3 %
- Evapotranspiration = 59 to 73 cm/year
- Groundwater Recharge = 45 to 55 cm/year
- Surface Water Runoff = 0 cm/year

CALIBRATION RESULTS

- Average Soil Moisture Content = 12.3%
- Evapotranspiration = 49 cm/year
- Groundwater Recharge = 66 cm/year
- Surface Water Runoff = 0.1 cm/year

FINAL CALIBRATION VARIABLES

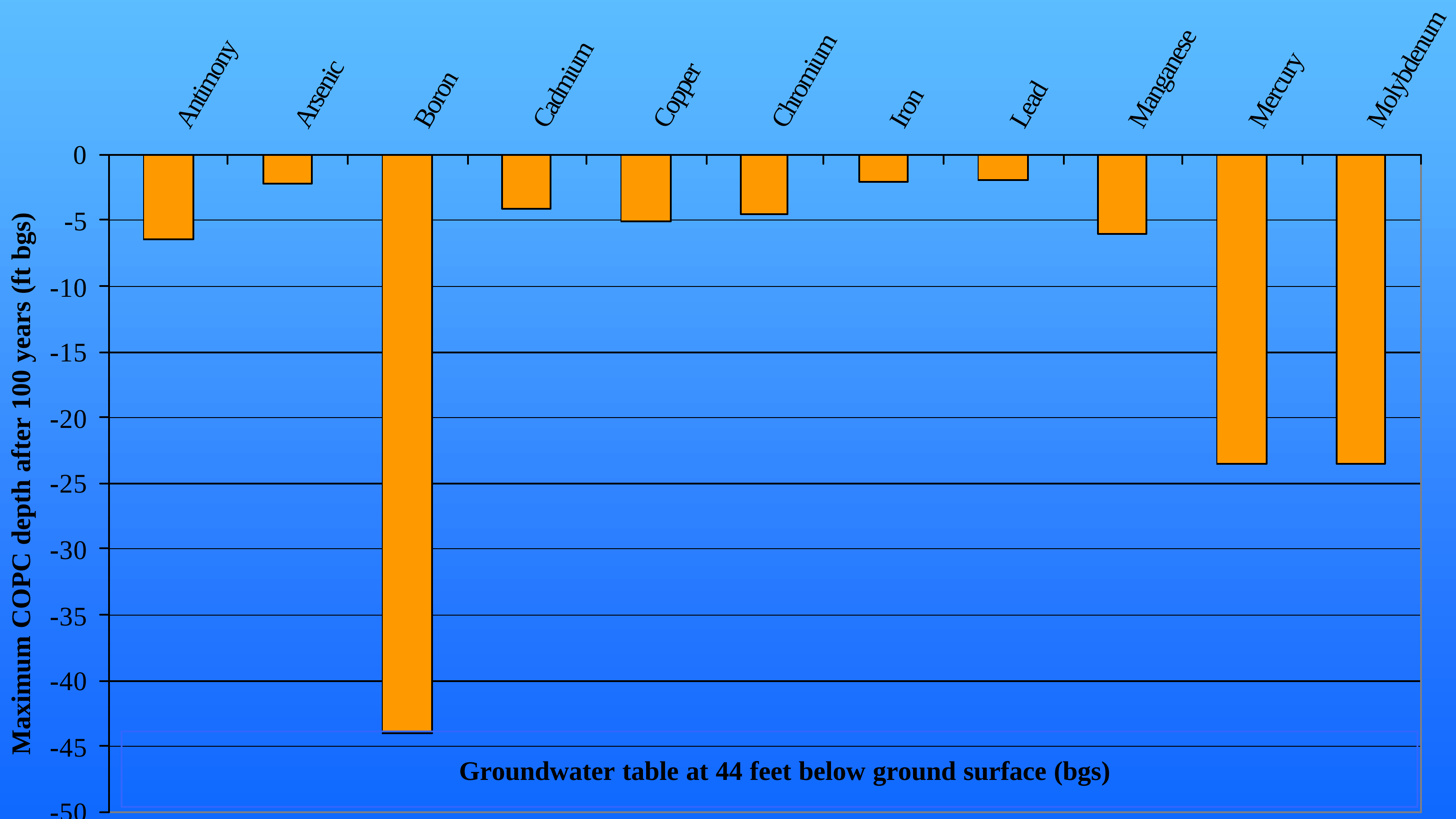
- Effective Porosity = 0.454
- Disconnectedness Index = 3.9
- Intrinsic Permeability = 3.0E-09 cm^2

DEMO 1 SOIL COCS MODELED

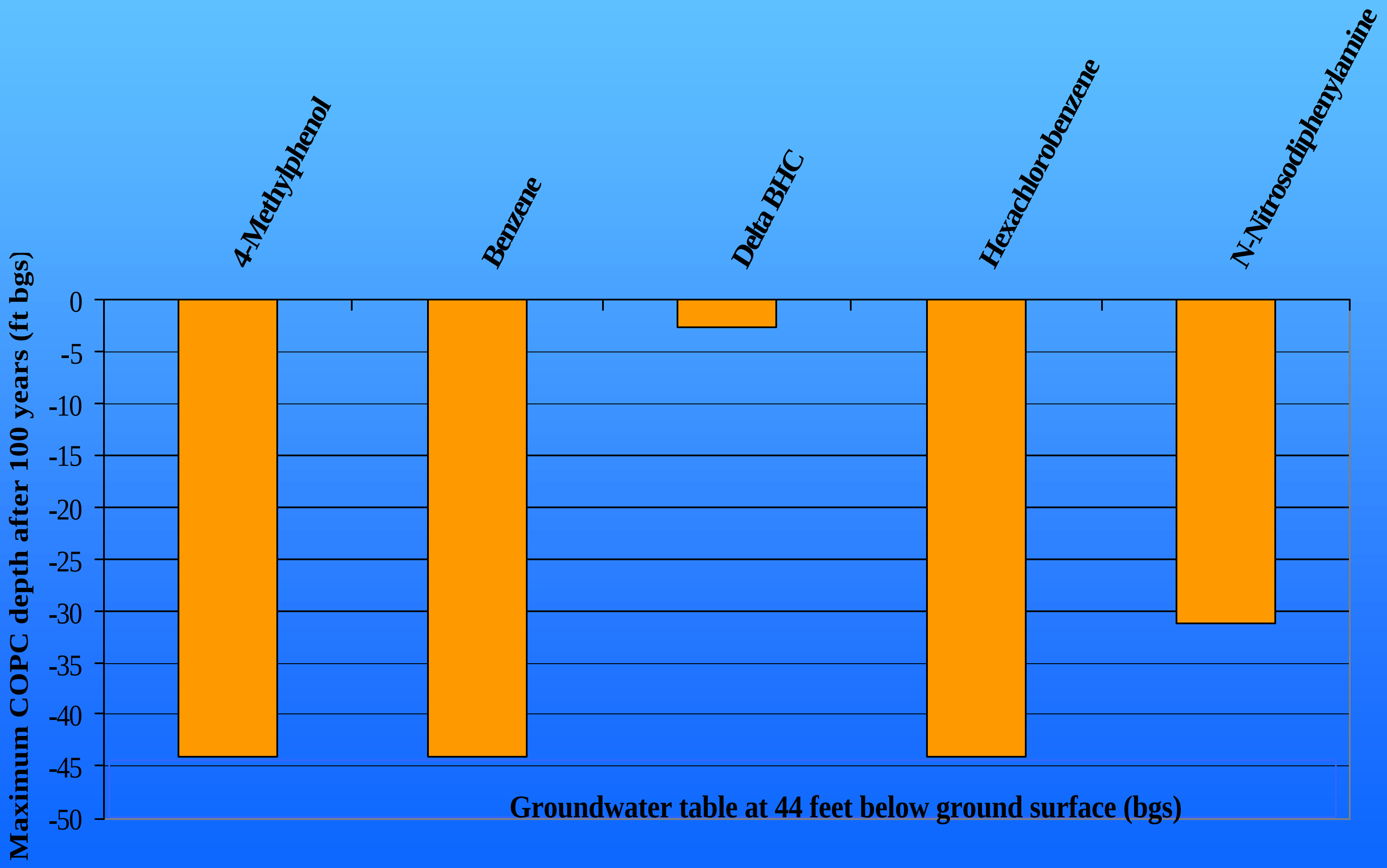
- Antimony
- Arsenic
- Barium
- Boron
- Cadmium
- Copper
- Chromium
- Iron
- Lead
- Manganese
- Mercury
- Molybdenum
- Silver
- Thallium

- 2-Methylnapthalene
- Benzo(b)fluoranthene
- Carbazole
- Napthalene
- Gamma BHC (Lindane)
- Delta BHC
- 2,3,7,8-TCDD
- MCPP
- PCP
- 4-Methylphenol
- Benzene
- Hexachlorobenzene
- N-nitrosodiphenylamine

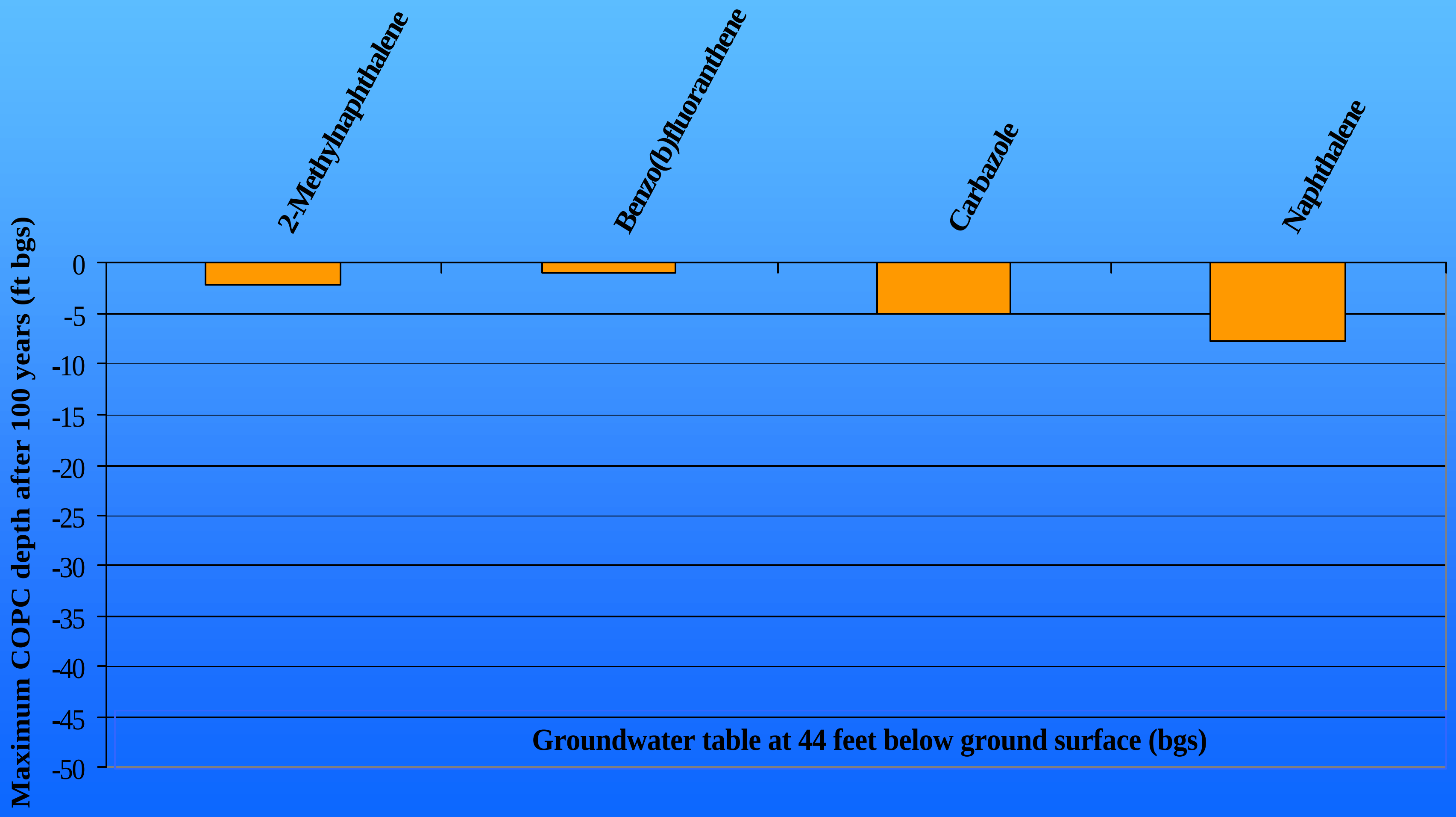
METAL COC RESULTS



VOC AND SVOC COC RESULTS



PAH COC RESULTS



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PESTICIDE/HERBICIDE COC RESULTS

GROUNDWATER INPUT PARAMETERS

- Hydraulic Conductivity = 300 ft/day (9144 cm/day)
- Horizontal Hydraulic Gradient = 0.0015 (cm/cm)
- Thickness of Mixing Zone = 16 ft (500 cm)
- Width of Contaminated Zone Perpendicular to Groundwater Flow Direction = 148 ft (4500 cm)
- Background COC Concentration = 0 ug/L

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COCS REACHING GROUNDWATER IN INITIAL MODEL SIMULATIONS

- Boron
- 4-Methylphenol
- Benzene
- Hexachlorobenzene

REVISED MODEL CONSTRUCTION

- Depth of Soil Contamination = 0 to 1 ft
- Area of Soil Contamination = 400-500 ft^2
- Depth to the Water Table = 44 ft
- Average Contaminant Level of Detections
- Biodegradation half-lives were Utilized

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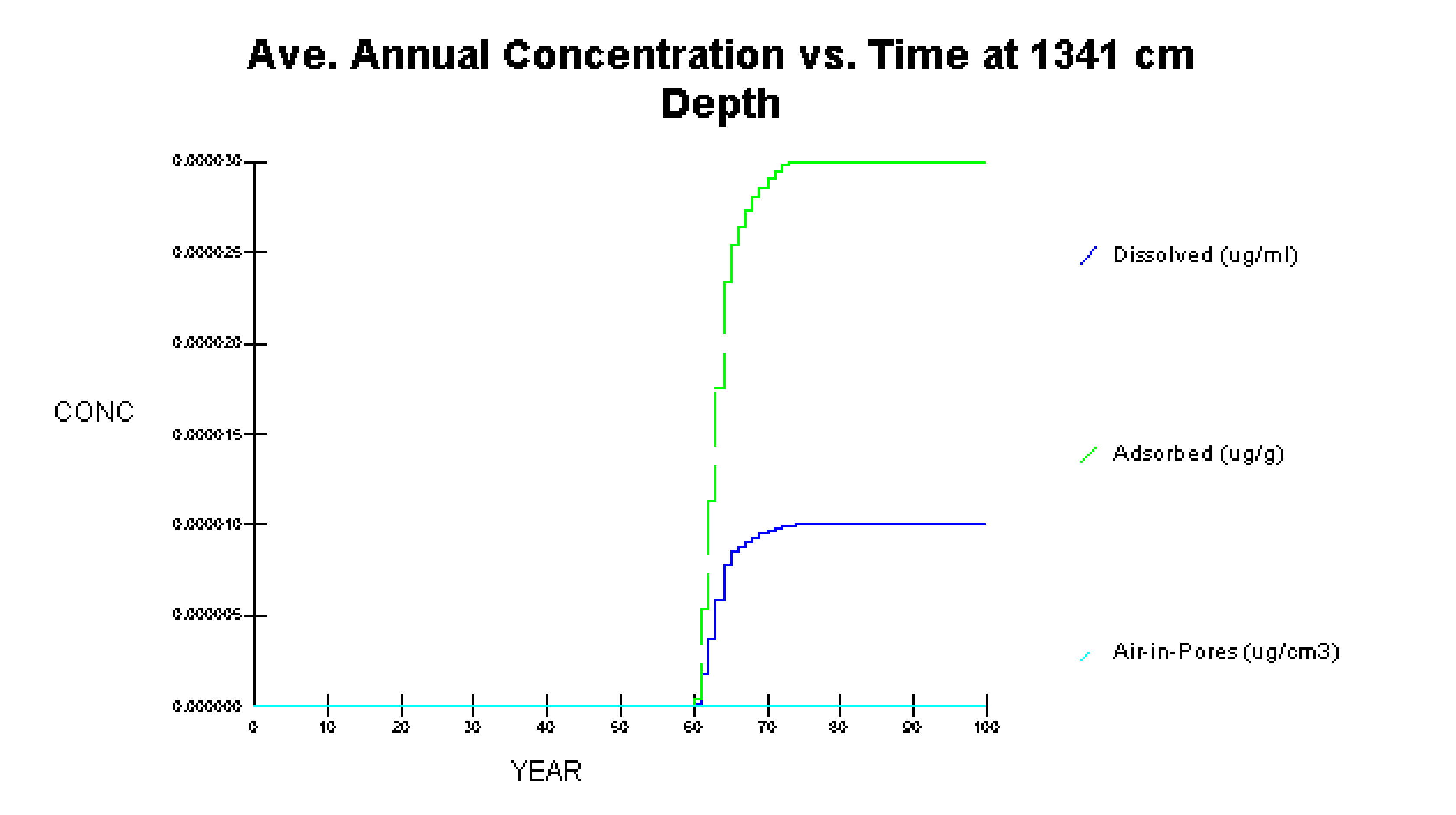
MAXIMUM CONCENTRATION OF COCS REACHING GROUNDWATER

COCs	Maximum Concentration (ug\L)	MMR – PRG (ug\L)
Boron	10	328
4-methylphenol	1.6E-11	18.2
Benzene	1.4E-10	0.4
Hexachlorobenzene	1.4E-11	0.04

BORON RESULTS



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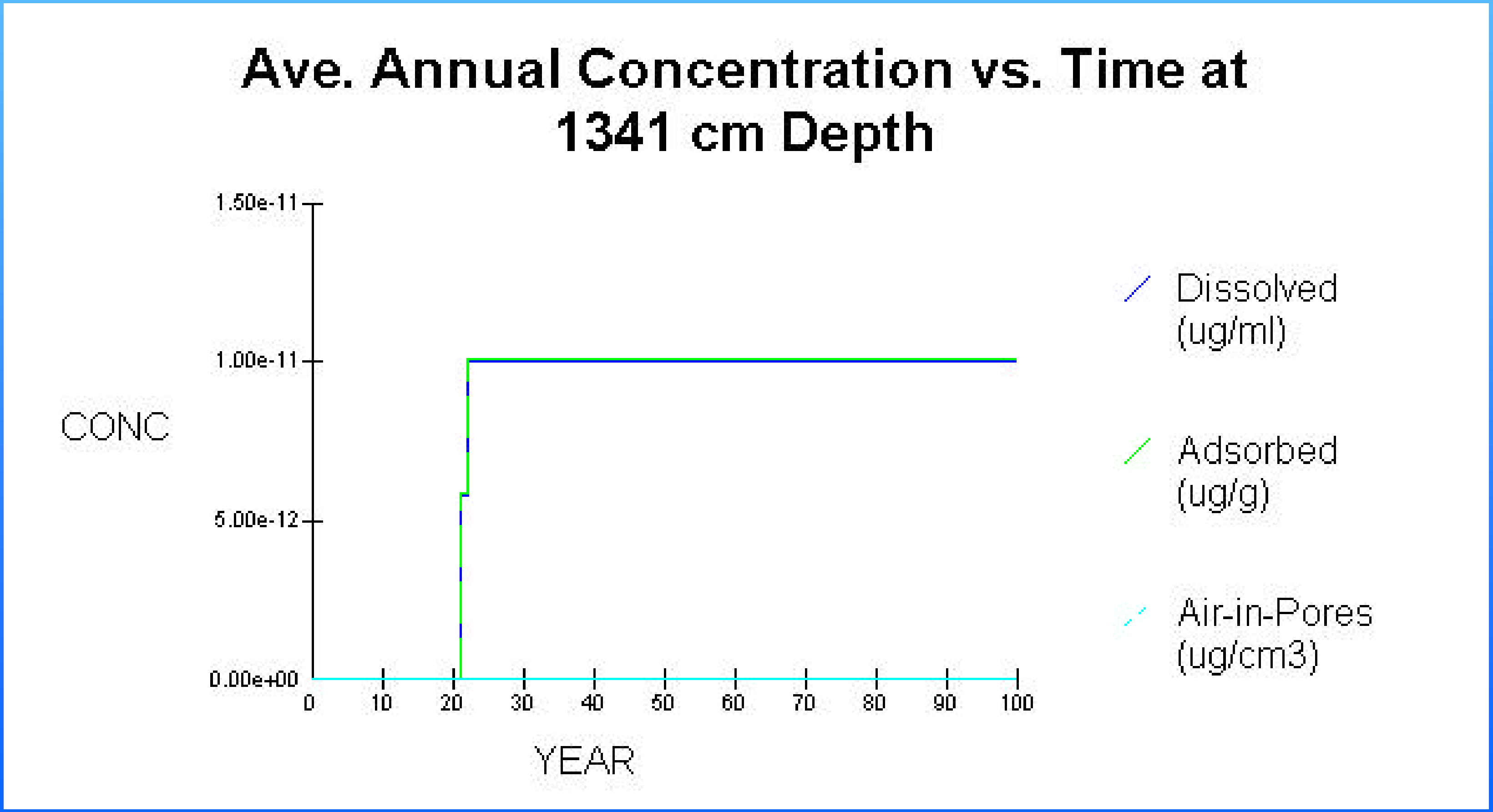
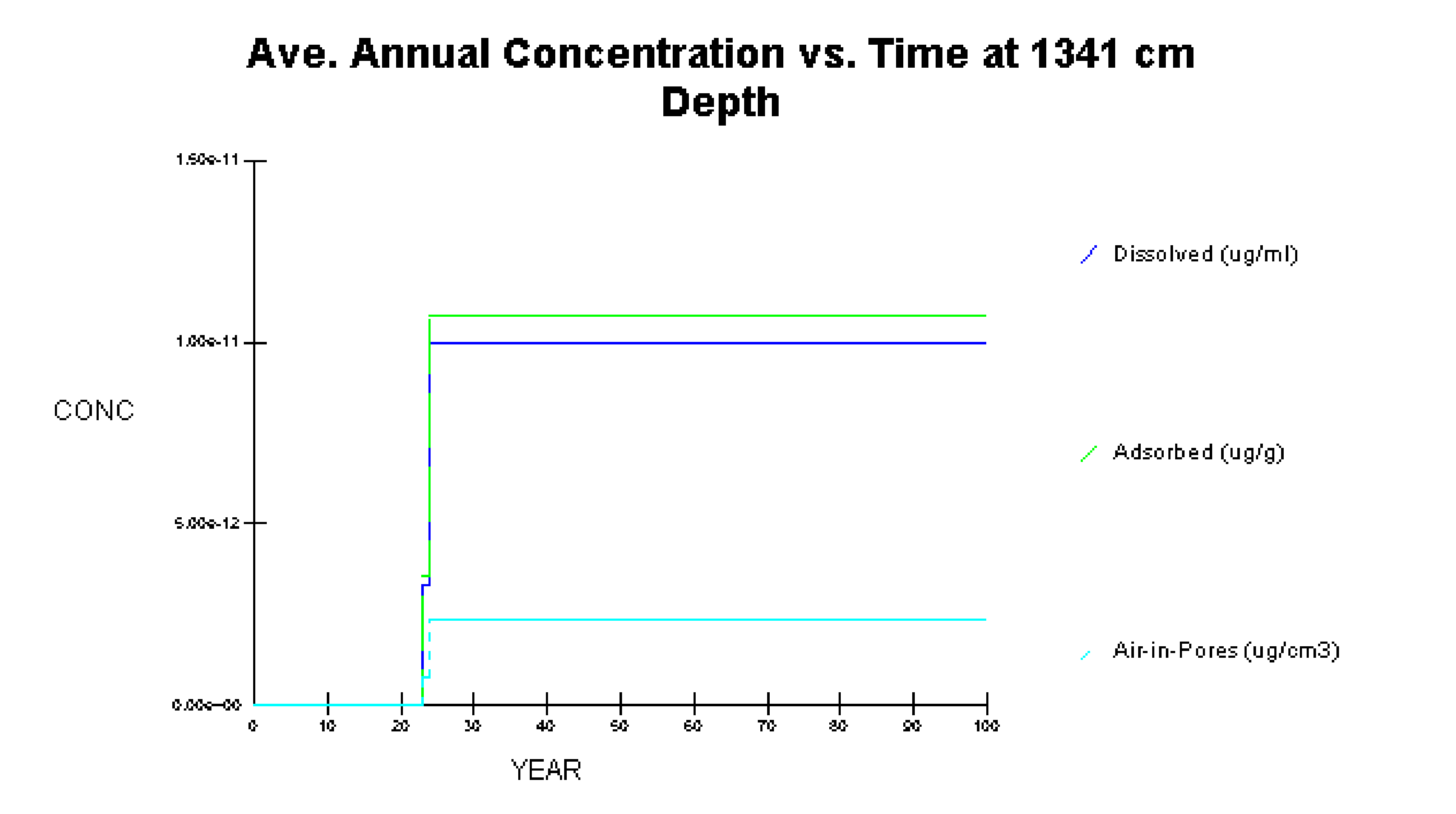
4-METHYLPHENOL RESULTS



BENZENE RESULTS



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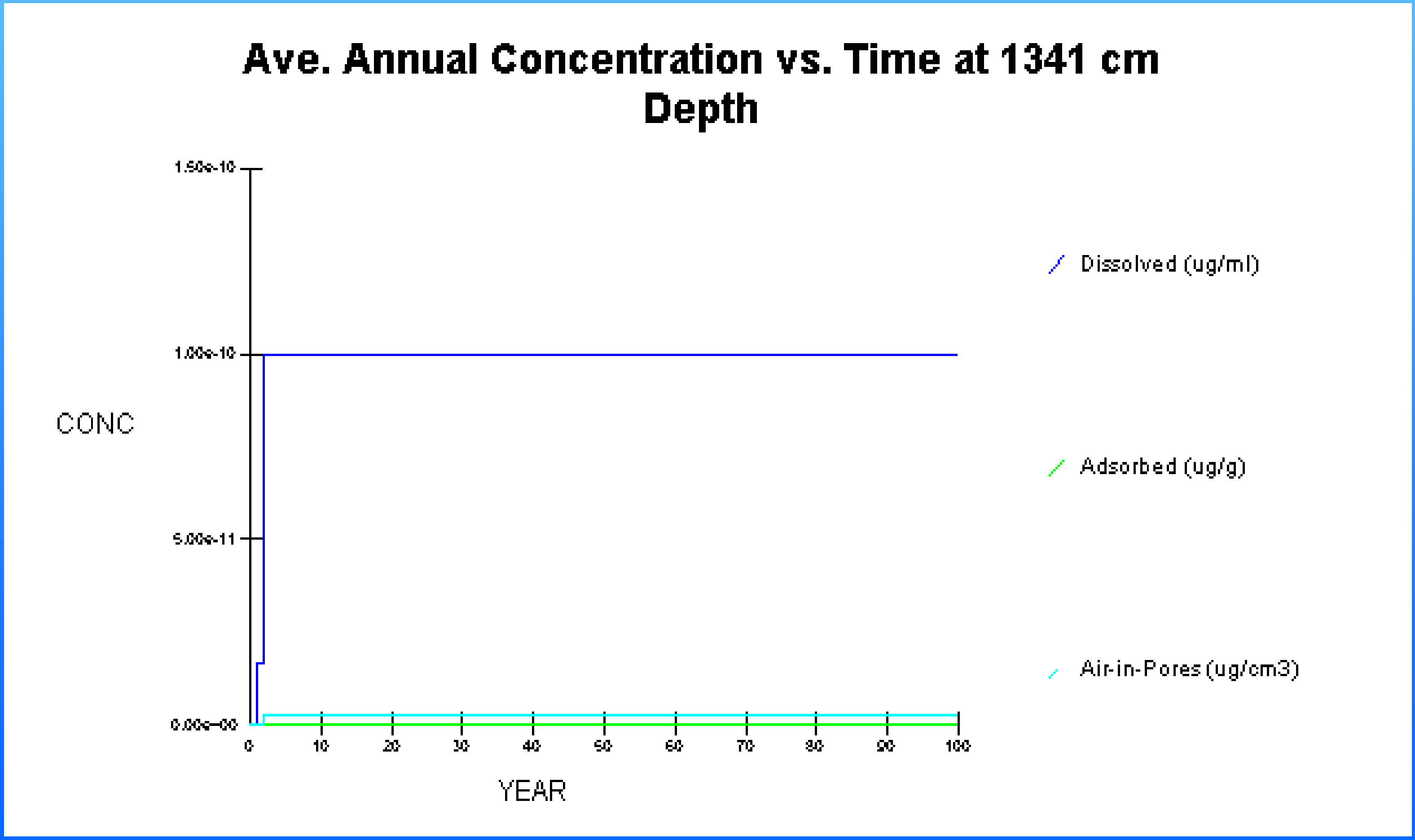
HEXACHLOROBENZENE RESULTS



CONCLUSIONS

- Model simulations of the COCs with SESOIL agree with known F&T properties.
- Model simulation results agree with Demo 1 groundwater data (Boron, 4-Methylphenol, Benzene, Hexachlorobenzene = ND).
- Preliminary model simulations indicate 2A-DNT, 4A-DNT, and 2,4-DNT, HMX, RDX, TNT have potential to reach groundwater.

GUN & MORTAR UNSATURATED ZONE MODELING RESULTS

MODEL CONFIGURATION

- Initial setup was based on Demo 1, i.e. conservative approach.
- G&M positions consist of 38 separate locations
- If a COC was identified reaching groundwater then a second simulation was conducted using site-specific information

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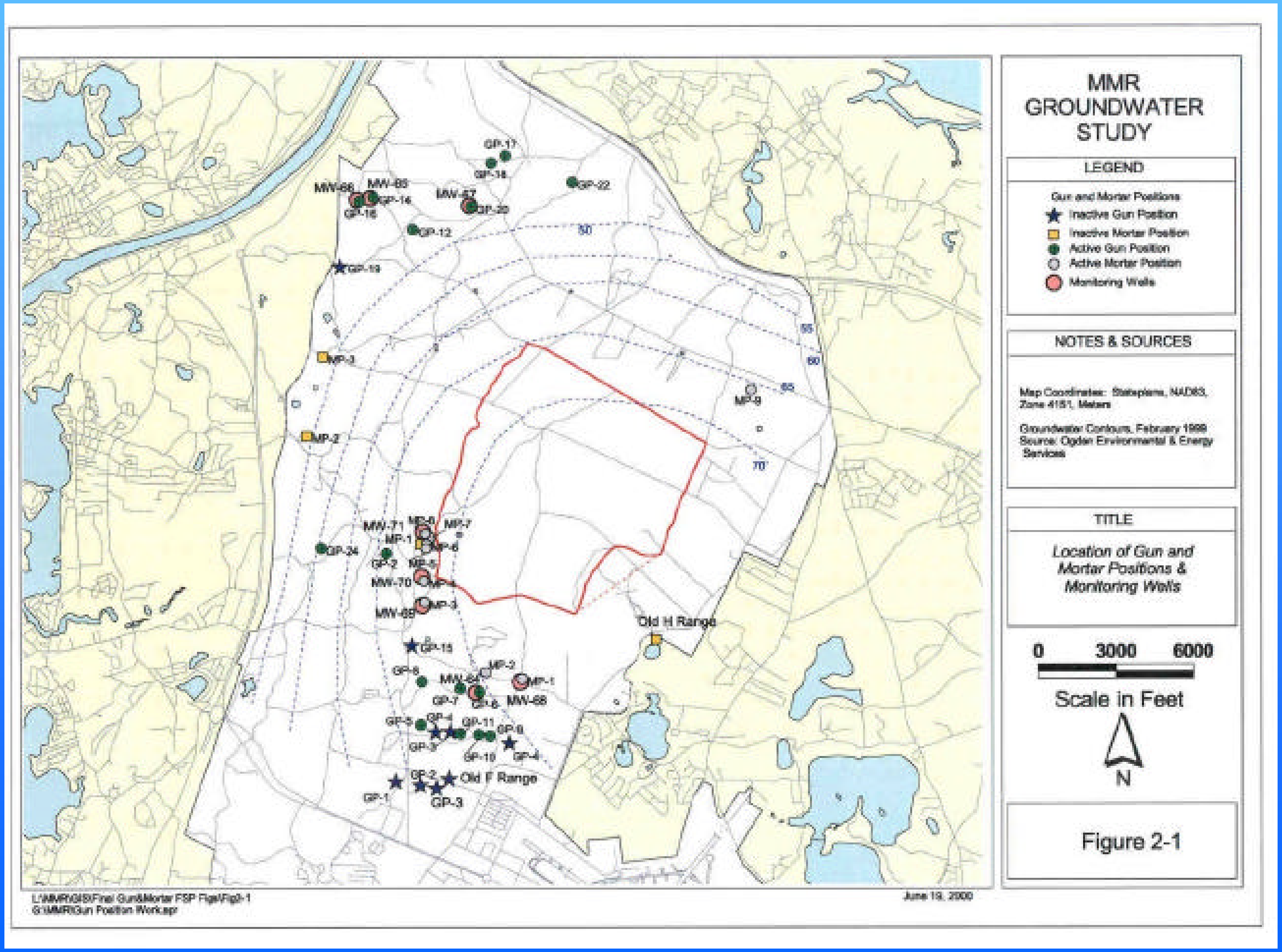
GUN & MORTAR LOCATIONS



GENERAL MODEL CONSTRUCTION

- Depth of Soil Contamination = 0 to 1 ft
- Area of Soil Contamination = 2 acres
- Depth to the Water Table = 115 ft
- Maximum Contaminant Level for any G&M Position was Used
- Model calibration targets same as Demo 1

SPECIFIC SITE PARAMETERS

- Bulk Density = 1.123 g/mL
- Effective Porosity = 0.547
- Organic Carbon Content = 3.32 percent
- Moisture Content = 14.73 percent
- Number of Soil Layers = 4
- Number of Soil Sublayers = 10

G&M SOIL COCS MODELED

- Antimony
- Arsenic
- Barium
- Boron
- Cadmium
- Copper
- Chromium
- Iron
- Lead
- Manganese
- Mercury
- Molybdenum
- Phosphorus

- 2-Methylnapthalene
- Acenanapthylene
- Benzo(a)anthracene
- Benzo(a)pyrene
- Benzo(b)fluoranthene
- Benzo(b)fluoranthene
- Carbazole
- Dibenz(a,h)anthracene
- Dibenzofuran
- Napthalene
- Pyrene
- Chrysene
- Ideno(1,2,3-c,d) pyrene

- Alpha BHC
- Alpha Chlordane
- Beta BHC
- DDT
- Dieldrin
- Gamma Chlordane
- MCPP
- PCB-1254
- PCB-1260
- PCP

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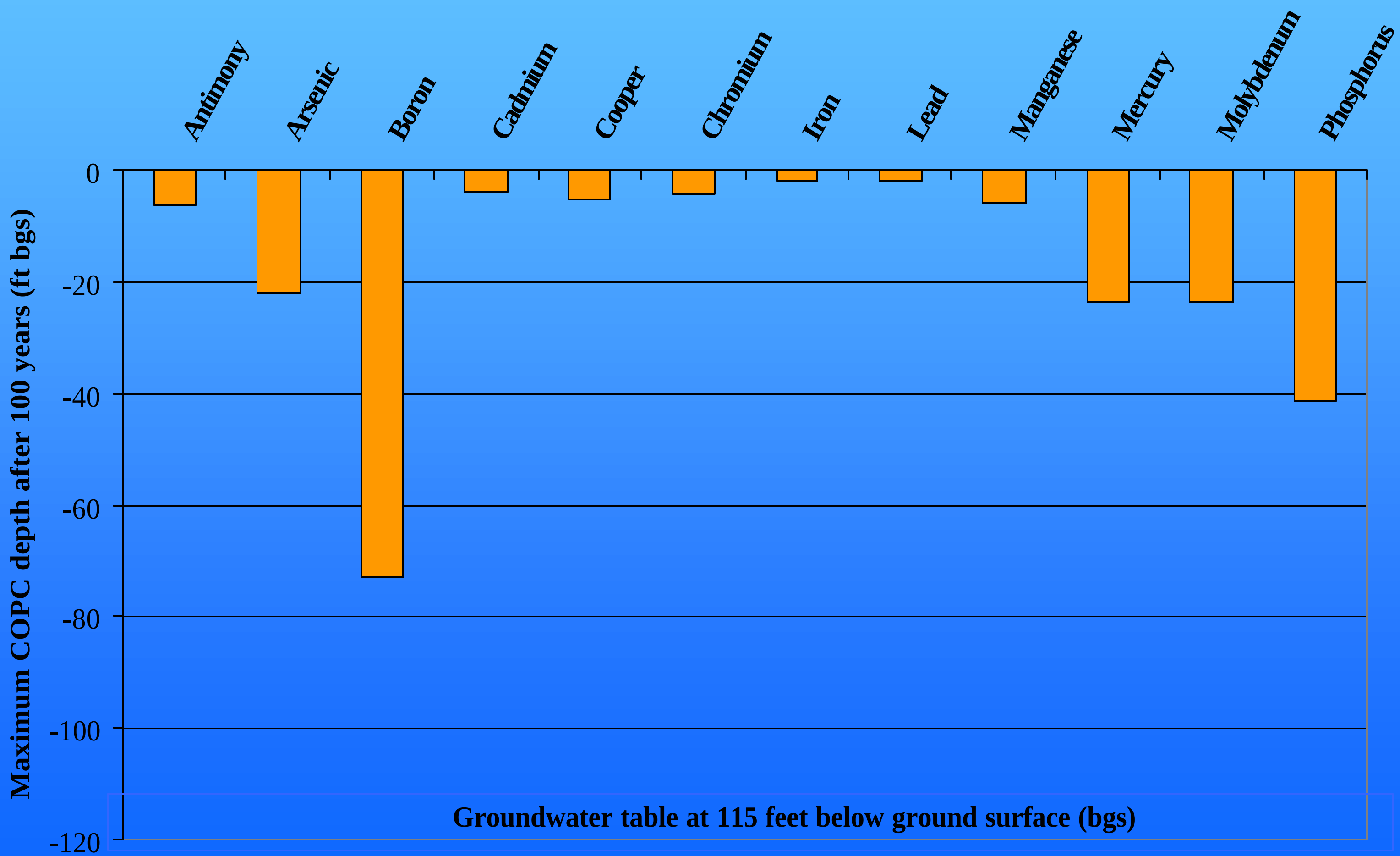
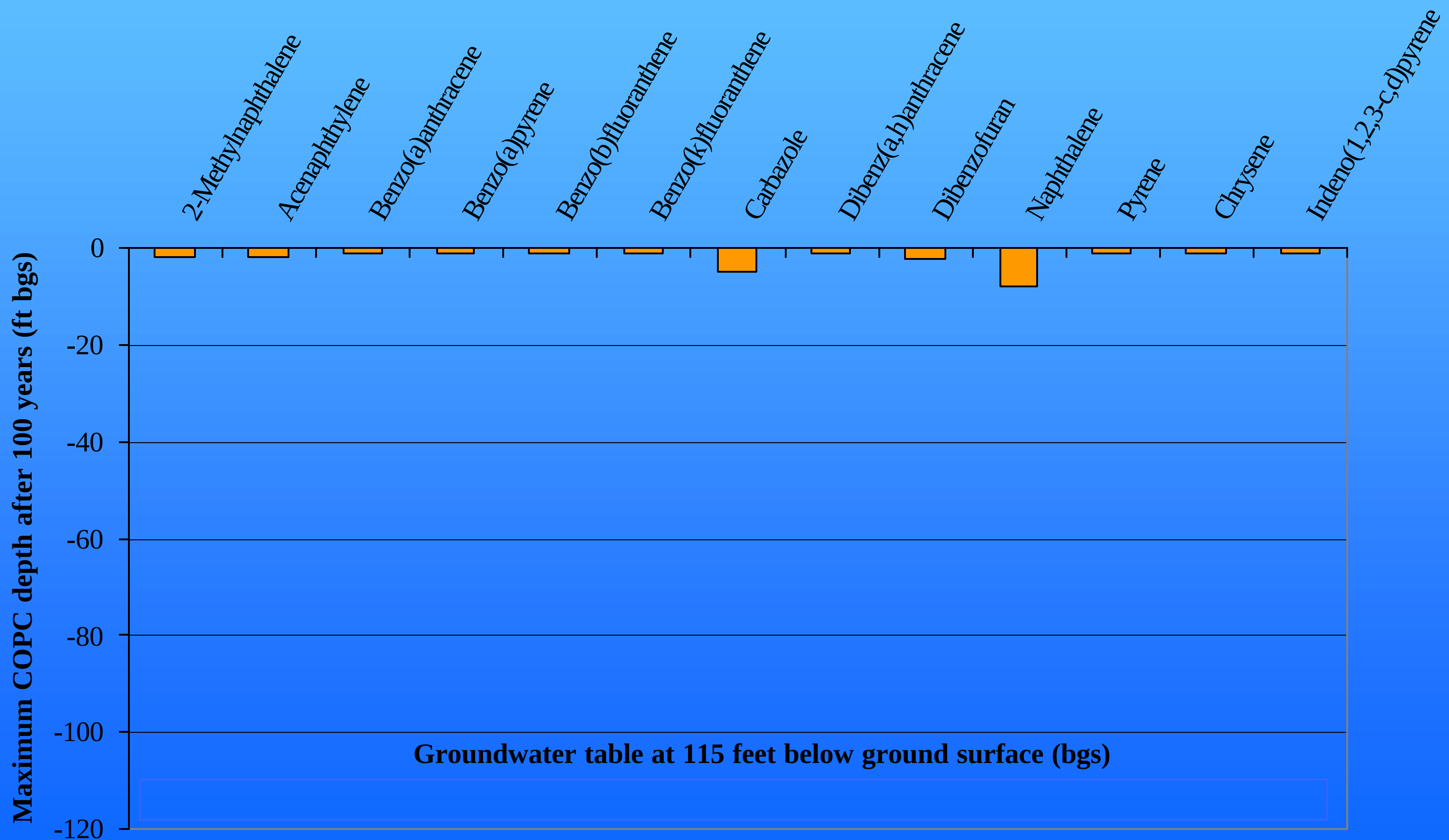
METAL COC RESULTS



PROPELLANT COC RESULTS

PAH COC RESULTS



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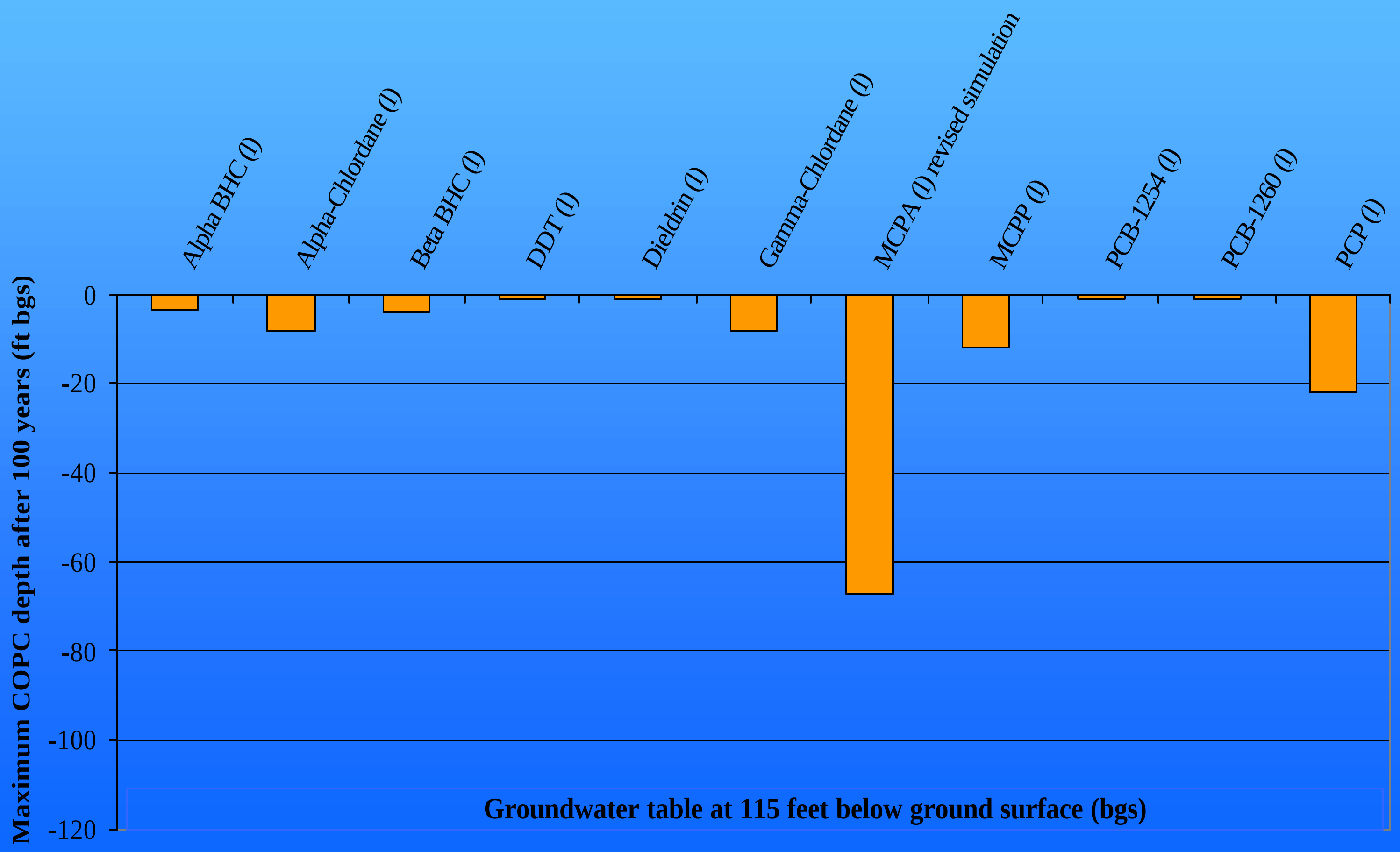
PESTICIDE/HERBICIDE COC RESULTS



CONCLUSIONS

- Model simulations did not identify any groundwater COCs.
- Model simulation results agree with known F&T properties.
- Model simulation results agree with G&M groundwater data
- Model simulation results agree with previous CHPMM conclusions at CS-18 (GP-9)

DEMO 1 PRELIMINARY SATURATED ZONE FATE AND TRANSPORT MODELING RESULTS

Tod Monks, AMEC

SATURATED ZONE MODELING OUTLINE

- INTRODUCTION
- DEMO 1 SATURATED ZONE MODELING OBJECTIVES
- DEMO 1 SITE CONCEPTUAL MODEL
- DEMO 1 PRELIMINARY MODEL ASSUMPTIONS
- DEMO 1 PRELIMINARY FLOW MODEL
- DEMO 1 MODPATH RESULTS
- PHASE II OBJECTIVES
- DISCUSSION

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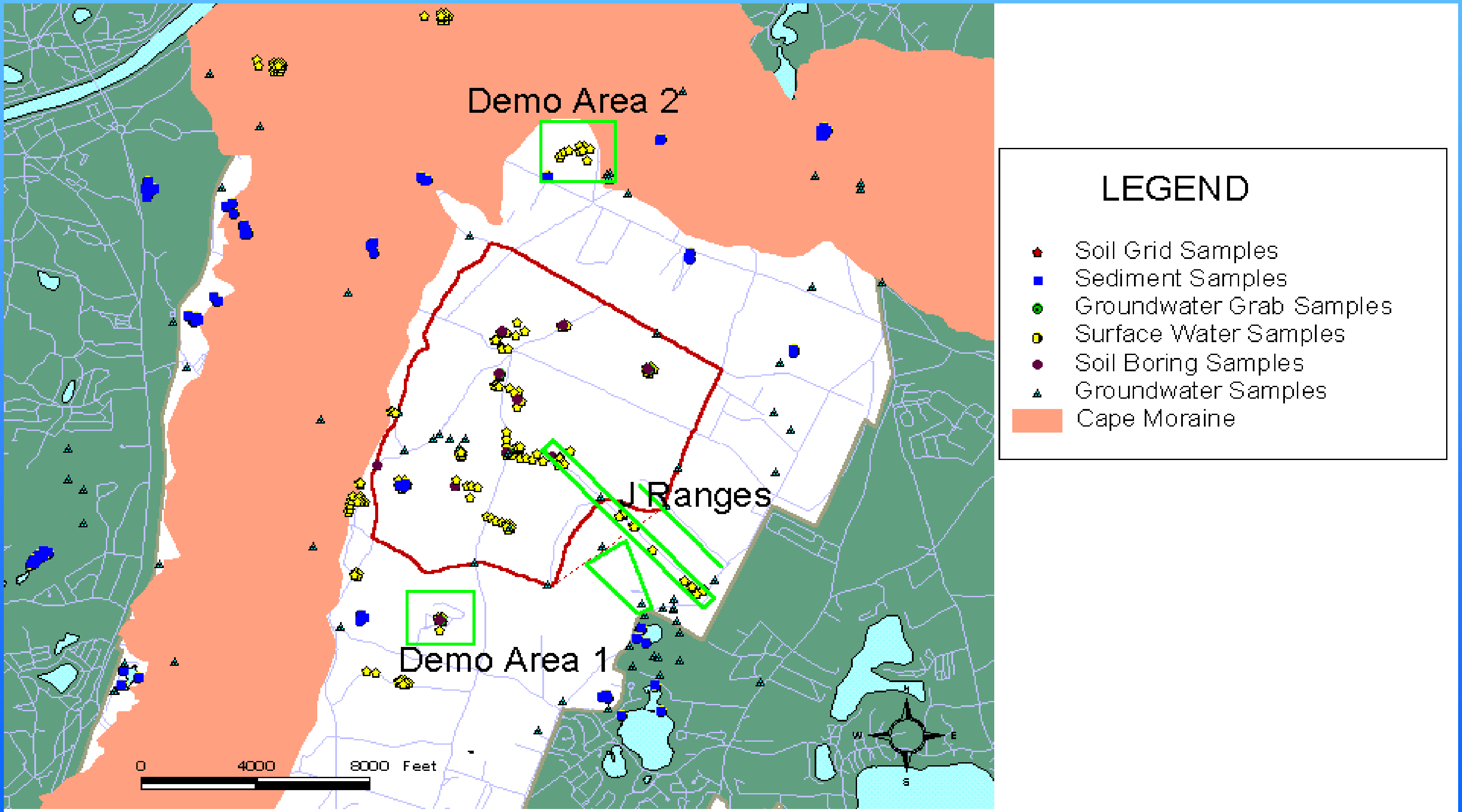
LOCATION MAP



MODELING OBJECTIVES

- Primary Objectives

  - Develop preliminary groundwater flow and contaminant transport model(s) for Demo 1 using the GMS version of MODFLOW and MT3D to effectively simulate present and future contaminant distributions.

  - Include appropriate present or planned water supply wells in the model(s) to assess potential impacts on groundwater flow and contaminant transport at Demo 1 and down-gradient of Demo 1.

MODELING OBJECTIVES

- Related Tasks

  - Conduct sensitivity analysis to quantify the uncertainty in calibrated model(s) caused by uncertainty in the estimates of aquifer parameters and transport parameters.

  - Document Demo 1 modeling approach, results, and conclusions.

SATURATED ZONE MODELING SITE CONCEPTUAL MODEL

- Hydrogeologic Setting
- Present Extent of Contamination

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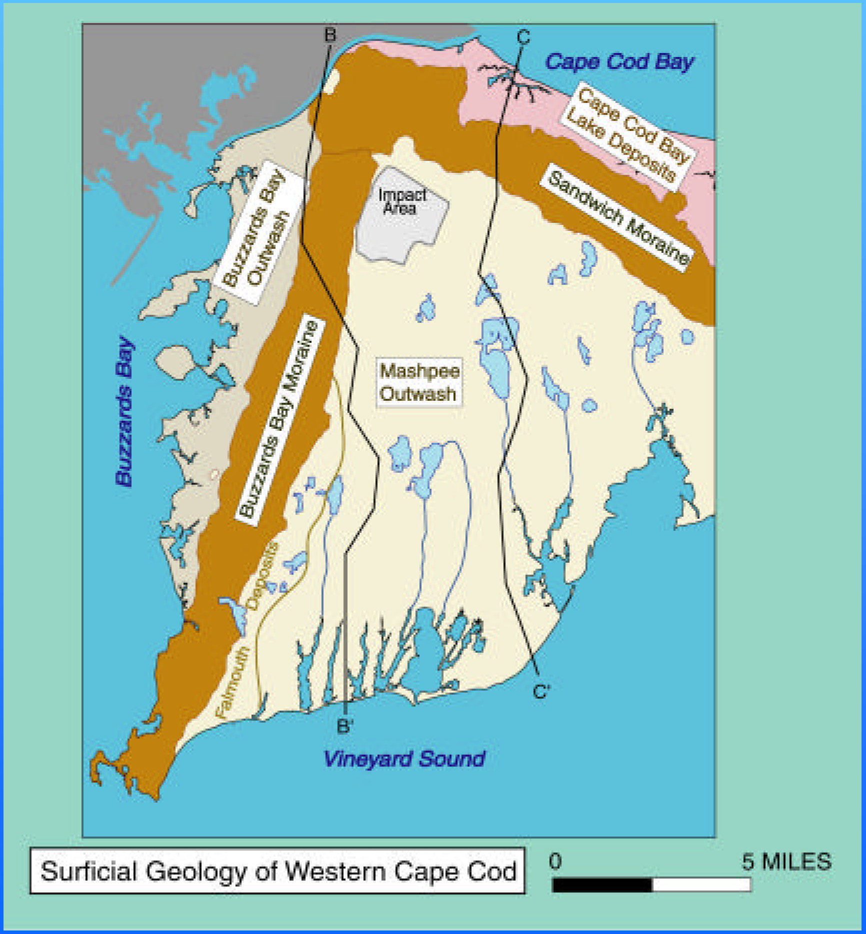
SURFICIAL GEOLOGY



SATURATED ZONE MODELING PRELIMINARY ASSUMPTIONS

- Model Extent and Boundary Conditions
- Steady State versus Transient Flow Model
- Model Discretization
- Model Calibration
- Parameter Selection/Range

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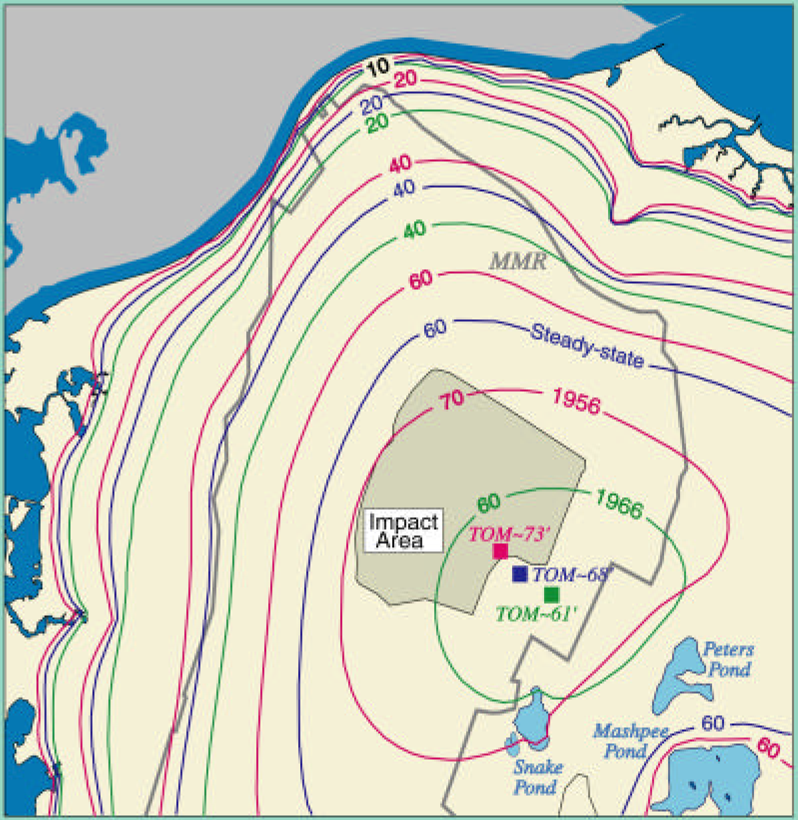
TRANSIENT/STEADY-STATE HEADS

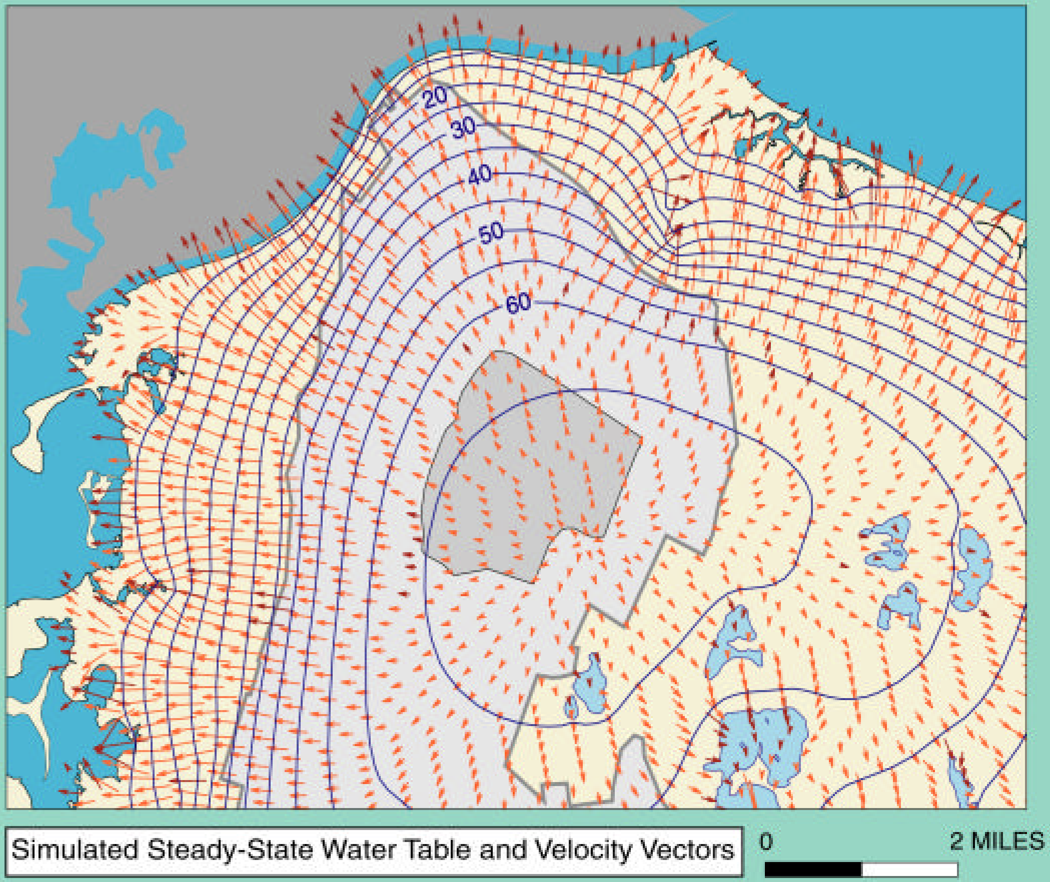


Water Levels for High (1956), Low (1966), and Steady-State Conditions

0 1 MILE

(USGS Presentation)

VECTOR MAP



Simulated Steady-State Water Table and Velocity Vectors

(USGS Presentation)

SATURATED ZONE MODELING PRELIMINARY GW FLOW MODEL

- Comparison With USGS Regional Groundwater Flow Model
- Discrepancy

DEMO 1 SATURATED ZONE MODELING PARTICLE TRACK ANALYSIS

- Comparison with USGS Results

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MODEL COMPARISON

Particle-Tracking Results for 1993, 1998, and 2000 Regional Models

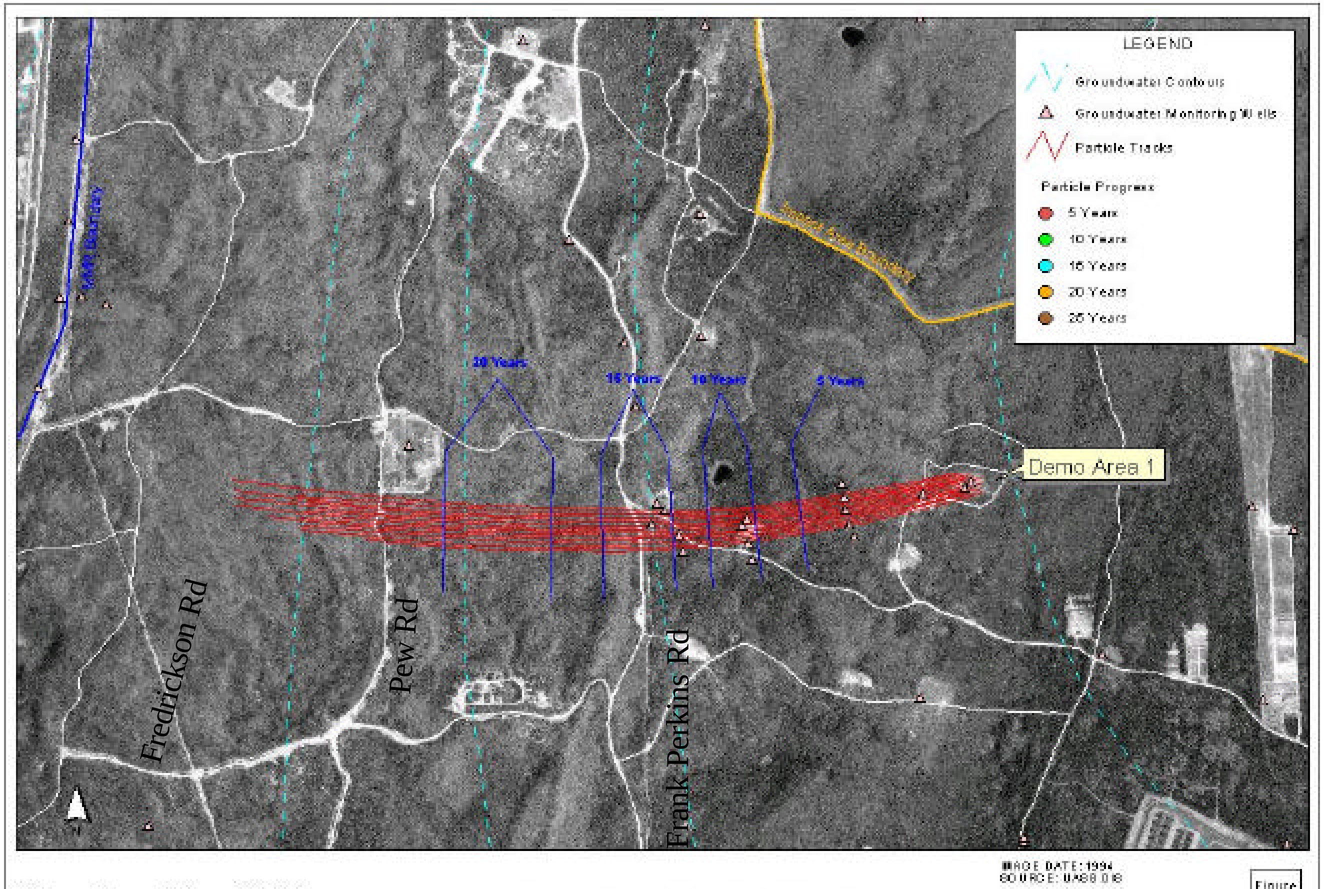
0 2 MILES

USGS Presentation)

PHASE II OBJECTIVES

- Calibrate Contaminant Transport Model to Present Steady State Conditions for RDX and Other COCs as Required.
- Identify Present Impacts on Groundwater Flow and Contaminant Transport Due to Water Supply Wells.
- Conduct Sensitivity Analysis

DEMO 1 PARTICLE TRACKS



Demo Area 1 Particle Tracks

Source: Jacobs Engineering

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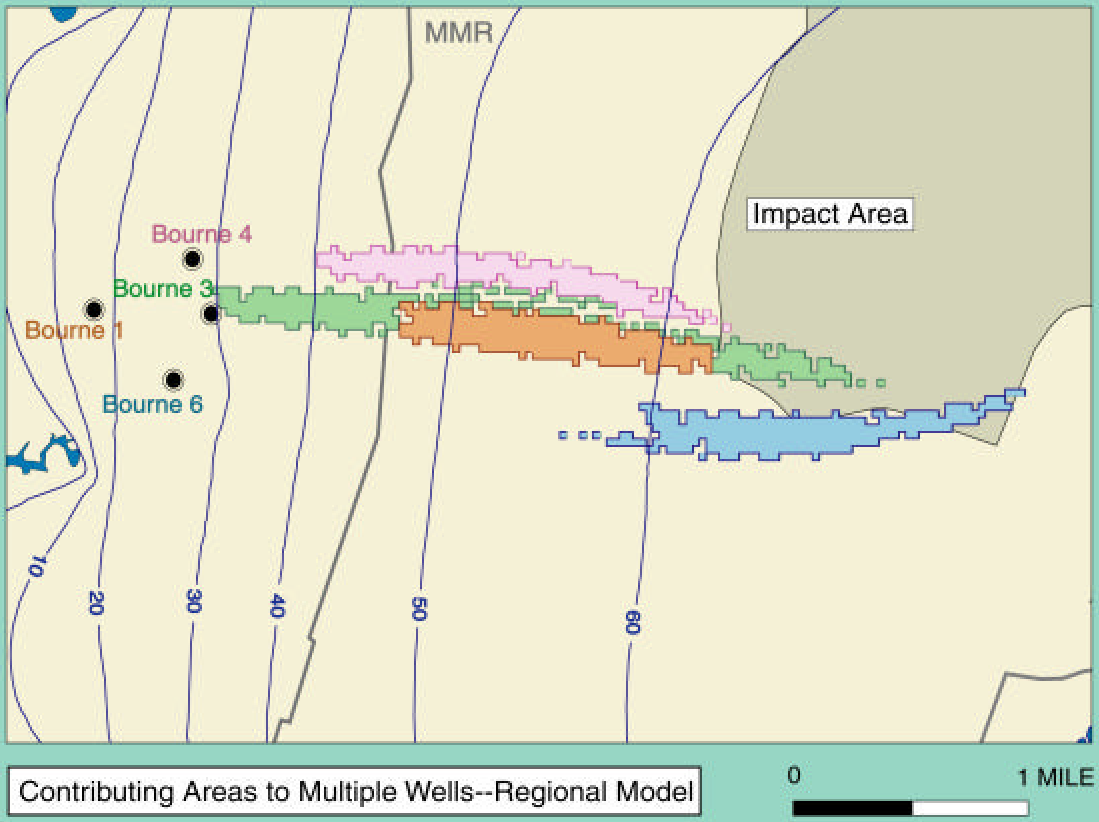
BOURNE ZOC—REGIONAL



USGS Presentation)

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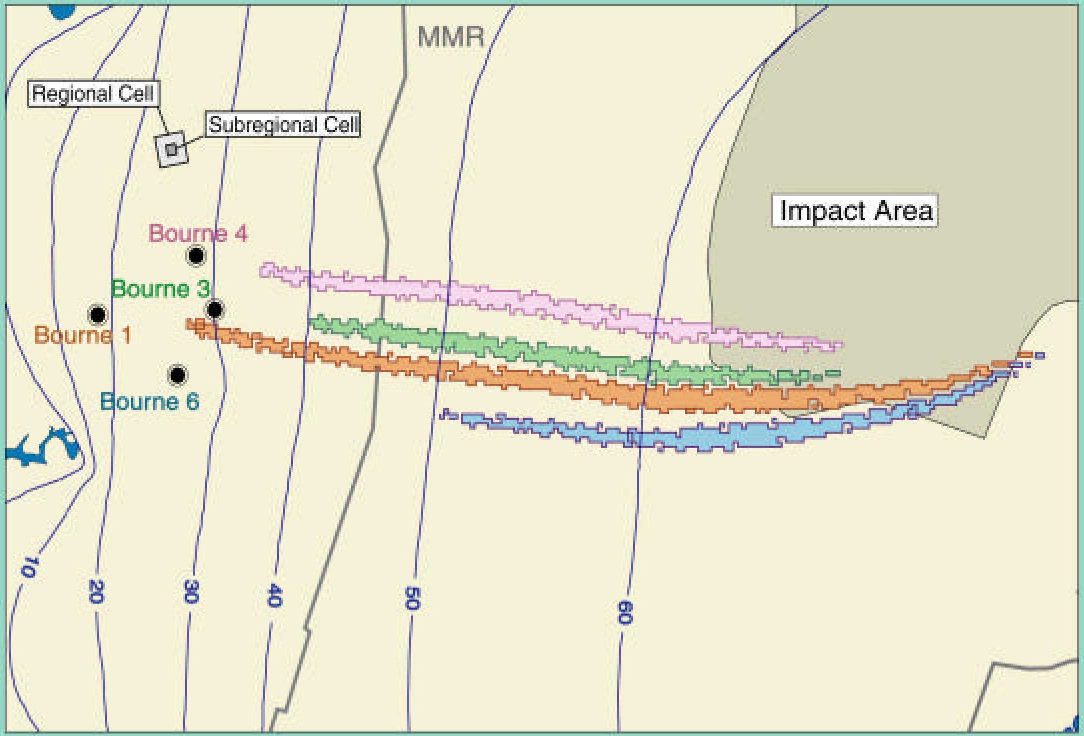
BOURNE ZOC--SUBREGIONAL



Contributing Areas for Multiple Wells--Subregional Model

USGS Presentation)

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CENTRAL IMPACT AREA SATURATED ZONE MODEL PLAN

Jay Clausen, AMEC

CENTRAL IMPACT AREA OBJECTIVES

- Predict Movement and Fate for those COCs Reaching the Aquifer
- Utilize Model for Assessing Remedial Options
- Utilize Model for Engineering Design

MAJOR MODELING STEPS

- Development of Sub-Regional Model
- Calibration of Sub-Regional Model
  - Ground Water Flow
  - Fate and Transport (HMX and RDX)
- Sensitivity Analysis
- Model Predictions

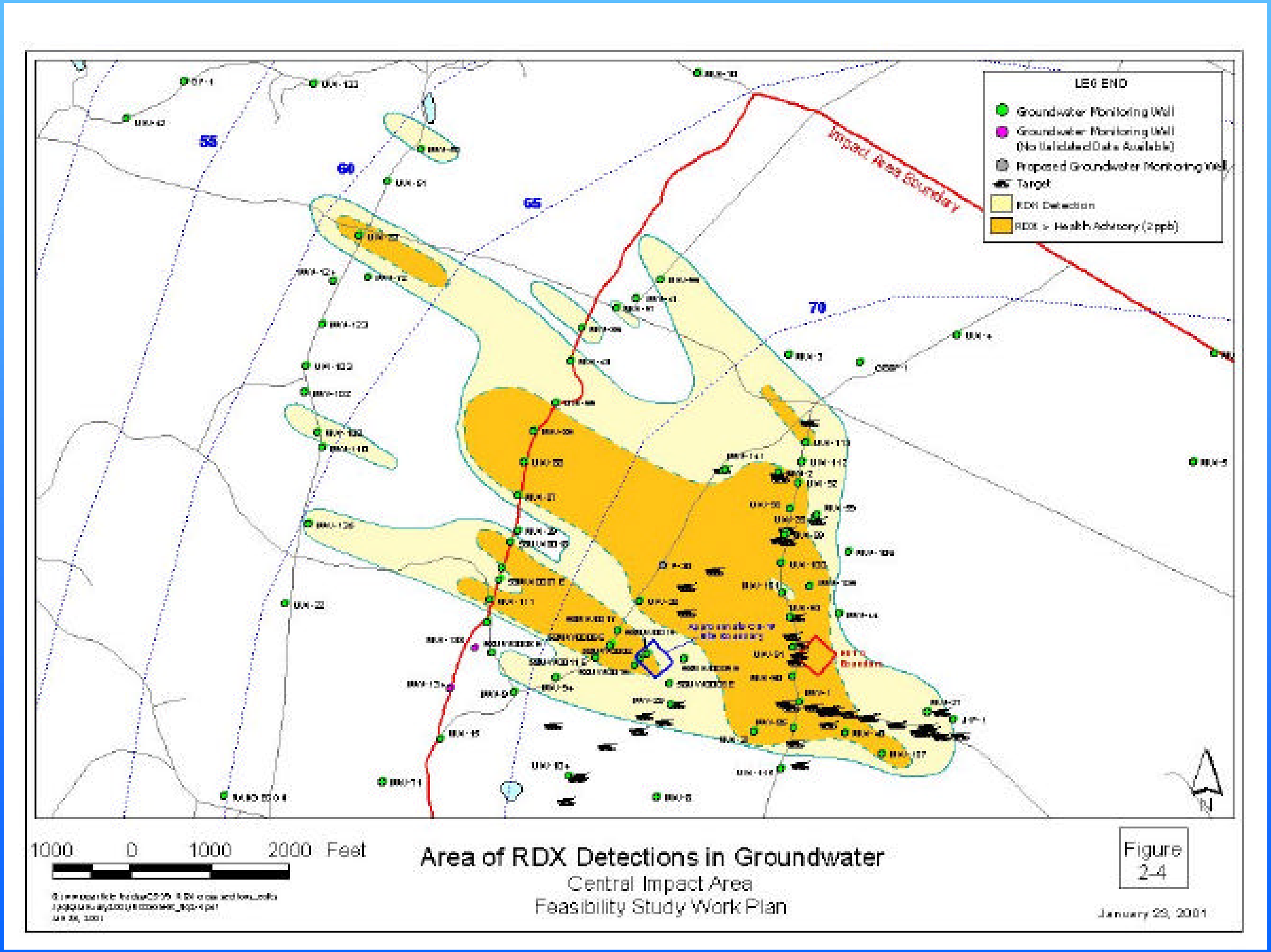
MODEL SPECIFICS

- The Central Impact Area is Northwest of Mound
- Horizontal Gradients Predominate
- Flow Direction and Gradients Insensitive to Seasonal Fluctuations in Precipitation and Aquifer Recharge
- Model Domain size will be a Function of Identifying the Source Location(s)
- Impacts to Existing Extraction Systems

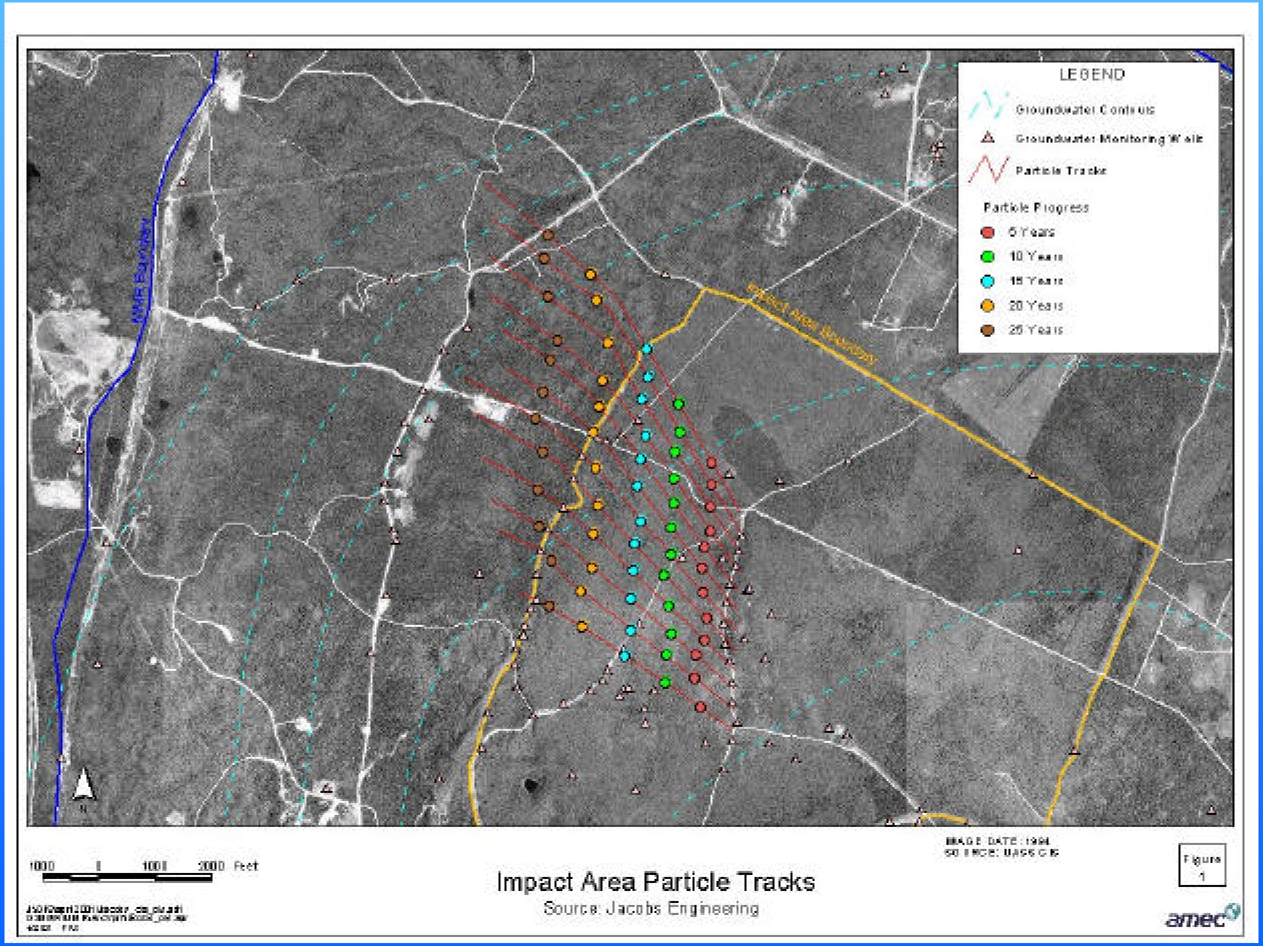
MODEL DISCRETIZATION

- Interpreted/Identified Source Areas
- Maximum Observed /Predicted Penetration depth of COCs
- Interpreted/Expected Thickness of the Contaminant Plume(s)
- Interpreted/Expected Width of the Contaminant Plume(s)
- Interpreted/Expected Preferential Direction of the Contaminant Plume(s) Migration
- Characteristic Peclet Number for the Sub-regional Fate-and-Transport Model

RDX EXTENT


LEGEND
Groundwater Monitoring Well
Groundwater Monitoring Well (No Validated Data Available)
Proposed Groundwater Monitoring Well
Target
RDX Detection
RDX > Health Advisory (2 ppb)
Impact Area Boundary
55
60
65
70
N
1000 0 1000 2000 Feet
Area of RDX Detections in Groundwater
Central Impact Area
Feasibility Study Work Plan
Figure 2-4
January 23, 2001

RATE OF GROUNDWATER MOVEMENT



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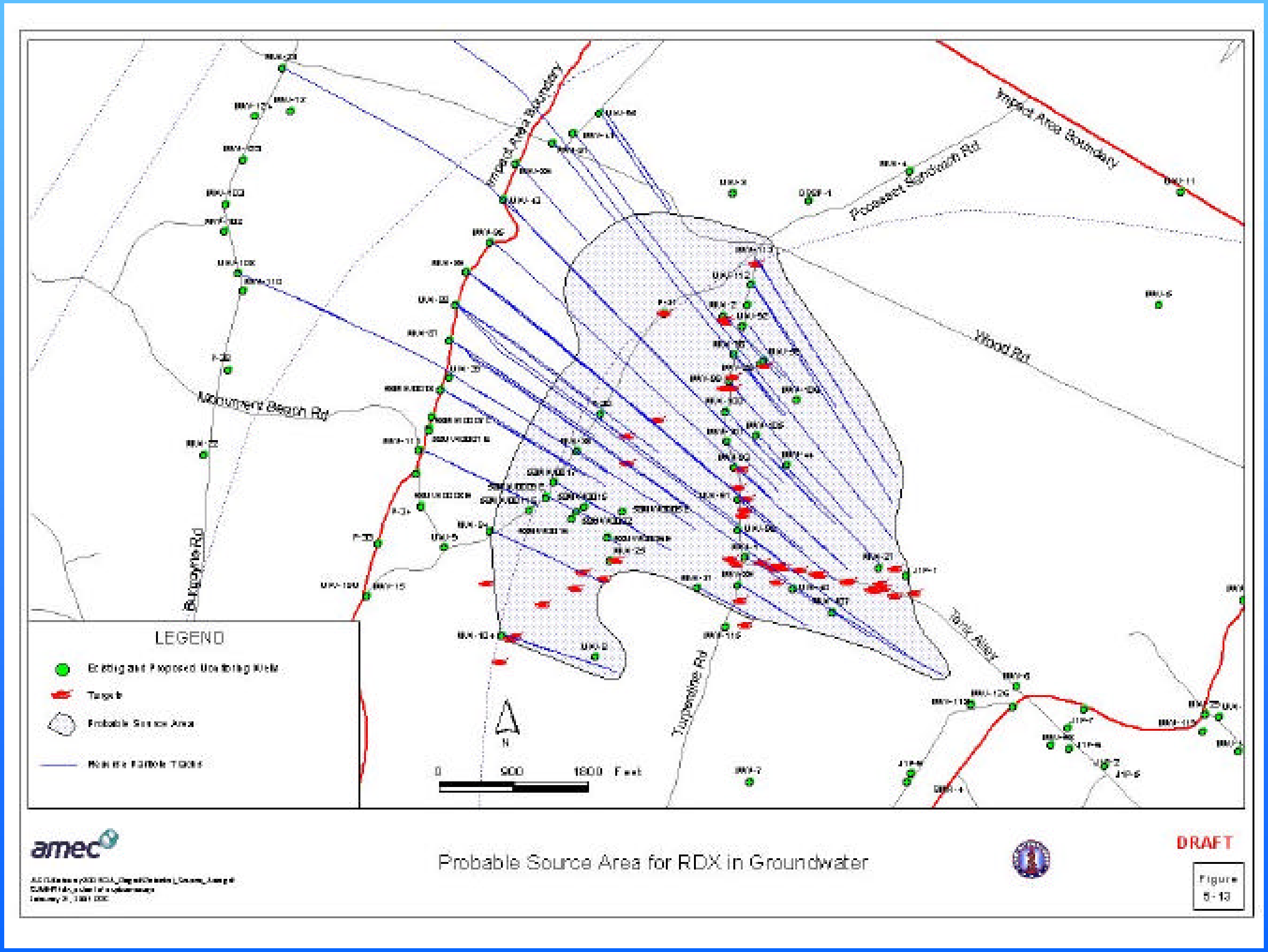
SOURCE AREA



SCHEDULE

- Central Impact Area: Saturated Zone F&T Modeling in 06/14/01 Central Impact Area Groundwater FS Screening Report
- Central Impact Area: Unsaturated Zone Modeling of COCs in 07/17/01 Central Impact Area Soil Report
- Preliminary FS Assessment of remedial option in Central Impact Area Groundwater PSI Workplan 10/10/01
- Development of Soil PRGs in Central Impact Area FS Screening Report 11/21/01
- Groundwater Engineering Design, TBD

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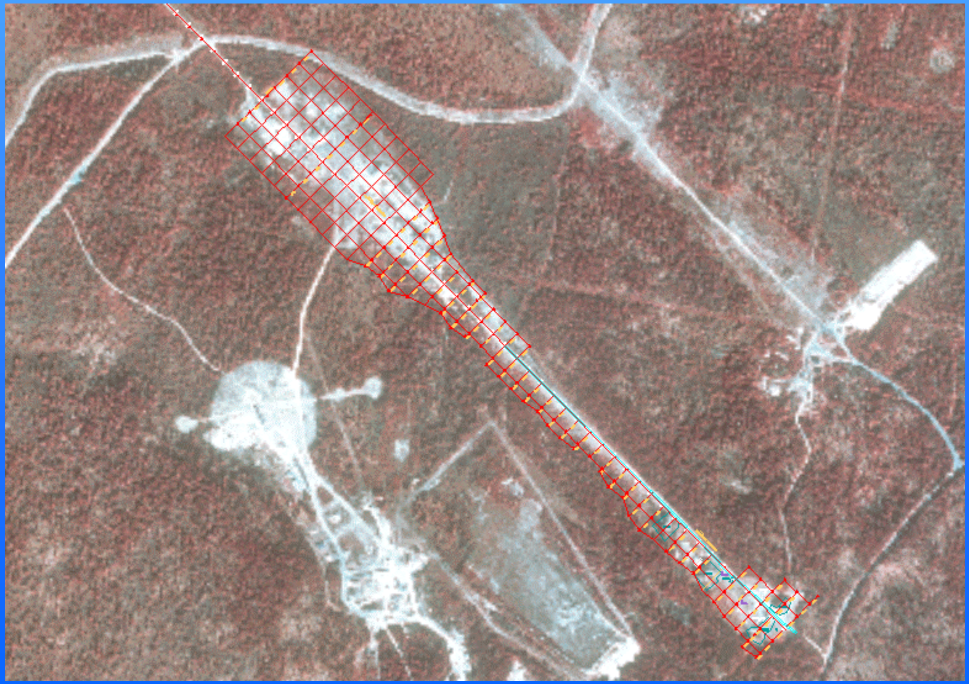
SATURATED ZONE F&T MODELING APPROACH FOR J RANGES

Jacob Zaidel, AMEC



MAJOR MODELING STEPS

- Development of Sub-Regional Model
- Calibration of Sub-Regional Model
  - Ground Water Flow
  - Fate and Transport (HMX and RDX)
- Sensitivity Analysis
- Model Predictions

DEVELOPMENT OF SUB-REGIONAL MODEL

- Specifics of J Ranges Area
- Model Extent
- Boundary Conditions
- Grid Refinement

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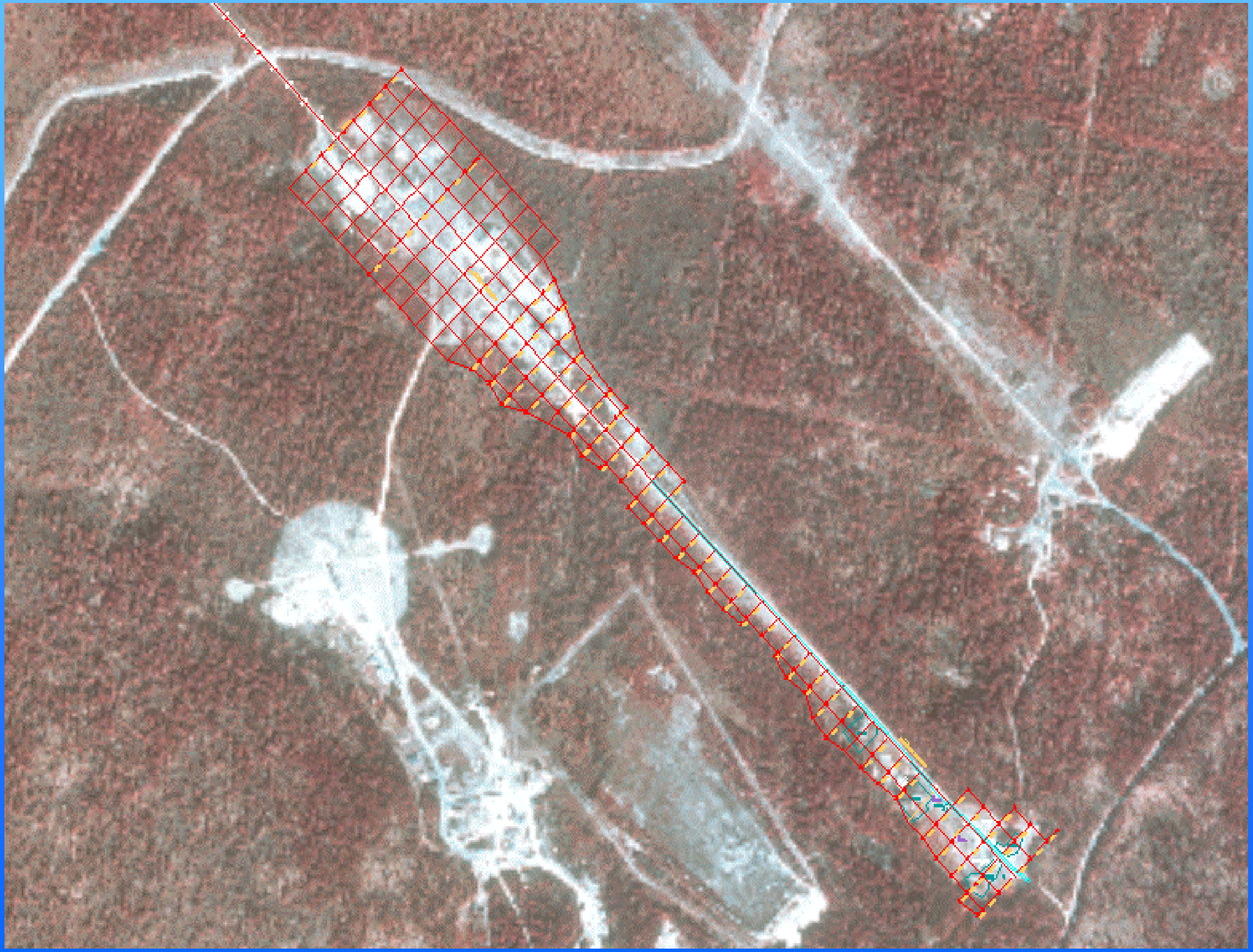
AERIAL PHOTO OF J RANGES



SPECIFICS OF J RANGES AREA

- Ground Water Mound
- Radial/Semi-Radial Flow
- Significant Vertical Flow Component
- Transient Effects
- Relatively high K zone
- Snake and Peters Ponds
- Existing Extraction System
- Proximity of MMR Boundary

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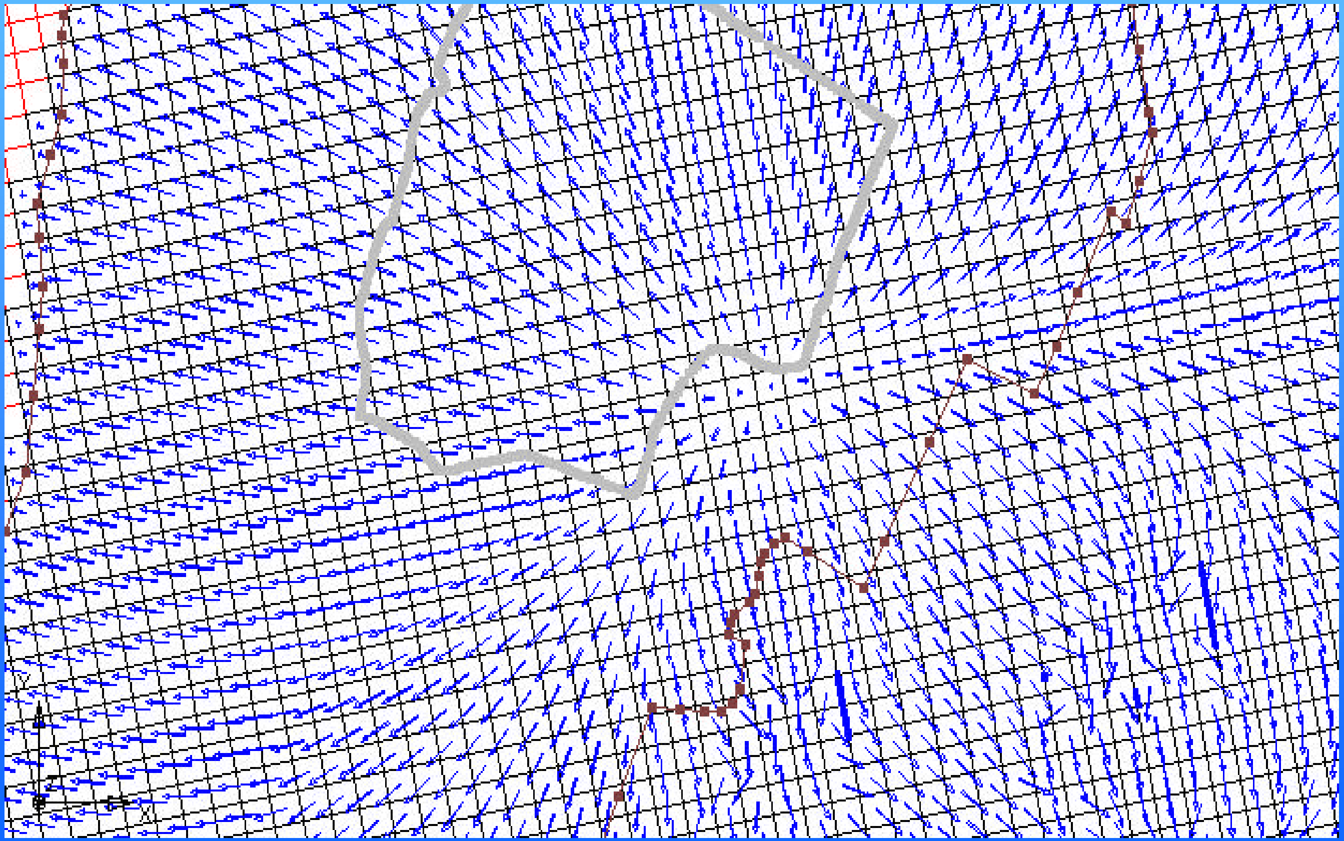
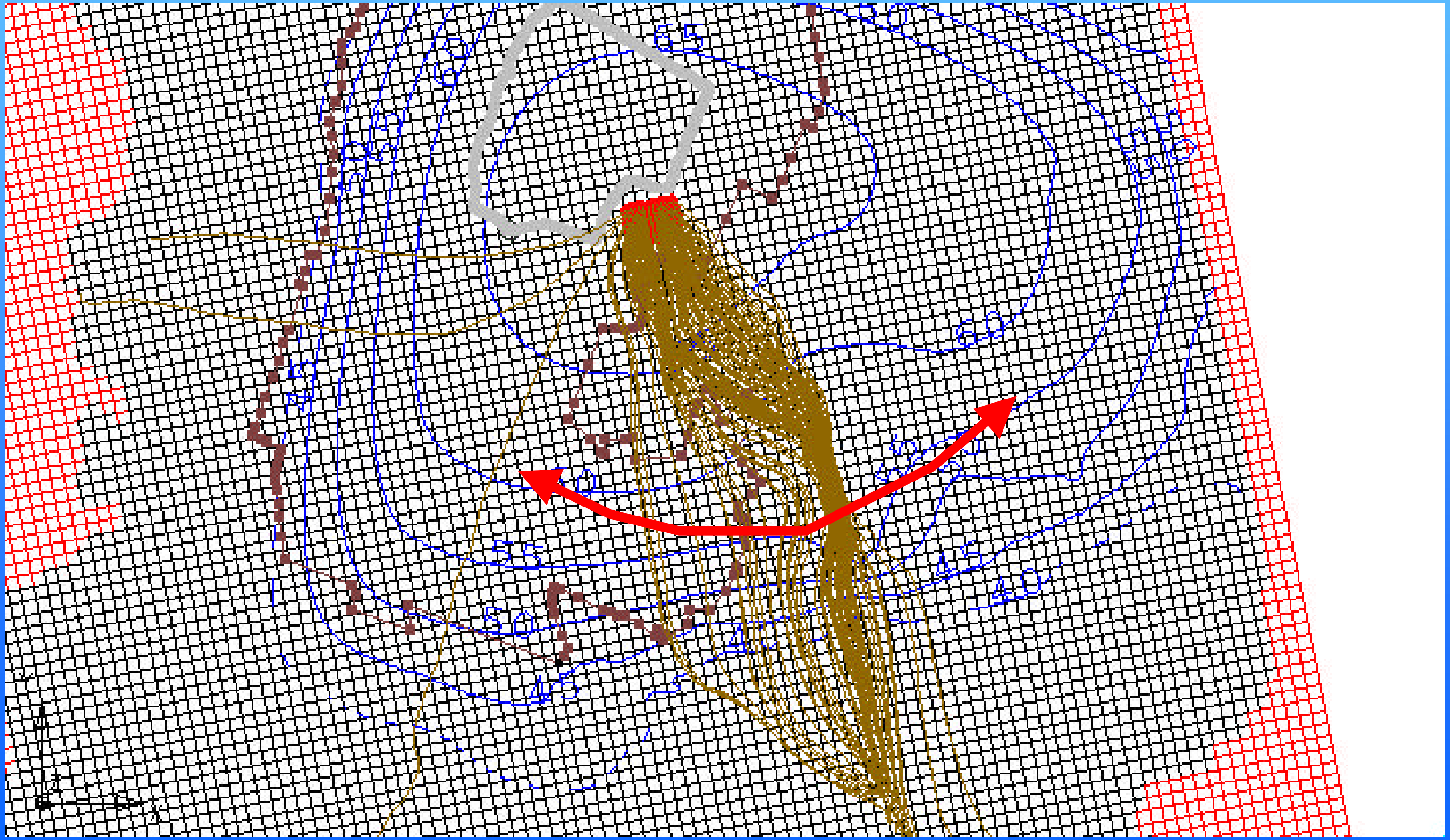
VARIATIONS IN FLOW DIRECTION IN J RANGES AND ADJACENT AREAS



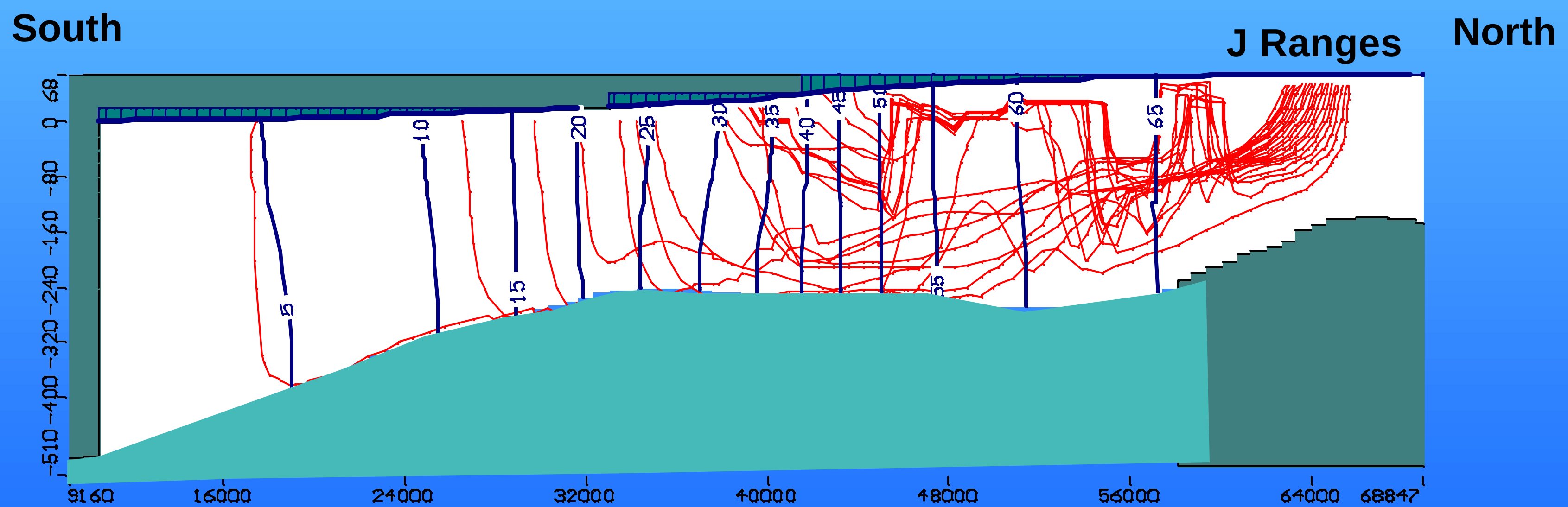
(Based on USGS Steady-State Regional Model)

VARIATIONS IN FLOW PATHS ORIGINATING FROM J RANGES



(Based on USGS Steady-State Regional Model)

PARTICLE TRACKS IN NORTH-SOUTH CROSS-SECTION



(Based on USGS Regional Steady-State Model)

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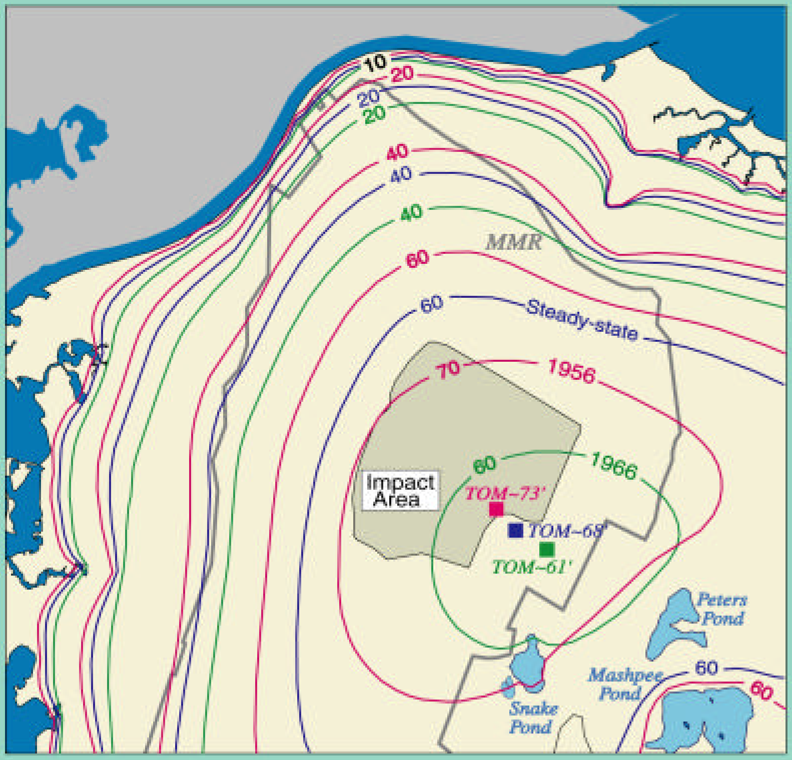
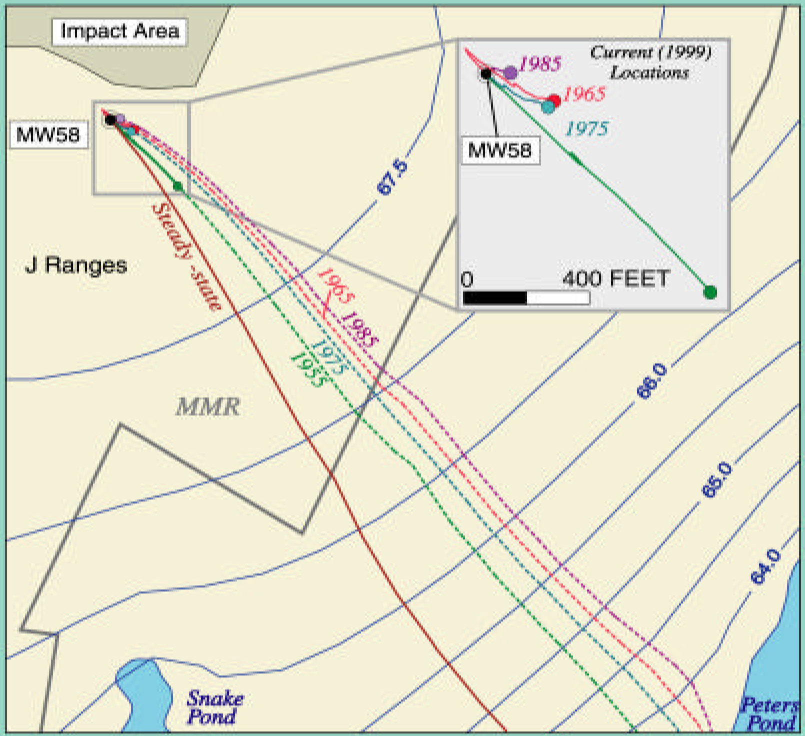
TRANSIENT HYDRAULIC HEADS



Water Levels for High (1956), Low (1966), and Steady-State Conditions

(USGS Modeling Presentation)

PARTICLE TRACKS ORIGINATING FROM J RANGES AREA



Transient v. Steady-State Particle Tracking--J Ranges

(USGS Modeling Presentation)

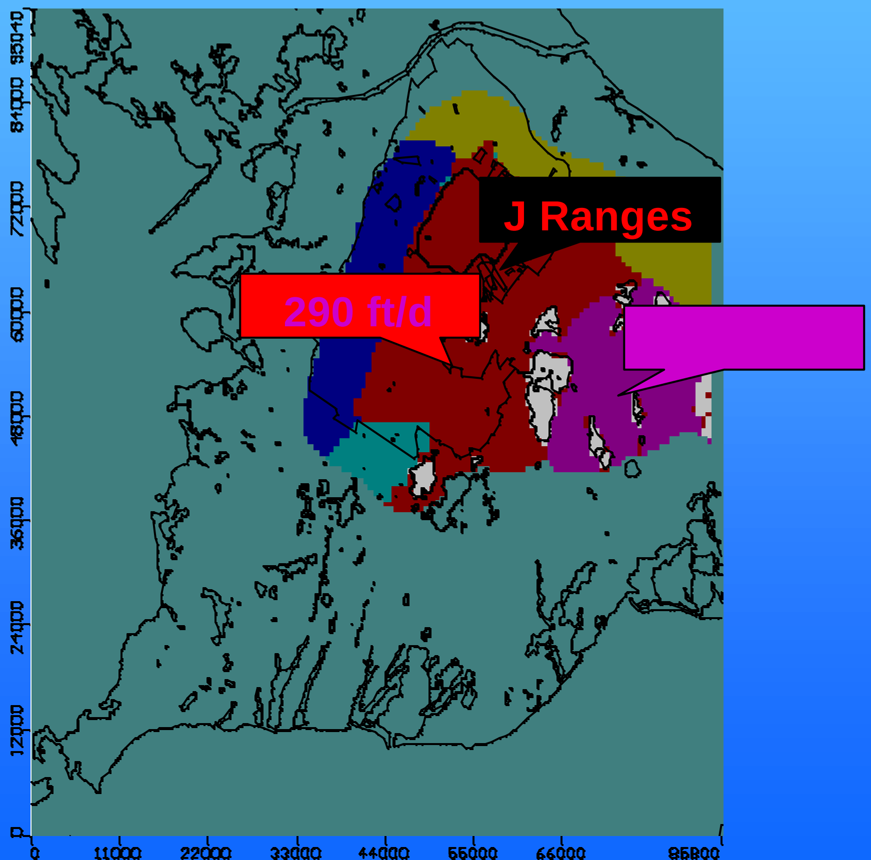
HYDRAULIC CONDUCTIVITY VALUES FOR J RANGES

Model Layer	Elevation* (ft.asl)	K (ft/d)	K in J Ranges (ft/d)
1	above 40 ft	125 - 350	290
2	20 to 40	125 - 350	290
3	0 to 20	125 - 300	290
4	-20 to 0	100 - 290	290
5	-40 to -20	70 - 230	230
6	-60 to -40	70 - 230	230
7	-80 to -60	30 – 200	125
8	-100 to -80	10 - 125	70
9	-140 to -100	10 - 70	30
10	bedrock** to -140	10 - 70	30
11	NA	10 - 30	NA

*In the central portion; ** about –200 to –150 ft.asl

(based on USGS Regional Model)

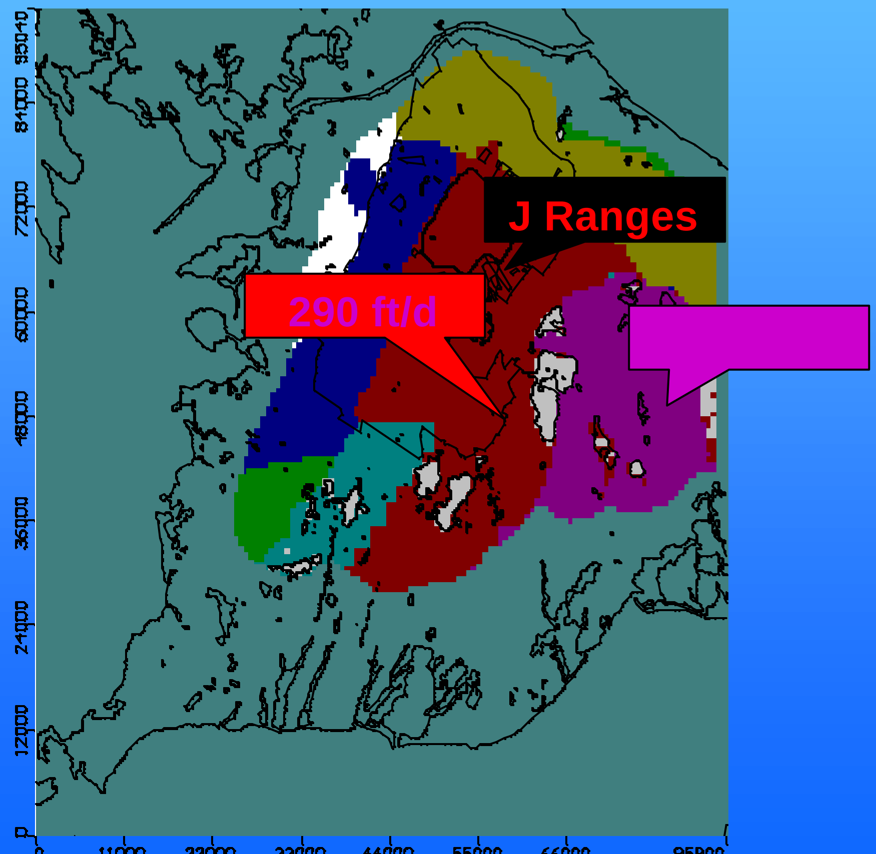
DISTRIBUTION OF HYDRAULIC CONDUCTIVITY IN LAYER 1



(based on USGS Regional Model)

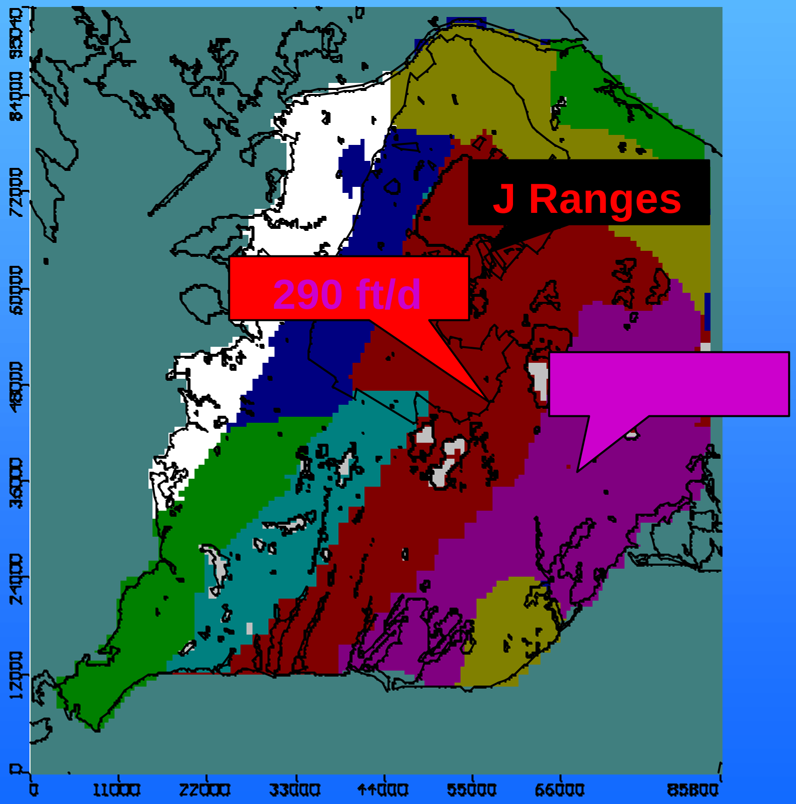
Environmental Programs

DISTRIBUTION OF HYDRAULIC CONDUCTIVITY IN LAYER 2



(based on USGS Regional Model)

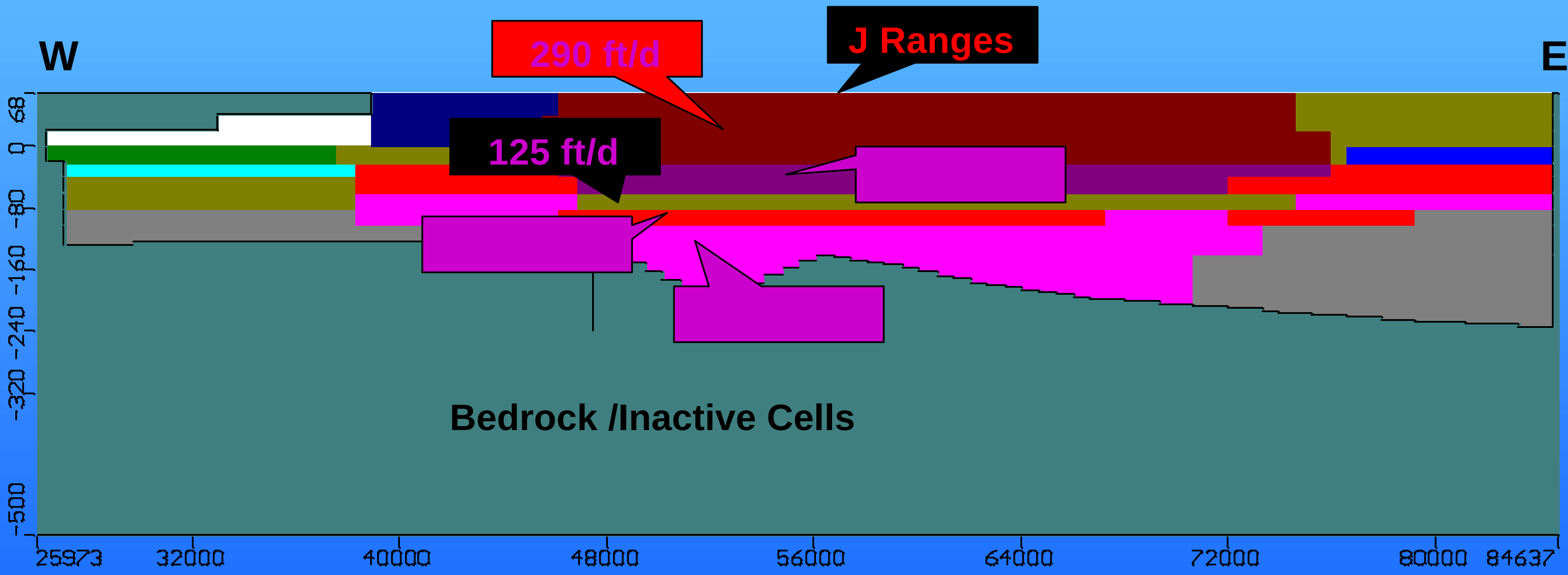
DISTRIBUTION OF HYDRAULIC CONDUCTIVITY IN LAYER 3



(based on USGS Regional Model)

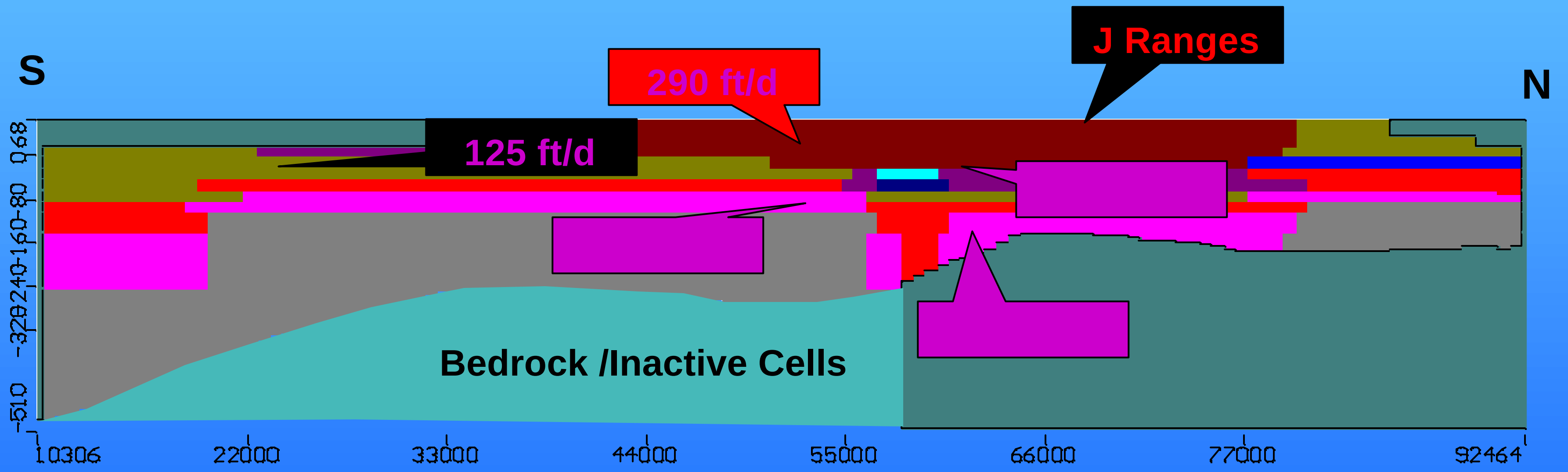
Environmental Programs

VERTICAL DISTRIBUTION OF HYDRAULIC CONDUCTIVITY EAST-EAST CROSS-SECTION



(based on USGS Regional Model)

VERTICAL DISTRIBUTION OF HYDRAULIC CONDUCTIVITY NORTH-SOUTH CROSS-SECTION



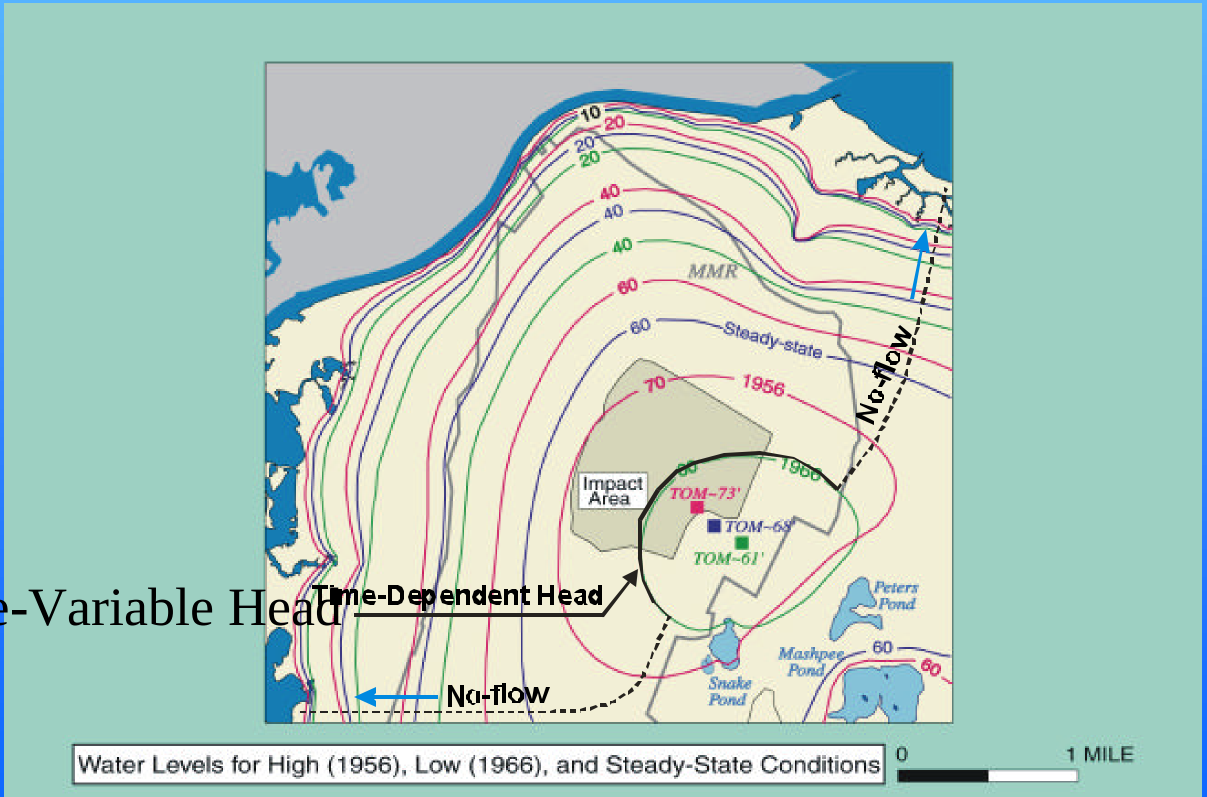
(based on USGS Regional Model)

Environmental Programs

IMPACT OF EXTRACTION SYSTEM ON FLOW PATHS

(USGS Modeling Presentation)

POSSIBLE UPGRADIENT BOUNDARY CONDITION FOR THE J RANGES SUB-REGIONAL MODEL

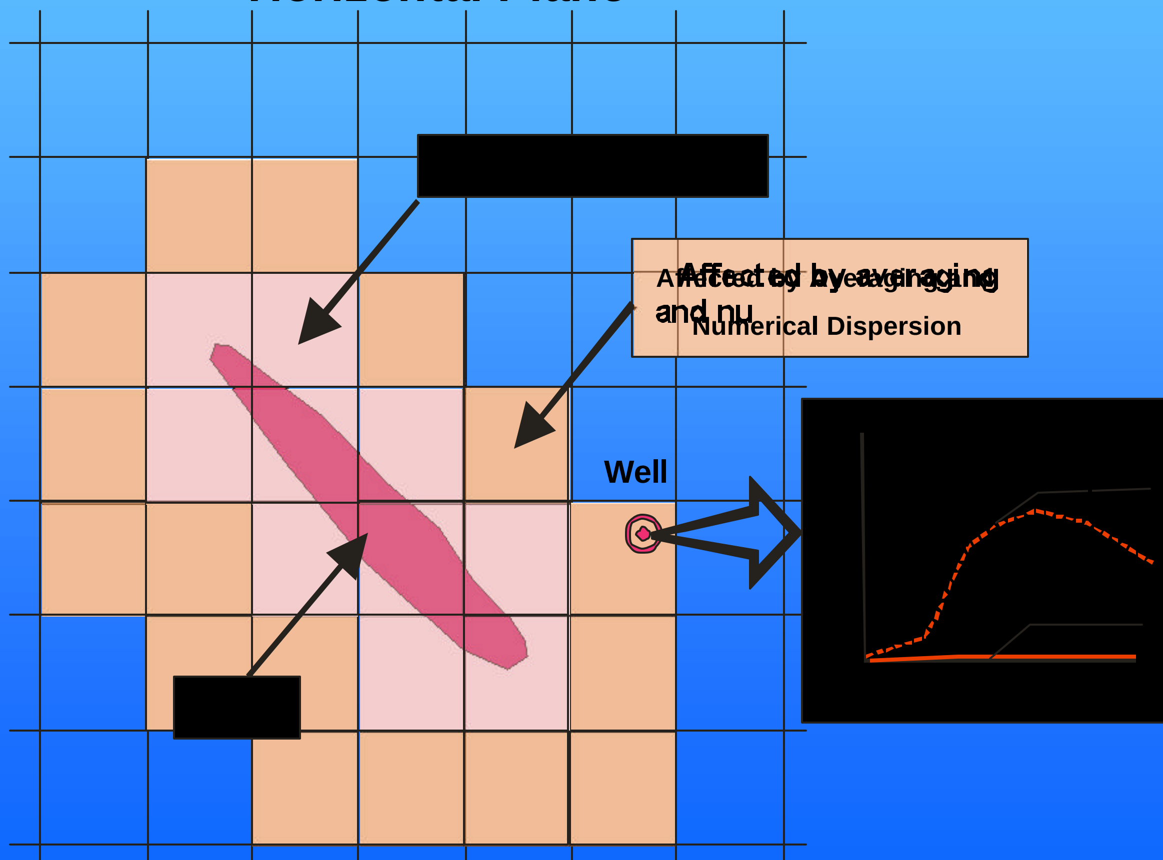


Time-Variable Head

USGS Presentation)

NUMERICAL GRID EFFECT IN TRANSPORT MODELING

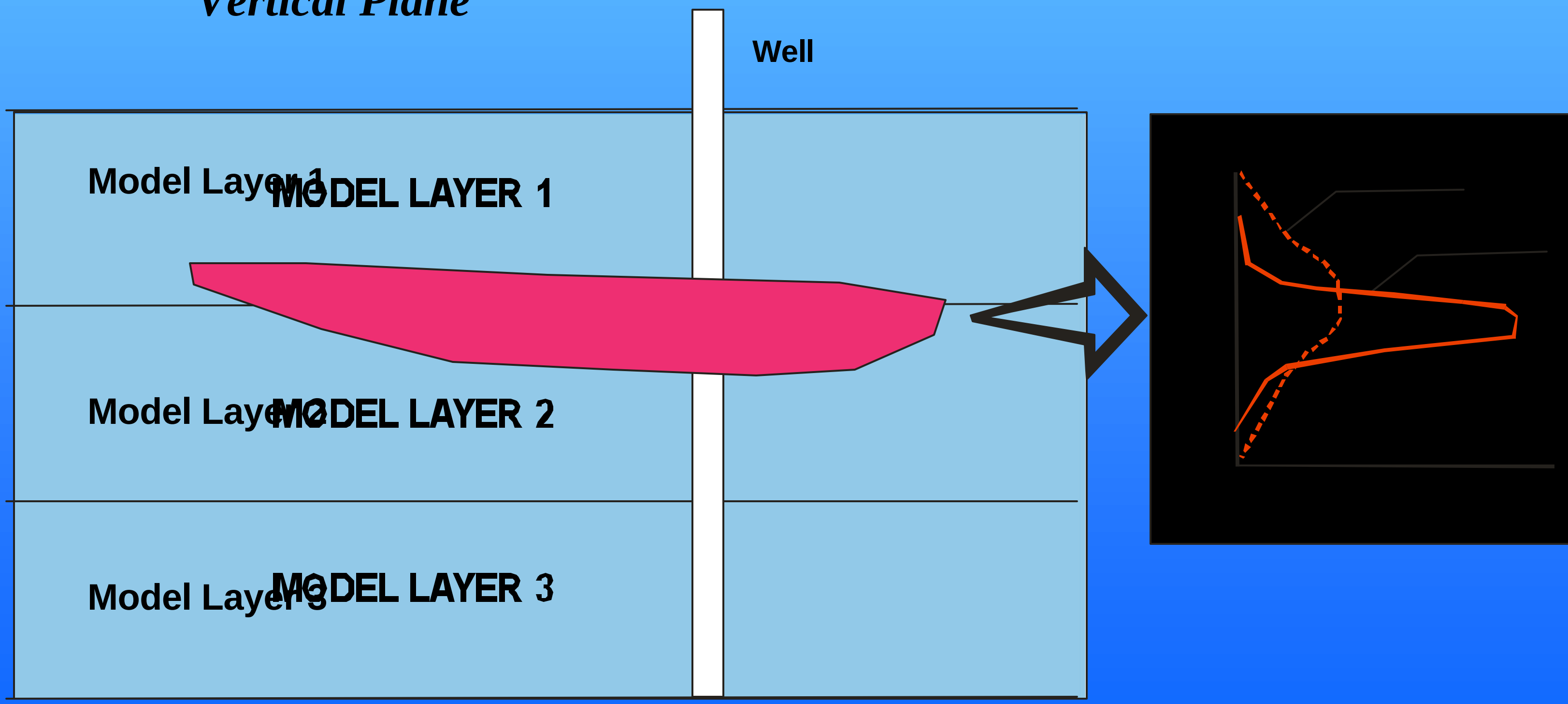
Horizontal Plane



NUMERICAL GRID EFFECT IN TRANSPORT MODELING

Vertical Plane

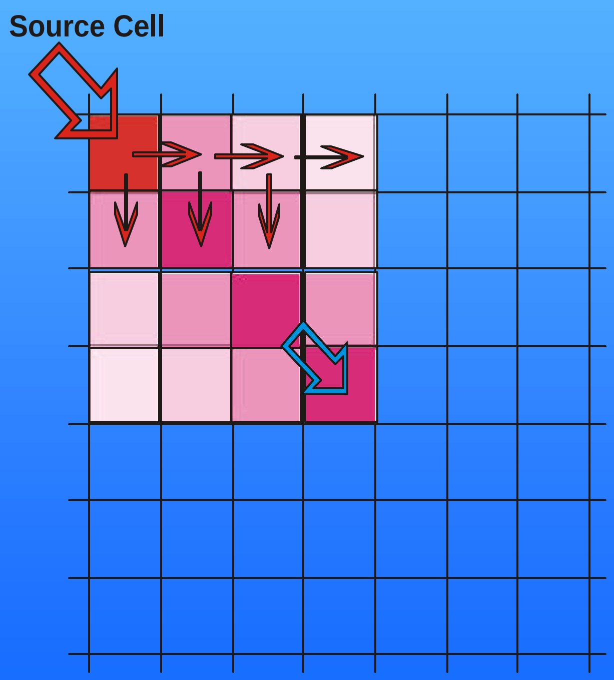
MONITORING WELL



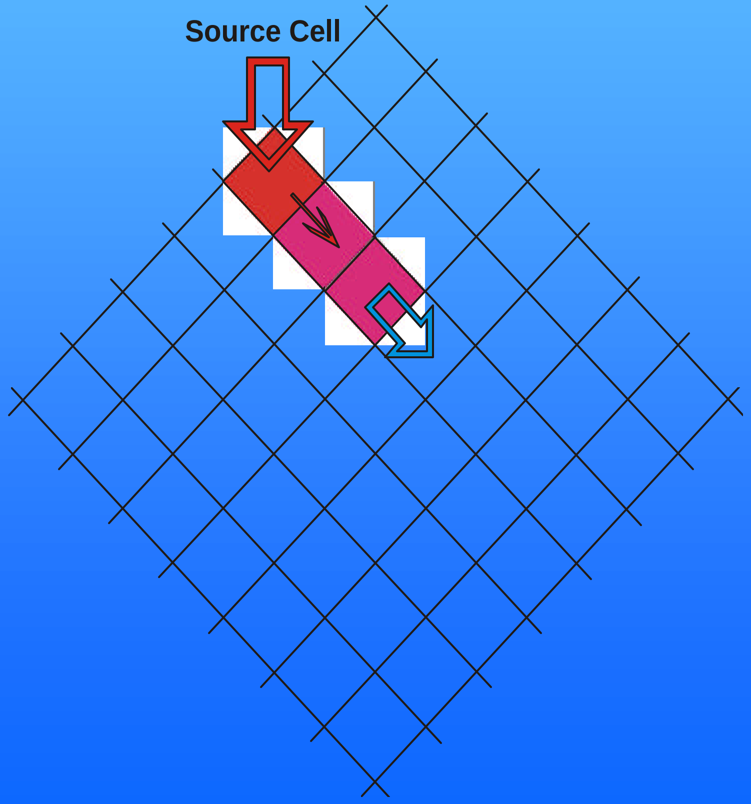
Environmental Programs

ORIENTATION ERRORS IN TRANSPORT MODELING

DIAGONAL GRID



PARALLEL GRID

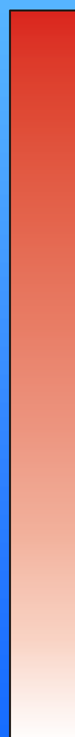


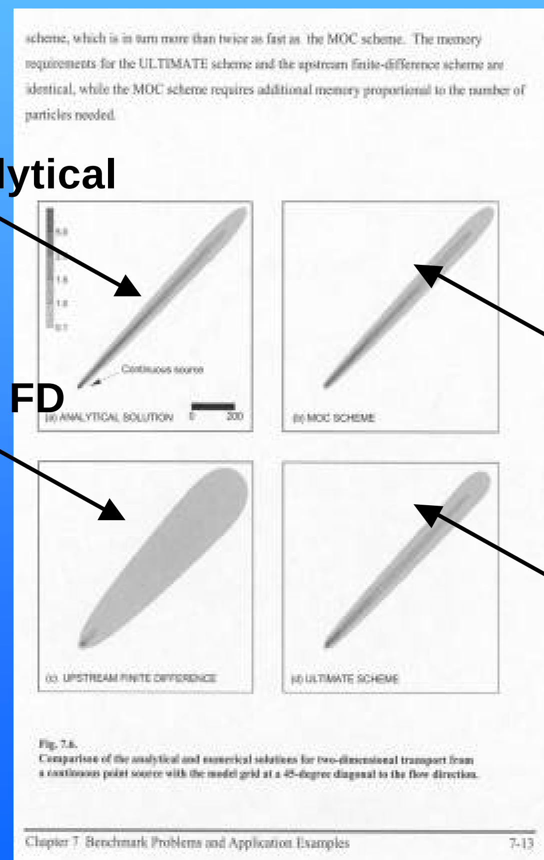
ORIENTATION ERRORS ACCORDING TO MT3DMS EXAMPLE SECTION 7.4)

Upstream FD

ULTIMATE FD

MOC





scheme, which is in turn more than twice as fast as the MOC scheme. The memory requirements for the ULTIMATE scheme and the upstream finite-difference scheme are identical, while the MOC scheme requires additional memory proportional to the number of particles needed.

Fig. 7.6.
Comparison of the analytical and numerical solutions for two-dimensional transport from a continuous point source with the model grid at a 45-degree diagonal to the flow direction.

Chapter 7 Benchmark Problems and Application Examples 7-13

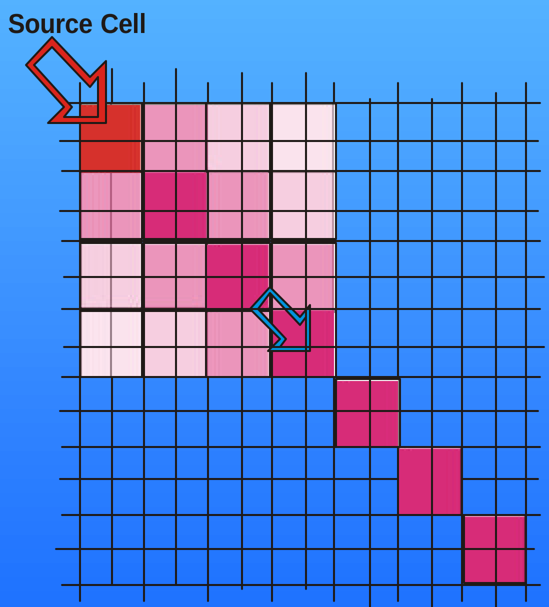
ESTIMATE OF CELL SIZE REQUIRED TO ACCURATELY SIMULATE NARROW PLUMES

- Pe = 7 (example 7.4 from MT3DMS User's Guide)
- Longitudinal Dispersivity (α_L) = 3 ft

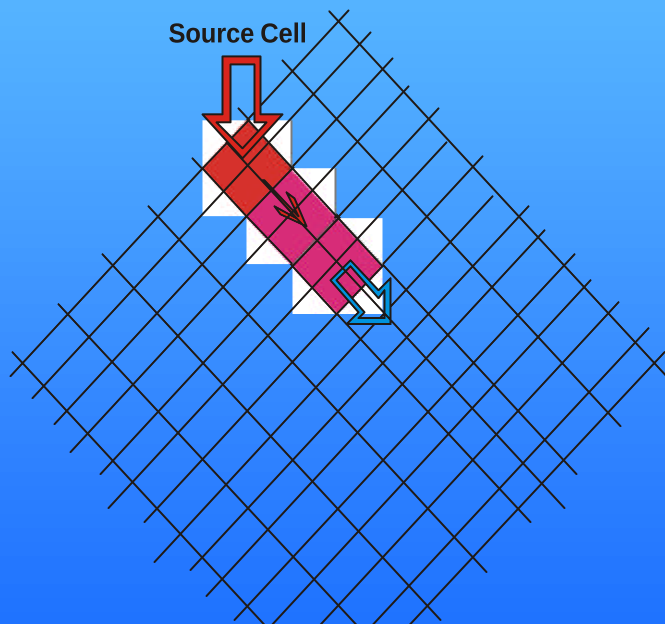
➲ DX = DY = Pe* α_L = 7*3 ft = 21 ft

MESH REFINEMENT FOR TWO DIFFERENT GRID ORIENTATIONS

DIAGONAL GRID



PARALLEL GRID



DIAGONAL GRID	PARALLEL GRID
$N=100*n^2$	$N=10*n*(n+9)$
n=10	n=10
N=10,000	N=1,900

CALIBRATION OF SUB-REGIONAL MODEL

- Ground Water Flow
  - Use USGS Calibrated Regional Model
  - Utilize additional local geological data
  - Introduce additional calibration points (if required)
  - Check the flow calibration and particle tracks
  - Adjust input parameters, if necessary
- Fate and Transport (HMX and RDX)
  - Use SESOIL output for source concentrations
  - Assign Kd, dispersion and degradation parameters
  - Calibrate to the observed concentration levels
  - Re-calibration of unsaturated and/or ground water flow model may be required

Environmental Programs

Major F&T Components

Component	Description	Effect on Solution	Expected Importance
Advection	Migration along flow path	Preserves concentration levels along flow paths	High
Dispersion	Spreading around center of mass	Smears concentration fronts	Unknown
Retardation	Sorption to solid phase	Slows front propagation	Low
Degradation	Transformation into another chemical	Reduces concentration levels	Low
Leaching	Contaminant loading from unsaturated zone	Controls concentration levels in source area and total mass	High

SUMMARY

- Transient model may be required for the J Ranges Area
- Modeling results are expected to be sensitive to spatial and temporal variations in the input parameters
- Significant mesh refinement, resulting in horizontal cell sizes of 20– 50 ft, may be required to simulate narrow plumes
- Introduction of additional model layers may be required from the numerical or geological point of view

SUMMARY (CONT.)

- Modeling advective transport may require the application of MOC
- Grid rotation may be required if the main narrow plume(s) will be proven to migrate at an angle of 40-50 degrees to the existing regional scale grid. This rotation is expected to optimize the refined grid system and reduce the orientation error
- F&T model calibration can be iterative, i.e linked with unsaturated and/or saturated flow models re-calibration