<u>TUESDAY, SEPTEMBER 19, 2006, CONFERENCE ROOM T-2B3, TWO WHITE FLINT NORTH, ROCKVILLE, MARYLAND</u>

ACNW WORKING GROUP MEETING ON USING MONITORING TO BUILD MODEL CONFIDENCE - DAY 1 (OPEN)

4) 8:30 - 8:40 A.M. **<u>Opening Remarks and Introductions</u>** (MTR/JHC/LSH)
The ACNW Chairman will make opening remarks regarding the conduct of today's sessions. ACNW Member Dr. James Clarke will provide an overview of the Working Group Meeting (WGM), including the meeting purpose and scope, and introduce invited subject matter experts.

SESSION I: ROLE OF MODELS AND MONITORING PROGRAMS IN LICENSING

5)	8:40 - 9:20 A.M.	Vernon Ichimura (Energy Solutions-Duratek-Chem Nuclear) and David Scott (Radiation Safety Control, Inc.) will discuss the licensee's perspective on the role of models and monitoring in demonstrating compliance with licensing criteria.
6)	9:20 - 10:00 A.M.	James Shepherd and Mark Thaggard from NRC headquarters will discuss the staff's perspectives on the use of ground water monitoring and modeling for regulatory decision making.
	10:00 - 10:15 A.M.	*****BREAK*****
7)	10:15 - 11:00 A.M.	Matt Kozak from Monitor Scientific LLC and David Esh from NRC headquarter staff will address the role of monitoring in model support and performance assessment evaluations.
8)	11:00 - 12:00 P.M.	**Session I Panel Discussion** (All) Committee Member Clarke will moderate and Dr. George Hornberger from the University of Virginia will lead a panel discussion by Committee members and invited subject matter experts on the role of models and monitoring programs in licensing activities.
	12:00 - 1:00 P.M.	*****LUNCH*****

SESSION II: EVALUATING RADIONUCLIDE RELEASES AND GROUND WATER CONTAMINATION (CASE STUDIES)

9)	1:00 - 1:30 P.M.	Michael Fayer from the Pacific Northwest National Laboratory (PNNL) will discuss lessons learned from remedial actions at the Hanford site with emphasis on contaminant fate and transport.
10)	1:30 - 2:00 P.M.	Brian Looney from the Savannah River National Laboratory will discuss how detection, characterization and delineation of contaminant plumes can be used to support environmental management and environmental protection objectives.
11)	2:00 - 2:45 P.M.	Tom Burke and Mike Hauptman from the Brookhaven National Laboratory will discuss characterization, and modeling and monitoring basis for tritium plume management strategies at Brookhaven National Laboratory.
12)	2:45 - 3:15 P.M.	Steve Yabusaki from PNNL Hanford will discuss the use of subsurface simulation to build, test, and couple conceptual process models to better understand controls on the observed uranium plume behavior at the Hanford site.
	3:15 - 3:30 P.M.	*****BREAK*****

13) 3:30 - 4:00 P.M. Vernon Ichimura from Energy Solutions-Duratek-Chem Nuclear will discuss groundwater contaminant migration modeling projections at the Barnwell low-level waste site.

14) 4:00 - 5:00 P.M. **Session II Panel Discussion** (All)
ACNW Committee Member Clarke will moderate and Dr. Hornberger will lead a panel discussion by invited experts on radionuclide release and ground water contamination.

5:00 P.M. Adjourn

WEDNESDAY, SEPTEMBER 20, 2006, CONFERENCE ROOM T-2B3, TWO WHITE FLINT NORTH, ROCKVILLE, MARYLAND

ACNW WORKING GROUP MEETING ON USING MONITORING TO BUILD MODEL CONFIDENCE - DAY 2 (OPEN)

15) 8:30 - 8:45 A.M. **Opening Remarks and Introductions** (MTR/JHC/LSH)
The ACNW Chairman will make opening remarks regarding the conduct of today's sessions. ACNW Member Clarke will provide an overview of the WGM, including the meeting purpose and scope, and introduce invited subject matter experts.

SESSION III: FIELD EXPERIENCE AND INSIGHTS

16) 8:45 - 9:05 A.M. Brian Andraski from the U.S. Geological Survey (USGS) will discuss how environmental monitoring and modeling are being integrated to refine unsaturated-zone models to capture the essential features and processes of contaminant migration at the USGS Amargosa Desert Research Site, Nevada.

17) 9:05 - 9:25 A.M. Van Price from Advanced Environmental solutions, LLC, will discuss model value with a focus on conceptual model development and the dynamic modeling process.

18) 9:25 - 9:45 A.M. Robert Ford from the U.S. Environmental Protection Agency (Robert S. Kerr Laboratory) will discuss site characterization to support development of conceptual transport models.

19) 9:45 - 10:05 A.M. Craig Benson from the University of Wisconsin-Madison will discuss modeling of hydrology covers for waste containment including the role of monitoring in improving model results.

10:05 - 10:20 A.M. ***BREAK***

20) 10:20 - 10:40 A.M. Glendon Gee from PNNL will discuss waste isolation using evapotranspiration (ET) type covers and reliability of current models in predicting ET cover performance.

21) 10:40 - 11:00 A.M. Jody Waugh from the U.S. Department of Energy (Grand Junction) will discuss monitoring and testing of engineered covers for uranium mill tailings, and the use of natural analog with monitoring and modeling to project long-term performance of covers.

22) 11:00 - 12:00 P.M. **Session III Panel Discussion** (All)
Committee Member Clarke will moderate and Dr. Hornberger will lead a panel discussion by Committee members and invited subject matter experts on field experiences and insights.

12:00 - 1:00 P.M. ***LUNCH***

SESSION IV: OPPORTUNITIES FOR INTEGRATING MODELING AND MONITORING

23) 1:00 - 1:30 P.M. ACNW Committee Member Clarke and Tom Nicholson from NRC's Office of Research will discuss modeling and monitoring integration issues.

24) 1:30 - 2:00 P.M. Thomas Fogwell from Fluor Hanford will discuss integrating modeling and monitoring activities to support long-term interactions and control of contaminants.

2:00 - 2:15 P.M. ***BREAK***

25) 2:15 - 3:15 P.M. **Session IV Panel Discussion** (All)
Committee Member Clarke will moderate and Dr. Hornberger will lead a panel discussion by invited experts on the integration of modeling and monitoring programs.

26) 3:15 - 4:15 P.M. **Roundtable Wrap Up Discussion** (All)
Committee Member Clarke will moderate a roundtable discussion by invited experts on the use of monitoring programs to enhance confidence in models and model results.

27) 4:15 - 4:30 P.M. ACNW Chairman Ryan and the other Committee members will discuss their impressions of the WGM and a possible letter report to the Commission.

4:30 P.M. Adjourn

THURSDAY, SEPTEMBER 21, 2006, CONFERENCE ROOM T-2B3, TWO WHITE FLINT NORTH, ROCKVILLE, MARYLAND

28) 8:30 - 8:35 A.M. **Opening Remarks by the ACNW Chairman** (Open) (MTR/JHF)
The Chairman will make opening remarks regarding the conduct of today's sessions.

29)	8:35 - 10:00 A.M.	**<u>Disposition of Public Comments on Spent Nuclear Fuel Transportation Package Responses to Tunnel Fire Scenarios (NUREG/CR-6886 for the Baltimore Tunnel and NUREG/CR-6894 for the Caldecott Tunnel)</u>** (Open) (RFW/MPL) NMSS/SFPO representatives will brief the Committee on the public comments received for the two tunnel fire studies and how these comments were addressed in the final versions of the two NUREGs, expected to be released shortly for publication.
	10:15 - 10:30 A.M.	*****BREAK*****
30)	10:30 - 11:00 A.M.	**<u>Discussion of Potential ACNW Letter Reports</u>** (Open) (All) Discussion of possible ACNW reports on: 30.1) ACNW Working Group Meeting on Using Monitoring to Build Model Confidence (JHC/LSH) 30.2) Disposition of Public Comments on Transportation Package Responses to Tunnel Fire Scenarios (RFW/MPL)
31)	11:00 - 12:00 P.M.	**<u>Discussion of Draft ACNW Letter Reports</u>** (Open) (All) Continued discussion of proposed ACNW reports listed under Item 3.
	12:00 - 1:00 P.M.	*****LUNCH*****
32)	1:00 - 4:30 P.M.	**<u>Discussion of Draft ACNW Letter Reports</u>** (Open) (All) Continued discussion of proposed ACNW reports listed under Item 3.
33)	4:30 - 5:00 P.M.	**<u>Miscellaneous</u>** (Open) The Committee will discuss matters related to the conduct of ACNW activities and specific issues that were not completed during previous meetings, as time and availability of information permit. Discussions may include future Committee Meetings.
	5:00 P.M.	**Adjourn**

ENERGYSOLUTIONS
We're part of the solution

Role of Models in Demonstration, Compliance with Licensing Requirements

presented to the ACNW
September 19, 2006
by Vernon Ichimura

Overview

- Barnwell Disposal Site
- Review of Regulation
- Focus on Measurement
- Use of Models

Barnwell Disposal Site -- Summary

- Licensed to dispose LLRW in 1971
- Current license area is 235 Acres
- Approximately 12 million curies received
- After decay, approximately 3 million curies remain
- Current area used for disposal is 105 acres
- Approximate area remaining is 10 acres
- Approximate disposal volume is 28 million cubic feet
- Approximate disposal volume remaining is approximately 2 million cubic feet


BWMF

ENERGYSOLUTIONS
We're part of the solution


P&H
P&H
7 12:00PM

Regulations

Demonstrate by measurement and/or model during operations and after site closure that concentrations of radioactive materials which may be released to the general environment in groundwater, surface water, air, soil, plants or animals will not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public.

Operational

- <u>Real</u> dose to workers
- In 2005 – Average Annual Dose to a Radiation Workers was 241 millirems

Environment

- <u>Hypothetical</u> dose to any member of the public
- In 2005 – Average Annual Dose to Public - - Negligible
- In 2005 – Average Hypothetical Dose by Groundwater/Surface Water at the Compliance Location is less than 5 millirems.

Focus on Measurement

- At location adjacent to waste disposal operations
- Around and in closed disposal trenches
- On the disposal site
- At boundary and compliance locations
- At off-site locations around the disposal site
- Distant from the disposal site - - for background evaluations

Measurement On All Pathways

- Direct exposure
- Airborne
- Surface Water
- Soils
- Plants
- Groundwater

Use of Simple Models or Well Documented Models Which Have Been Checked

- Simple “calculator”, handbook, and analytical models - - - based on theoretical principles
- Commercial or public domain models
- Run validation
- Check model results with measurements
- Independent “peer-review” of model and projections

Use of Models - - Examples

- Estimate boundary dose rates due to disposal operations
  - What is the necessary shielding required for groups of waste packages and waste configurations
  - Simple inverse square law models and Microshield®
  - Verify with measurements

- Estimate radionuclide concentration at the site boundary in surface soil and surface water
    - Measurements of radionuclide concentration in soils
    - Erosion calculations and measurements
    - Runoff calculation and measurements
    - Estimate radionuclide concentration at the boundary
    - Verify with measurements

- Estimate radionuclide concentration at a compliance location in groundwater and surface water
  - Measurements of radionuclide concentrations
  - Measurements of hydraulic data
  - Perform groundwater flow and transport modeling
  - Verify with measurements

Roles of Models

- Models are needed to demonstrate compliance
- Models are simplification of reality and contain numerous assumptions
- Models must be checked with measurements
- Models should be updated as new information becomes available

Groundwater Monitoring in Support of License Termination at Yankee Nuclear Power Station

Advisory Committee on Nuclear Waste
U.S. Nuclear Regulatory Commission
Rockville, MD, September 19 & 20, 2006

Dave Scott, Project Hydrogeologist, Radiation Safety & Control Services, Inc.
Greg Babineu, Yankee Atomic Electric Company
Eric Darois, CHP, Radiation Safety & Control Services, Inc.

YR Operational History

- PWR, Operated from 1960 to 1992
- Built adjacent to Sherman Reservoir in the northern Berkshires using a Vapor Containment Design
- Initially 485 MWt, Uprated to 600 MWt in 1963
- Permenantly Ceased Operations in 1992
- Significant IX Pit Leak in 1963
- Fuel Clad for ~14 years was Stainless Steel
- During the period 1960-1980 the SFP did not have an interior stainless liner


2006/08/30

Yankee Rowe Potential Groundwater Contaminating Events

- SFP Unlined From 1960 Until 1980
- IX Pit Leak First ID'ed in 1963; Repaired in 1965
- Outside Storage Of Contaminated Materials
  - Refueling Equipment
  - Waste
- Redistribution of Soil Contamination
  - RCA Snow Removal
  - Rain – Storm Drains
  - Wind
- RX Head Impact – Outside Soil Contamination
- Underground Drain Pipe Leak in Radwaste Warehouse

Criteria For License Termination

- All Pathways TEDE < 25 Millirem/yr (10 CFR 20.1402), and Residual Radioactivity ALARA
- H-3 Concentration in Resident Farmer's Well Less Than 20,000 pCi/L
  - Average yield of well serving family of four: 1323 m^3/yr (0.665 gpm)
- Other GW Contaminants Less Than Limits Defined in LTP License Condition

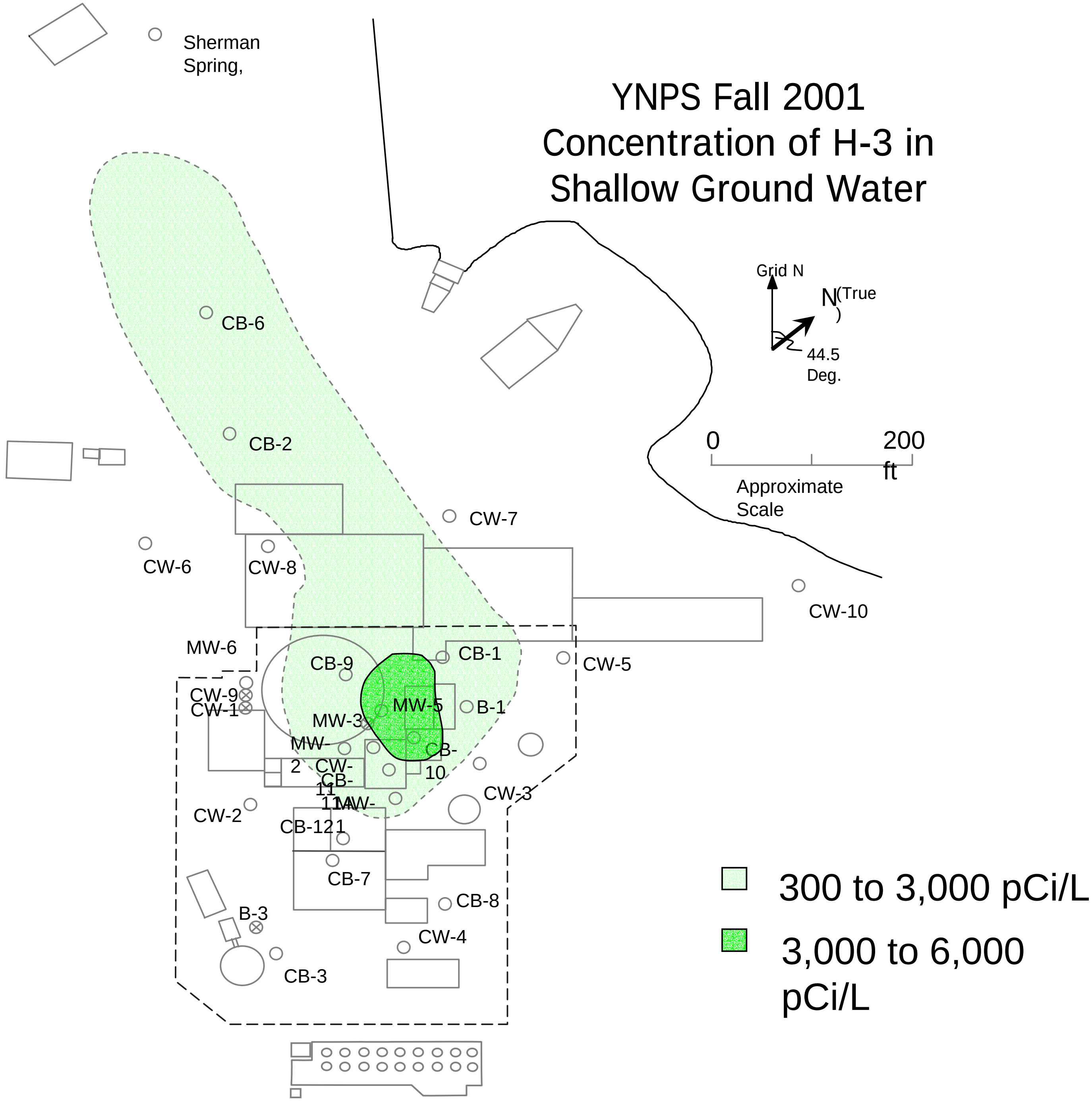
Initial GW Monitoring Activities

- First 10 Monitoring Wells Drilled in 1993
- 24 Wells Added During ‘94, ’97, ‘98 and ‘99
  - Virtually all in shallow outwash aquifer <30 feet deep
  - 18 in radiologically controlled area (RCA)
  - 5 in industrial area outside RCA
  - 3 outside industrial area
  - 8 in construction fill area, upgradient of RCA
- 2 Additional Monitoring Points
  - Sherman Spring (monitored since 1965)
  - Plant potable water well (bedrock)

Initial GW Monitoring Activities (continued)

- Periodic Sampling and Analysis for:
  - Tritium
  - Gamma-emitters
  - Chemical constituents
- One Round of Analysis for Sr-90
- Identified Tritium Plume
  - Maximum concentration ~ 5,000 pCi/L
  - Extends downgradient from SFP/IXP

YNPS Fall 2001 Concentration of H-3 in Shallow Ground Water



Comprehensive GW Monitoring From 2003

- Evaluated Accumulated Historic GW Data
- Resulting Recommendations:
  - Drill additional wells
  - Fully characterize deeper aquifers beneath outwash, down to bedrock
  - Improve procedures for drilling, sampling & analysis
    - Define DQO/DQA
    - Begin use of rotosonic drilling, low-flow sampling, quarterly sampling
    - Standardize and expand list of radionuclide analytes to 22

Comprehensive GW Monitoring From 2003

- Established monitoring program that included:
  - – Suites of radionuclide analytes determined by location, based on HSA and LTP
  - – New locations for wells based on site geology
    - Intermediate depth sand lenses (30 -100 feet)
    - Bedrock (some as deep as 300 feet)
    - Multiple wells at same location for vertical profile
  - – Frequency of monitoring that will adequately measure changes in GW quality

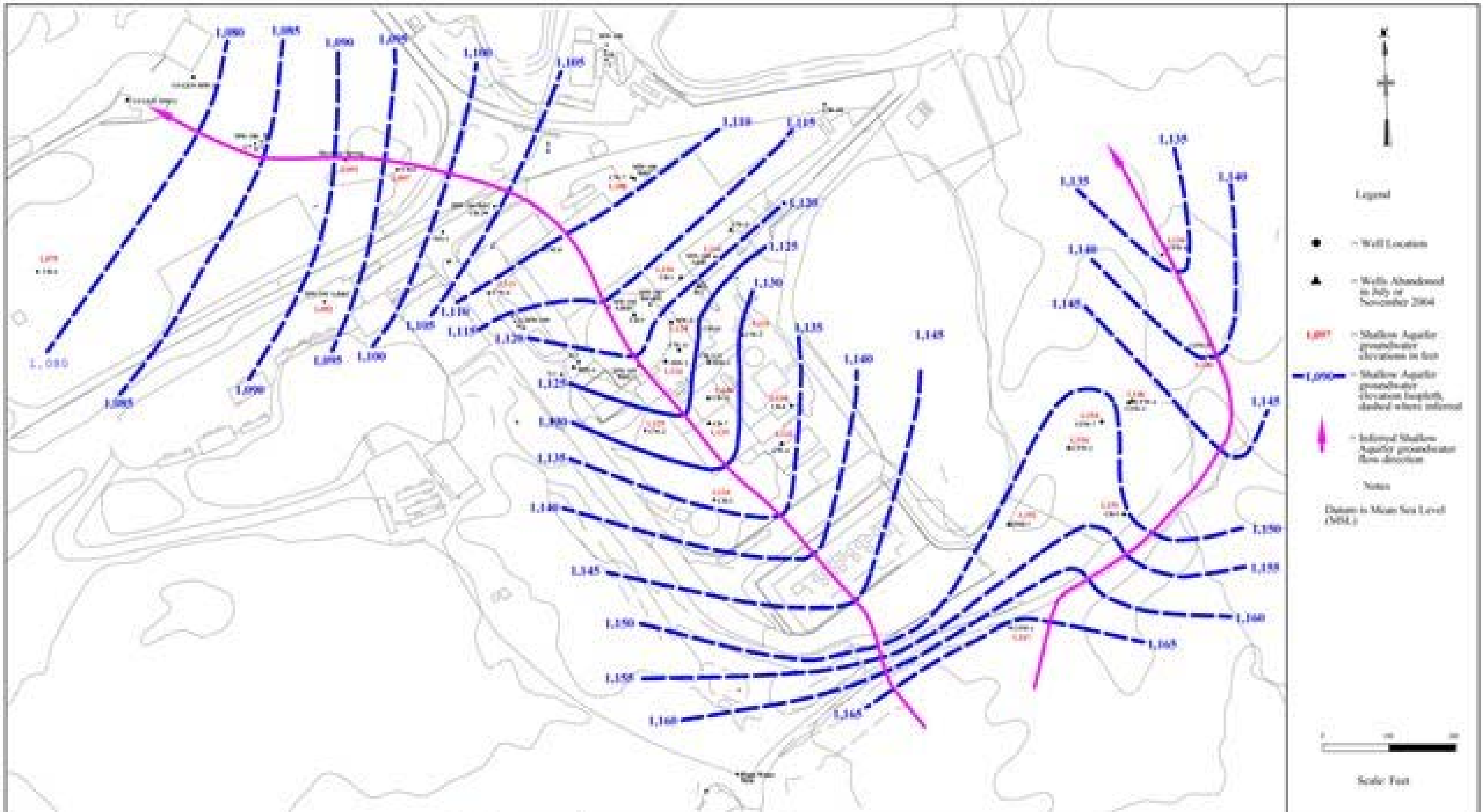
2003 MW Drilling Program

- 17 Wells Installed by Rotosonic Method
  - "Telescoped" up to 4 drill casings to properly isolate multiple aquifers
  - Characterized complex stratigraphy
  - Determined vertical distribution of tritium
- Explored Entire Thickness of Sediments and Shallow Bedrock
  - 2 wells into shallow outwash aquifer
  - 8 wells into deeper sand lenses interlayered within underlying lodgement till
  - 7 wells into bedrock
- Maximum depth of 295 feet

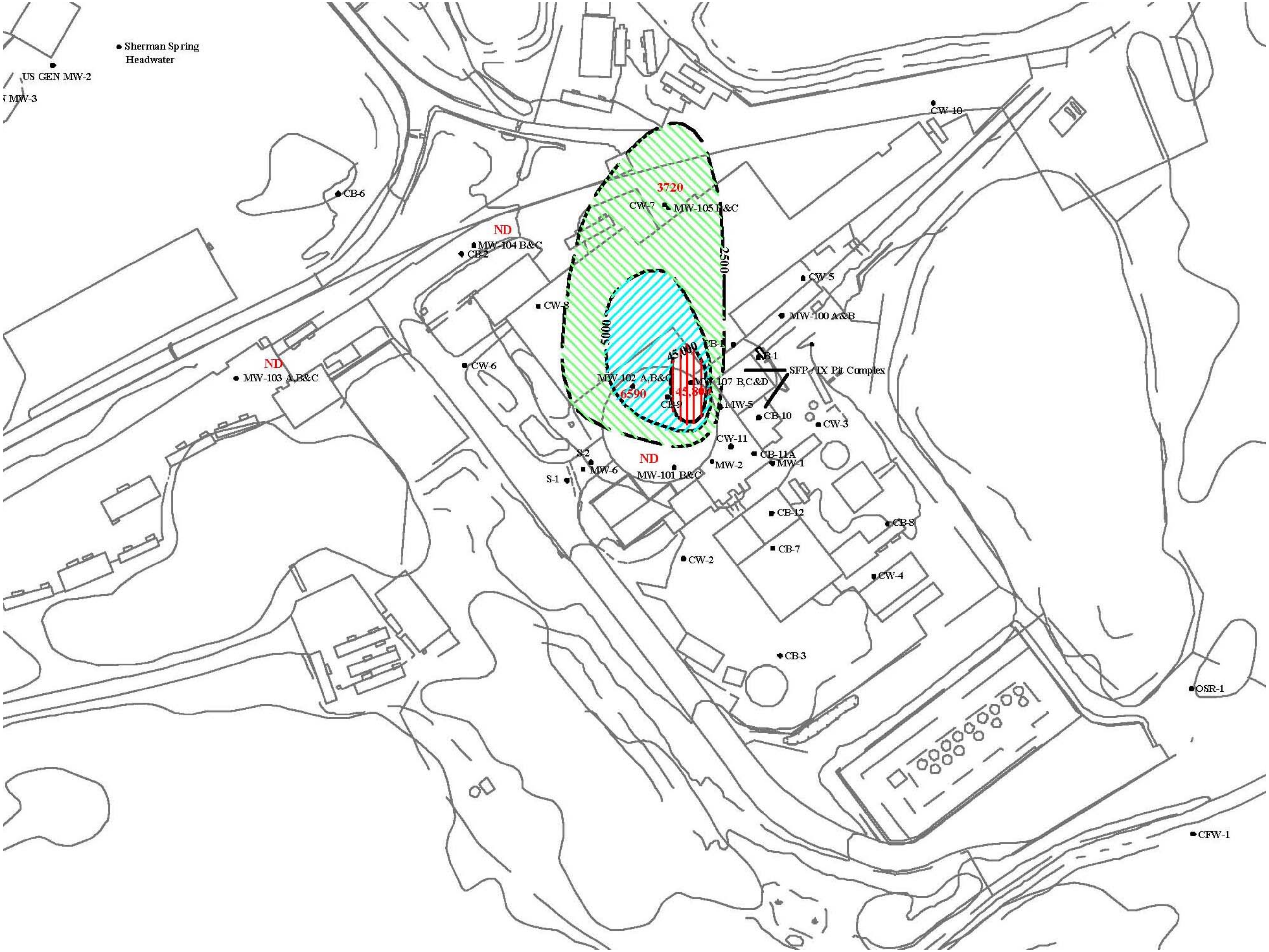
Results of 2003 Investigation

- Tritium only plant-related radionuclide in GW
- One H-3 plume in shallow (outwash) aquifer
  - Maximum concentration ~ 3,500 pCi/L
  - Aligned with direction of shallow GW flow (NW)
- A second H-3 plume in deeper sand lenses
  - Maximum concentration ~ 45,000 pCi/L
  - Direction of deeper GW flow toward Deerfield River
- H-3 in one bedrock well ~ 5,000 pCi/L

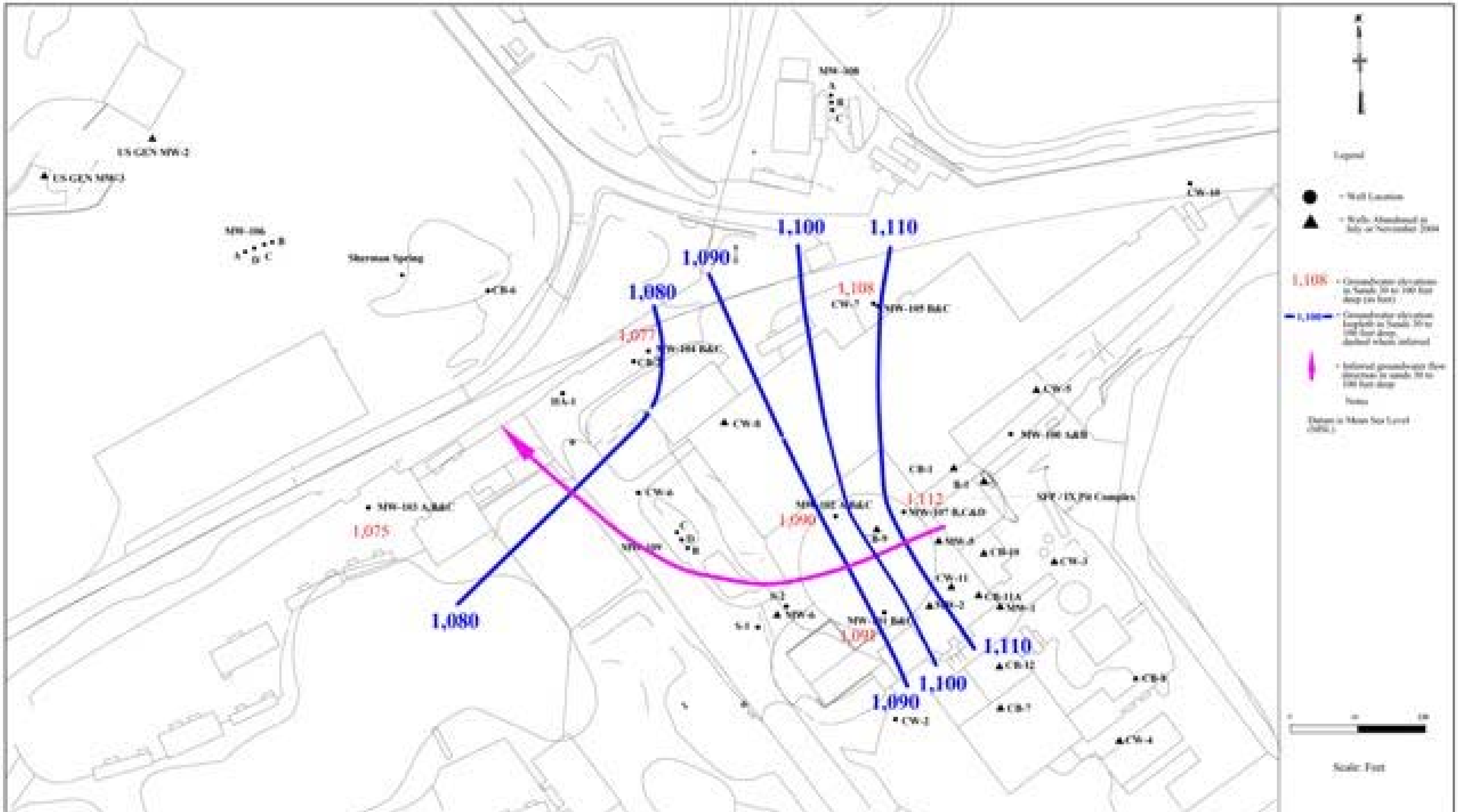

Sherman Spring
Headwater
ND
US GEN MW-2
W-3
CW-10
ND
CW-7
MW-105 B&C
CB-6
430
MW-104 B&C
CB-2
1160
CW-5
ND
CW-8
2500
1500
500
MW-100 A&B
2140
CB-1
B-1
SFP / IX Pit Complex
ND
MW-103 A,B&C
CW-6
158
MW-102 A,B&C
MW-107 B,C&D
2990
CB-9
2620
MW-5
CB-10
1240
CW-3
162
1850
CW-11
212
CB-11A
MW-1
S-2
MW-6
MW-101 B&C
MW-7
1780
580
S-1
214
540
CB-12
CB-8
CB-7
CW-2
CW-4
CB-3
OSR-1
CFW-1
266



Yankee Nuclear Power Station Rowe, Massachusetts	Ground Water Elevations in the Shallow Aquifer (less than 25 feet deep) on August 15, 2004	Revision: 1 MARCH 2005	FIGURE 12



Sherman Spring
Headwater
US GEN MW-2
N MW-3
CW-10
CB-6
3720
CW-7
MW-105 B&C
ND
MW-104 B&C
CB-2
2500
CW-5
CW-8
MW-100 A&B
5000
45,000
CB-1
ND
MW-103 A,B&C
CW-6
MW-102 A,B&C
MW-107 B,C&D
SFP / IX Pit Complex
6590
CB-9
MW-5
CB-10
CW-3
CW-11
ND
CB-11A
S-2
MW-6
MW-2
MW-1
MW-101 B&C
S-1
CB-12
CB-8
CB-7
CW-2
CW-4
CB-3
OSR-1
CFW-1



Yankee Nuclear Power Station
Rowe, Massachusetts

YANKEE

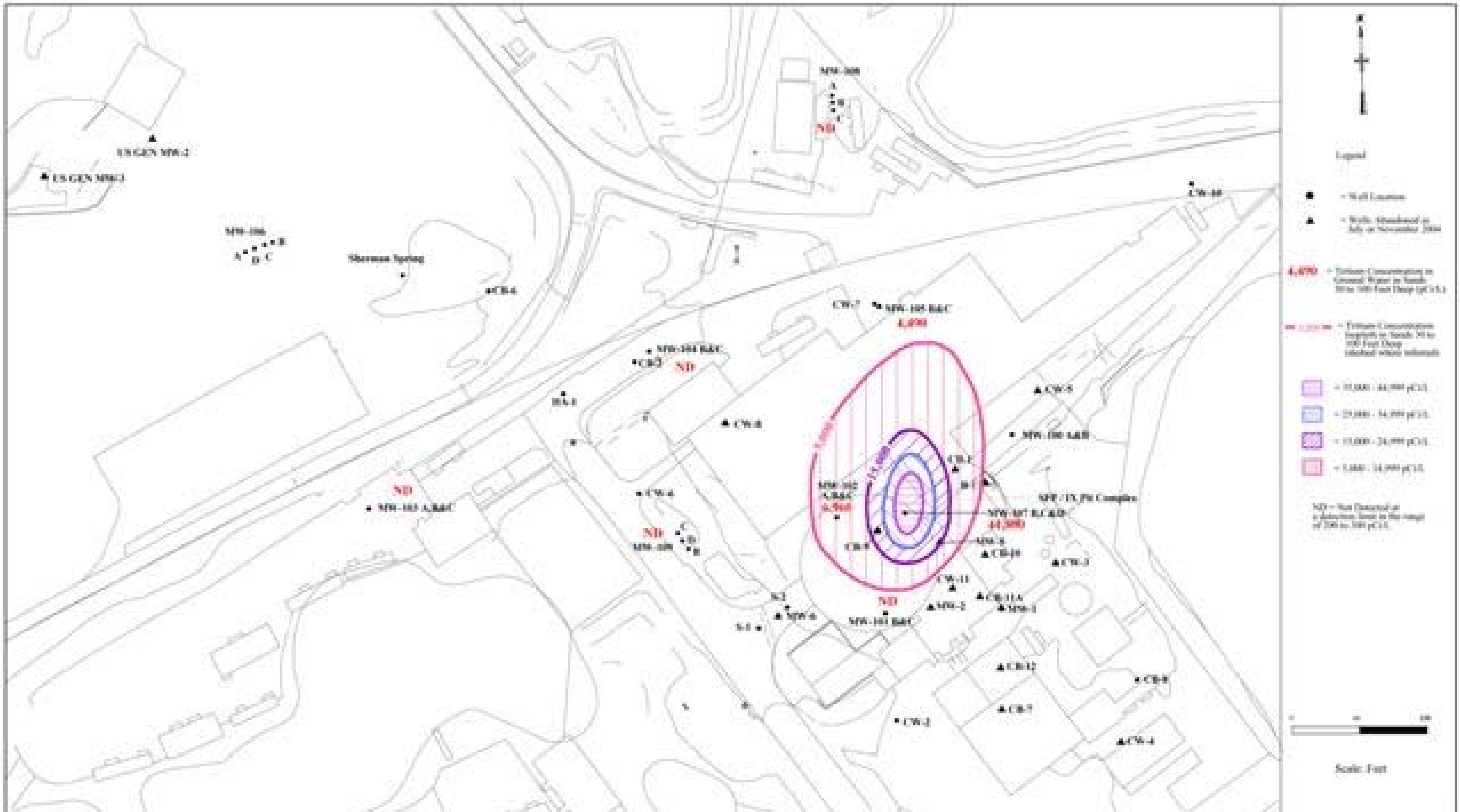
Ground Water Elevations in Sands 30 to 100 Feet Deep on August 15, 2004

Revision: 0
FEBRUARY 2005

FIGURE 16

2004 MW Drilling Program

- 10 Additional Monitoring Wells Installed by Rotosonic Method
  - 2 into shallow outwash aquifer
  - 5 into deeper sand lenses interlayered within underlying lodgement till
  - 3 into bedrock
- Well Locations Chosen to Bound the Shallow and Deeper H-3 Plumes
- Studied Interconnectivity Between Aquifers by Monitoring GW Levels With Data-Logging Pressure Transducers



Yankee Nuclear Power Station
Rowe, Massachusetts

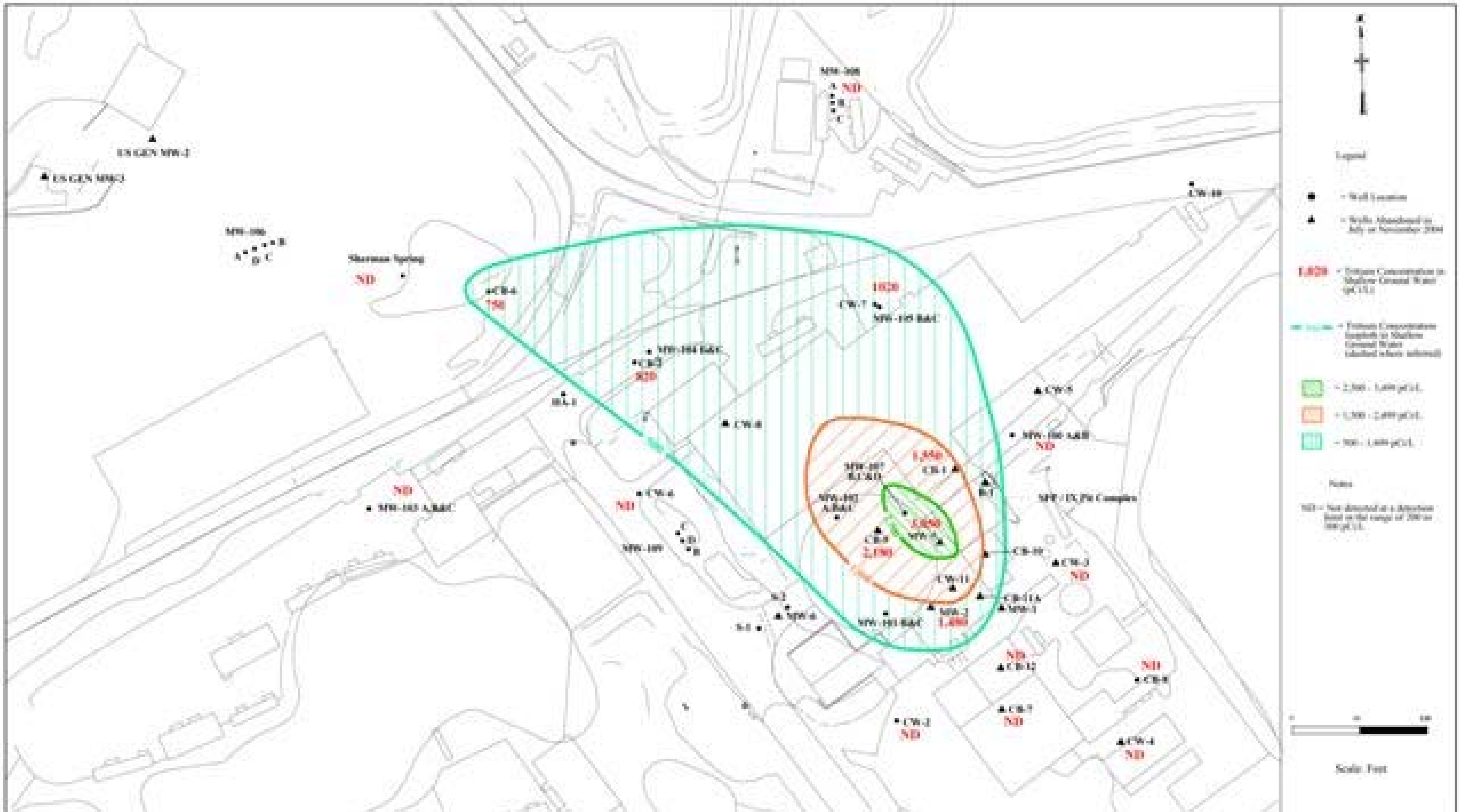
Tritium in Sands 30 to 100 Feet Deep in August 2004

Revision: 1
MARCH 2005

FIGURE 37

Groundwater Flow Characteristics

- Flow in Shallow Aquifer Relatively Fast (1 to 2 feet per day, or K ~ 5 ft/day)
- Net Flow Rate in Deeper GW is Much Slower – Controlled by Discontinuous Sand Lenses Within Lower Permeability Matrix of Lodgement Till



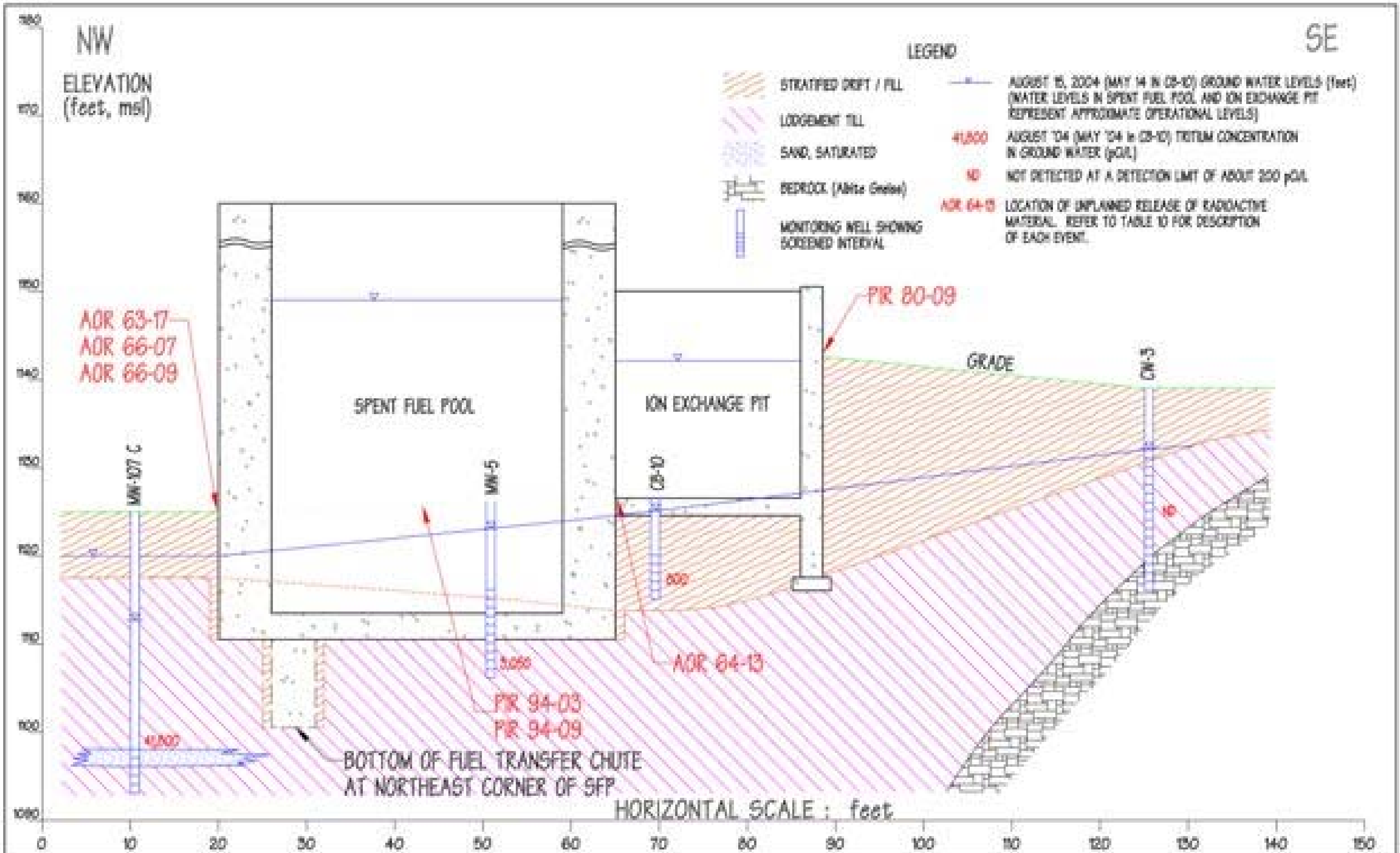
Yankee Nuclear Power Station **Rowe, Massachusetts** YANKEE	**Tritium in the Shallow Aquifer** **(less than 25 feet deep) in August 2004**	**Revision: 1** **MARCH 2005**	**FIGURE 33**

Source of Tritium Plumes

- Primary Source is the SFP/IX Pit Complex:
  - Maximum H-3 concentration occurs close to SFP/IX Pit in both shallow and deeper aquifers
  - IX Pit is known to have leaked ~ 1963
  - Repaired early in 1965
- REMP Monitoring Detected Tritium in Sherman Spring, 550 feet Downgradient of SFP/IX Pit
  - Peaked~7.2E06 pCi/L in Dec 1965, after IXP repaired
  - Declined continuously (<200 pCi/L since '93 except for spike during demolition in 2005)
- IX Pit Emptied in 1995, Demolished in 2005
- SFP Emptied in 2003, Demolished in 2005

Contaminant Transport Mechanisms

- Tritium Entered Deeper GW Along Deep Foundations and Piping
  - Downward flow potential in vicinity of SFP/IXP, shown by multiple-depth well clusters
- H-3 Became “Trapped” in Deeper Sands and Slowly Diffuses into Shallow Aquifer
  - This condition may sustain the low-concentration shallow plume, which otherwise may have attenuated

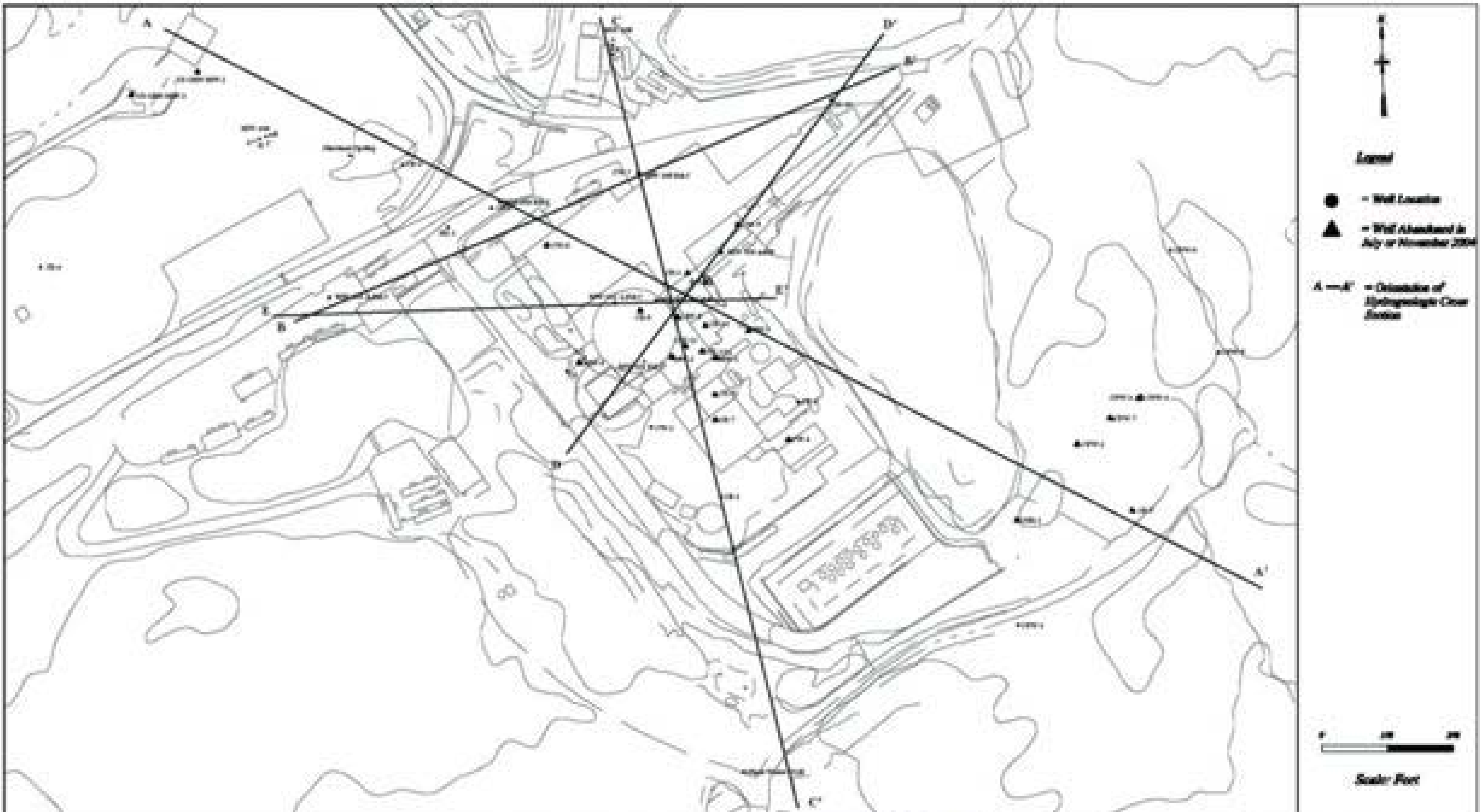


Yankee Nuclear Power Station
Rowe, Massachusetts

Cross-Section Showing West Wall of SFP/IXP Complex, Looking East

Revision: 0
MARCH 2005

FIGURE 25



	Yankee Nuclear Power Station	YANKEE	*Date: February 2005*	*Figure: 7*
	Location of Cross Sections		*Revision: 1*	

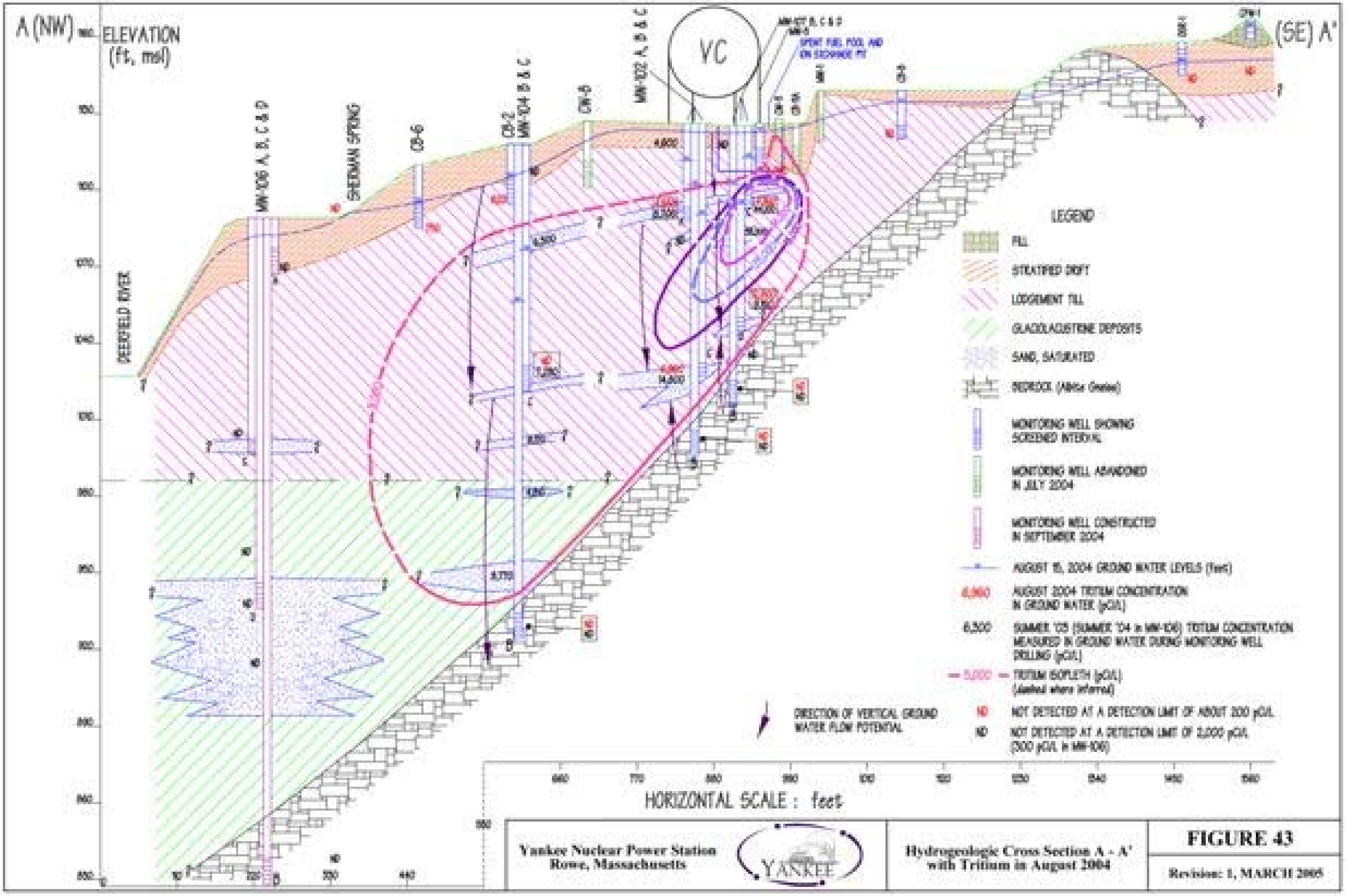


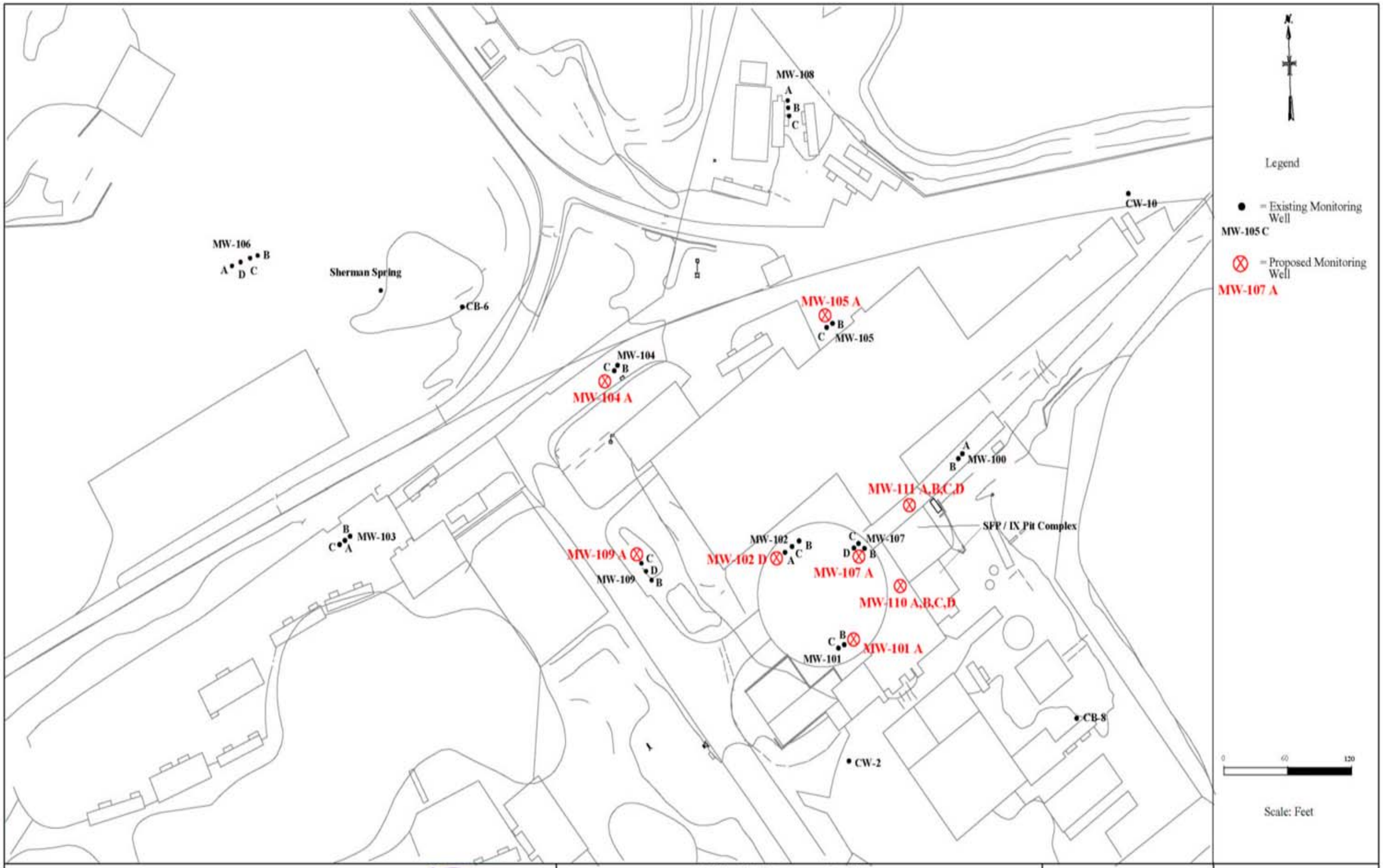
FIGURE 43

Hydrogeologic Cross Section A - A' with Tritium in August 2004

Revision: 1, MARCH 2005

2006 MW Drilling Program

- 17 Additional Wells Drilled by Rotosonic Method
- 3 Multi-Depth Well Clusters Drilled in Key Locations:
  - At IX Pit Leak
  - Adjacent to Lowest Part of SFP Foundation
  - Downgradient of Septic Leach Field
  - To Confirm Plume Source and Absence of Additional Radionuclides in GW Other Than H-3
  - To Better Define Interconnectivity of Aquifers
- 2 to Bound the Sand Lens with Highest H-3
- 6 Shallow Wells to Replace a Few Abandoned to Facilitate Plant Demolition



Yankee Nuclear Power Station
Rowe, Massachusetts

YANKEE

Well Network for Post-Decommissioning Phase of Ground Water Monitoring

Revision: 1
SEPTEMBER 2005

FIGURE 40

Preliminary Results of Ongoing 2006 Investigation

- H-3 Still the Only Plant-Related Nuclide
- Drilling Results Confirm Sand Lenses in Deep Till are of Limited Extent
- Pumping Tests Conducted to Determine:
  - Hydrogeologic Parameters (K, S) for Key Lenses
    - 24-Hr Constant Rate Test in Well With Highest Tritium
  - Hydraulic Connection Between Sand Lenses
    - 2-Hour Pressure Transient Tests in 12 Selected Wells
  - Pressure Transducers Monitor WL in Nearby Wells

Preliminary Results of Ongoing 2006 Investigation (con't)

- Numerical Fate and Transport Computer Model Under Development
  - Will Incorporate:
    - Stratigraphic Model From Drilling Results
    - Water Level Measurements With PXDs
    - Groundwater Sample Analysis Results
    - Pumping Test Results
  - To Validate Site Conceptual Model
  - To Predict H-3 Concentrations at Compliance Point
  - To Demonstrate Compliance with Criteria for License Termination

Yankee Rowe Lessons Learned

- The Rowe Site has Multiple Aquifers
- Contamination can Migrate Through Multiple Aquifers to Depths >100 feet.
- Hydrogeologic Investigation is an Iterative Process
- Important to Develop a Hydrogeologic Conceptual Site Model:
  - To Aid Well Placement
  - To Understand Contaminant Transport
  - To Define Aquifer Characteristics
- Long Term Data Trends Are Important
  - Allow Bias Detection
  - Identify Seasonal Fluctuations
  - Identify New Contaminant Releases

Yankee Rowe Lessons-Learned (continued)

- Water-Level Monitoring is Instructive
  - May Demonstrate Connection or Isolation of Aquifers
  - Useful for Calibration of Numerical Model
- Early Investigations at YNPS Not Sufficiently Rigorous
  - MWs not deep enough
  - Little Regulatory Involvement
- Involve All Stakeholders
- Analyze for Wide Suite of Radionuclides
- Include Non-Rad Constituents for Site Closure

Response to Selected ACNW Working Group Focus Questions

- Q1. Why are GW compliance monitoring data not used to enhance confidence in numerical models after site characterization and licensing is complete
  – Regarding operating power stations: GW characterization during plant design and construction was not sufficiently detailed to support contaminant fate & transport models
    - GW monitoring methods were in their infancy when the last power station was built (early 1970s)
  – Rigorous GW investigation should occur during plant construction with wells drilled near and downgradient from key sources of primary water:
    - Spent Fuel Pool
    - Refueling Water Storage Tanks
    - Condensate Tanks

- Data from the initial detailed investigation can be used to:
  - Build a numerical model
  - Respond to contaminant releases more expeditiously (stratigraphy, GW flow directions and contaminant flow paths already known)
- Long-term GW monitoring data used to:
  - Detect contaminant releases
  - Refine numerical model - change in state variables measured over time used to improve model calibration
    - Hydraulic head (water levels)
    - Water temperature
    - Tidal influence
    - Surface water stage
    - Contaminant concentration temporal trends
      - » Tritium or other radionuclides
      - » Hydrocarbons, solvents and degradation products
      - » Inorganic constituents: chlorides, boron

Response to Selected ACNW Working Group Focus Questions

- Q6. New Methods and Analytical Tools That Should be Pursued:
  - GW age determination by measuring the ratio of ^{3}H to ^{3}He may improve calibration of models of some GW systems
    - Aid definition of GW flow paths
    - Identify contaminant transport zones
  - Soil-gas surveys of ^{3}He concentrations can be useful for delineating shallow tritium plumes


YANKEE
Questions?

Limitations with Integrating Monitoring and Modeling in the Context of Decommissioning

Mark Thaggard
Division of Waste Management
and Environmental Protection
US Nuclear Regulatory Commission

Presented before: The Advisory Committee on Nuclear Waste
Working Group Meeting on Using Monitoring to Build Model Confidence

September 19-20, 2006
Rockville, Maryland

NRC Decommissioning Requirements

- Unrestricted release
  - 25 mrem/year + ALARA
  - 1000-year compliance period
  - Assessment only considers on-site activities
- Restricted release
  - 25 mrem/year with restrictions in-place
  - 100 or 500 mrem/year if restrictions fail
  - 1000-year compliance period
  - Assessment needs to consider both on-site and off-site activities

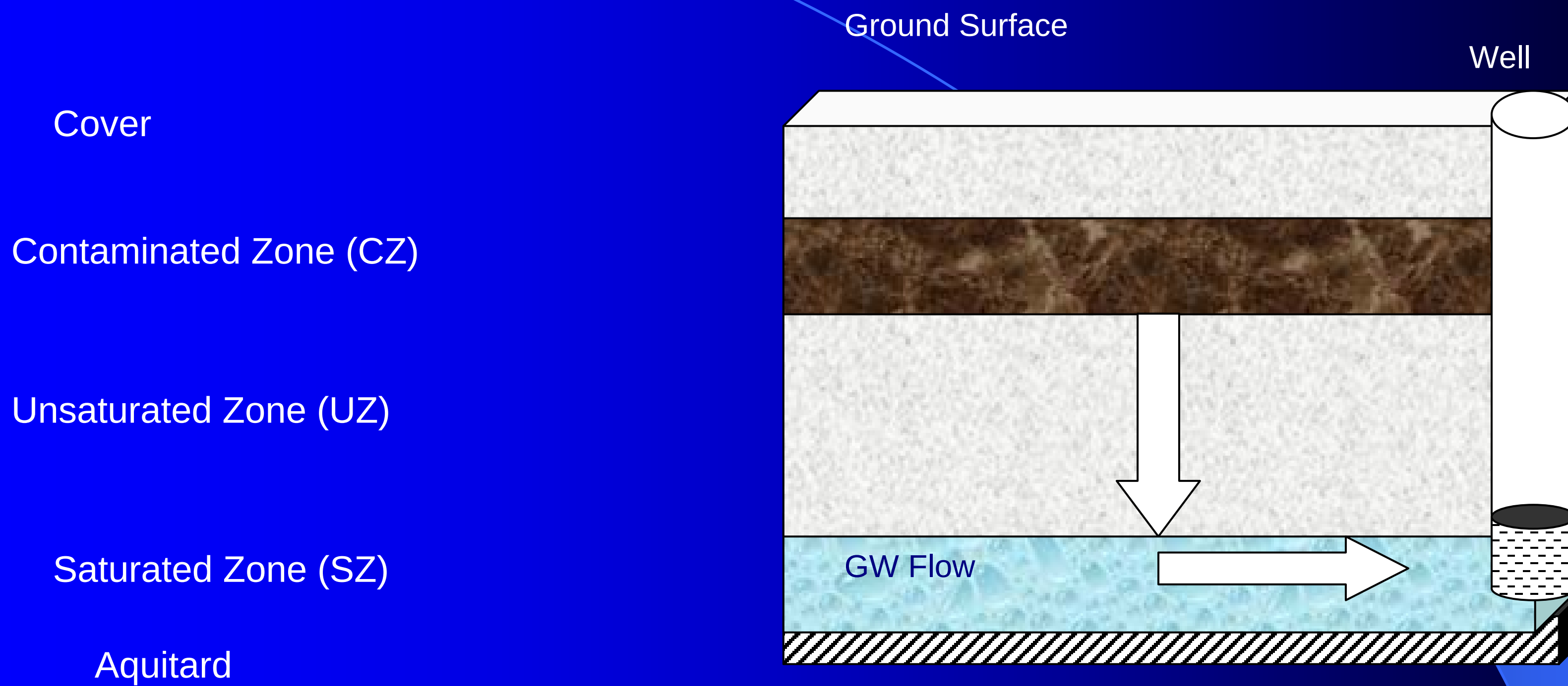
Characteristics of the NRC Decommissioning Program

- Roughly 300 sites are decommissioned each year
- Vast majority have no environmental contamination – mostly buildings
- Limited number of sites are known to have groundwater contamination
- Restricted release is being considered at only a couple of sites

Common Modeling Used in Decommissioning

- Vast majority of decommissioning accomplished through use of screening tables
  - Screening tables were developed by the NRC
  - Assumes no existing groundwater contamination
  - Monitoring information needed to confirm this assumption
- RESRAD is the primary tool used for carrying out analyses
- More complex modeling may be needed for:
  - Assessing off-site impacts (restricted release)
  - Addressing existing groundwater contamination
- Limited application for use of complex groundwater modeling in decommissioning

RESRAD Conceptual Model

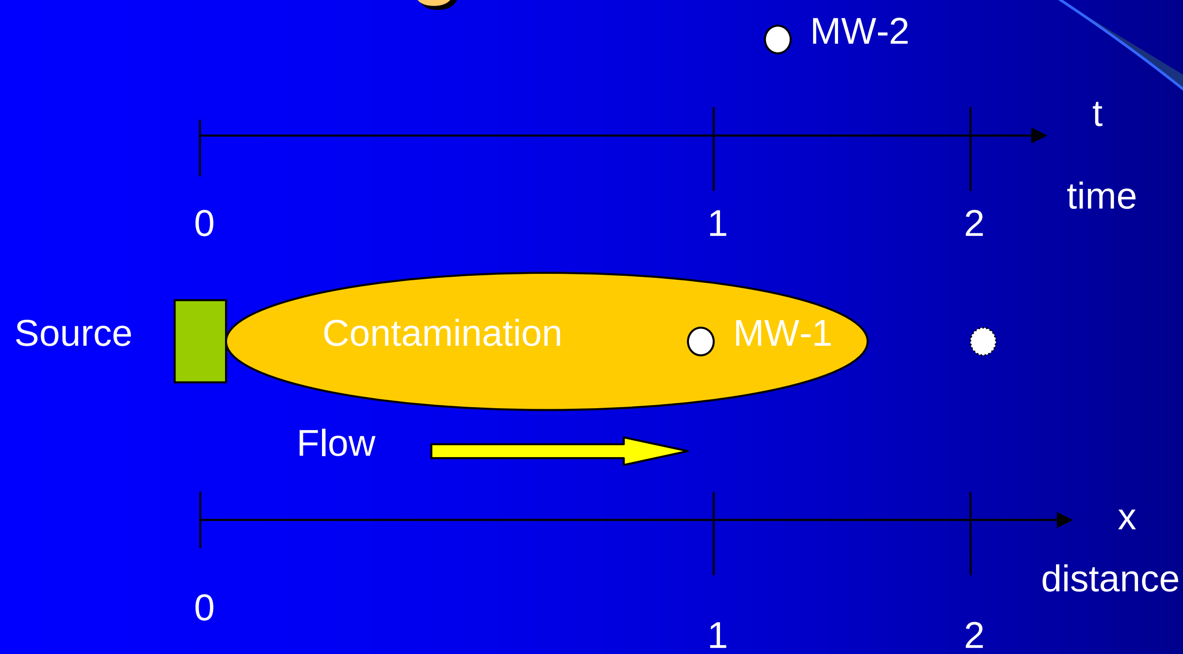


- Assumes 1-D vertical transport
- Assumes no dispersion in the UZ and SZ
- Considers adsorption in CZ, UZ, and SZ
- Assumes well located either in source or immediately down-gradient
- Requires definition of limited number of hydrologic parameters

Integration of Monitoring with RESRAD

- Characterization data used to develop site-specific hydrologic parameters
- Monitoring data can be used to calibrate Kd values
  - Very limited success
    - Information when the gw contamination occurred is often uncertain
    - Requires an assumption that $Kd_{CZ}=Kd_{UZ}=Kd_{SZ}$
    - Requires special consideration for handling decay-chain products
  - Useful as a broad indicator of the likelihood of groundwater contamination

Practical Considerations for Site with Existing Groundwater Contamination



Velocity = $(x_1 - x_0)/(t_1 - t_0)$

-or -

Velocity = $(x_2 - x_1)/(t_2 - t_1)$

- Only a few sites have existing gw contamination
- If available, can be used to calibrate velocity
- Usually t_0 is uncertain
- Monitoring program designed for other purposes
  - NPP REMP wells at site boundary
  - MW-2 in wrong location

Practical Considerations (cont.)

- Existing groundwater monitoring data typically covers a very short time period
  - Primarily intended for verifying no contamination
  - Usually undertaken during decommissioning

Summary

- Most decommissioning accomplished through either the use of screening tables or RESRAD
  - Limited opportunity for integrating monitoring and modeling
  - Monitoring used to define hydrologic parameters and gain insights on the likelihood for contaminants to reach the water table
- Limitations on integrating existing groundwater data
  - Small number of sites with existing groundwater contamination
  - Uncertainties on when the source originated
  - Monitoring program often designed for other purposes

3D GEOSPATIAL MODELS TO SUPPORT DECISIONS IN COMPLEX DECOMMISSIONING

OUTLINE

- 3 D MODEL CAPABILITIES
- EXAMPLES OF DECOMMISSIONING APPLICATIONS
- ADDITIONAL USES OF 3 D MODELING
- CONCLUSIONS

3D MODEL APPLICATIONS

- IN *COMPLEX SITE TRACKING SYSTEM* (AND SDMP) ~ FOUR DOZEN SITES
  - EXTENSIVE SUBSURFACE CONTAMINATION
  - CONTAMINANT MIGRATION
    - AIRBORNE DISPERSION/DEPOSITION
    - SURFACE WATER TRANSPORT
    - GROUND WATER TRANSPORT
- FINAL STATUS SURVEY REPORTS CONTAIN HUNDREDS OF PAGES OF SITE DATA

WHY 3D MODELS ?

- **VISUALLY DISPLAY SELECTED DATA**
- **ANALYZE VARIATIONS IN PLUME CHARACTERISTICS IN TIME AND IN SPACE**

NRC DP/LTP REVIEW

- IS "DESCRIPTION OF CONDITION OF SITE" ADEQUATE?
  - CHARACTERIZATION OF CONTAMINATION
  - LOCATION OF CONTAMINATION
  - VOLUME OF CONTAMINATION

- WILL PLANNED ACTIVITIES REDUCE RESIDUAL CONTAMINATION TO PROPOSED RELEASE LEVELS?

NRC LICENSE TERMINATION DECISIONS

- DID THE ACTIVITIES AS EXECUTED REMEDIATE EXISTING CONTAMINATION?
- WAS FINAL STATUS SURVEY CONDUCTED PER PLAN?
- DOES SURVEY REPORT DEMONSTRATE COMPLIANCE WITH APPROVED LIMITS?

RESTRICTED RELEASE

- **IS THE CONFIGURATION OF THE WASTE ACCEPTABLE FOR THE EXPECTED COMPLIANCE PERIOD ?**
- **IS THE PROPOSED MONITORING ADEQUATE TO DETECT RELEASES ?**

3-D MODEL CAPABILITIES

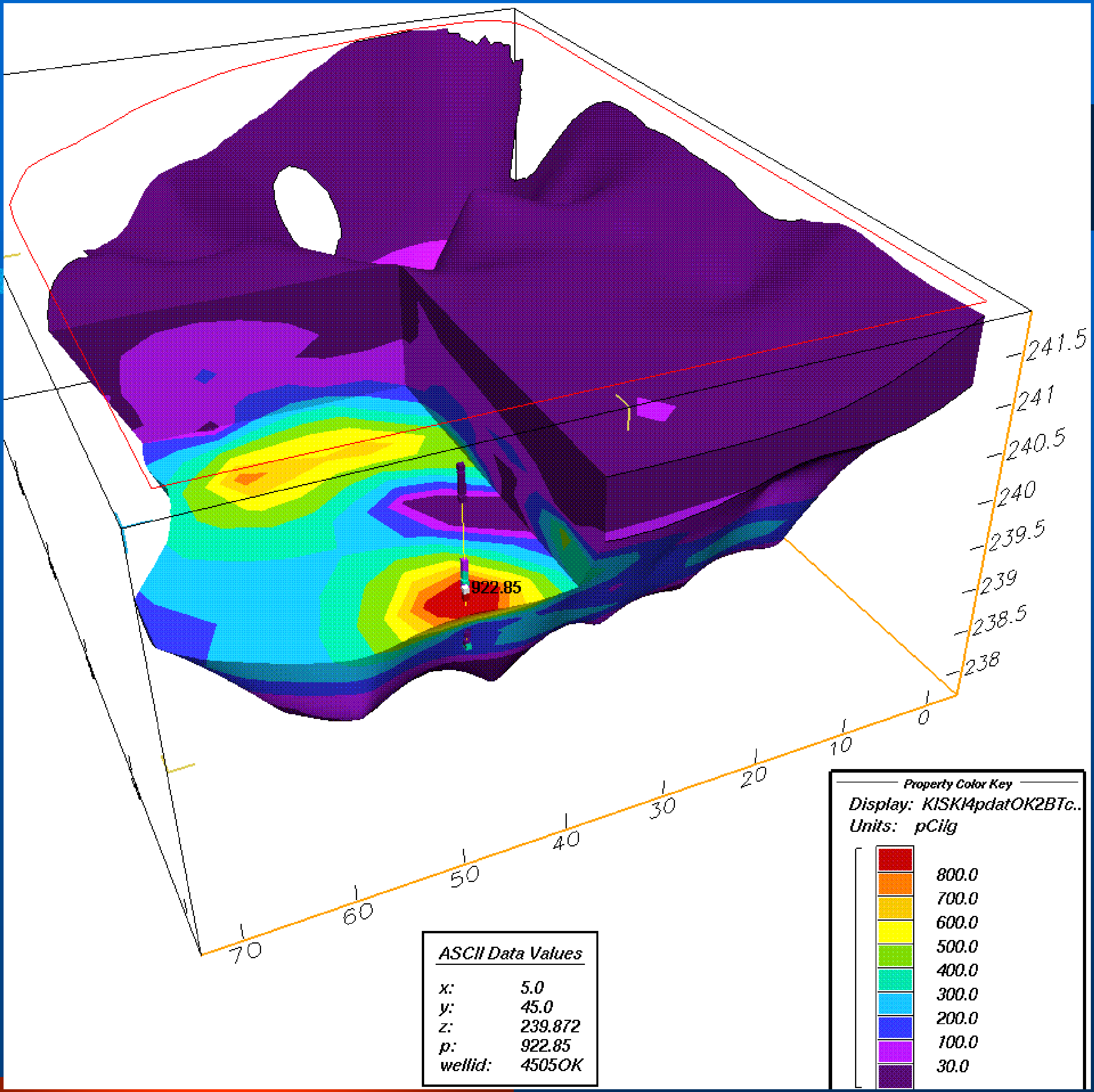
- 3D HYDROGEOLOGIC FRAMEWORK AND PROPERTY MODELS ENABLED VISUALIZATION AND ANALYSIS OF VARIATIONS IN CONTAMINANT CONCENTRATIONS AND PLUME GEOMETRY IN SPACE AND TIME FOR:
  - ASSESSMENT OF DATA DISTRIBUTION
  - DELINEATION OF CONTAMINANT SOURCE AREAS
  - DEFINITION OF VERTICAL AND LATERAL MIGRATION PATHWAYS
  - CALCULATION OF CONTAMINANT PLUME VOLUMES

EXAMPLES

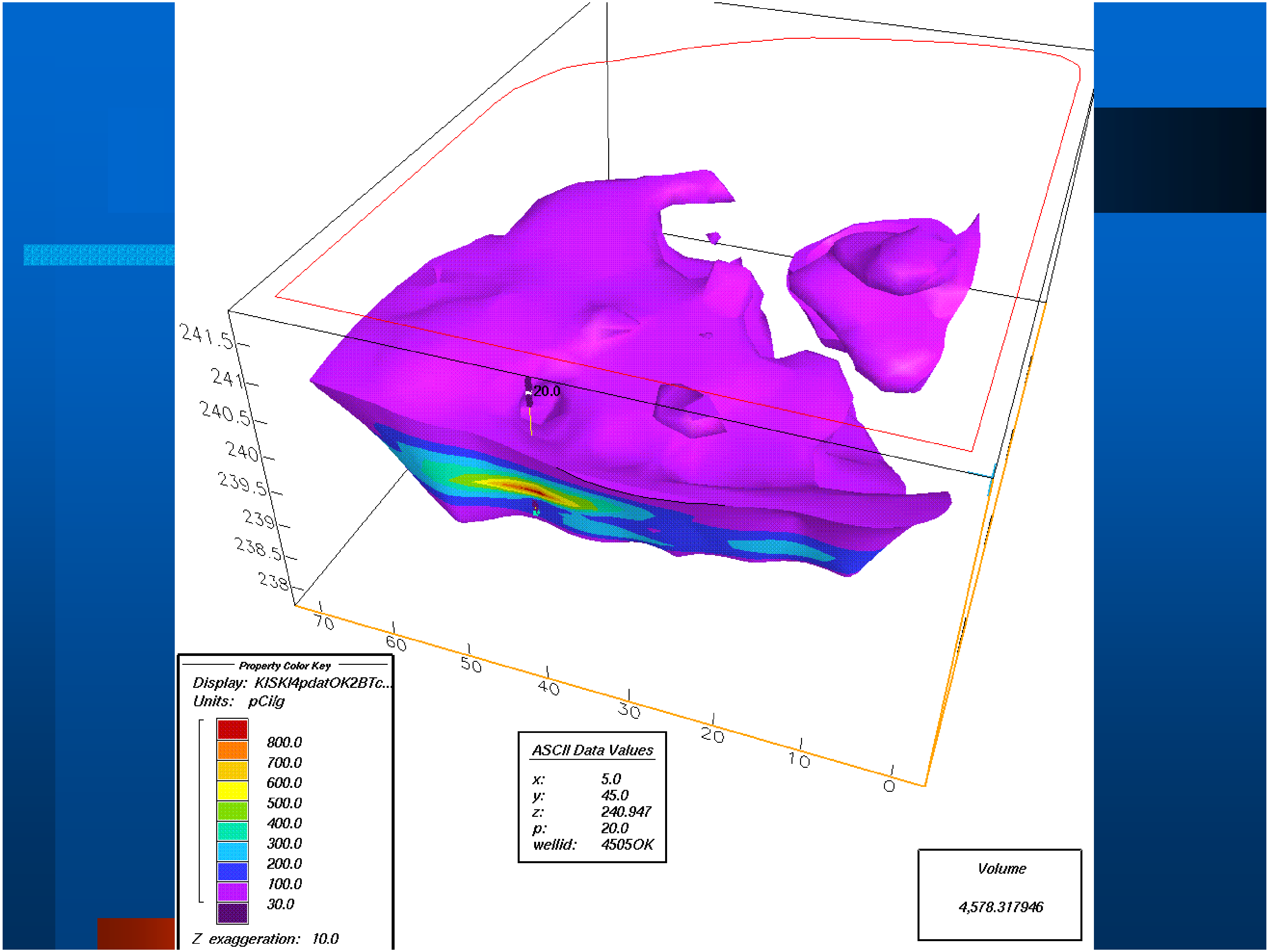
- KISKI VALLEY
- BIG ROCK POINT

KISKI VALLEY

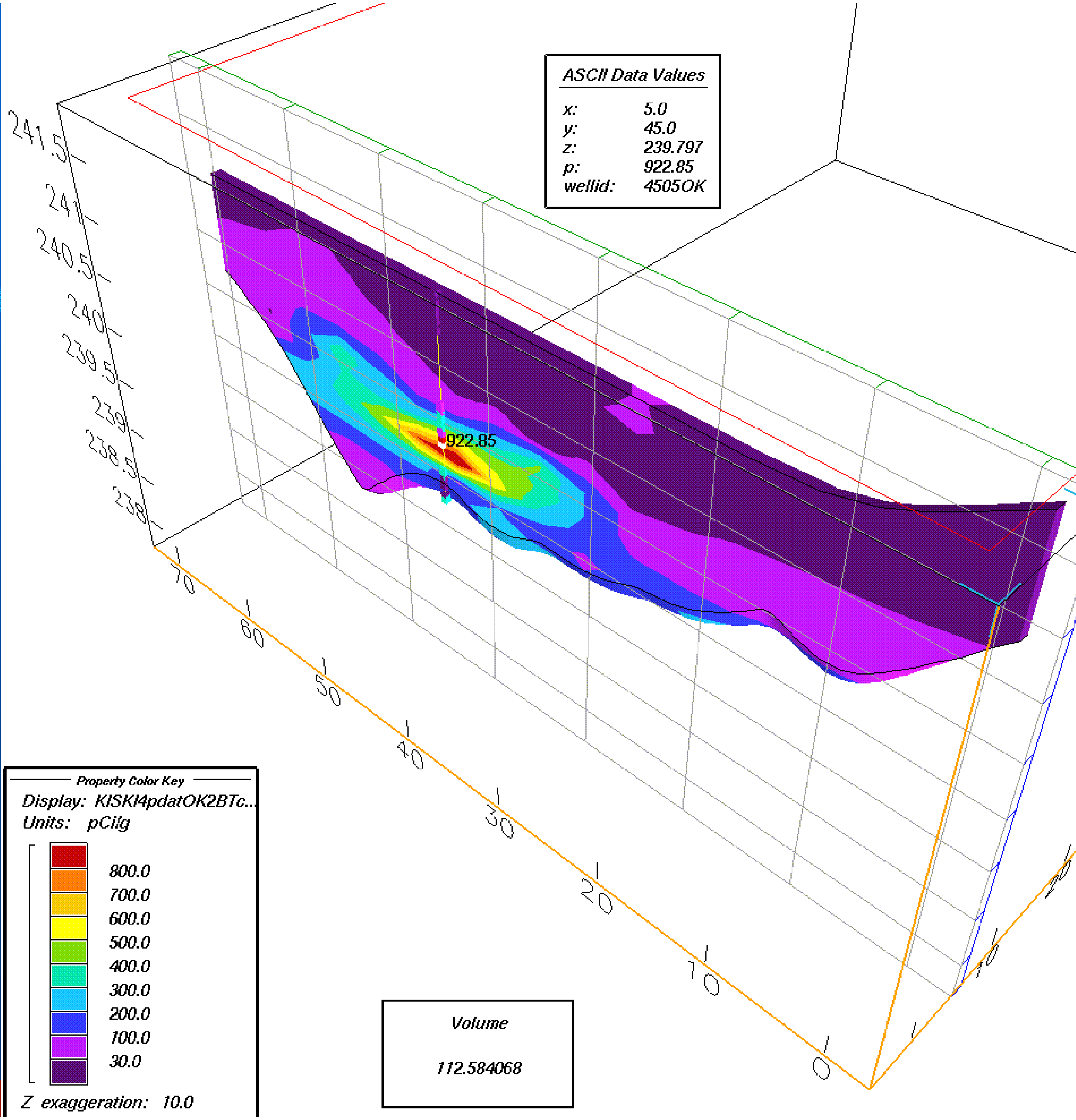
- 3D EVALUATION OF CONTAMINANTS
  - CONCENTRATION BY LOCATION
  - VOLUME OF SPECIFIC CONCENTRATIONS
- CONCLUDED NO FURTHER REMEDIATION REQUIRED
  - HIGH COST TO REMEDIATE
  - LOW LIKELIHOOD OF PUBLIC DOSE



241.5
241
240.5
240
239.5
239
238.5
238
0
10
20
30
40
50
60
70
922.85
ASCII Data Values
x: 5.0
y: 45.0
z: 239.872
p: 922.85
wellid: 4505OK
Property Color Key
Display: KISKI4pdatOK2BTc..
Units: pCi/g
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
30.0



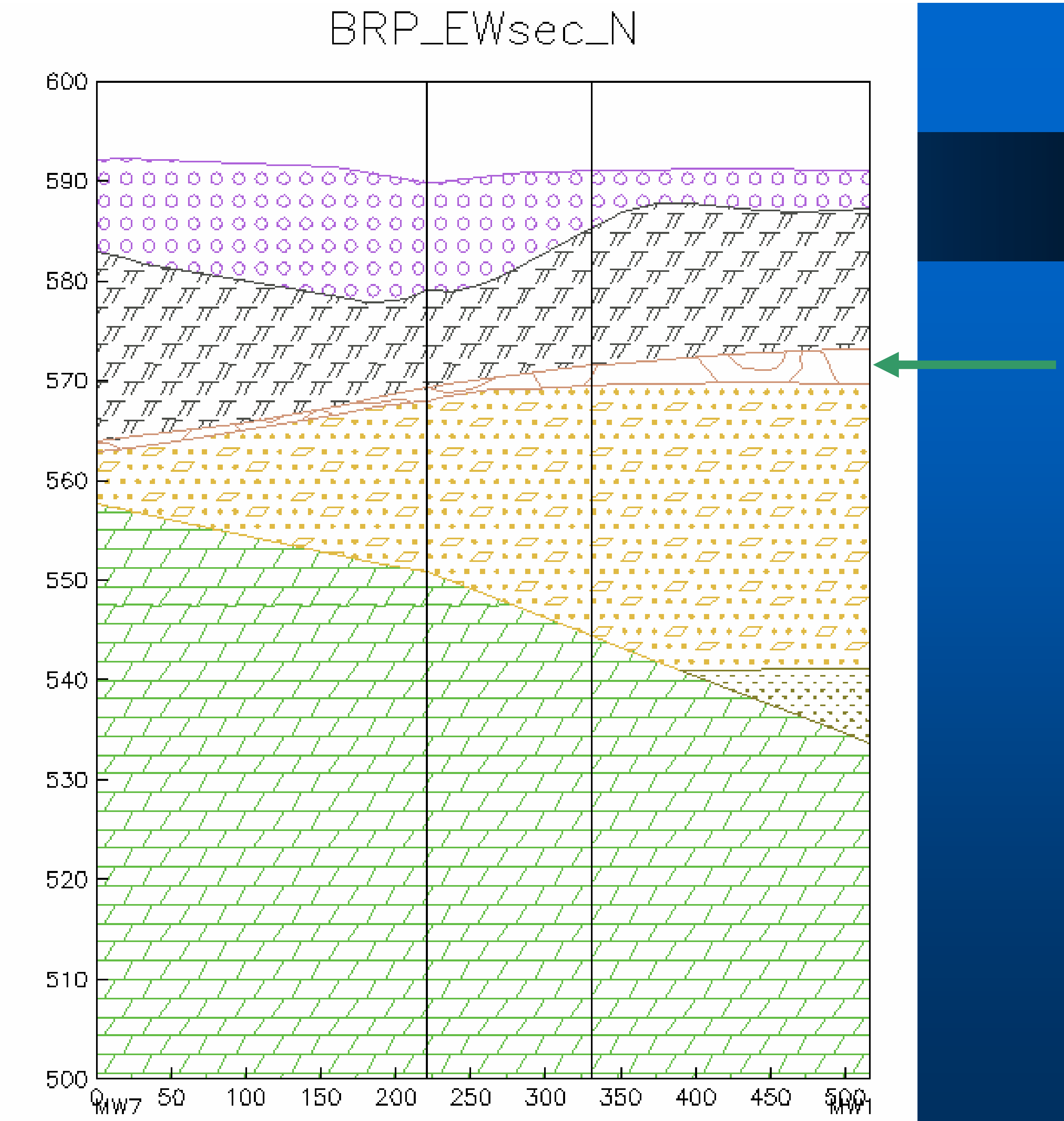
241.5
241
240.5
240
239.5
239
238.5
238
20.0
70
60
50
40
30
20
10
0
Property Color Key
Display: KISKI4pdatOK2BTc...
Units: pCi/g
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
30.0
Z exaggeration: 10.0
ASCII Data Values
x: 5.0
y: 45.0
z: 240.947
p: 20.0
wellid: 4505OK
Volume
4,578.317946



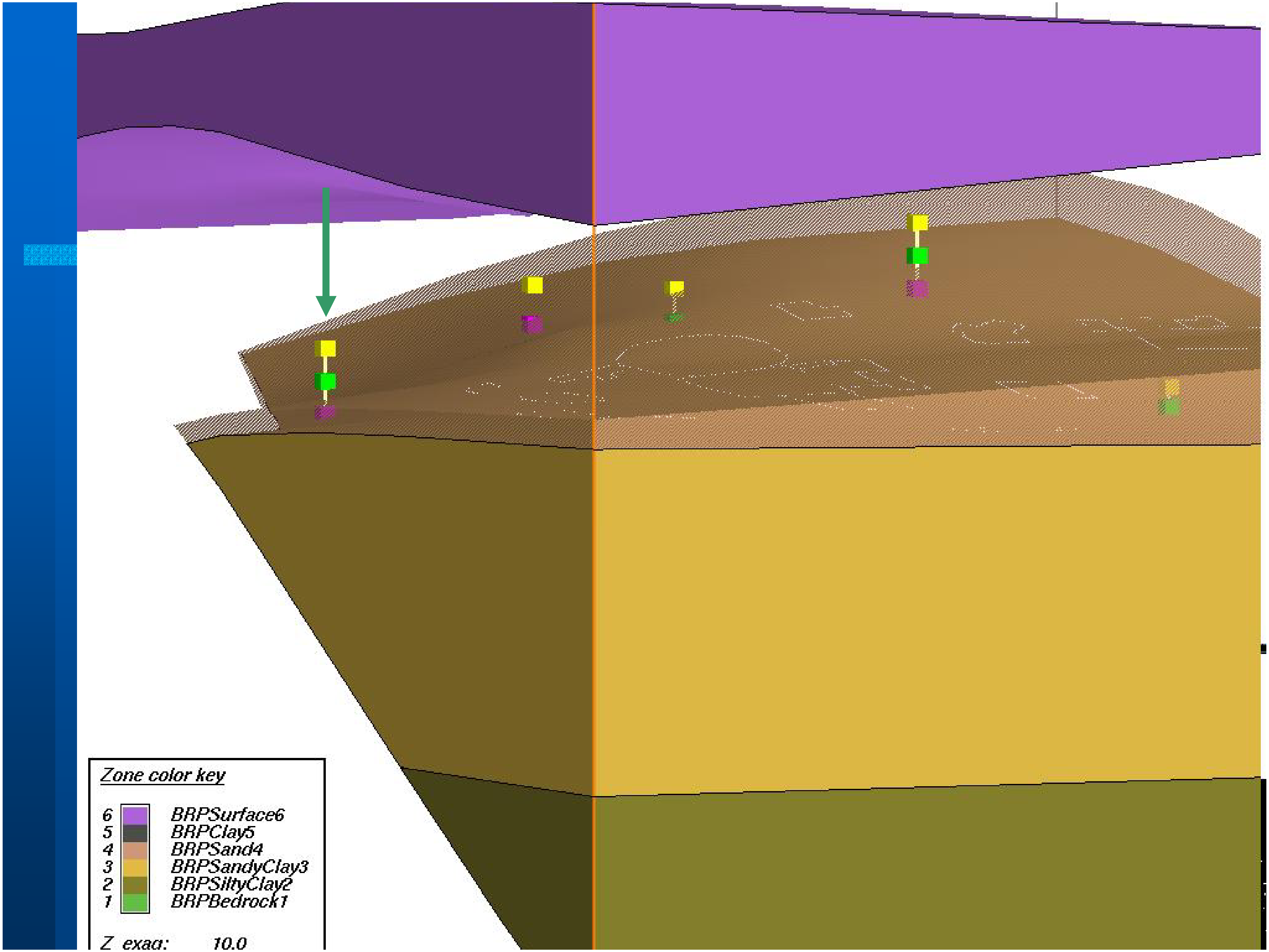
ASCII Data Values
x: 5.0
y: 45.0
z: 239.797
p: 922.85
wellid: 4505OK
922.85
241.5
241
240.5
240
239.5
239
238.5
238
70
60
50
40
30
20
10
0
10
20
Property Color Key
Display: KISKI4pdatOK2BTc...
Units: pCi/g
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
30.0
Z exaggeration: 10.0
Volume
112.584068

BRP EVALUATION

- TRITIUM RELEASED BENEATH TURBINE BUILDING IN 1984
- SHALLOW GROUND WATER SYSTEM IMPACTED
- ONE MONITORING WELL CLOSED
- REMAINING WELL LOCATION (Z) QUESTIONED RELATIVE TO “AQUIFER”



BRP_EWsec_N
600
590
580
570
560
550
540
530
520
510
500
0
MW7
50
100
150
200
250
300
350
400
450
500
MW1



Zone color key
6 BRPSurface6
5 BRPClay5
4 BRPSand4
3 BRPSandyClay3
2 BRPSiltyClay2
1 BRPBedrock1
Z exag: 10.0

BRP RESOLUTION

- DISCUSSED MODELS AND DATA WITH SITE GEOLOGIST

- LICENSEE ADDED TWO MONITORING WELLS TO MONITOR POTENTIAL MIGRATION PATH

ADDITIONAL USES OF MODELS

- ASSIST IN PLACEMENT OF WELLS FOR COMPLIANCE MONITORING.
- ASSIST IN PLACEMENT OF WELLS FOR CONTROLLING CONTAMINANT MIGRATION (WHEN PUMP AND TREAT IS EFFECTIVE).
- DETERMINE MATERIAL VOLUMES FOR EXCAVATION OR FOR PUMP AND TREAT AND ASSOCIATED COSTS

PLANNED FUTURE USES

- Land use and exposure scenarios
- Institutional control boundaries
- Detailed ground cover – time lapse
- Integrate with 3-D subsurface modelling

CONCLUSIONS

- USES STATE-OF-ART GIS TOOLS AND TECHNIQUES
- EFFECTIVE VISUALIZATION TOOL
- FACILITATES TIMELY DECOMMISSIONING AT EXISTING SITES

THE END

Jim Shepherd, Project Engineer,
Decommissioning Directorate
USNRC MS T7 E18
Washington, DC 20555

jcs2@nrc.gov
301-415-6712

Integration of Performance Assessment and Monitoring

Matthew W. Kozak

Monitor Scientific LLC

Denver, CO

mkozak@monitorsci.com

Scope of the presentation

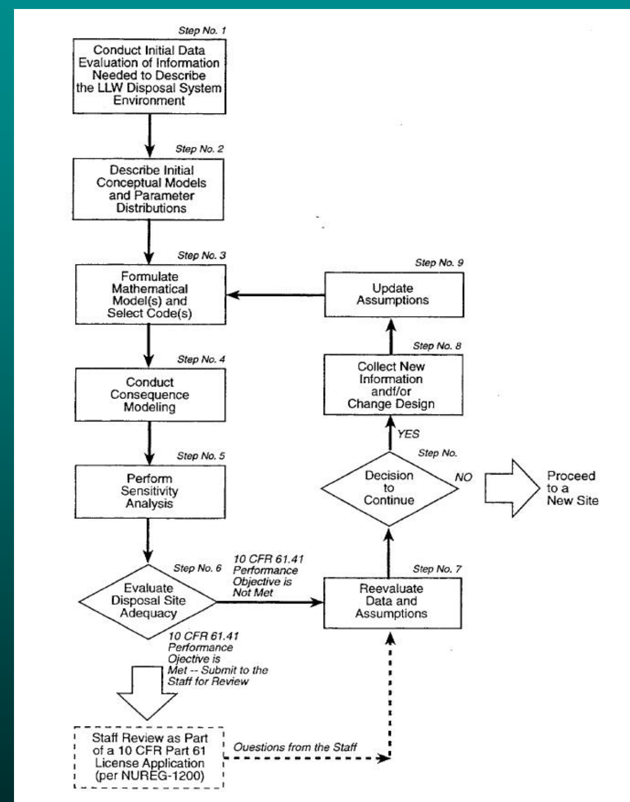
- Definitions
- Issues in using monitoring information from a performance assessment perspective
- Conclusions

Definitions

- Monitoring
  - Observations directed at dependent variables of performance assessment models
  - This context is well understood and commonly used in the context of RCRA and CERCLA
- Data Collection
  - Observations directed at independent variables (input parameters) of performance assessment models
  - Clearly provides the necessary input for the performance assessment, but it is necessary to set priorities
- Some “monitoring” programs are really directed toward data collection

Data Collection

- **Performance assessment is an unusual activity**
  - **Projection of doses over long time periods**
  - **Need for modeling as the basis for decisions**
  - **Decisions in the absence of observations of the model output**
- **NRC guidance on the need for integration of performance assessment and data collection**



NUREG-1573

Monitoring

- Two distinct situations
  - A proposed facility
  - An existing facility, potentially with an existing plume
- The utility of monitoring differs for these two situations
- For a proposed, modern, engineered repository, a monitoring system will never be expected to have a positive hit for many lifetimes into the future
  - View monitoring as an approach to public confidence
  - Technically largely irrelevant
  - Except for ancillary data collection
- What can we do with monitoring data from existing facilities?

Monitoring Results:
Negatives, False or Otherwise

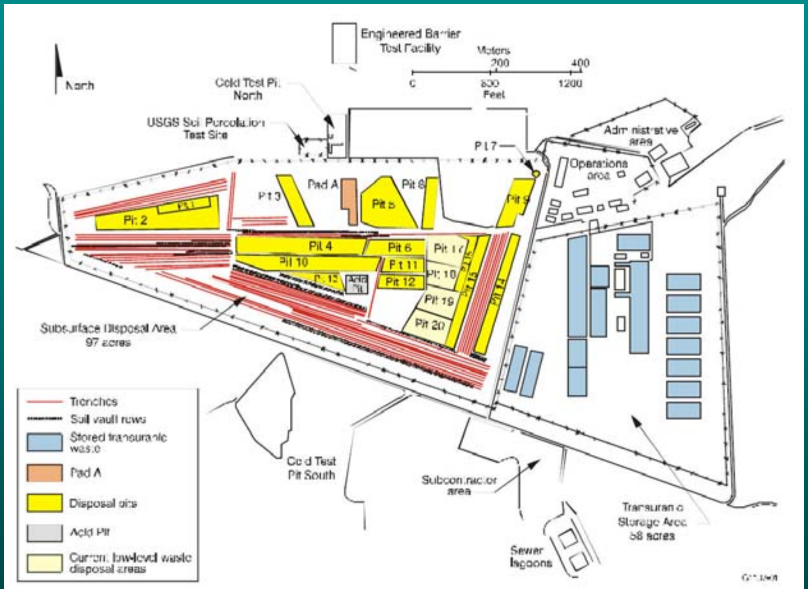
- No observed migration from the repository
- Surface inspection suggests some degradation of the engineered system
- What can be concluded?


Novi Han, Bulgaria, circa 1994


Novi Han, Bulgaria, circa 2004

Monitoring Results:
False Positives

- Plutonium observed in deep clay interbeds
- Not confirmed by subsequent monitoring
- Led to substantial effort
  - "Calibrate" performance assessment
  - Additional monitoring
  - Public furor
- Now there is substantial evidence that the original observations were false positives



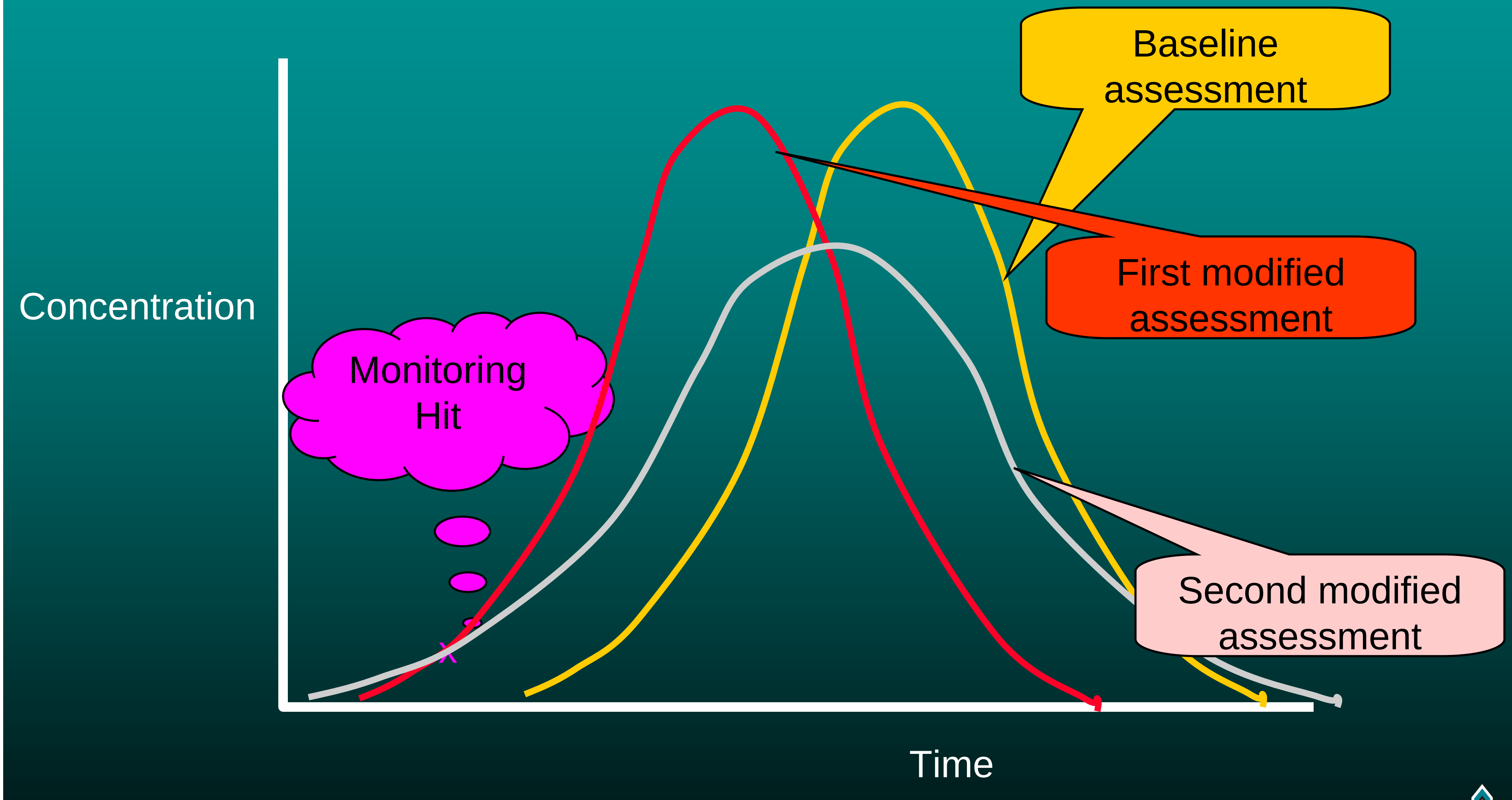
INL Radioactive Waste Management Complex

Monitoring Results:
True Positives

- Observations of Ra-226 migration outside the vault
- Initial performance assessment showed negligible consequences of those observations
- Other issues were more important
- The decision was not made based on good technical grounds

Disposal Vault at Chisenau, Republic of Moldova

What does a monitoring observation mean?



Monitor Scientific

What does a monitoring hit mean for performance assessment?

- Early arrival times are not necessarily worse than later, but are perceived to be
- Early monitoring hit may be indicative of greater dispersion or a fast path not critical to risk
- Calibration of the performance assessment to the observation may actually make it less conservative
  - It may be possible to improve operational limits
  - But should not fundamentally change regulatory decisions

Summary

- Data collection is an integral part of performance assessment
- From a purely technical view, monitoring is largely irrelevant for new facilities
  - However, "monitoring" networks may provide useful information for data collection
  - Monitoring may reduce risk associated with societal perceptions
- Monitoring is of limited utility for operational facilities
  - Negatives do not provide confidence because of the high potential for false negatives
  - Significant issues with false positives
  - Limited use for true positives
- Positive hits should be used with caution, but political and social pressures may overwhelm such caution

Conclusions

- **All knowledge about a facility is useful**
- **Monitoring programs should be designed for both monitoring and data collection**
- **Results (either positive or negative) need to be treated carefully**

Integrating Monitoring with Performance Assessment

David W. Esh

Division of Waste Management and Environmental Protection

US Nuclear Regulatory Commission
Contact info: (301) 415-6705, dwe@nrc.gov

Presented to: The Advisory Committee on Nuclear Waste, Working Group Meeting on Using Monitoring to Build Model Confidence, September 19-20, 2006

Performance Assessment

- Performance assessments are used to demonstrate compliance with dose criteria
- Performance assessments may adopt ‘conservatism’ in order to manage uncertainty
- In theory, actual risk and the performance assessment compliance risk estimate would be identical
- In practice, the actual risk is unknown and the compliance risk estimate likely represents a substantial deviation

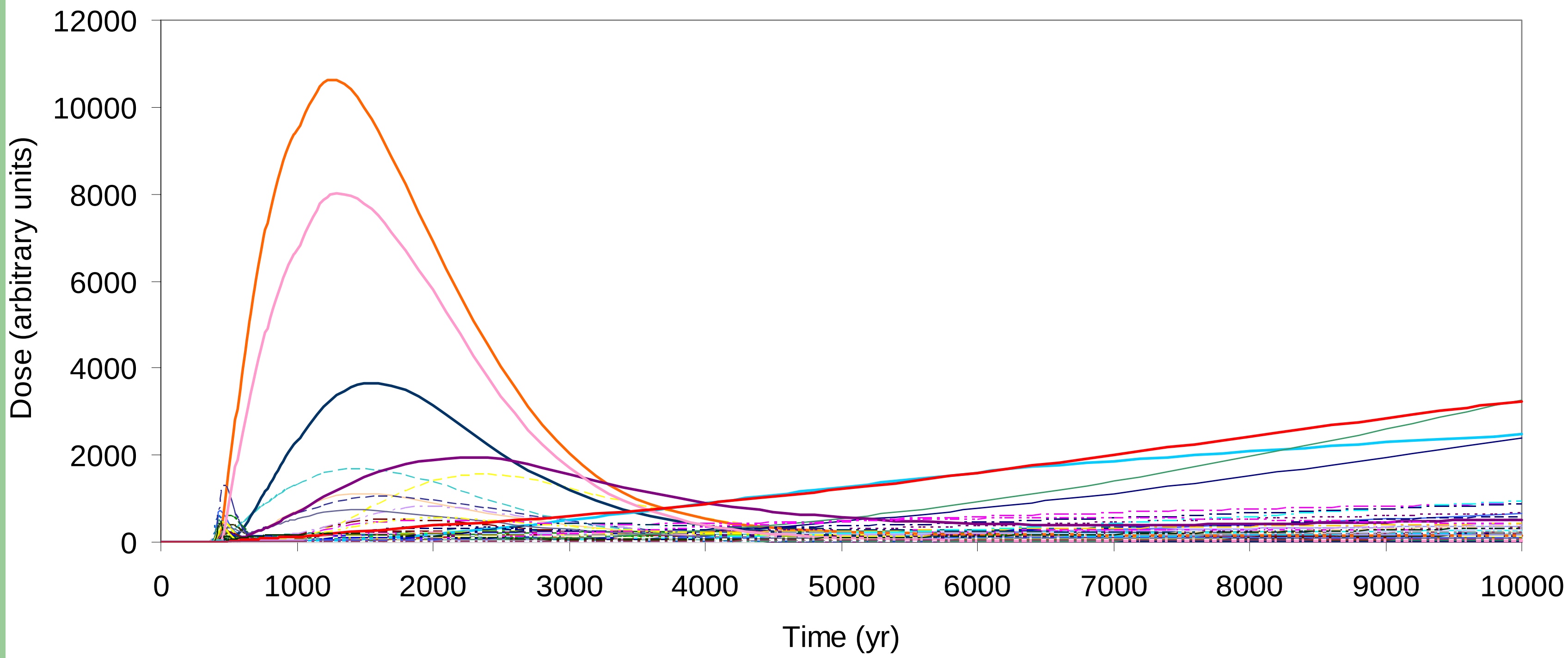
Model Support

- Performance assessment results are only as good as the support provided for the models
- Performance assessments can not be validated in the traditional sense
- Building confidence in performance assessment results can take a variety of approaches
- Model support is essential to regulatory decision making

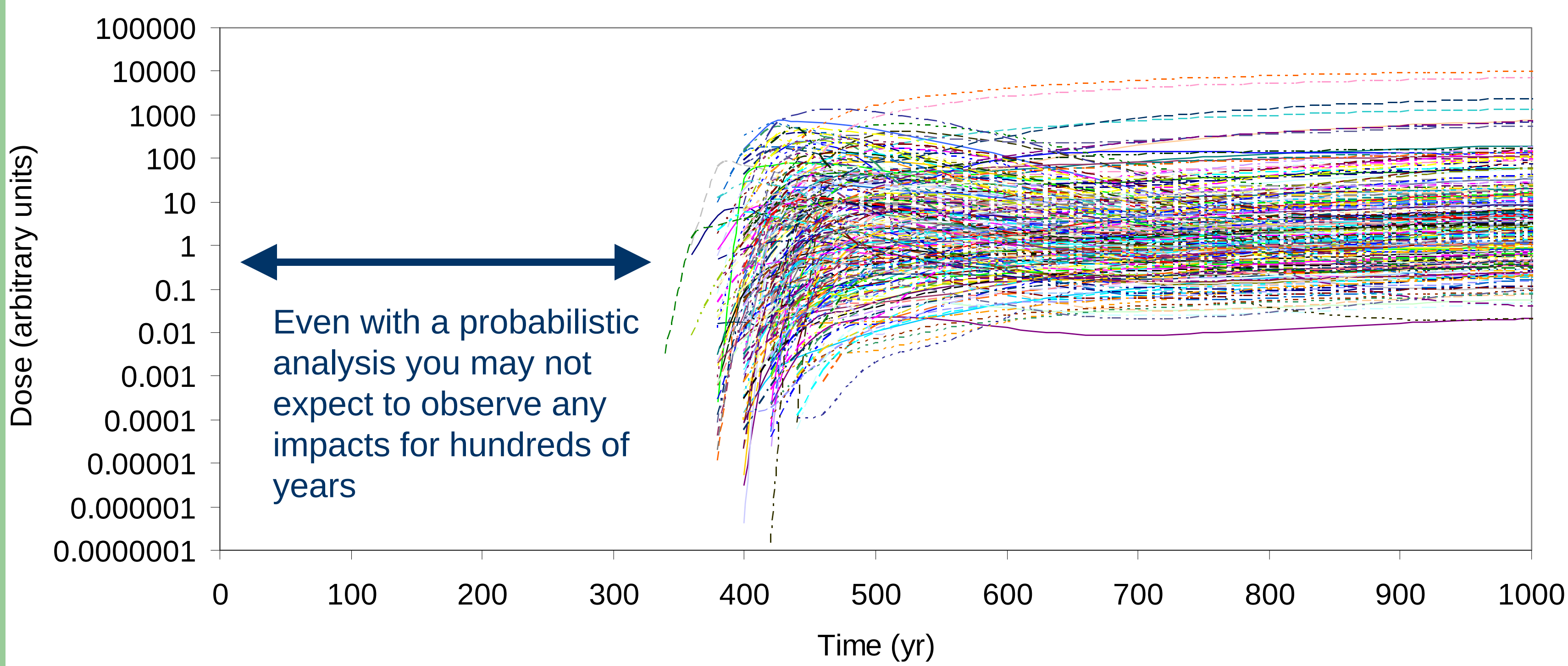
Monitoring

- Traditionally, monitoring is used to observe the concentration of contaminants in environmental media
- Monitoring systems are rarely developed to corroborate the performance assessment conceptual models
- Monitoring of engineered systems for waste issues has been limited and sporadic, but when done extensively has yielded extremely valuable observations

Monitoring and PA: The Problem



Monitoring and PA: The Problem

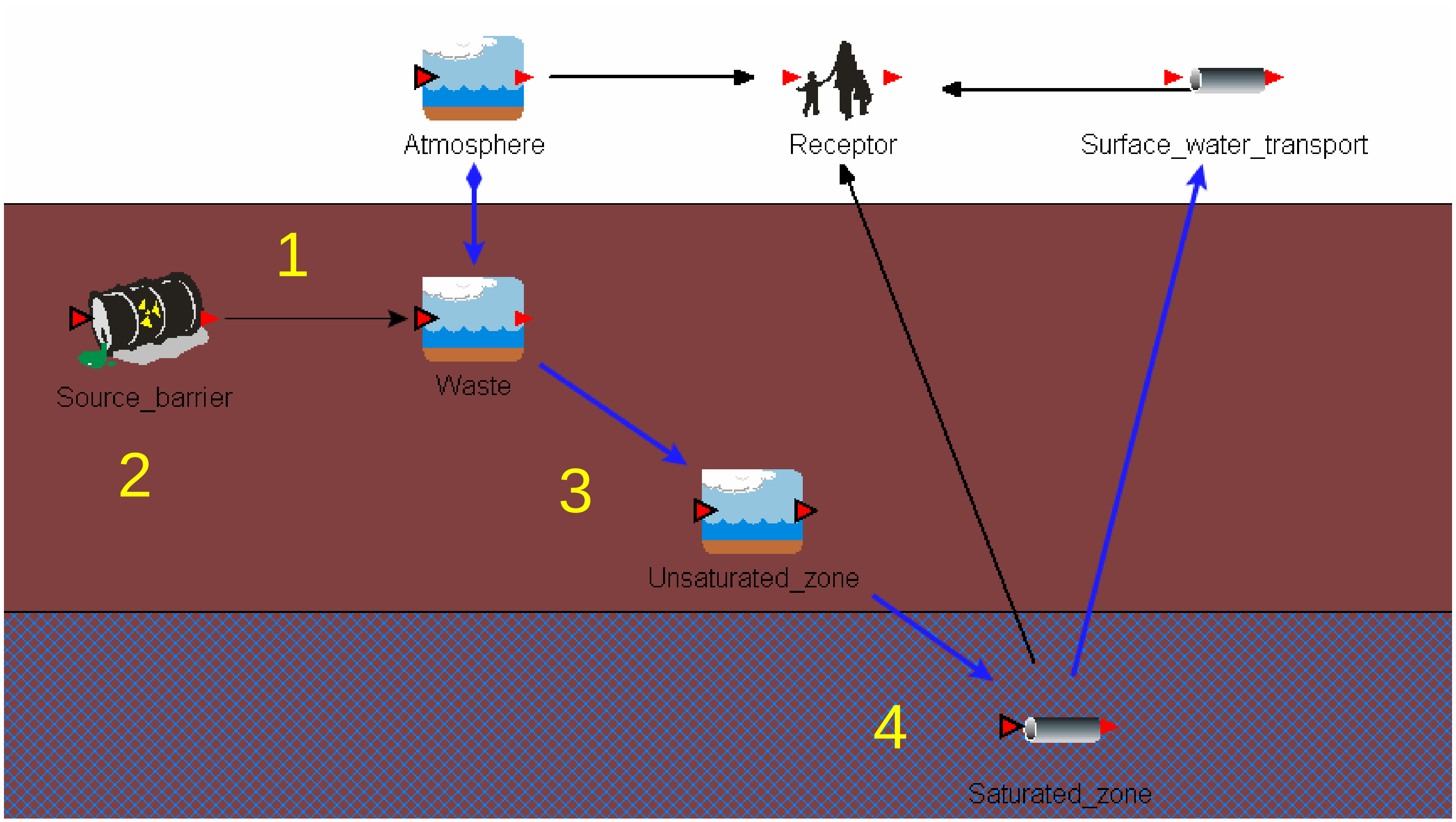


- A very distant future NRC regulator (Dick Codell's great^13-grandson) would be the first person to observe impacts

Performance Indicators

- Compliance monitoring (i.e., traditional environmental monitoring), should be supplemented with monitoring of performance indicators
- Indicators of natural and engineered system performance should be identified considering the performance assessment estimates
- Performance indicators are observables that are precursors of eventual dose impacts
- Successful use of performance indicators would be to confirm the conceptual representation of the system
- In most cases it is expected that observed environmental concentrations will not compare well with performance assessment estimates

Performance Indicators - Examples



Performance Indicators - Examples

- For points 1 through 4 on the previous slide, use of conservative tracers and dyes may go a long way to confirming conceptual models of environmental transport
- Different dyes and conservative tracers could be deliberately introduced into various regions of the system during construction, which could be used to confirm the hydrologic conceptual model
- Moisture content may be a gross indicator of the saturation state of the system, but may not give sufficient information about moisture flow rates (e.g., due to discrete features which may dictate transport)

Performance Indicators - Barriers

- Performance indicators of engineered barriers would be very specific to the barrier type and functionality
- Example – bulk cementitious barrier performance may be evaluated by analyzing alkalinity in water near the barrier and the in situ stress of the barrier
- Small representative samples of barrier materials may be installed in the same environment of the barrier and retrieved at different intervals to verify degradation rates and processes.

Monitoring

- Caution is needed to ensure the monitoring system does not introduce pathways for water or contaminants
- Caution is also needed in interpreting the results of monitoring, which will likely be uncertain and possibly complex
- Confirmation should be based on verifying the conceptual representation of the system, and not on matching numbers

Conclusions

- Monitoring plans should have an objective of supplying confirmation of performance assessment conceptual models, in addition to satisfying regulatory requirements of characterizing environmental concentrations
- Monitoring plans need to recognize the spatial and temporal challenges
- Monitoring should be designed into the system (e.g., conservative species and dyes)
- Confirmation of conceptual models is different from matching performance assessment model estimates with observed impacts

Contaminant Transport Considerations at the Hanford Site

Mike Fayer

mike.fayer@pnl.gov

Presented at the ACNW WG Meeting

September 19-20, 2006

Rockville, MD

Outline

- Recommendations
- Generic Transport Considerations
- Site-Specific Examples
- *Summary*

Contaminant transport in the subsurface environment is governed by a complex relationship of site- and contaminant-specific features, events, and processes. Recognizing and addressing that complexity is key to adequately understanding, monitoring, and predicting contaminant transport.

Recommendations

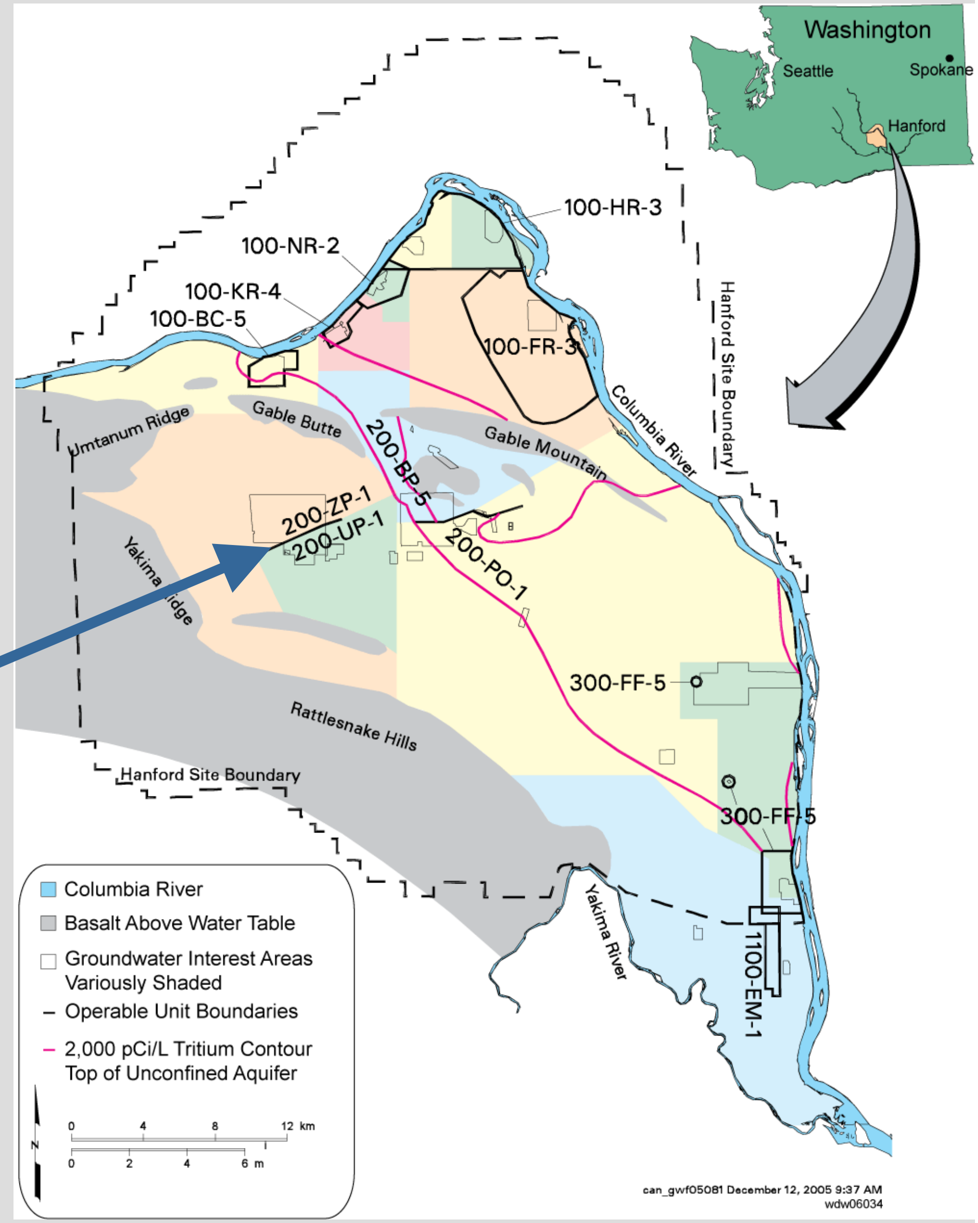
- Expand Definition of Compliance Monitoring and rename Compliance Assessment
  - Regulatory
  - Environment, Safety, &Health (ES&H)
  - Performance
- Assign Compliance Assessment Owner
  - Monitoring
  - Modeling
- Conduct Regular External Peer Reviews
- Include Entry Portals for New Data, Science, Legal, and Public Interests

Some Generic Transport Considerations

- Gas, liquid, aqueous solution, solid?
- Dilute or concentrated?
- Pure or mixed?
- Diffusion or advection dominated?
- Uniform, homogenous, and isotropic geologic media – or not?
- Constant or variable flow conditions?
- Constant or variable transport conditions?
- Future conditions within baseline conditions?

Hanford Site

- Construction started in 1943
- 1517 km^2 (586 mi^2)
- Ceased production 1987
- Remediation is current mission

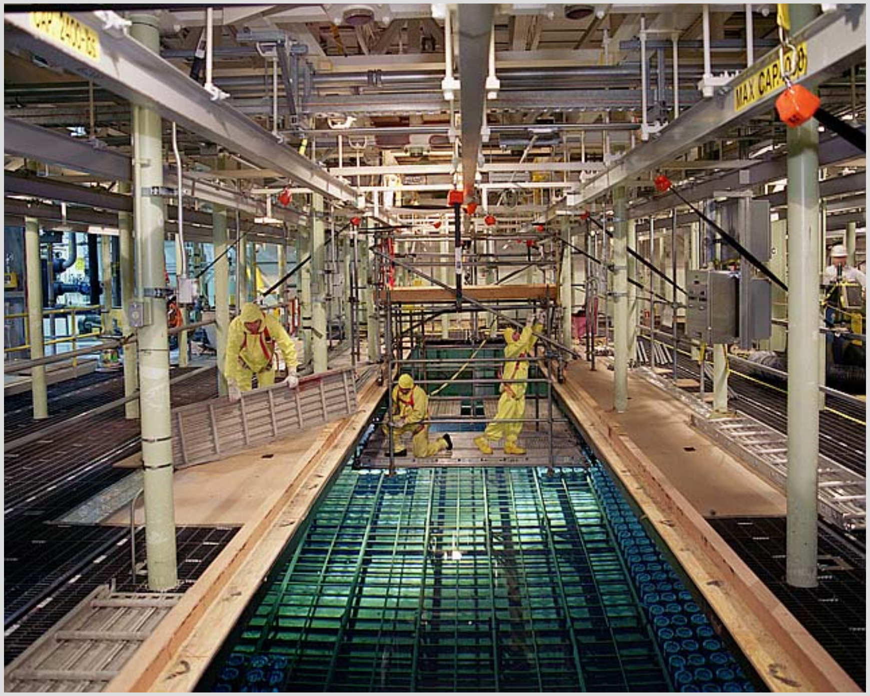


Example 1: Insufficient Early Characterization

- Fluid properties different than water
- pH as high as 14
- Ionic concentrations > 5 molar
- Dissolution/ precipitation
- Unknown leak points
- Poorly known geology beneath

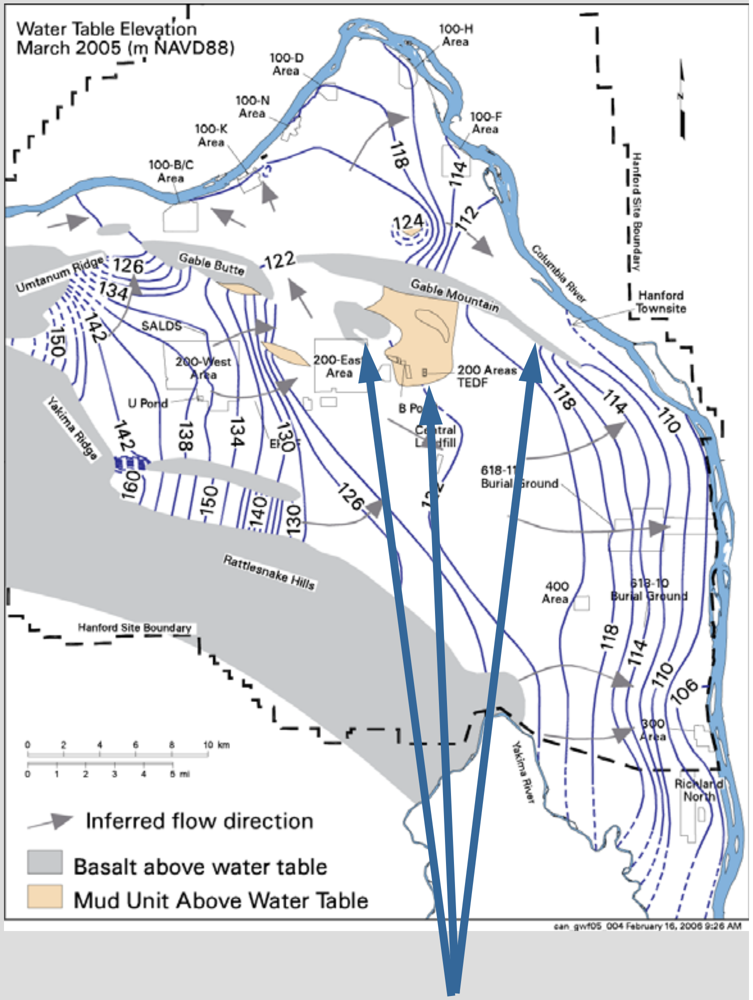
Example 2: Untested Monitoring System

- Groundwater contamination beneath K basins suggested leaking pool
- Leak detection system did not detect leak
- No record that leak detection system ever tested to confirm functionality



Example 3: Changing Flow Conditions

- Groundwater rising 1944 to 1979
- Boreholes screened in upper 5 m of aquifer
- Groundwater falling 1979 to present
- Net result:
  - Loss of groundwater monitoring as wells go dry
  - Water table dropping below basalt and mud tops in some locations, altering flow rates and directions
  - Some borehole locations no longer provide meaningful results



Basalt and mud tops appearing above water table in last 10 years

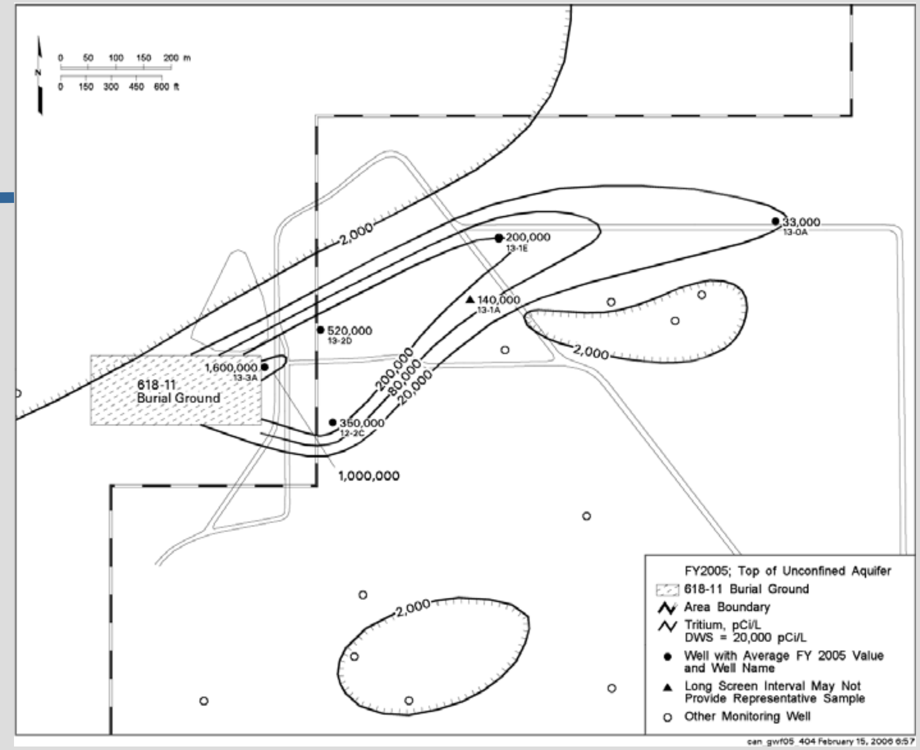
Example 4: Changing Flow Conditions

- Burial grounds, reactors, and disposal trenches near river
- Limited source remediation; unknown uranium source(s) remains
- Recurring contamination from vadose zone caused by surface infiltration and intermittent high river stage

Battelle

Pacific Northwest National Laboratory
U.S. Department of Energy

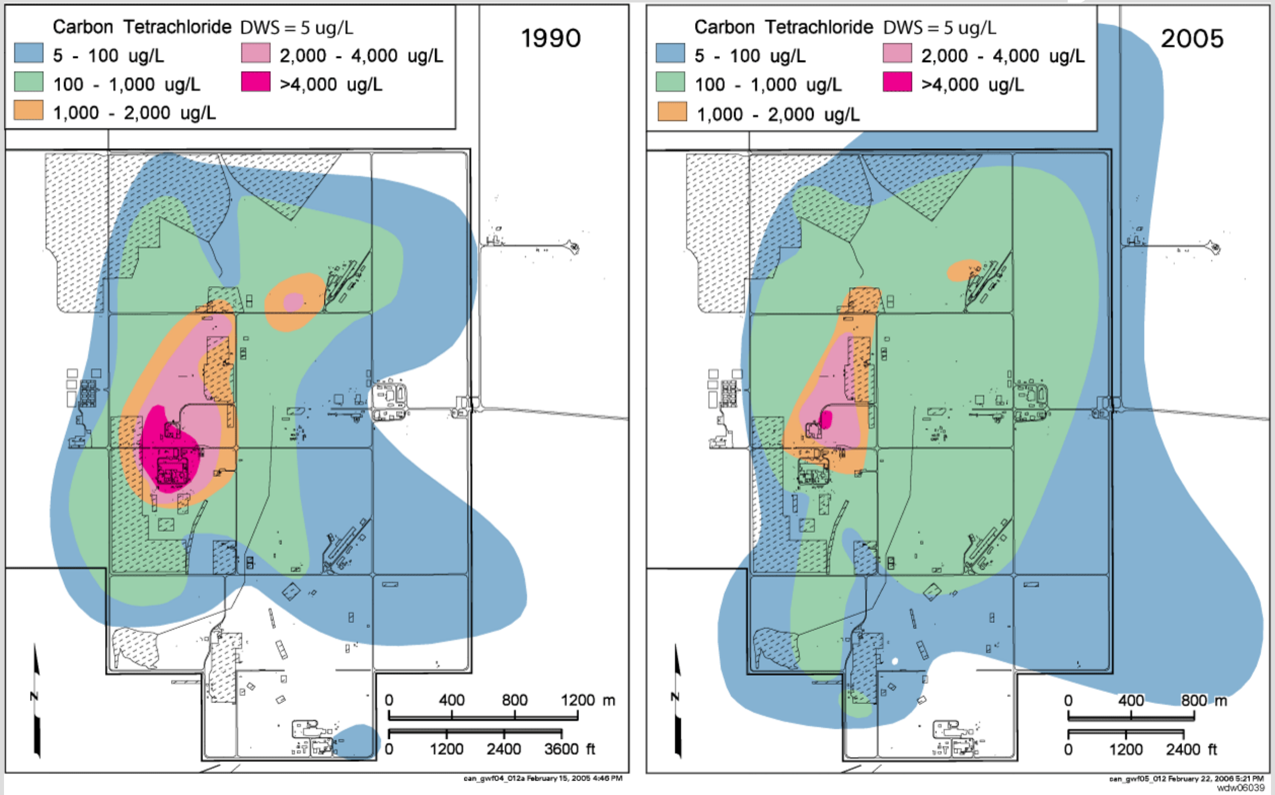
Example 5: Inventory Uncertainty



2005 Tritium Plume at 618-11
(plume undetected prior to January 1999)

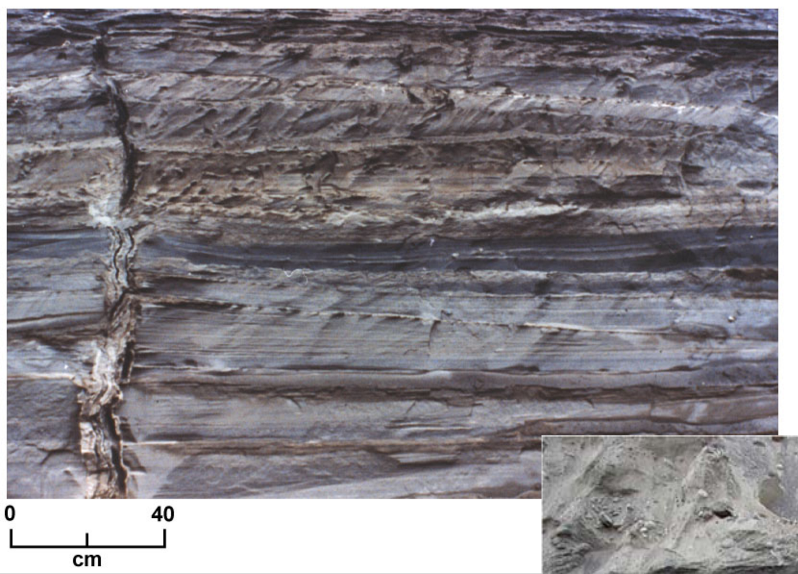
- Burial ground not monitored for tritium (not in inventory)
- Measurement to track regional plume in 1999 yielded unexpectedly high concentration of tritium (initially > 1 M pCi/L, later peak at >8M pCi/L) compared to nearby groundwater concentrations ranging from 2,000 to 20,000 pCi/L
- Significant effort expended to understand, quantify, and monitor new tritium plume (more wells; soil gas)

Example 6: Contaminant Source Location Uncertainty

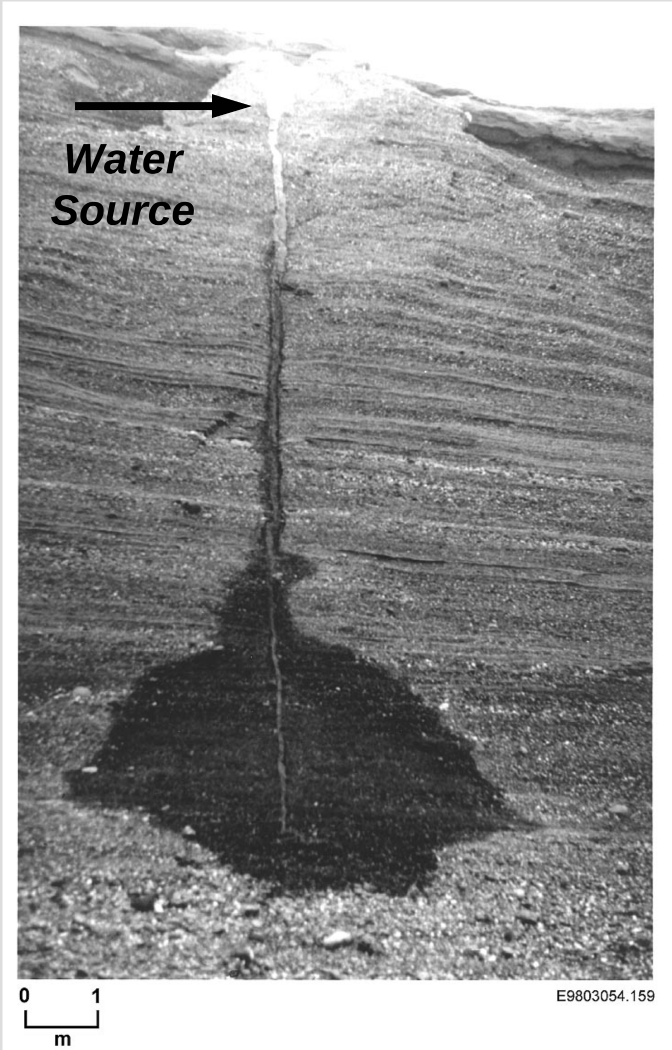


- Carbon tetrachloride (CCL_4) disposed to vadose zone
- Mass balance of removed and detected CCL_4 shows a shortfall
- Where is remaining CCL_4?

Example 7: Complex Subsurface



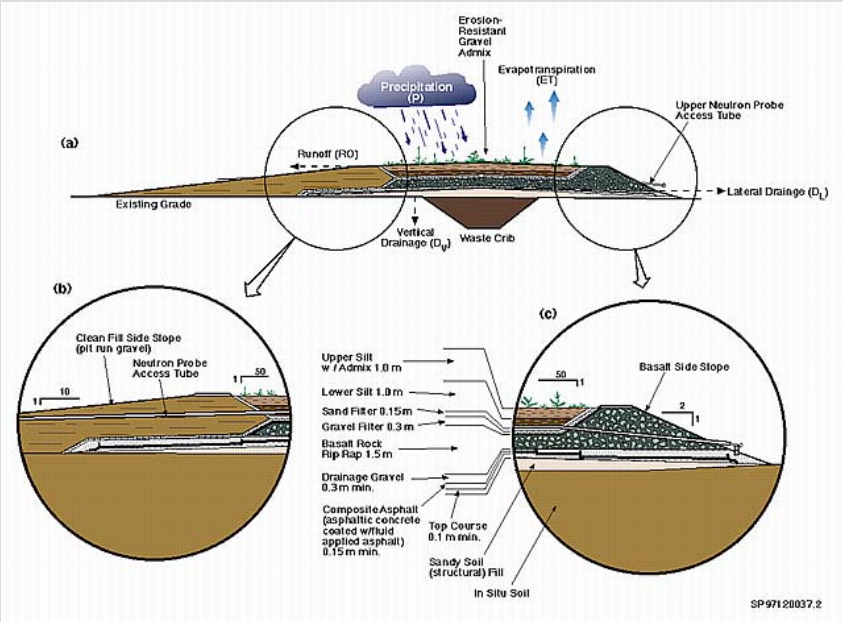
- Geologic features are not perfectly flat, continuous, uniform, homogeneous, or isotropic
- Manmade features (e.g.,boreholes, transfer lines, tanks) add to variability
- Such variability has implications for pathways, hydraulics, and geochemistry



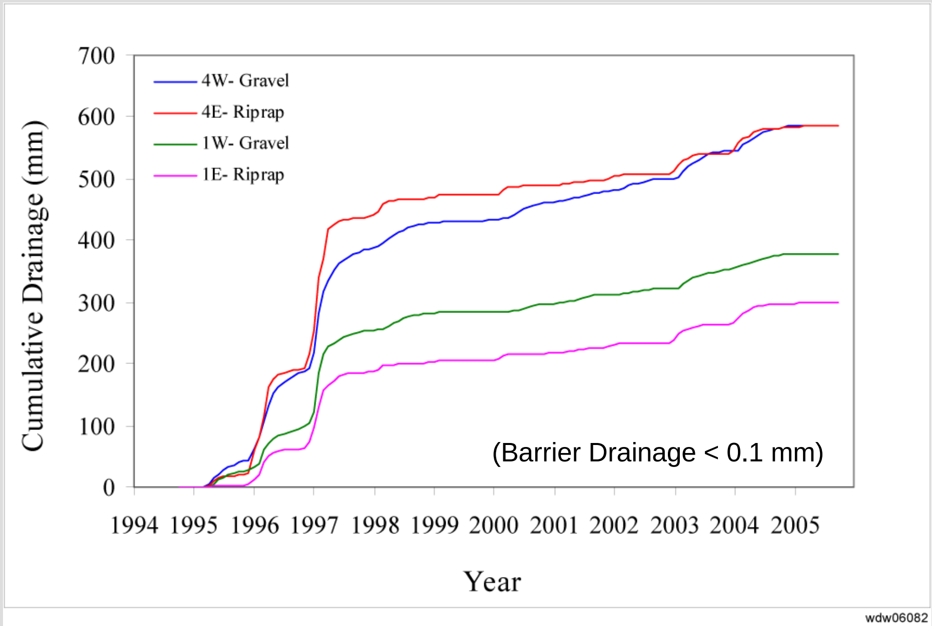
Example 8: Unintended Consequences

- Top of surface barrier works as designed: d < 0.1 mm/yr
- Large gravelly side slopes create infiltration source: d > 20 mm/yr

Prototype Hanford Barrier



Cumulative Side Slope Drainage



Summary

Contaminant transport in the subsurface environment is governed by a complex relationship of site- and contaminant-specific features, events, and processes. Recognizing and addressing that complexity is key to adequately understanding, monitoring, and predicting contaminant transport.

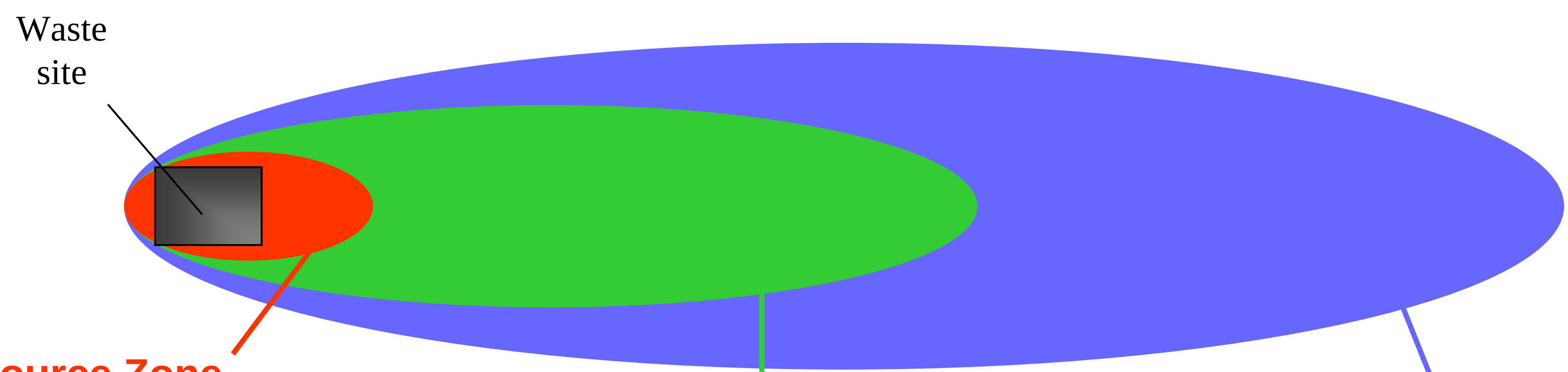
Detection, characterization and delineation of contaminant plumes

Brian Looney
Savannah River National Laboratory

a presentation to the
NRC ACNW 173rd Meeting
15 February 2005

SRNL™
SAVANNAH RIVER NATIONAL LABORATORY
We Put Science To Work

Anatomy of a Contaminated Site



Source Zone

Characteristics:
High Concentrations
Significantly perturbed geochemistry

Need:
Aggressive technologies to limit long term damage

Examples:
destruction or stabilization in place; heat/steam; chemical oxidation or reduction; immobilization.

Primary Groundwater / Vadose Zone Plume

Characteristics:
Moderate to high aqueous/vapor phase concentrations

Need: Baseline methods or moderately aggressive alternatives

Examples: pump (gas or water) and treat; recirculation wells; enhanced bioremediation

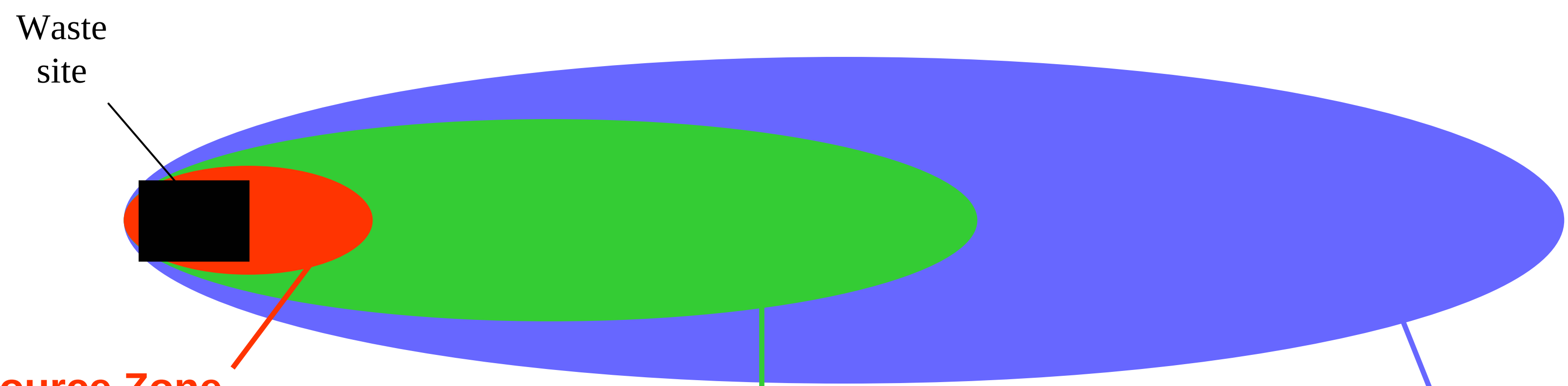
Dilute Plume / Fringe

Characteristics:
Low aqueous/vapor phase concentrations;
Large water volume.

Need: innovative technologies - sustainable low energy concepts

Examples: Passive pumping (siphon, barometric, etc.); bioremediation;phytoremediation, geochemical stabilization

Treating a Contaminated Site



Source Zone

<u>Costs:</u>
$/lb contaminant or $/cu yd. Removal examples:
< *$50-$100/cu yd or*
< *$100/lb for chlorinated solvents*

hot spot characterization reduces cleanup volume

Primary Groundwater/Vadose Zone Plume

<u>Costs:</u>
$/treatment volume (gallon/cu ft)
example:
<$0.5-$10 / 1000 gallons

zone of capture characterization needed, optimize extraction to reduce treatment volume

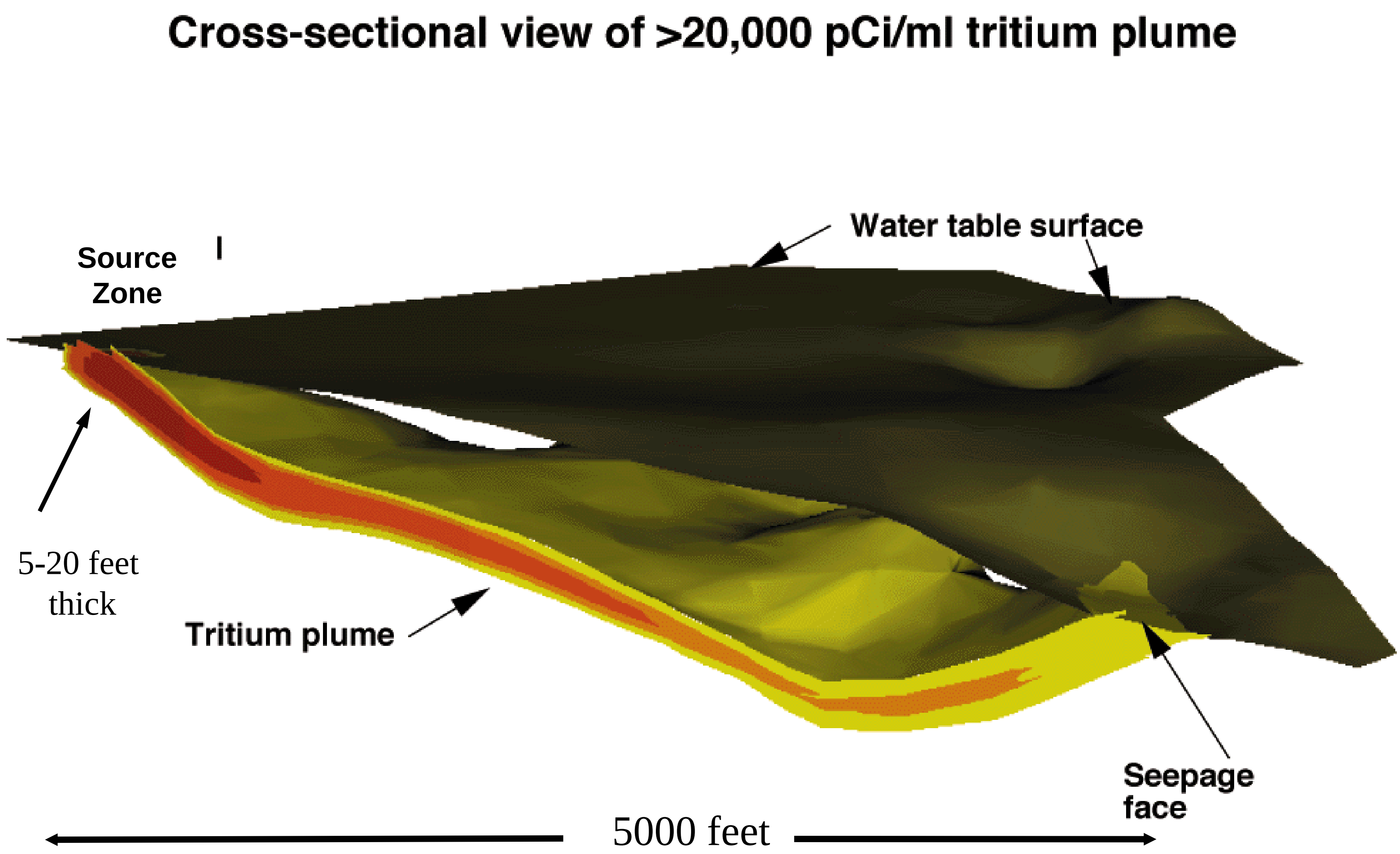
Dilute Plume/Fringe

<u>Costs:</u>
Operation and maintenance costs $/time

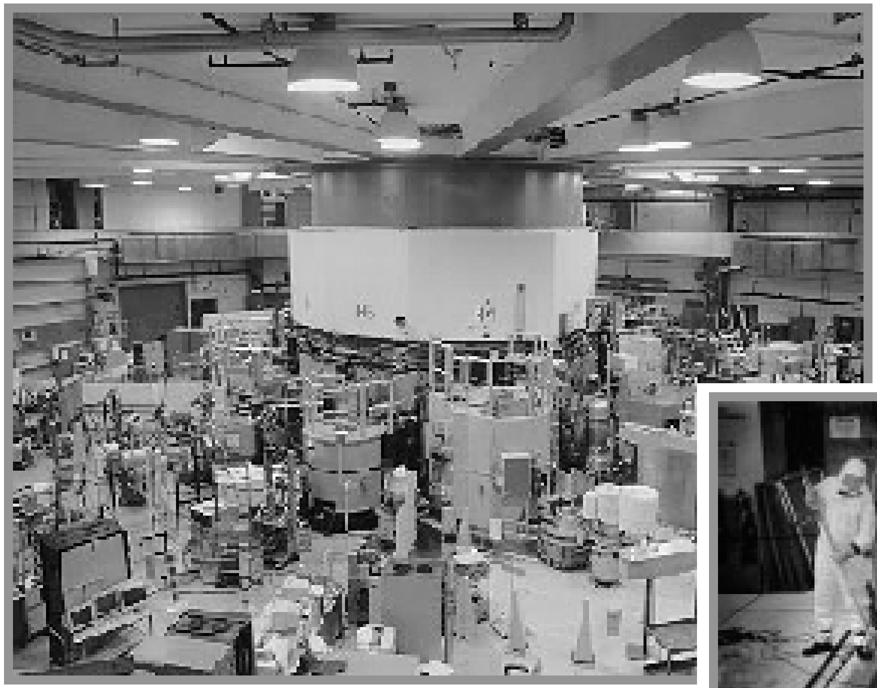
mass transfer and flux characterization needed

SRNL

Tritium plume: Savannah River Site “Old Burial Ground”

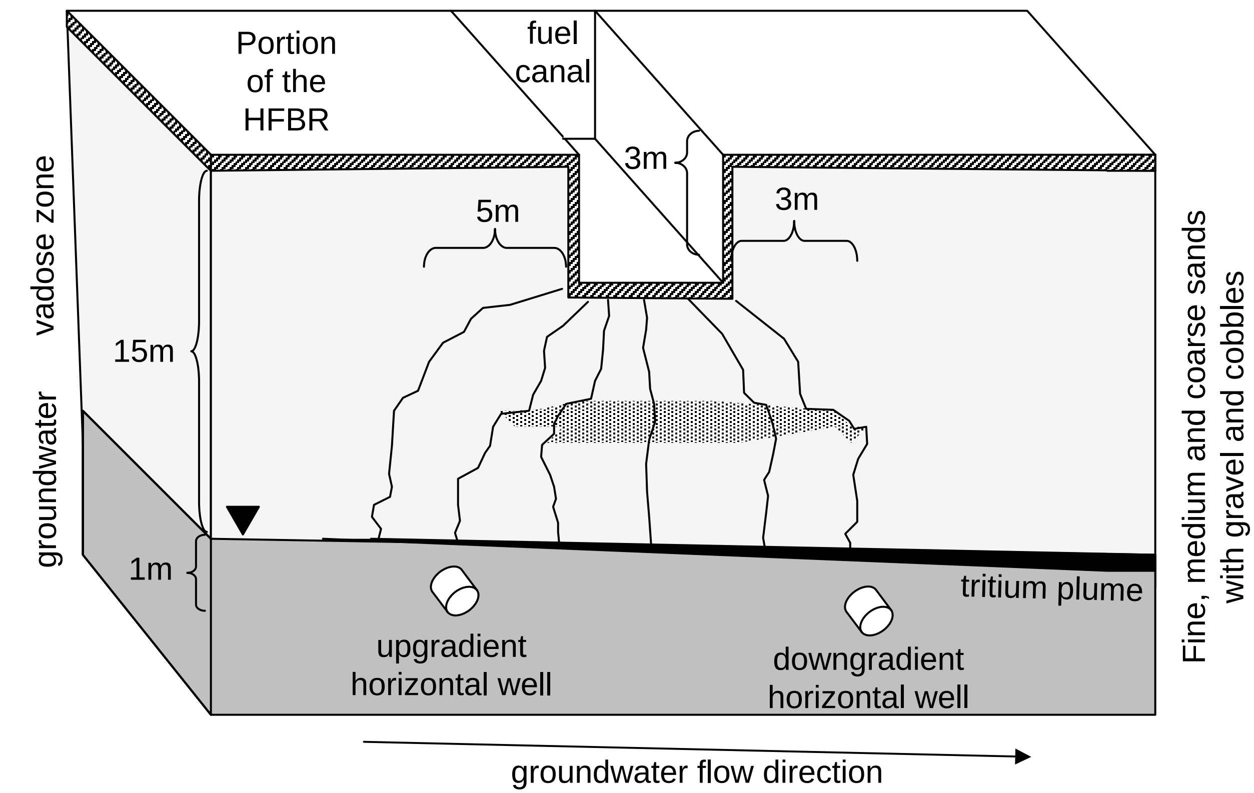


EXAMPLE

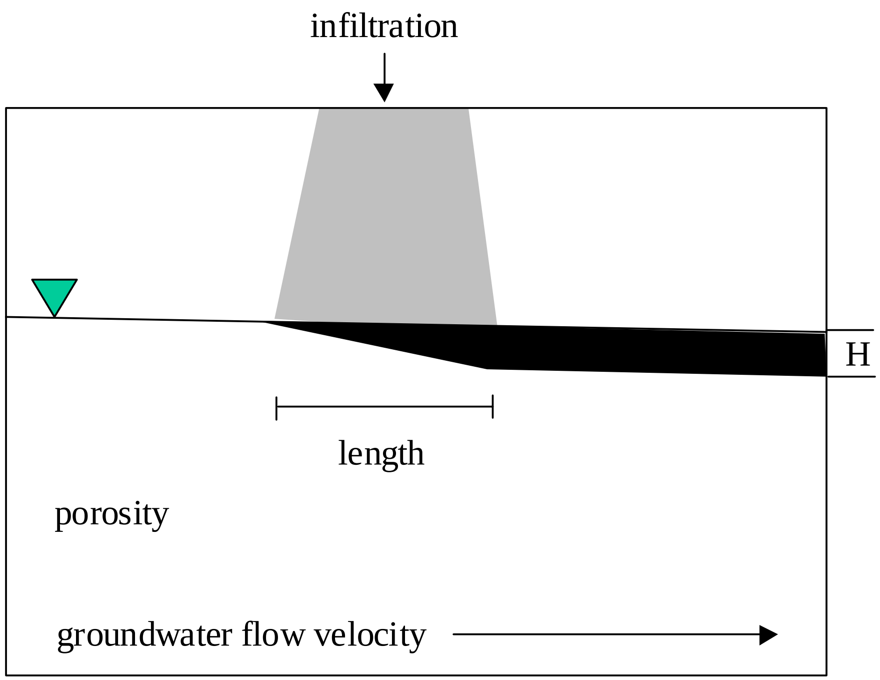


Pictures of the inside of the Brookhaven High Flux Beam Reactor showing the research stations (above) and the leaking fuel canal (right).

Conceptual Model Development



All dimensions are
approximate, not to scale

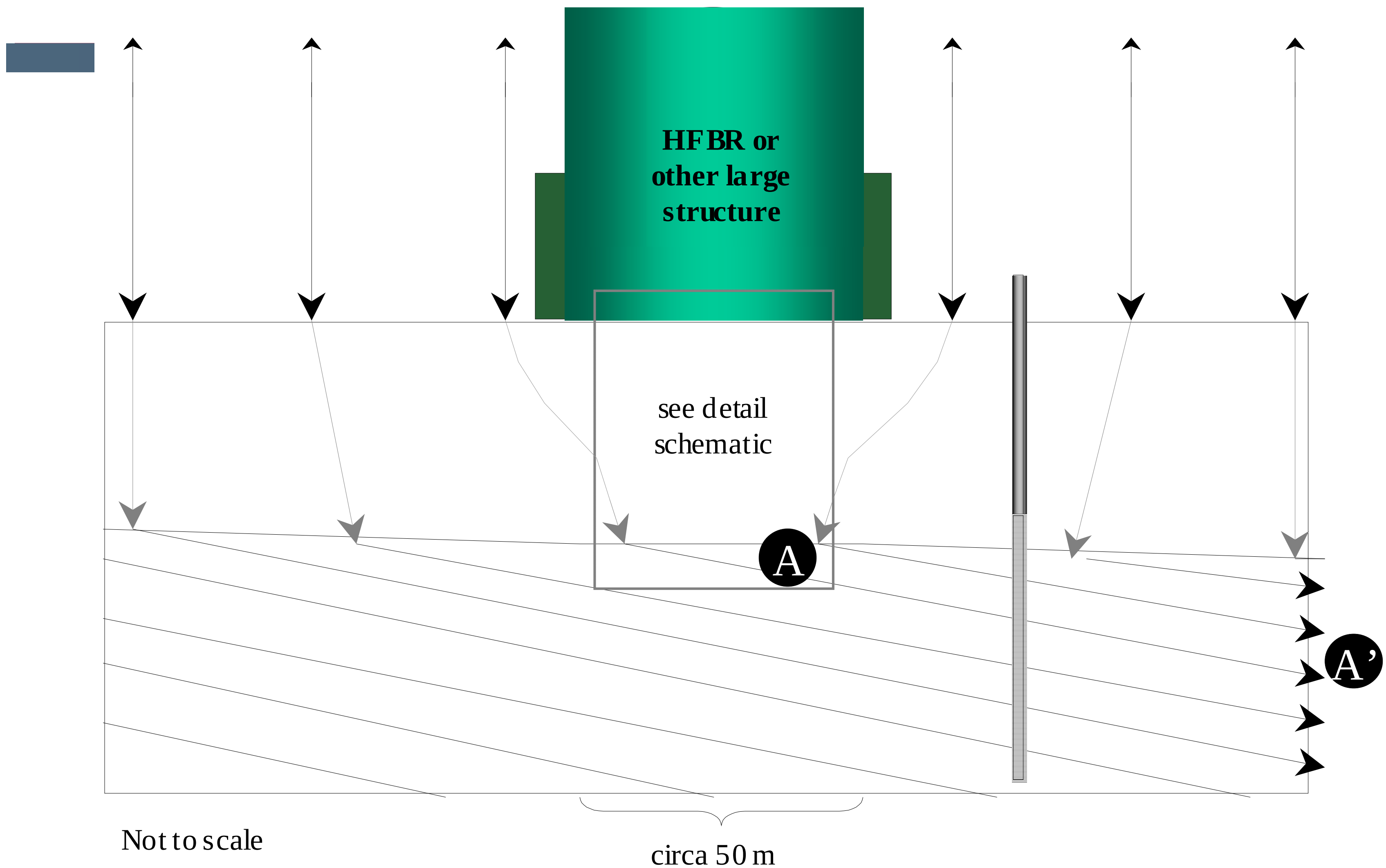


A simple estimate of the plume thickness that builds up beneath a disposal area based on the balance of vertical and horizontal flow was developed as part of the DOE PATHRAE family of risk assessment codes.

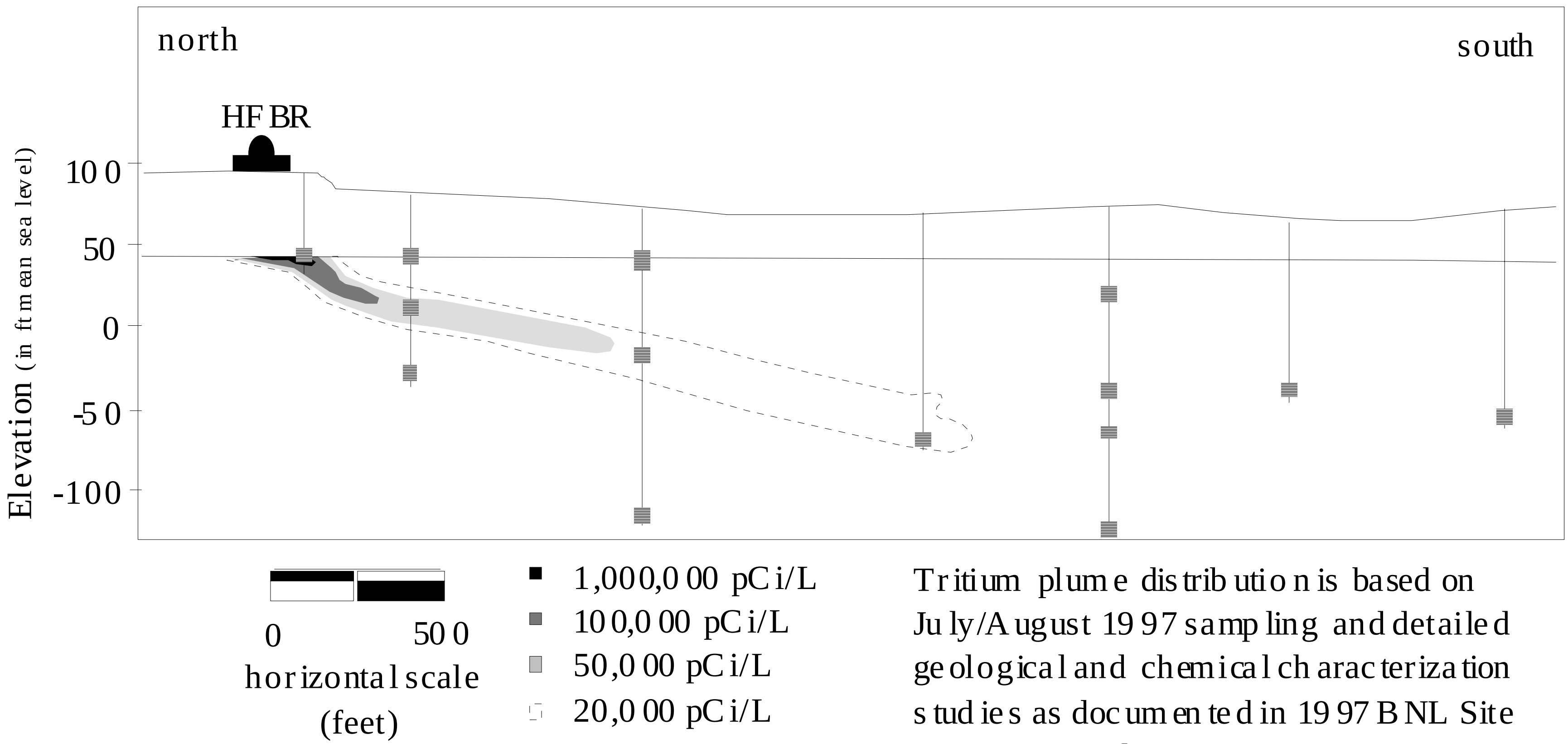
$$H = \frac{\text{(infiltration)} * \text{(length of waste input parallel to groundwater flow)}}{\text{(porosity)} * \text{(velocity of groundwater flow)}}$$

All terms are in consistent units (e.g., m, m/day, etc.)

SRNL

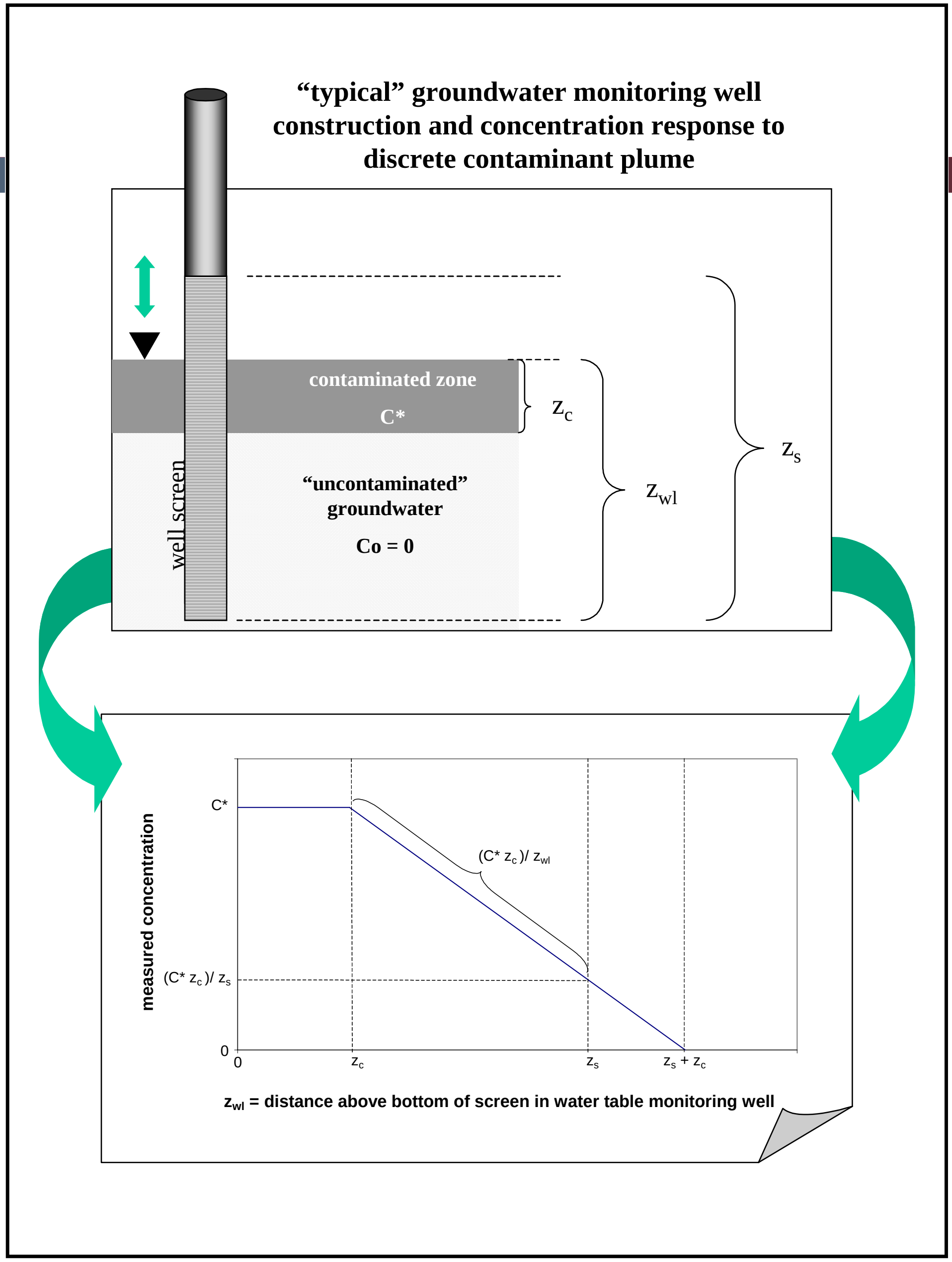

HFBR or
other large
structure
see detail
schematic
A
A'
Not to scale
circa 50 m

SRNL



Tritium plume distribution is based on July/August 1997 sampling and detailed geological and chemical characterization studies as documented in 1997 BNL Site Environmental Report.

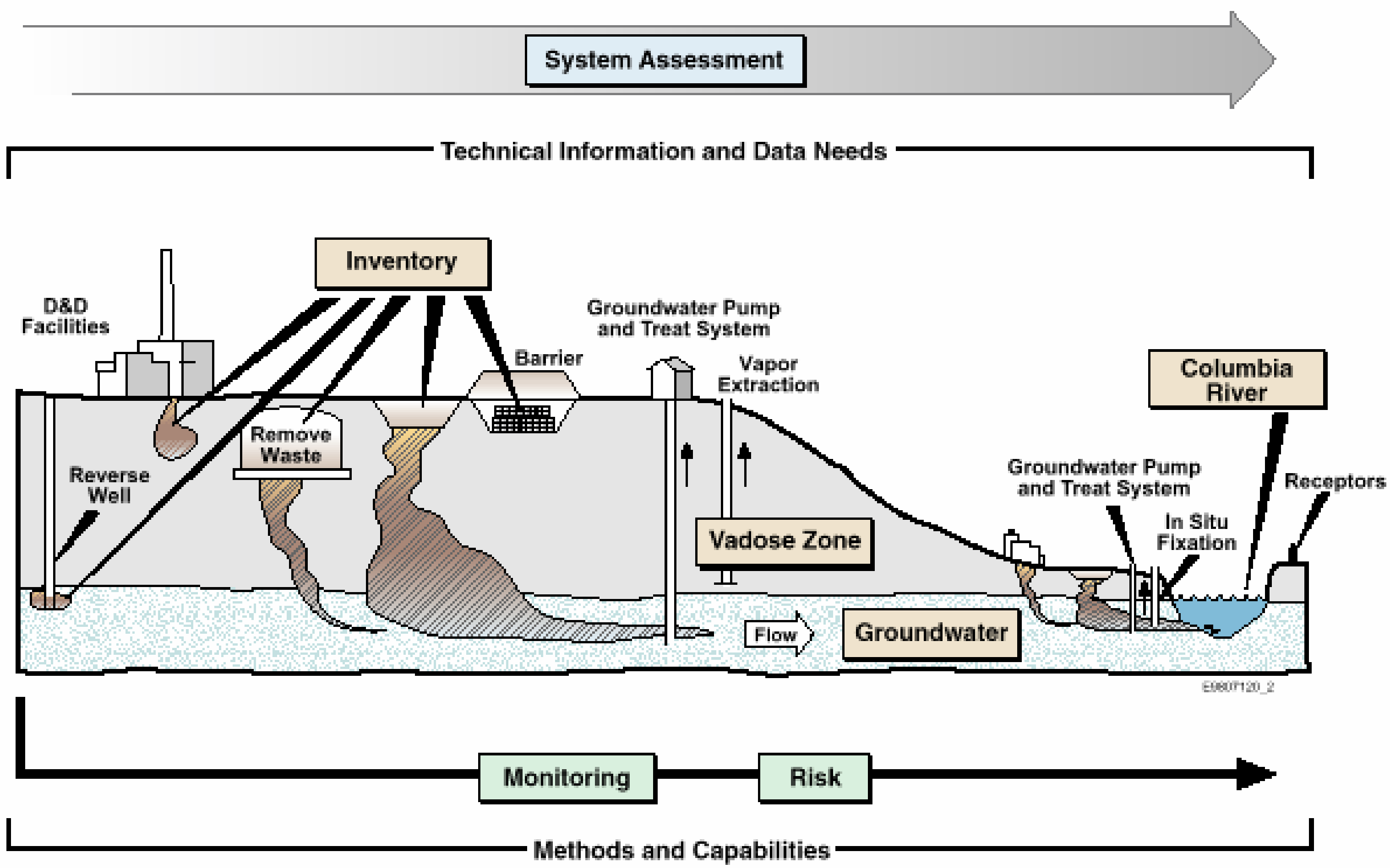
SRNL



"typical" groundwater monitoring well construction and concentration response to discrete contaminant plume
contaminated zone
C*
z_c
z_{wl}
z_s
"uncontaminated" groundwater
Co = 0
well screen
measured concentration
C*
$(C^* z_c)/ z_{wl}$
$(C^* z_c)/ z_s$
0
0
z_c
z_s
$z_s + z_c$
z_{wl} = distance above bottom of screen in water table monitoring well

SRNL

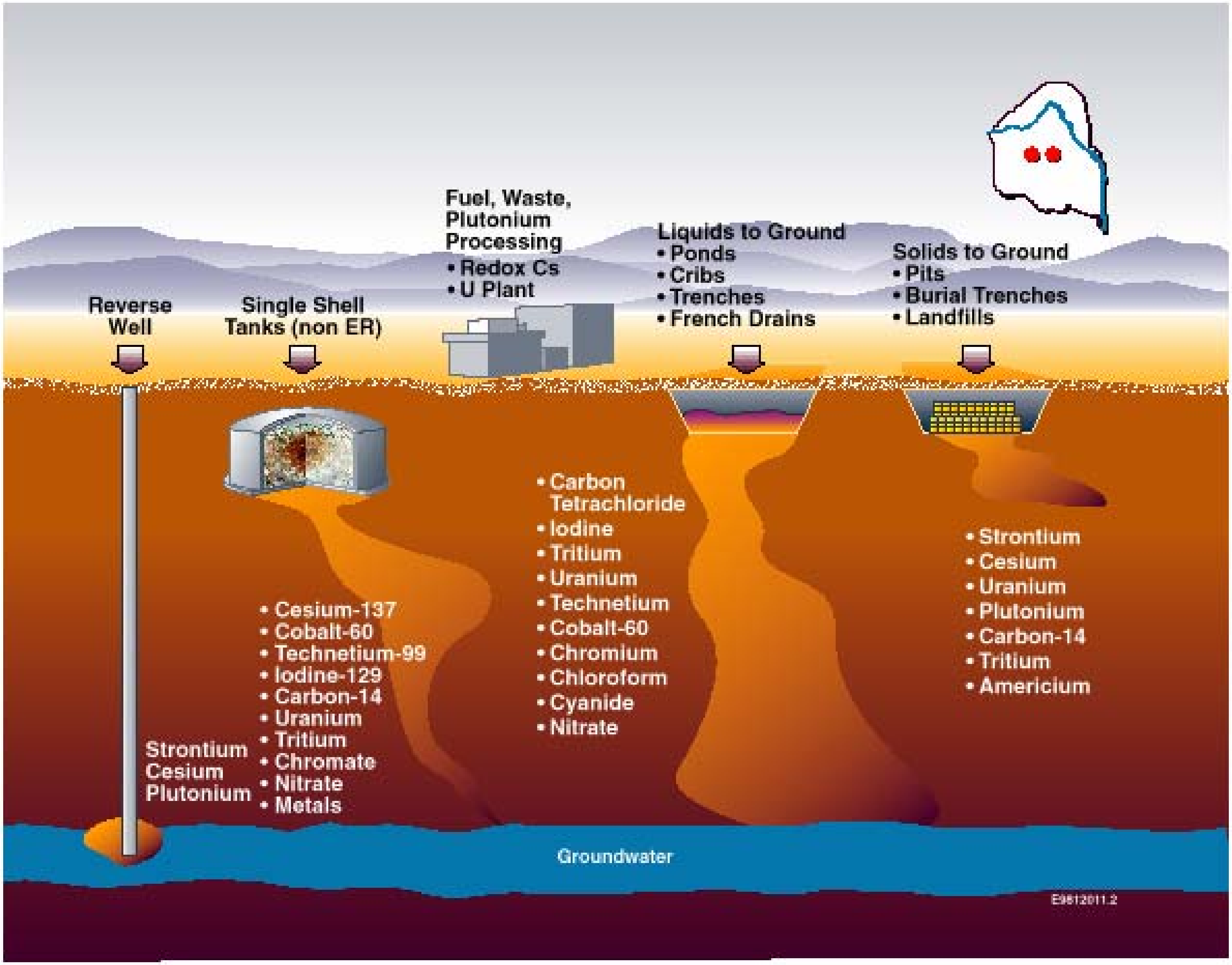
Hanford Sitewide



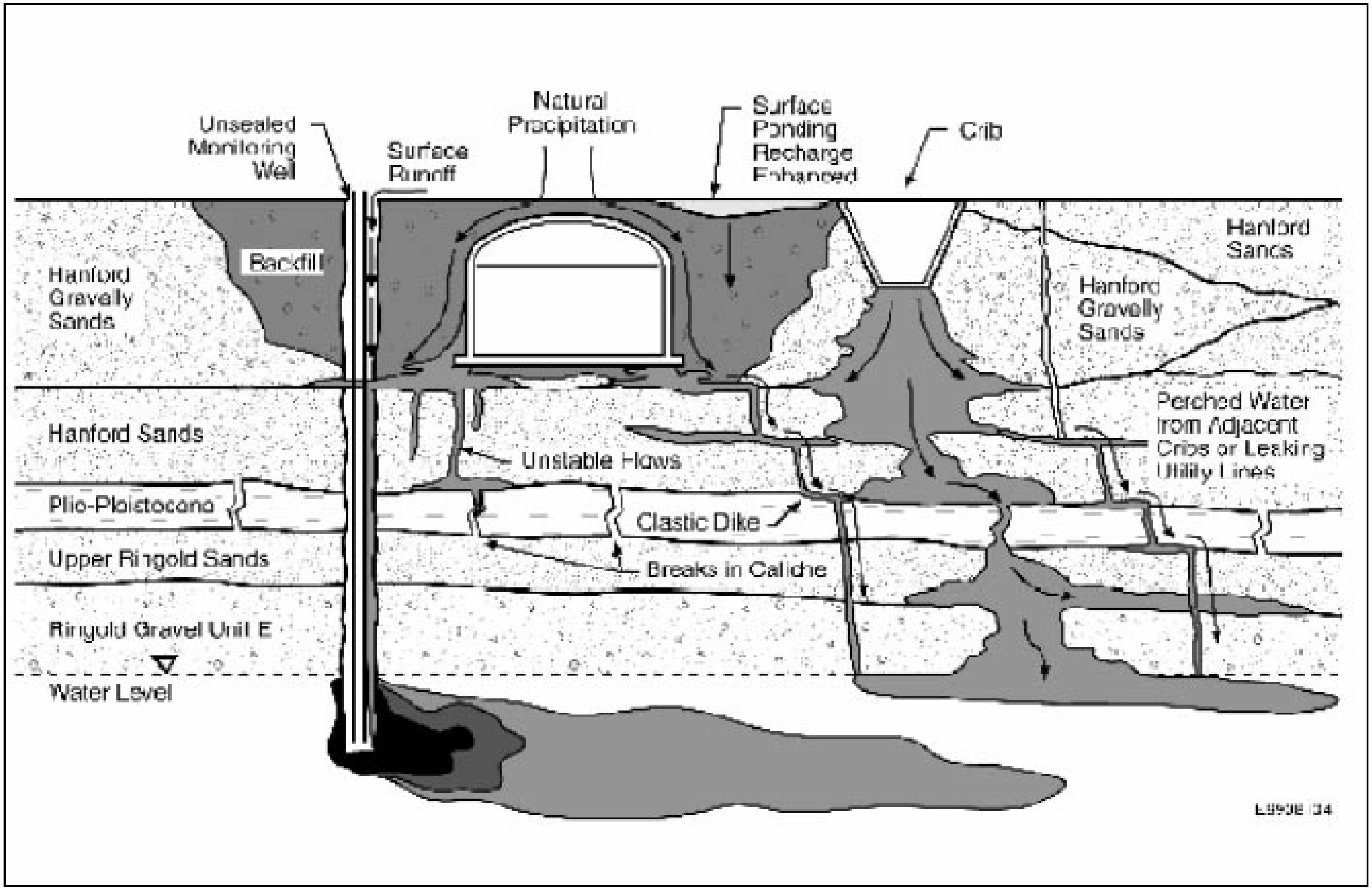
Controls and constraints on the system assessment are the regulatory path and the remediation options.

SRNL

Hanford Tanks – Central Plateau



Vadose and Shallow Groundwater

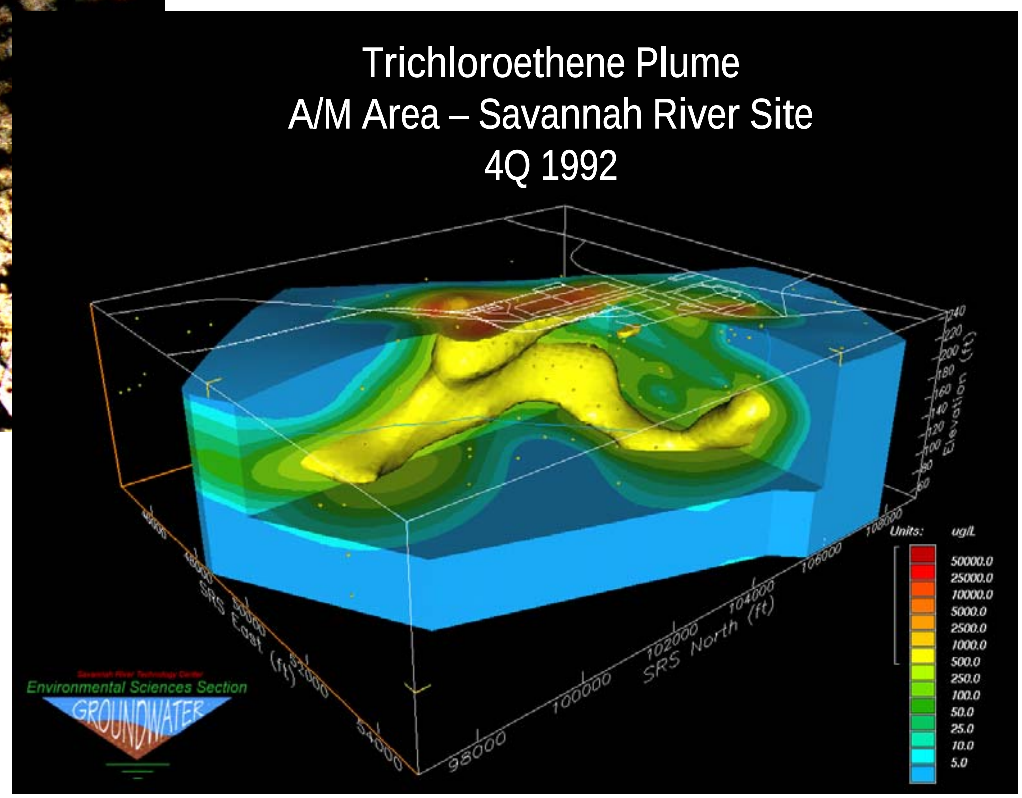


Conceptual Model Factors to Remember

- Three Dimensional Contaminant Plume Geometry
  - understand plume trajectory and incorporate controlling boundary conditions and hydrogeology into models
  - collect depth discrete data
- Subsurface Heterogeneity
  - optimize models based on all characterization data collected at various scales – beware of sampling on arbitrary grids if contaminant strongly controlled by lithology or geochemistry
  - understand depositional environments and post depositional processes
- Uncertainty and Sensitivity
  - bounded based on data

SRNL

EXAMPLES



SRNL

Innovative Characterization and Improved Access

Depth discrete sampling

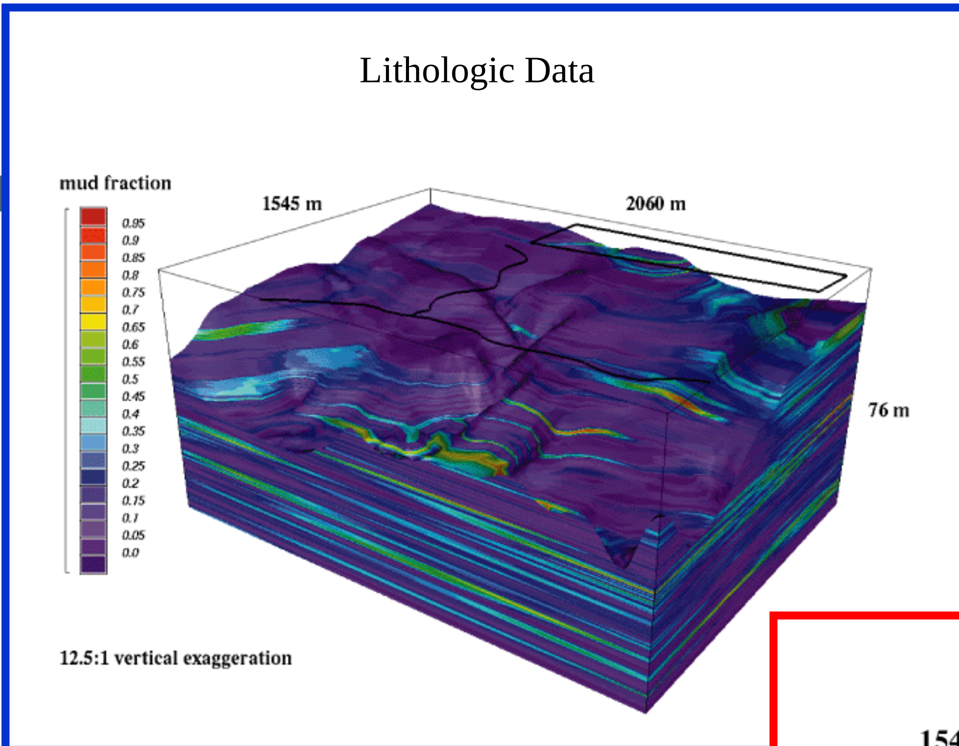
Horizontal wells

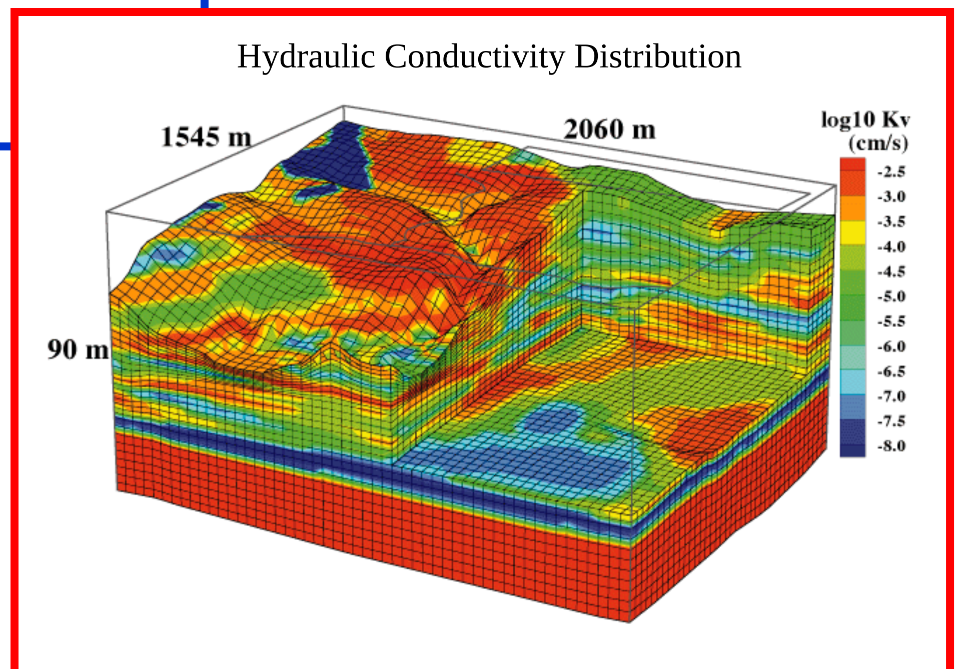
Geometry Considerations

- Match access to conceptual model geometry
  - Drilling and access methods
  - Well construction
- Data collection during access & borehole logging
  - Lithology (tip & sleeve, core examination, etc.)
  - Electrical, hydrologic and thermal properties
  - Samples - solid, liquid, gas
  - Spectroscopy - fluorescence, Raman
- Innovative Field based Methods (e.g., push pull tests) are very promising

SRNL™

EXAMPLE





SRNL

Summary Thoughts

- Consider early warning systems
  - Vadose monitoring and sensors…
  - Tracers and indicators…
- Consider plume geometry
  - Exploit opportunities
  - Avoid pitfalls
- Consider nonstandard approaches
  - Geophysics
  - Phases (e.g., gas)
  - Push pull testing
- Consider geochemistry
  - Integrate into design of facility (“defense in depth”)
  - Use in monitoring optimization

SRNL™

Field Data

SRNL

Minimally Invasive -- Geophysics

- Surface geophysical methods good for geologic trends, interfaces, and changes but be aware of spatial resolution.
- Geophysics in existing boreholes can often provide important information.
  - e.g., measurable impacts on electrical conductivity, geochemistry, etc.
  - Use of existing boreholes maximizes return on monitoring system investment
  - But construction and location may compromise usefulness
- Consider adding subsurface access at key locations

SRNL™

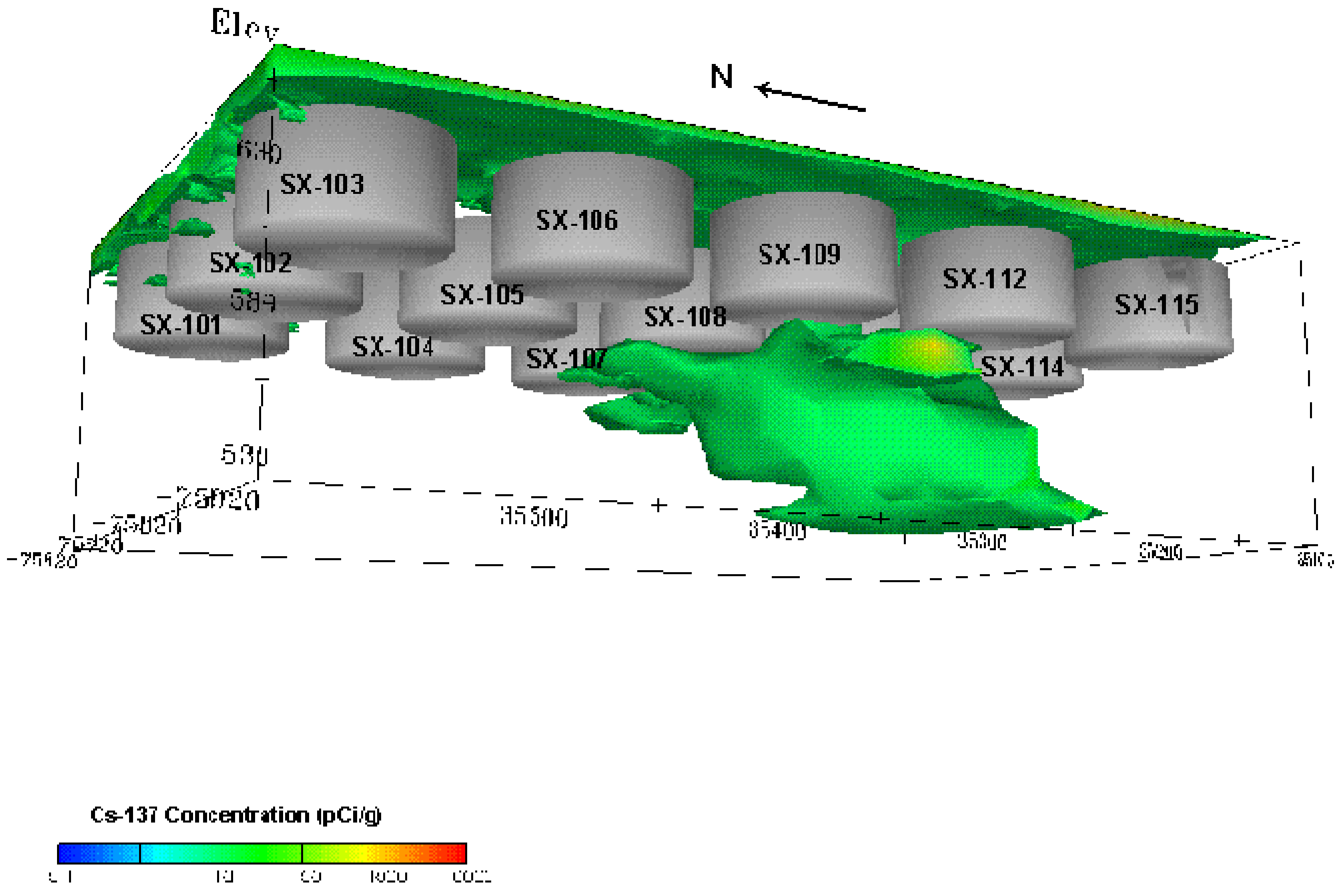


Figure 39. Visualization of the Cs-137 Contamination With an Isolevel of 10 pCi/g at the SX Tank Farm Viewed From the Northwest

SRNL

Gas: the forgotten phase in metals and radionuclide...

Remediation?!

Monitoring?

Characterization?

SRNL

General Conceptual Basis

- Case studies for tritium, mercury, uranium/thorium, suggest that gas phase monitoring may complement other methods for cost effective monitoring of metals and radionuclides.
- Soil gas monitoring of metals has its roots in the field of exploration geochemistry with supporting scientific literature
- Gas sampling is often inexpensive, many analytes are simple to analyze in the gas phase (well suited to emerging sensor developments), many configurations are possible to interrogate subsurface volumes….

SRNL

The Three Classes of Soil Gas Monitoring

- Monitor contaminant gases directly
  - tritium
  - mercury
- Monitor contaminant using diagenetic and contaminant indicator gases (such as decay products or cocontaminants)
  - uranium / thorium
- Monitor conditions for contaminant mineral stability using diagnostic gases
  - classical exploration geochemistry

SRNL

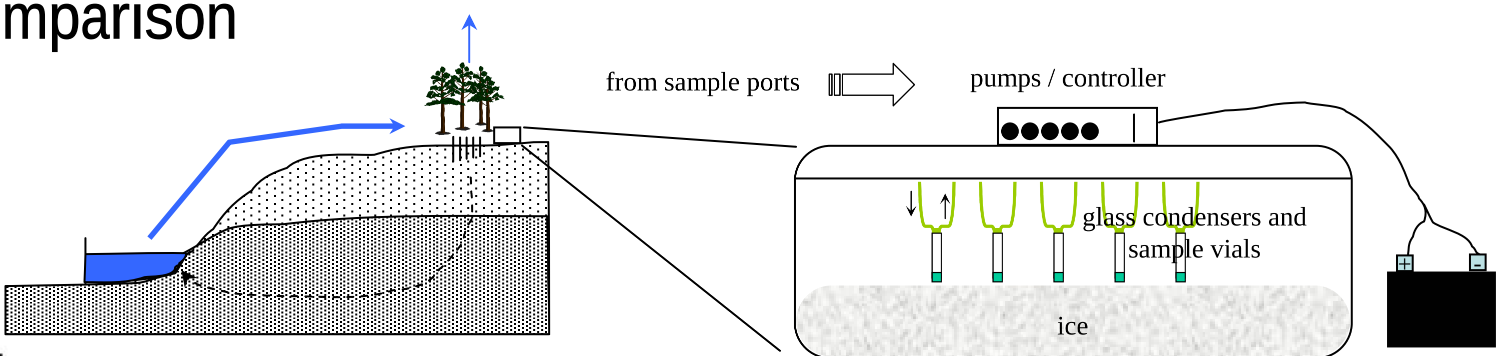
Monitor contaminant gases directly.

- Tritium (T) is the most obvious contaminant for direct monitoring
  - At most sites subsurface tritium is in the form of water molecules in which one or both hydrogen atoms have been replaced by tritium (HTO or T_20)
  - for monitoring purposes, the characteristics of "contaminated" and "uncontaminated" water are "identical"
  - tritium can be sampled using soil gas from a vapor extraction probe and followed by condensation of the moisture using a cold trap
- This approach has been used at the Department of Energy (DOE) Savannah River Site (SRS) radioactive waste burial ground and to monitor irrigation-evapotranspiration of tritium contaminated groundwater.

SRNL

Monitor contaminant gases directly...

- Groundwater irrigation project collected discharging plume using a dam in an existing topographic valley and pumped the water to irrigate a pine plantation
- 18 plots, 5 depths per plot, sampled monthly for 2.5 years
- Production systems consisted of an ice chest, ice, 5 mini-sampling pumps, pump controller circuit, battery, glass u-tubes fitted for sample vials, and associated tubing.
- Suction lysimeter and soil core data were collected for comparison

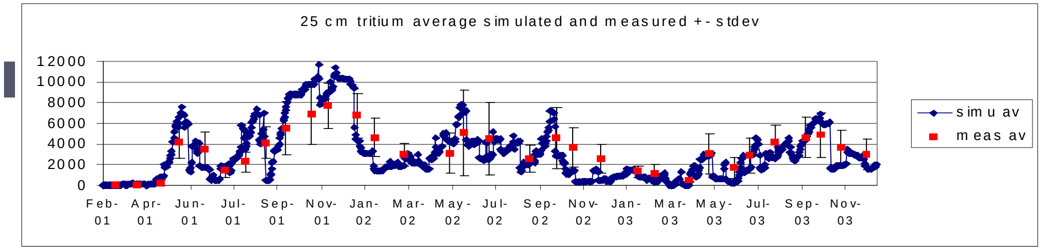


SRNL

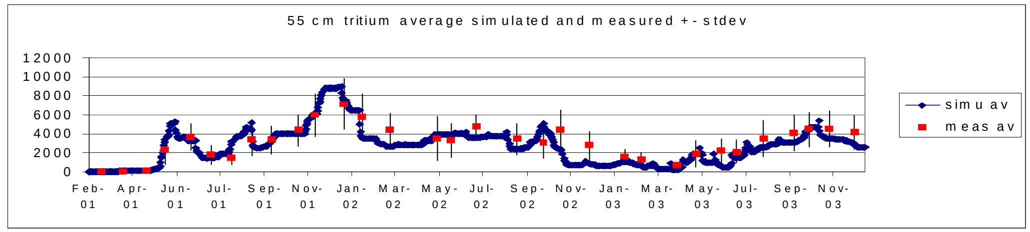
Monitor contaminant gases directly....

- Gas phase system was reliable and inexpensive.
- The results were used to develop the process control model and long term permit requirements

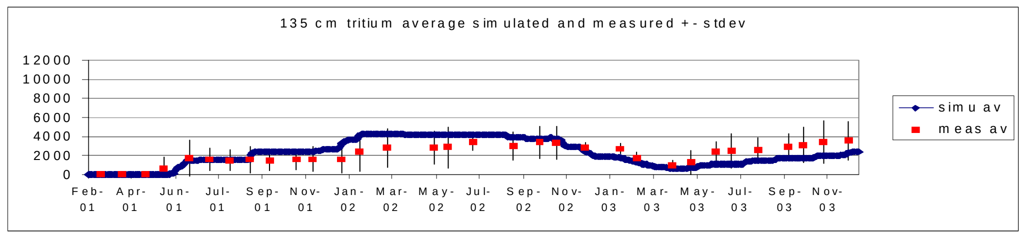
25cm



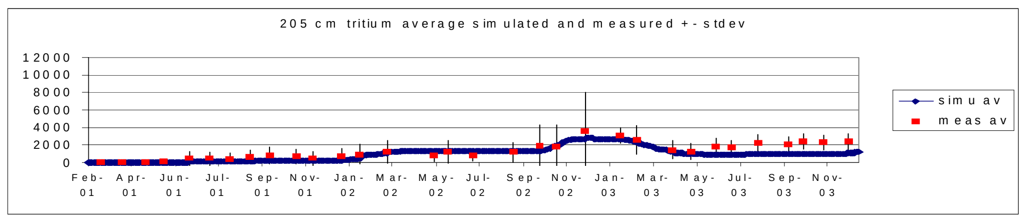
55cm



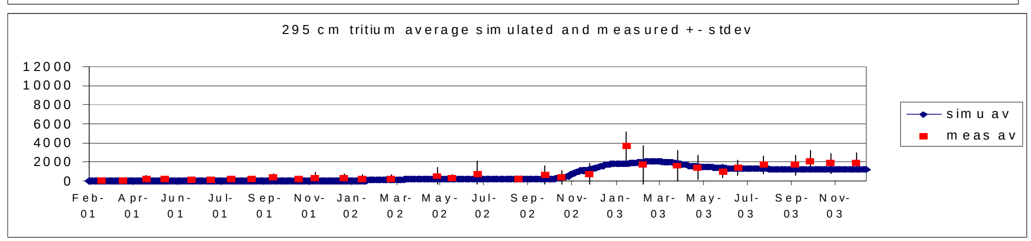
135cm



205cm



295cm



Example data from:

Karin T. Rebel, S.J. Riha, J. Seaman, C. Barton, **The use of dynamic modeling in assessing tritium phytoremediation**

Monitor contaminant gases directly…..

- Several inorganic contaminants are candidates for direct measurement in the gas phase -- e.g., Hg, Sb, As, Sn, and others
- Mercury is a classical example with a large amount of literature (Klusman, 1993; Biester et al., 1999; Kromer et al., 1981, and others)
- Mercury can be sampled directly as a gas, or by thermal desorption of soil to provide speciation and mineralogy data.

SRNL

Monitor contaminant gases directly- Synopsis

- Candidate inorganic contaminants for direct measurement in the gas phase include Hg, Sb, As, Sn, and others
- Candidate radionuclides include tritium, ^{14}C, and radon

- Direct measurement of contaminant gases potentially applicable to both characterization and monitoring phases. Past work suggests that some geochemical information can be derived from the data in some cases (e.g., mercury speciation, thermal remediation monitoring, etc.). Well suited to use emerging sensors as appropriate.

- Limitations: Relatively few contaminants are represented in the gas phase. Gas-solid-solution equilibria can be complex and gas phase concentrations can sometimes be controlled by variable biological reactions.

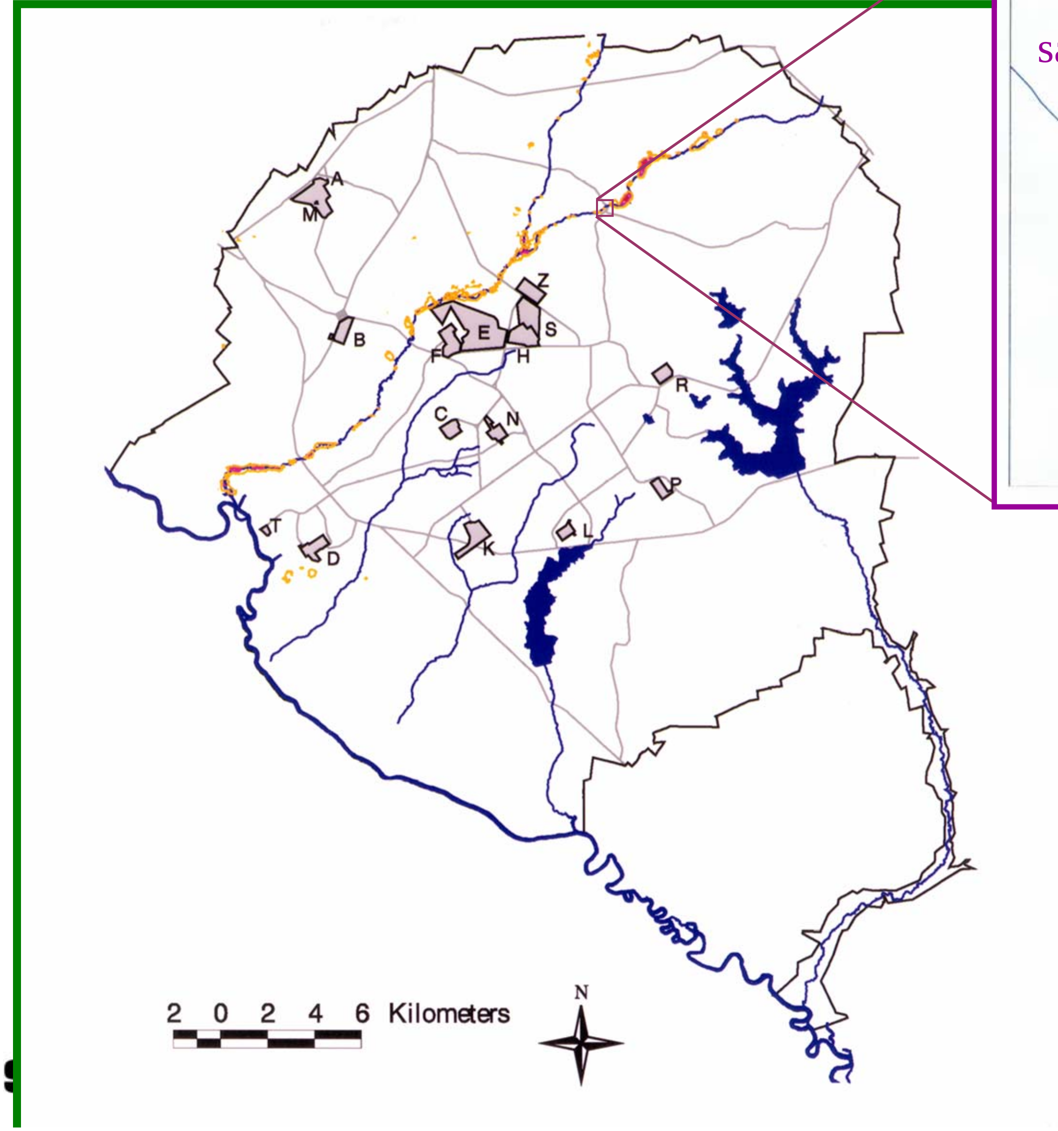
SRNL

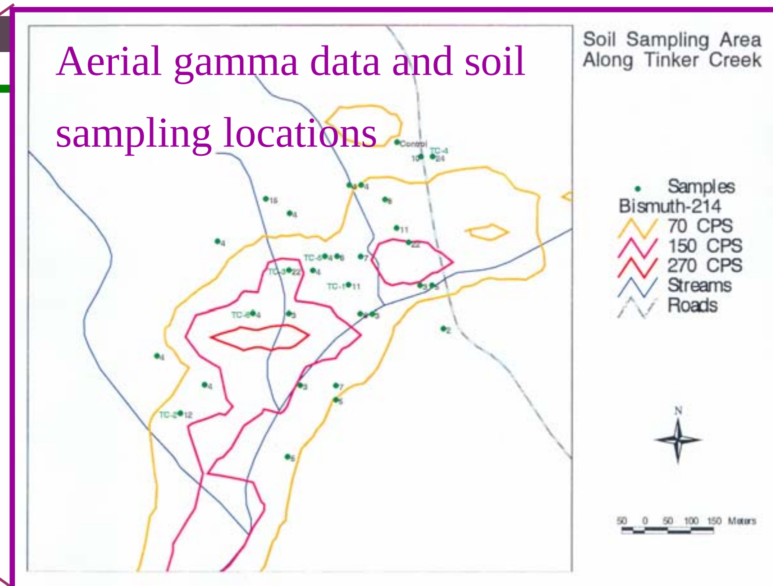
Monitoring Contaminant Indicator gases.

- Radon to monitor Uranium (^{222}Rn) and Thorium (^{220}Rn or ^{222}Rn) is a good example (see Gates and Gunderson, 1992)
- Case Study - A remote sensing variant of this approach was applied at SRS.

SRNL

Monitoring Contaminant Indicator gases..

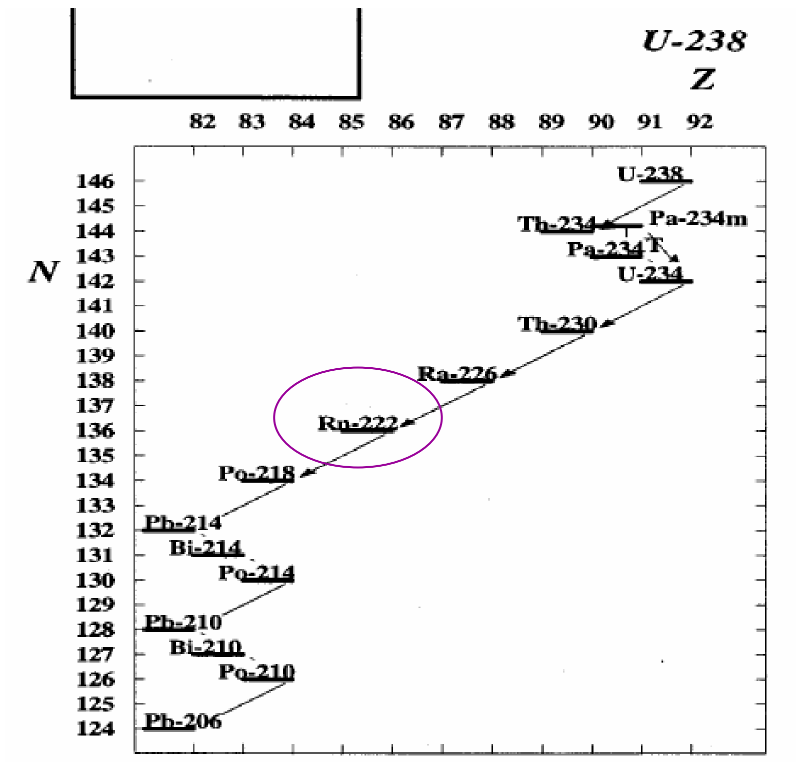


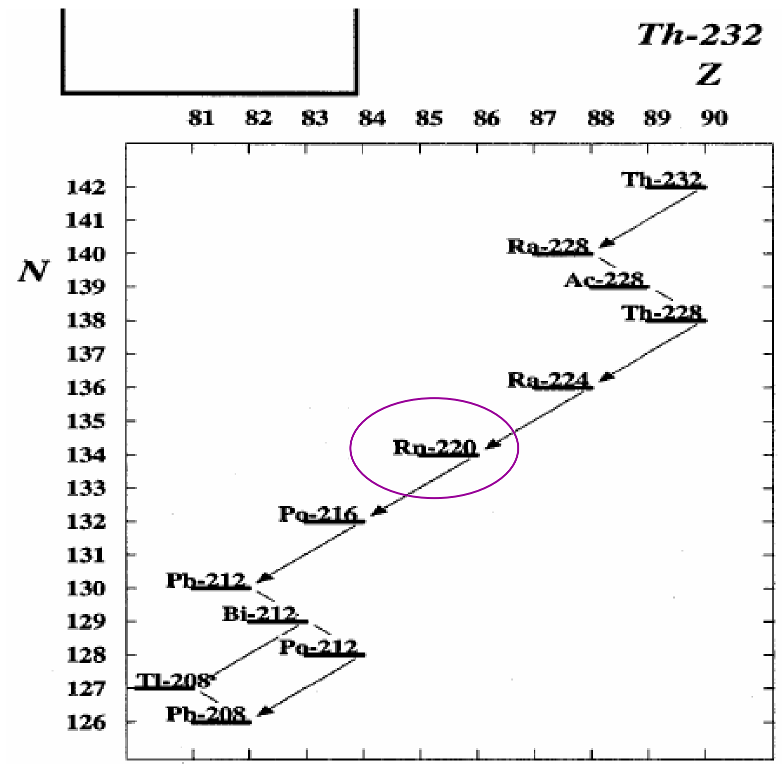


^{214}Bi "anomalies" from 1991 aerial gamma survey indicated "areas where uranium and its daughters appear enriched relative to thorium"

Monitoring Contaminant Indicator gases...

Hypothesis for why ^{214}Bi “anomalies” would occur is related to gas phase migration of ^{222}Rn ($t_{1/2}$ = 3.8 days) versus ^{220}Rn ($t_{1/2}$ = 55 seconds)

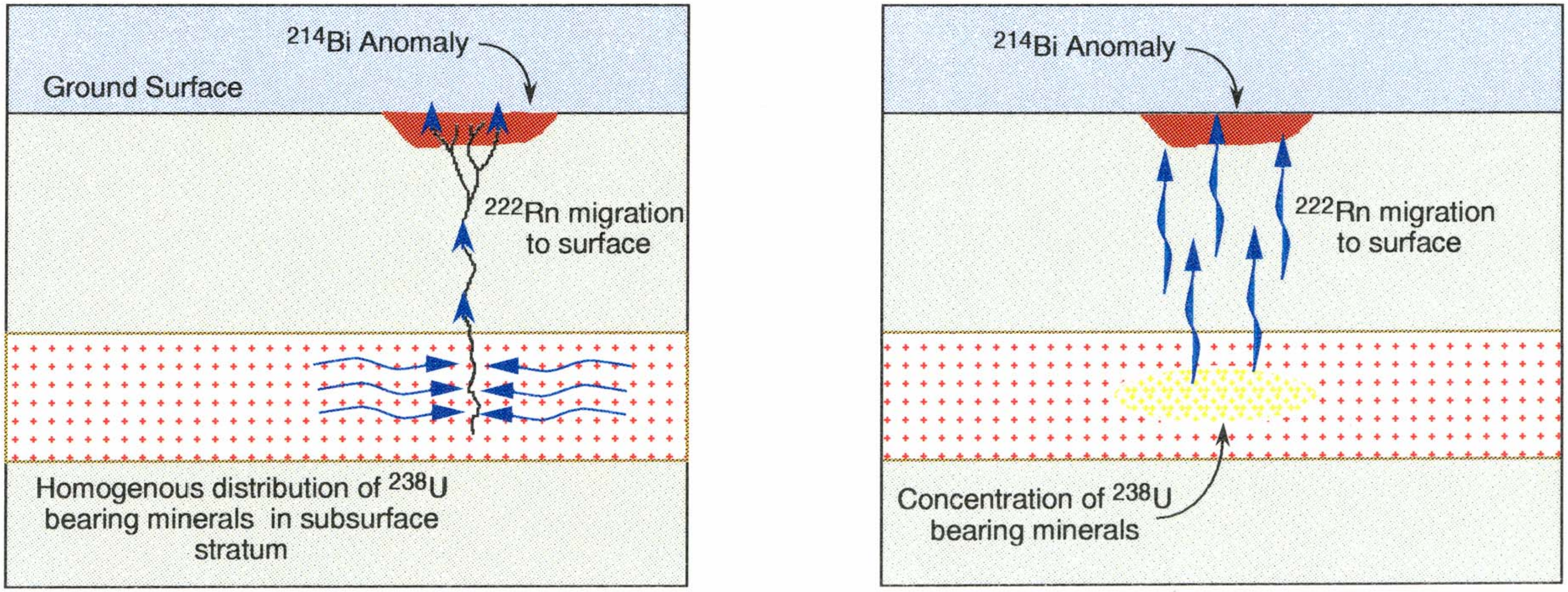




SRNL

Monitoring Contaminant Indicator gases....

Conceptual Model of the Formation of ^{214}Bi Anomalies



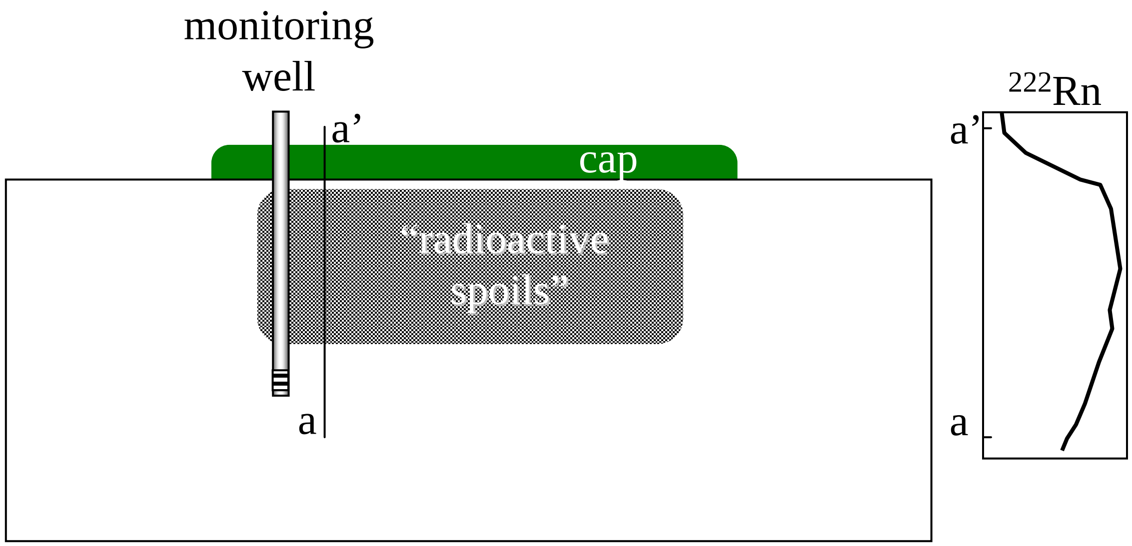
Homogenous distribution of uranium-bearing minerals in subsurface formation such as the McBean Formation. ^{222}Rn migrates to surface through fractures and other discrete pathways.

Heterogenous distribution of minerals bearing uranium. ^{222}Rn migrates from uranium accumulations to surface through soil pores

SRNL

Monitoring Contaminant Indicator gases…..

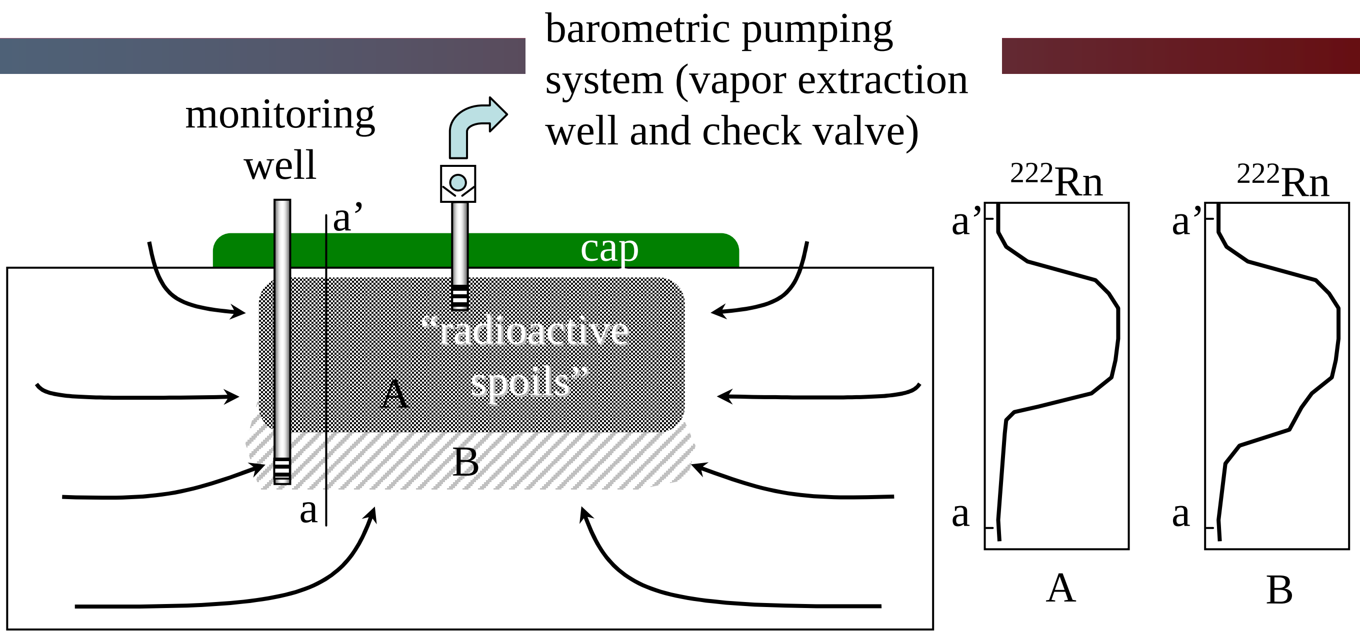
How can something like this be this be used in innovative monitoring?



Baseline

high ^{222}Rn concentration in radioactive waste (e.g., UMTRA) diffuses into surrounding soil. Difficult to interpret monitoring well data….

Monitoring Contaminant Indicator gases......



Barometric Pumping - Air Flow

A: because of the induced flow, "low" ^{222}Rn in monitoring well is a robust indicator of no radionuclide migration

B: if significant radionuclide migration occurs, a radon signal will develop in monitoring well

Monitoring Contaminant Indicator gases Synopsis

- Candidate inorganic contaminants for indicator measurement in the gas phase include ?
- Candidate radionuclides include U, Th, Ra (using Rn), tritium (using ^3He to ^4He ratio) and others
- A direct measure for one contaminant gas (e.g., tritium) may serve as a leading indicator for other contaminants (similar to Nevada Test Site groundwater)

- Indicator measurement of contaminant gases is potentially applicable to both characterization and monitoring phases. Because of differences in half lives, some information on transport might be derived from the data (e.g., lead isotope profiling). Radon work well suited to existing field measurement equipment or passive samplers.

- Limitations: Relatively few contaminants are represented. Some methods that are theoretically viable use relatively costly analyses.

SRNL

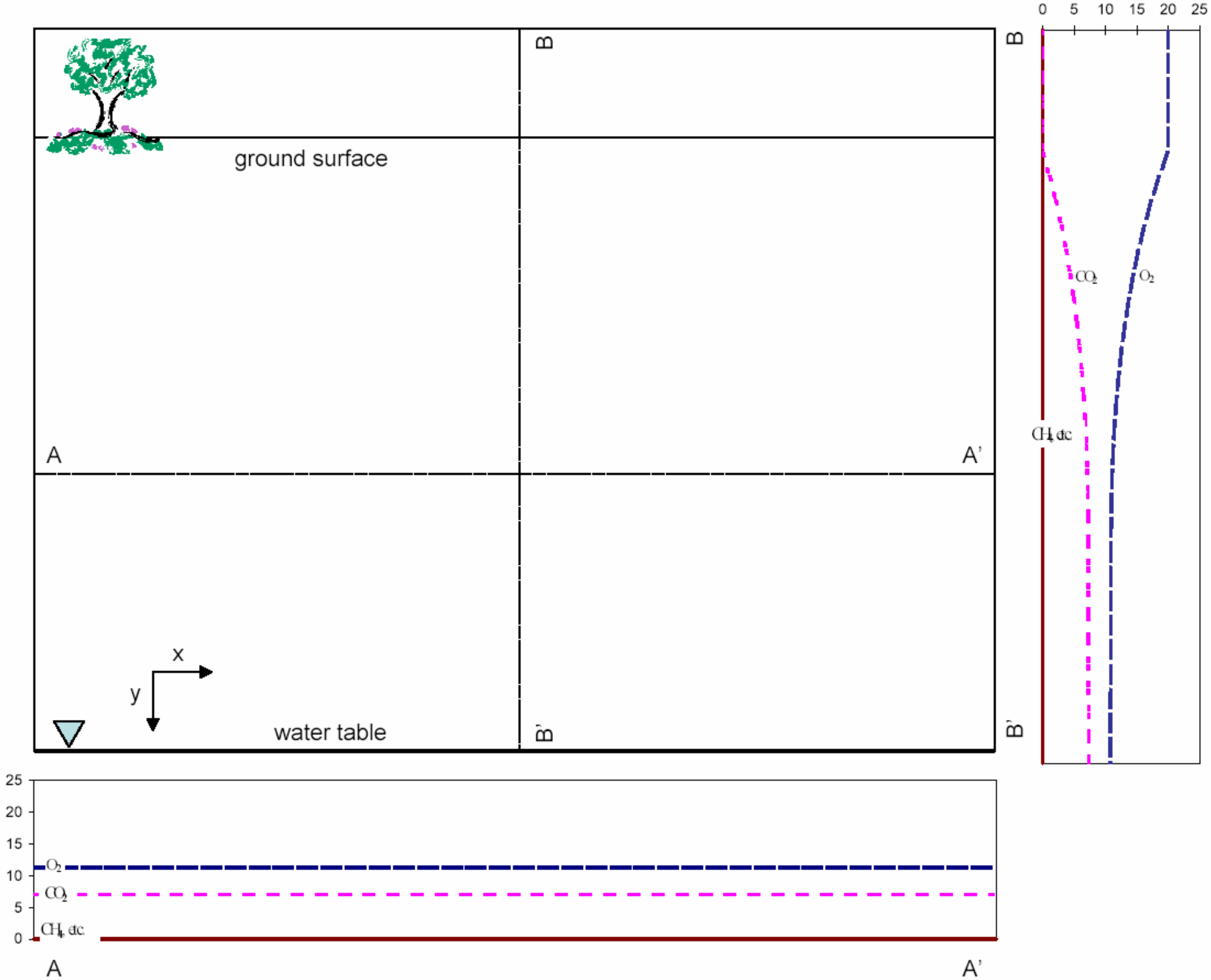
Monitoring Diagnostic gases.

- Use classical exploration geochemistry concepts to document contaminant and mineral stability (e.g., controlling geochemistry)
- Concept is compatible with NABIR and other initiatives that rely on redox conditions for stabilization of contaminants
- Good analog in natural deposits of metals
- Case Study - summary of exploration geochemistry literature (Kusman, 1993; Jaacks, 1993; Highsmith, 2004; Hamilton, 2000, 2004a, 2004b)...

SRNL

Monitoring Diagnostic gases..

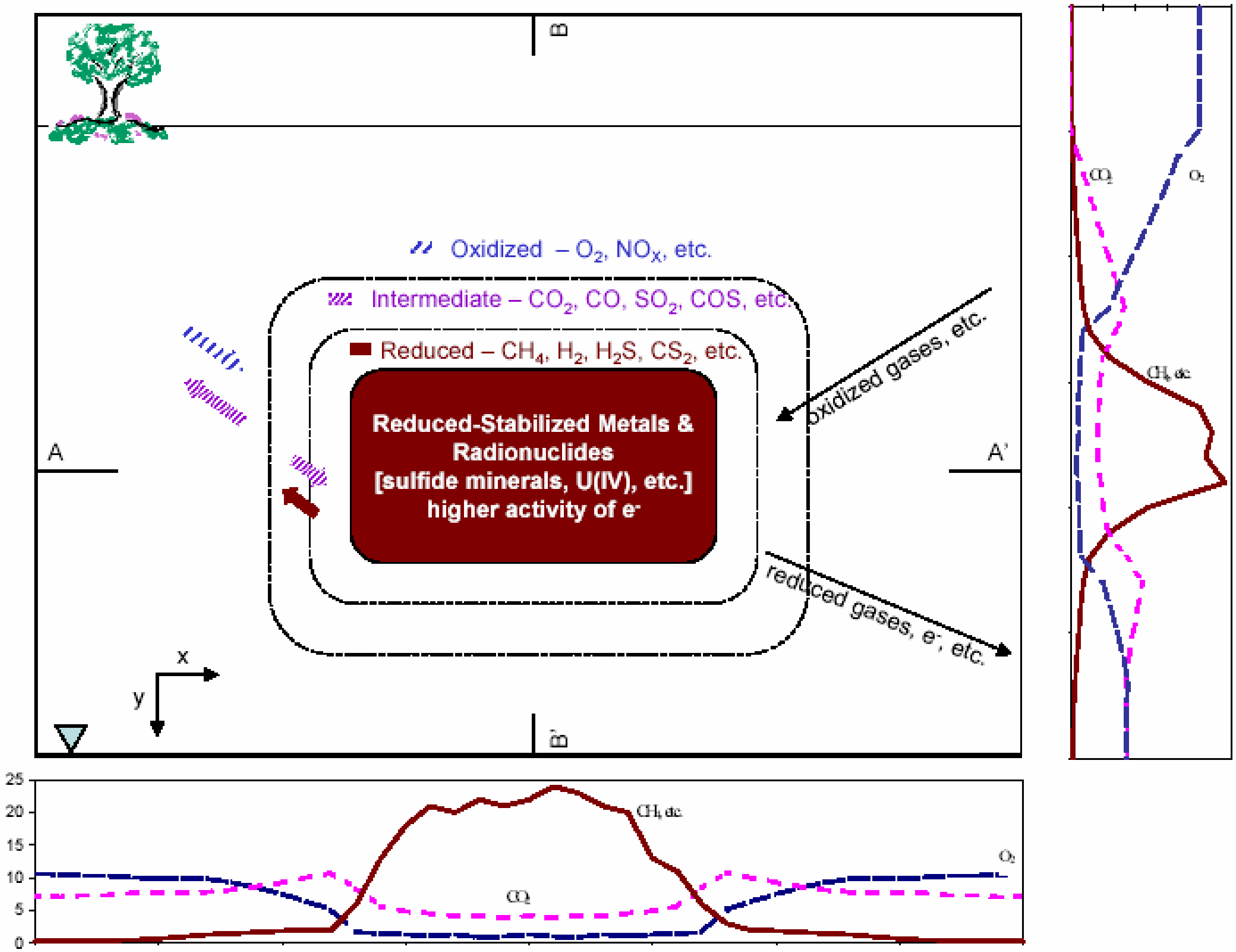
Conceptual framework (Baseline)



SRNL

Monitoring Diagnostic gases..

Conceptual framework (Applied)



Monitoring Diagnostic gases Synopsis

- Candidate inorganic contaminants for indicator measurement in the gas phase include “many”
- Candidate radionuclides include “many”

- Measurement of diagnostic gases is most applicable to document stability (lack of mobility) for metal and radionuclides. May have particular applicability for monitoring following in situ stabilization technologies. Most analyses are well suited to existing (low cost) field measurement equipment.

- Limitations: Indirect measurement. May not provide definitive information due to geochemical complexities.

SRNL

Conclusions for gas phase

- Developing the next generations of innovative long term monitoring for radionuclides might benefit from an expanded view and by considering alternative phases for sampling and analysis
- gas samples provide an opportunity for early warning systems and vadose monitoring rather than waiting for groundwater contamination – especially for tritium and similar contaminants
- gas sampling may be more reliable than traditional suction lysimeters for appropriate contaminants
- The three different approaches to gas phase monitoring can be combined with each other, along with traditional monitoring and with emerging sensor developments as needed to address inherent limitations of the various paradigms.

SRNL

Summary Thoughts

- Consider early warning systems
  - Vadose monitoring and sensors…
  - Tracers and indicators…
- Consider plume geometry
  - Exploit opportunities
  - Avoid pitfalls
- Consider nonstandard approaches
  - Geophysics
  - Phases (e.g., gas)
  - Push pull testing
- Consider geochemistry
  - Integrate into design of facility ("<u>defense in depth</u>")
  - Use in monitoring optimization

SRNL™

Remediation Technologies for Metals and Radionuclides

- Remediation strategies for metals and radionuclides are limited to two broad categories – *stabilization* and *extraction*. (except for radioactive decay -- no degradation!)
- *Stabilization* technologies can be broken into a few classes including: redox processes, directed precipitation reactions, indirect manipulation, and other (e.g., thermal). Stabilization technologies can be deployed by direct reagent addition, by using a permeable reactive barrier, or by other means (e.g., desiccation)
- *Extraction* is generally performed by plants (phytoextraction) or by mobilization and flushing with aqueous reagent (ligands, complexing agents, or acids), but can employ other concepts (e.g., nonaqueous reagents or gas sparging)
- Biological processes may be able to assist in all of the these various categories and classes

SRNL™

1. Is bioremediation effective for…

- These contaminants:
  - Tritium
  - Tc-99
  - I-129
  - Uranium
  - Sr-90
  - Cs
  - Chromium
  - Plutonium
  - Mercury
  - Thorium
  - Radium
  - Lead (?)

SRNL

Matrix of Environmental Management Options for Selected Metals and Radionuclides in Subsurface Systems

Summary Notes for Each Contaminant

Most of the stabilization methods can be implemented within a permeable reactive barrier (PRB) (e.g., using solid reagents, or biological substrates such as bark or peat). Surface wetland treatment systems may be viable for sequestering many of these contaminants.
Some of the stabilization methods can be implemented by direct addition of reagents to the subsurface or by direct injection of reagents.
(those where bioremediation can make a substantive contribution are italicized)

	STABILIZATION			EXTRACTION				
Contaminant	redox	directed precipitation	indirect manipulation	phytoextraction	aqueous reagents	nonaqueous phase isolation/extraction	gas sparging	Summary Notes for Each Contaminant
tritium	●	●	●	○ / ●	●	●	○ / ●	Tritium is best addressed using creative isolation / hydrologic management strategies. Relatively short half-life minimizes long term issues. Phytoextraction (evapotranspiration) has been implemented. Minimal other
technitium 99	◎ / ○	●	○ / ●	--	--	○ / ●	●	*Most common concept is reduction of Tc(VII) to Tc(IV) and enhanced sorption and/or precipitation of oxide.*
iodine 129	○	◎ / ○	○ / ●	--	--	○ / ●	○ / ●	*Directed precipitation possible (e.g., with copper and stable iodine). Redox manipulation is possible in combination with nonaqueous isolation/extraction or sparging.*
uranium	◎ / ○	◎ / ○	○ / ●	--	○ / ●	--	●	*Substantive redox stabilization observed. Directed precipitation and indirect manipulation possible. Complex chemistry complicates long-term stability and isolation.*
strontium 90	●	●	◎ / ○	--	○ / ●	--	●	*Behaves similar to calcium and can be manipulated indirectly (e.g., by co-precipitation) or extracted (but will require aggressive reagents). Relatively short half life minimizes long-term issues.*
cesium	●	●	○ / ●	○ / ●	○ / ●	--	●	Minimal opportunities for stabilization and manipulation (other than sorption). Relatively short half life minimizes long term issues.
chromium	◎ / ○	●	○ / ●	--	--	--	●	*Most common concept is toxicity reduction by reduction of Cr(VI) to Cr(III).*
plutonium	○	●	○ / ●	--	--	--	●	*Pu has limited mobility under most conditions, but is least mobile in reduced valence state -- thus redox stabilization is possible. Complex chemistry complicates long-term stability and isolation.*
mercury	○	○ / ●	○ / ●	--	--	○ / ●	○ / ●	*Directed precipitation possible (e.g., with sulfide). Redox manipulation is possible in combination with nonaqueous isolation/extraction or sparging.*
thorium	●	●	○ / ●	--	--	--	●	Minimal opportunities for manipulation for stabilization (stable and relatively insoluble under most conditions)
radium	●	●	○ / ●	--	--	--	●	Minimal opportunities for manipulation for stabilization (stable and relatively insoluble under most conditions except brines)
lead	●	◎ / ○	◎ / ○	○ / ●	○ / ●	--	●	*Significant research and implementation of a wide range of possible treatments -- including directed precipitation, indirect manipulation and phytoextraction. Subsurface deployments have included reagent addition and*

Key to symbols used in table	
◎	Potentially applicable class of technology. Assumes approapriate and reasonable site conditions without major incompatibilities. Documentation of long-term stability may be needed.
◎ ○	May be applicable as described above. This designation is for technologies that may require more development, that have more uncertainty, or that have a narrower envelope of applicability.
○	Data or evidence are in the literature that suggest the possibility of using this class of technology for the subject contaminant -- but with significant uncertainties at this time.
○ ●	similar to above with more uncertainty and/or with a narrower envelope of applicability.
●	Technology class is not a likely candidate
--	limited data or unknown

Summary Thoughts

- Consider early warning systems
  - Vadose monitoring and sensors…
  - Tracers and indicators…
- Consider plume geometry
  - Exploit opportunities
  - Avoid pitfalls
- Consider nonstandard approaches
  - Geophysics
  - Phases (e.g., gas)
  - Push pull testing
- Consider geochemistry
  - Integrate into design of facility ("defense in depth")
  - Use in monitoring optimization
- Need sensitive and leading indicators that trigger technically based operational decisions or contingencies

SRNL

Focus Questions

- *Defining the Problem*
- *Q1.* Are there any technical or programmatic reasons why compliance monitoring programs are not designed and compliance monitoring data are not used to support and enhance confidence in models after site characterization has been completed and a site has been licensed?
- *Defining Opportunities*
- Q2. Do you know of any specific compliance and other monitoring programs and data at NRC-licensed facilities that could be used to improve models but are not currently used for that purpose?
- *Q3.* What modification in compliance monitoring program design or additional data collection can practically and realistically be instituted so that most use can be made of the monitoring data to improve models?
- *Defining Difficulties/Limitations*
- Q4. What are the technical and programmatic difficulties and limitations for integrating compliance monitoring programs and modeling at NRC-licensed facilities, with a view to make most use of the monitoring data to increase confidence in model results?
- *Defining Technological Solutions/Know How/State of the Art*
- *Q5.* Do you know of demonstrated methods, techniques, approaches, or analytical tools that could be used to integrate monitoring data and models more effectively?
- *Q6.* Do you know of new methods, techniques, approaches, or analytical tools that are promising and should be pursued?
- *Defining Programmatic Actions*
- Q7. What programmatic actions do you recommend be considered or undertaken that can promote the use of monitoring data to support models and enhance confidence in the model results more effectively?
- *Summing Up*
- Q8. To sum up, do you have specific recommendations on how to improve the integration of compliance monitoring programs and modeling to increase confidence in model results for NRC-licensed facilities?
- Q9. To sum up, do you have specific recommendations or suggestions on a path forward?

SRNL

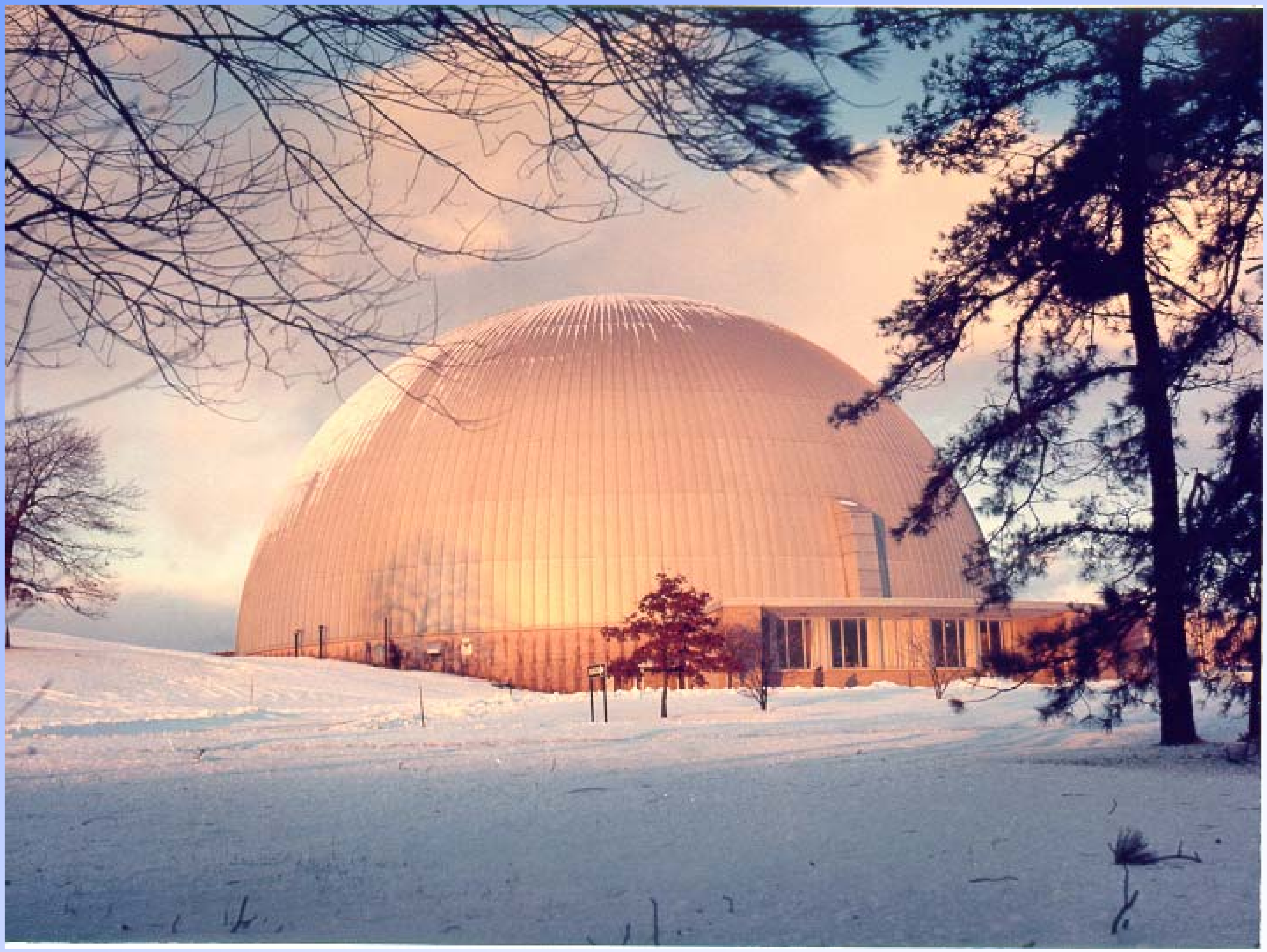
HFBR Tritium Plume

Tritium Investigation and Remediation at Brookhaven National Laboratory

Thomas Burke PE, Michael Hauptmann PE,

September 19, 2006

High Flux Beam Reactor (HFBR)



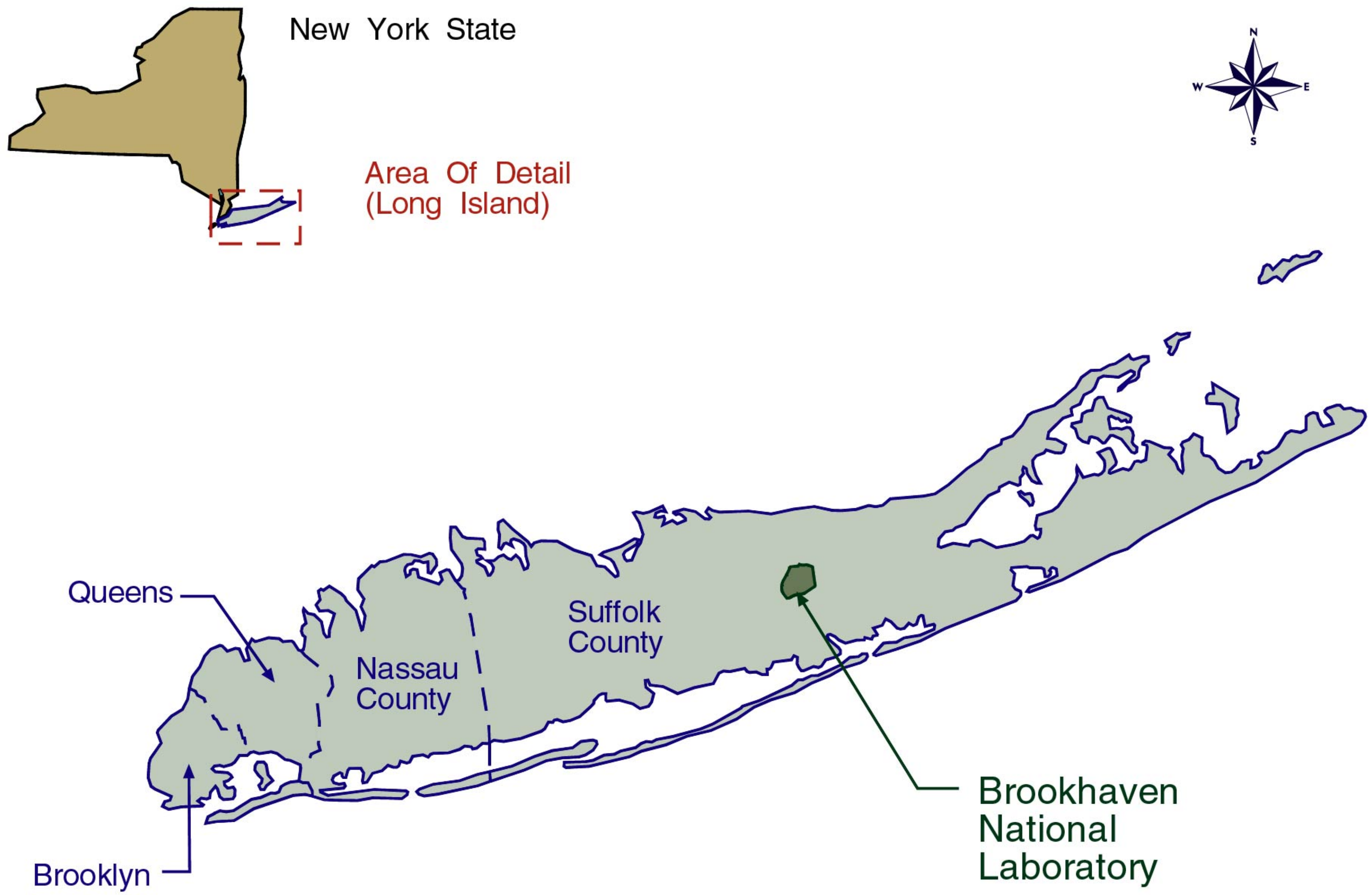


Figure 1
BNL Location Map

MLD - 11/08/96
gis3/dwgs/bnl-nys.map

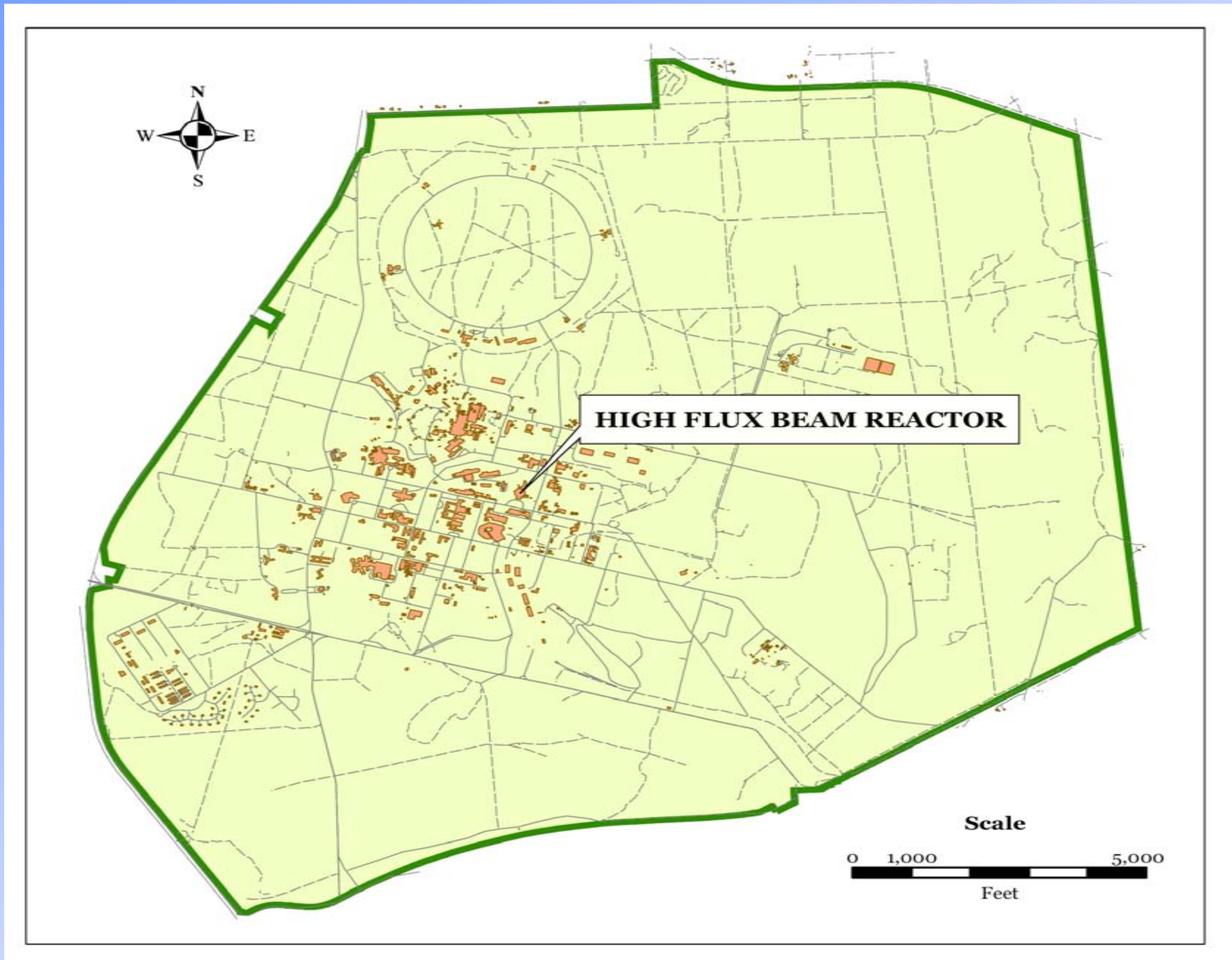
Brookhaven National Laboratory

- Department of Energy, National Laboratory Established in 1947

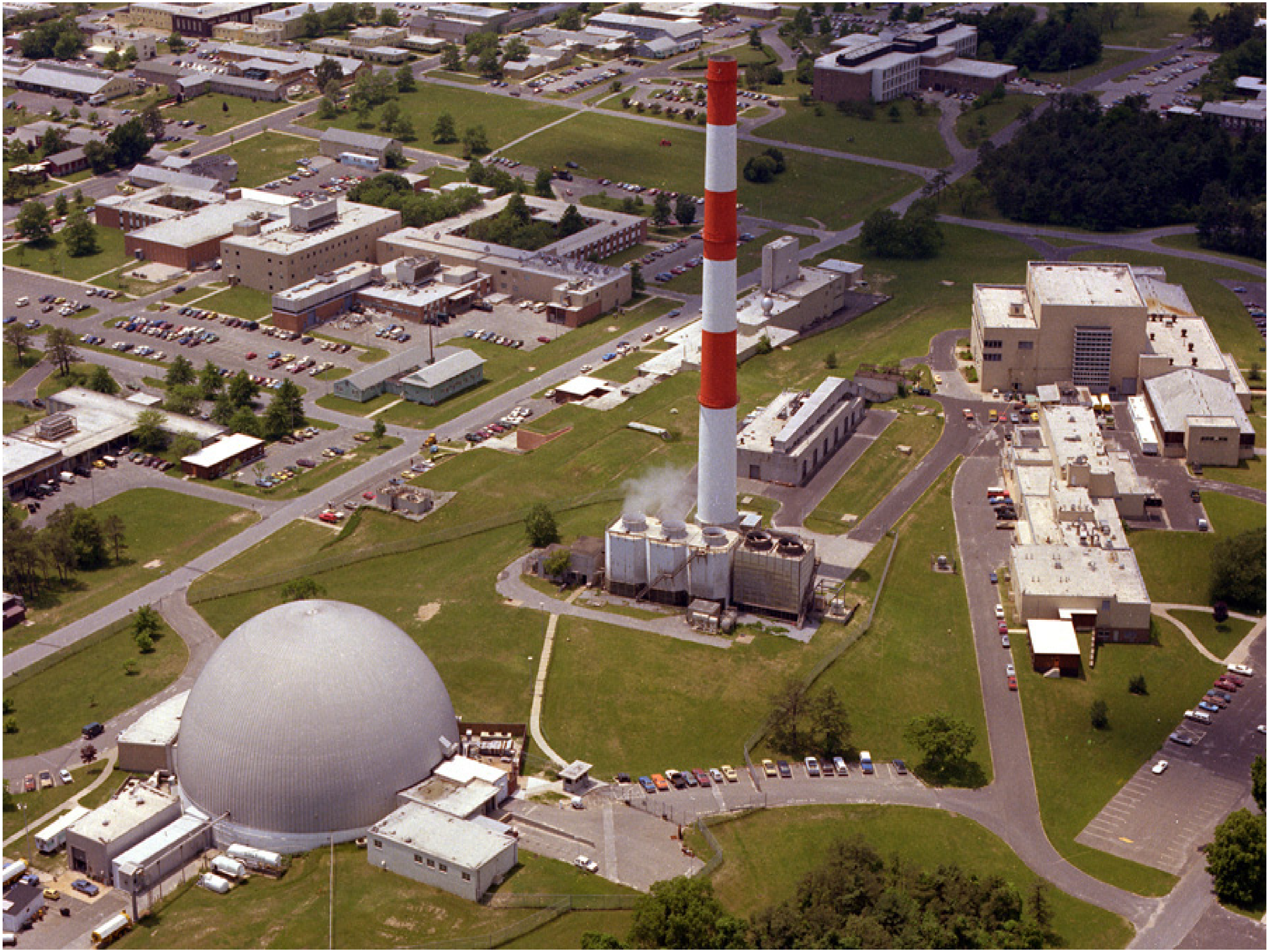
- 2700 Employees

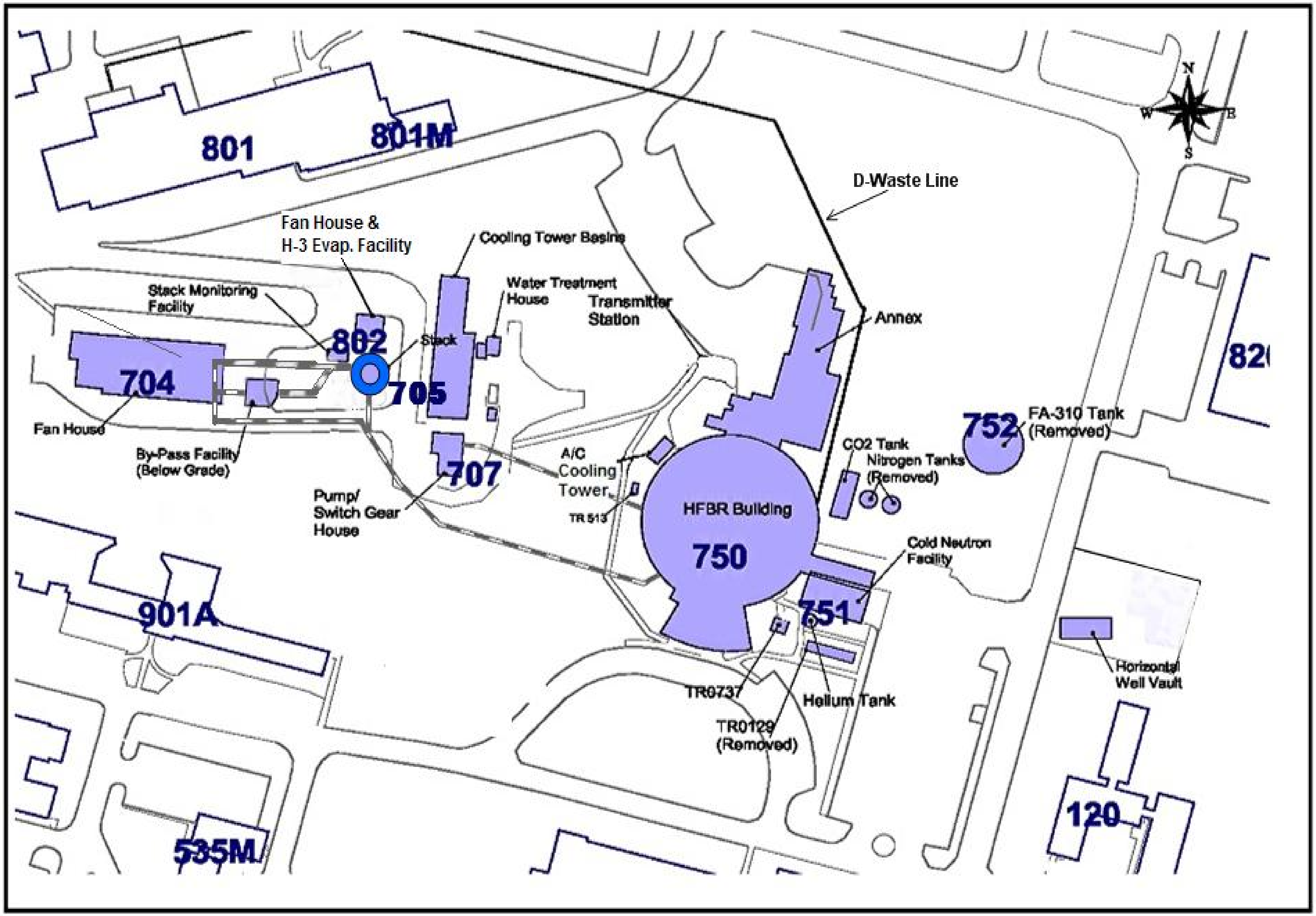
- ~5300Acres

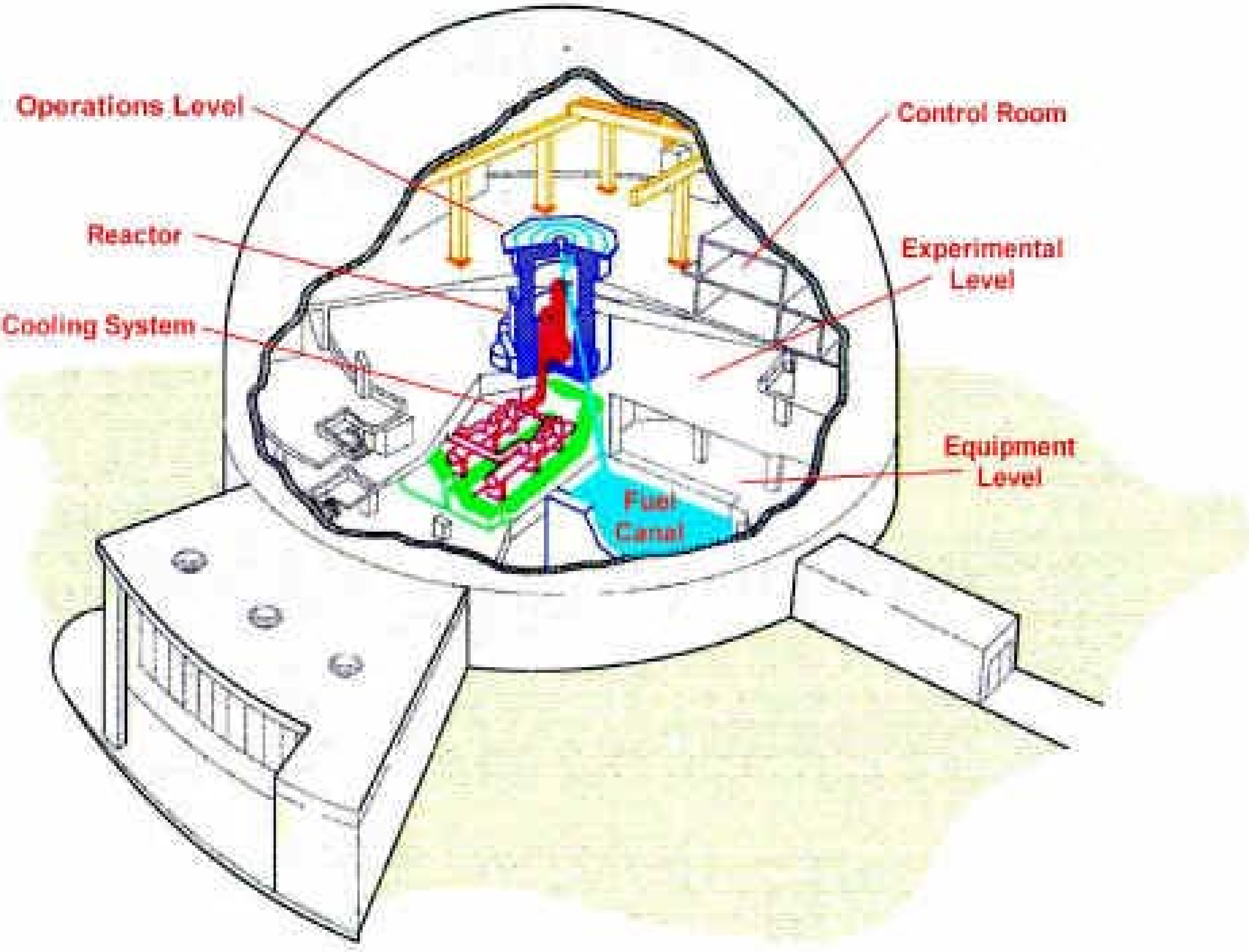
HFBR Location



BROOKHAVEN
NATIONAL LABORATORY



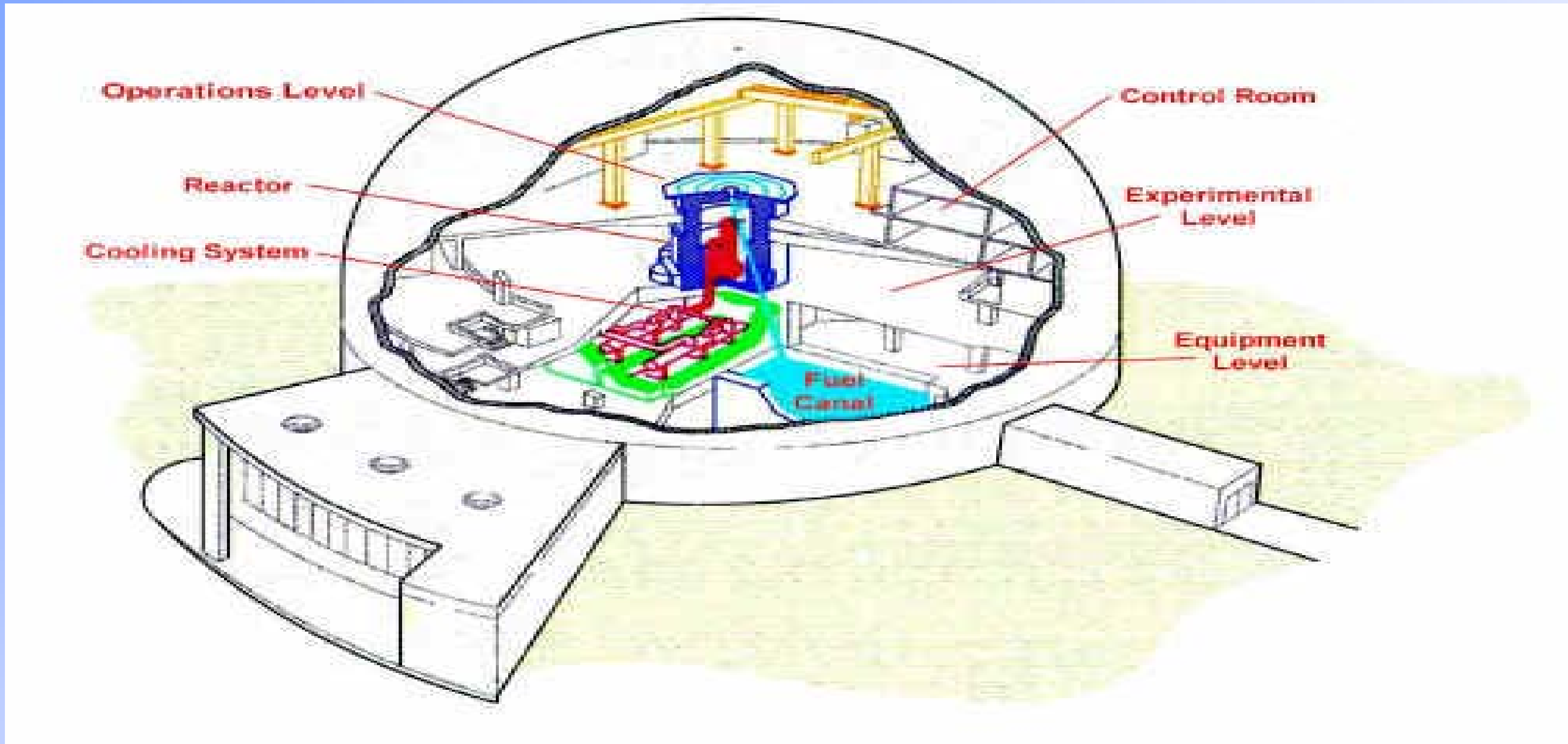

801
801M
N
W
E
S
D-Waste Line
Fan House &
H-3 Evap. Facility
Cooling Tower Basins
Stack Monitoring
Facility
Water Treatment
House
Transmitter
Station
Annex
802
Stack
704
705
82
Fan House
By-Pass Facility
(Below Grade)
707
A/C
Cooling
Tower
752
FA-310 Tank
(Removed)
CO2 Tank
Nitrogen Tanks
(Removed)
Pump/
Switch Gear
House
TR 513
HFBR Building
750
Cold Neutron
Facility
901A
751
Horizontal
Well Vault
TR0737
Helium Tank
TR0129
(Removed)
120
535M



Operations Level
Control Room
Reactor
Experimental
Level
Cooling System
Equipment
Level
Fuel
Canal

Building 750

- Hemispherical dome (inside diameter 176’ 8”)
  - Supported on cylinder wall (22’ 4” high)
  - Reinforced concrete foundation slab/mat (5’ thick)



Reactor History

- Originally designed power level of 40 megawatts
- Achieved criticality on October 31, 1965
- Shut down in 1989 to reanalyze the safety impact of a hypothetical loss-of-coolant accident
- Restarted in 1991 at 30 megawatts

Reactor History (continued)

- Shutdown in 1996 for routine maintenance and refueling
- December 1996, tritium discovered in groundwater down gradient of the HFBR
- The source was determined to be the spent fuel pool
- Remediation of the tritium plume and the HFBR Spent Fuel Pool being performed CERCLA
- Secretary of Energy announced permanent closure based on program budget concerns in November 1999

Regulatory Framework

- BNL is a federal Superfund site (CERCLA)
- 1992 Interagency Agreement (IAG)
  - Department of Energy, U.S. EPA Region II and New York State
  - Suffolk County Department of Health Services also actively involved
- BNL has 30 Areas of Concern divided into seven Operable Units/Study Areas

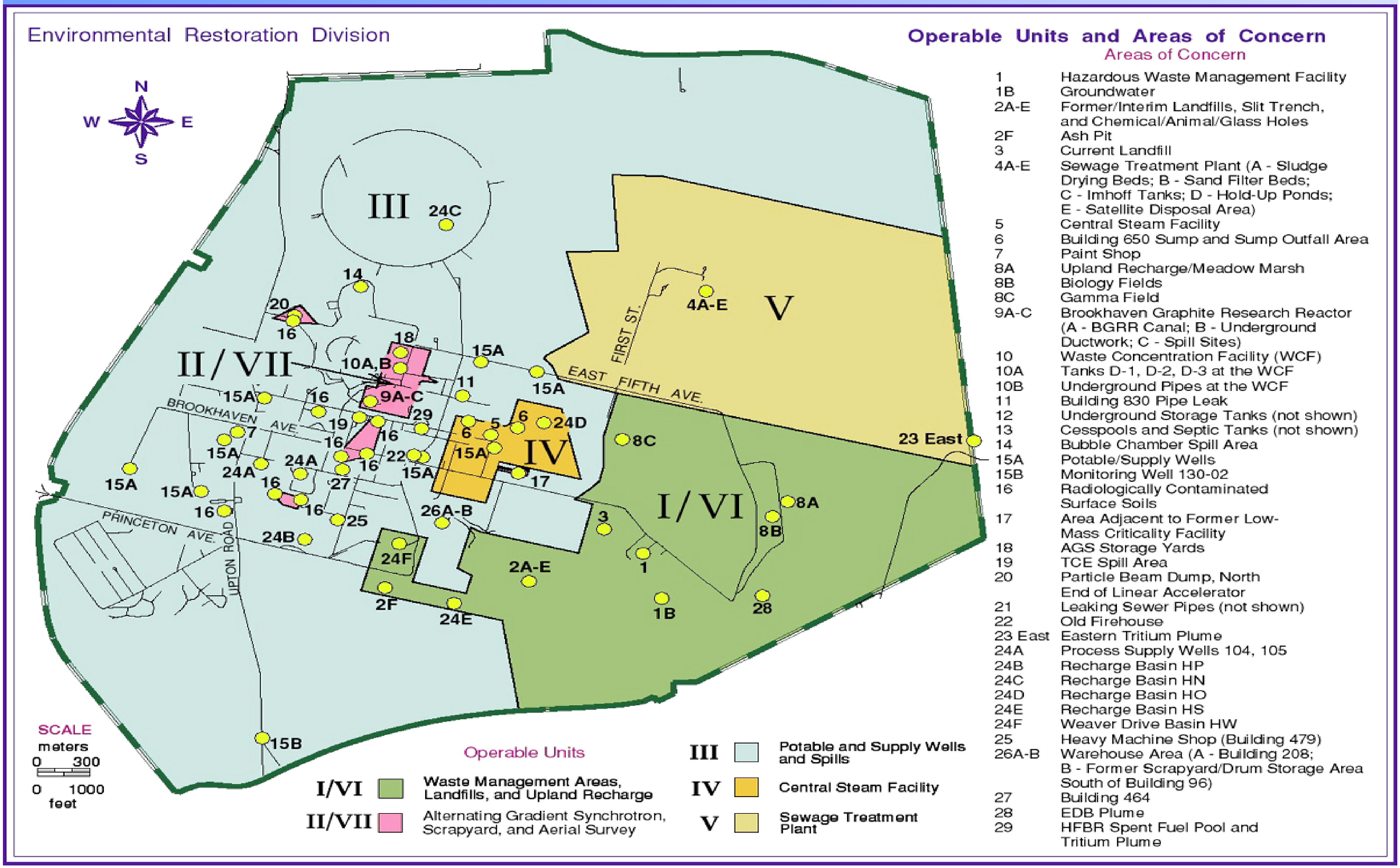
Hydrogeologic Conditions

- Sole source Aquifer
- Upper Pleistocene deposits consisting of glacial tills & outwash deposits (Upper Glacil Aquifer)
- Hydraulic conductivity ~175 ft/day (range 20-300)
- Anisotropy 10:1
- Annual precipitation 48 inches, approximately ½ pecolates to aquifer as recharge
- HFBR 73 feet to Water Table
- Spent Fuel Pool bottom 23 feet to water table

Groundwater Contamination

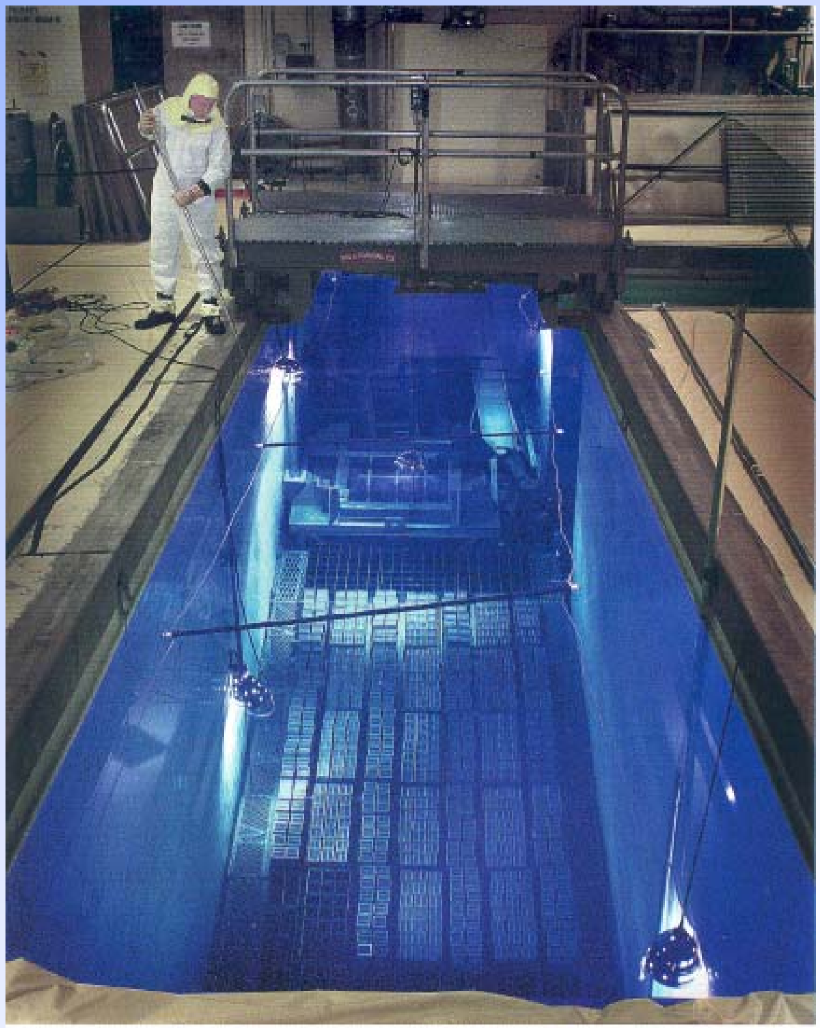
- Volatile organic compounds (VOCs) (7000 ug/l)
- Tritium (5.1×10^6 pCi/l)
- Strontium-90 (3200 pCi/l)

Operable Units & Areas of Concern



Spent Fuel Canal

- Canal chemistry:
  - Trace amounts of Co, Zn, Cr & Mn
  - Tritium ranging from 40 million pCi/l to 140 million pCi/l
- Leaked for 12 years
  - 6 to 9 gal/day
  - Total release of 5 to 6 curies of tritium



Canal Liner

HFBR Initial Characterization

- Well Drilling (piezometers, geoprobes, vertical profiles)
- Sampling (tritium gross alpha & beta, VOCs)
- Groundwater modeling (MODFLOW, MT3D) Detailed conceptual site model already existed (189 rows, 223 columns 8 layers, covering 200 square miles)

HFBR Groundwater Modeling

- Range of GW modeling: simple mass balance calculations, analytical 2-D advection & 3-D dispersion model, more complex numerical model (MODFLOW)
- Range of modeling provided similar results
- Regional and local finite difference numerical modeling (MODFLOW)Telescopic mesh refinement for local finite difference models
- MODFLOW& MT3D showed plume was in equilibrium (best match to plume geometry).

Tritium Transport Processes

- Advection
- Dispersion
- Radioactive decay
- Retardation
- Chemical/biological reaction- none

HFBR Initial Characterization

- 3 Geoprobes
- 9 Drill rigs with support crews
- Vertical profiles being installed 18 hours a day
- 5 analytical labs (48 hour TAT)

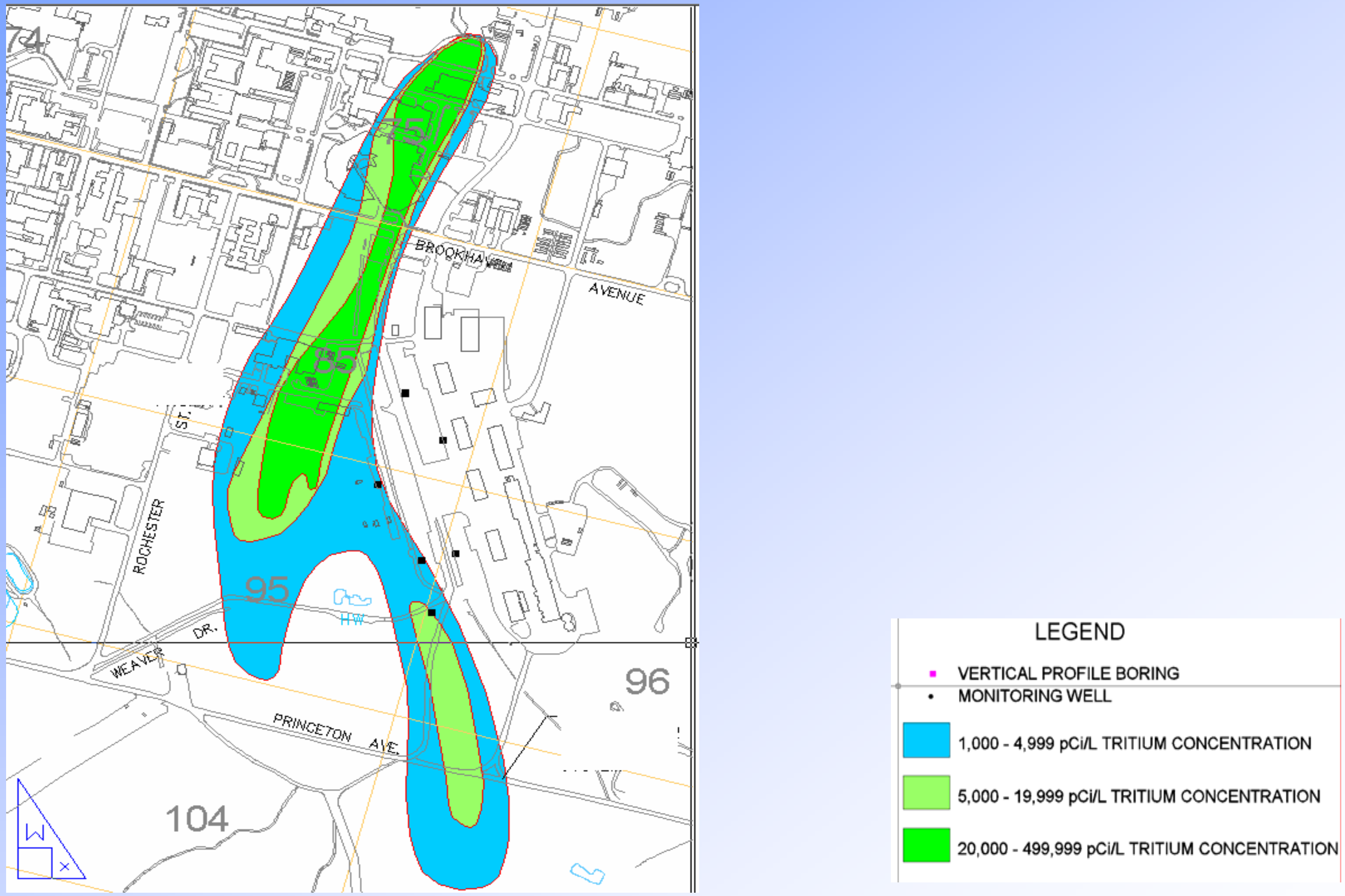
HFBR Initial Characterization

- 30 Piezometers
- 51 Monitoring Wells
- 45 Geoprobes
- 77 Vertical Profile temporary wells
- 1900 Samples (Tritium, VOCs, etc)
- Plume Characterization & Remediation cost $6,300k

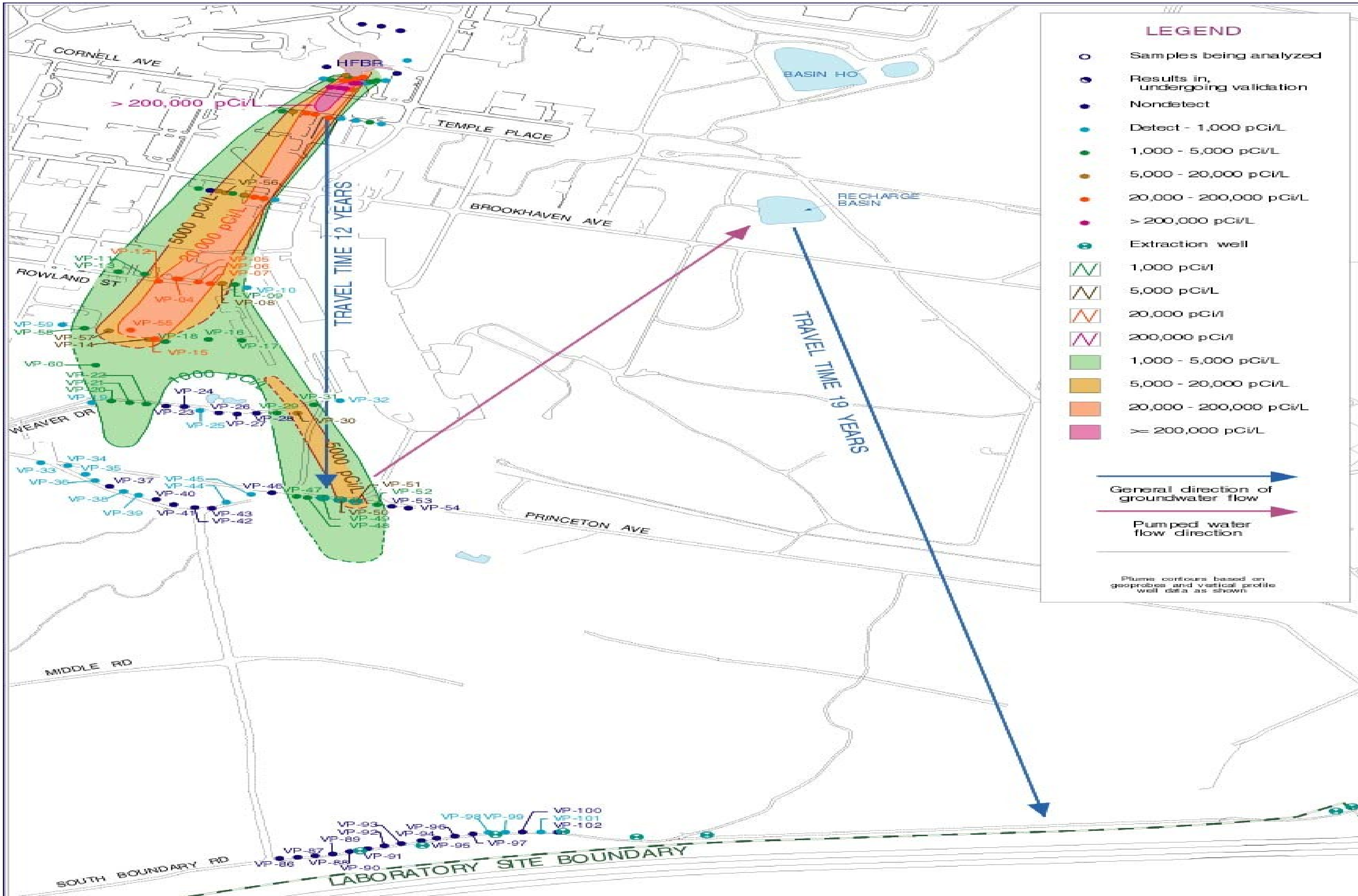
HFBR Continued Monitoring

- Monitoring well network of 159 wells
- Augmented by temporary wells (vertical profiles and geoprobes)
- Annual Monitoring costs $180k

HFBR Tritium Plume – 1997



BROOKHAVEN NATIONAL LABORATORY



ENVIRONMENTAL RESTORATION DIVISION

BROOKHAVEN NATIONAL LABORATORY

Figure 1-2
HFBR Tritium
Plume Characterization

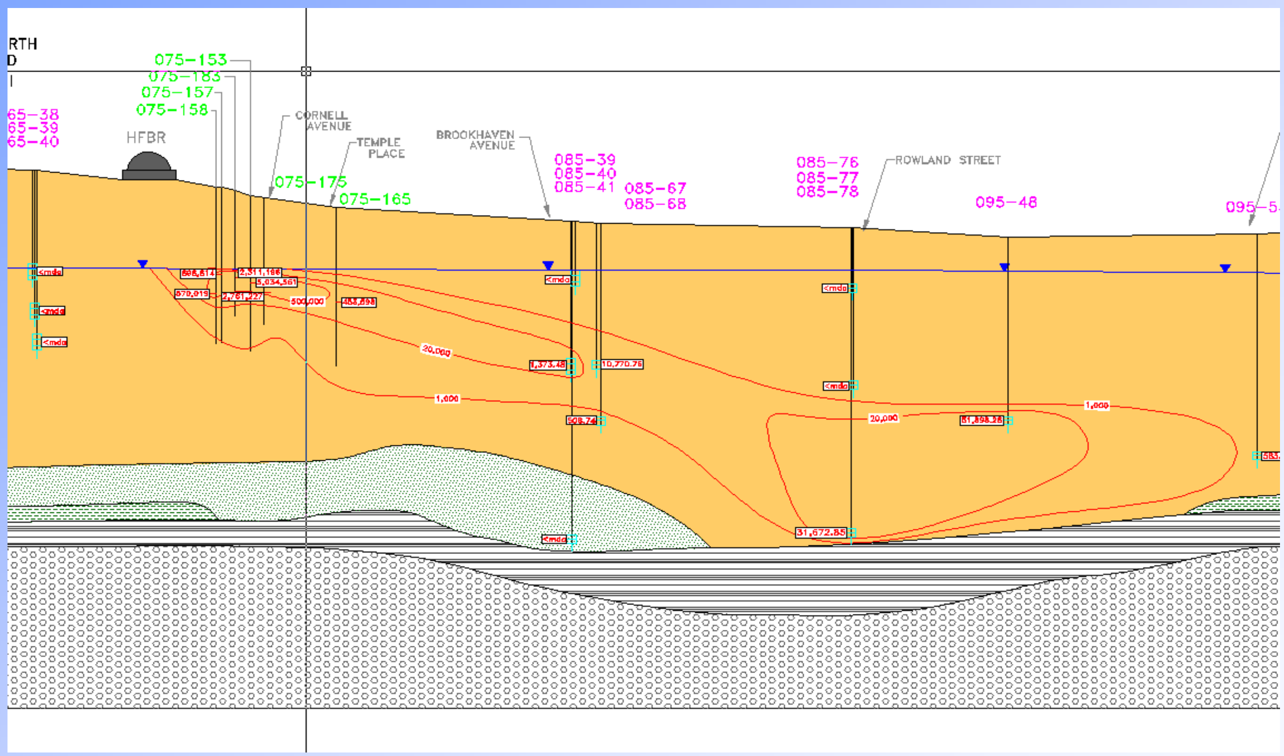
HFBR TRITIUM PLUME

January 15, 1998

SCALE

MLD - 03/10/98

HFBR Tritium Plume Cross Section - 1999



Clean Up Goals

OU III Record of Decision

- Clean up to MCLs in 30 years of less
- Prevent or minimize further migration of tritium in the groundwater (plume growth)

HFBR Tritium Plume Remediation

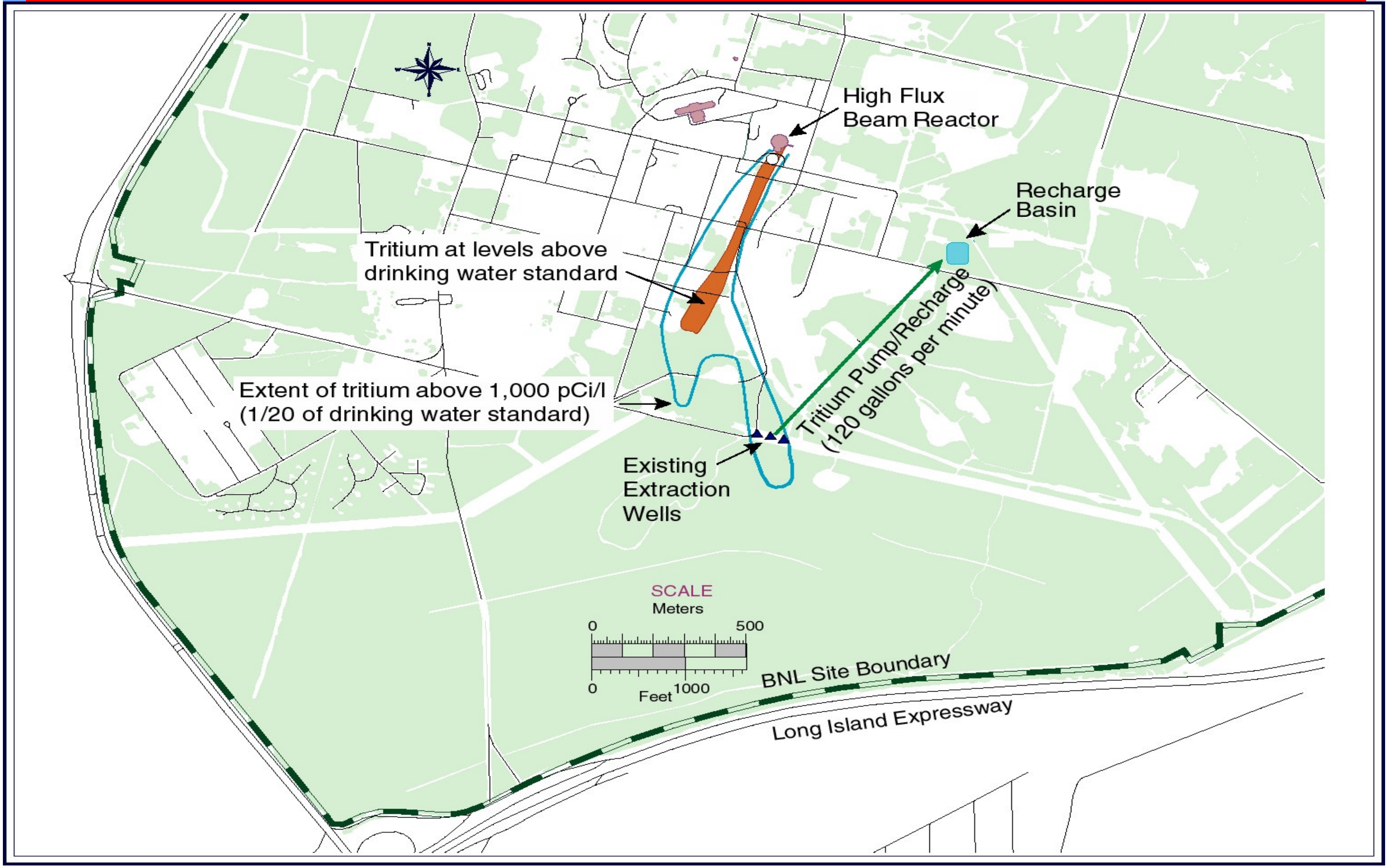
- Hydrogeologic Evaluation based on iterative Monitoring and Modeling resulted in three-fold approach:
  - Pump and recharge system at leading edge of plume.
  - Low flow pumping near the HFBR (source).
  - Monitored Natural Attenuation of the entire plume (plume management).

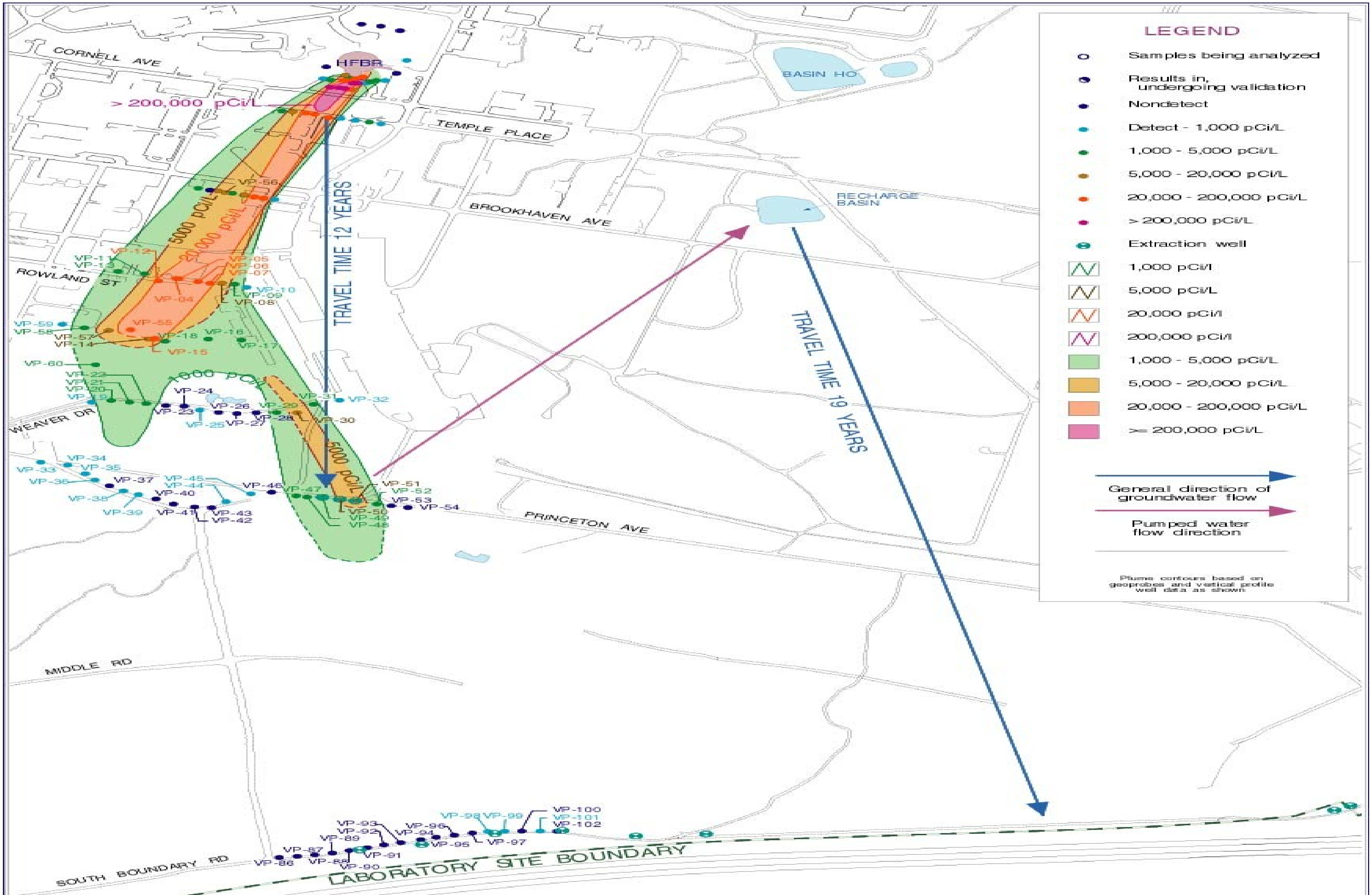
Tritium Plume Pump and Recharge System Design

Modeling provided groundwater flow direction, capture zone estimate, time to cleanup, and pumping well locations/rate. Quarterly monitoring verified capture and plume behavior.

- Designed and built plume pump and recharge system at the end of the plume in 1997 with carbon treatment for VOCs.
- Pump and recharge system designed to provide more time for plume to decay and attenuate on BNL site.

HFBR Tritium Plume Pump and Recharge - 1997





ENVIRONMENTAL RESTORATION DIVISION

BROOKHAVEN NATIONAL LABORATORY

Figure 1-2
HFBR Tritium
Plume Characterization

HFBR TRITIUM PLUME

January 15, 1998

SCALE

Meters: 0 100 200

Feet: 0 100 200 300 400 500 600

MLD - 03/10/98
[my.gis]ou3trit/map2010.aml
[Mac]ou3trit/map2010-r17b.ill

Tritium Plume Pump and Recharge System Operation

Modeling provided groundwater flow direction, time to cleanup, and pumping well locations/rate. Quarterly monitoring verified capture and plume behavior.

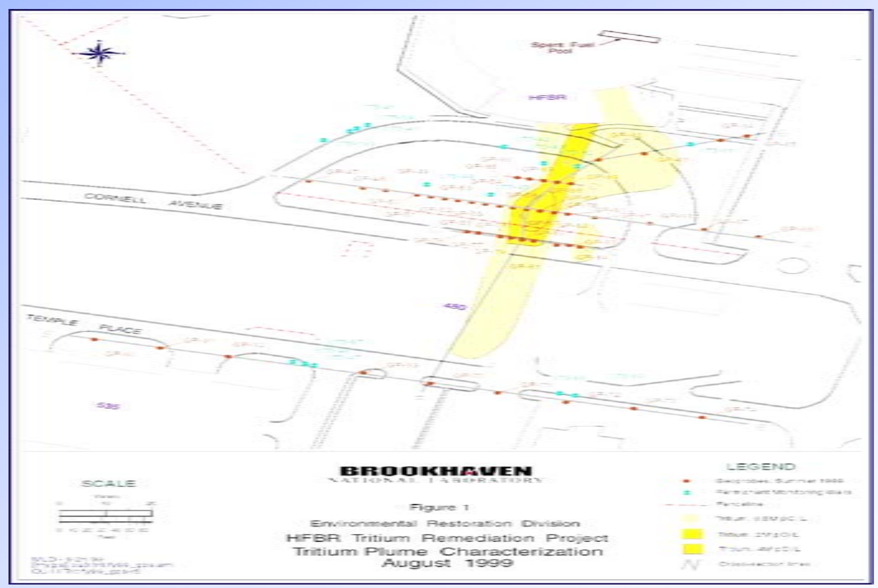
- 3 extraction wells
- Total of 120 gpm (3 x 40 gpm)
- Carbon treatment for VOCs
- After three years of pumping, system placed in standby mode in September 2000.

Tritium Plume

Carbon Treatment for VOCs

Tritium Plume Low Flow Extraction Design

Modeling provided pumping trigger concentration (750,000 pCi/L) and stop concentration (500,000 pCi/L) based on travel time to pump and recharge extraction wells and tritium dispersion and decay. Monitoring provided verification of the results.

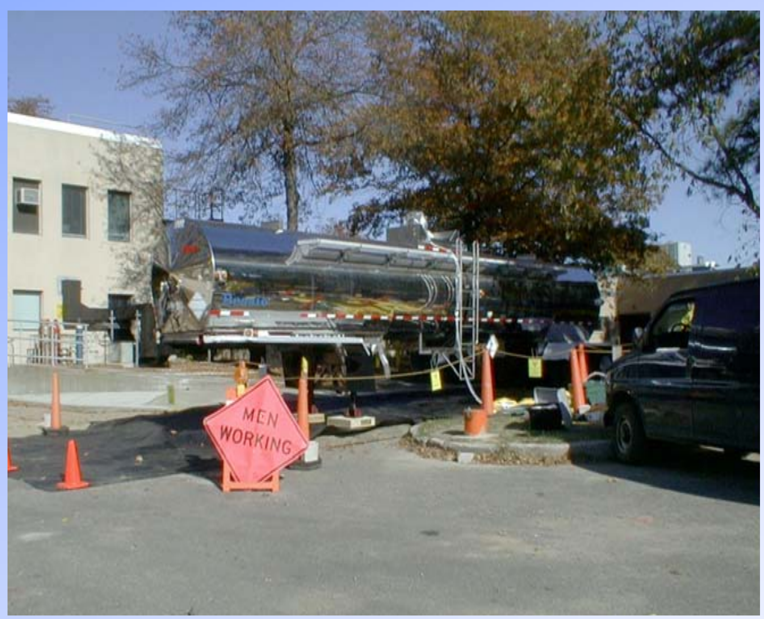


Tritium Plume Low Flow Pumping Operation

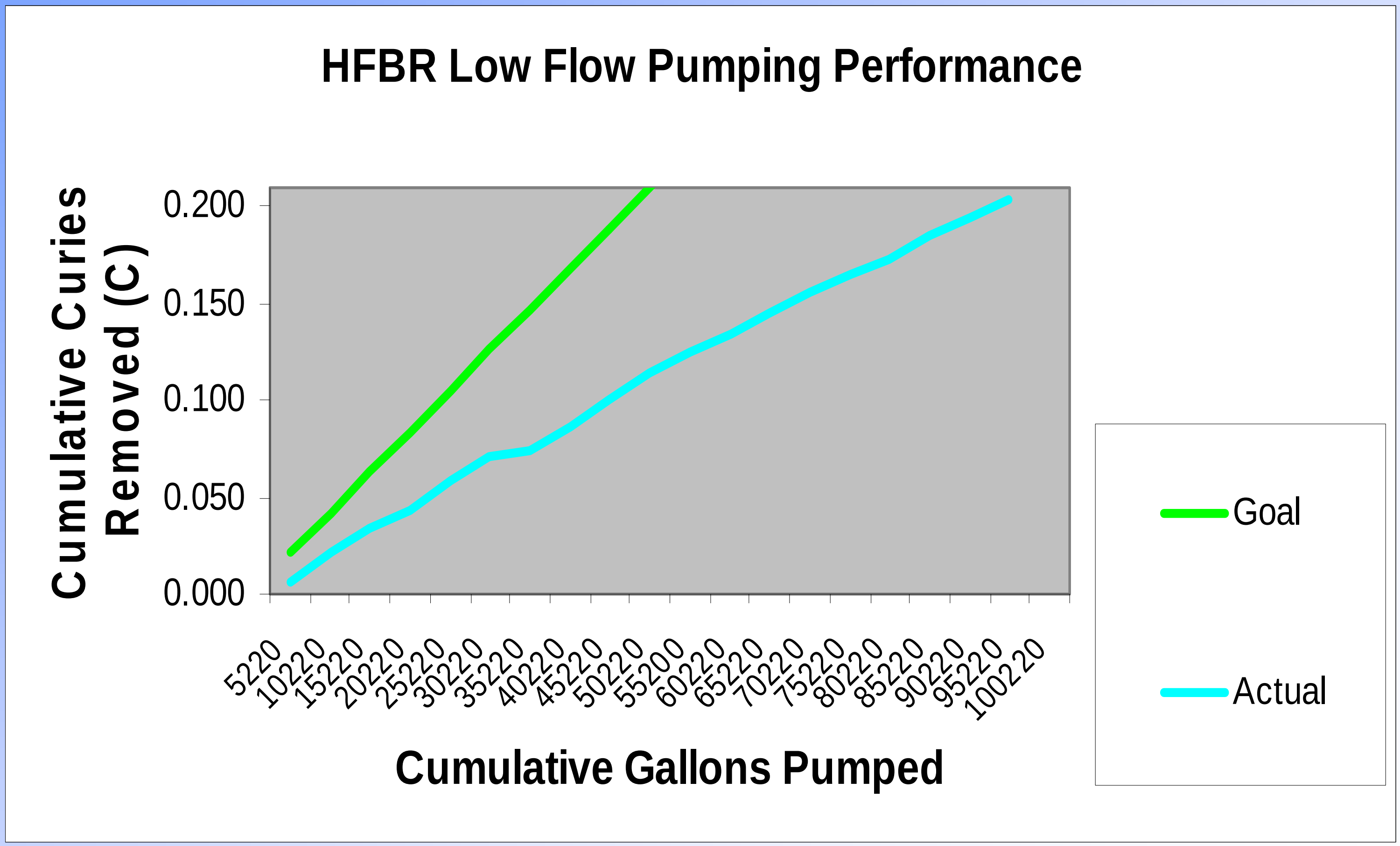
High concentrations at the head of the plume near the source were extracted if concentrations exceeded 750,000 pCi/L.

Total of 95,000 gallons and approximately 0.2 Ci out of 1.0 Ci were extracted.

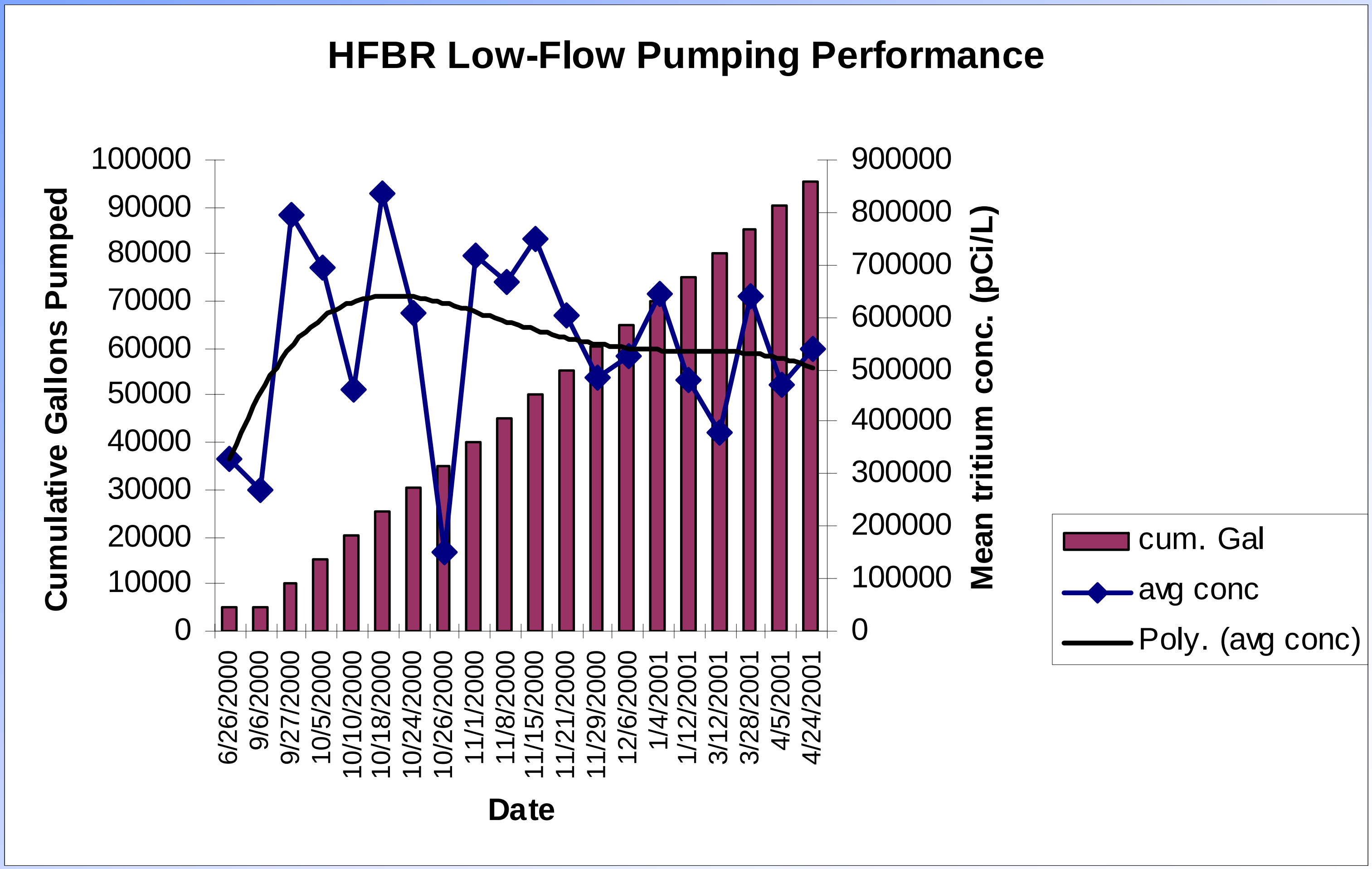
System inactive since April 2001.



Tritium Plume Low Flow Pumping Results



Tritium Plume Low Flow Pumping Results

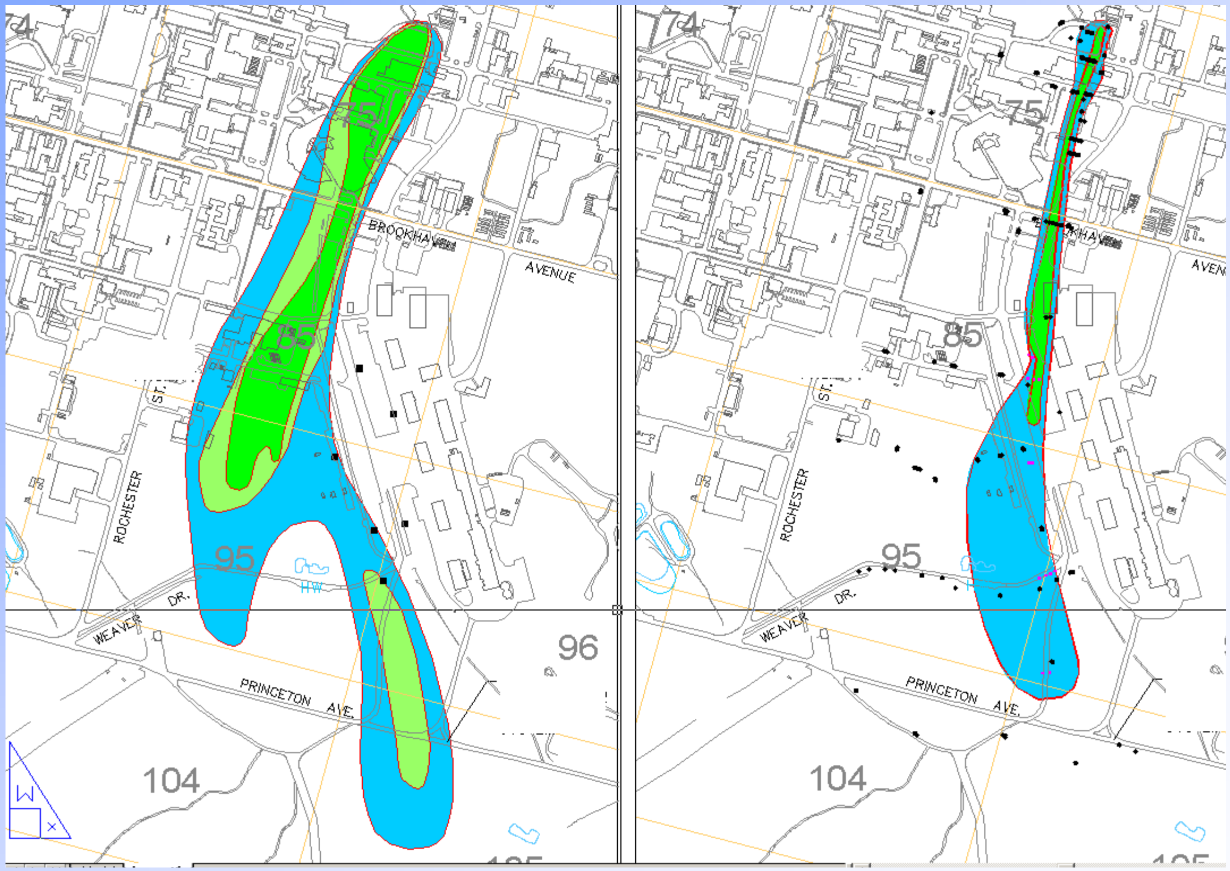


Tritium Plume Management

- Quarterly, semi-annual and annual monitoring provide verification of modeled plume behavior.
- Geoprobes, vertical profiles and permanent wells are used to maximize efficiency.
- Iterative approach results in improved model verification and increased monitoring efficiency.

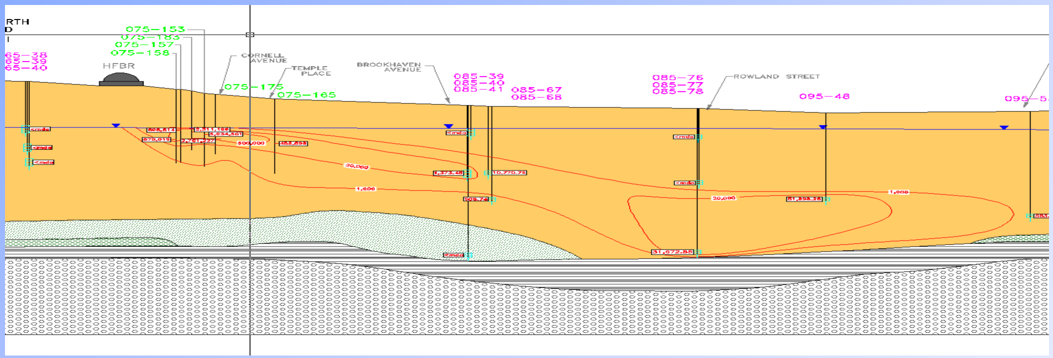
HFBR Tritium Plume 1997 - 2004

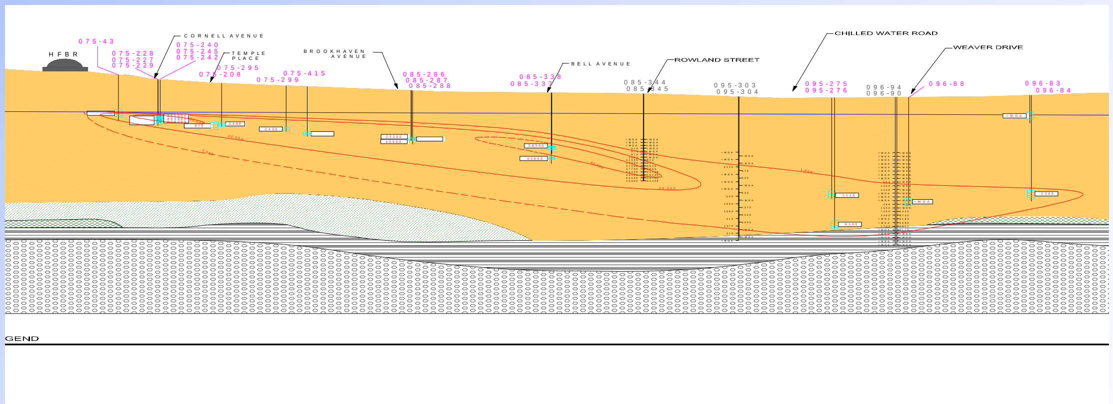
There has been significant success in plume management.



HFBR Tritium Plume
Cross Section – 1999 and 2004

The plume has remained within its original envelope and concentrations have decreased ~5X.





HFBR Tritium Plume - Current Status and Lessons Learned

- Downgradient portion is naturally attenuating.
  - Pump restart trigger of 20,000 pCi/L at Weaver Drive never exceeded.
- Upgradient portion is attenuating but receiving additional tritium from the unsaturated zone beneath the HFBR.
  - Influence of regional groundwater elevation.
  - Low flow pumping trigger level has not been exceeded since 2001.
- Monitored Natural Attenuation to continue~10 yrs.
- Permanent wells for monitoring tritium in most groundwater may have some drawbacks.
- Temporary wells (Geoprobes) more accurate and cost effective.

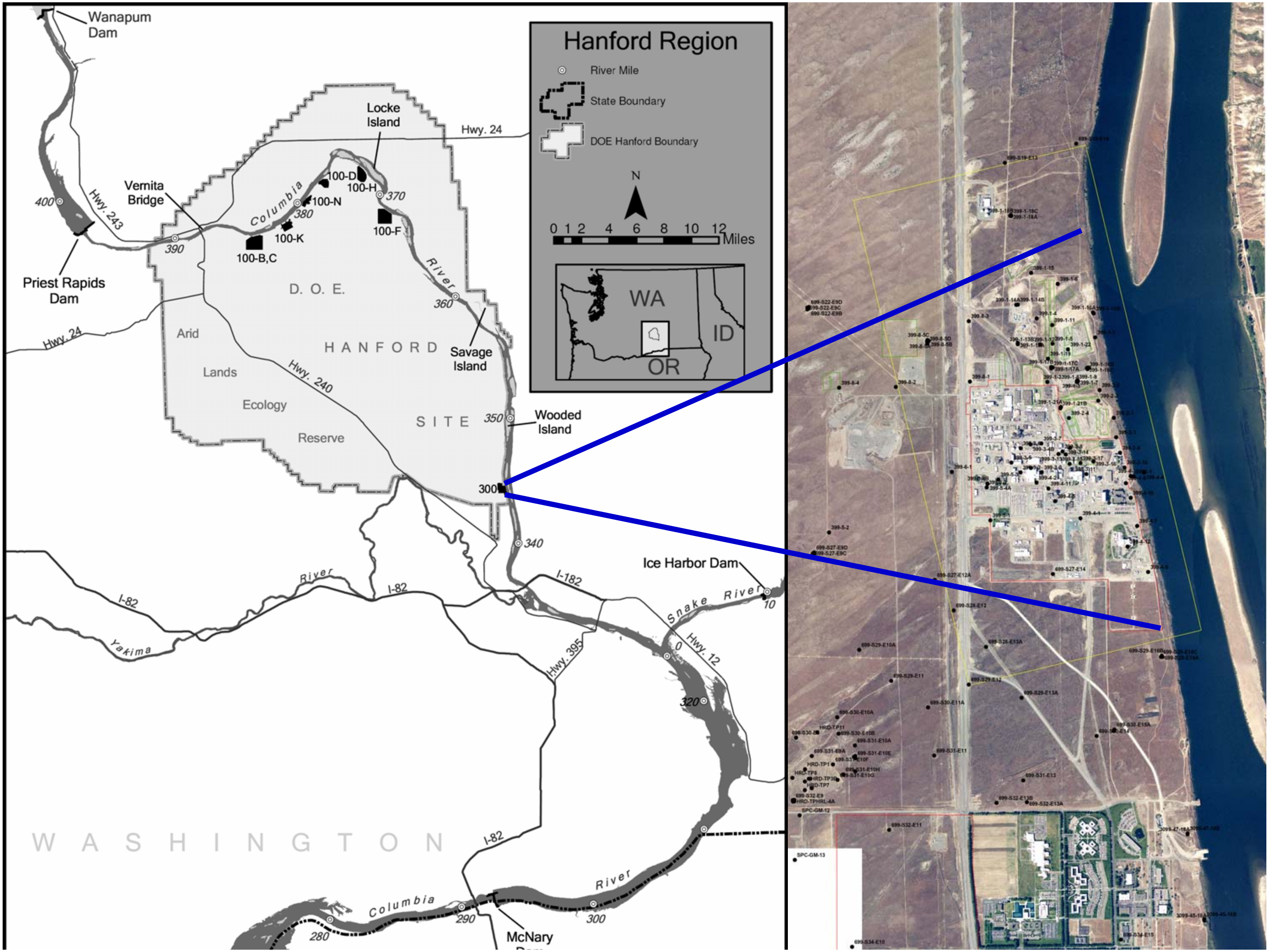
Uranium Reactive Transport in a Vadose Zone-Aquifer-River System

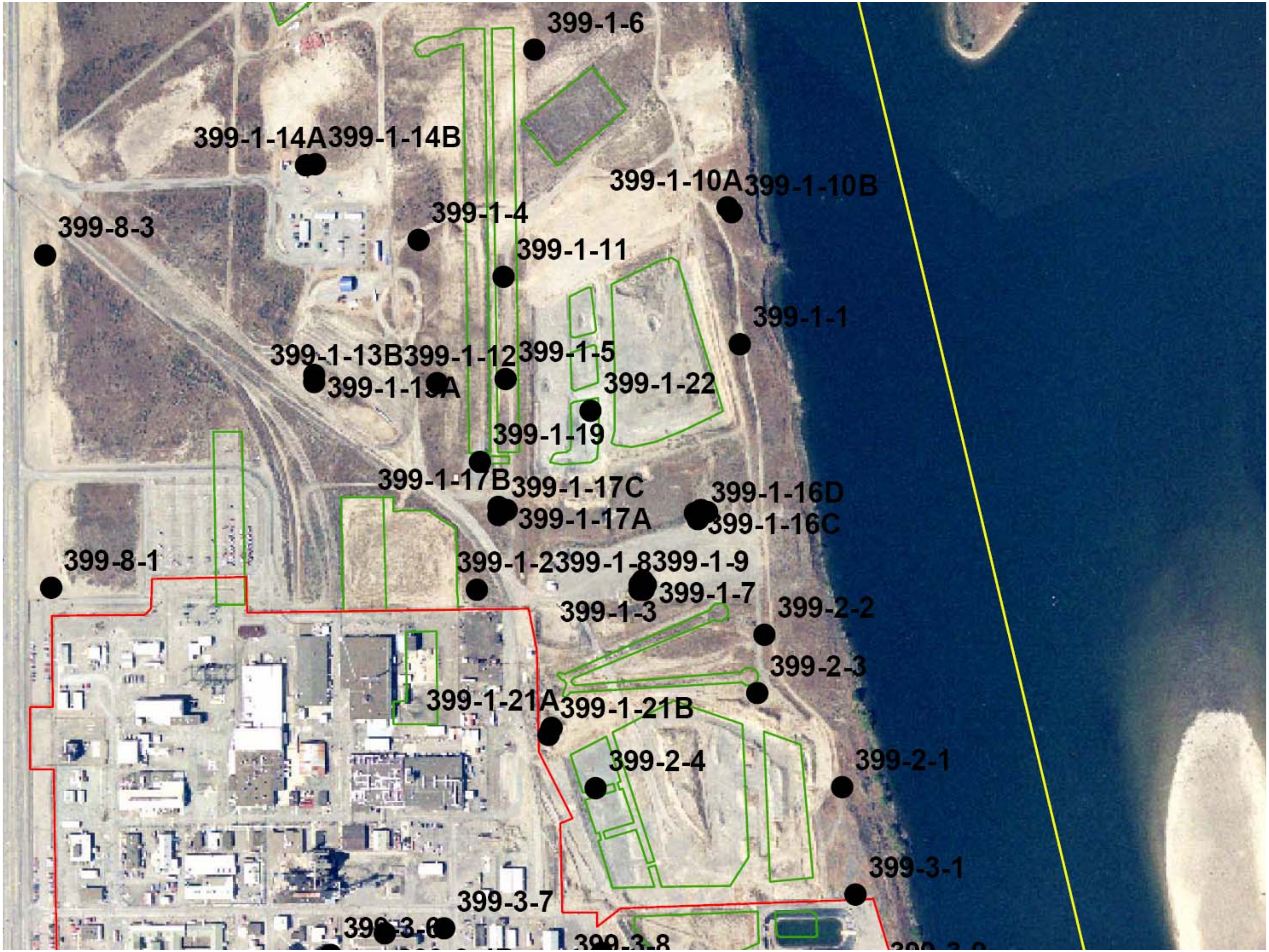
Steve Yabusaki
Pacific Northwest National Laboratory

Advisory Committee on Nuclear Waste WG Meeting
“Integrating Monitoring and Models to Enhance Confidence in Model Results”
September 19-20, 2006
Washington, D.C.

General Themes

- Monitoring and modeling should be consistent with the scales of the controlling processes
- Modeling provides systematic framework
  - characterization of processes and properties
  - design of sampling/monitoring schemes
  - interpretation of monitoring data


Hanford Region
River Mile
State Boundary
DOE Hanford Boundary
N
0 1 2 4 6 8 10 12
Miles
WA
ID
OR
Wanapum Dam
Priest Rapids Dam
Vernita Bridge
Locke Island
Hwy. 24
Hwy. 243
400
390
380
370
360
350
340
320
300
290
280
10
0
Columbia River
100-D
100-H
100-N
100-K
100-B,C
100-F
D. O. E.
HANFORD
SITE
Arid
Lands
Ecology
Reserve
Hwy. 240
Savage Island
Wooded Island
300
Ice Harbor Dam
I-182
I-82
Snake River
Hwy. 12
Hwy. 395
Yakima River
WASHINGTON
McNary Dam



399-1-6
399-1-14A
399-1-14B
399-1-10A
399-1-10B
399-1-4
399-8-3
399-1-11
399-1-1
399-1-13B
399-1-12
399-1-5
399-1-22
399-1-19
399-1-17B
399-1-17C
399-1-17A
399-1-16D
399-1-16C
399-8-1
399-1-2
399-1-8
399-1-9
399-1-7
399-1-3
399-2-2
399-2-3
399-1-21A
399-1-21B
399-2-4
399-2-1
399-3-1
399-3-7

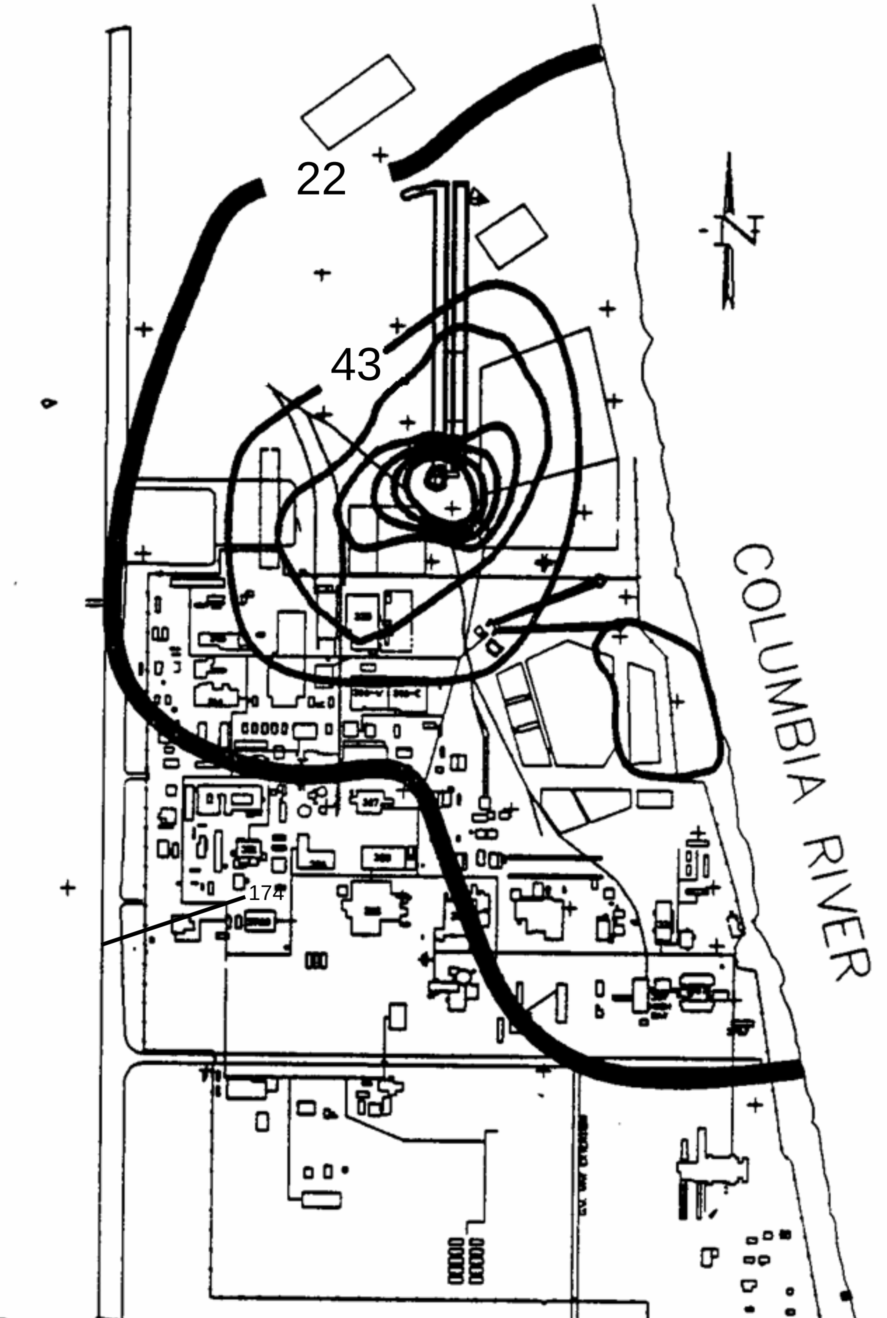
Hanford 300 Area in 1962

Operational History of the 300 Area Process Ponds and Trenches

- Fabrication of nuclear fuel elements for the Hanford reactors results in uranium liquid waste streams
  - Unlined waste ponds
    - South Process Pond – 1943 to 1975
    - North Process Pond – 1948 to 1975
  - Unlined process trenches
    - 316-3 Trenches – 1953 to 1963
    - 316-5 Trenches – 1975 to 1994
  - 10 m to water table
- Complex, poorly documented waste disposal history
  - Estimated 70,000 kg of uranium to process ponds
  - 1.55 to 7.57 million liters per day discharge to ponds

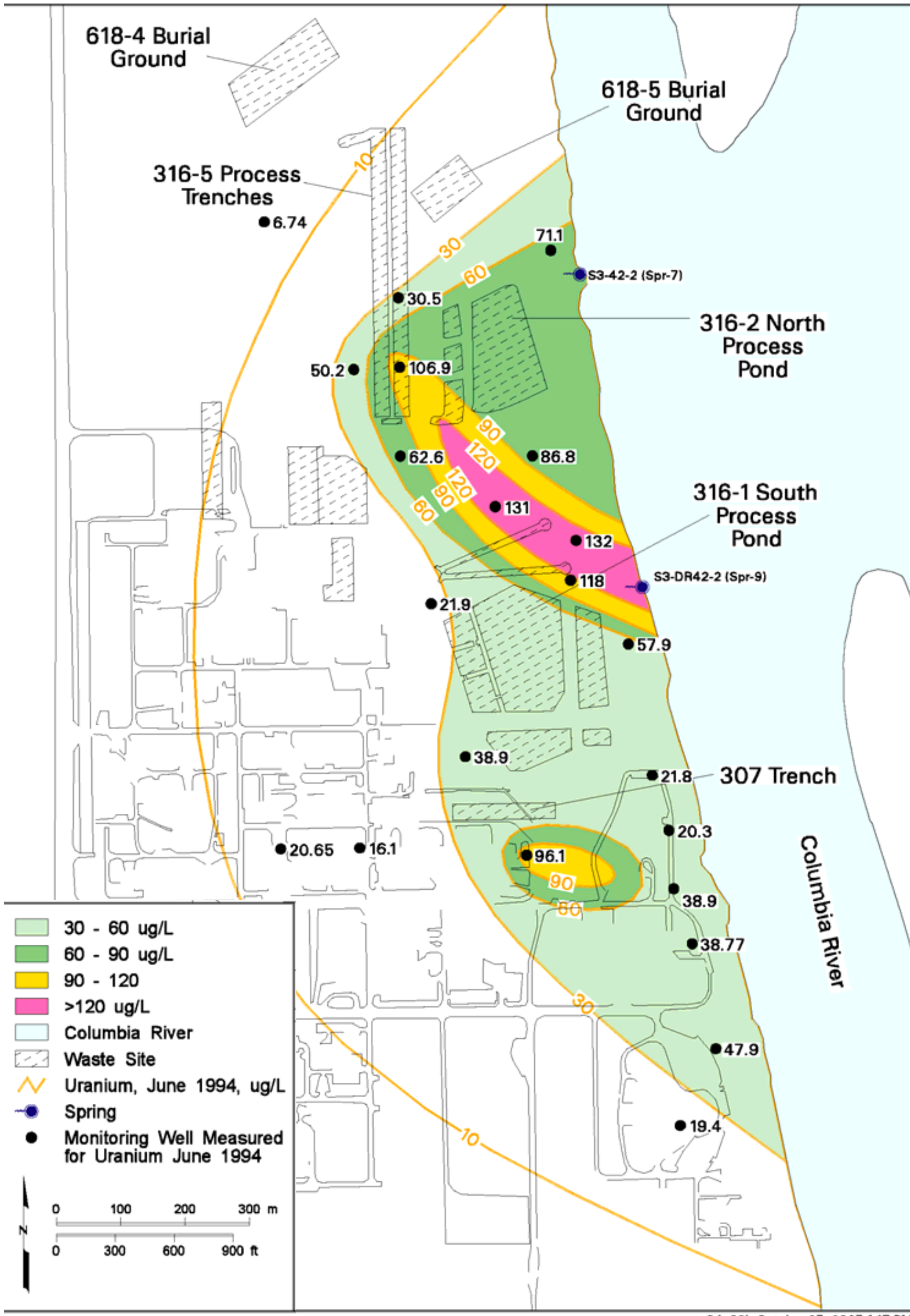
1990 Uranium Plume

- Large area exceeding drinking water standard
- Hot spot at south end of 316-5 trenches at high river stage
- 1991 Expedited Response Action
  - Remove contaminated soils from process trenches
  - End discharge of uranium to process trenches
- 1993 groundwater flow and uranium transport analysis predicted cleanup to < 20 ug/L in 3 to 10 years



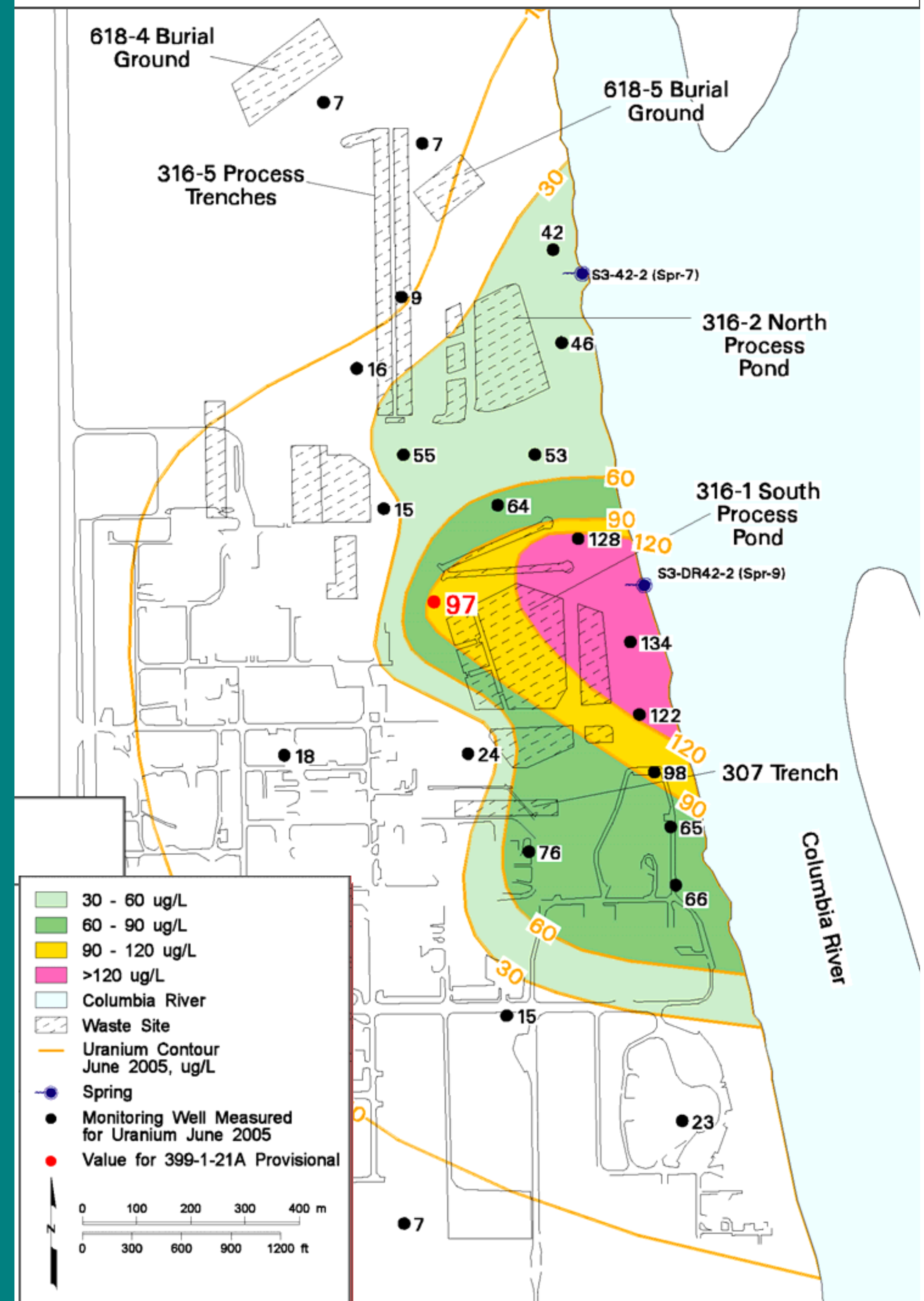
1990 Uranium (ug/L)

Shaded 300 Area Uranium, June 1994



can pete04 23b October 25, 2005 1:17 PM

Shaded 300 Area Uranium, June 2005



can pete05 35a December 01, 2005 4:45 PM

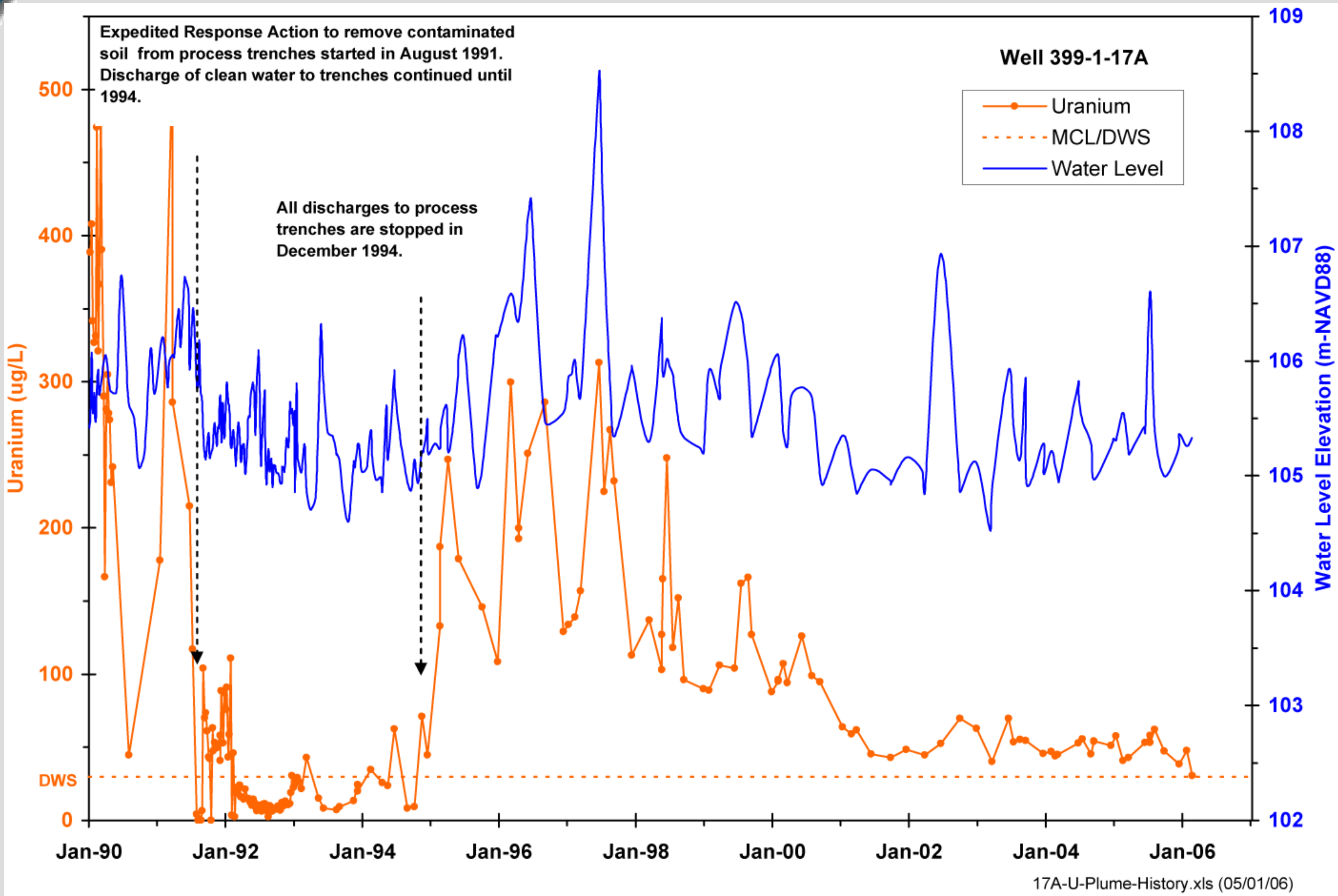
1993 Conceptual Model

Modeling Assumptions in Phase I Remedial Investigation

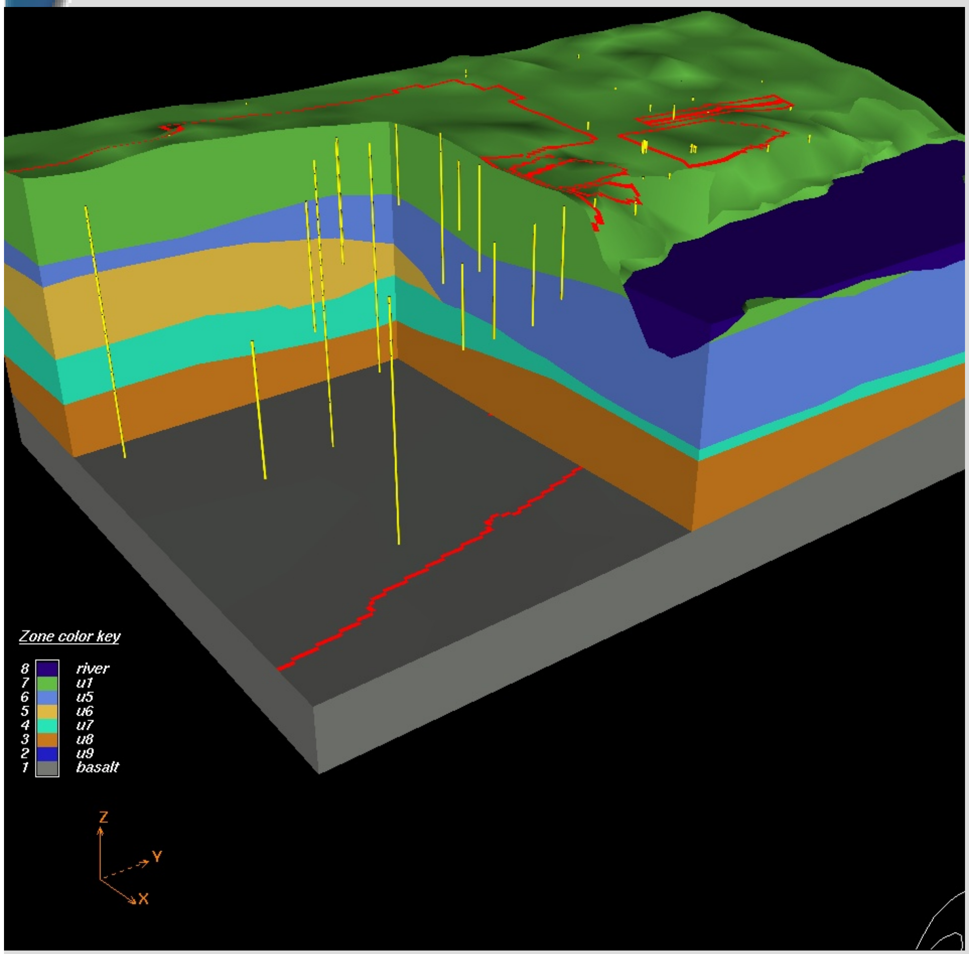
- 3-D saturated unconfined aquifer; **vadose zone not modeled**
  - Flow field driven by **monthly** changes in river stage fluctuations
  - Uranium mobility controlled by "best estimate" **constant K_d** ~1-2 ml/g
- No interaction between aquifer and river
- No interaction between aquifer and vadose zone

Final Prediction: U < 20 ug/L in **3 to 10 years** by natural flushing

Aquifer Water Levels and Uranium Concentrations

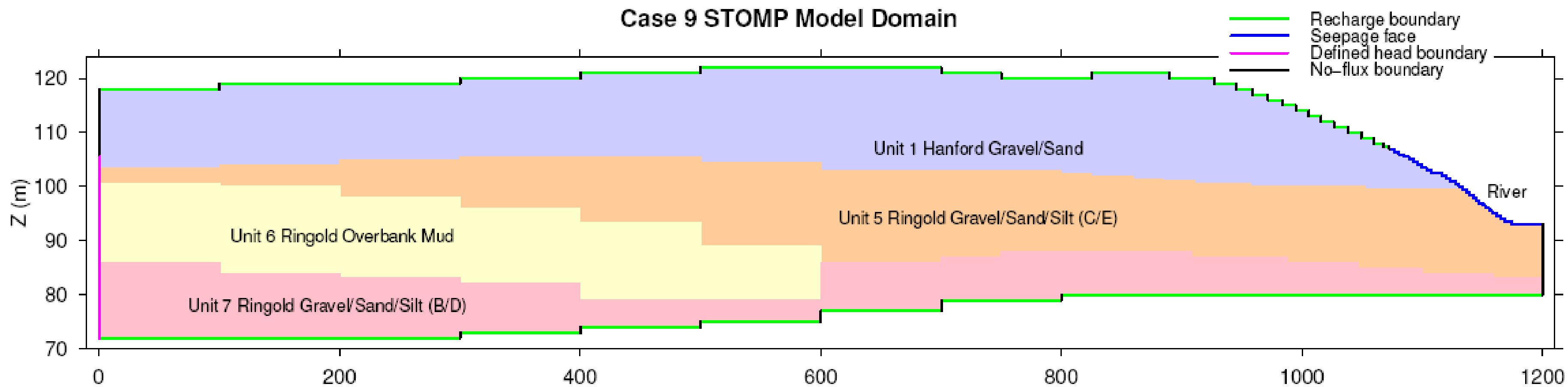


Flow and Transport: Vadose Zone – Aquifer – River System

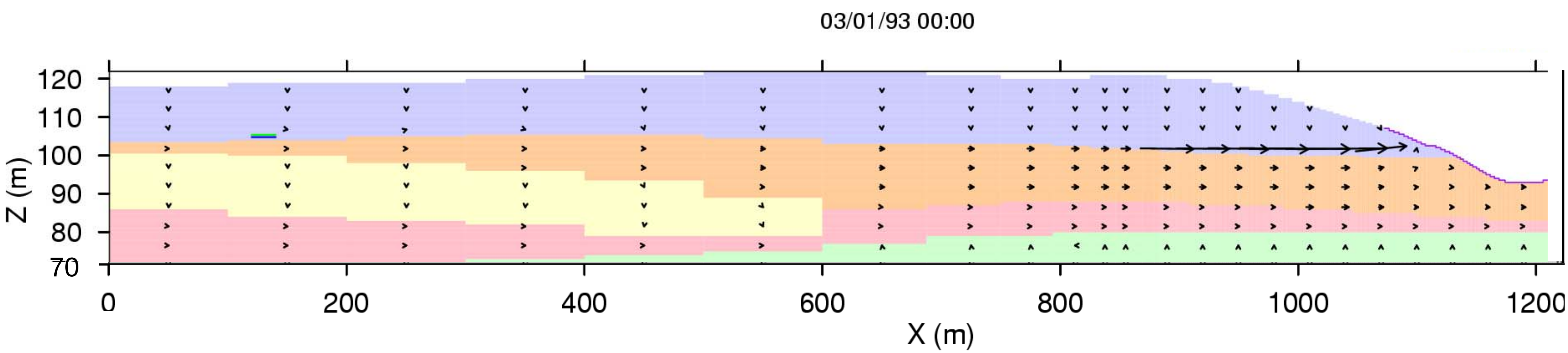


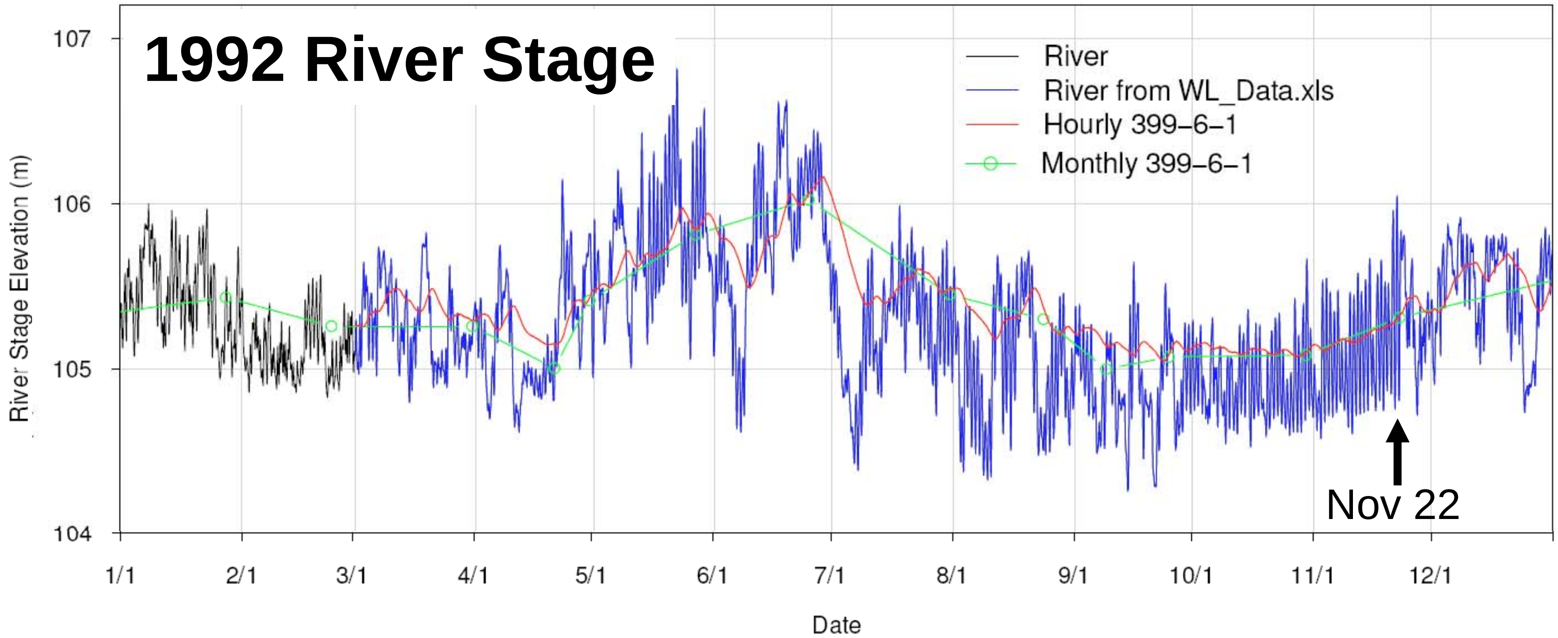
- 2-D and 3-D modeling
- Most current hydrogeology
- Flow and transport driven by hourly river stage fluctuations
- Investigate dynamics of riverbank storage and fluxes across aquifer - river interface
- Investigate release of uranium from contaminated vadose zone sediments due to water table fluctuations

Flow and Transport: Vadose Zone – Aquifer – River System

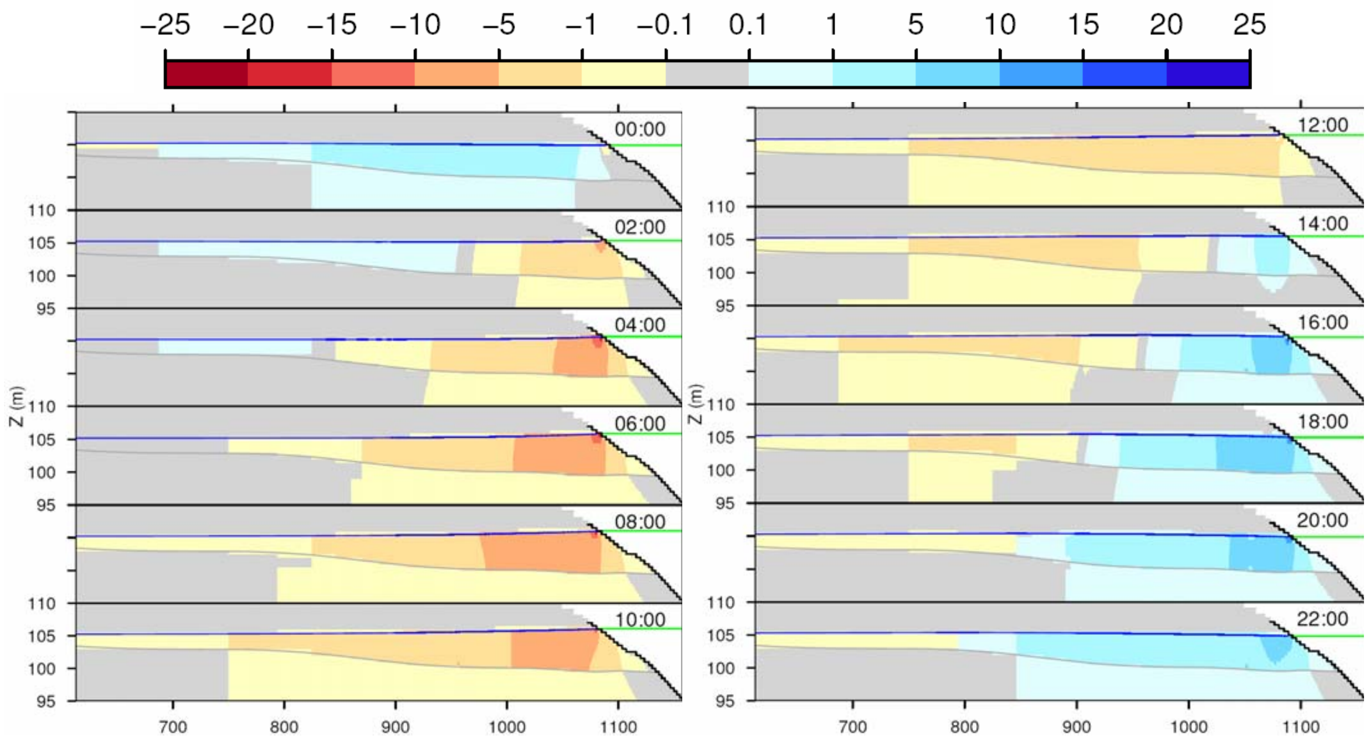


Material	K_l [(a)] ($m\,d^{-1}$)	ϕ [(b)]	ψ [(c)] (cm)	λ [(d)]	θ_r [(e)]
U1, Hanford Gravel/Sand	1500	0.25	23.04	0.7465	0.1471
U5, Ringold Gravel/Sand/Silt (C/E)	150	0.18	71.31	0.5193	0.1299
U6, Ringold Overbank Mud	0.01	0.18	71.31	0.5193	0.1299
U7, Ringold Gravel/Sand/Silt (B/D)	43	0.18	71.31	0.5193	0.1299
U8, Lower Ringold Mud	5e-5	0.18	71.31	0.5193	0.1299
Basalt	5e-5	0.18	71.31	0.5193	0.1299

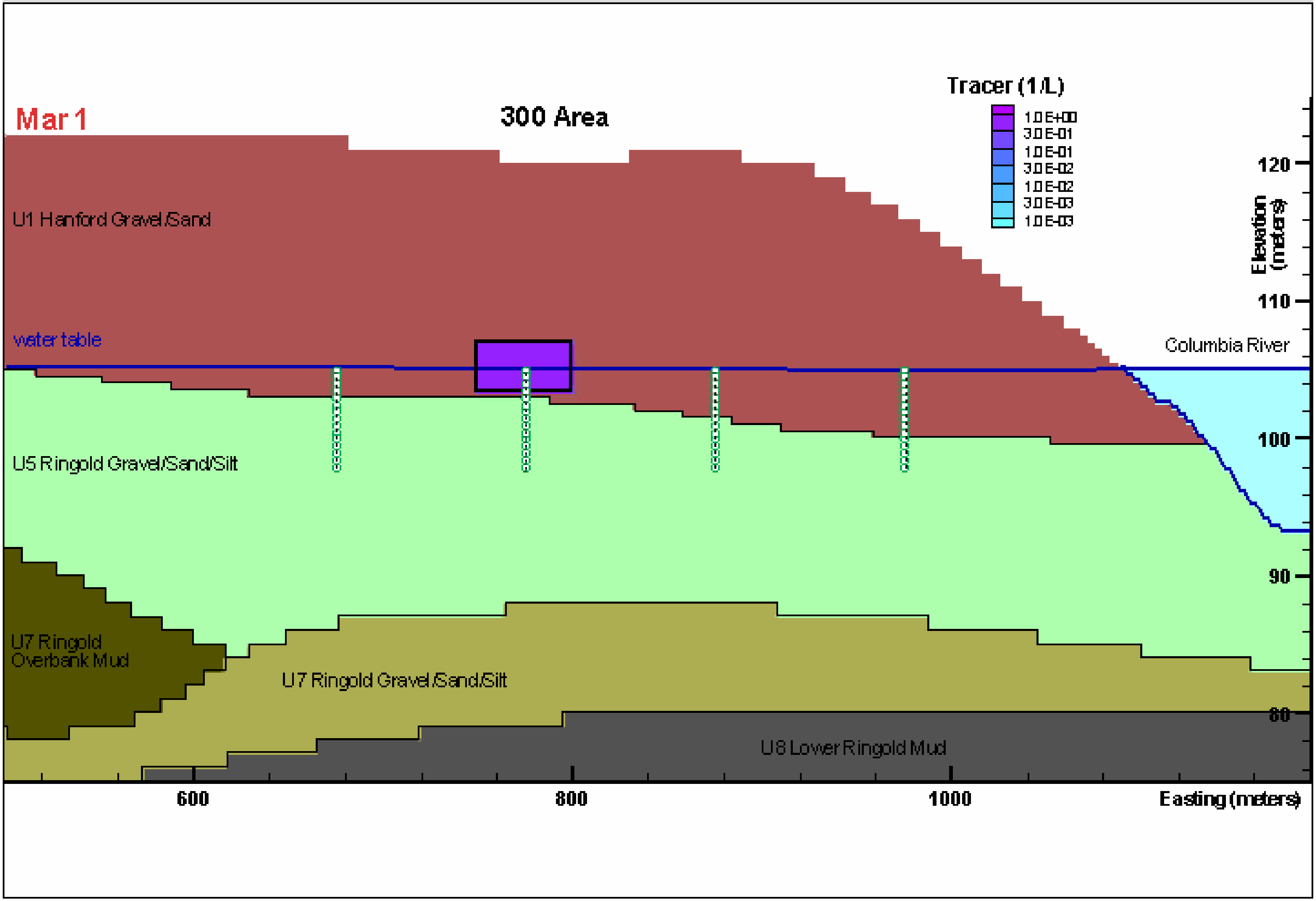


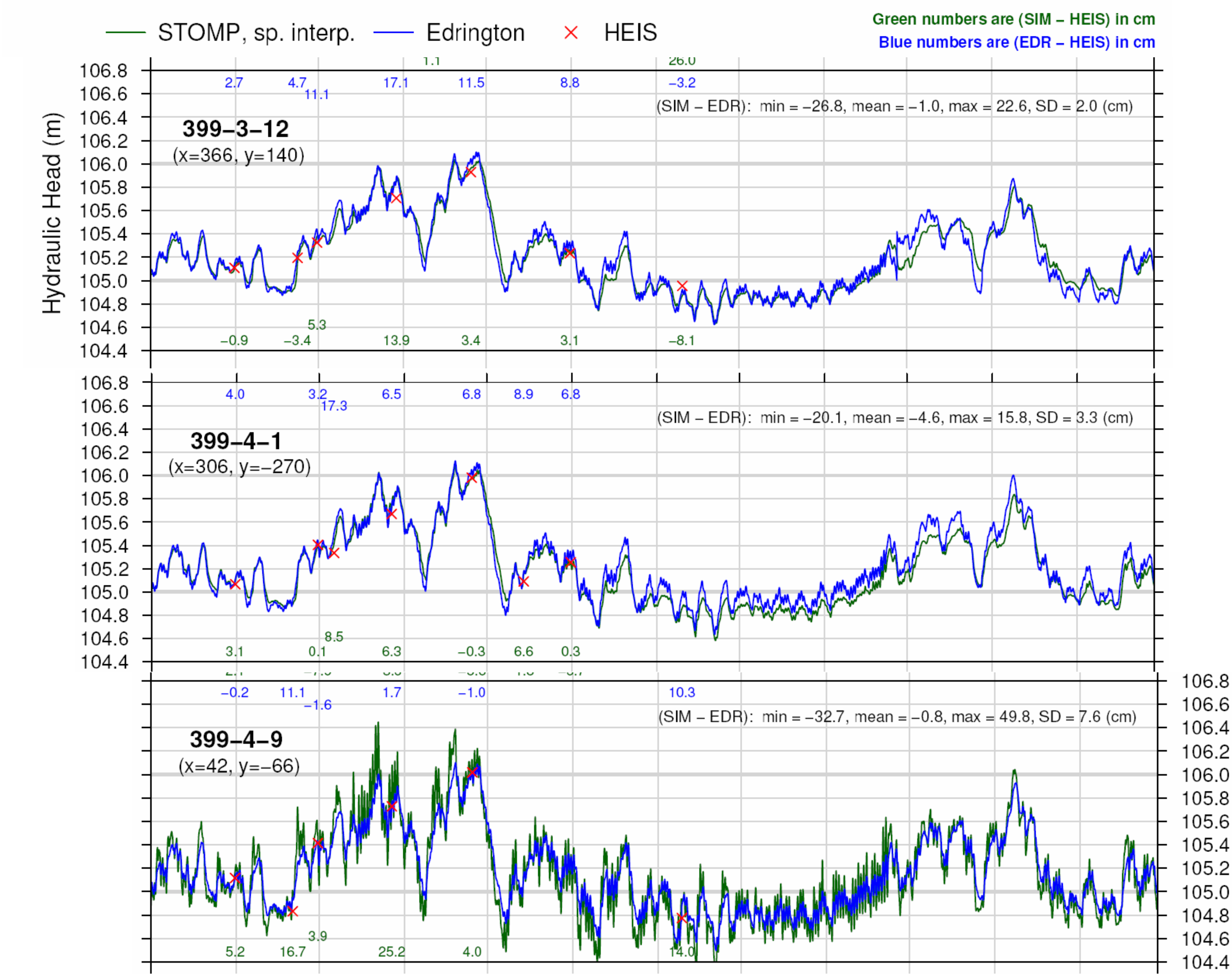


X-Direction Groundwater Flux (m/d) (Nov 22, 1992)



Tracer Transport

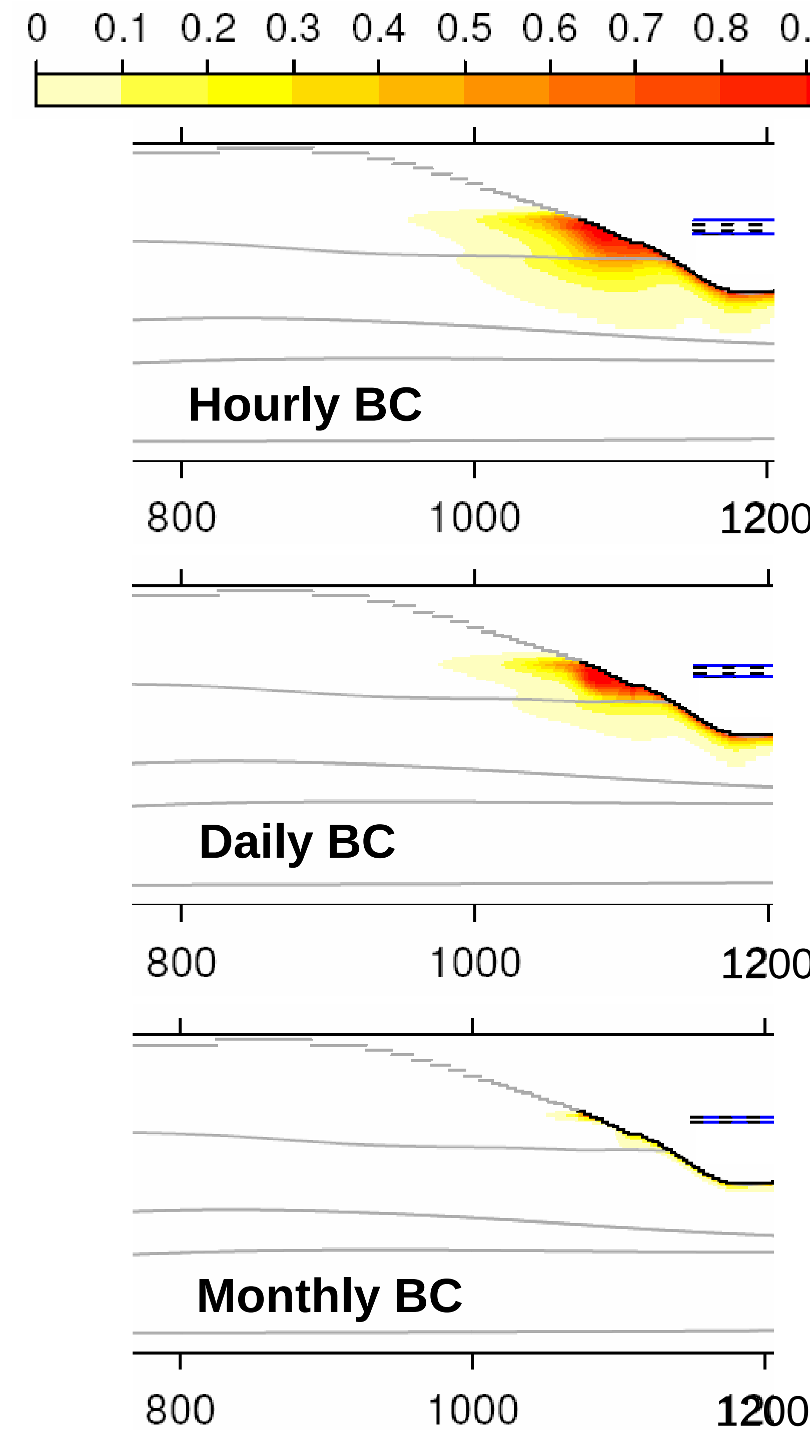




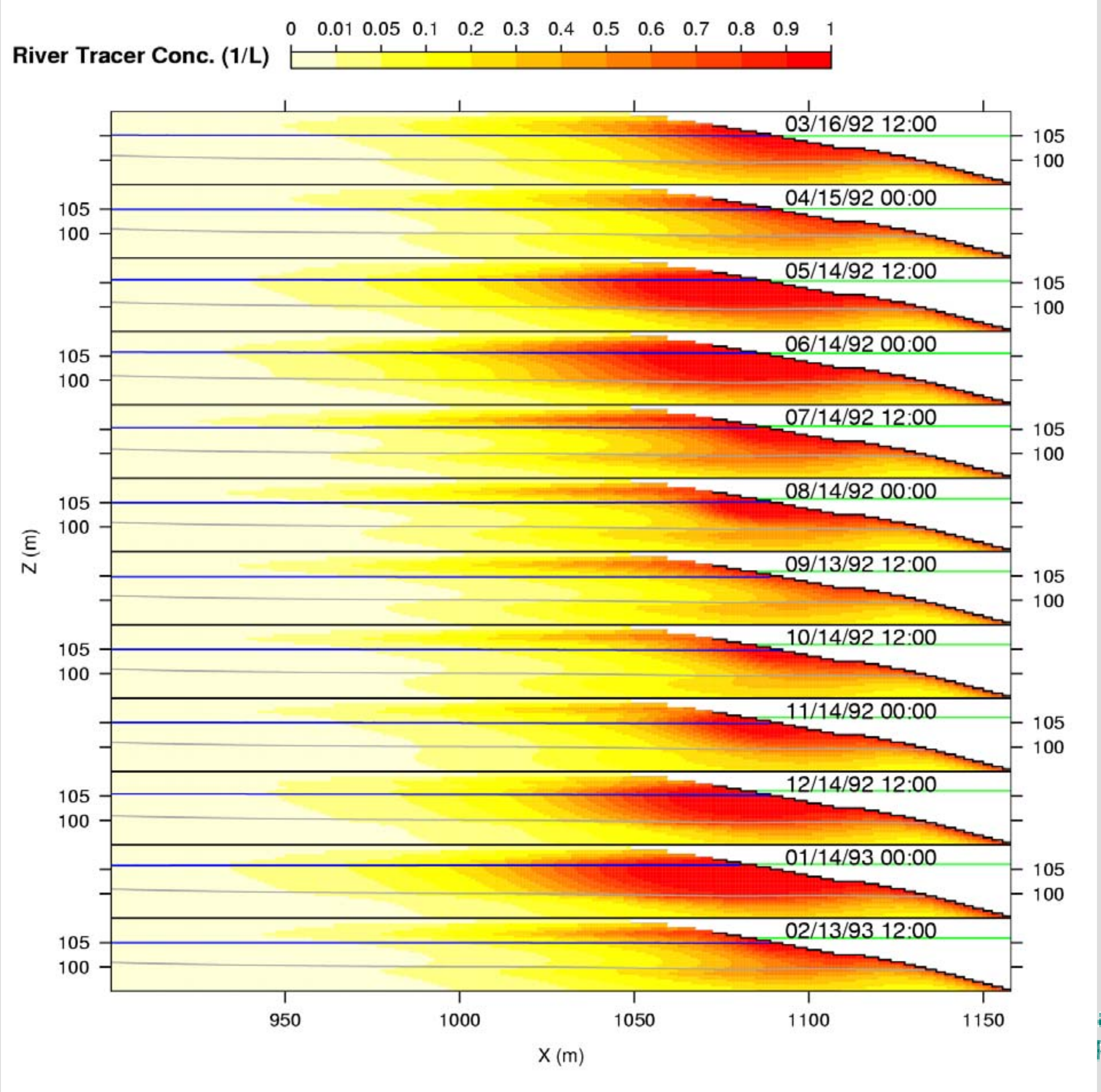
STOMP, sp. interp.
Edrington
HEIS
Green numbers are (SIM – HEIS) in cm
Blue numbers are (EDR – HEIS) in cm
Hydraulic Head (m)
399–3–12
(x=366, y=140)
(SIM – EDR): min = –26.8, mean = –1.0, max = 22.6, SD = 2.0 (cm)
399–4–1
(x=306, y=–270)
(SIM – EDR): min = –20.1, mean = –4.6, max = 15.8, SD = 3.3 (cm)
399–4–9
(x=42, y=–66)
(SIM – EDR): min = –32.7, mean = –0.8, max = 49.8, SD = 7.6 (cm)

Aquifer-River Mixing

- “Normal” mixing zone extends ~150 m inland
- Averaging river stage fluctuations over daily period reduces size of mixing zone
- Monthly average essentially eliminates mixing with river water

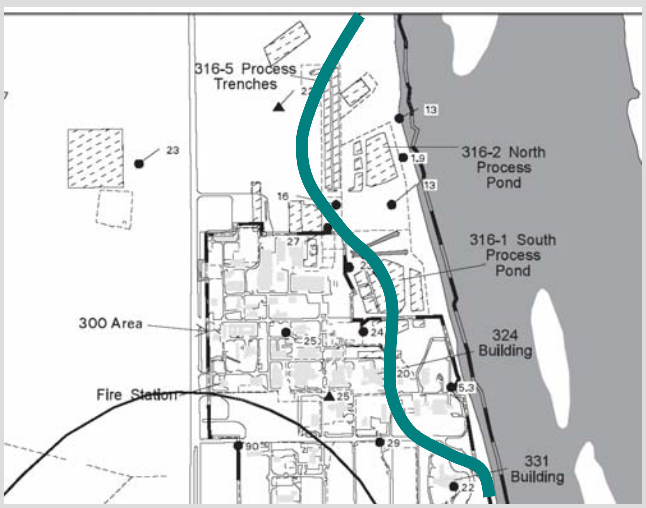


Seasonal Variation in Mixing Zone

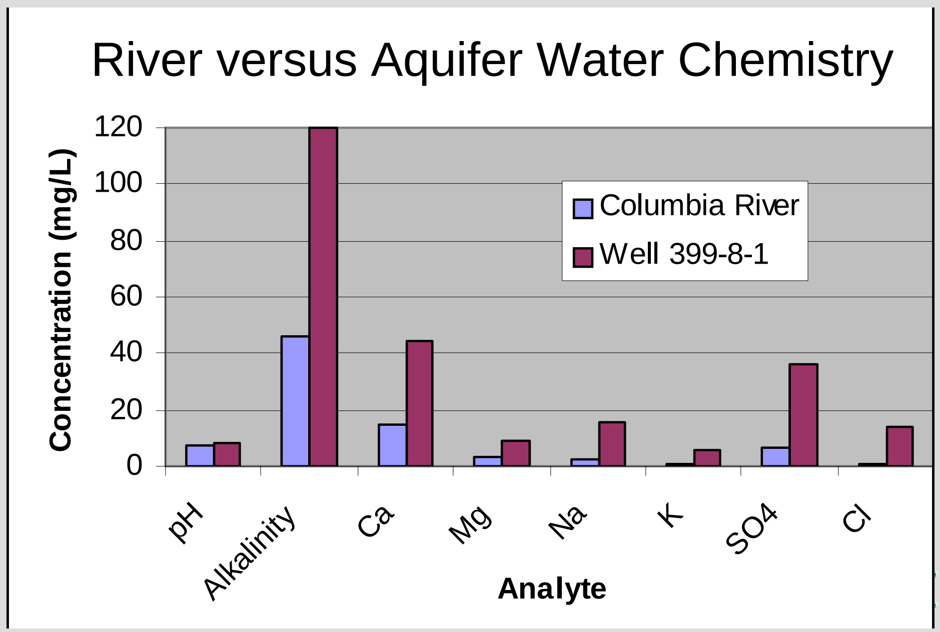


Aquifer-River Solution Chemistry

- River water influx occurs during high stage
- Prolonged seasonal high stage period allows mixing in aquifer with river water
- Significant differences in solution chemistry

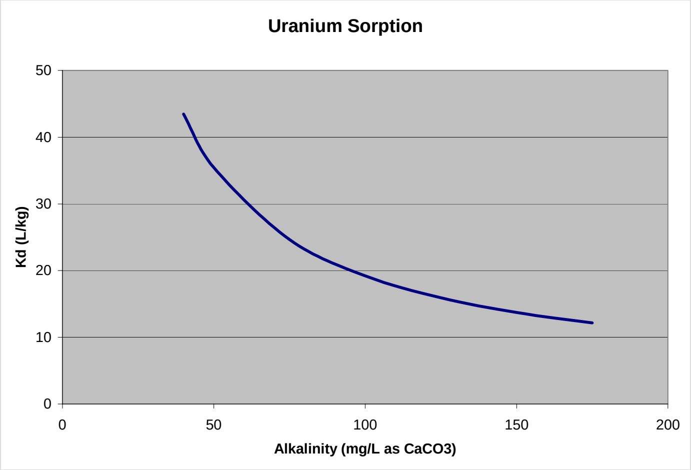


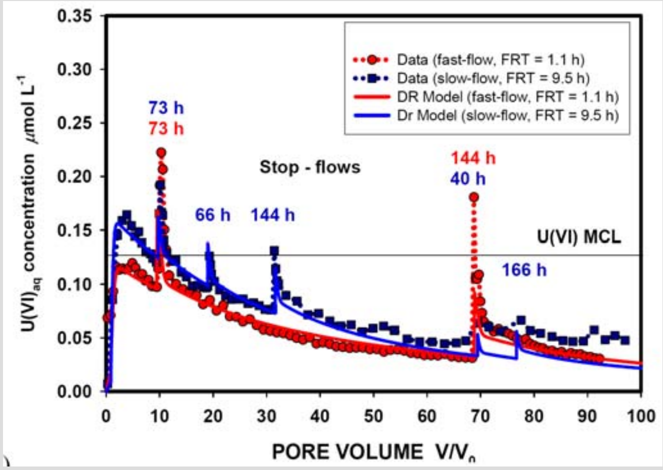
2002 Nitrate Concentration



Uranium Geochemistry

- Constant K_d not consistent with experimental observations
  - Uranium sorption varies strongly with transition between aquifer and river water chemistries (e.g., U, Ca, pH, alkalinity concentrations)
  - Rate-limited uranium sorption identified in column experiments with flow rates consistent with field observations
- Key Issues
  - Uranium leaching from contaminated vadose zone sediments by water table fluctuations
  - Changing uranium geochemistry during mixing and exchange of river and groundwater





Uranium Geochemical Process Models

- Preliminary three-reaction generalized composite surface complexation model (Jim Davis, USGS)
  - accounts for bicarbonate concentration, sediment surface area, and aqueous U(VI) complexation (21 reactions)
  - 1 strong site and 2 weak site reactions:

$$2S(OH)_2 + UO_2^{++} + 2H_2CO_3 = SO_2UO_2(HCO_3CO_3)^{---} + 5H^+ \qquad \log K = -16.3$$

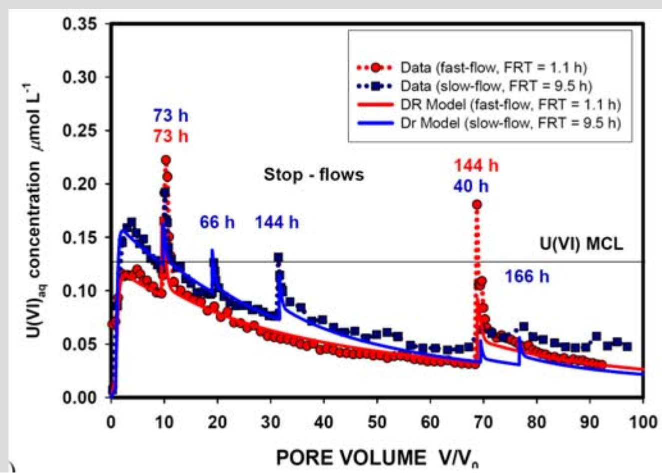
$$2W(OH)_2 + UO_2^{++} + 2H_2CO_3 = WO_2UO_2(HCO_3CO_3)^{---} + 5H^+ \qquad \log K = -20.64$$

$$2W(OH)_2 + UO_2^{++} + 2H_2CO_3 = WO_2UO_2(CO_3)^{----} + 6H^+ \qquad \log K = -28.01$$

- Multisite model with variable uranium mass transfer kinetics (Chongxuan Liu, PNNL):
  - Accounts for reaction rates and rate-limited diffusion processes
  - Distributed rate parameters were assumed to follow the Gamma statistical distribution (two parameters):

$$\frac{\partial S}{\partial t} = \sum_{i=1}^{N} \frac{\partial S_i}{\partial t}; \qquad \frac{\partial S_i}{\partial t} = \alpha_i \left[f_i(\alpha_i) K_d{}^i C - S_i \right]$$

$$f_i(\alpha_i) = \int_{\alpha_i}^{\alpha_i + \Delta\alpha_i} \frac{\beta^{-\eta} \tau^{\eta-1}}{\Gamma(\eta)} \exp\left(-\frac{\tau}{\beta} \right) d\tau$$



Battelle

Field-Based Reactive Transport Modeling

Account for full sediment size distribution

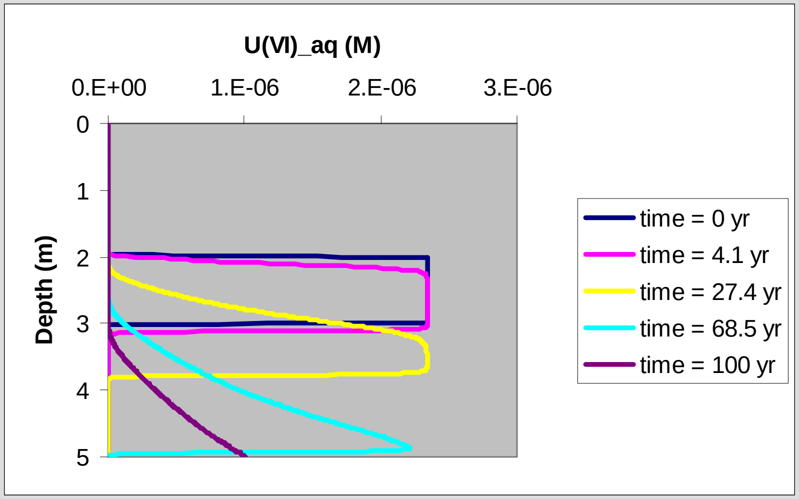
- < 2 mm size fraction in the lab studies
  - Specific surface area: 27.2 m^2/g
  - 8% of total sediment
- Preliminary assumption: gravels are unreactive
  - apportion 8% of the 2.06 kg/L field bulk density for surface complexation

Size (mm)	Mass Distribution (%)
Cobbles	
>12.5	74.5
2.0 – 12.5	17.2
Sand	
1.0 – 2.0	2.64
0.5-1.0	2.34
0.25 – 0.5	0.78
0.149 – 0.25	0.33
0.106 – 0.149	0.19
0.053 – 0.106	0.20
Silt + Clay	
<0.053	1.78

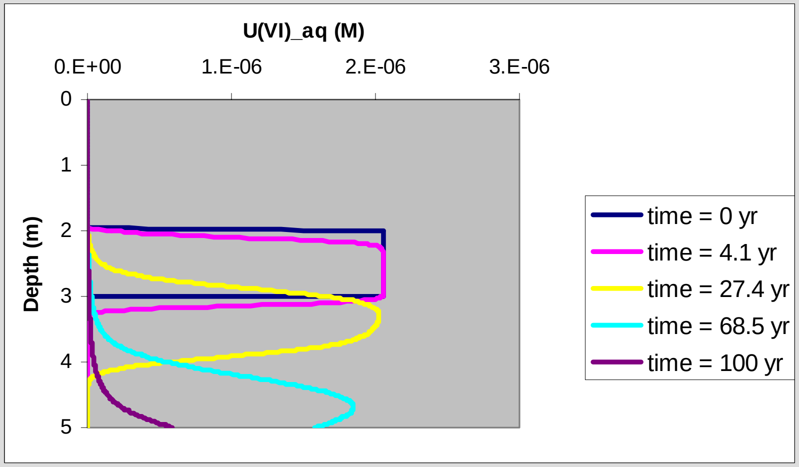
Unsaturated Flow Model Parameters	Value	Units
Horizontal Hydraulic Conductivity	1500	m/d
Vertical Hydraulic Conductivity	150	m/d
Air entry pressure	23.04	cm
Brooks-Corey λ	0.7465	
Residual Saturation	0.1471	
Relative Permeability Method	Burdine	
Porosity	0.25	
Bulk Density	2.06	Kg/L
Recharge Rate	60	mm/yr
Calculated Water Content	0.08	

1-D Unsaturated Reactive Transport Simulation

- 1-D reactive transport simulation
  - 60 mm/yr recharge results in 0.75 m/yr pore velocity
  - 5 m of vadose zone
  - 1 m of contaminated sediment in the middle
    - 30 nM/g U contaminated zone
- GC-SCM
  - Sorption front requires over 30 years to move 1 m
  - Kd = 12.4 L/kg for this solution chemistry
  - Lowest sediment contamination level results in U(VI) above MCL (0.126 uM)
- Multisite kinetic model
  - Very similar to GC-SCM result
    - Kd = 14 similar to the GC-SCM
    - impact of kinetics largely minimized by long transport time scales



Generalized Composite SCM



Multisite Kinetic Model

Battelle

1-D Aquifer-River Interactions

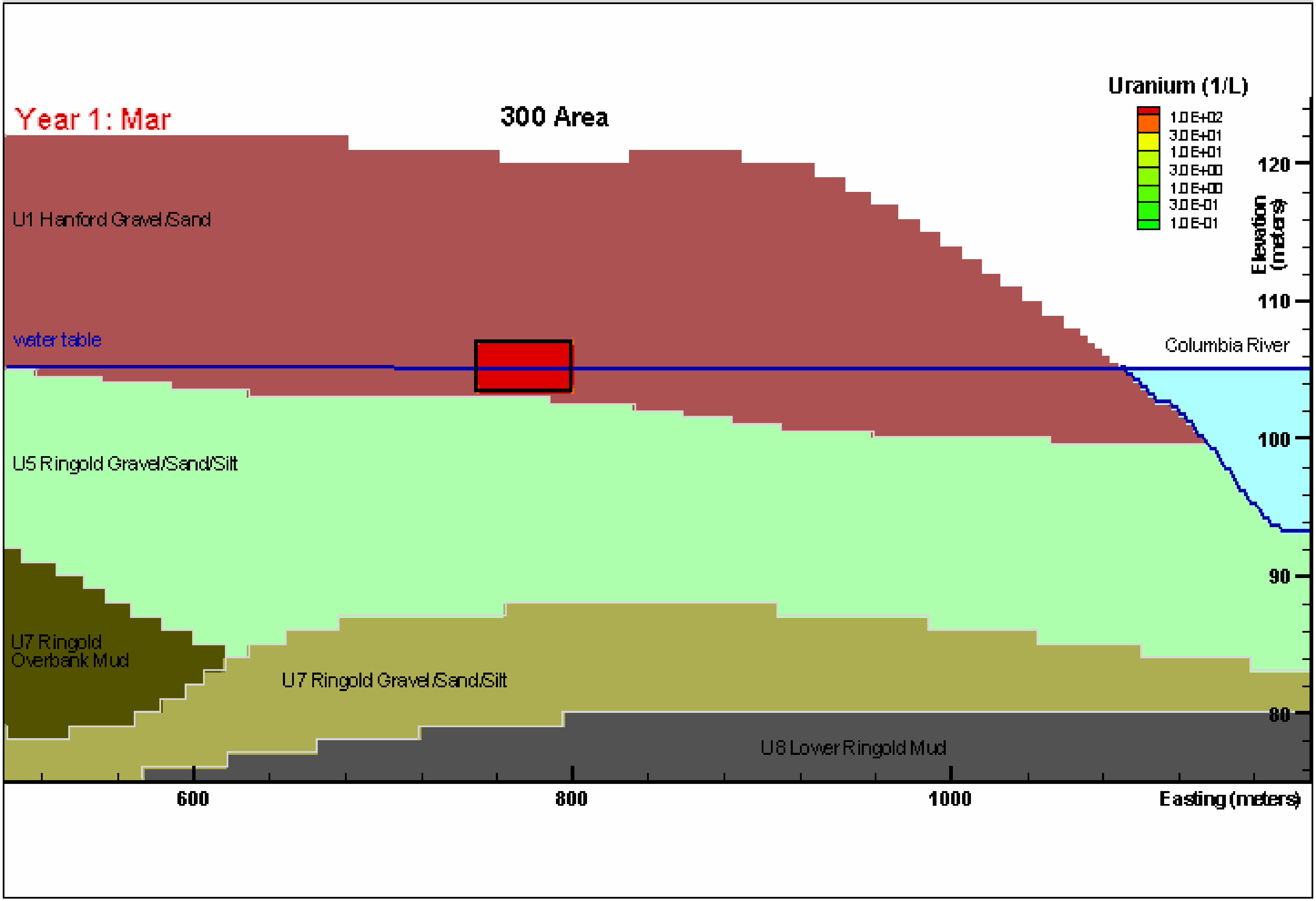
Adapt GC-SCM for the situation where the solution chemistry changes from river water to groundwater

- 1.4 m/d groundwater
- 30 nM/g U-contaminated sediments
- Initial equilibrium with river water
  - 5.76E-8 M aqueous U
  - Intrinsic Kd > 500 L/kg
- After influx of groundwater
  - Aqueous U is 2.50E-6 M
  - Intrinsic Kd = 13.5 L/kg

Solution Chemistry

Components	River water (USGS 6/1/2000)	1988 Well 399-8-3
pH	7.1	7.7
HCO3-	9.18e-4 M	2.66e-3 M
K+	1.75e-5	1.50e-4
NO3-	8.55e-6	1.73e-4
Sr++	1.23e-6	0
Na+	1.00e-4	9.87e-4
Ca++	3.74e-4	1.10e-3
Mg++	1.48e-4	4.10e-4
Cl-	3.10e-5	2.75e-3
SO4--	7.08e-5	3.25e-4

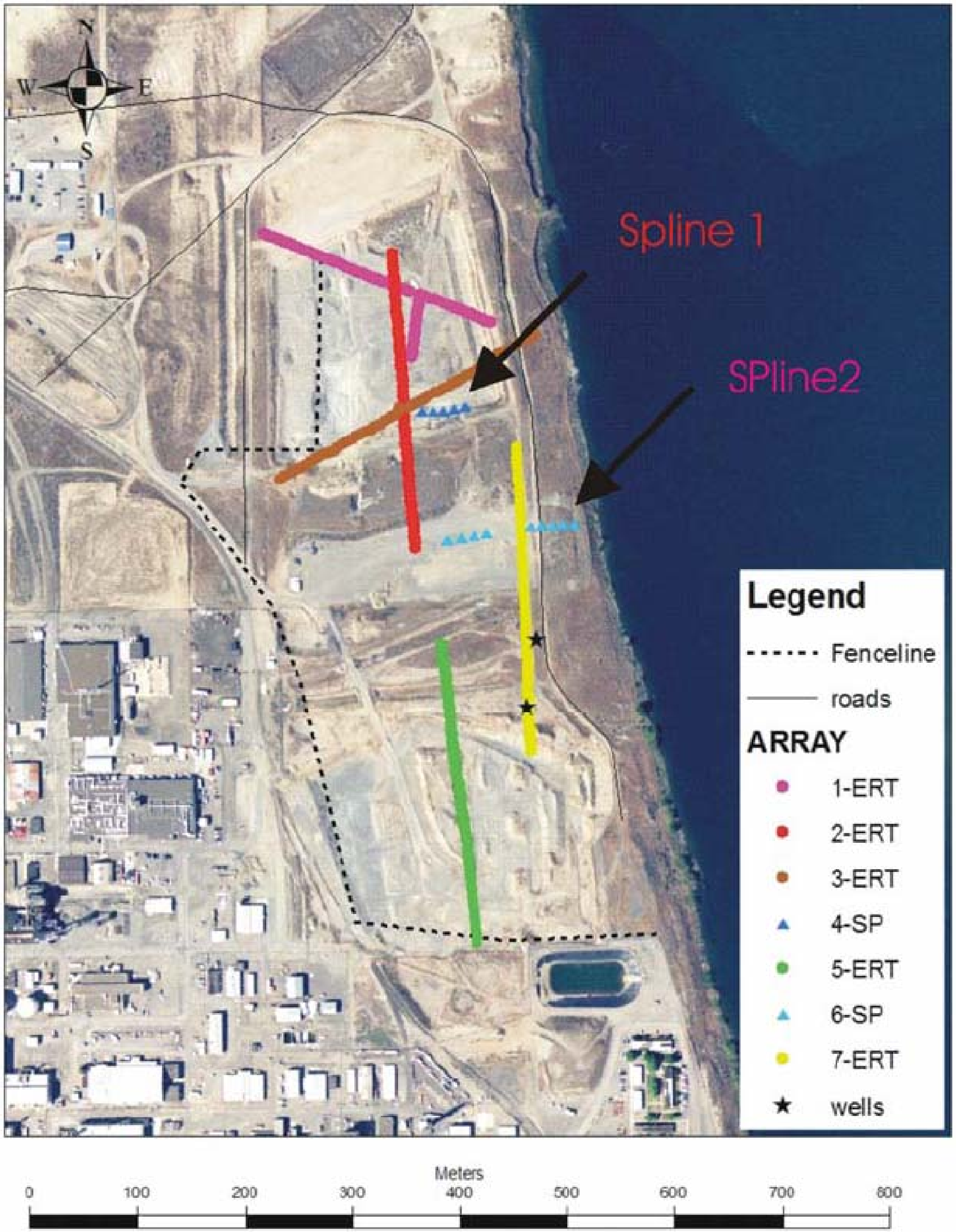
Uranium Transport Simulation



Modeling Summary

- Interaction between hourly river stage dynamics, highly transmissive and heterogeneous sediments, and spatially variable uranium create field situation more complex than 1993 conceptual model
  - Lower vadose zone uranium accessed by high river stage
  - Diurnal cycling of high pore velocities
  - Mixing zone of aquifer and river water chemistries
    - dictated by river forcing and hydraulic conductivity
    - sensitive to temporal resolution
    - implications for uranium mobility
- Work in progress
  - Ongoing limited field investigation (LFI): sediment cores for detailed analysis, geophysical logging to map uranium distribution
  - Laboratory studies provide framework for understanding uranium mobility
    - Solution chemistry
    - Kinetics
  - Field-scale studies identify large-scale transport context for understanding uranium fate

Battelle



Geophysical Characterization

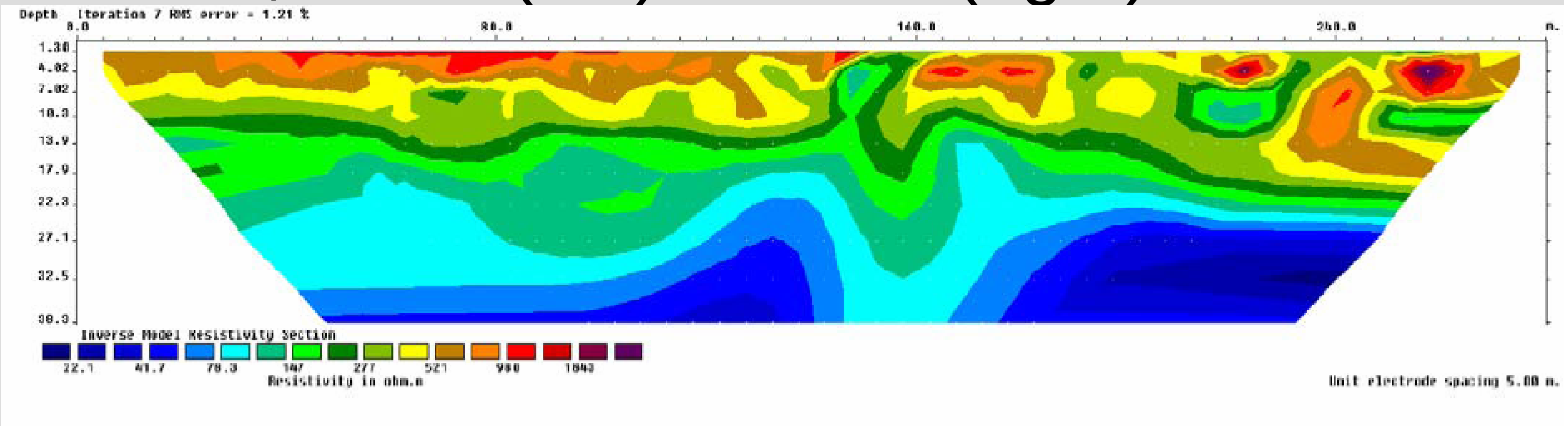
- Performed by Andy Ward (PNNL) and Roelof Versteeg (INL)
- Surface electrode deployment
  - March 2006: successful test of single ERT and SP lines
  - August 2006: Full grid of SP, ERT/IP electrodes

Preliminary Resistivity Plots

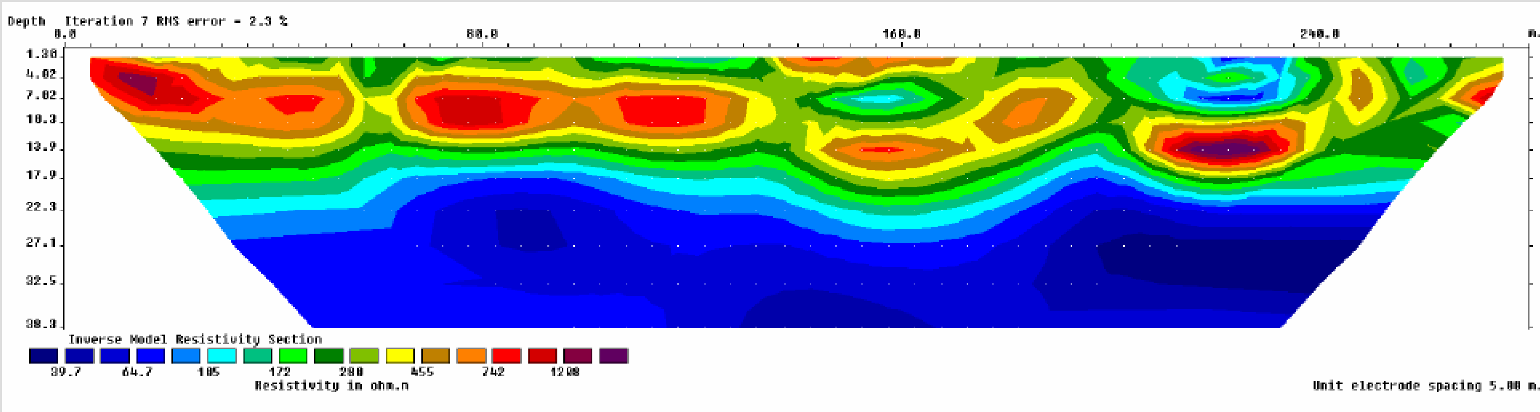
North Process Pond

(high resistance ~ coarse unsaturated sediment)

- Line 2, south (left) to north (right)



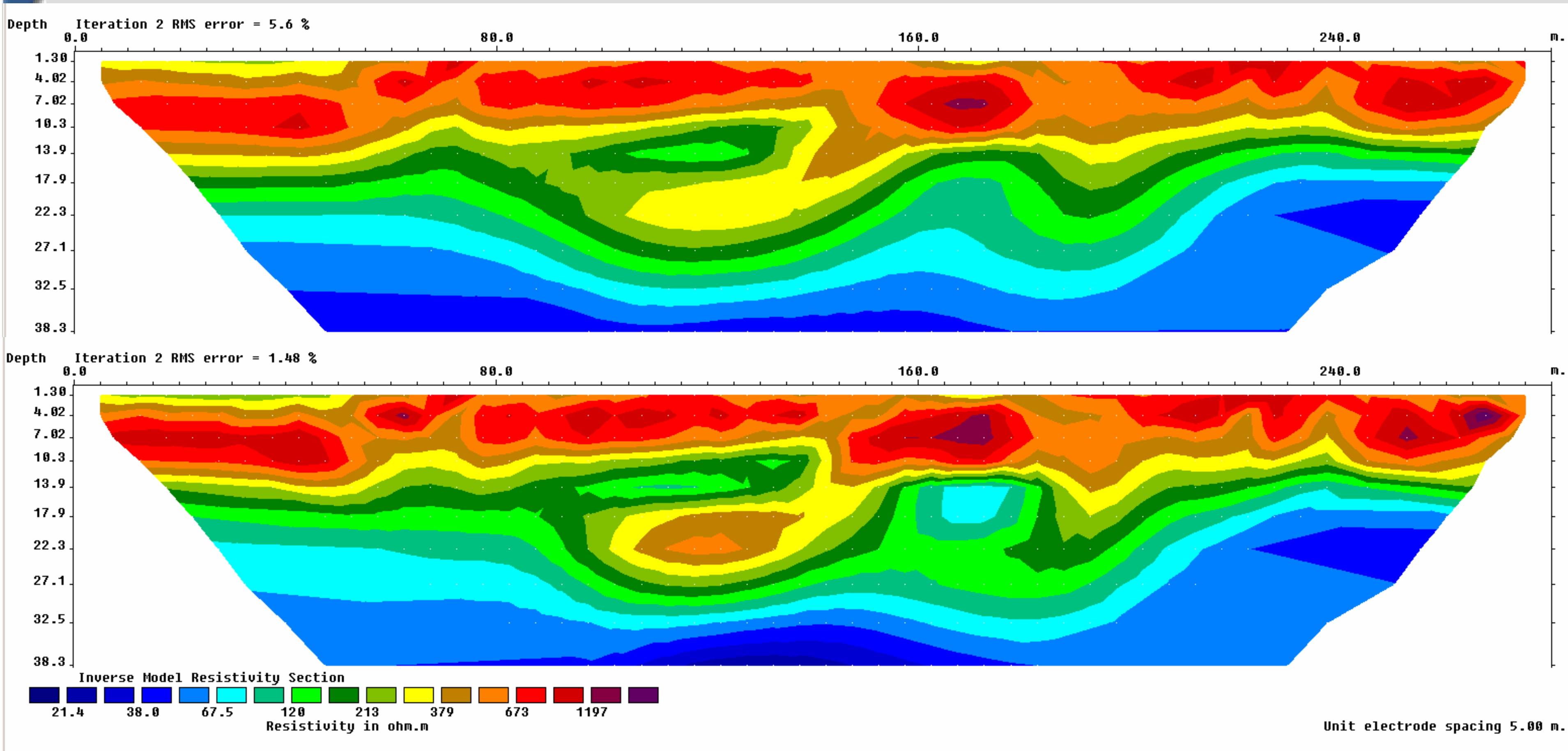
- Line 3, west (left) to east (right)



Time-Lapse ERT

Parallel to Shoreline between Process Ponds

- Line 7, south (left) to north (right)
- 3-Day time series



First Grid Deployment

- 120 SP electrodes at 30 m spacing
- 60 ERT electrodes at 5 m spacing per transect
- Screening/Scoping for final grid specification

Battelle

Geophysics Summary

- Preliminary ERT data
  - Fit of synthetic to simulated data provide high confidence in the resulting subsurface imagery
  - Heterogeneous material distribution
  - Time-dependent behavior
- Preliminary Grid Deployment of SP, ERT/IP electrodes
  - 3-D imaging of lithology, sediment properties
  - Spatially and temporally variable flow behavior
- Next Steps
  - Borehole logs and water depth to interpret layers in terms of lithology
  - SP survey analyzed with hourly water level to identify groundwater flow field
  - Induced Polarization for material property distribution
  - Identification of permanent electrode locations
  - Integrate new geophysical information into flow and transport modeling

Barnwell Low-Level Radioactive Waste Disposal Facility Groundwater Migration Modeling Overview

presented to the ACNW
September 19, 2006
by Vernon Ichimura

Overview

- Focus on compliance demonstration in groundwater and surface water
- Assumptions, judgment, and measurements
- Determine maximum hypothetical dose rate by the following evaluations:
  - Pre-licensing Evaluation - - 1971
  - USGS Site Characterization - - 1982
  - NRC Environmental Assessment - - 1982
  - Barnwell Site Environmental Radiological Performance Verification Model - - 1996
  - Barnwell Site Environmental Radiological Performance Verification - - 2003

Pre-licensing Evaluation

- Began in 1967.
- Obtain existing information from the Savannah River Site and "Barnwell Nuclear Fuel Plant" Safety Analysis Report.
- Solicit opinion of experts.
- Characterization by <u>collecting data</u>
  - Geology – Boreholes
  - Hydrology – Water Level
  - Water Quality and Chemistry
  - Ion Exchange Properties
- Development of a <u>Conceptual</u> Migration Model.

Pre-License – Safety Analysis

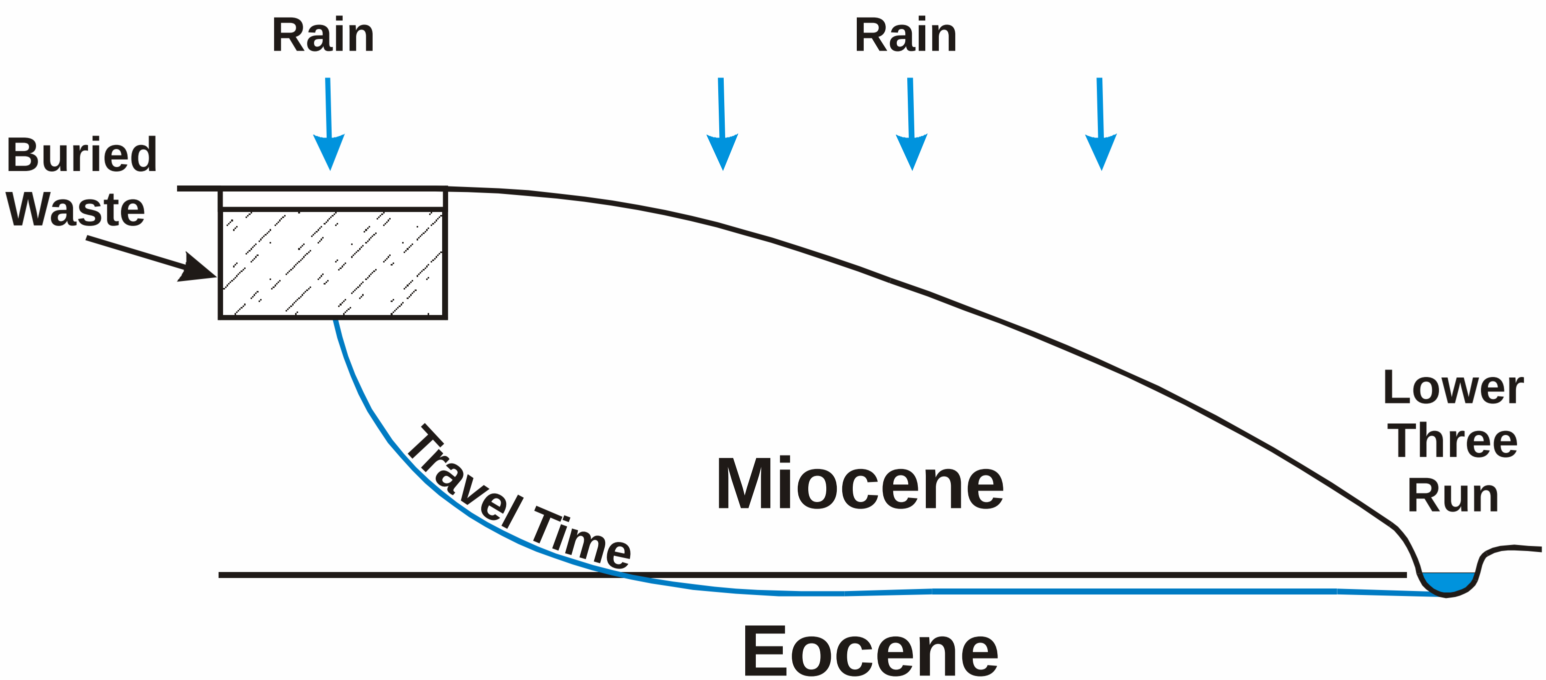
Nuclear Safety Associates, 1971

- Assumed Inventory
  - Gross Beta - Gamma 60,000 Ci
  - Strontium 90 40,000 Ci
  - Cobalt 60 150,000 Ci
  - Plutonium 239 80,000 Ci
- Source Term Calculated from “release fraction” estimated from existing disposal sites and dilution by infiltration.
- Assume infiltration of 6 inches.

Pre-License – Safety Analysis (continued)

- Distance of travel 3,000 feet.
- <u>Assumed</u> shortest groundwater travel-time 75 years.
- <u>Assumed</u> radionuclides travel-time 750 years.
- <u>Assumed</u> stream flow rate is 10 cubic feet per second.
- <u>Assumed</u> mixing in the stream.
- Showed with decay, all radionuclides should be 1,000 to 10,000 times lower than Maximum Permissible Concentration.

Conceptual "Barnwell Burial Model" 1971



copied from Nuclear Safety Associates, 1971

USGS – Cahill, 1982

- Site specific characterization by <u>observations</u> and <u>measurements</u>
  - Stratigraphic interpretations
  - Geophysical logs
  - Hydraulic properties
  - Water elevation data
  - Stream flow rates
  - Water chemistry
  - Measurement of radioactivity in cores

USGS – Cahill, 1982 (continued)

- Development of a 3-dimensional finite difference regional flow model - - calibrated to
  - <u>Measured</u> groundwater levels
  - <u>Measured</u> hydraulic properties
  - <u>Measured</u> stream flow rates

USGS – Cahill, 1982 - Results

- Recharge rate is approximately 15 inches/year.
- <u>Showed</u> “zone 1 and zone 2” contributed to most of the groundwater flow to local streams.
- <u>Showed</u> groundwater movement is towards Mary’s Branch Creek.
- Estimated groundwater travel-time from the disposal site to the creek is approximately 50 years.

Environmental Assessment

NUREG 0879, 1982

- Assumption that most recharge to zone 1 enters zone 2.
- Two dimensional finite difference flow model.
- Flow model is two dimensional.
- Assumption that study area is surrounded by “No-Flow” boundaries.
- Assumption that all groundwater enters a creek.
- Calibrated by matching heads by adjusting hydraulic properties.

Environmental Assessment

NUREG 0879, 1982

(continued)

- Two dimensional, finite difference transport model, with retardation and decay.
- Assumed source-term 1/10 percent of total activity (January, 1981) is released over 100 years. The list of radionuclides are:
  - » Tritium
  - » Carbon 14
  - » Cesium 134
  - » Cesium 137
  - » Cobalt 60
  - » Iron 55
  - » Strontium 90
- Calculated concentrations of radionuclides available to a hypothetical user of groundwater at the creek.

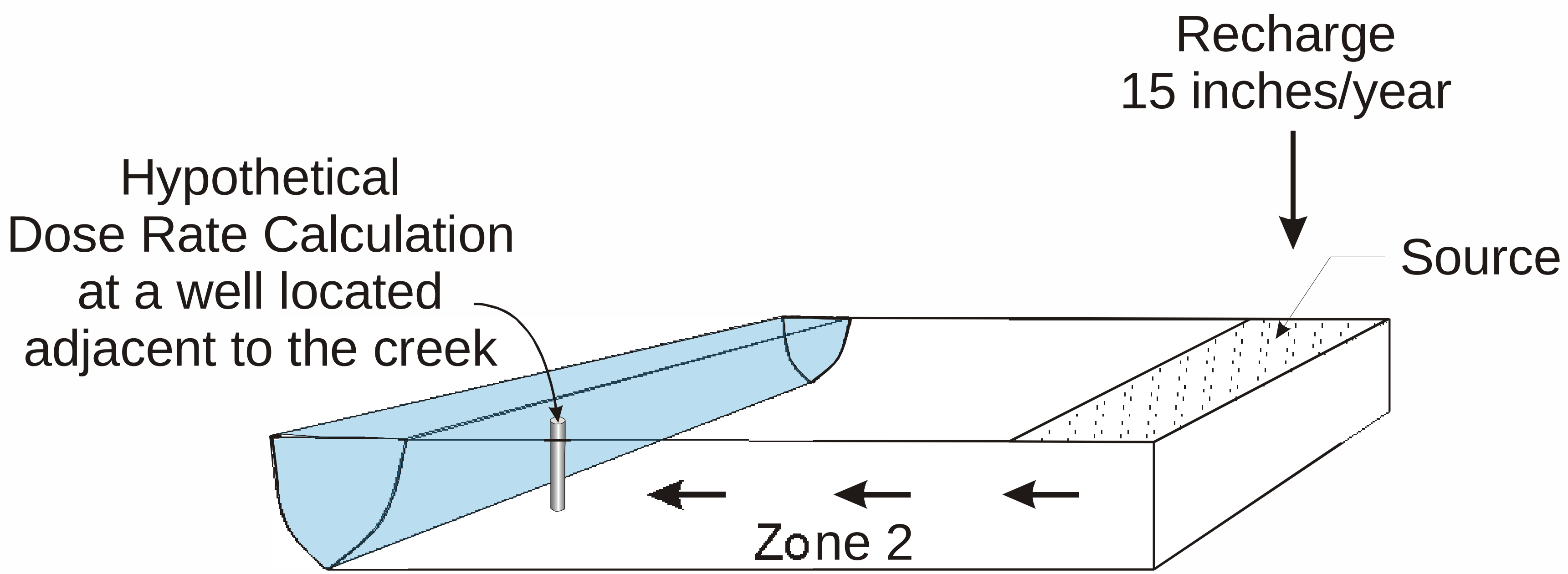
Environmental Assessment

NUREG 0879, 1982

(continued)

- Showed tritium is the most important radionuclide at the creek.
- Calculated hypothetical dose rate is less than 4 mrem/year from tritium at the creek.
- Calculated hypothetical dose rate is approximately 5 mrem/year from strontium 90 at the creek (at a later time).
- Negligible contribution from other radionuclides.

Conceptual Migration Model

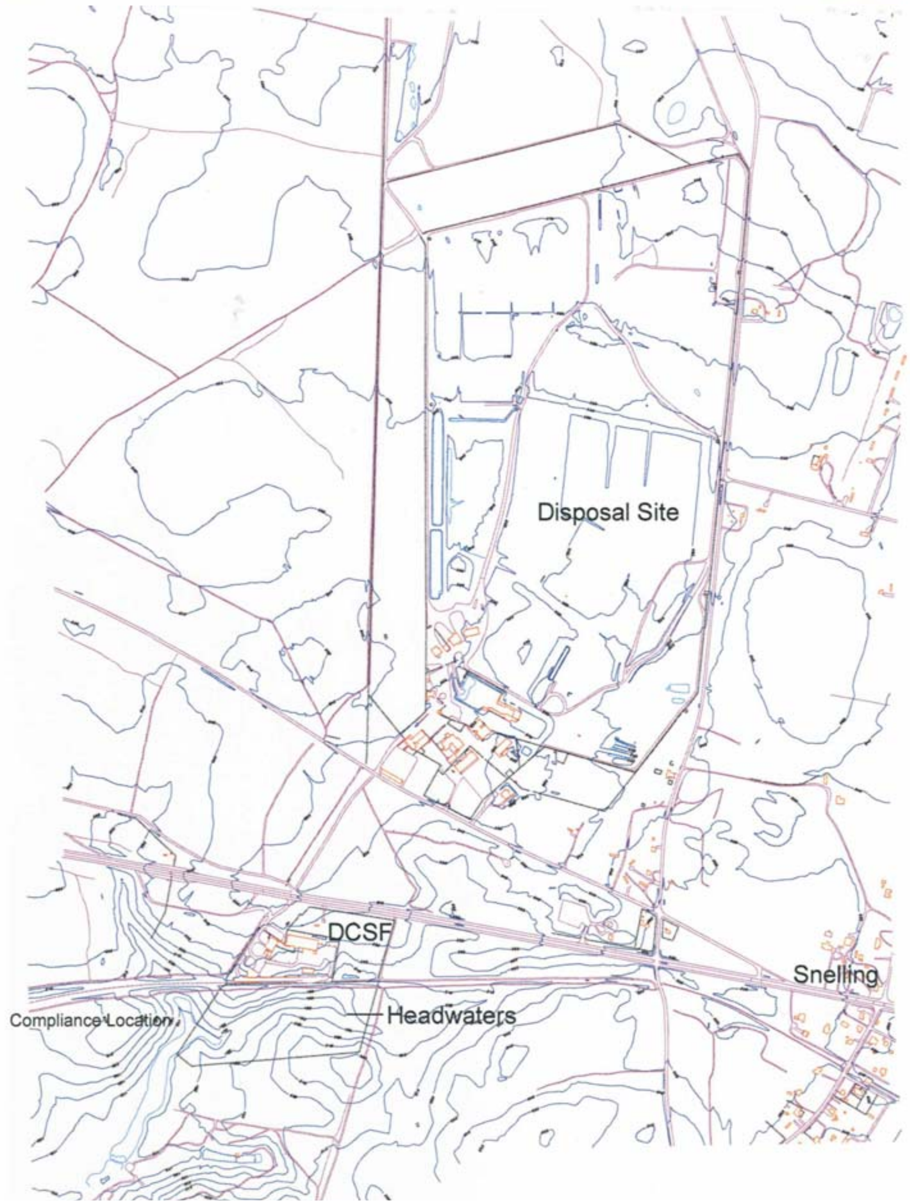


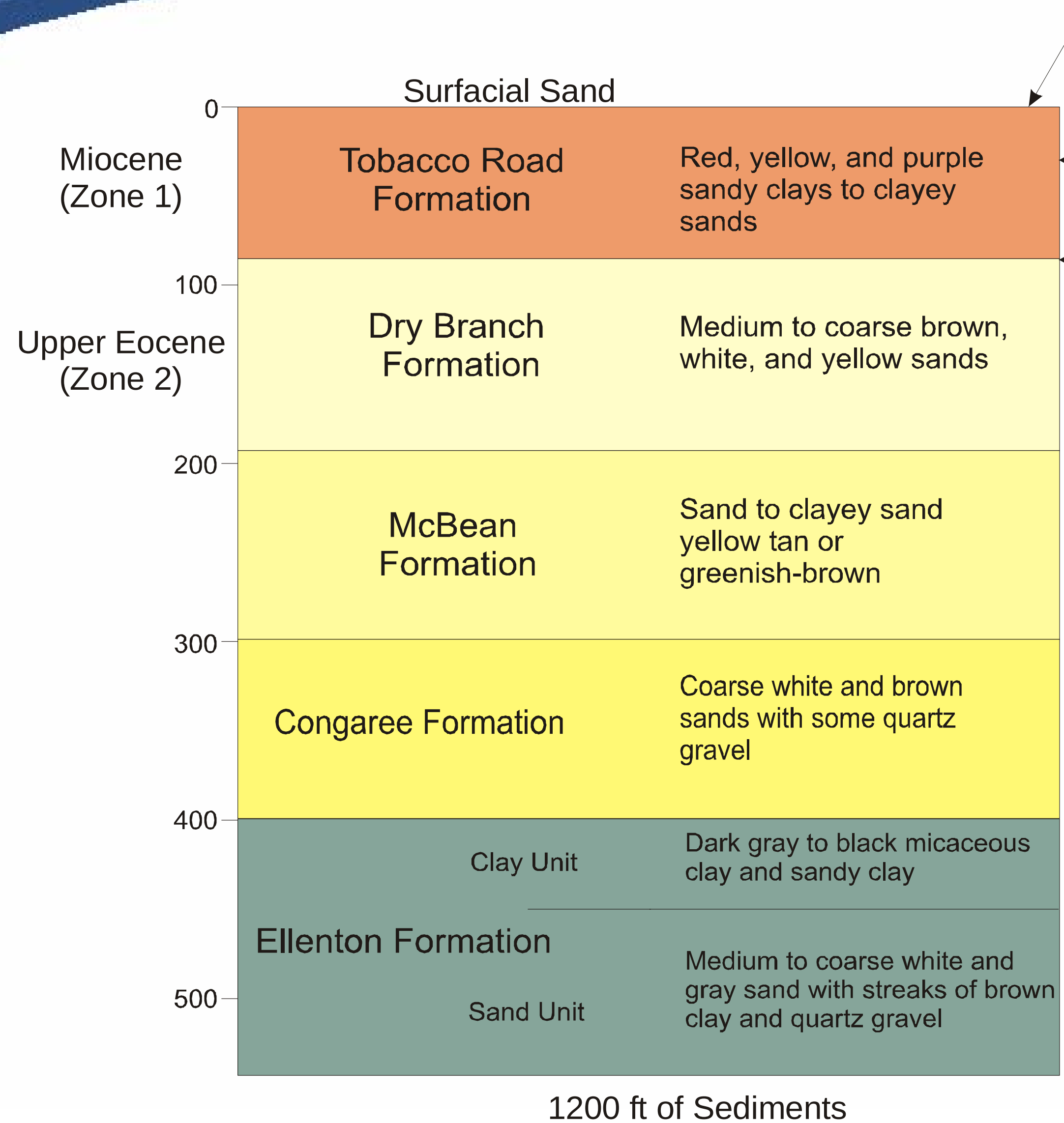
NUREG 0879

Barnwell Site Environmental Radiological Performance Verification, 2003

- Model development - - 1996
- Based on numerous measurements
  - Continue collection of geologic and hydrologic data
  - Routine measurements - - Environmental Monitoring
  - Special Studies - - Stream Flow Measurements
    - - Special Characterization Studies
    - - Radionuclide Inventory Characterization
- Some statistics - - Groundwater Monitoring
  - Greater than 400 sample locations
  - Long-term measurements (approximately 25 years)

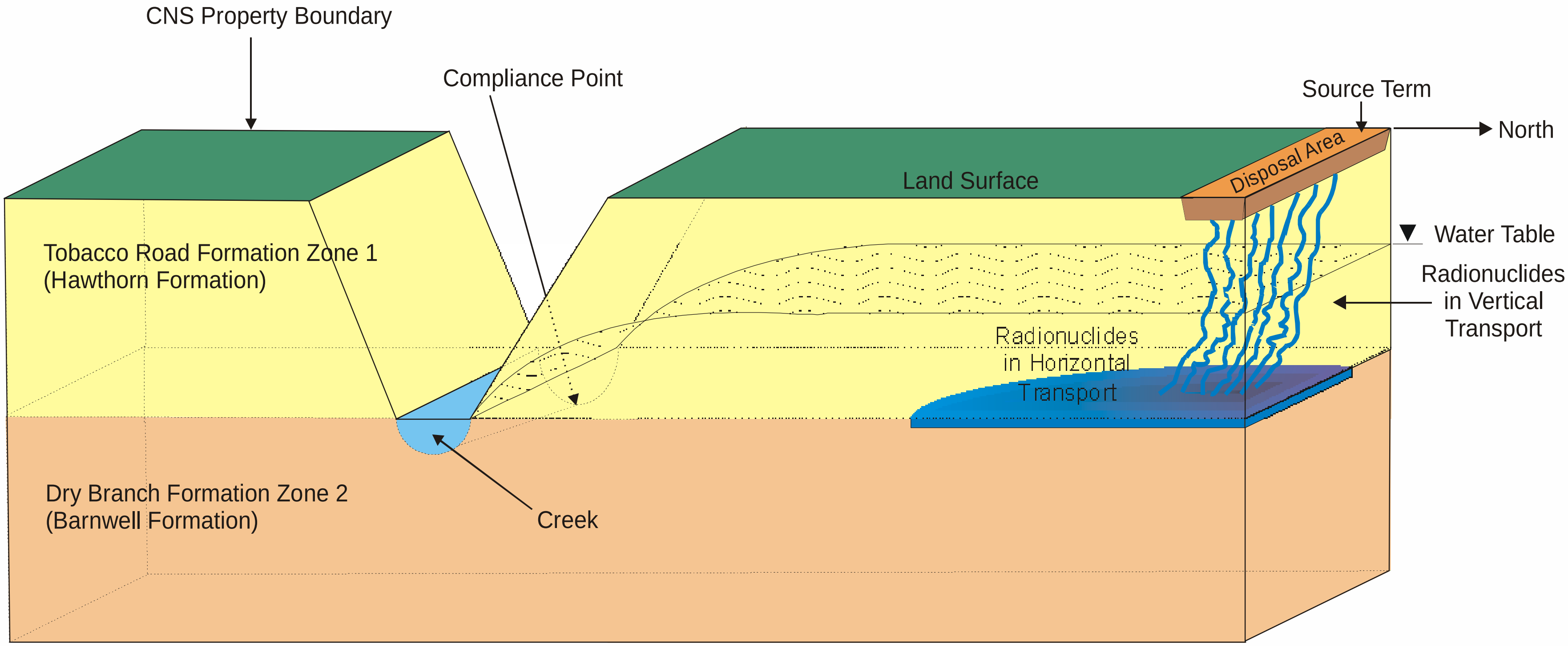
ENERGYSOLUTIONS
We're part of the solution





Generalized stratigraphic column for Barnwell site adapted from Cahill (1982) and Nystrom and Willoughby (1991).

Conceptual Model of Radionuclides in Transport



Conceptual model for the transport of mobile radionuclides.

Numerical Model

- Three-Dimensional Flow
- MODFLOW and MODPATH
- Transport in Zone 2 - - Numerous one-dimensional stream tubes – advective transport with decay and retardation.
    - Source term – measured maximum average
    - Source term – calculated from radionuclide inventory
- Stream Flow - - a series of mixing cells to calculate dilution.

Calibrated To

- Measured hydraulic properties.
- Measured average groundwater elevation measurements.
- Measured Stream flow rate.
- Measured pond falling head rates.
- Measured radionuclide (tritium) arrival and location measurements.
- Measured maximum-average tritium and carbon 14 concentrations.

Model Results

- Maximum hypothetical dose rate – tritium 13 mrem/year
- Maximum hypothetical dose rate – carbon 14 <1 mrem/year

Measurement

- Hypothetical dose rate – tritium <5 mrem/year
- Hypothetical dose rate – carbon 14 <1 mrem/year

Real Dose Rate

- Negligible

Projection

- Methodology
  - Determine radionuclide inventory at the Barnwell Site.
  - Determine a source-term calibrated to tritium and carbon 14 inventory.
  - Assume distribution coefficients from Sheppard and Thibault, 1991, are applicable.
  - Calibrate a model for tritium and carbon 14.
  - Determine which radionuclide arrives at the compliance location within 2,000 years.
  - Calculate hypothetical dose rate from radionuclides which arrive within the 2,000 year period.

Projection

- Results
  - Tritium and carbon 14 are most important.
  - Iodine 129 and technetium 99 are small dose contributors.

Monitoring and Modeling to Improve Understanding of Contaminant-Transport Processes in an Arid Environment

B.J. Andraski, D.A. Stonestrom, C.J. Mayers, M.A. Walvoord, R.L. Michel, R.J. Baker, R.G. Striegl, and D.P. Krabbenhoft

U.S. Department of the Interior
U.S. Geological Survey

OUTLINE

- Introduction
- Environmental monitoring & modeling
  - Tritium
  - Elemental mercury (Hg^0)
- Conclusions

INTRODUCTION

USGS Amargosa Desert Research Site (ADRS)

- Adjacent to Nation's first commercial LLRW facility (Beatty, Nevada)

Overall objective

- Improve understanding of processes controlling unsaturated-zone transport of water and mixed-waste contaminants in arid environments.

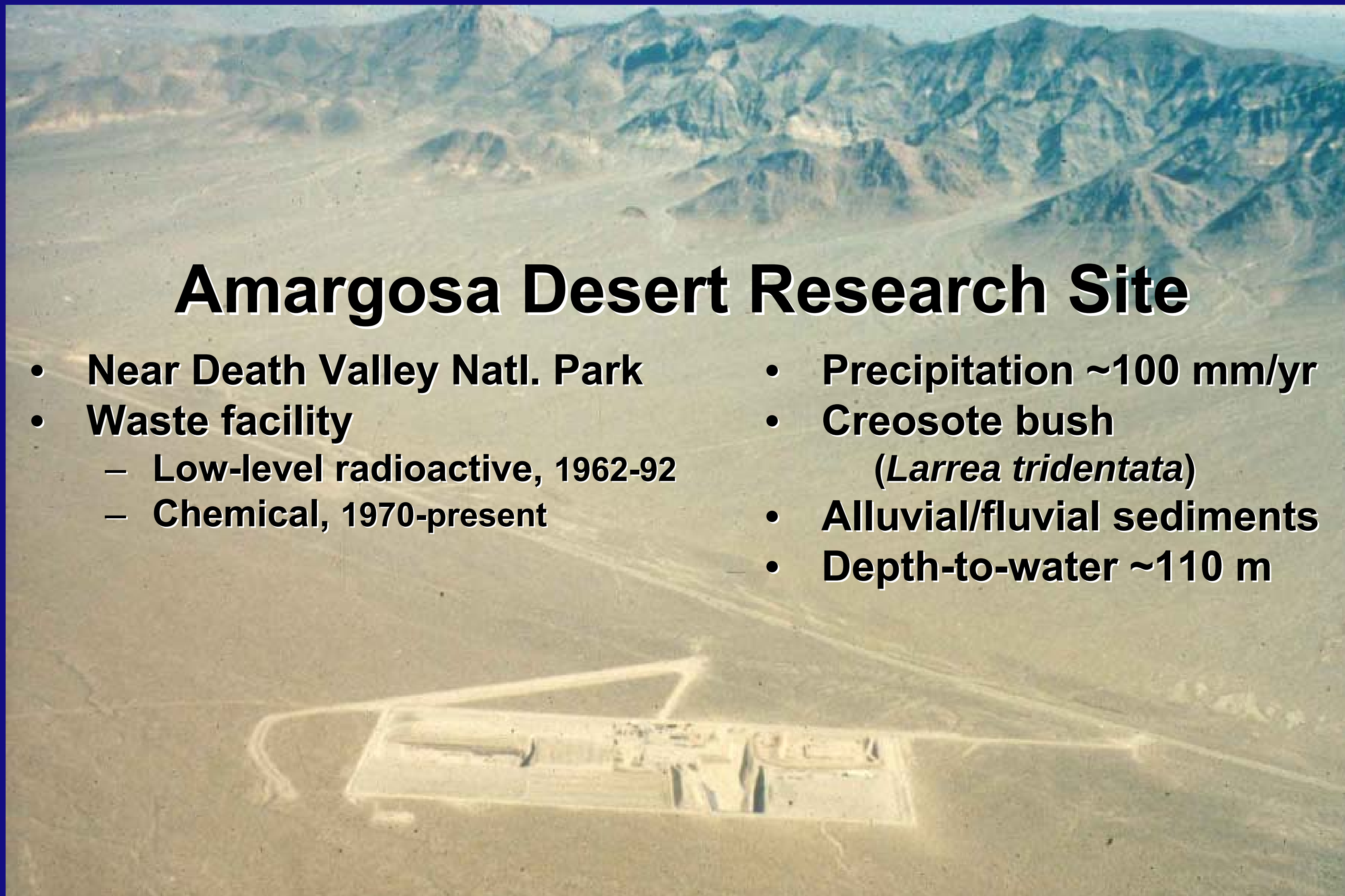
Experimental approach

- **Field-intensive research with multiple lines of data**
  - Weather; ET; plants; soil & sediment properties;
    soil water content, potential, temperature, & gas monitoring; geology; geophysics; microbiology; ground water
  - Contaminant data
    - Tritium, radiocarbon, VOCs, elemental mercury
- **Field data integrated with modeling**
  - Test & refine conceptual & numerical models
- **Natural & perturbed/contaminated conditions**

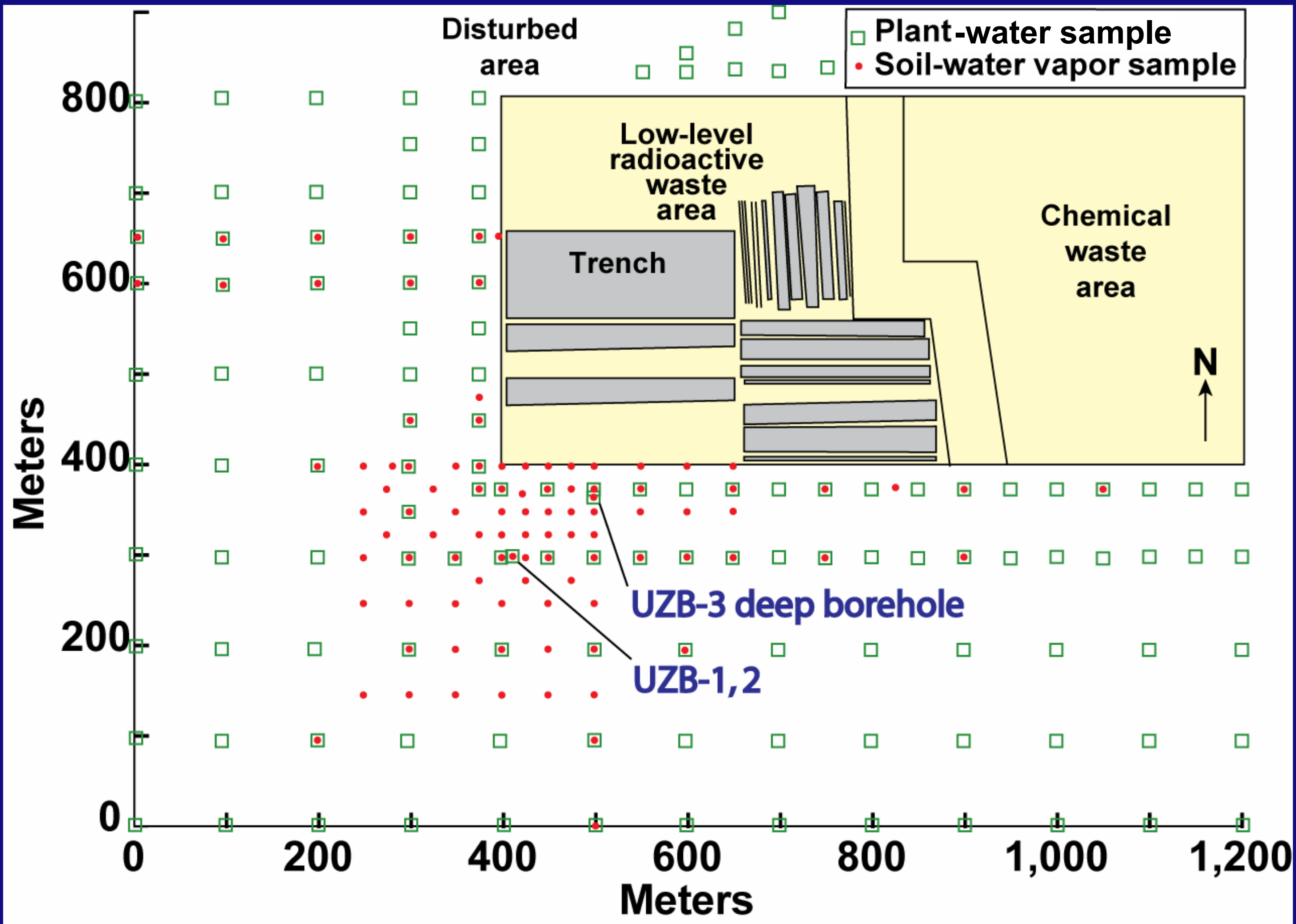
USGS science for a changing world

Amargosa Desert Research Site

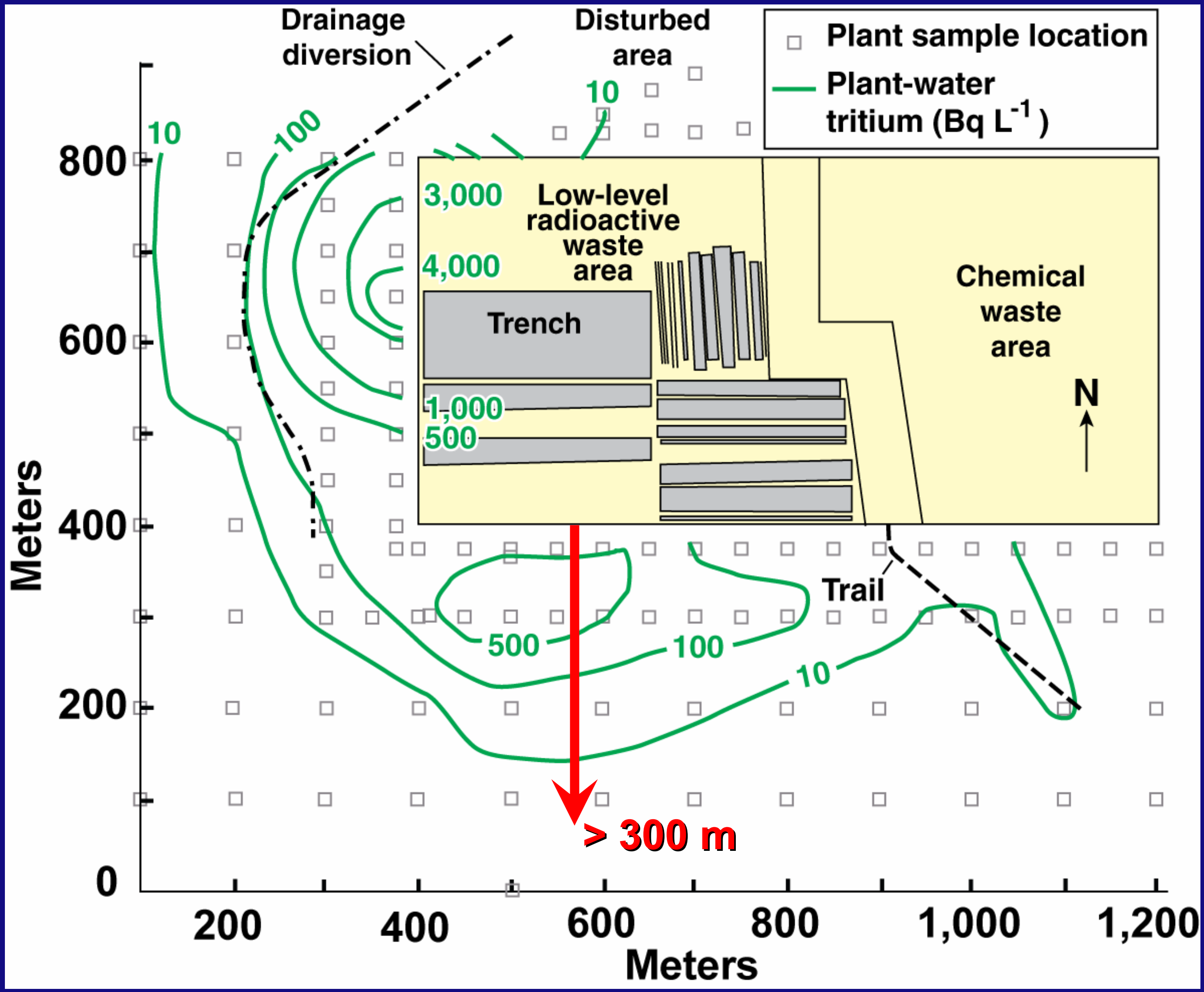
- **Near Death Valley Natl. Park**
- **Waste facility**
  - **Low-level radioactive, 1962-92**
  - **Chemical, 1970-present**
- **Precipitation ~100 mm/yr**
- **Creosote bush (*Larrea tridentata*)**
- **Alluvial/fluvial sediments**
- **Depth-to-water ~110 m**



TRITIUM MONITORING — Deep UZ, Soil, Plants

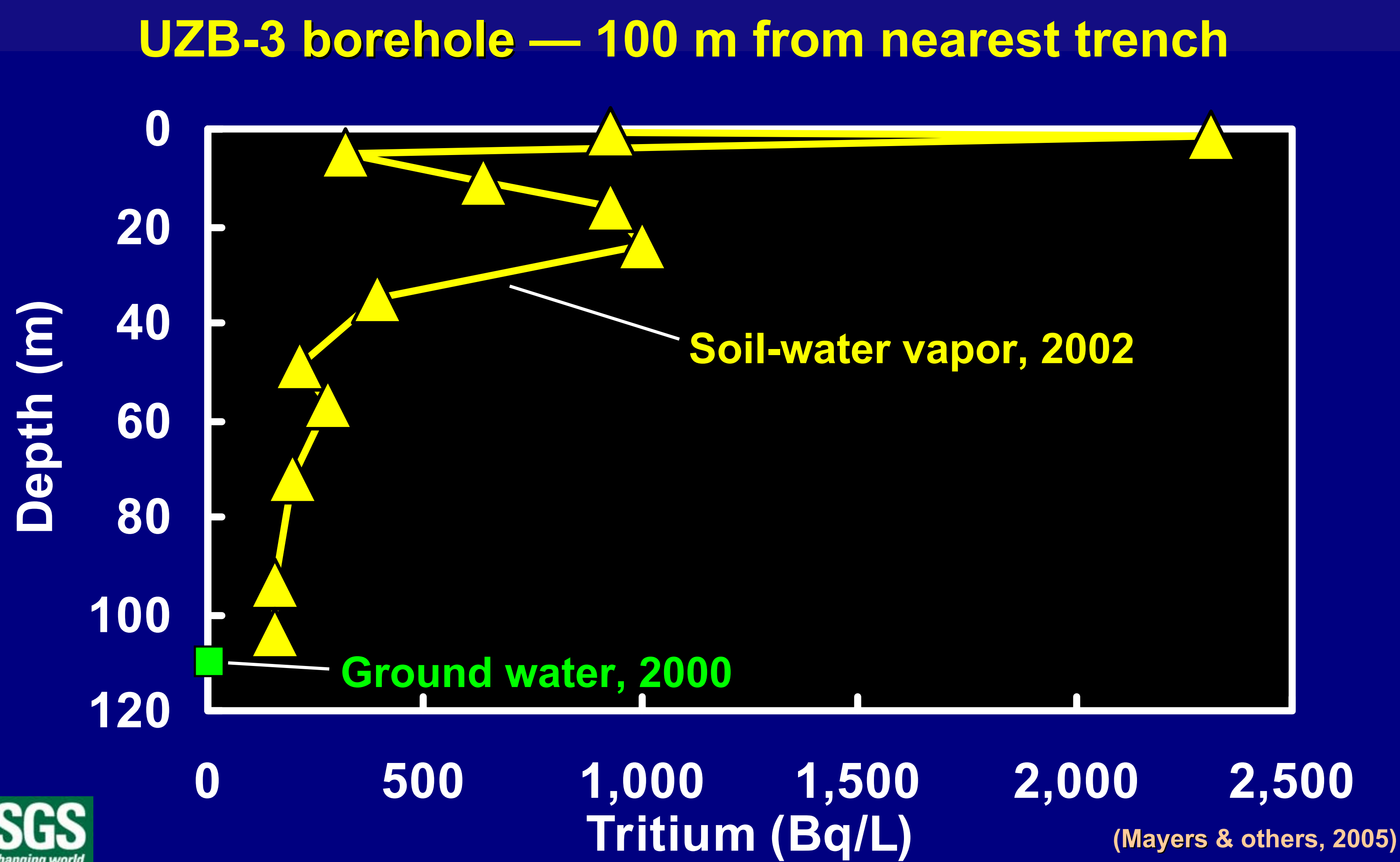


Plant Sampling & Extrapolation to Shallow-Subsurface Transport



(Andraski & others, 2003; 2005)

Tritium Monitoring in Deep Unsaturated Zone



TRITIUM-TRANSPORT MODELING

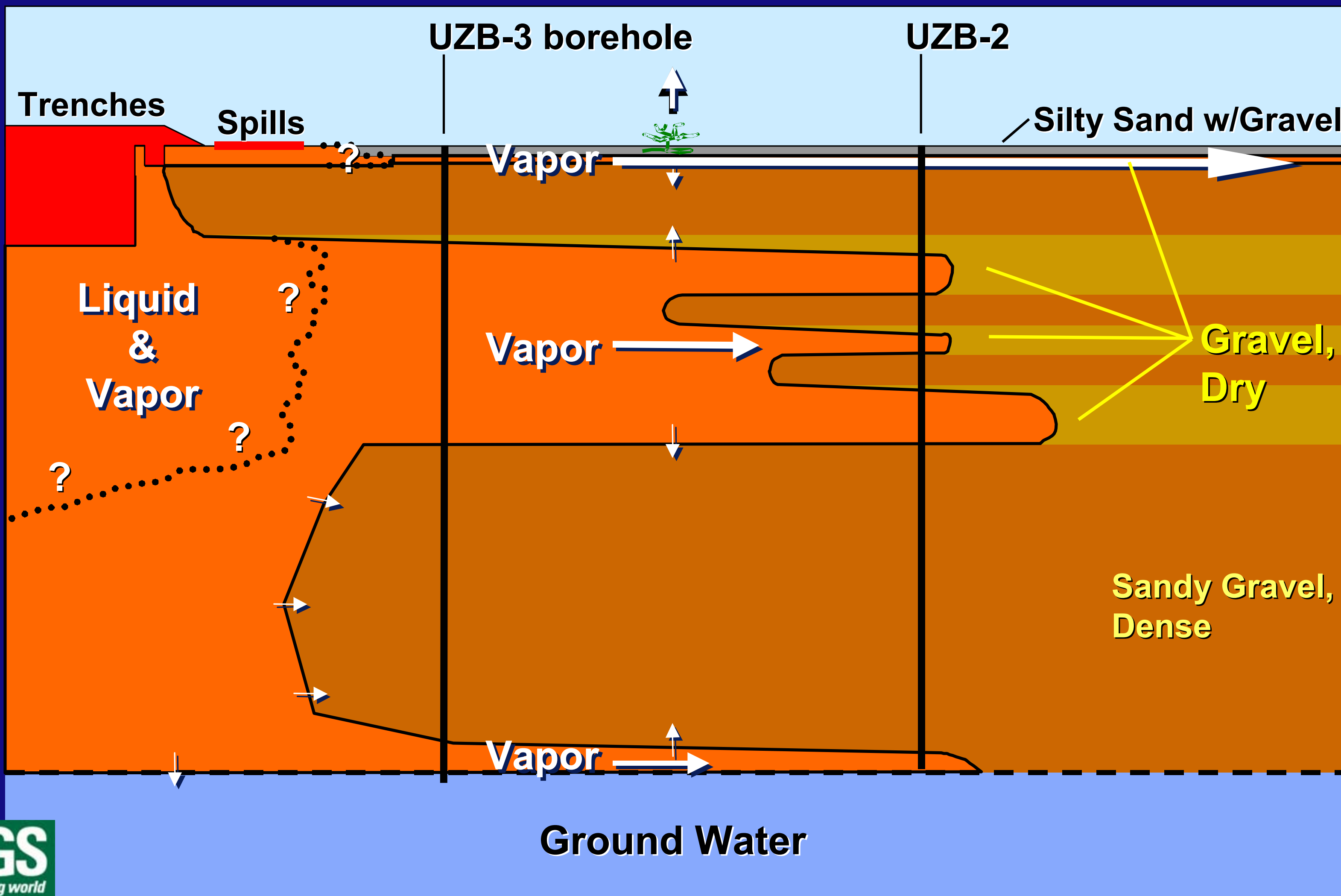
Initial Work (Striegl & others, 1996)

- **Models**
  - Diffusive (Smiles & others, 1995)
  - Advective (Striegl & others, 1996)
- **Results … numerical models fell short**
  - Modeled transport (~15 m) under predicted observed by ≥ 10 X
- **Initial conceptual model**
  - Lateral, subsurface liquid transport along preferential paths … ???

USGS
science for a changing world

… further data collection, refined conceptual model …

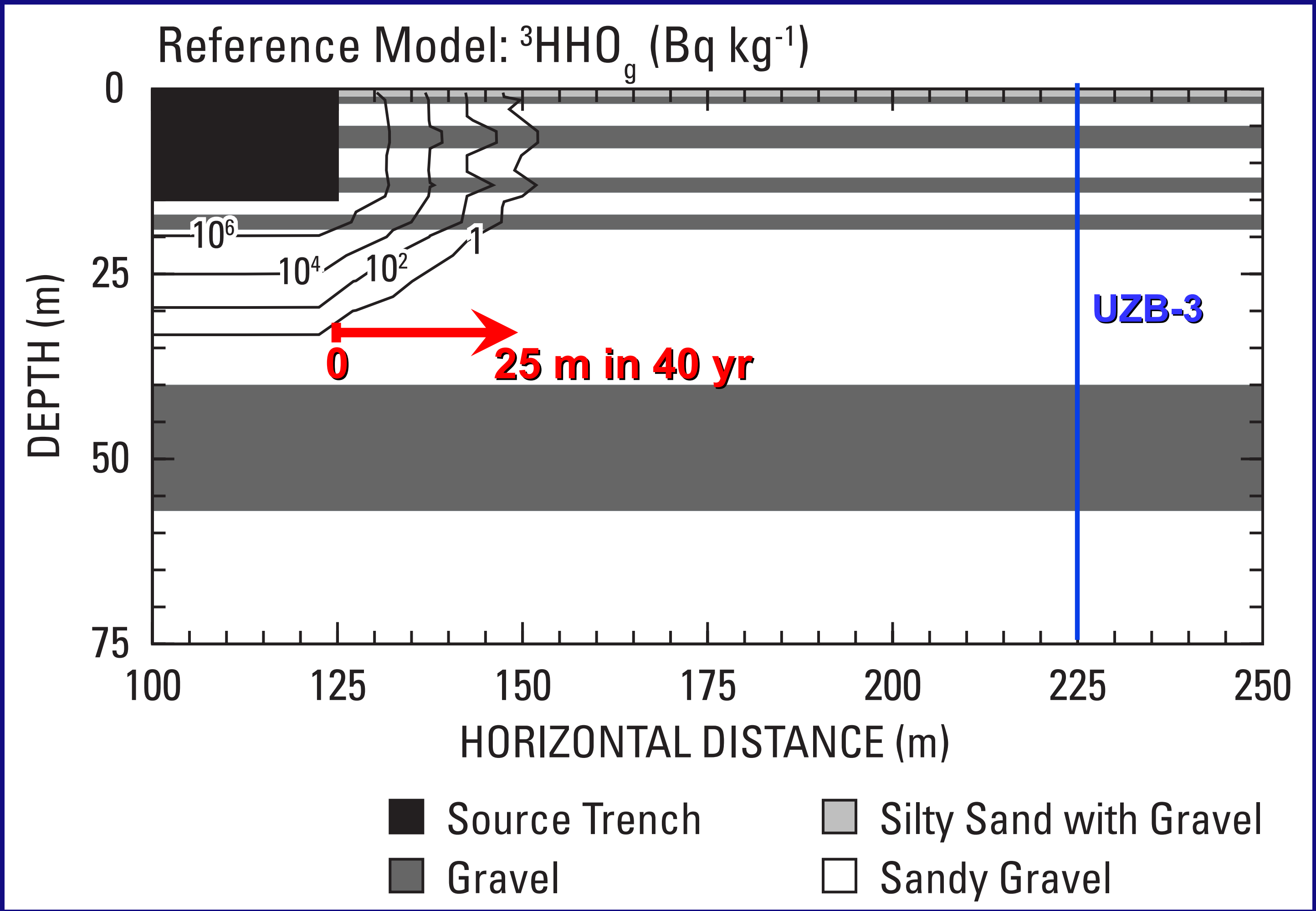
Predominantly lateral, vapor-phase transport controlled by stratigraphy



USGS
science for a changing world

Tritium-Transport Modeling — Phase II

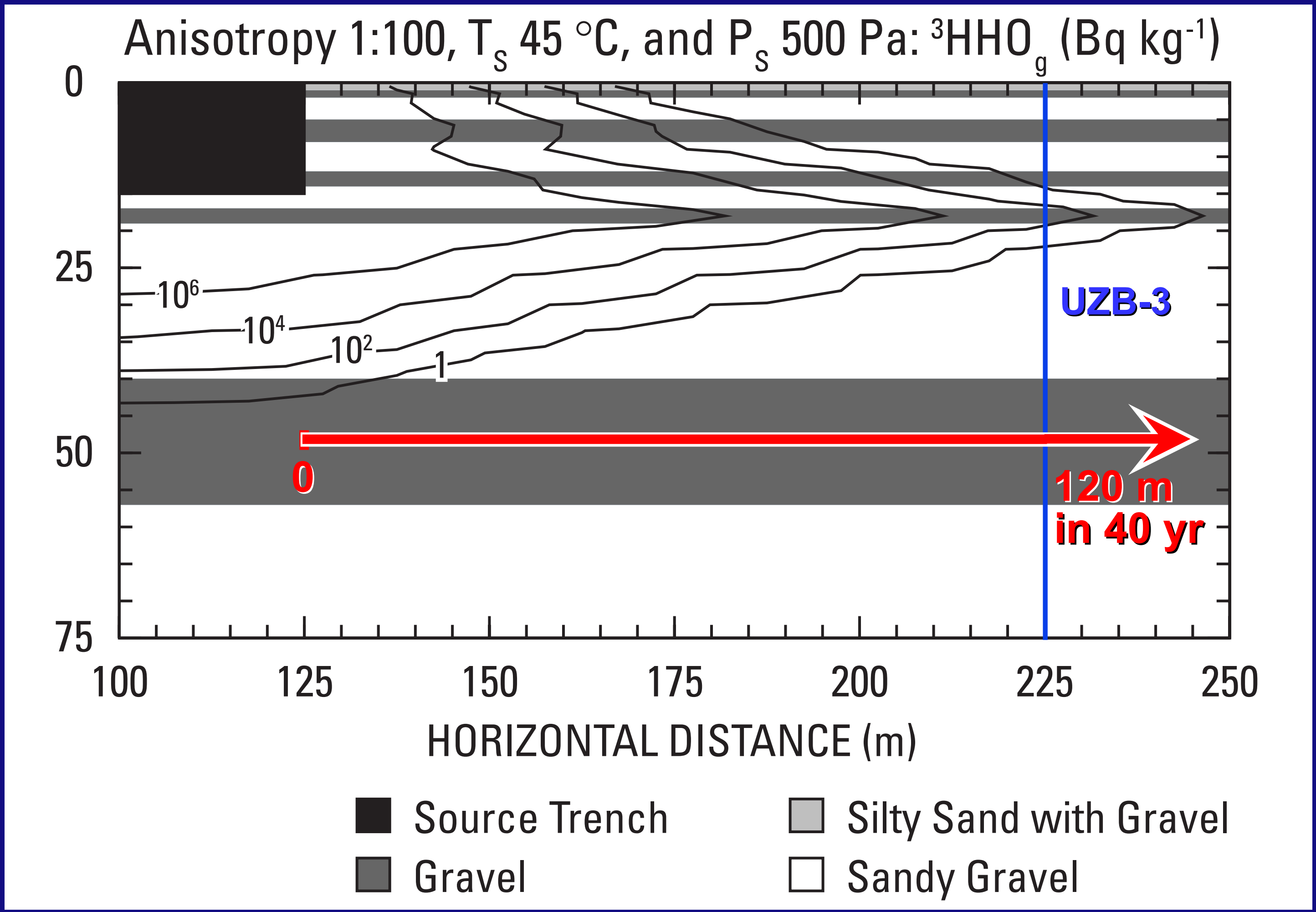
TOUGH2–coupled liquid-gas-heat; non-isothermal, heterogeneous domain



(Mayers & others, 2005)

Tritium-Transport Modeling — Phase II

Effects of anisotropy, source temperature & pressure forcing



(Mayers & others, 2005)

USGS science for a changing world

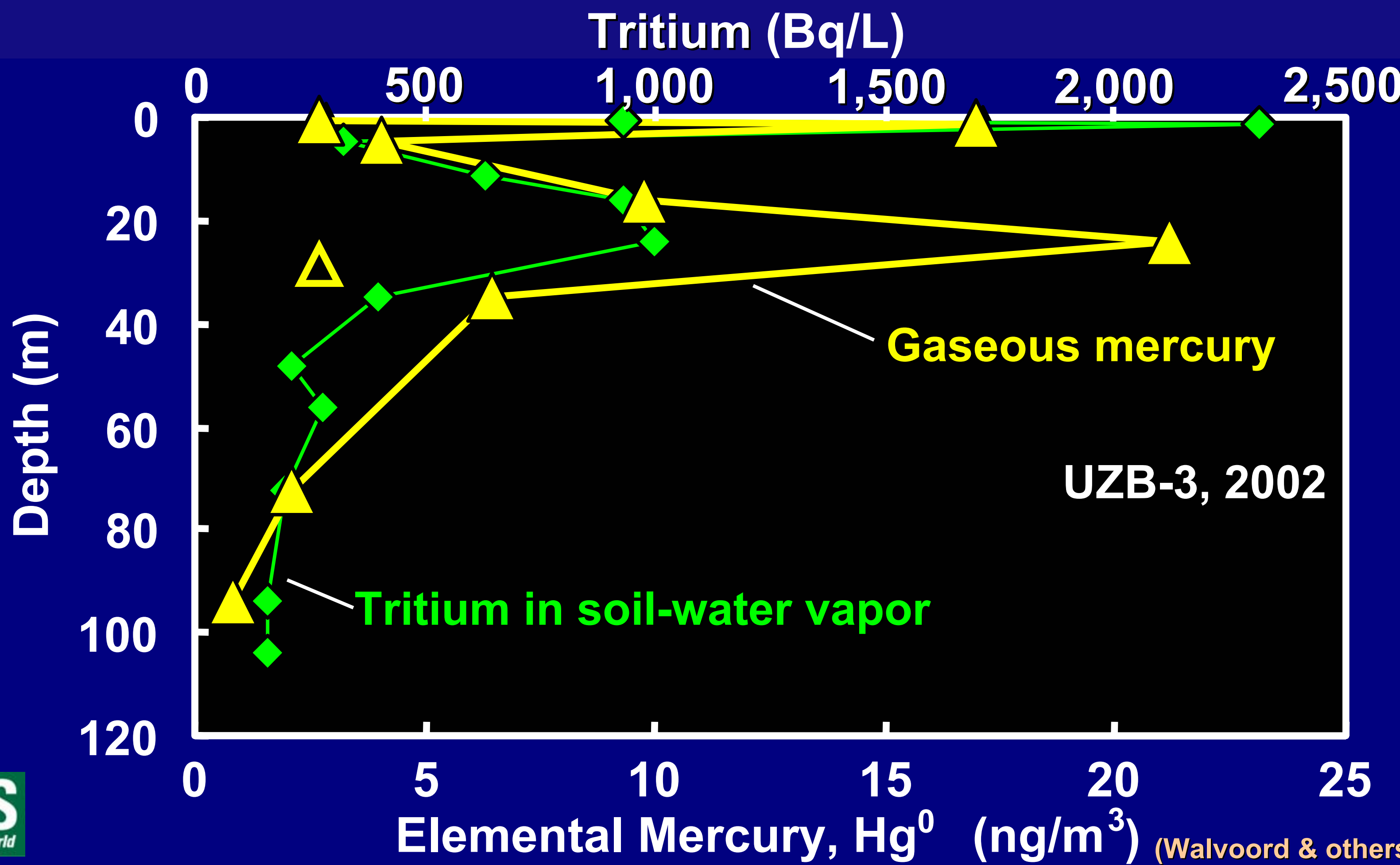
Tritium Transport – Summary

- **Monitoring data**
  - Plant-based mapping identified kilometer-sized plume
  - Tritium migrating throughout 110-m thick UZ
    - — Predominantly lateral, gas-phase transport along preferential paths
- **Phase II modeling results**
  - Large anisotropy & source forcing needed to enhance transport
  - Discrepancies between theory & measurements are reduced … but not eliminated
- **Other processes enhancing gas-phase transport?**
  - Coupling between organic compounds & tritium?
  - Barometric pumping?

USGS science for a changing world

MERCURY MONITORING — Deep Unsaturated Zone

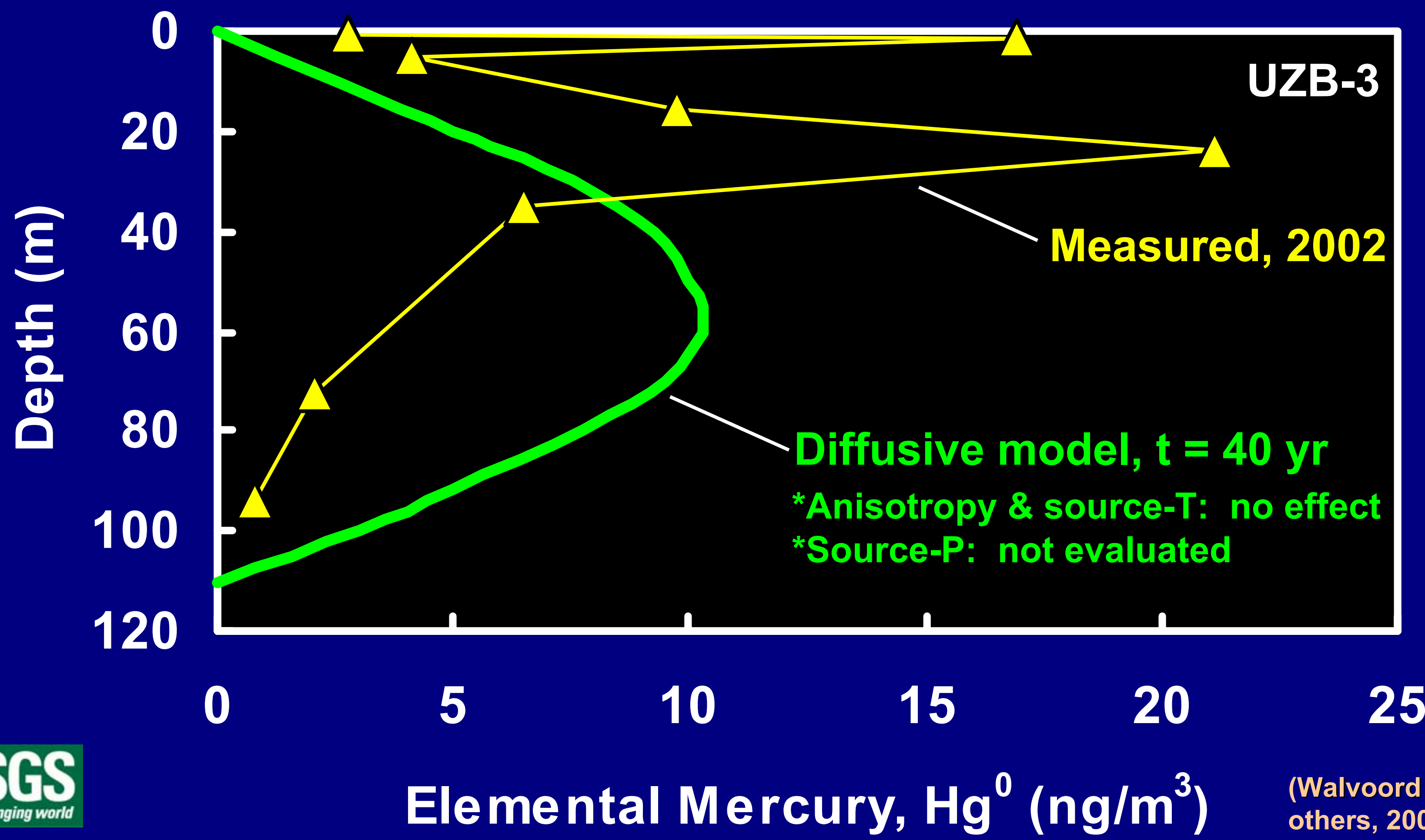
Strong correlation between mercury & tritium concentrations



(Walvoord & others, 2006)

INITIAL MERCURY-TRANSPORT MODELING

FEHM–liquid-gas-heat; non-isothermal, heterogeneous domain



(Walvoord & others, 2006)

USGS science for a changing world

Mercury Transport – Summary

- **Monitoring Data**
  - Like tritium …
    - — Gaseous Hg^0 migrating long distances along preferential paths
  - Confirm dominance of gas-phase transport in desert soils
- **Initial Modeling Results**
  - Diffusive model produced a poor approximation of measured profiles
  - Unlike tritium …
    - — Anisotropy & source-T forcing did not produce preferential-flow pattern
- **Other Processes?**
  - Source-pressure forcing, barometric pumping?

CONCLUSIONS

- We CAN measure the contaminants
- We CAN map the contaminants
- But … our present models CANNOT accurately reproduce observed extent or distribution of transport

USGS
science for a changing world

CONCLUSIONS — continued

- We will continue to integrate monitoring & modeling to explore questions & refine models

- Ultimately … better process understanding is needed to develop & build confidence in UZ transport models

USGS
science for a changing world

Amargosa Desert Research Site

http://nevada.usgs.gov/adrs/

USGS Toxic Substances Hydrology Program

http://toxics.usgs.gov/

Toward a Modeling Mindset for Nuclear Facility Site Performance

Integrating ground-water modeling with ground-water monitoring

My message for this talk

- The concept of “model” means a lot more than just a computer simulation of flow / transport
- Today’s modeling effort also includes data management, visualization, and communication
- State of the art allows near real-time data integration and visualization at reasonable cost
  - Characterization
  - Monitoring
  - Simulation
  - Communication

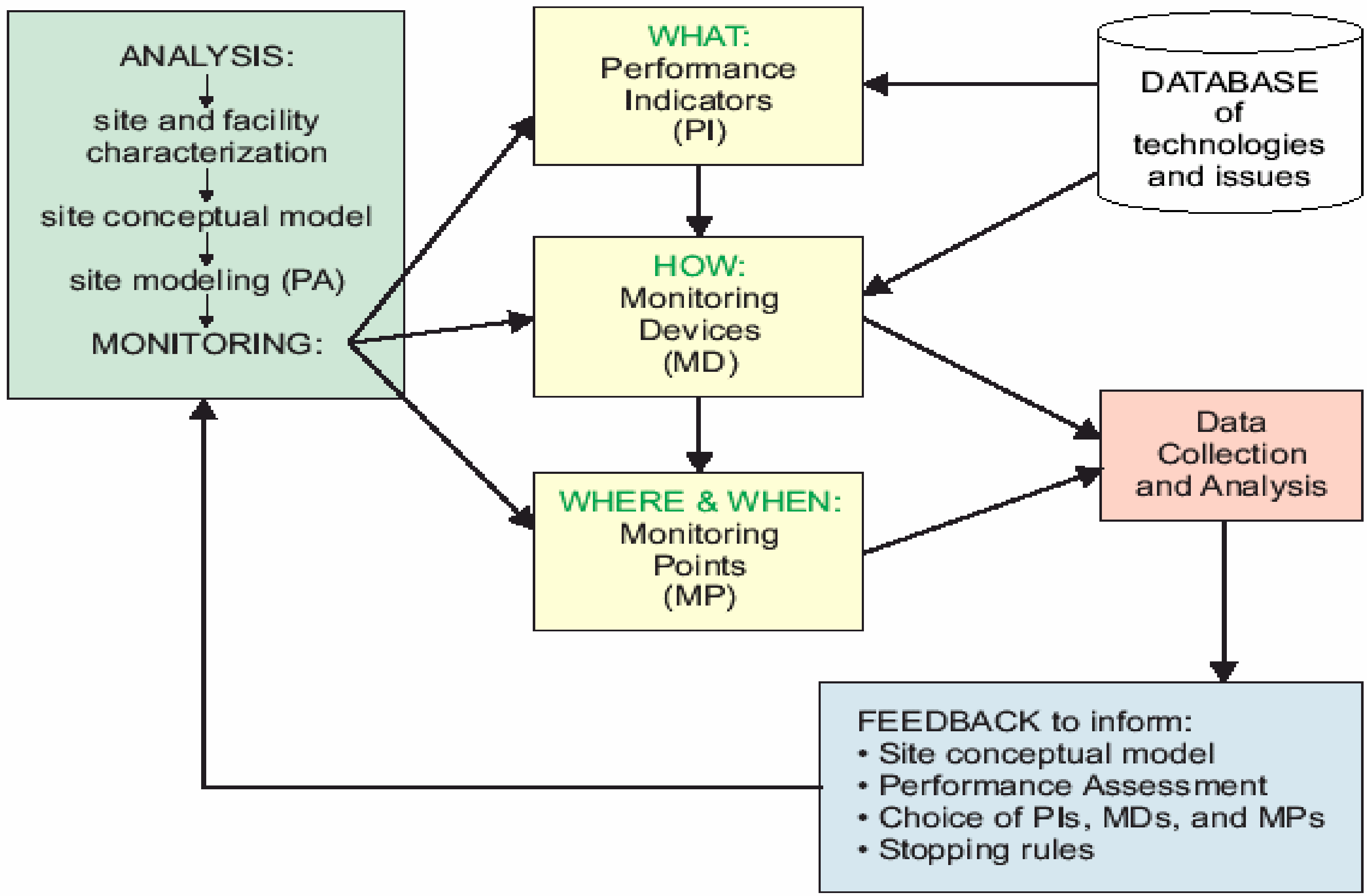
NRC Monitoring Strategy Project

- Goal of project is to provide logic and guidance for ground-water monitoring at NRC-licensed sites
- Focus has been on "Performance Confirmation Monitoring"
  - Monitoring to test the hypothesis that a site is performing within a design envelope of defined risk or is consistent with PA
  - Performance; Compliance; Detection
- Draft strategy developed
- Various presentations at NGWA, AGU, GSA meetings
- Currently in testing phase using data from DOE, DoD, and USGS sources as illustrations

For NRC Staff AES Has Presented Short Workshop Overviews of:

- Site Characterization
- Conceptual model development
  - Ground-water perspective
    - Site
    - Facility
- Performance assessment
- Geochemistry of transport
- Flow and transport modeling (Simulation)
- Data management, visualization, and analysis

Strategy Overview



Indicators of System Performance

- Chemical
  - Risk drivers - Cs, Sr …
  - Indicators – pH, H-3,
- Physical
  - Water pressures / contents – moisture profile in cap
- Interpreted
  - Spatial - bullseye on contour map
  - Non-spatial – control chart anomaly

Systems Analysis
Leads to Monitoring Requirements

- Site Characterization
  - Controls on flow and transport
    - Fractures
    - Depositional models Slide 10
    - Permeability
- Facility
  - Potential leakage or failure
  - Operating history – spills, leaks
  - SAR
- Performance assessment
  - Assumptions
  - Input data
  - Failure modes, weaknesses

Conceptual Model
many facets

- Site –
  - Physical - geology, hydrogeology
  - Chemical – controls on chemical transport
- Facility
  - Inventory
  - Likely leaks (from SAR analysis…)
    - Pathways – e.g. gravel fill around underground lines
- Characterize (puzzle pieces) - Conceptualize – Simulate - Revise

Characterization vs Monitoring
(in Site Performance Context)

- Characterization allows development of CSM
- CSM allows modeling / simulation
- Modeling allows prediction
- Monitoring allows refinement
- Refinement allows confidence

Some things you can do with a model

- Establish separate sources or releases
  - RF overlapping plumes Slide 11
- Predict plume behavior in the future
- Communicate risk or safety factors to stakeholders
- Back-calculate from observations to improve estimates of parameters
- Evaluate alternative hypotheses
  - Congaree levee example Slide 12

Associate Source and Plume

Use probable source locations, groundwater flow paths, and daughter product distribution to delineate plume


N
© 2006 Europa Technologies
Image © 2006 DigitalGlobe
©2006 Google
Pointer 33°55'50.94" N 81°01'46.95" W elev 128 ft
Streaming |||||||||| 100%
Eye alt 10533 ft

A backwards look

- History of subsurface modeling
  - Water resource studies
  - Mineral resource studies
- A matter of scale
- A matter of detail
- Mining and petroleum applications – **profit related**
  - Lots of software development
- Environmental applications – **cost related**

So What is a Model?

- State of practice 1990-
  - Commissioned like a work of art by a patron
  - Computer resource hog
  - Expensive
  - Once done, resting on a shelf
- State of art 2006
  - Database for all characterization data
  - Visualization for communication support
  - Dynamic use of new site data
  - Desk-top computer adequate
- State of Practice 2010+ ?
  - Could be routine practice at every facility with an environmental program

A 1986 Modeling Example

- Conceptual model
- Predictive results
- Monitoring Observations

Conceptual Model

1986 model

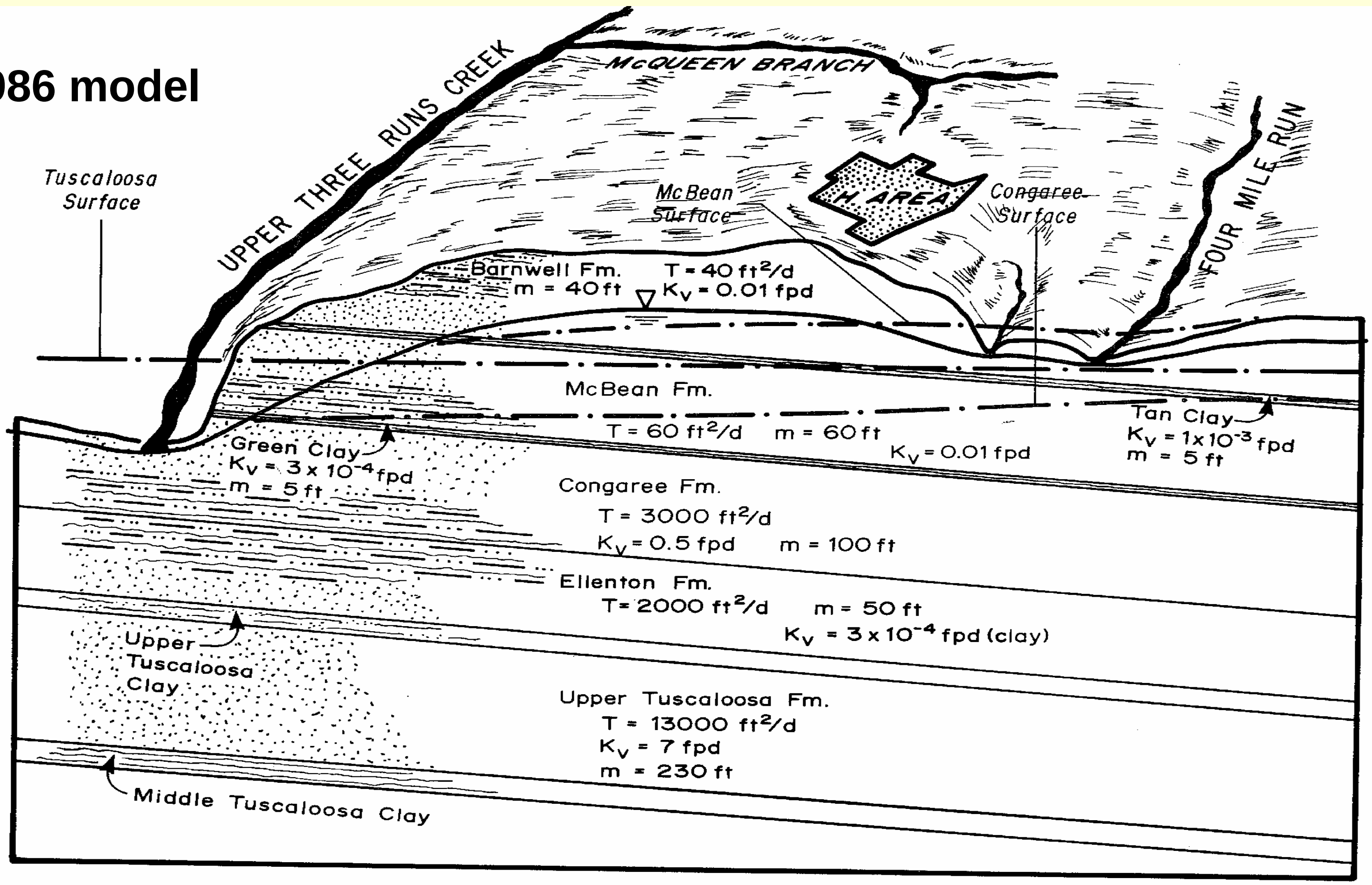


Figure 1.3 Summary of hydrogeologic conditions for the General Separations Area.

12

Prediction Made with Model

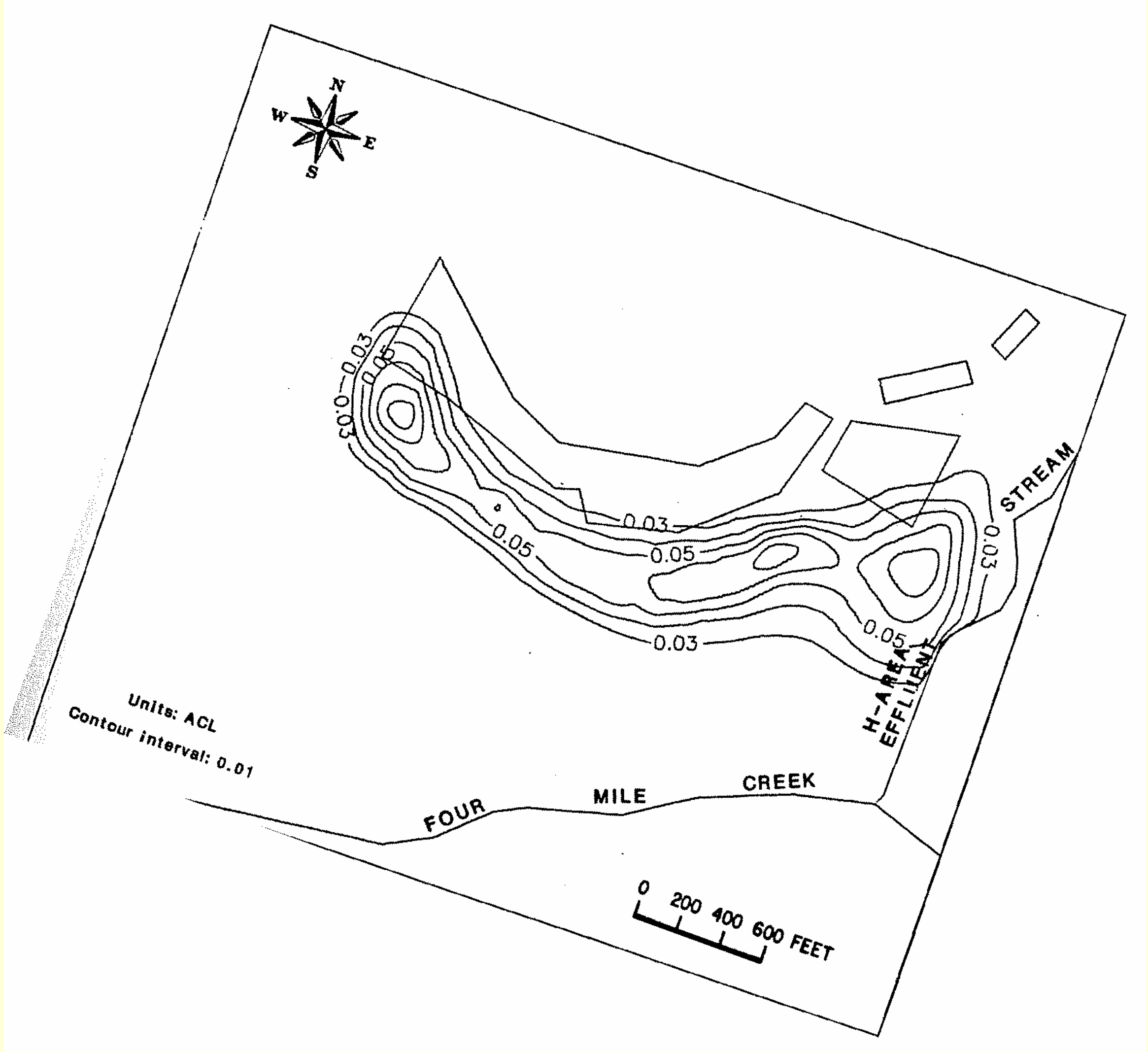
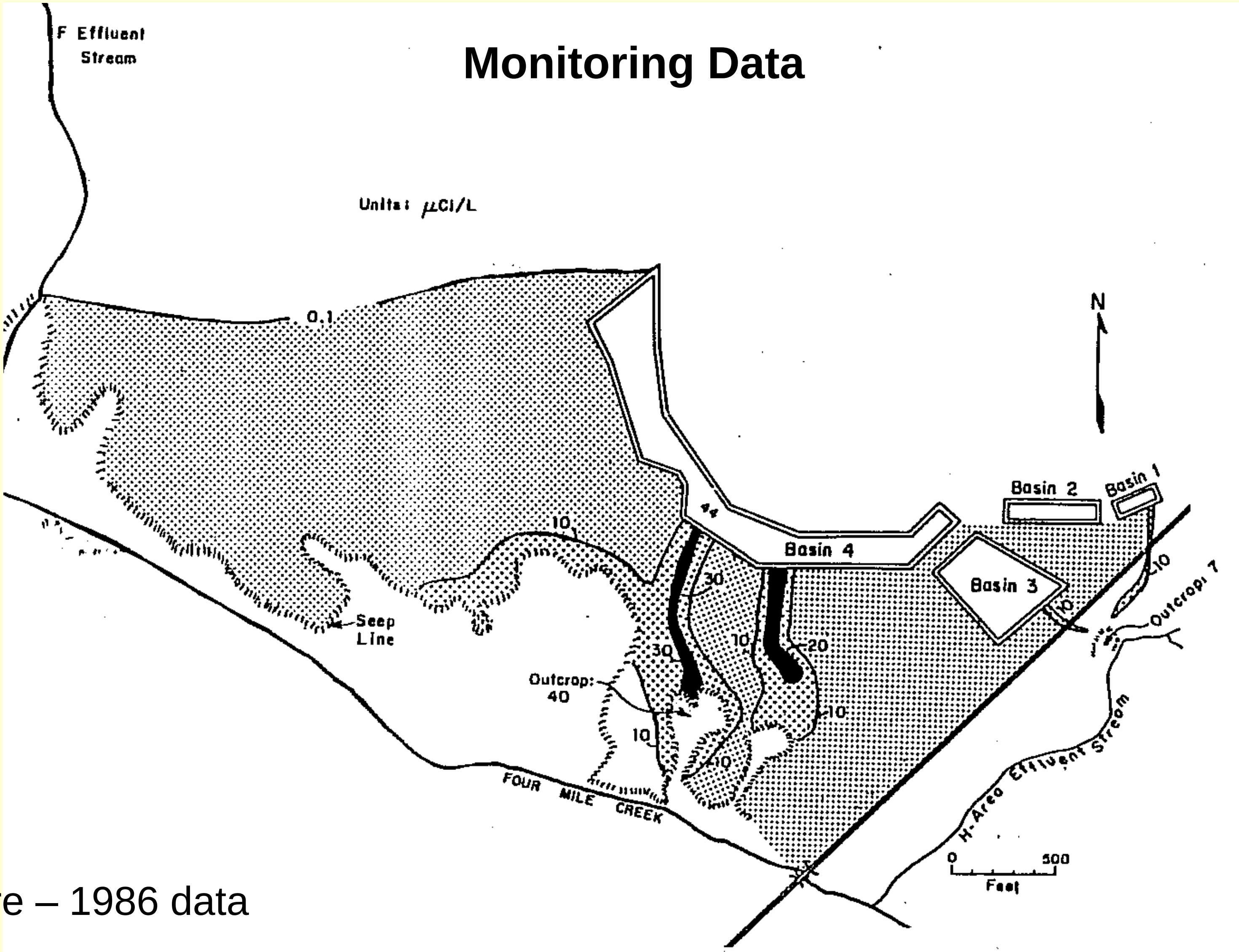


Figure 2.16 H Area Concentrations in the Barnwell aquifer at the end of 45 years of operation, R = 5.0.

Monitoring Data



Pre – 1986 data

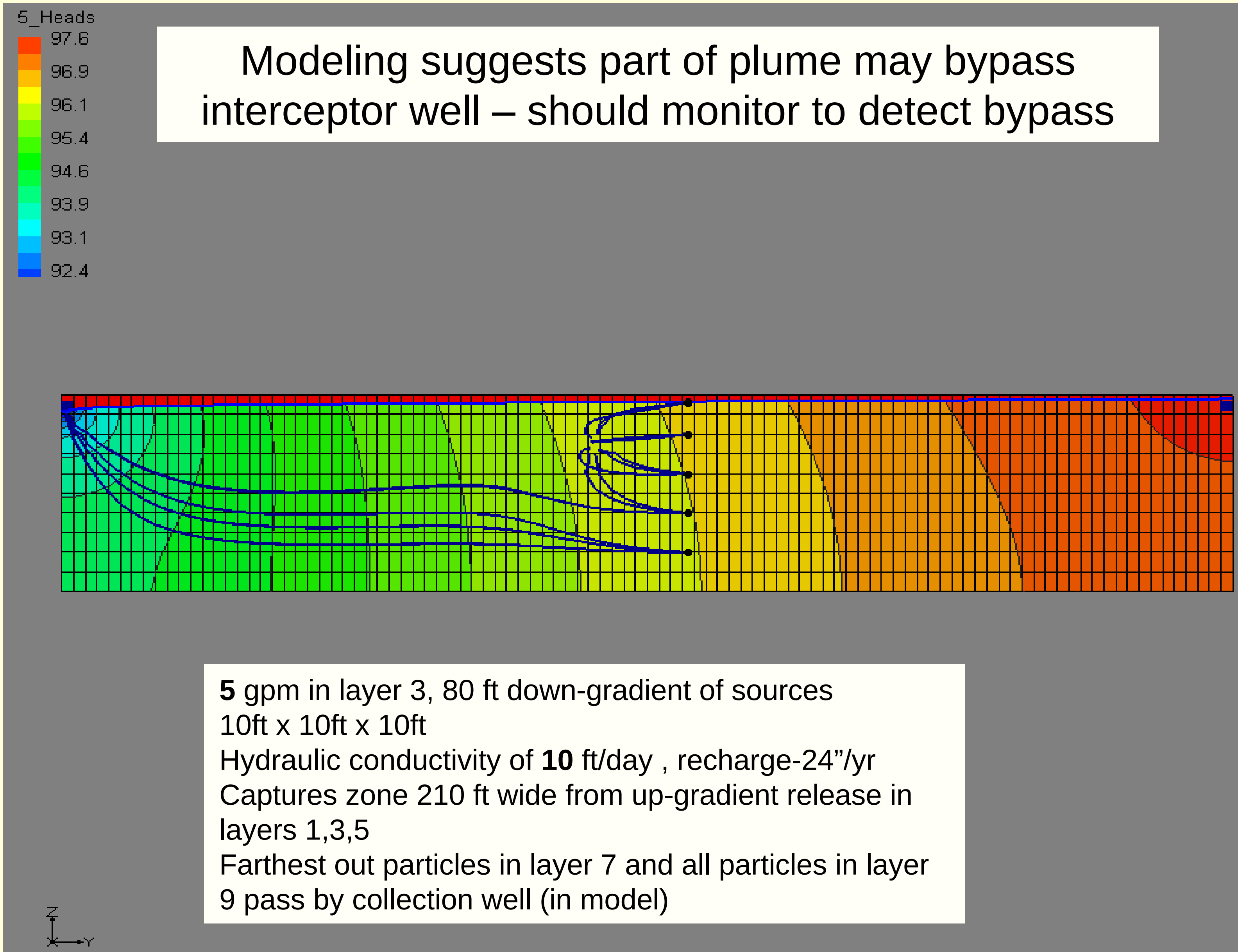
FIGURE 3. Isoconcentration Contours of Tritium in Ground Water at H-Area Seepage Basins

The Modeling-Monitoring Connection

Wang and Anderson, 1981, Introduction to Groundwater Modeling, Chapter 1, Page 1

- "Good field data are essential when using a model for predictive purposes
- An attempt to model a system with inadequate field data can also be instructive as it may serve to identify areas where detailed field data are critical to the success of the model.
- In this way, a model can help to guide data collection activities."

Modeling suggests part of plume may bypass interceptor well – should monitor to detect bypass

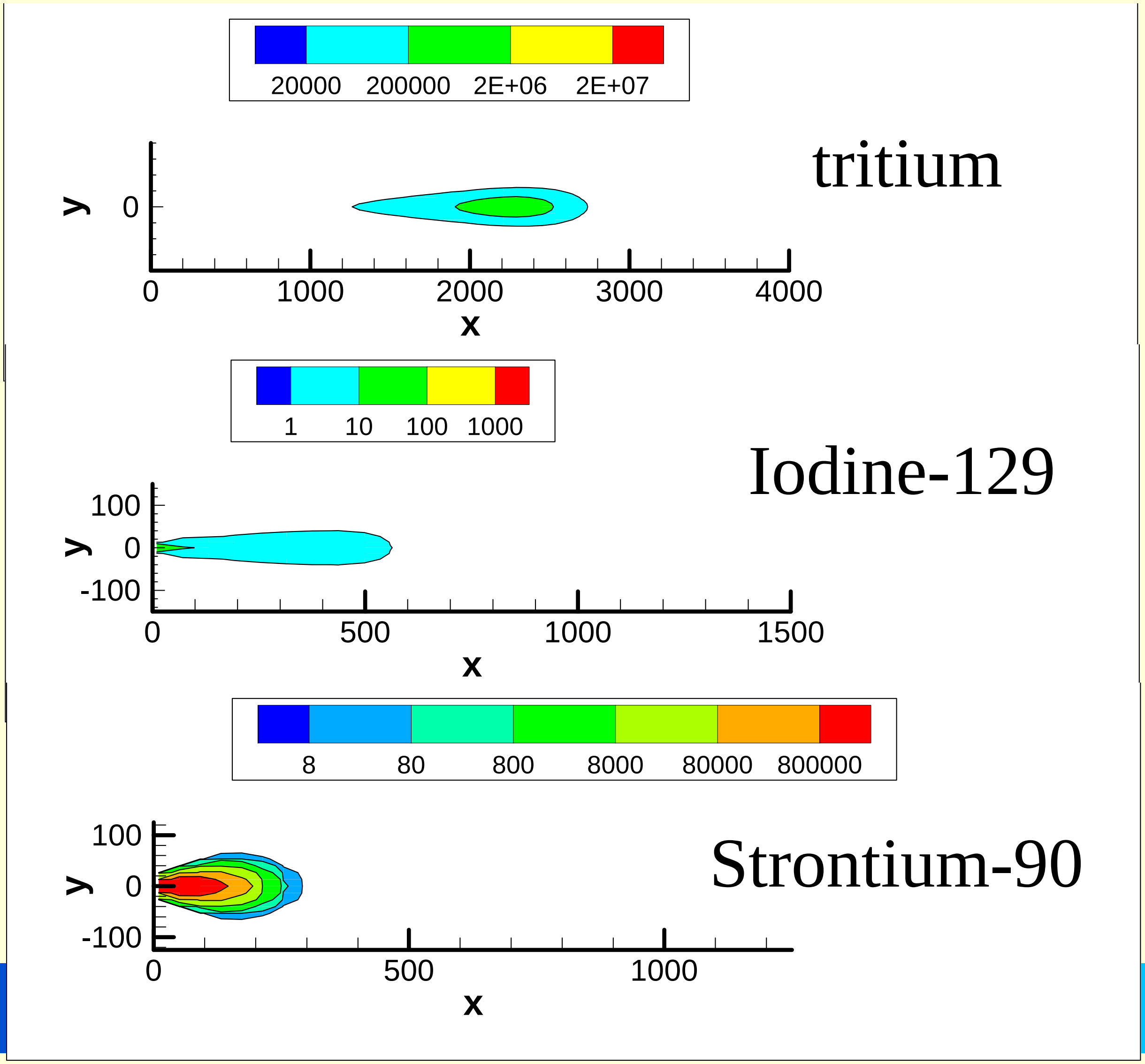


5 gpm in layer 3, 80 ft down-gradient of sources
10ft x 10ft x 10ft
Hydraulic conductivity of **10** ft/day , recharge-24"/yr
Captures zone 210 ft wide from up-gradient release in layers 1,3,5
Farthest out particles in layer 7 and all particles in layer 9 pass by collection well (in model)

Simple analytical example along flow path

Tritium could pass observation point before Sr arrives.

If H3 detected, look upgradient for others. Don't abandon wells after H3 is low.



BNL--HFBR

- 6 – 9 gallons / day of tritiated water to a “dry” vadose zone
- Installed **up-gradient and down-gradient horizontal wells** to confirm (0.6 – 1.6 meters below WT)--- (but < 5000 pCi/L when sampled)
- Relatively **fast moving aquifer** (0.3 m/day) created thin plume beneath HFBR (estimated to be about 0.3 m)
- The plume spreads downward **after emerging** from beneath the HFBR

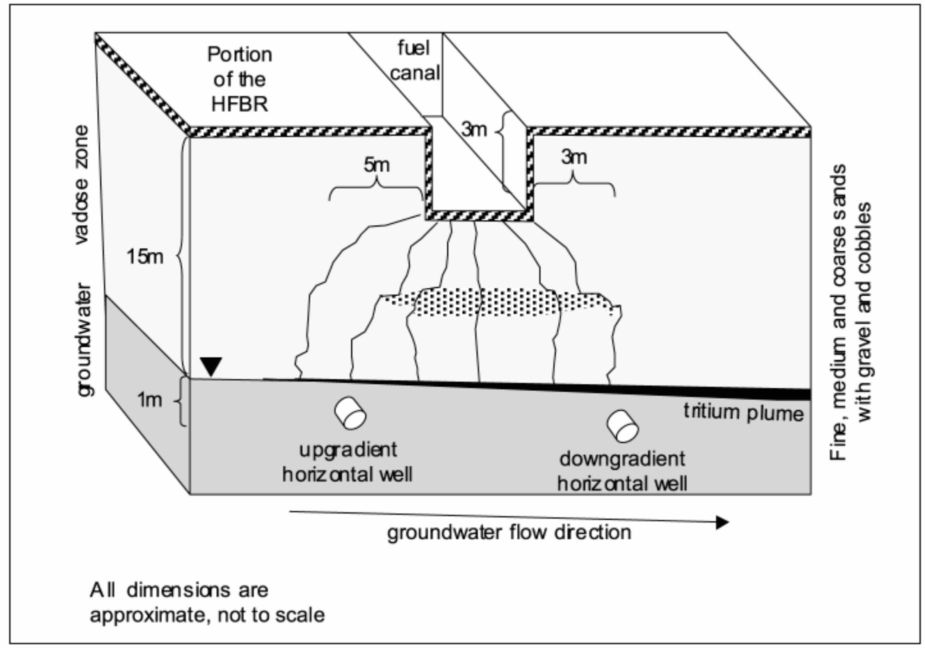


Figure 2. Detail schematic of vadose zone and shallow groundwater beneath the HFBR. Flow lines from a small continuous leak in a dry vadose zone spread out widely, especially when they encounter gravel and cobble zones.

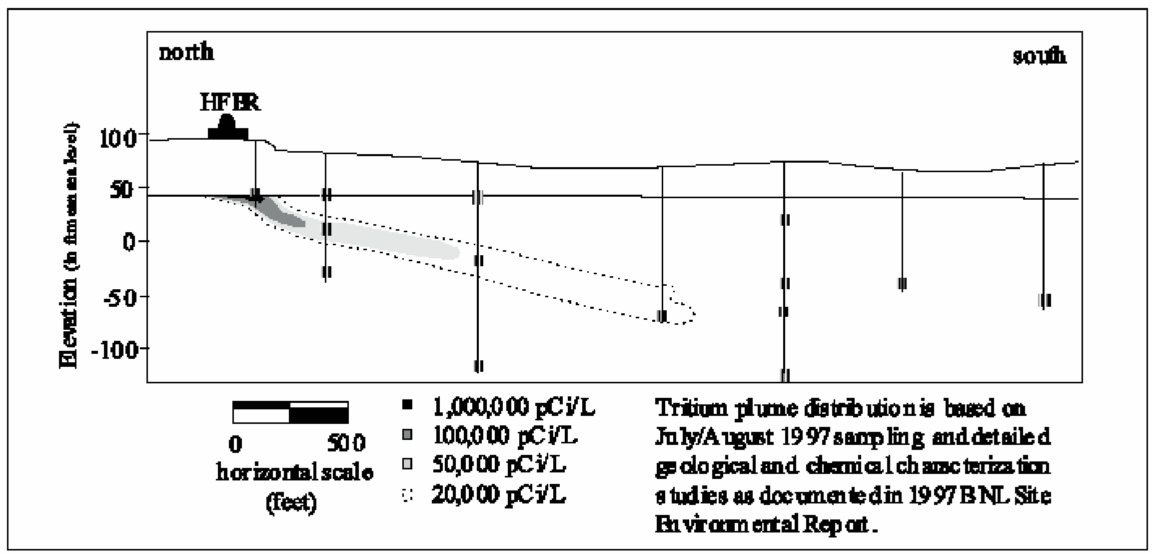
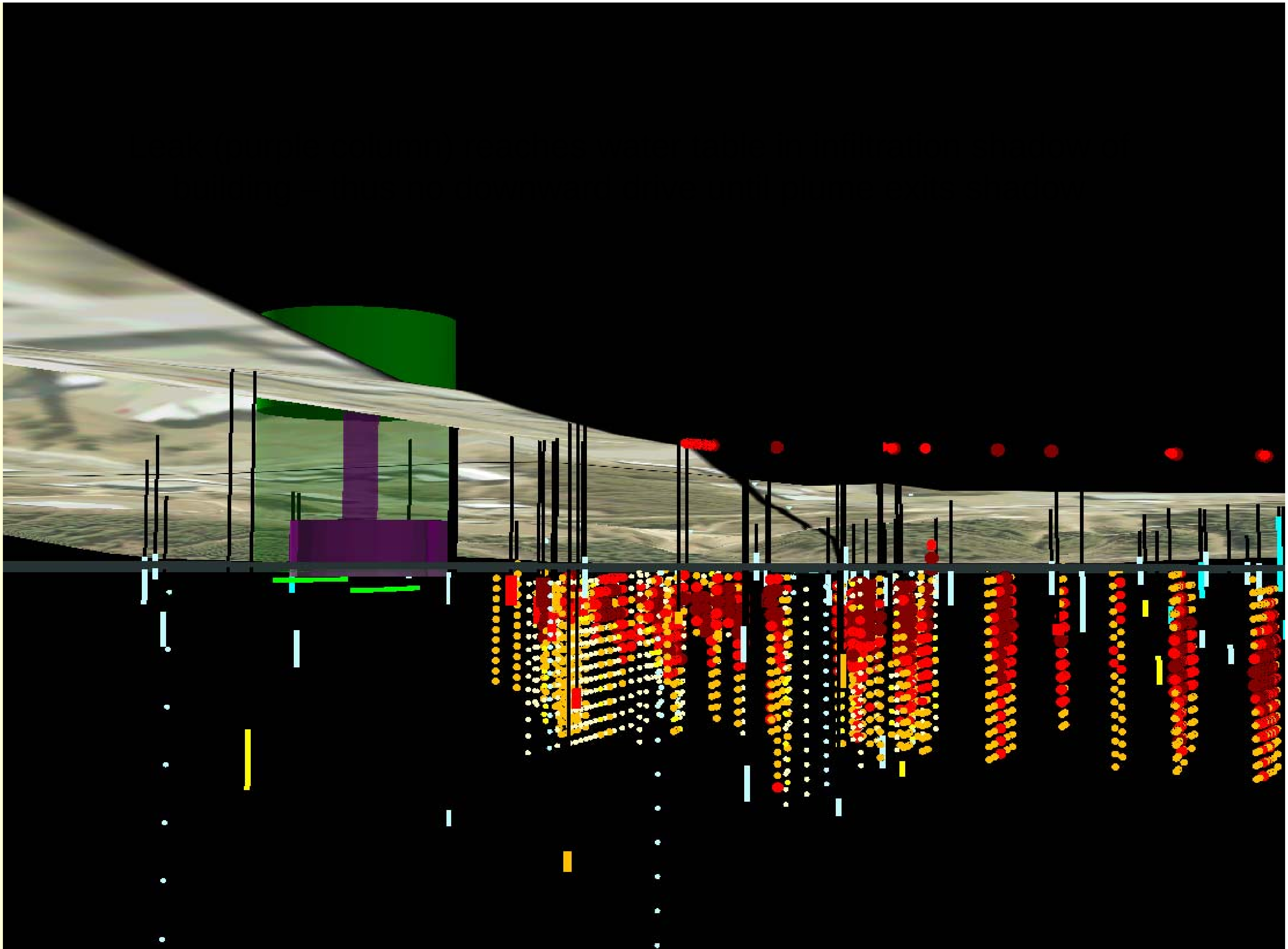
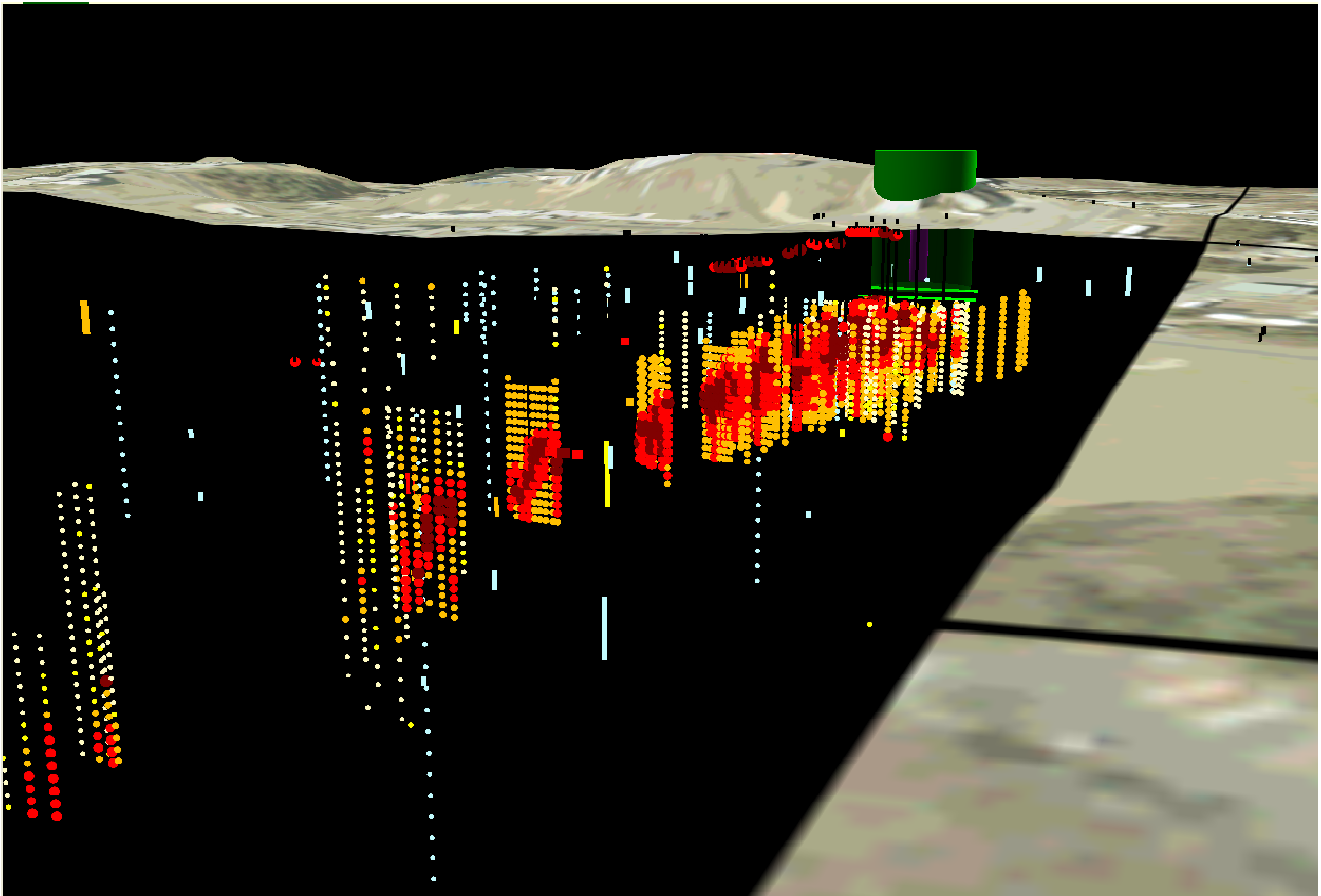
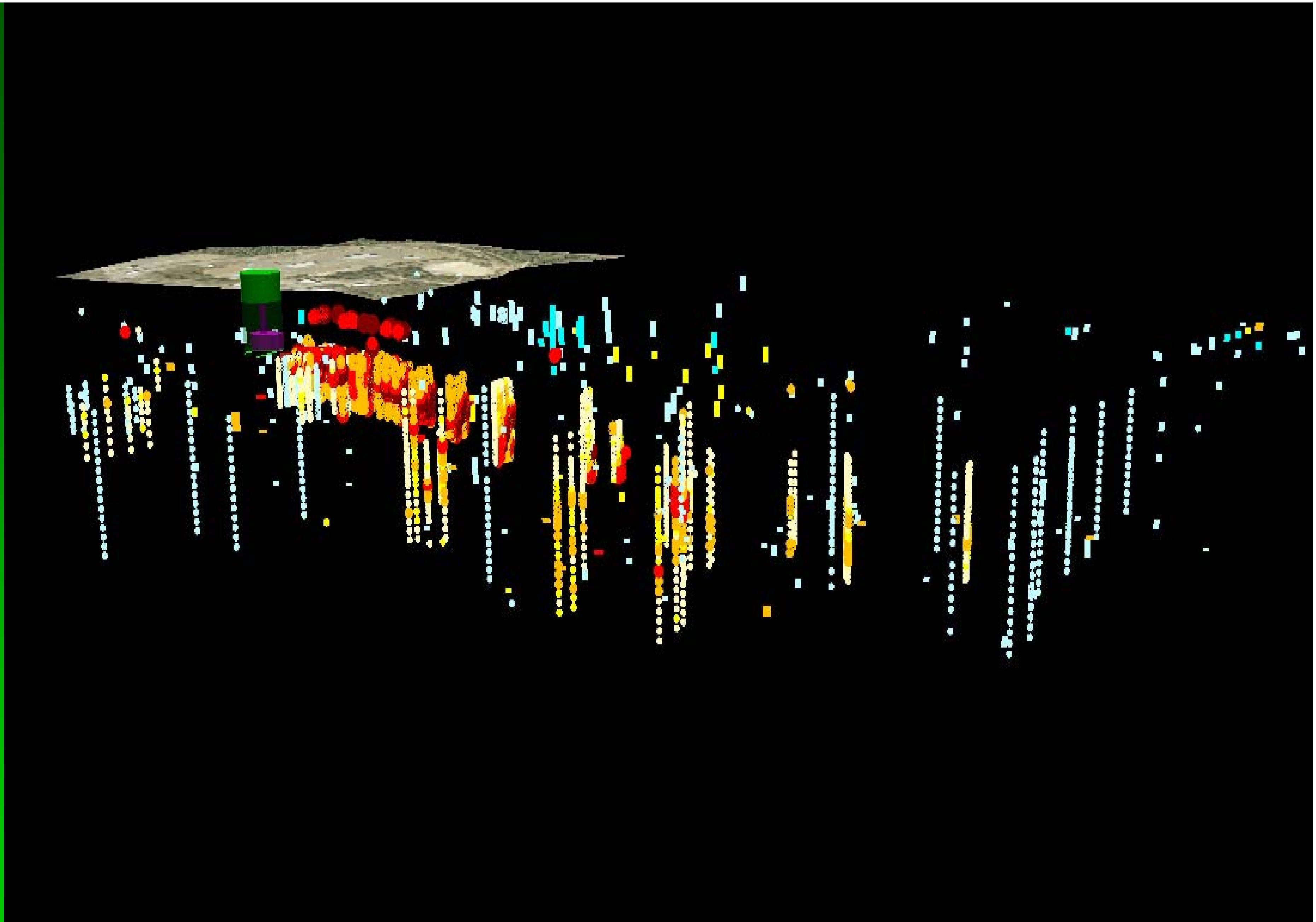


Figure 5. Observed tritium plume geometry at the HFBR.







Summary

- Ground-water flow and transport models should be combined with data storage and visualization
- New monitoring data can be compared with models in near-real time
- Monitoring of performance indicators can be used to spot off-normal conditions before they become serious problems
- Currently-available software can provide powerful visualization tools for management review and stakeholder communication

Alluvial Fan Depositional Setting

Systems Analysis Leads to Monitoring Requirements

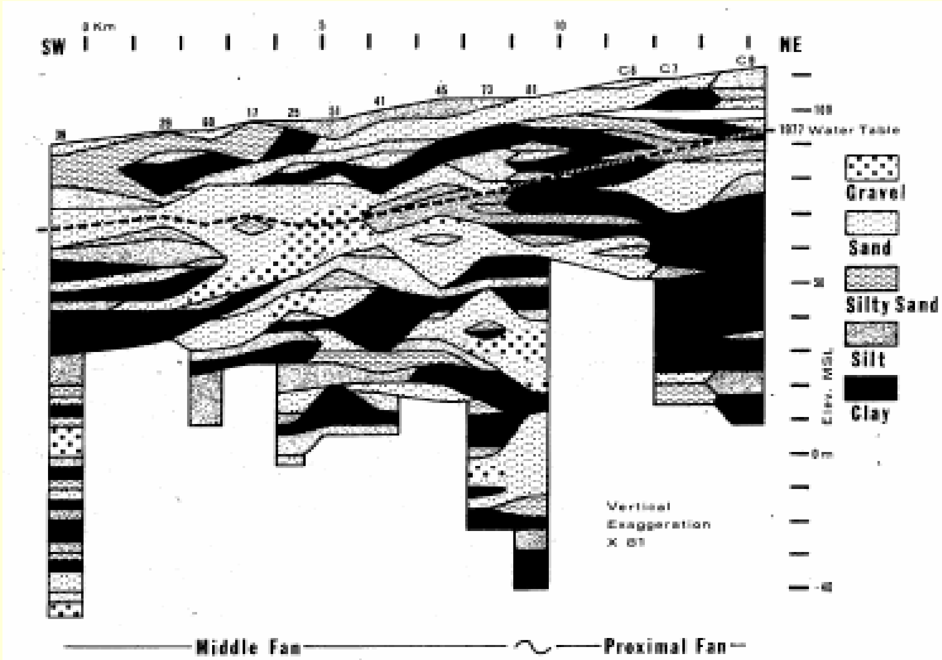


Figure 9. Downfan cross section based on Fresno (39) and Clovis (C9) municipal wells on lower proximal and upper middle Fresno fans. Cross section extends from Sec. 5, T. 13 S., R. 21 E. at C9 to Sec. 31, T. 13 S., R. 20 E. at 39.

- Revised Version 9/15/06

Site Characterization to Support Model Development for Contaminants in Ground Water

Robert G. Ford

U. S. Environmental Protection Agency
Ground Water & Ecosystems Restoration Division
Ada, OK

Acknowledgement: Steven Acree, Elise Striz, Bill Brandon

Advisory Committee on Nuclear Waste

Working Group Meeting on Using Monitoring to Build Model Confidence

September 19 - 20, 2006

What Controls Contaminant Transport?

➢ Physical constraints:

- Contaminant source mass and distribution
- Subsurface flow velocities
- Spatial distribution of flow paths
- Temporal variability of flow velocity & direction

➢ Chemical constraints:

- Contaminant properties (decay rate, degradation rate, sorption affinity)
- Aquifer sediment properties (mass distribution, sorption affinity, chemical stability)
- Ground-water chemistry – as it affects 1) contaminant chemical speciation and 2) sediment mineral stability & sorption characteristics

This information determines accuracy of conceptual or predictive site model, which is the basis for projecting contaminant transport.

Questions to be Addressed through Site Characterization & Analysis

- What are the transport pathways within the aquifer?
- What is the rate of fluid flow along critical transport pathways?
- What processes control attenuation of the contaminant along transport pathways?
- What are the rates of attenuation & capacity of aquifer to sustain contaminant attenuation?

The data collected to address these questions also serve as the input into reactive transport models that may be employed as one of the tools to 1) assess the accuracy of the Conceptual Site Model relative to observed contaminant transport behavior, and 2) to test future projections of transport based on anticipated land-use scenarios.

Characterizing Site Hydrogeology

Characterization Goals

- Identify pathways of contaminant transport relative to compliance boundaries and risk receptors
- Establish GW monitoring network that allows collection of data to identify spatial heterogeneity and temporal variability of hydrologic and biogeochemical characteristics of aquifer
- Establish GW monitoring network that supports collection of samples that are representative of aquifer conditions (*drilling methods & materials important!*)
  - Avoid alteration of hydraulic conductivity
  - Avoid alteration of geochemistry adjacent to well screen

USEPA Monitoring Well Screening Tool

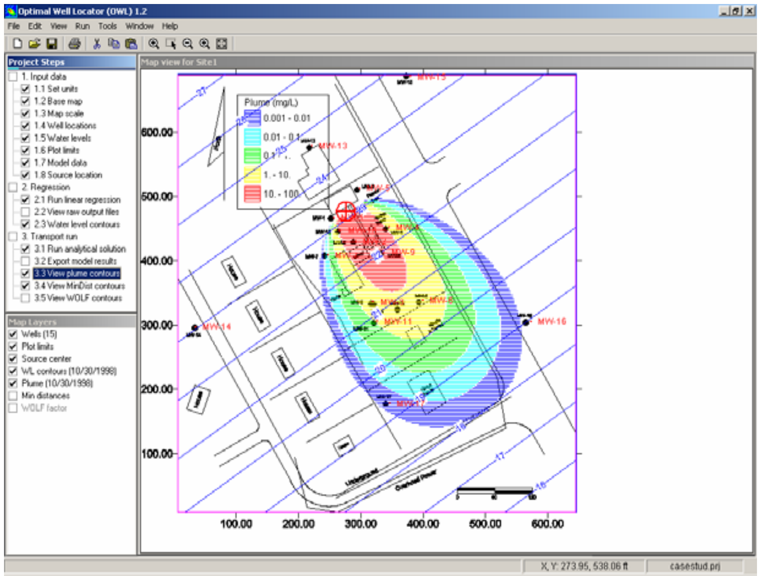
Optimal Well Locator (OWL) Version 1.2

Objective: To provide a simple tool for non-modelers to evaluate the ground water flow, plume migration and MW network at their site using typically collected site data.

- What is the variation in magnitude and direction of ground-water flow over time?
- How does this variation affect plume migration at the site over time?
- Are the existing monitoring wells able to intercept the plume? Where is the best place to put a new monitoring well?

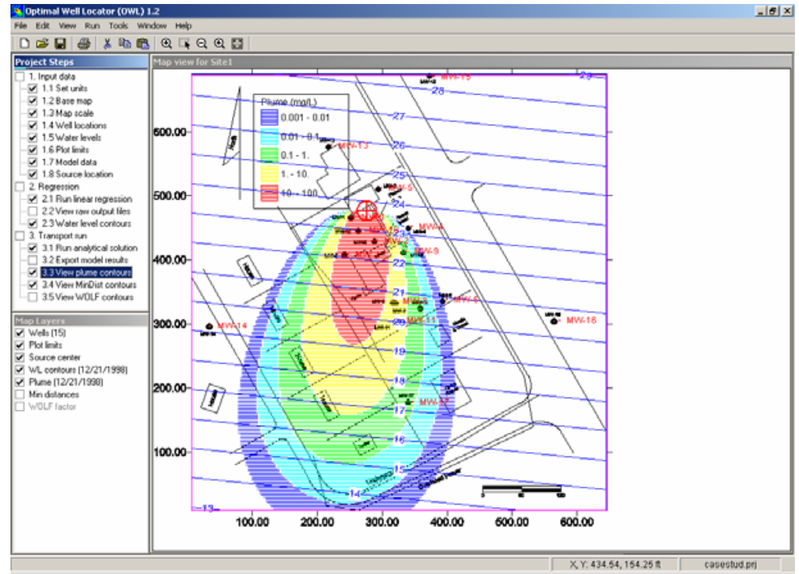
Center for Subsurface Modeling Support (CSMoS)
U.S. EPA/NRMRL/GWERD Ada, OK
http://www.epa.gov/ada/csmos/models/owl.html

Plume Migration Path 10/30/98



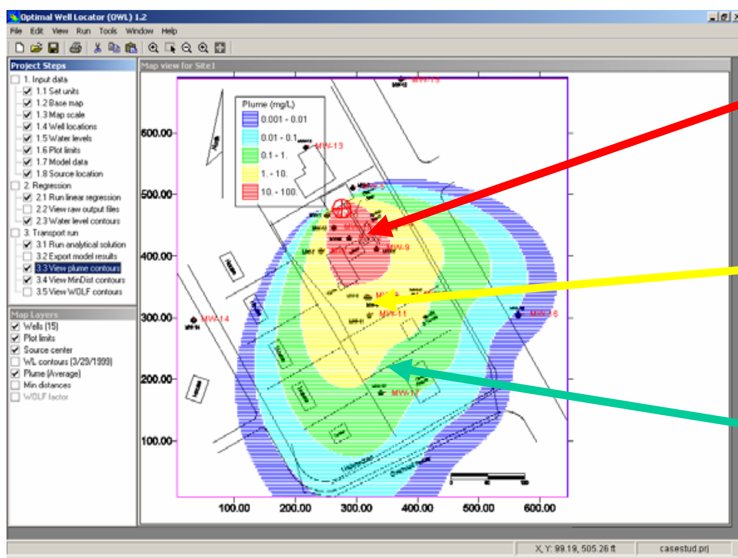
t = 6 years
k = 514 ft/yr
ϖ = .45
R =1
No decay
α_x=30 ft
α_y=3 ft
C_0 =125 mg/l

Plume Migration Path 12/21/98



Average Composite Plume (6)

$$C_{avg}(i,j) = \frac{1}{n}\sum_t C(i,j,t)$$



Red : 10-100 mg/l
Existing MW coverage good

Yellow: 1-10 mg/l
Existing MW coverage sparse

Green: 0.1-1.0 mg/l
One existing MW

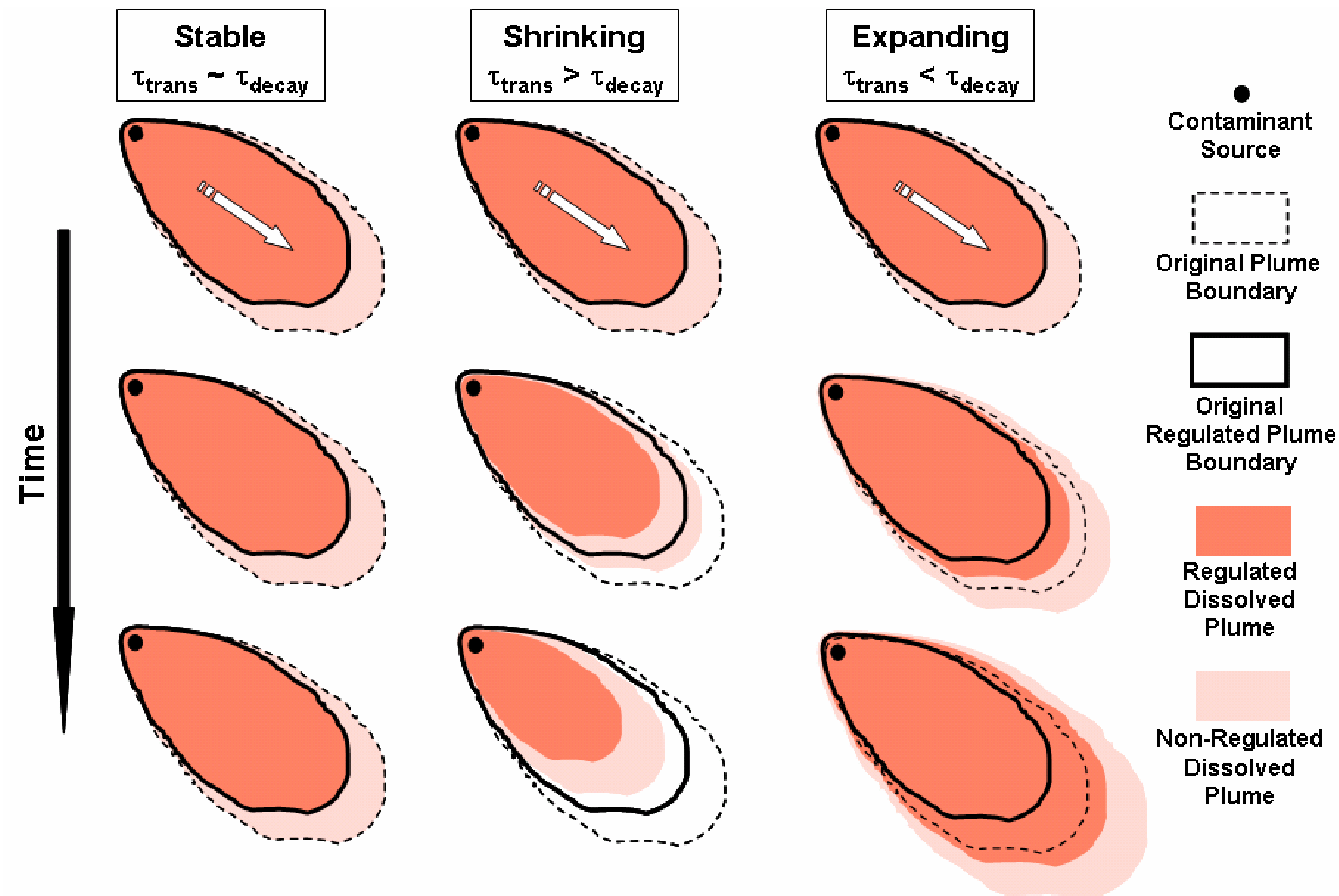
Characterizing Site Biogeochemistry

Characterization Goals

- Identify reaction mechanisms/processes that control contaminant transport
- Collect data that 1) support evaluation of Conceptual Site Model and 2) verify performance of identified transport process(es)
- Employ sample collection and analysis procedures that:
  1) maintain sample integrity
  2) characterize the factors that control contaminant degradation or partitioning between aqueous and solid matrices

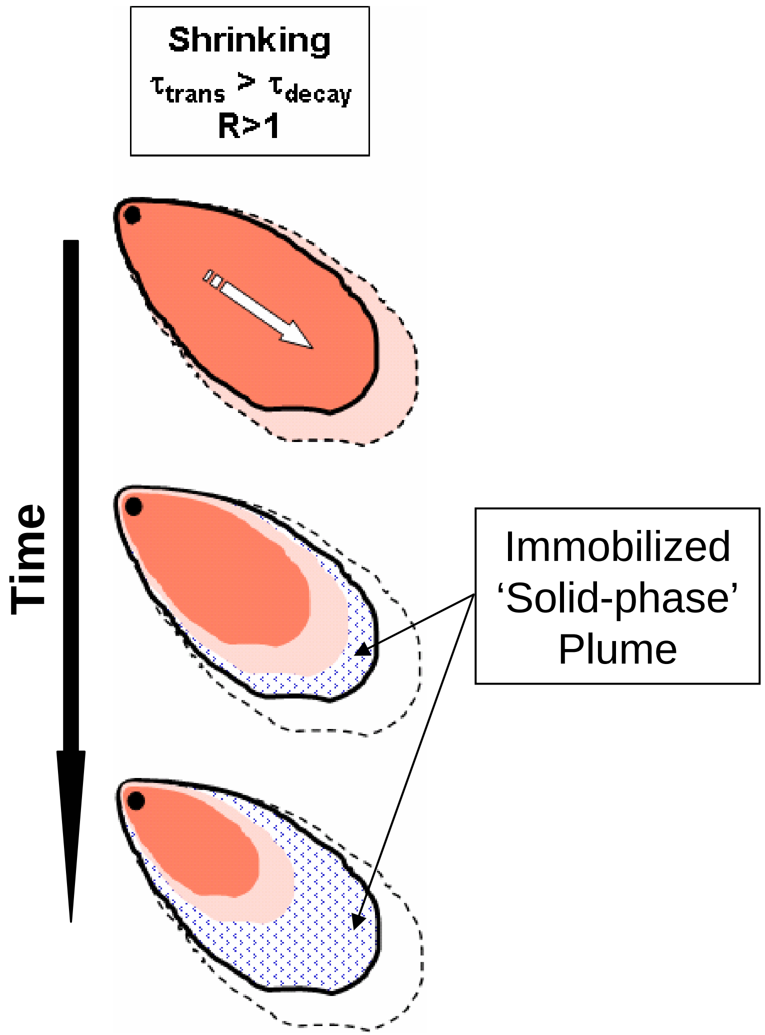
Subsurface 'Dissolved' Plume Behavior

Decaying Radionuclide - Conservative Physical Transport, Uncontrolled Source
(Regulated = exceeds Risk-based or ARAR criterion; τ = characteristic time)



Subsurface Plume Behavior

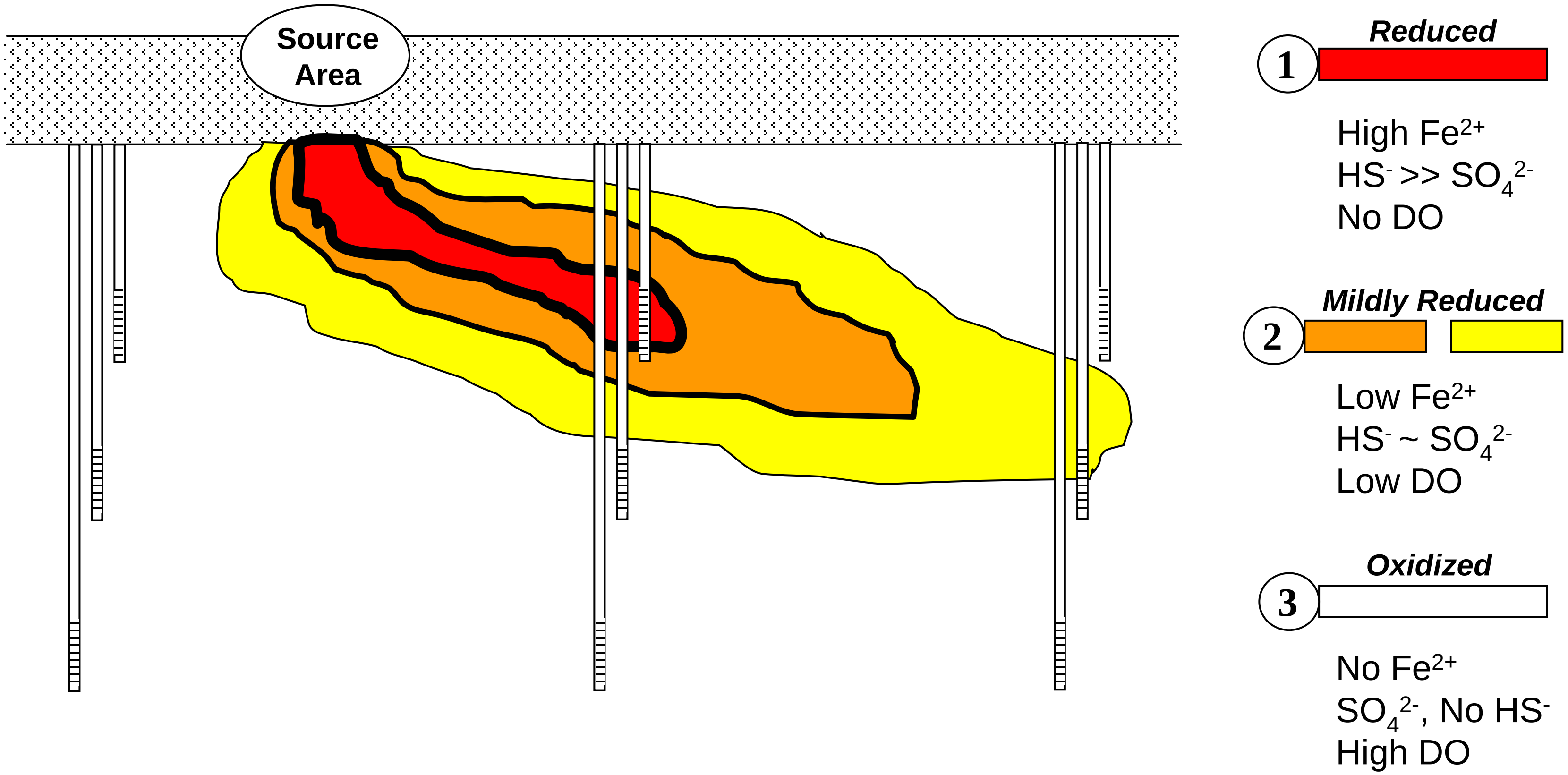
Decaying Radionuclide – Non-conservative Physical Transport, Uncontrolled Source



- Significant mass of non-conservative radionuclide may be accumulated onto aquifer solids
- '*Solid-phase*' plume represents contaminant mass attenuated at any point in time
- Future scenarios for evolution of '*solid-phase*' plume
  1) Declines in mass & spatial distribution due to decay
  2) Remains invariant in mass & spatial distribution
  3) Evolves to new state that serves as source for development of new dissolved plume
     - Radioactive decay produces more mobile daughter product(s)
     - Changes in ground-water chemistry cause re-mobilization

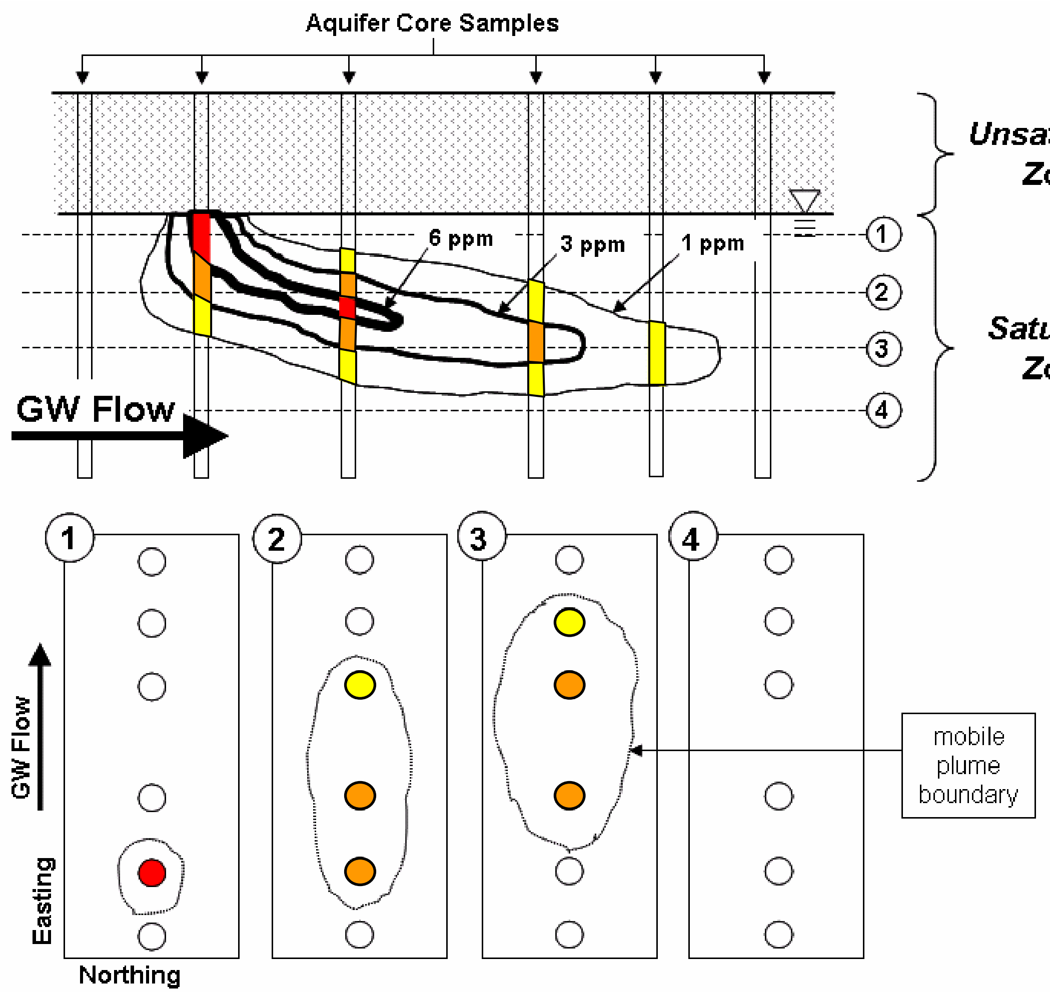
Schematic of Possible Scenario for GW Monitoring Program

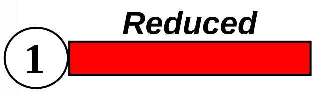
Mixed Organic-Inorganic Contaminant Plume



GW Monitoring Scenario

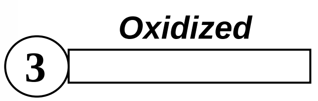
Sediment Redox Chemistry





Reduced Fe Minerals
Sulfides
Anaerobic Microorganisms

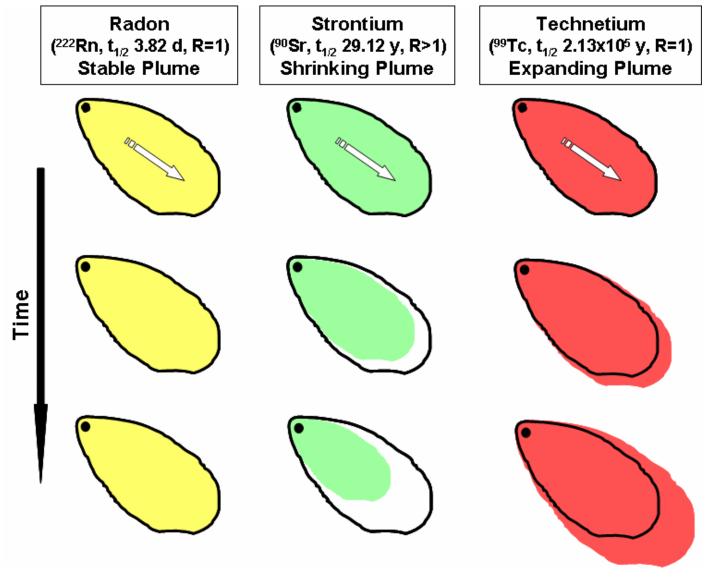
Mixed Fe(II)-Fe(III) Minerals
Carbonates-Sulfides?
Mixed Populations



Fe Oxides
No sulfides (unless native)
Aerobic Microorganisms

Importance of Proper Sample Collection to GW Compliance Monitoring

1) Proper identification of ‘plume’ extent for individual contaminants
   - ‘plume’ may contain *dissolved* and *solid* components
2) Prevent misidentification of plume geochemistry
   - Loss of viable organisms that can be cultured to determine degradation rates
   - Transformations in sediment mineralogy resulting in misleading identification of mineral(s) controlling contaminant sorption
3) Insure accuracy of estimates of sediment reactivity to engineered *in-situ* remediation technologies

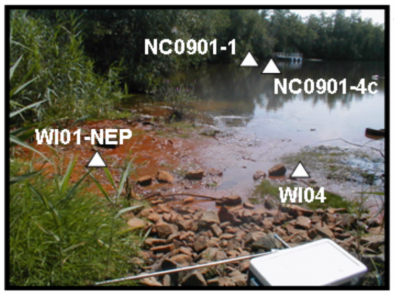


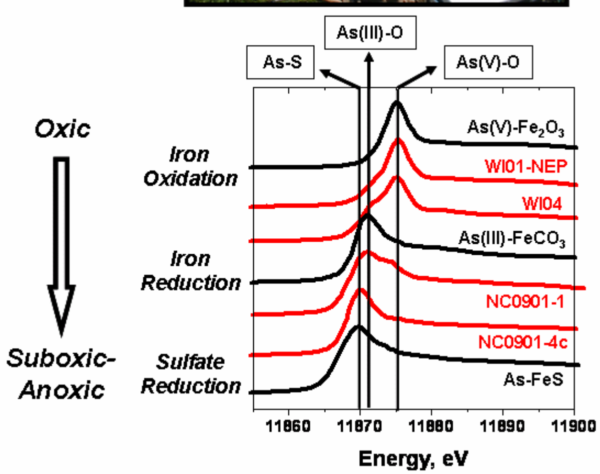
Principles in Practice

Industri-Plex Superfund Site

- ***'Enhanced' MNA*** chosen as part of site remedy for restoration of GW contaminated with arsenic

EPA Region 1 – OU2





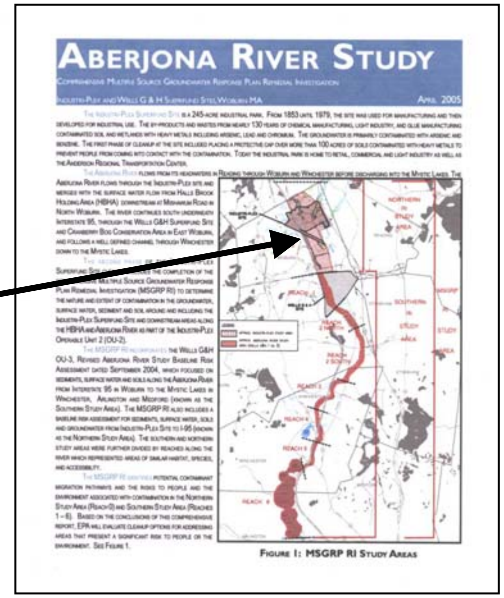

ABERJONA RIVER STUDY

Figure 1: MSGRP RI Study Areas

http://www.epa.gov/region01/superfund/sites/industriplex/237453.pdf

Supporting Documentation

- EPA/ORD Final Report to Region 1
  http://www.epa.gov/ne/superfund/sites/industriplex/230912.pdf
- EPA/ORD Research Brief
  http://www.epa.gov/ada/download/briefs/epa_600_s05_002.pdf
- EPA/ORD Research Report
  http://www.epa.gov/ada/download/reports/600R05161/600R05161.pdf

Thanks - Questions?

EPA/ORD Documentation Relevant to GW Sampling and Preservation

- Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures, EPA/540/S-95/504 - This document is intended to provide background information on the development of low-flow sampling procedures and its application under a variety of hydrogeologic settings. It is intended to support the production of standard operating procedures for use by EPA Regional personnel and other environmental professionals engaged in ground-water sampling. (http://www.epa.gov/ada/download/issue/lwflw2a.pdf)

- Workshop on Monitoring Oxidation-Reduction Processes for Ground-water Restoration, EPA/600/R-02/002 – This document provides a current survey of the scientific basis for understanding redox behavior in subsurface systems within the framework of site characterization, selection of remedial technologies, performance monitoring of remediation efforts, and site closure. (http://www.epa.gov/ada/download/reports/epa_600_r02_002.pdf)

- Performance Monitoring of MNA Remedies for VOCs in Ground Water, EPA/600/R-04/027 - This document provides technical recommendations regarding the types of monitoring parameters and analyses useful for evaluating the effectiveness of the natural attenuation component of ground-water remedial actions. (http://www.epa.gov/ada/download/reports/600R04027/600R04027.pdf)

Hydrology of Landfill Final Covers: Modeling and Monitoring

Craig H. Benson, PhD, PE
Geo Engineering Program
University of Wisconsin-Madison
Madison, WI 53706 USA
benson@engr.wisc.edu

www.uwgeoengineering.org

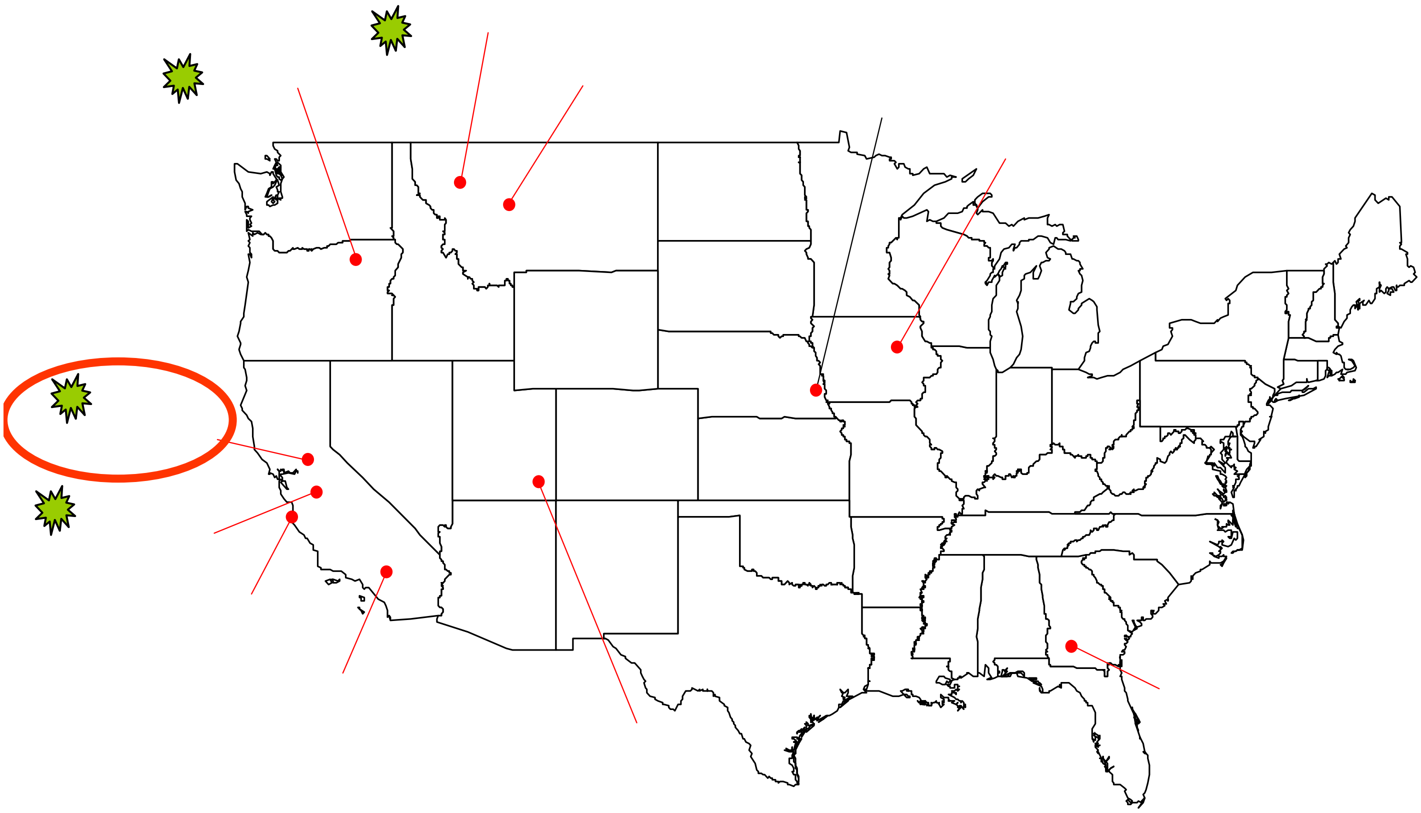
Research Questions:

- Do common numerical models used for design/evaluation of cover hydrology provide *accurate* predictions?
- How can we improve model predictions using field monitoring data?

Model Assessment

- Must be compared with field data.
- Must use measured properties as input to the greatest extent possible.
- Must match boundary conditions.

ACAP Field Sites in Modeling Study



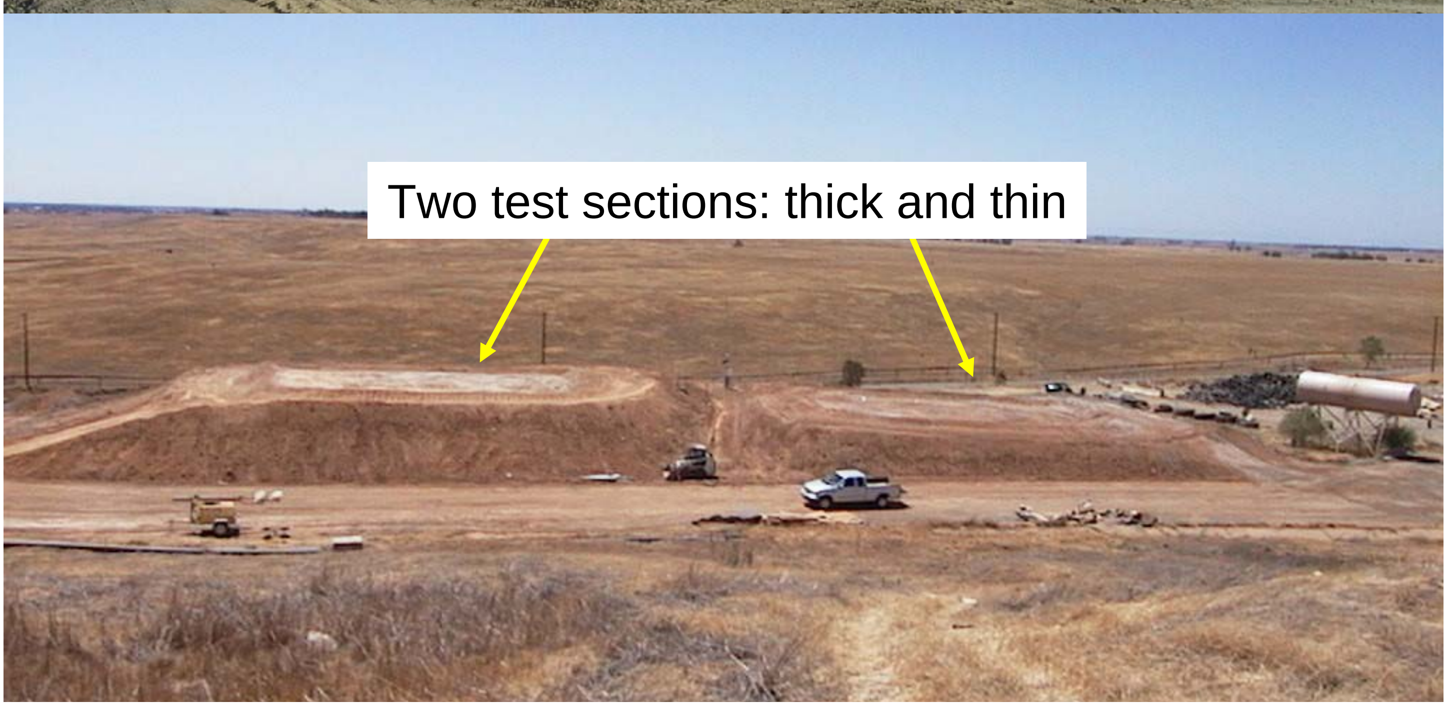
- site used in modeling study

Presentation focuses on model predictions and monitoring data from Sacramento site.

Po

Boardman, OR

Large Instrumented Lysimeters Constructed 1999-2000



Instrumented to measure all water balance components except ET over 10 x 20 m area.

ET obtained by difference.

Hydraulic Properties and Vegetation

- Collected undisturbed soil samples during construction for hydraulic properties. Surface layer sampled annually thereafter.
- Root density and LAI of vegetation periodically; wilting point inferred from monitoring data.

Models Evaluated

- HYDRUS-2D (USDA, J. Simunek) – 2D
- LEACHM (Cornell/Flinders U., J. Hutson) – 1D
- UNSAT-H (PNNL, M. Fayer) -1D
- Vadose/W (GeoSlope, G. Newman) – 2D

All four models commonly *used in practice* for simulating cover hydrology.

Underlying Physics

- Richards' Equation for Unsaturated Flow & Root Water Uptake

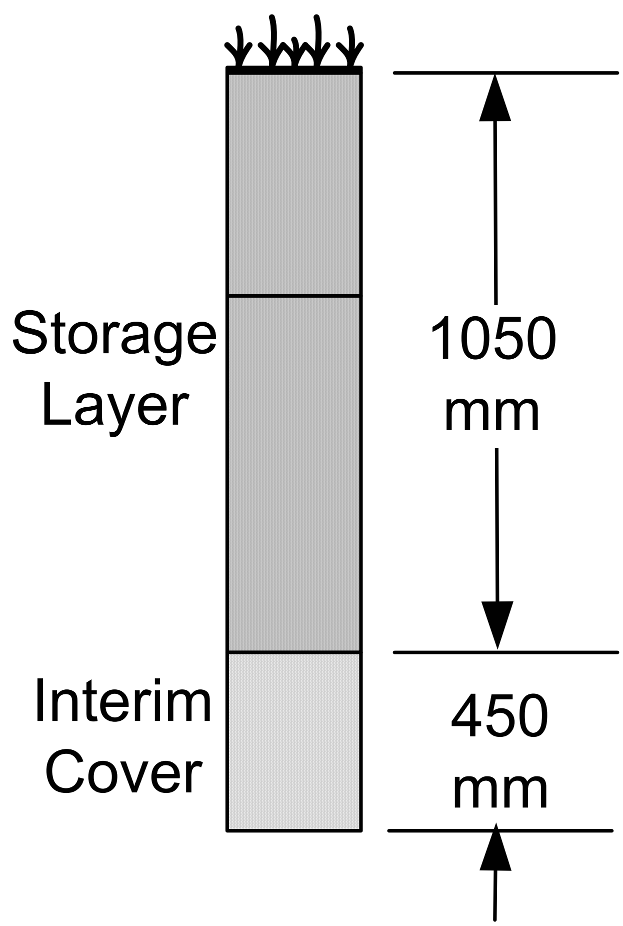
$$\frac{\partial \theta}{\partial \psi}\frac{\partial \psi}{\partial t} = -\frac{\partial}{\partial z}\left[K_T \frac{\partial \psi}{\partial z} + K_\psi + q_{vT}\right] - S(z,t)$$

Can be solved in 1-D or 2-D with existing codes, but most often in 1-D

- Boundary Conditions
  - atmospheric flux at surface (meteorology driven)
  - unit gradient or 'seepage face' at bottom, latter recommended by some for lysimeters

Sacramento Field Site

- Kiefer MSW Landfill, SE Sacramento, CA
- Semi-arid site
  - avg. precipitation (P) = 434 mm/yr
  - P/PET = 0.33
  - avg. daily temp. 3 ^{o}C (Jan) to 34 ^{o}C (Aug)
- Monolithic Cover
  - 1050 mm thick storage layer
  - 450 mm interim cover
  - broadly graded alluvium
  - Upper 150 mm highly weathered surface layer



Input Data

- Field-measured on-site meteorological data

- Field measured vegetation properties (leaf area index, or LAI, and root density distribution)

- Hydraulic properties: geometric mean K_s and α; arithmetic mean n, θ_s, θ_r

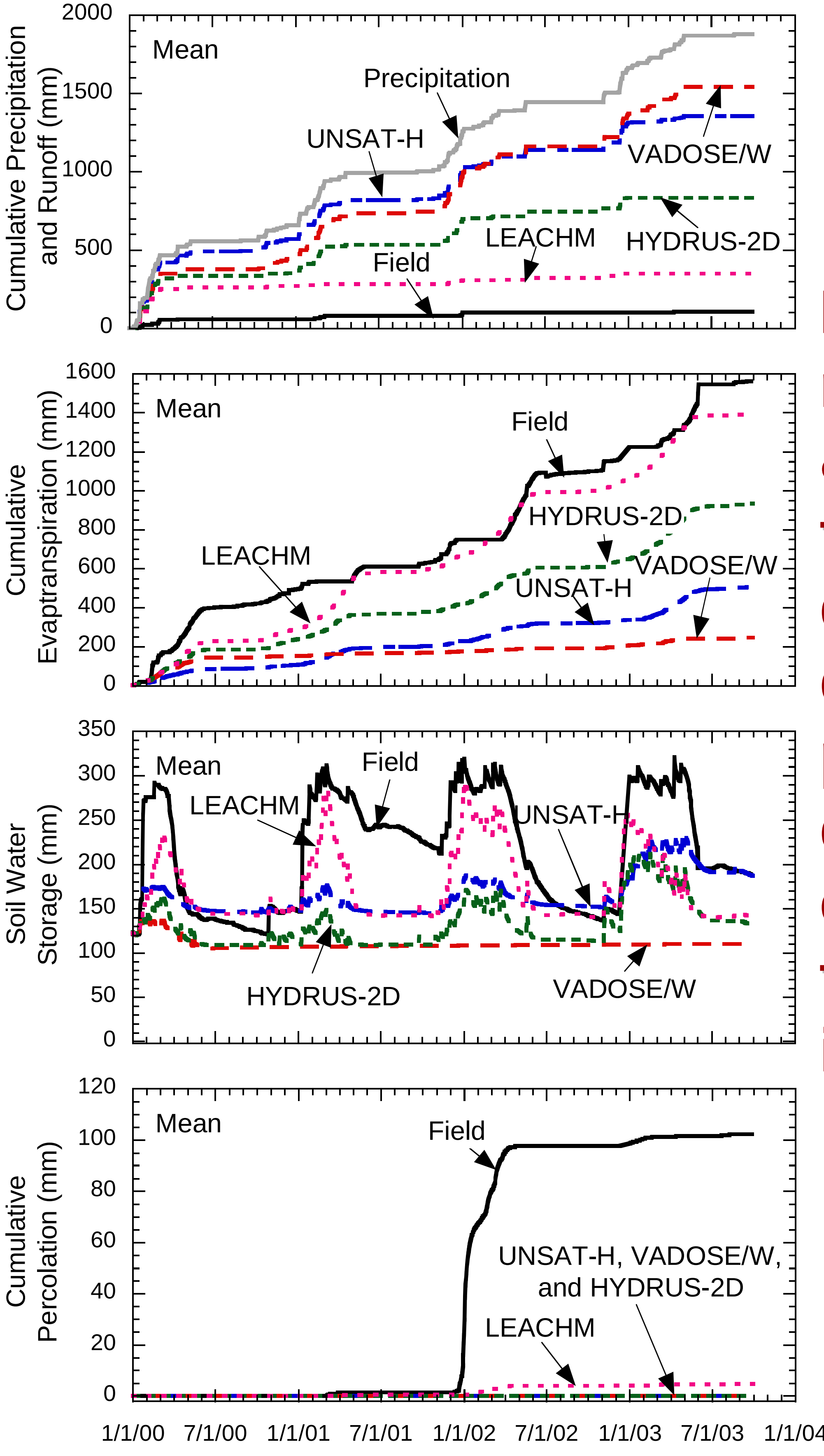
Layer	van Genuchten Parameters				Saturated Hydraulic Conductivity, K_s (cm/s)			
	θ_r	θ_s	α cm^{-1}	n	00	01	02	03
Surface (150 mm)	0.01	0.30	0.006	1.40	$6.4x10^{-7}$	$2.6x10^{-6}$	$1.6x10^{-5}$	$2.6x10^{-5}$
Storage (900 mm)	0.00	0.31	0.001	1.26	$1.3x10^{-6}$			
Interim (450 mm)	0.02	0.33	0.001	1.42	$6.2x10^{-6}$			

Boundary Conditions

- Surface: Atmospheric flux boundary
  - Infiltration
  - Evaporation (transpiration treated as sink)
  - Runoff computed as an excess quantity

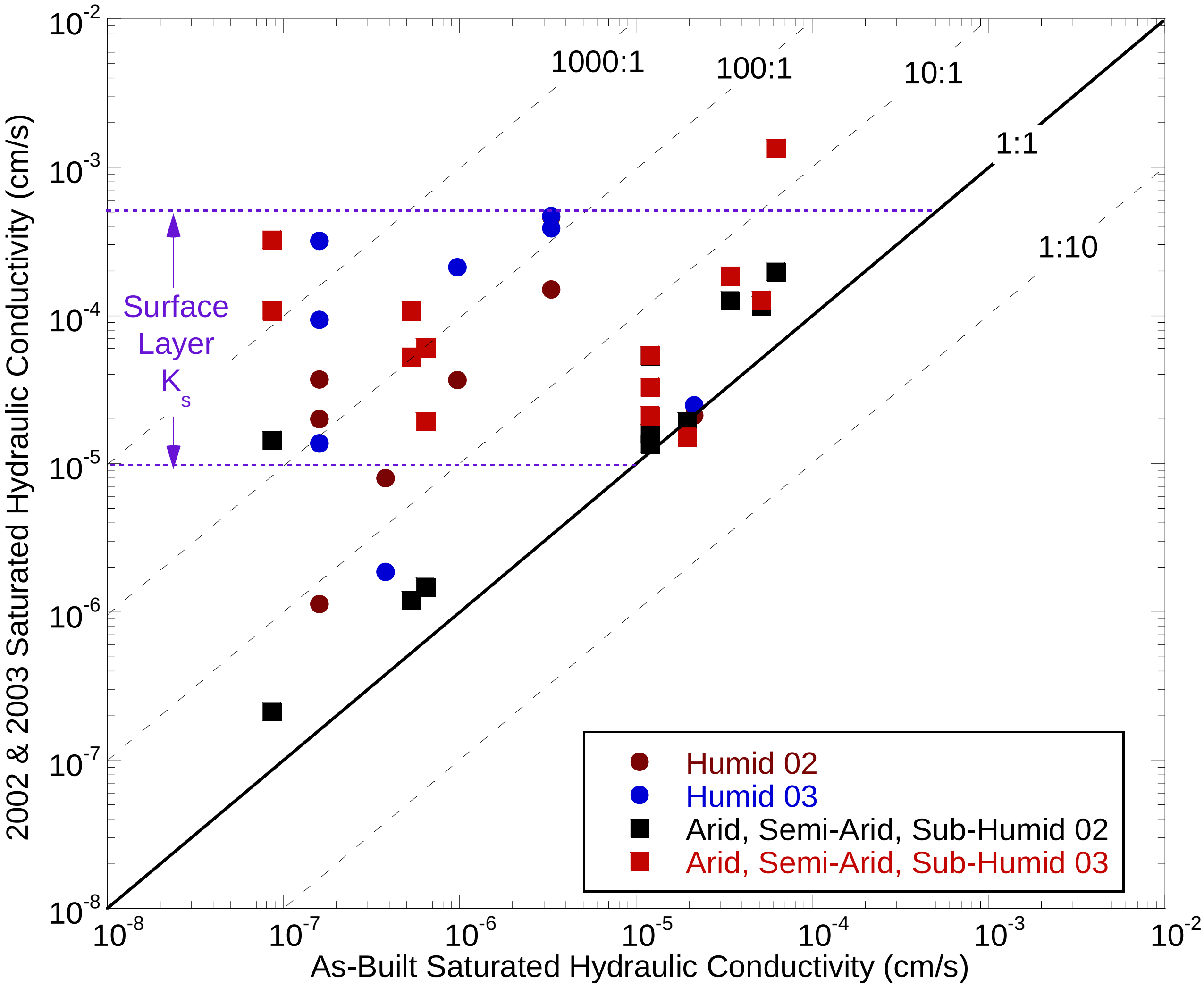
  While conceptually similar, *each model handles this boundary differently*.

- Lower Boundary - flux
  - Unit gradient: flux = K_ψ at boundary
  - Seepage face: flux = 0 unless bottom boundary is saturated, then flux = K_s
  - Appropriate boundary for lysimeter falls between unit gradient and seepage face. Capillary break should be accounted for, but flow into lysimeter drain does occur for conditions below saturation.



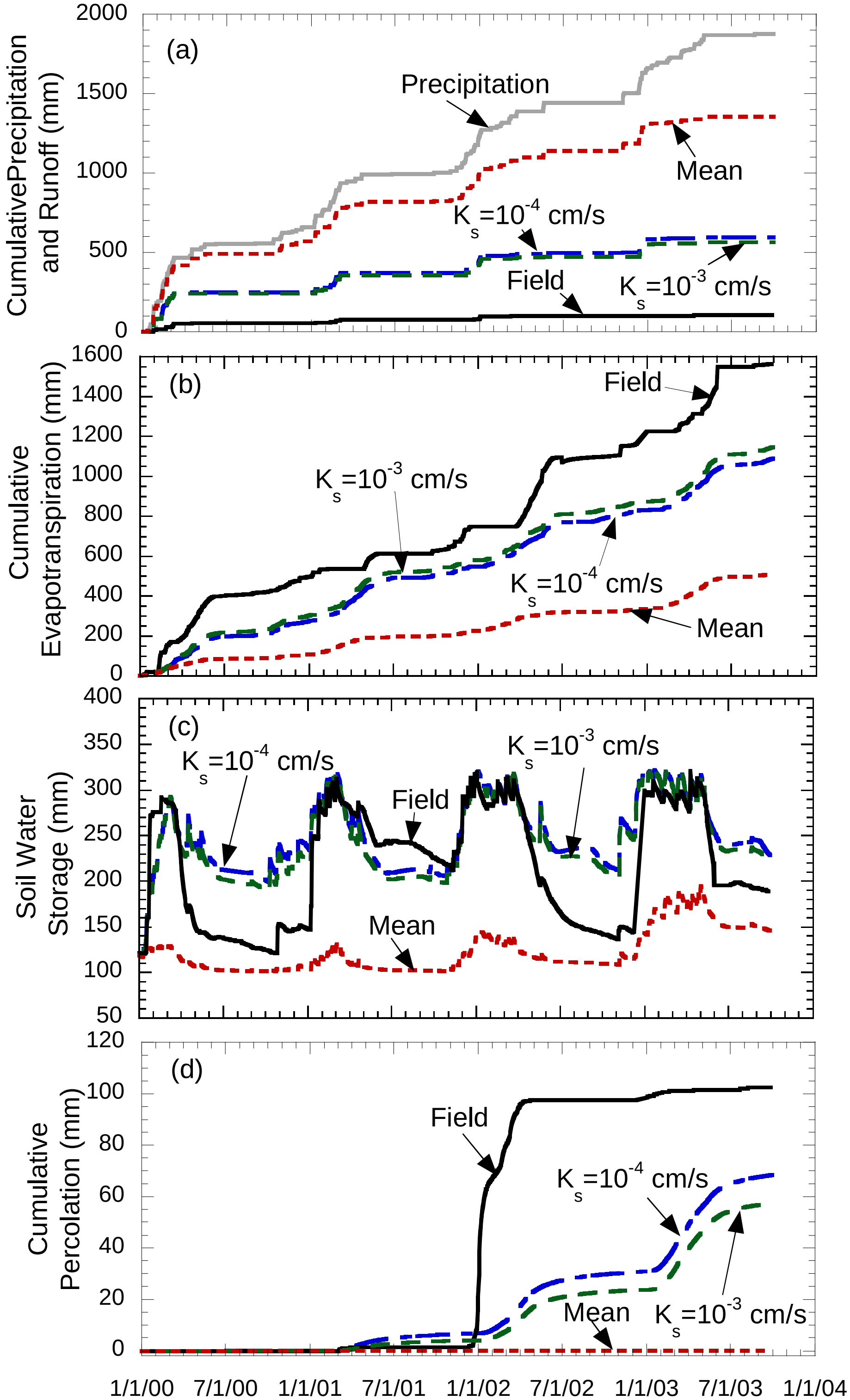
Four models & four distinctly different predictions despite essentially the same input.

Pedogenesis and Surface Layer Conductivity



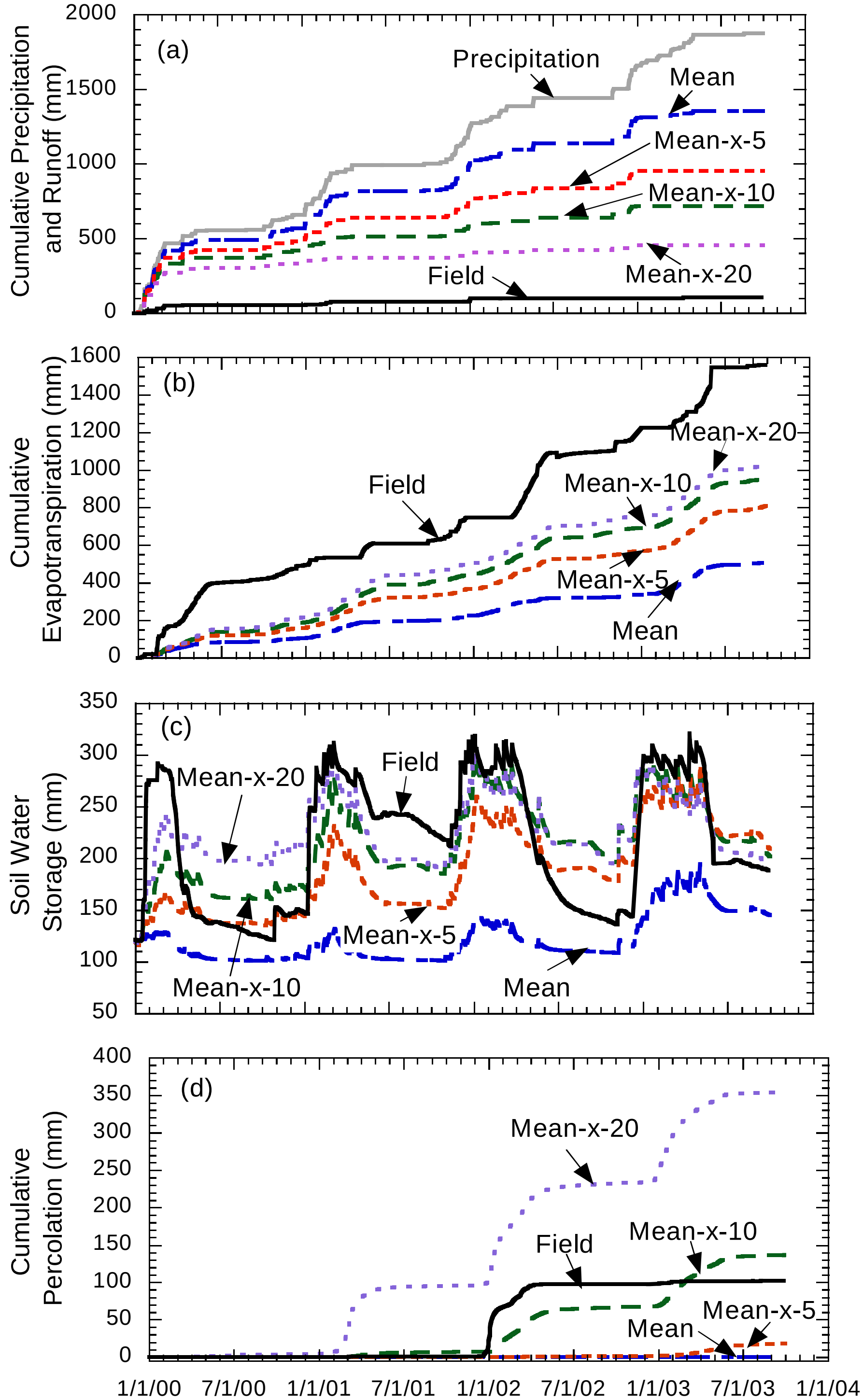
Saturated hydraulic conductivity of surface layer ranges between 10^{-5} and 10^{-3} cm/s, typically 10^{-4} cm/s.

UNSAT-H & Permeable Surface Layer



More water now enters the cover, but too much remains stored and too little drains.

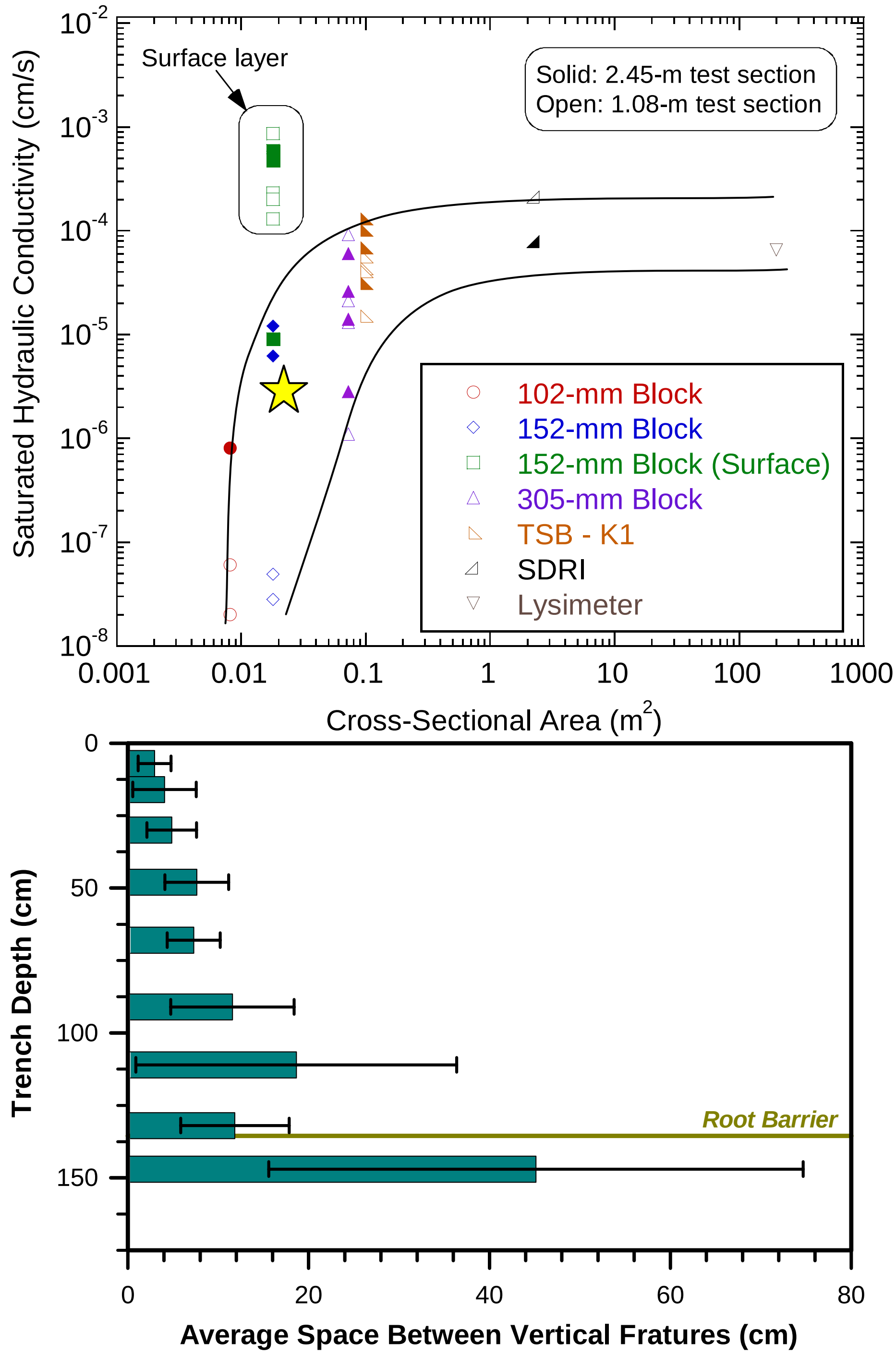
UNSAT-H & Permeable Storage Layer



More water now enters and drains from the cover, but too much still remains stored.

Decommissioning August 2005

Saturated Hydraulic Conductivity - 2005



Pedogenic changes in the water retention curves also observed.

Significant Factors Identified from Analysis of Monitoring Data

- Must account for pedogenic effects on soil properties.

- Pore interaction term in K_ψ; improve storage and drainage of water using ℓ = -1 to -3.

- Match precipitation intensity to more closely simulate runoff and infiltration.

- Account for temporal changes in vegetation species and effect on water removal.

- Lower boundary far less important than suggested by others.

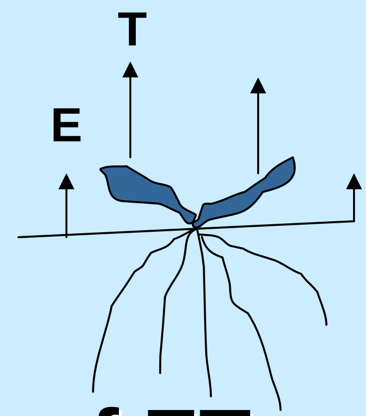
Summary of Observations

- Four models commonly used in practice to simulate landfill cover hydrology provided very different predictions using typical engineering data as input

- Assessing model accuracy not possible without monitoring data.

- Monitoring data and decommissioning studies led to improvements in model parameterization. Relevant to future predictions (or update predictions for a site).

- Models are an abstraction of reality and predictions depend greatly on input. Check ‘reasonableness’ of predictions against monitoring data if possible.



Monitoring and Modeling of ET Covers

Glendon W. Gee

Sept. 20, 2006

Outline

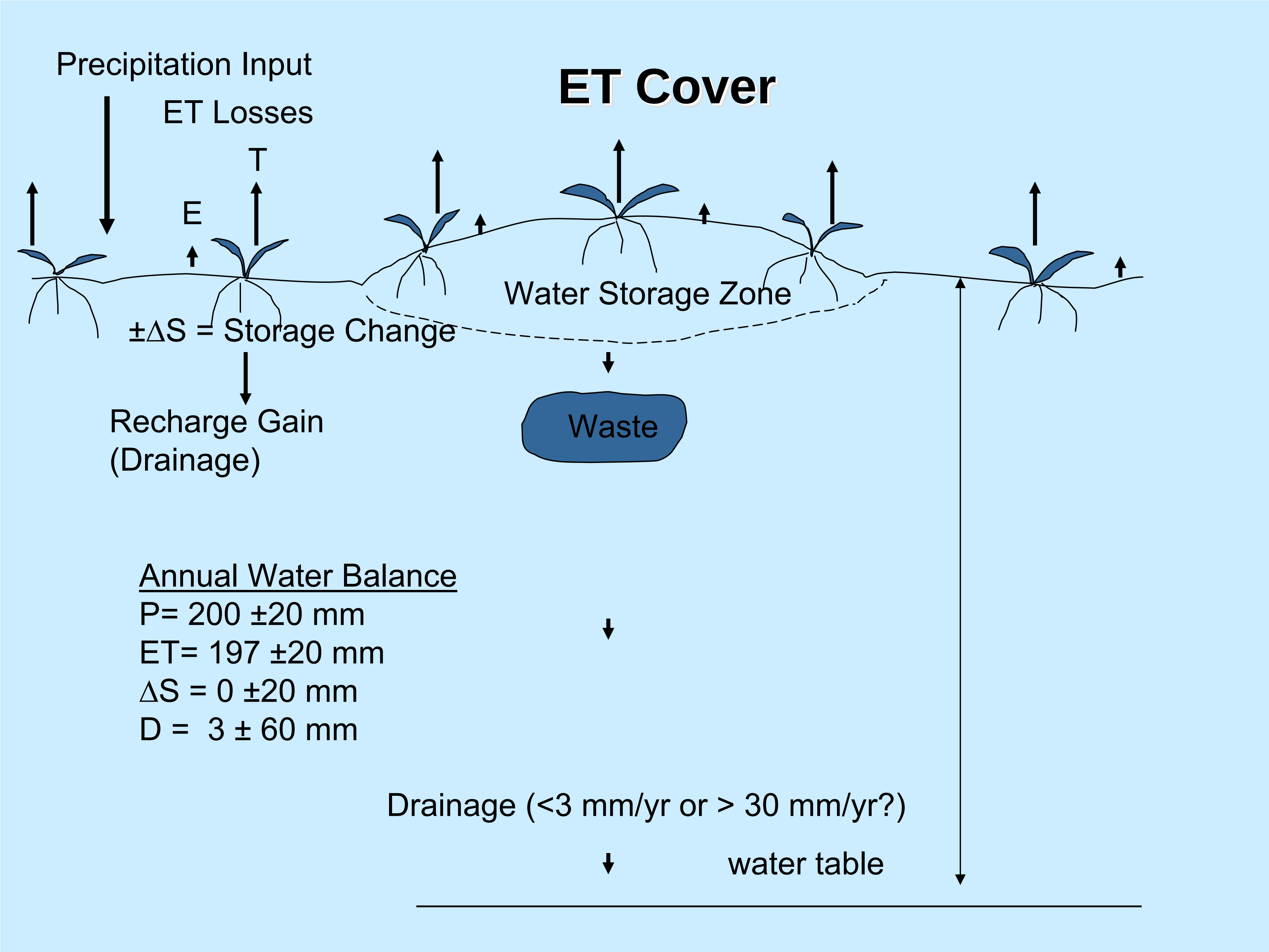
- ET Cover Concepts
- ET Monitoring and Modeling Needs
- Indirect Measurements
- Direct Measurements
- Modeling Issues
- Summary

ET Cover Concepts

- Evapotranspiration (ET) limits water intrusion
- Virtually All Covers are ET covers (i.e.,vegetated)
- Multilayer ET Covers (RCRA, Hanford, etc.)
  - Provides Redundant Protection
  - Long-Term Performance Considered in Design
  - Cost Typically High (more engineering)
- Simple ET Covers (monofill soil with vegetation)
  - Water Infiltration Control
  - Biotic Dynamics and Intrusion Issues
  - Erosion and Long-Term Issues

Approach to ET Water Balance

- Drainage is Estimated from Mass Balance of Water Inputs/Losses from Soil Volume
- Model Inputs (with associated uncertainties) Include:
  - **Precipitation**
  - **Evaporative Demand (Climate and Surface)**
  - **Runoff Potential (Surface Characteristics)**
  - **Water Storage (Soil Hydraulic Properties**)

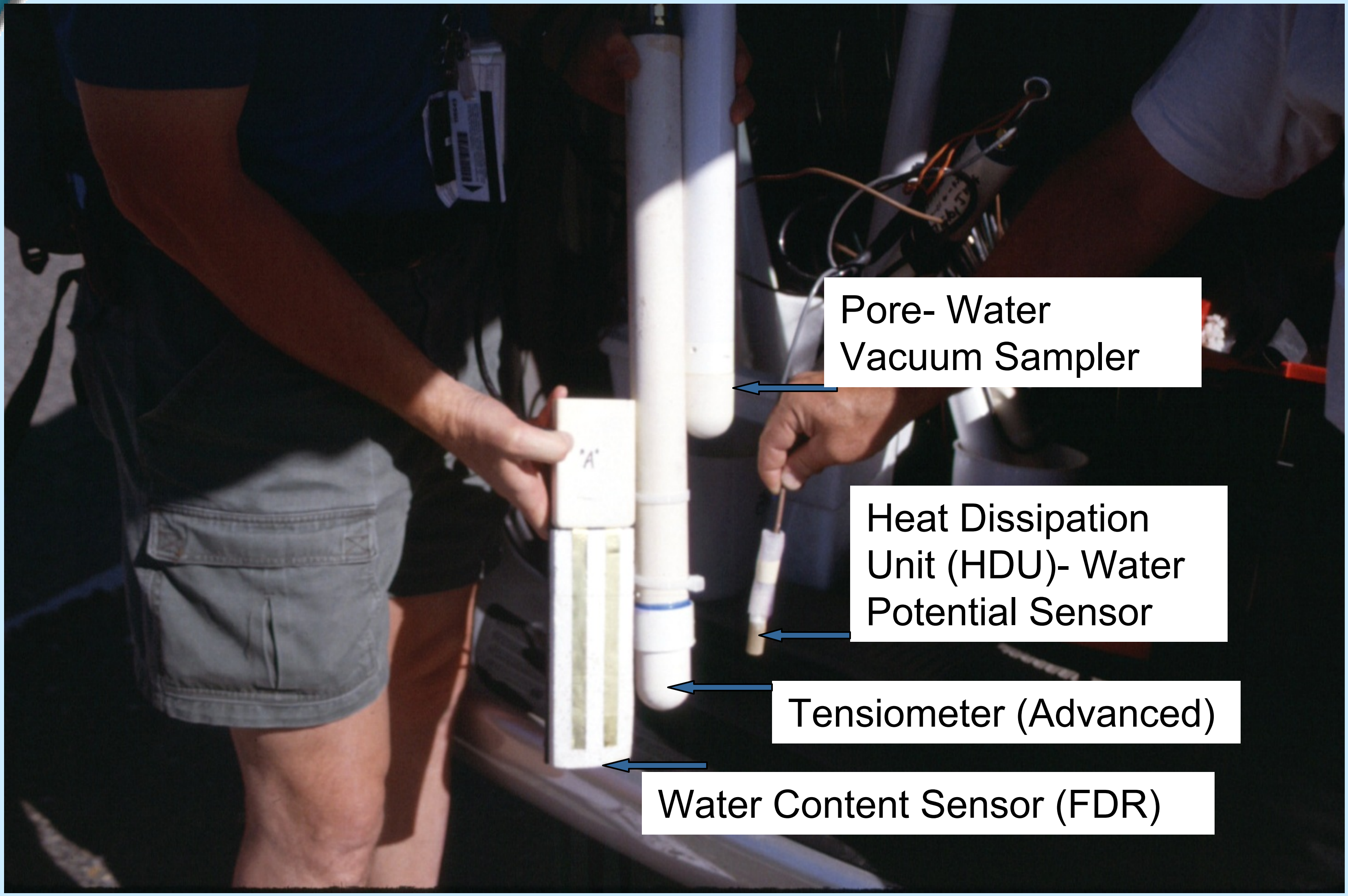


ET Cover
Precipitation Input
ET Losses
T
E
Water Storage Zone
±ΔS = Storage Change
Recharge Gain
(Drainage)
Waste
Annual Water Balance
P= 200 ±20 mm
ET= 197 ±20 mm
ΔS = 0 ±20 mm
D = 3 ± 60 mm
Drainage (<3 mm/yr or > 30 mm/yr?)
water table

Cover Monitoring Requirements

- Surface Inspections
  - erosion
  - subsidence
  - isolation, biotic intrusion, and plant cover
- Ground Water
  - up-gradient wells (2) - water chemistry
  - down-gradient wells (3) – water chemistry
- Vadose Zone – Water Balance
  - water intrusion limits (1 to 3 mm/yr or less)
    - water content
    - water potential
    - water flux (indirect or direct measurements)

Soil Water Monitoring



Drainage Monitoring

- Drainage Flux Estimates (Indirect)
  - Assumes that drainage can be estimated from water content or water potential measurements and an estimate of the unsaturated hydraulic conductivity
    - Drainage Flux = $-K(\theta)\ [\Delta\psi/\Delta z]$
      - $K(\theta)$ = unsaturated hydraulic conductivity
      - $\Delta\psi/\Delta z$ = water potential gradient
      - $\psi = f(\theta)$ through the soil water retention characteristic
    - $K(\theta)$ typically uncertain by more than an order of magnitude
    - Water content can be used to estimate water potential
    - More uncertainties in monitoring water contents or potentials

Monitoring- Direct

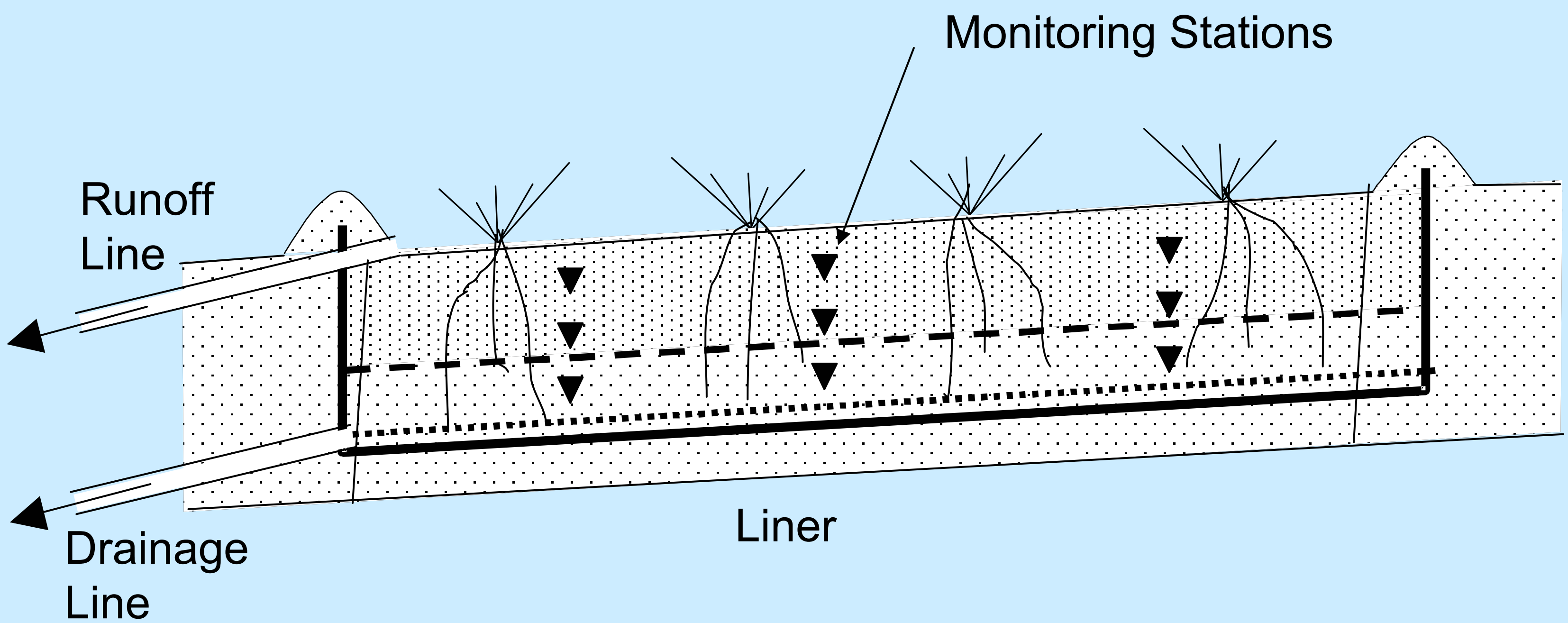
Lysimetry

- Controlled soil volume
- Direct measure of drainage

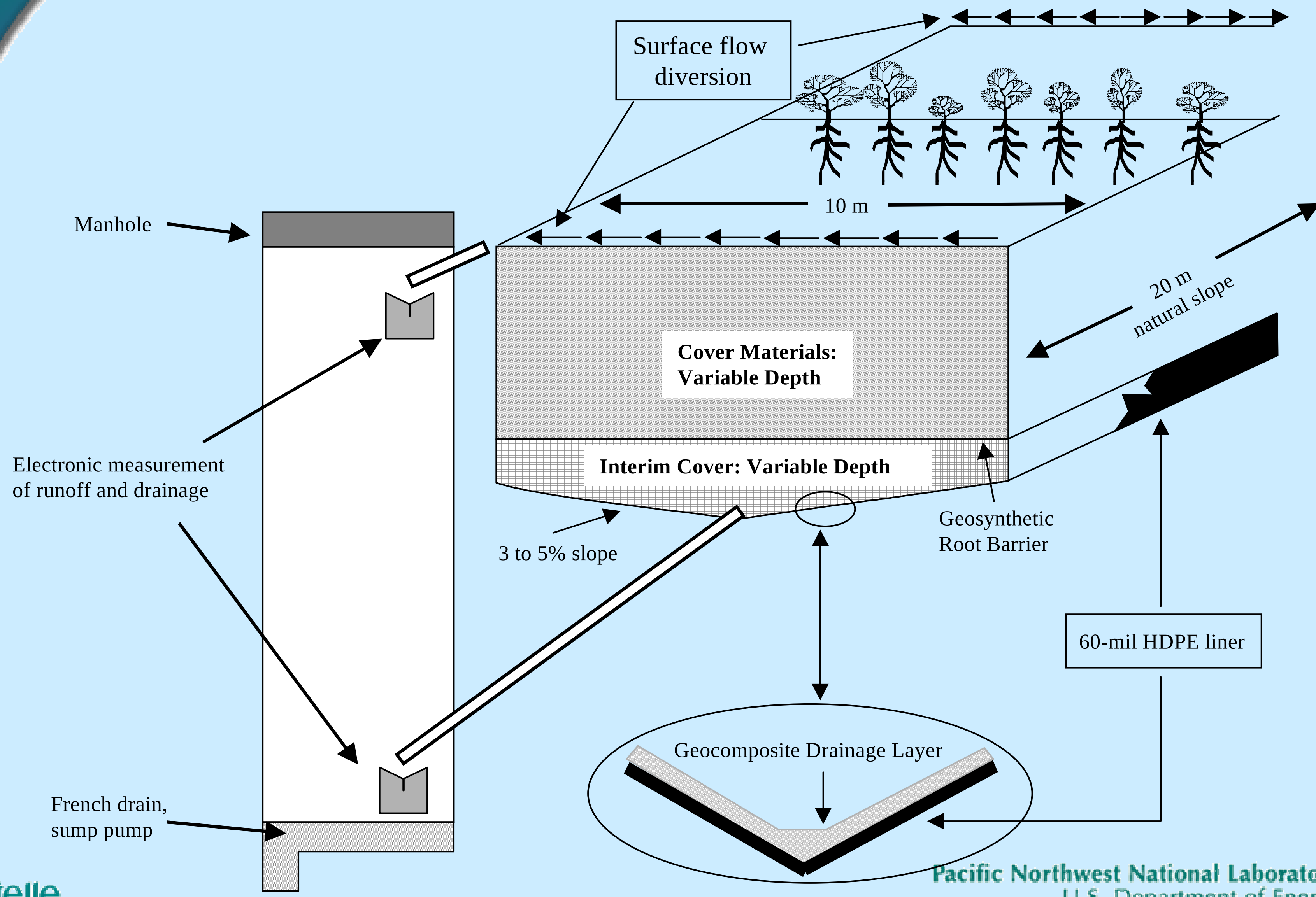
Hanford Barrier (1.5 m of Silt Loam over layers of coarse materials--capillary barrier)

Direct Monitoring

Lysimeter Test Pad –ACAP Sites



ACAP Runoff/Drainage Collection



Automatic-Drainage Collection
(Resolution of <0.01 mm)

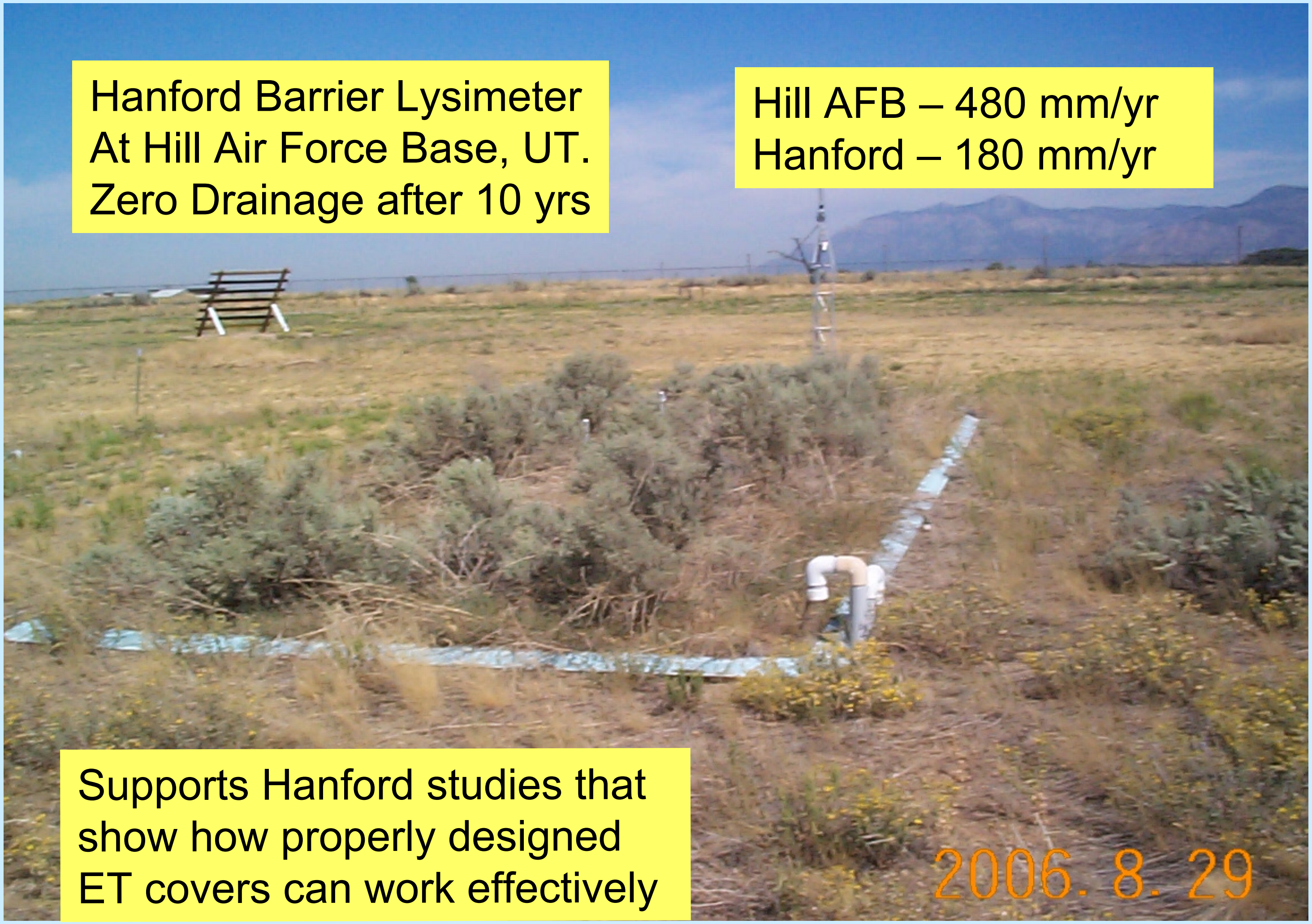
Modeling Requirements for Landfill Covers

- Modeling Requirements (Minimum)
  - Precipitation (and weather station records)
  - Soil Hydraulic Properties
  - Plant Leaf and Root Dynamics
- Simplest models use default parameters based on general characteristics- soil, plant, weather records
- Complex models require detailed on-site data.
  - Precipitation, wind speed, solar radiation, temperature, humidity, soil hydraulic properties, leaf area, rooting density and depth and plant phenology, etc.

ET Model Complexity

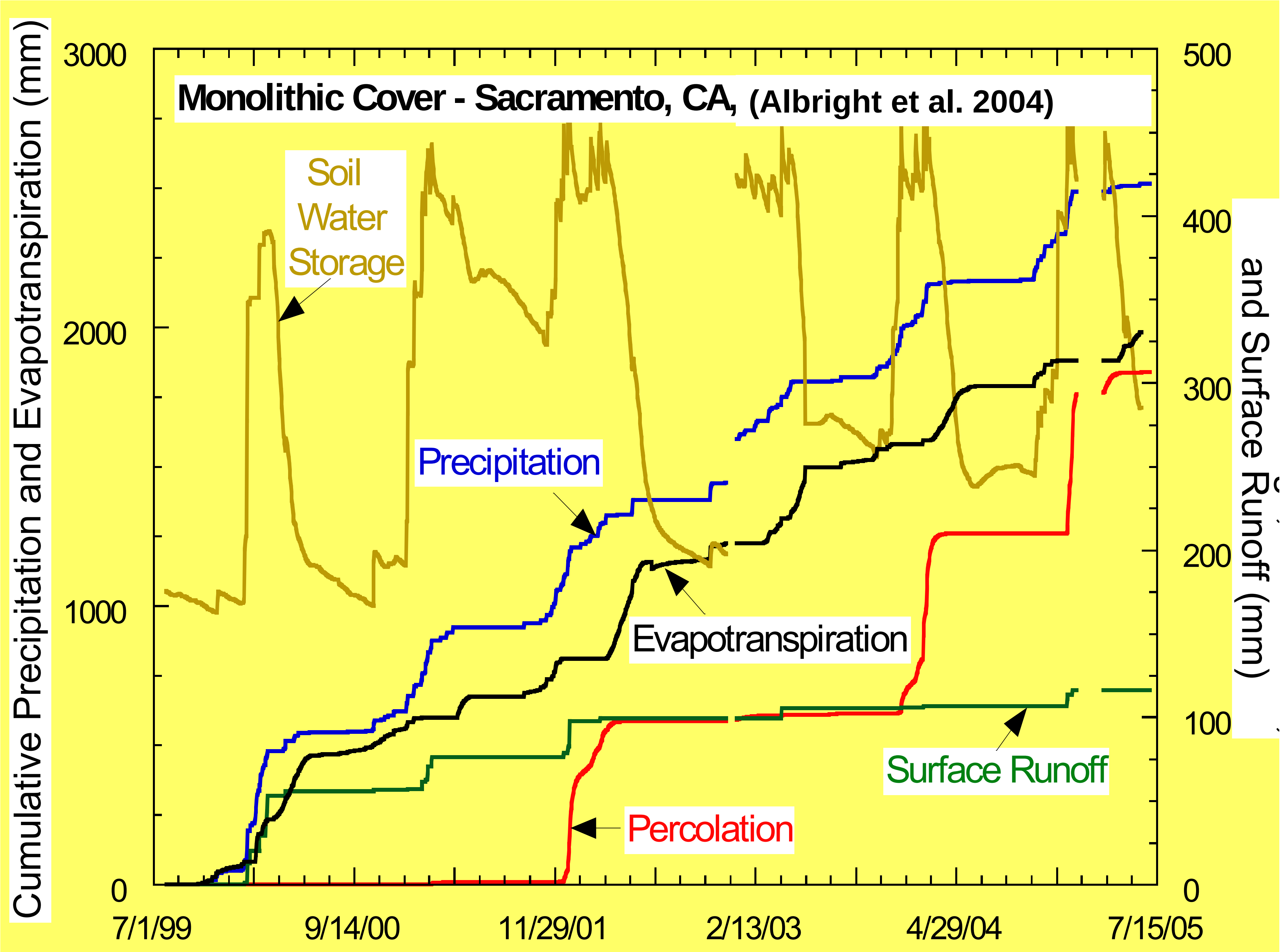
- Simple
  - HELP (EPA Cover Design Code)
  - STEWB-Modified KIM (NRC, Infiltration Code)
- Intermediate
  - EPIC (ARS- Crop Productivity Code)
- Complex
  - UNSAT-H (PNNL, 1D Richards Based)
  - HYDRUS-1, 2D
  - STOMP-2, 3D
- [Note: <u>All</u> ET models are limited by uncertainties in plant parameters and dynamics]

Hill Air Force Base Lysimeter (Example of ET Cover after 10 years)



Hill Air Force Base Monitoring and Modeling Results

- Water Balance Models (HELP, EPIC and UNSAT-H) adequately described results from the Hill AFB tests.
- Snowmelt caused LANL-type capillary barriers to drain at rates exceeding 50 mm/yr (water storage capacity of soil layer inadequate).
- Snowmelt captured in Hanford Barrier due to increased storage capacity of silt loam soil. Models show Hanford ET barrier effective under elevated precipitation conditions. Plant dynamics predictable at Hill Air Force Base (10 year test).


Monolithic Cover - Sacramento, CA, (Albright et al. 2004)
Cumulative Precipitation and Evapotranspiration (mm)
and Surface Runoff (mm)
3000
2000
1000
0
500
400
300
200
100
0
Soil Water Storage
Precipitation
Evapotranspiration
Surface Runoff
Percolation
7/1/99
9/14/00
11/29/01
2/13/03
4/29/04
7/15/05

Measured and Modeled Drainage at a Landfill in Sacramento, CA

Year	Precip. (mm)	Measured Drainage (mm)	Modeled Drainage (mm)
2000	650	0	0
2001	410	0	0
2002	430	100	0
2003	490	0	0
2004	400	110	0
2005	420	95	0

Summary

- Monitoring of an ET Cover for long-term performance will be a challenge
- Erosion Control – observable, repairable
- Biointrusion Control- likely repairable
- Water Intrusion – the greatest challenge – drainage control will be site and design specific. Time dependence of the plant (biotic) system will continue to be difficult to quantify. Redundancy in control should not be ignored.

Summary Cont.

- Water intrusion (drainage) monitoring
  - Indirect methods are too imprecise:
    - Water content sensing (TDR, Nprobes, electrical) is not flux
    - Water potential sensing (tensiometers, HDUs) is not flux
    - Water balance modeling (HELP, UNSATH, EPIC) uncertain
  - Direct methods are required:
    - Test-pad lysimeters are generally reliable to test minimal drainage rates of less than a few mm/yr, for extended times (>10 yrs).
- ET (Water Balance) Modeling
  - Plant dynamics are the largest uncertainty and plague all current models, from the simplest to the most complex. Plant parameters unfortunately cannot be readily engineered and have no safety factors built into them.

Performance Monitoring and Sustainability of Engineered Covers for Uranium Mill Tailings

ACNW WG Meeting on Integrating Monitoring and Models To Enhance Confidence in Model Results

September 19-20, 2006

W Jody Waugh
S.M. Stoller Corporation*
Office of Legacy Management
U.S. Department of Energy
Grand Junction, Colorado

***Work performed under DOE contract no. DE–AC01–02GJ79491.**

Acknowledgements

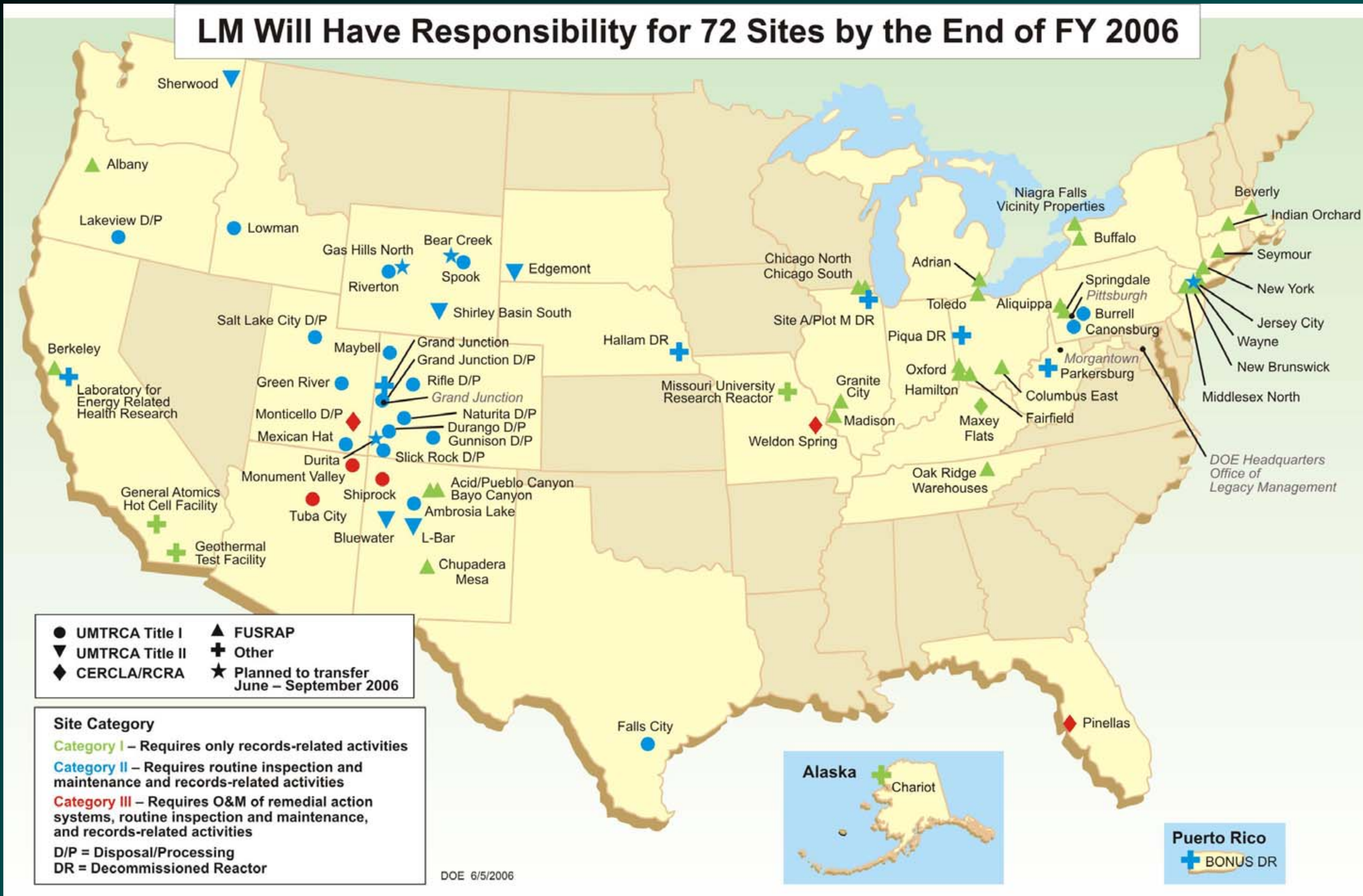
Sponsors:

- U.S. Department of Energy
  - Office of Legacy Management
  - Office of Environmental Management
- U.S. Environmental Protection Agency
  - Region 8, Denver
  - Alternative Cover Assessment Project

Collaborators:

- Glendon Gee, Pacific Northwest National Laboratory
- Craig Benson, University of Wisconsin
- Bill Albright, Desert Research Institute
- Cliff Ho, Sandia National Laboratory
- Daniel B. Stephens & Associates, Inc.
- John Gladden, SRS

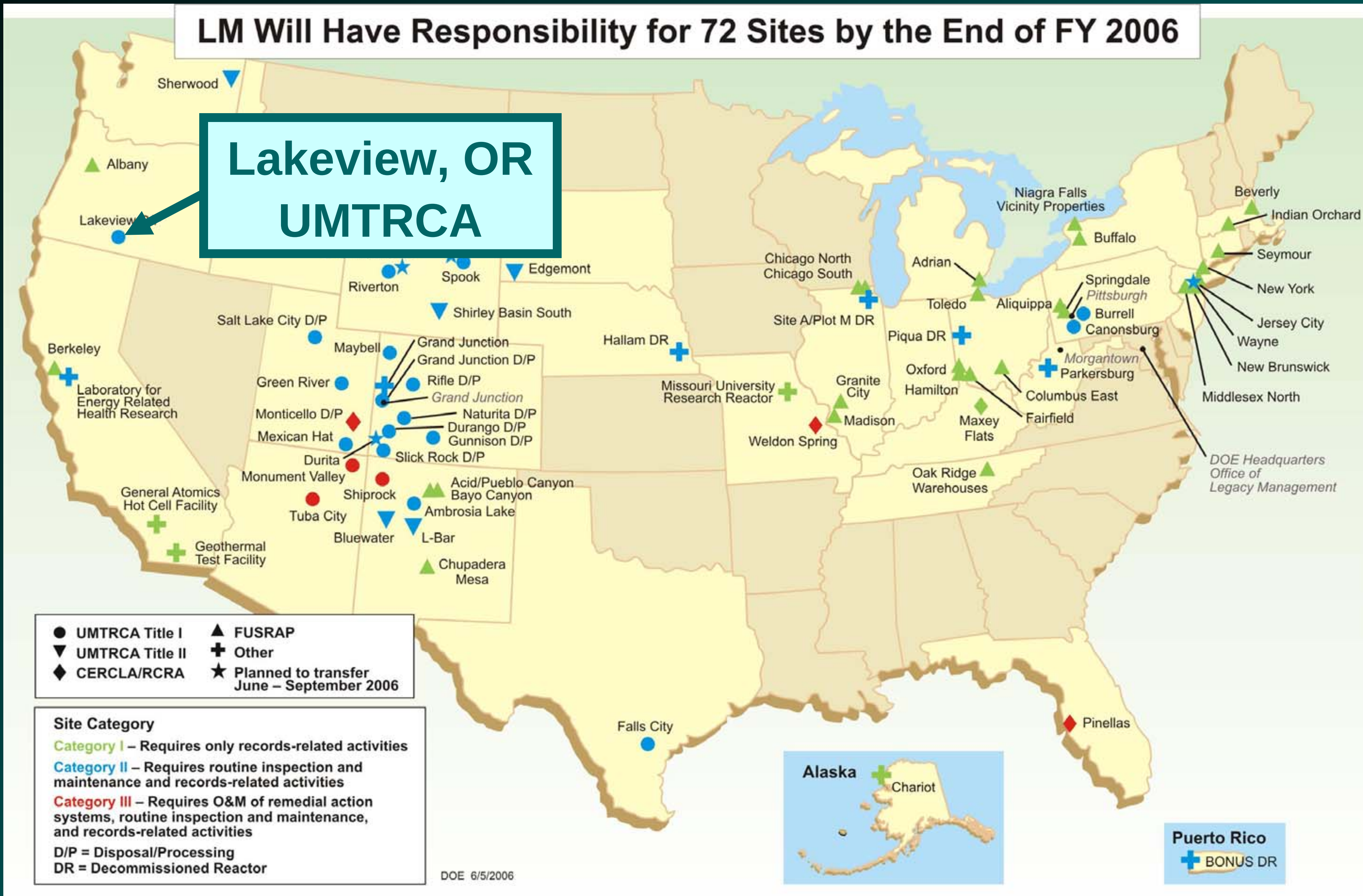
DOE Office of Legacy Management (LM) Sites



Site Transfer to LM: Cover Stewardship Questions

- How was the cover designed and constructed?
- How is it supposed to work?
- What and how do we monitor to show that it is working?
- What types of maintenance are required (and at what cost) to keep it working as designed?
- What are the *risks* if its not working as designed?
- Could we design sustainable repairs or renovations *if needed*?
- Can we expect the cover to continue working for 200 to 1000 years?

Lakeview Case Study

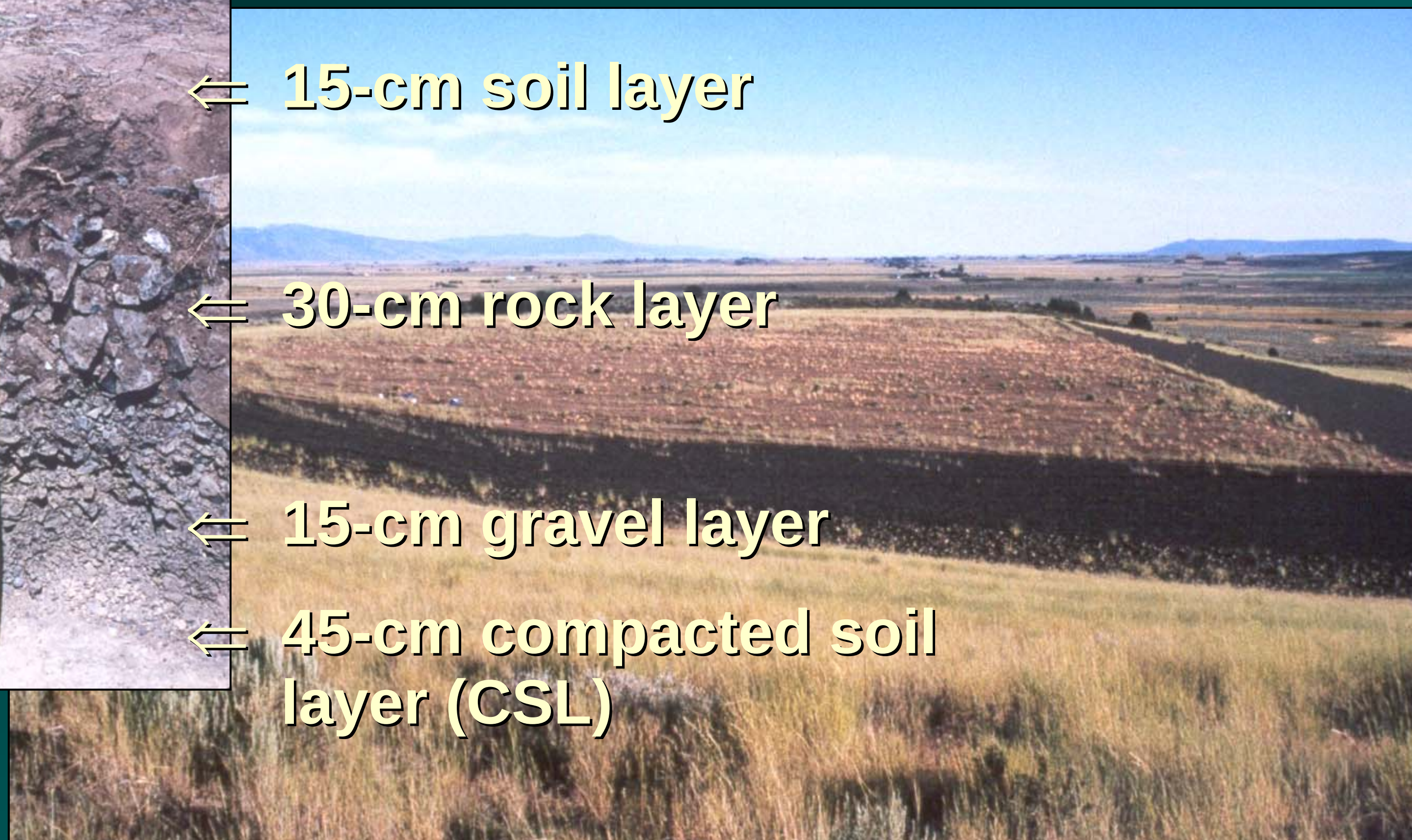


Site Transfer to LM: Cover Stewardship Questions

- **How was the cover designed and constructed?**
- **How is it supposed to work?**
- **What and how do we monitor to show that it is working?**
- **What types of maintenance are required (and at what cost) to keep it working as designed?**
- **What are the *risks* if its not working as designed?**
- **Could we design sustainable repairs or renovations *if needed*?**
- **Can we expect the cover to continue working for 200 to 1000 years?**

How was the cover designed and constructed?

Lakeview, OR (1986)
Precip. ~ 380 mm/yr



⇐ **15-cm soil layer**

⇐ **30-cm rock layer**

⇐ **15-cm gravel layer**

⇐ **45-cm compacted soil layer (CSL)**

Site Transfer to LM:
Cover Stewardship Questions

- How was the cover designed and constructed?
- **How is it supposed to work?**
- What and how do we monitor to show that it is working?
- What types of maintenance are required (and at what cost) to keep it working as designed?
- What are the *risks* if its not working as designed?
- Could we design sustainable repairs or renovations *if needed*?
- Can we expect the cover to continue working for 200 to 1000 years?

How is it supposed to work?
(Design Standards)

Permeability (40 CFR 264.301, 40 CFR 192)

- Satisfy ground water protection standards
- $< 1 \times 10^{-7}$ cm s^{-1} maximum K_{sat} and flux rate (target)

Longevity (40 CFR 192)

- 1000 years to the extent reasonably achievable
- At least 200 years

Site Transfer to LM: Cover Stewardship Questions

- How was the cover designed and constructed?
- How is it supposed to work?
- **What and how do we monitor to show that it is working?**
- What types of maintenance are required (and at what cost) to keep it working as designed?
- What are the *risks* if its not working as designed?
- Could we design sustainable repairs or renovations *if needed*?
- Can we expect the cover to continue working for 200 to 1000 years?

What and how do we monitor to show that it is working?

Routine cover monitoring <u>not required</u> by NRC!

Ground Water Monitoring

- **Monitor POC wells every 5 years**
- **Demonstrate compliance with GW protection standards**
- ***Measure of the performance of the disposal cell***

Annual *Visual* Inspections

- ***Identify changes or new conditions that may impact long-term performance of disposal cells***
- ***Determine need for maintenance, follow-up investigations, or corrective actions***

Follow-up Investigations
(non-routine monitoring)

Objective:

Identify changes or new conditions that may impact long-term performance of disposal cells

Observations / Issues:

- **Encroachment by Deep-Rooted Shrubs**
- **Effects on cover *permeability*, radon flux, bio-uptake**

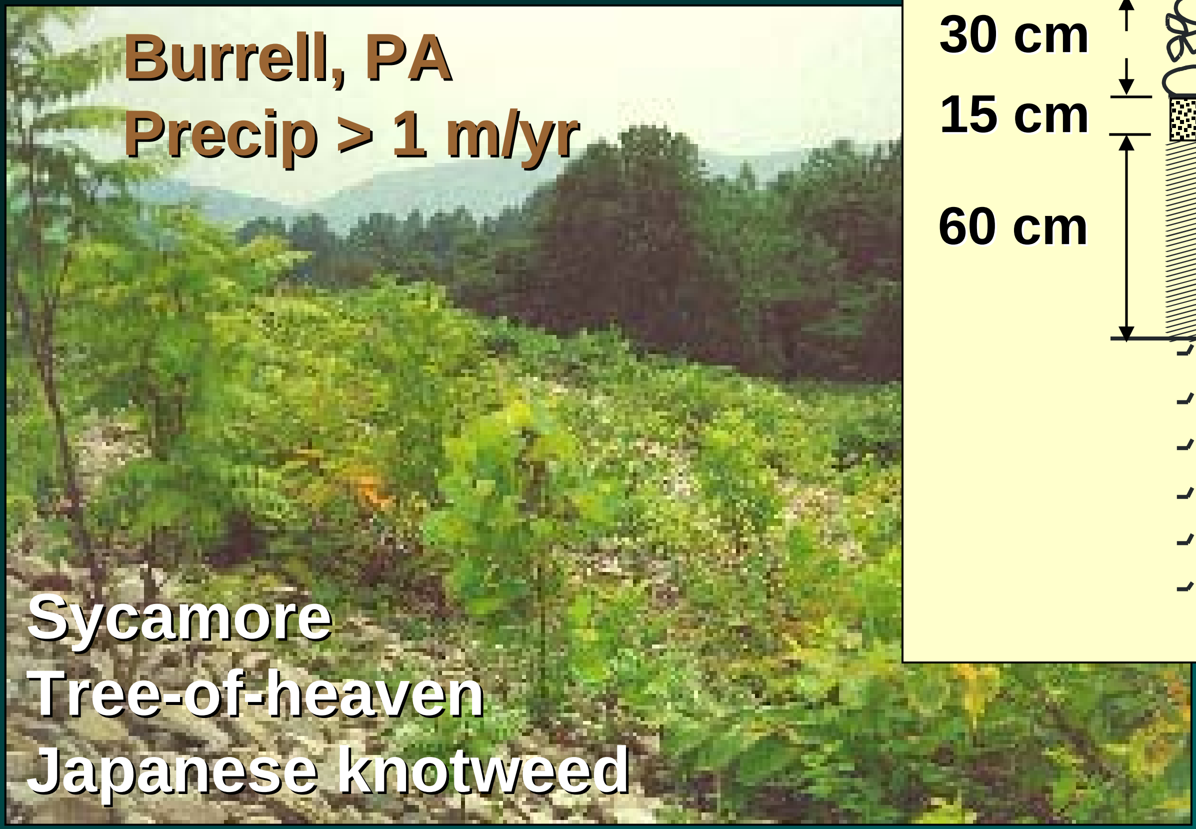
Shrub Encroachment Observations

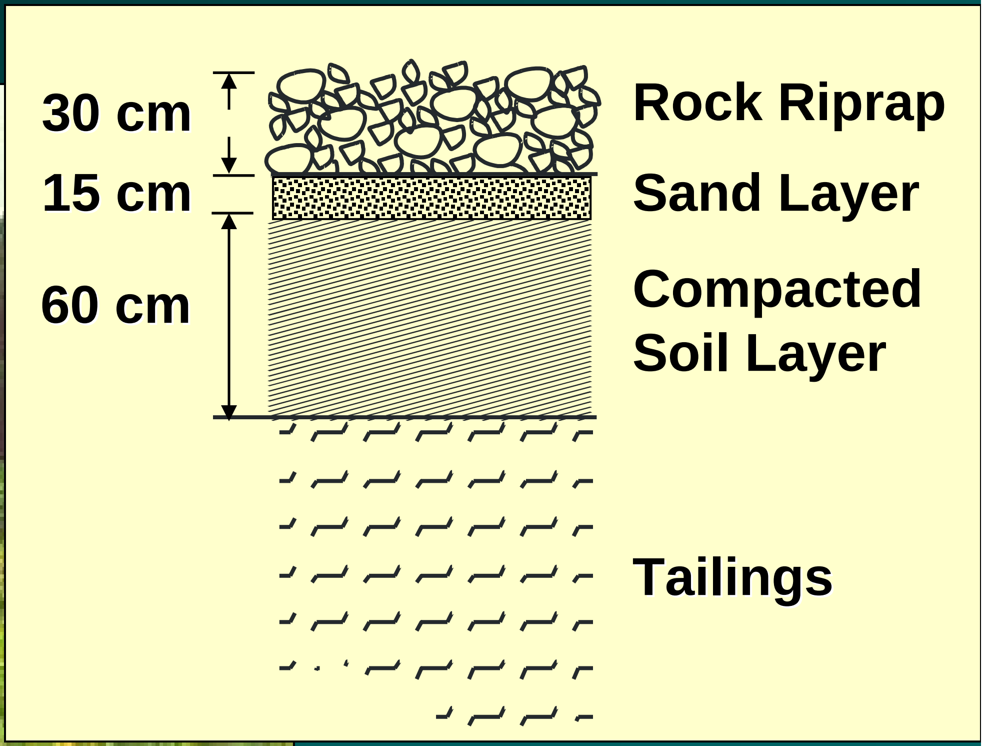
Sparse grass on top slope

Thin soil over rock created habitat for deep-rooted shrubs

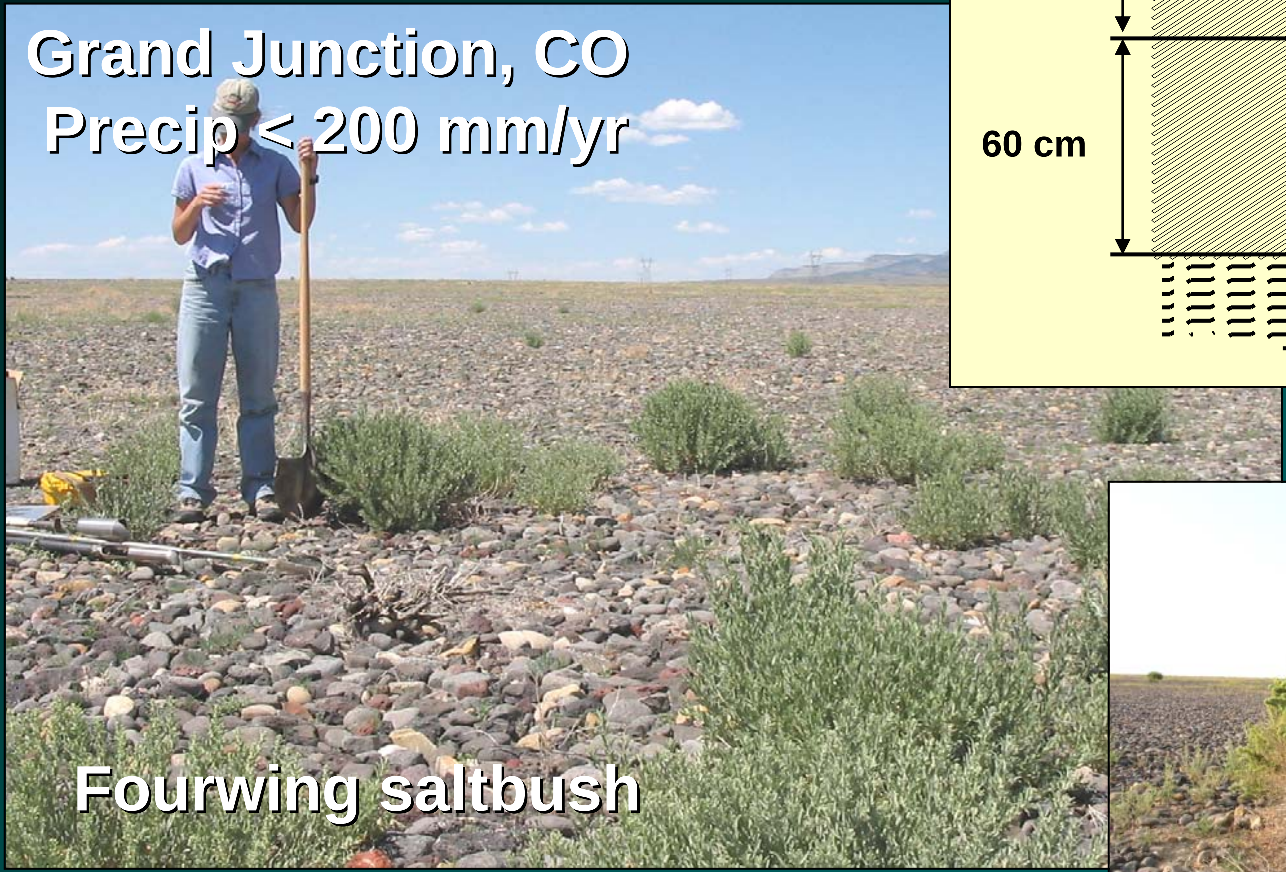
Sagebrush and rabbitbrush encroachment on top slope

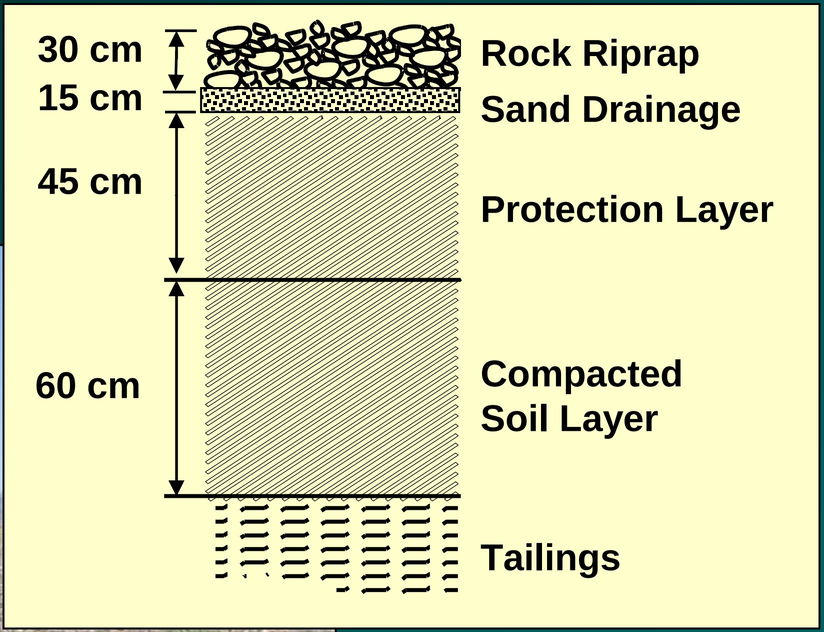
Shrub Encroachment: Burrell, PA





Shrub Encroachment: Grand Junction, CO





Shrub Encroachment: Follow-up Investigations

***Root Intrusion*: Are roots penetrating the compacted soil layer (CSL)?**

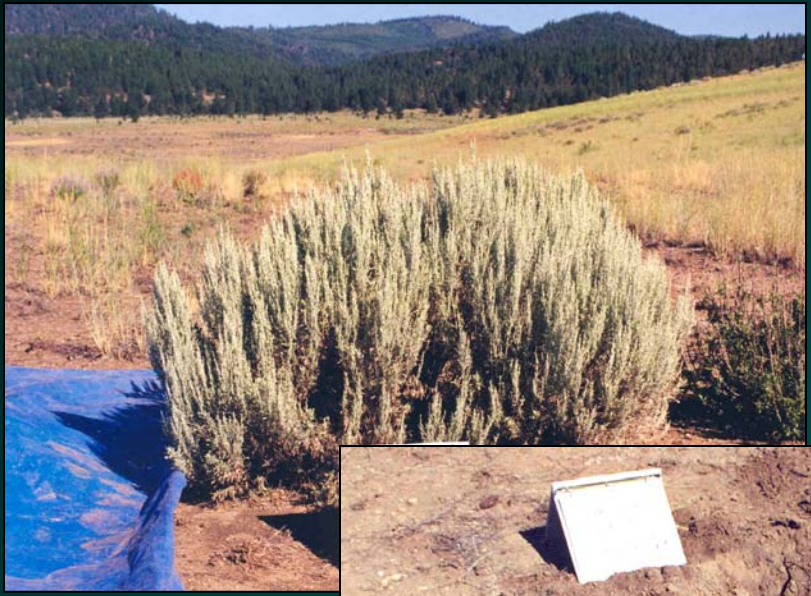
↓

***Permeability*: Has root intrusion increased the saturated hydraulic conductivity (K_{sat})?**

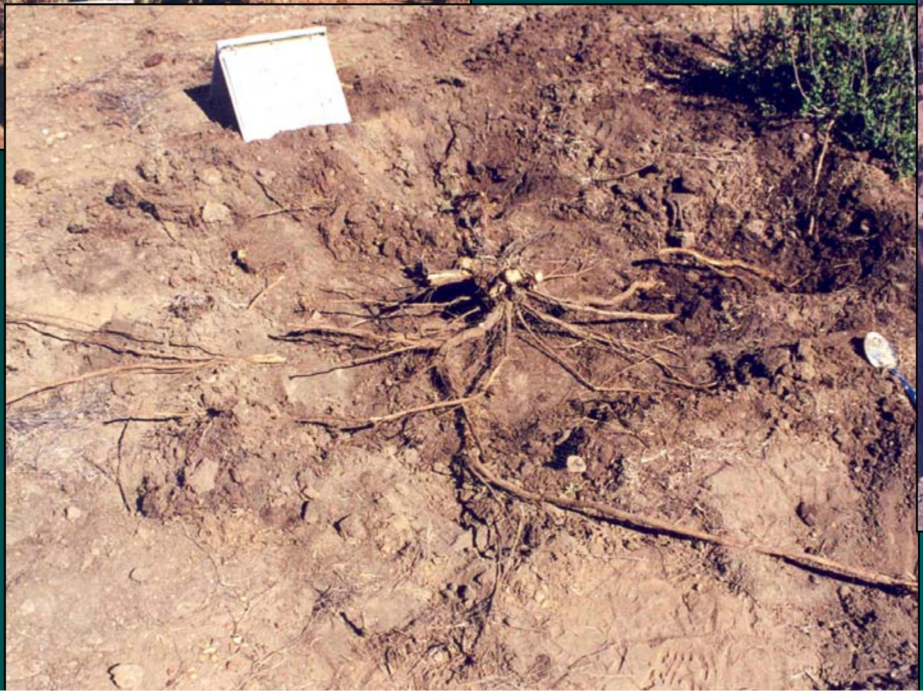
↓

***Percolation*: Has greater permeability caused significant movement of rainwater into tailings?**

Lakeview Sagebrush Root Intrusion



Sagebrush root intrusion of CSL



Shrub Recruitment

Sagebrush, Rabbitbrush, Antelope bitterbrush

Permeability

Objective

Measure root intrusion effects on saturated hydraulic conductivity *(K_{sat})* of the CSL

Tests

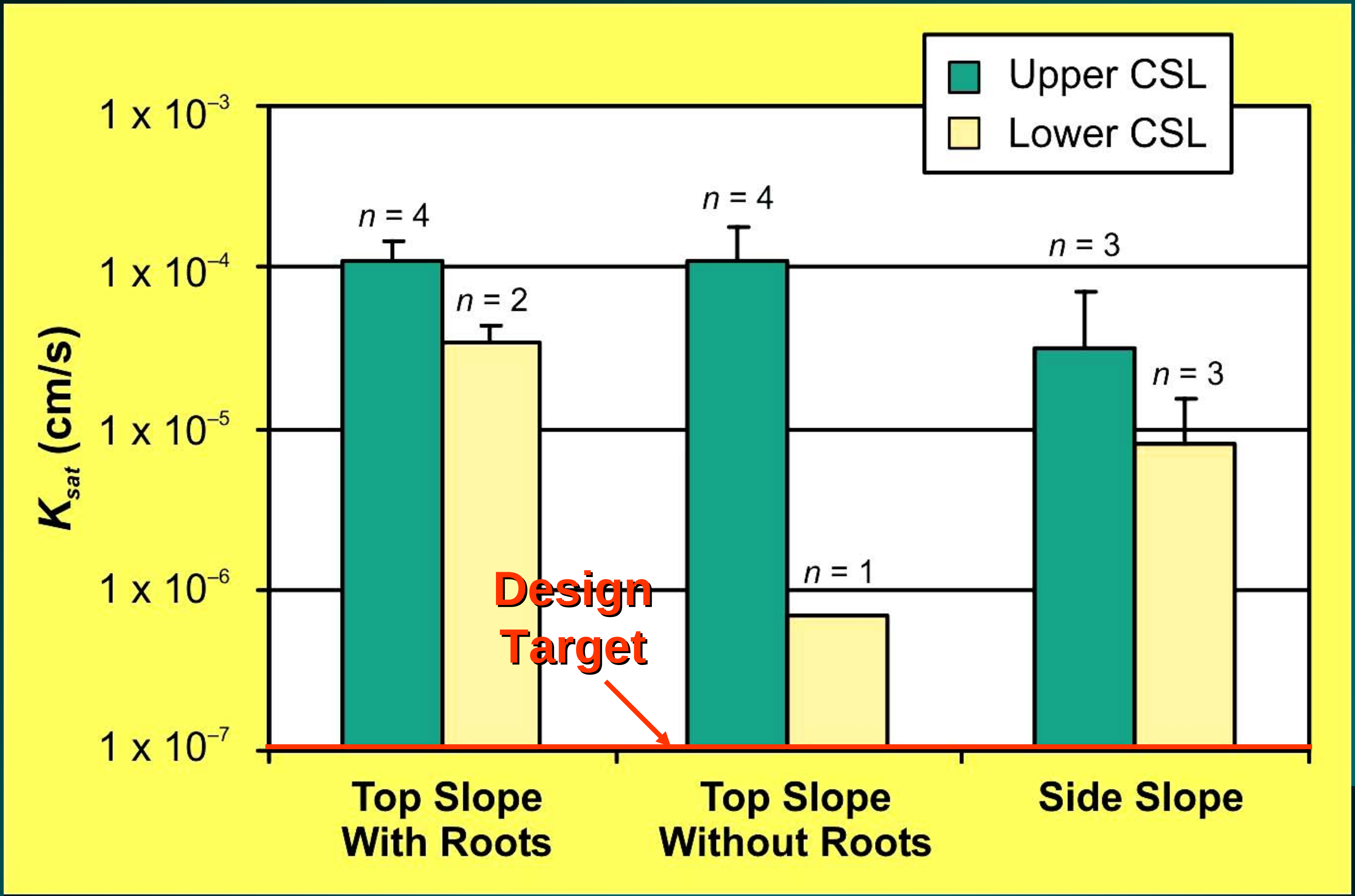
- Measure K_{sat} with air-entry permeameters (DBSA)
- Compare CSL K_{sat}
  - with and without roots
  - top slope and side slope
  - upper and lower CSL

K_{sat} Measurement:
Air-Entry Permeameters (AEP)

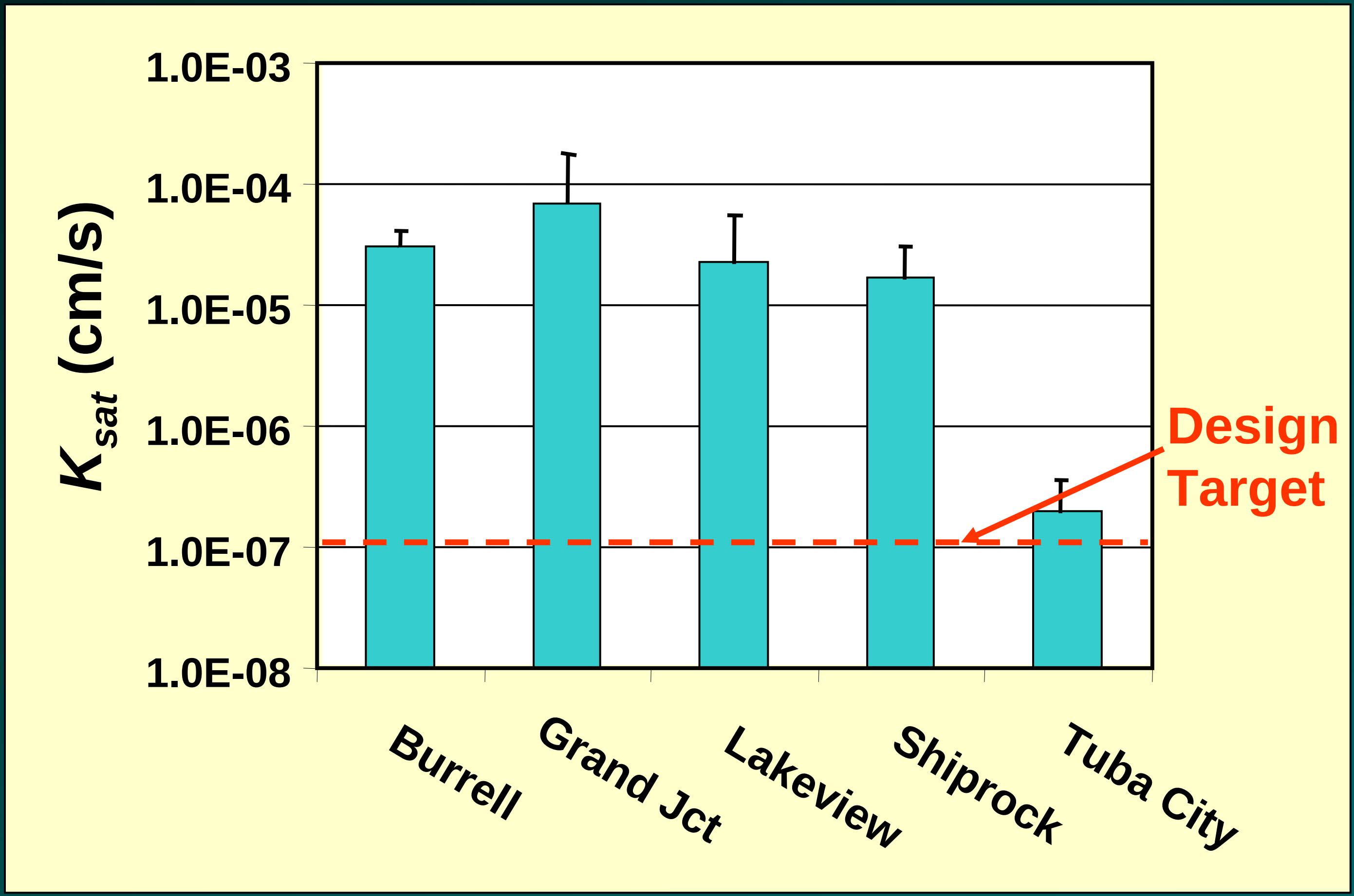
Manual AEP on side slope

Automated AEPs on top slope

Lakeview — K_{sat} Results



K_{sat} Results: Comparison with Other Sites



Permeability

Likely causes of preferential flow in CSLs

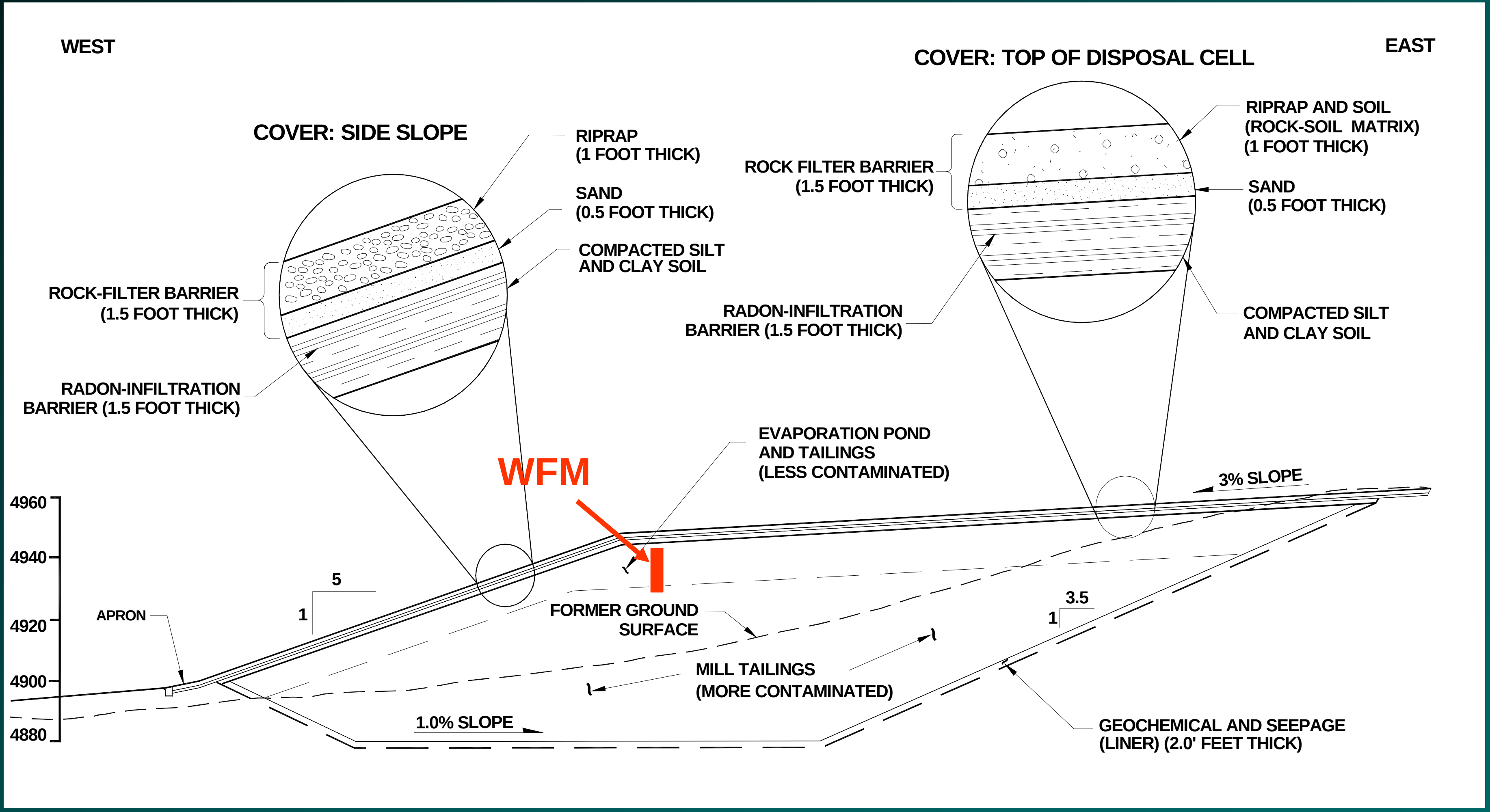
- Soil structure in CSL developing faster than expected
- Plant roots and burrowing/tunneling animals
- Freeze-thaw cracking and desiccation
- *Well-developed structure of borrow soils*

Test dye at structural planes

Sagebrush roots in CSL

Percolation
Water Flux Meters (PNNL wicking lysimeters)

Down-gradient locations on cover topslope

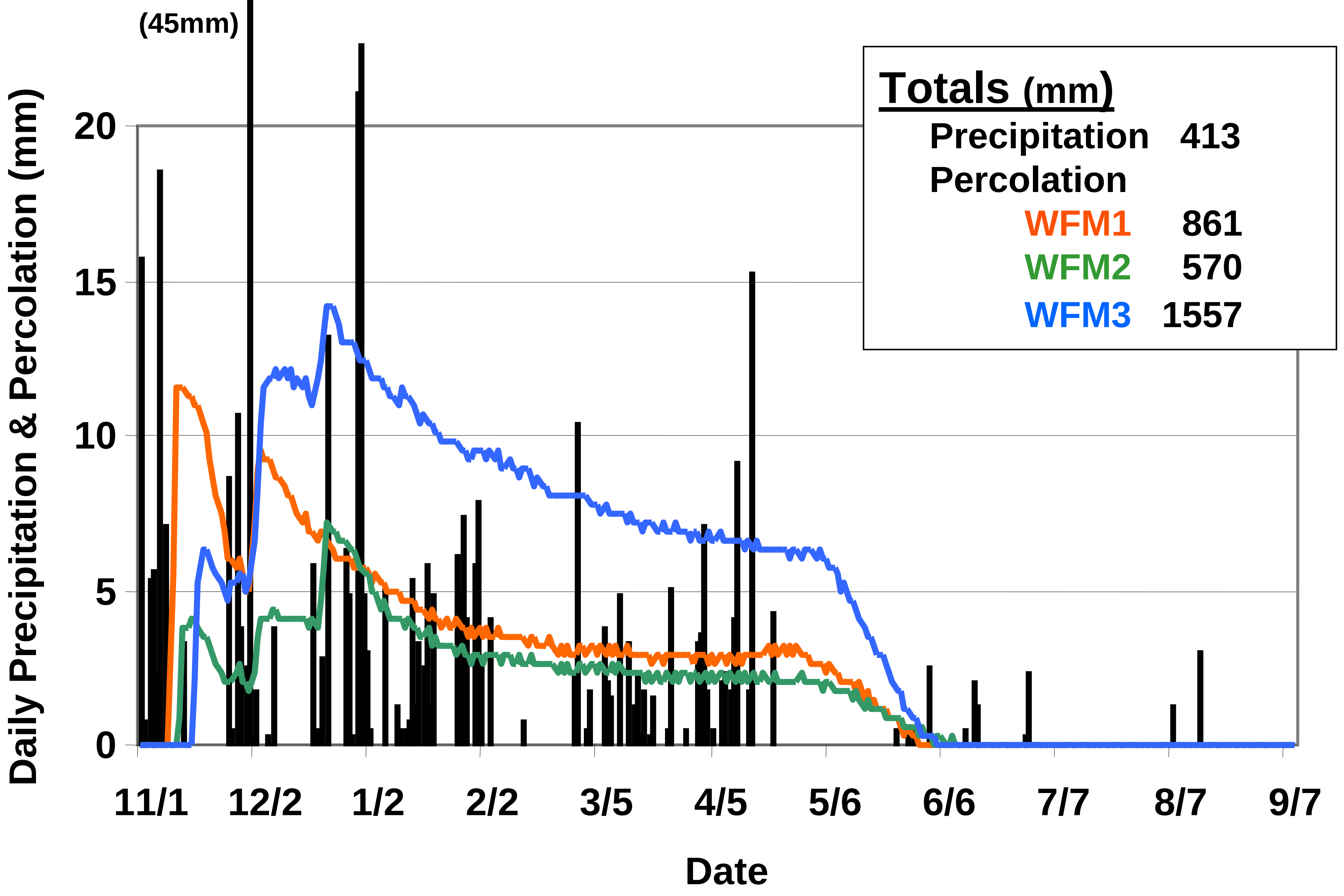


Water Flux Meter Installation

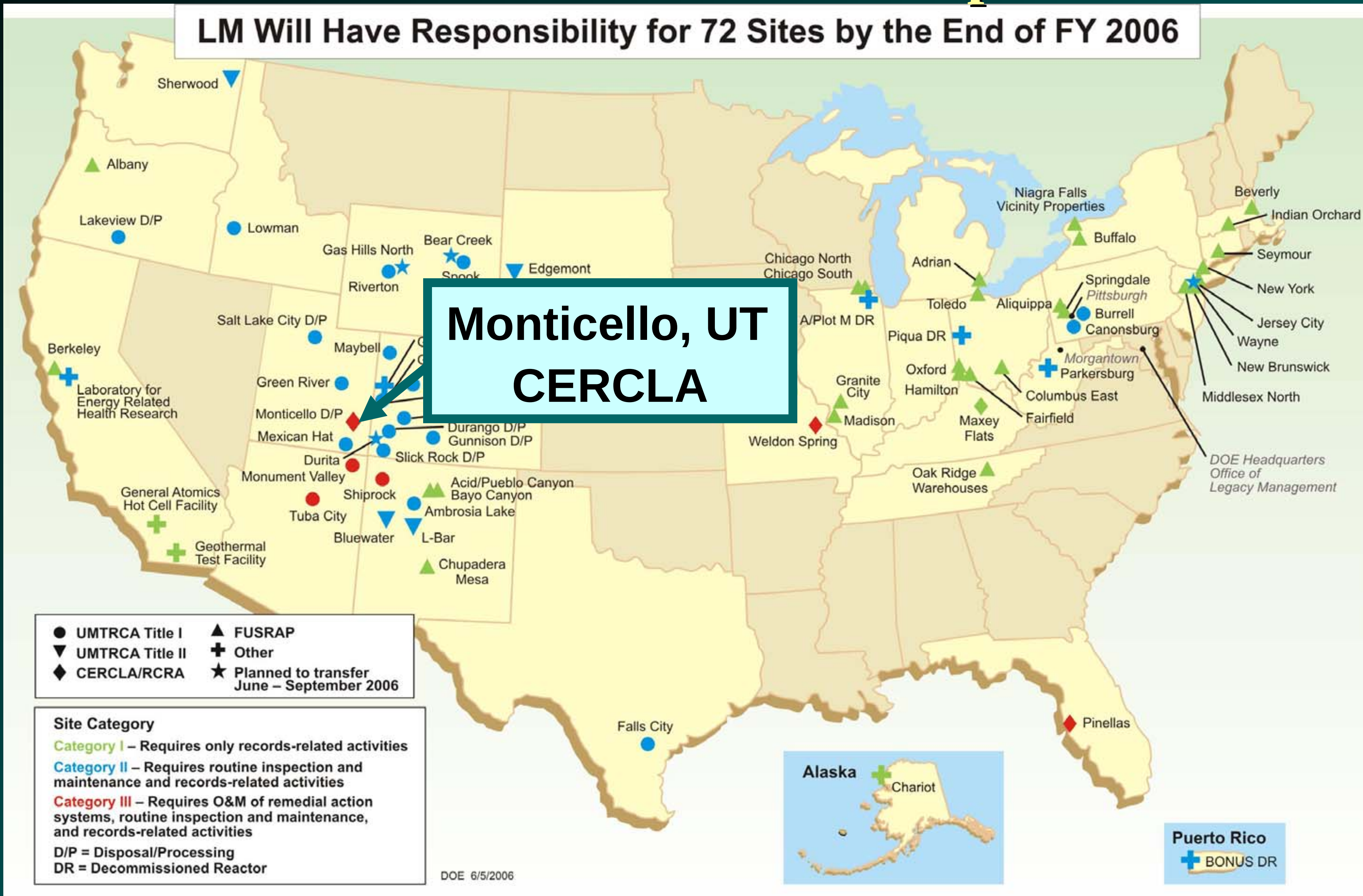
Flux meters installed
just below CSL in top slope

Pits opened:
- 3 on top slope
- 2 on side slope

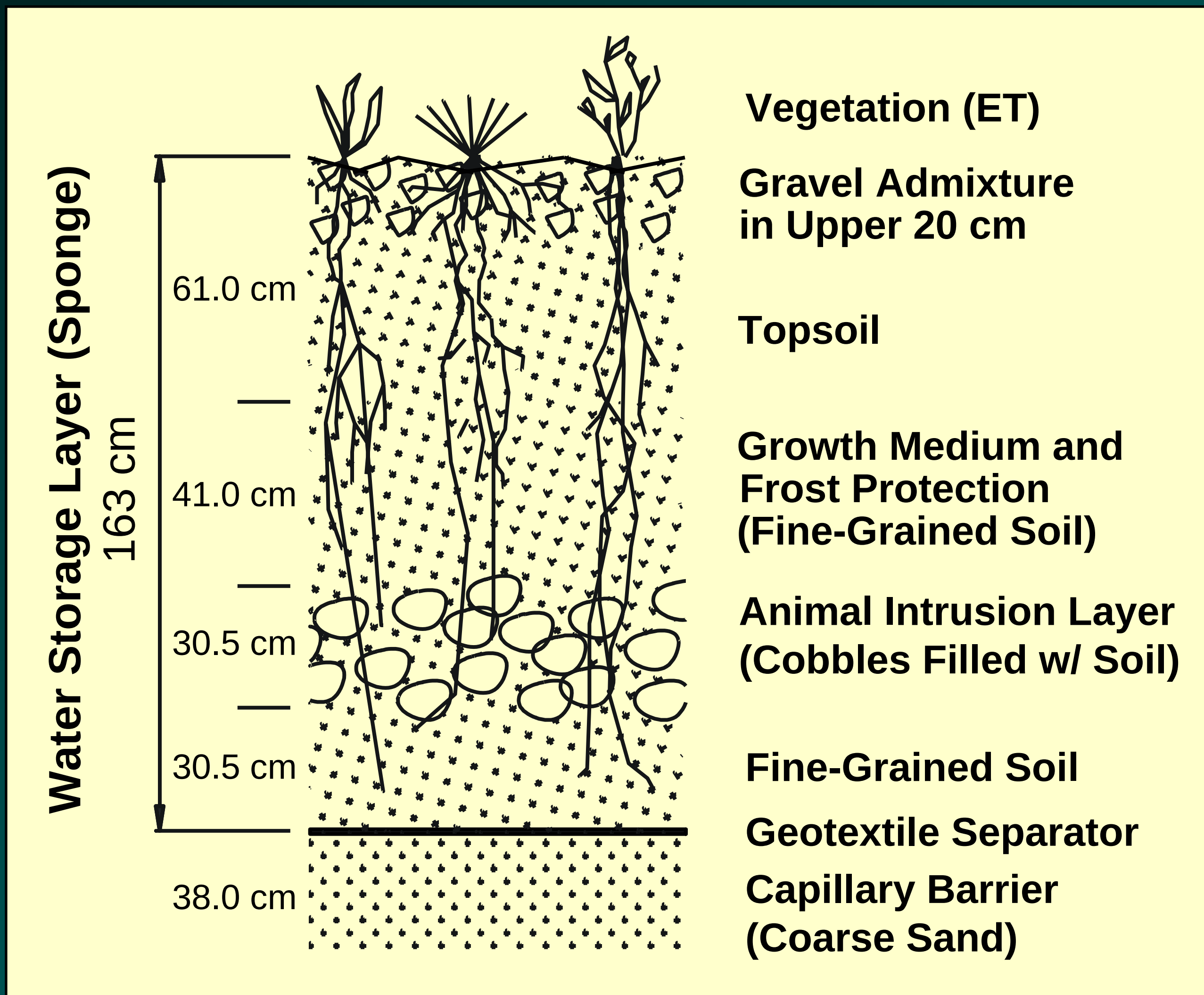
Lakeview: Water Flux Meter Results



Monticello, Utah
Alternative Cover Example

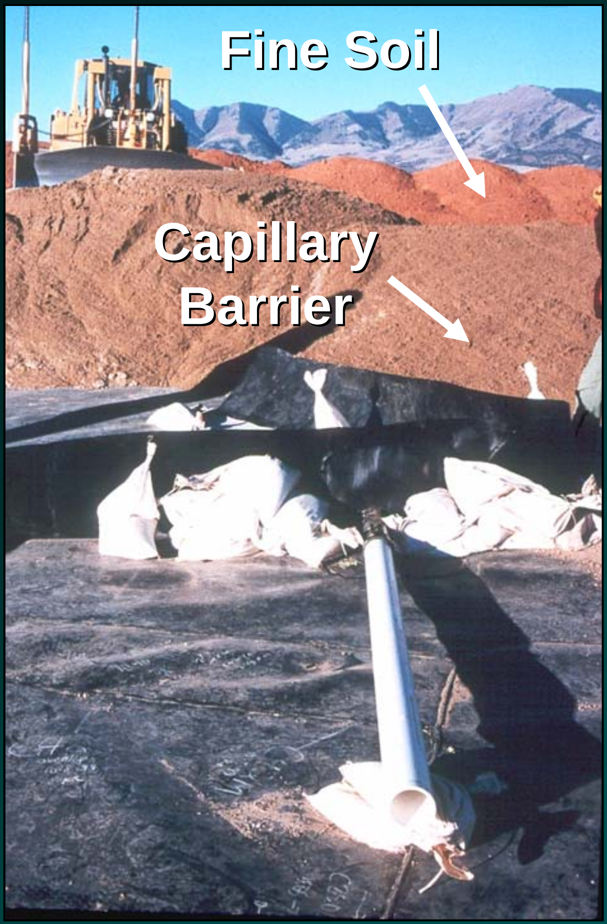


Monticello Alternative Cover Design: ET / Capillary Barrier



Embedded Lysimeter Instrumentation

(3-hectare lysimeter)

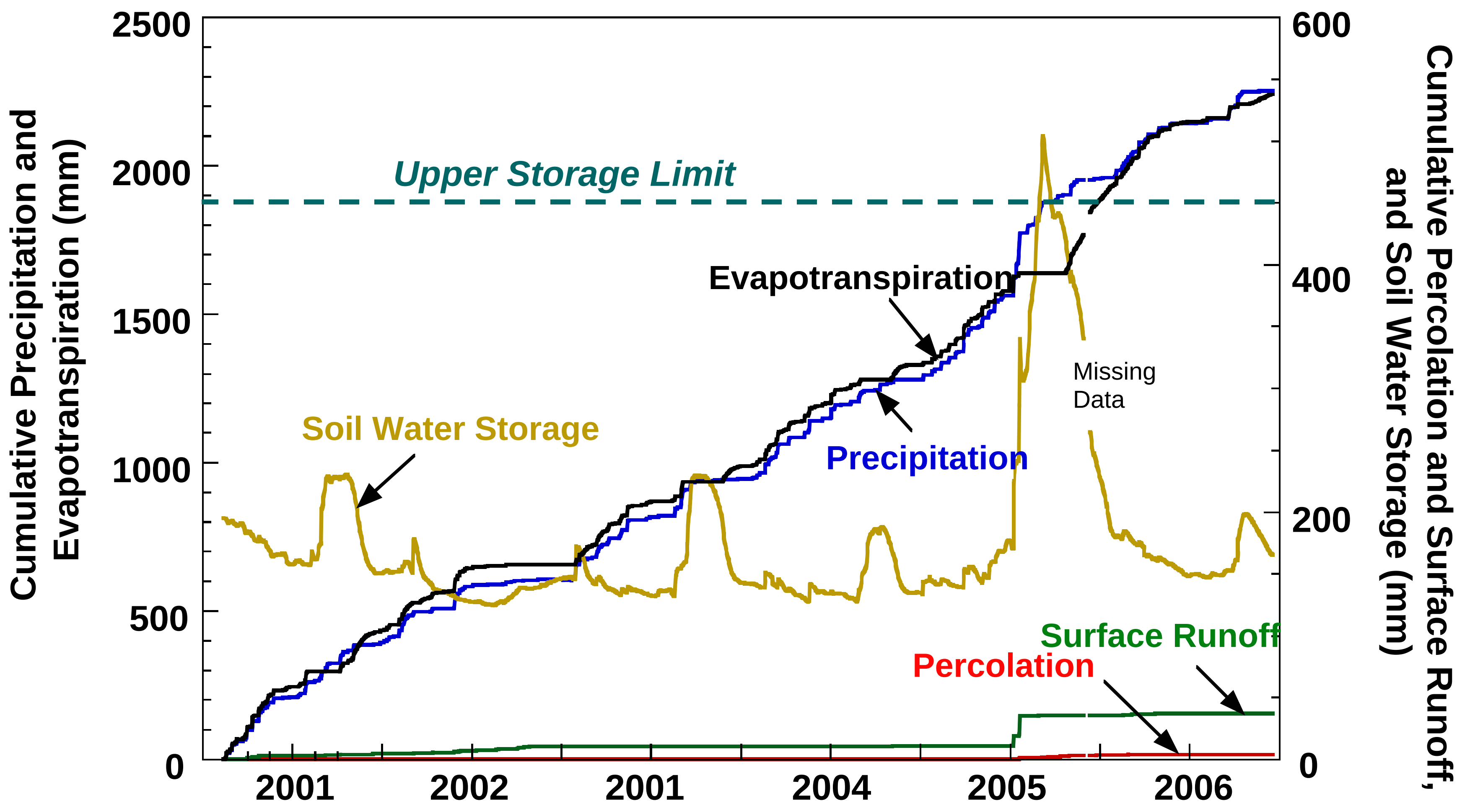


Drainage collection system

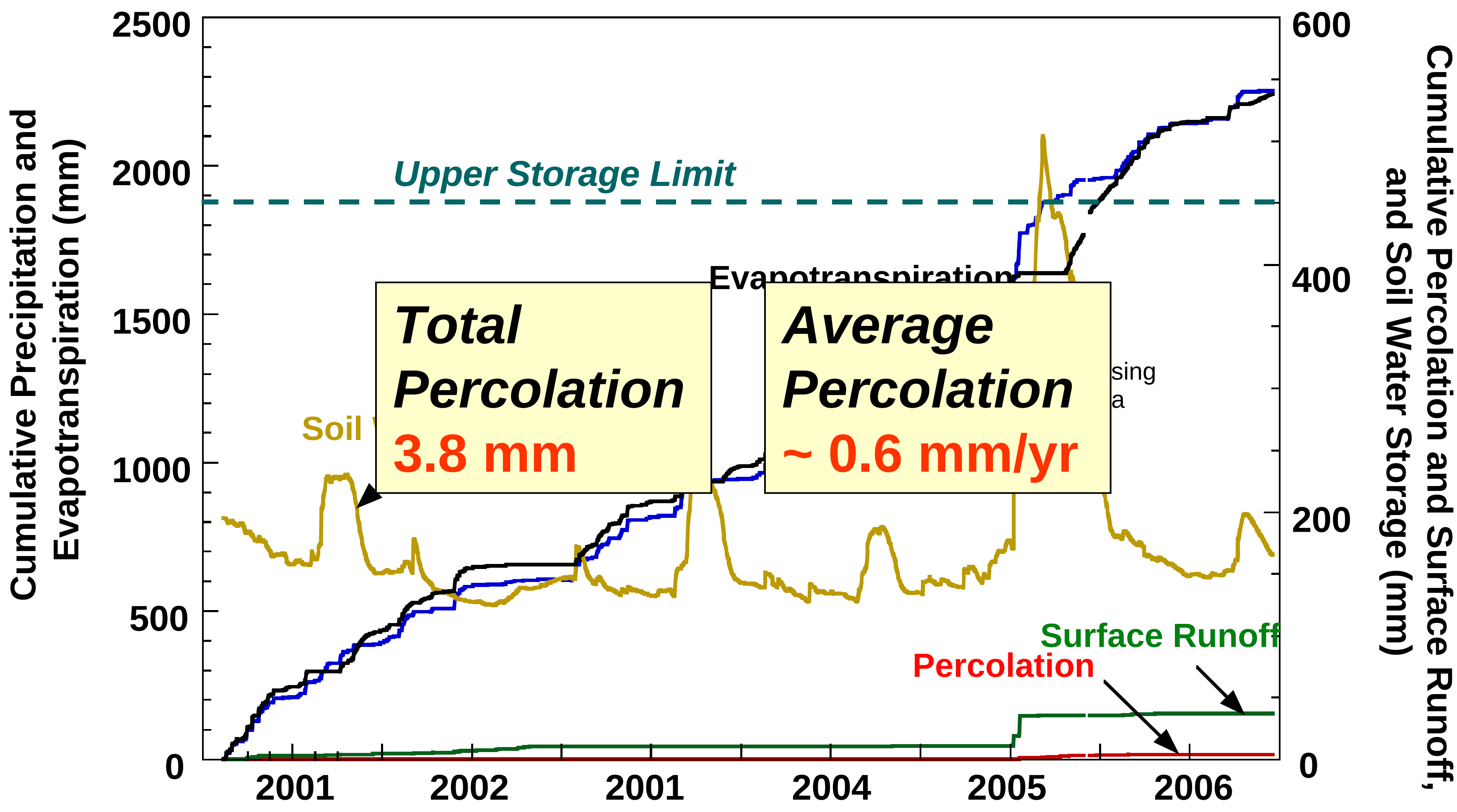
Drainage and Runoff:
Dosing siphons

Soil Moisture Nests:
- Water content TDR
- Water potential HDU

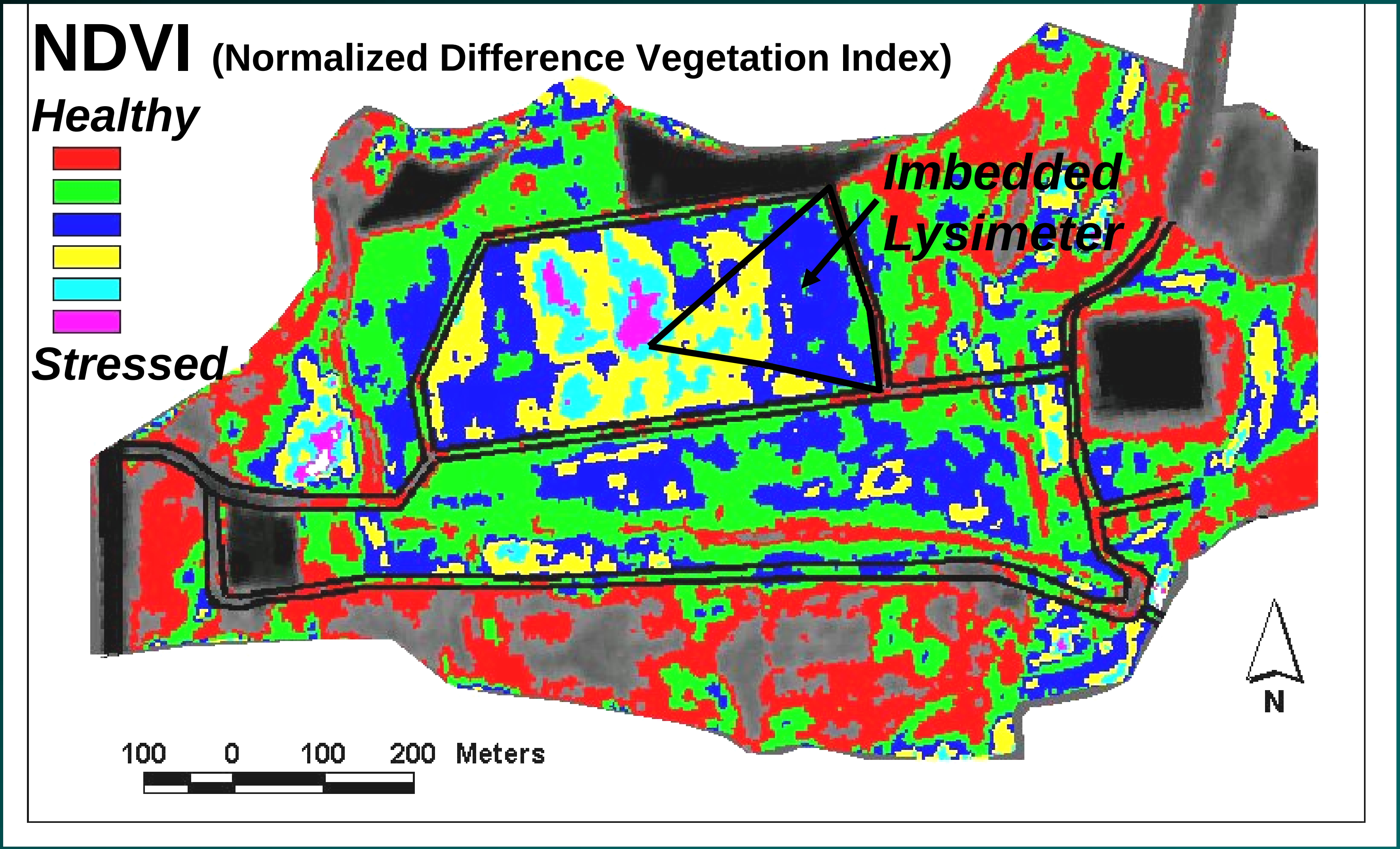
Embedded Lysimeter Water Balance



Embedded Lysimeter Water Balance



Performance Indicator: Remote Sensing of Vegetation Patterns
(John Gladden, SRS)



Site Transfer to LM: Cover Stewardship Questions

- How was the cover designed and constructed?
- How is it supposed to work?
- What and how do we monitor to show that it is working?
- **What types of maintenance are required (and at what cost) to keep it working as designed?**
- What are the *risks* if its not working as designed?
- **Could we design sustainable repairs or renovations *if needed*?**
- Can we expect the cover to continue working for 200 to 1000 years?

Could we design sustainable repairs or renovations if needed?

Lakeview:

Shrub encroachment may be the *solution*, not the *problem*!

LTS&M Vegetation Management Options:

- **Control plant growth**
- **Let them grow**
- **Facilitate beneficial ecological succession (*cover renovation*)**

Without intervention, Mother Nature will eventually transform low-permeability covers into ET-type covers.

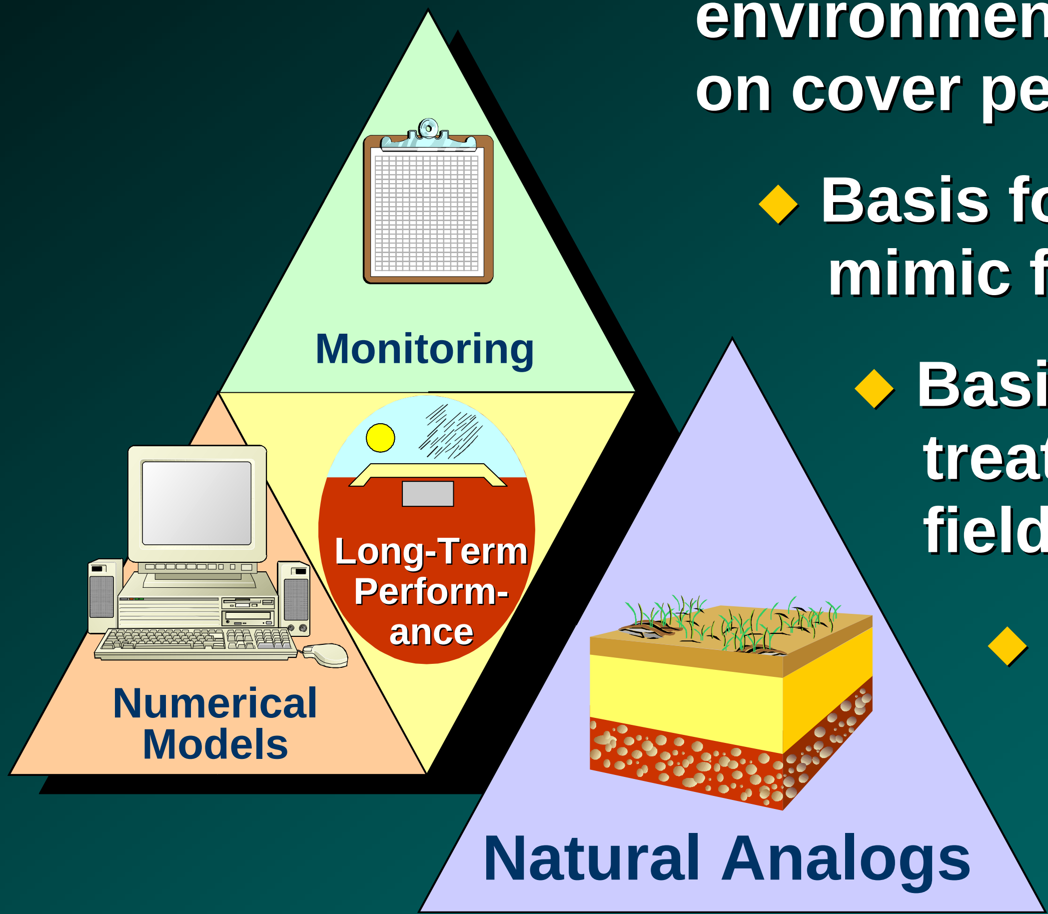
Site Transfer to LM: Cover Stewardship Questions

- How was the cover designed and constructed?
- How is it supposed to work?
- What and how do we monitor to show that it is working?
- What types of maintenance are required (and at what cost) to keep it working as designed?
- **What are the *risks* if its not working as designed?**
- Could we design sustainable repairs or renovations *if needed*?
- **Can we expect the cover to continue working for 200 to 1000 years?**

Long-Term Performance Evaluation Tools

Role of Natural Analogs

- **Tangible clues about future environmental conditions and effects on cover performance**
  - **Basis for designing covers that mimic favorable natural settings**
    - **Basis of hypotheses and treatments for short-term field studies (e.g. lysimeters)**
      - ***Basis for inferring future environmental scenarios for input to models***



Risk-Based Performance Modeling Process

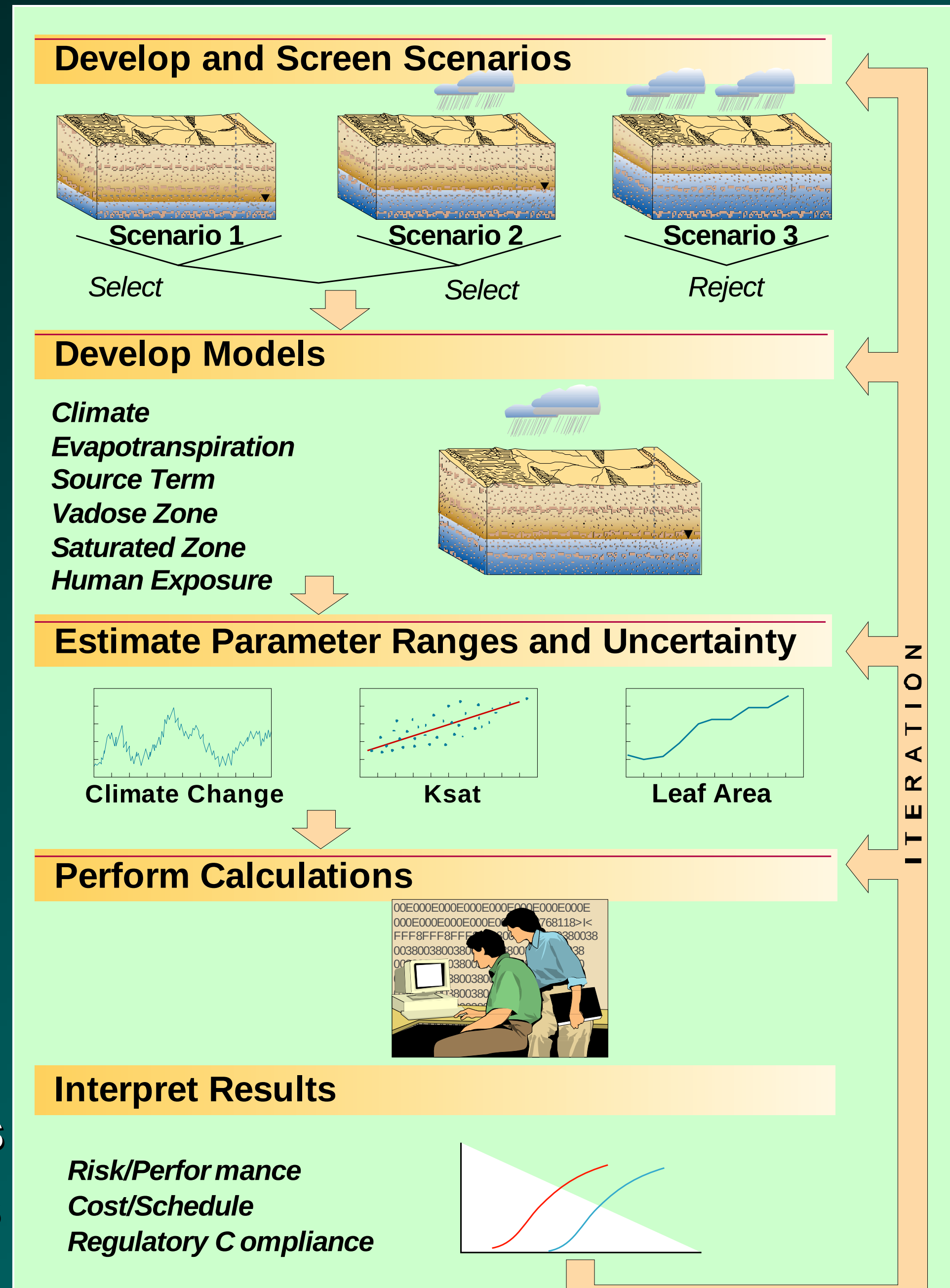
Natural Analog Data

- Develop scenarios for modeling future performance
- Estimate parameter ranges and uncertainty

Demonstration

FRAMES (PNNL)

- Probabilistic modeling platform
- Links cover water flux, source-term release, vadose-zone transport, saturated-zone transport, & exposure pathways
- Uncertainty/sensitivity analyses used to identify important monitoring parameters



(Cliff Ho, SNL)

Lakeview Leaf Area Index (LAI) Chronosequence

Lakeview Soil Analog: Permeability

Air-entry permeameter measurements of K_{sat} in lake sediment soil profiles (borrow source)

K_{sat} **1.6×10^{-5} cm/s**

8.2×10^{-5} cm/s

2.9×10^{-4} cm/s

Lakeview Climate Change:
Wet and Dry Ecology Analogs

Lakeview Conifer Site, OR

Soil: Drews loam

Vegetation: Mixed conifer

LAI: 1.62

Guano Basin Site, NV

Soil: Spangenburg loam

Vegetation: Big sagebrush

LAI: 0.43

Addressing Focus Questions:

Summary

- *Compliance* monitoring and modeling of cover performance are *not* required by NRC for uranium mill tailings.
- Limited *non-routine* soil hydrology and ecology monitoring:
  - Low-permeability covers *not* performing as designed
  - Monticello ET cover *is* performing as designed
  - Limited use of monitoring data for model improvement

Recommendations

- Monitor and model hydrological/ecological performance of covers as *early warning* of ground water non-compliance
- Use soil and ecological analog data to develop scenarios for modeling long-term cover performance
- FRAMES improvements:
  - Use Richard's Equation solution for unsaturated flow
  - Link soil hydrology with vegetation dynamics (e.g. TerreSIM)
- Use *in situ* instrumentation for *confirmation* monitoring/modeling
- Develop performance indicators or surrogates for *long term*

Coupling Monitoring Programs to Modeling

Thomas J. Nicholson[1], Ralph Cady[1] and Jacob Philip[1]
James Shepherd[2] and Jon Peckenpaugh[3]

[1]Office of Nuclear Regulatory Research
[2]Office of Nuclear Material Safety and Safeguards
[3]Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission

Contact: TJN@NRC.GOV or (301) 415-6268

ACNW Working Group Meeting on
Using Monitoring to Build Model Confidence
Rockville, Maryland
September 19- 20, 2006

Outline

- Objectives in Monitoring and Modeling
- Monitoring and Model Interface
- Generic Technical Issues
- Opportunities to Build Confidence in Modeling
- References

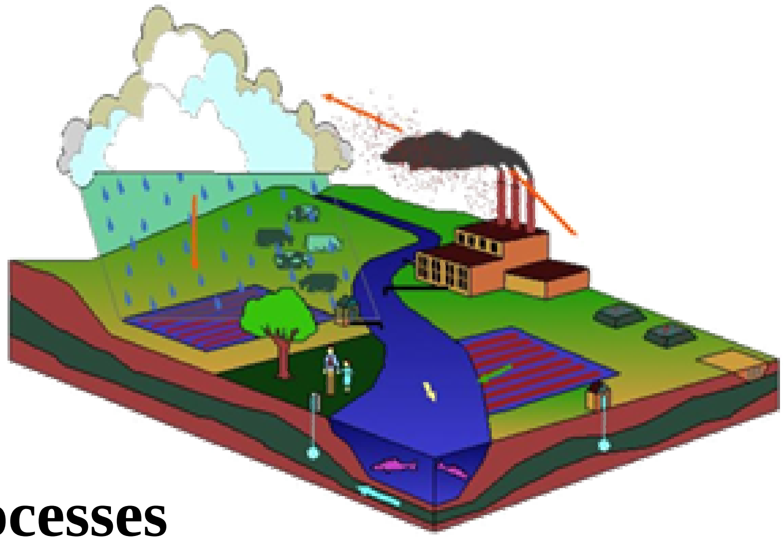
Objectives in Monitoring and Modeling

- ✓ **Characterize system**
- ✓ **Demonstrate understanding of the system**
- ✓ **Confirm site and engineered system behavior**
- ✓ **Demonstrate compliance**
- ✓ **Design remediation for non-compliance**

Objectives in Monitoring and Modeling

Why monitor and model?

Characterize natural and engineered systems:

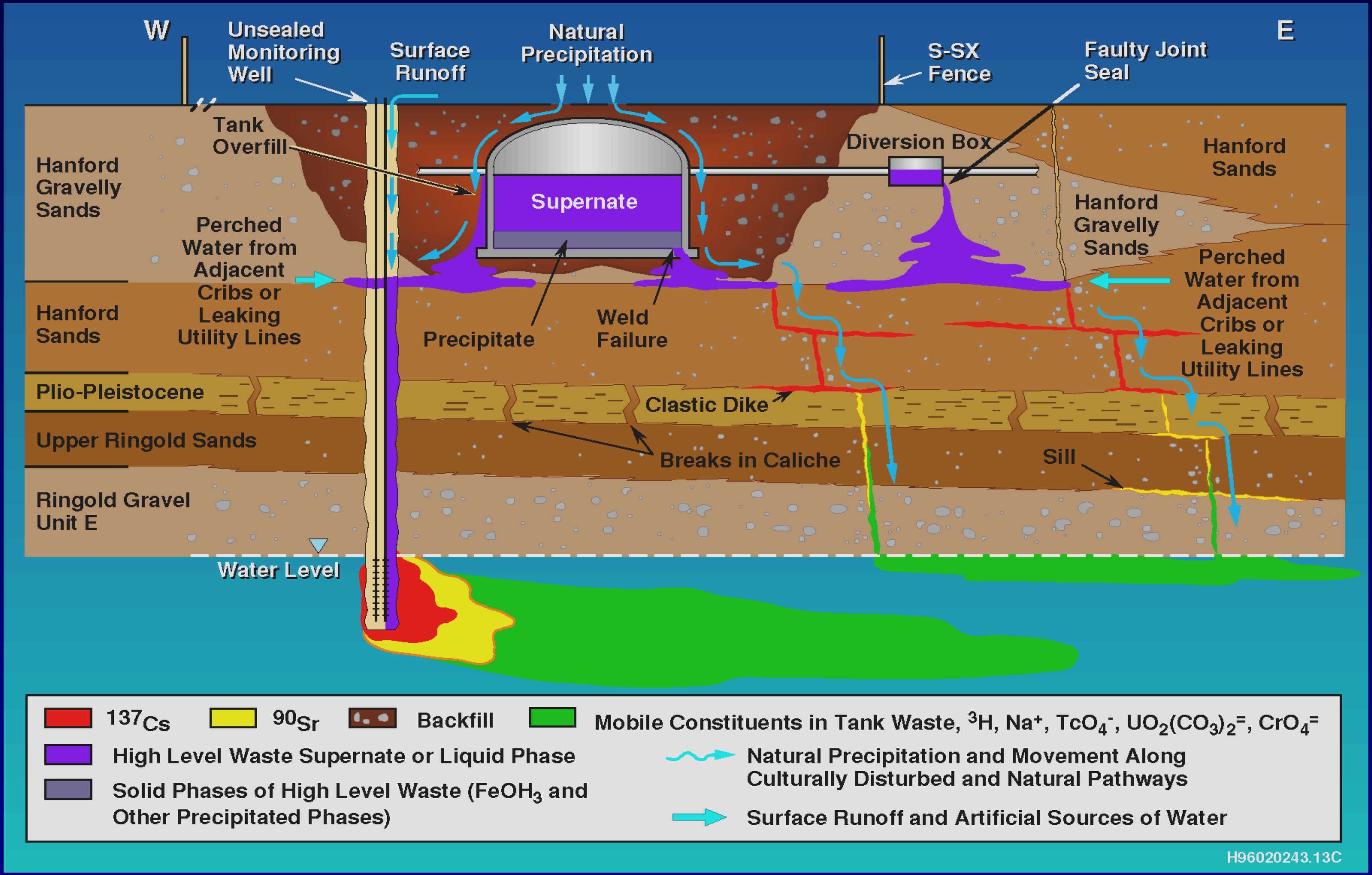


✓ **Collect information to identify significant Features, Events and Processes**

✓ **Develop and evaluate site conceptual models**

✓ **Guide data collection including monitoring, sampling and geophysical surveys**

Conceptual Model of a Complex Site



from Ward et al. (1997) after Caggiano et al. (1996)

Objectives of Monitoring and Modeling

✓ **Confirm behavior is within envelope of expected performance**

- of engineered structure, systems and components
- of natural systems

Site-Specific Model

- will probably not be simplified (abstracted) version used in PA
- may include state variables not in abstracted version
- state variables are potential ***Performance Indicators***

Objectives in Monitoring and Modeling

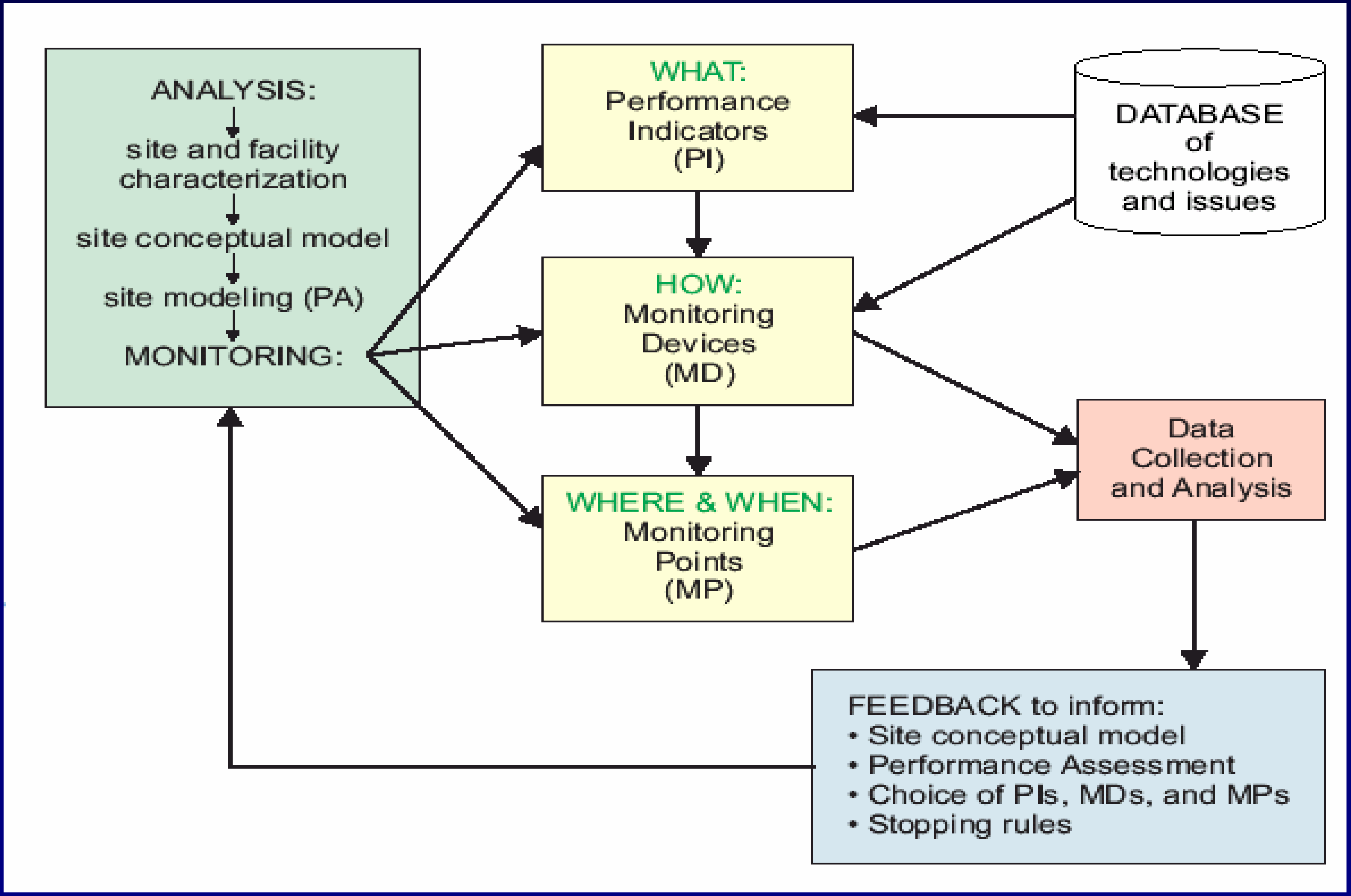
- ✓ **Assure compliance**
  - ➢ **with regulatory requirements**
  - ➢ **with proposed site-specific criteria (e.g., NEI voluntary guidelines such as H-3 concentrations and specified volume release notifications)**

Model is useful to:

- ➢ **demonstrate understanding of the system being monitored**
- ➢ **infer from point monitoring data to:**
  - ❖ **compliance boundary or**
  - ❖ **other receptor location**

- ➢ **Decisions on whether and how to remediate non-compliant excursions**
  - ❖ **monitoring and modeling during remediation to evaluate efficacy**

Monitoring and Model Interface



after AES, 2006

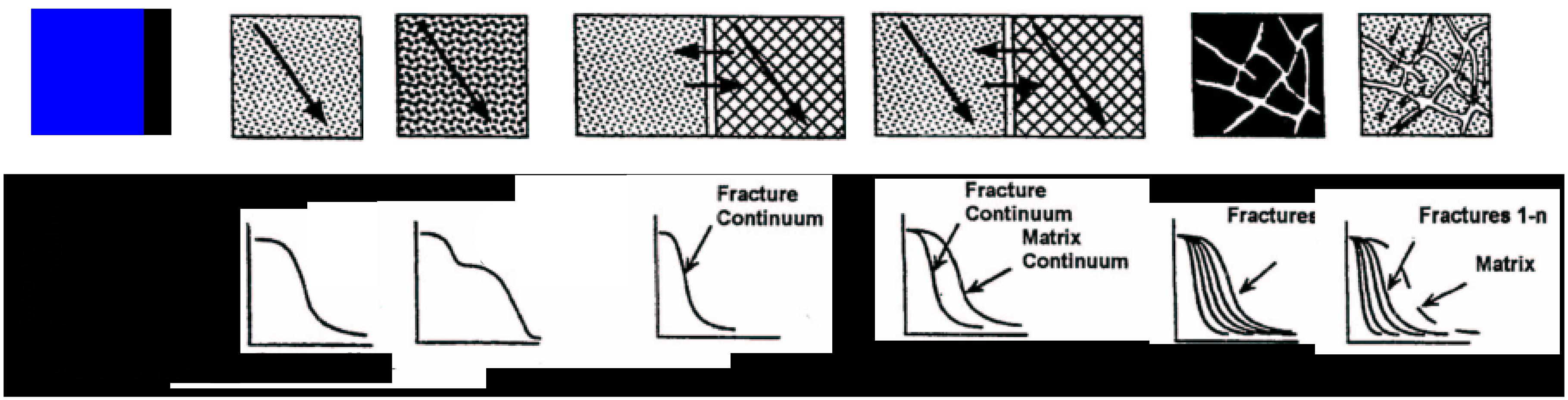
Generic Technical Issues

- **Modeling to assess monitoring data-quality objectives (DQO's)**
  - **Required quality constraints may be beyond current sensor technology**
  - **Stopping values?**
- **Couple monitoring to conceptual model and site performance assessment (PA) by:**
  - **Assessing monitored conditions to confirm that performance is within the envelope of the model**
- **Identify alternative conceptual flow and transport models**

Hierarchy of Conceptual Flow Models

Models to simulate flow in soils, sediments, unsaturated fractured rock (after Altman et al., 1996)

Water budget	Single conti-nuum	Equivalent matrix and fracture continuum	Dual porosity	Dual permeability	Discrete fractures without matrix	Discrete fractures with matrix
			Matrix Fracture	**Matrix Fracture**		



Complexity →

← **Model abstraction**

Generic Technical Issues

- ***What to monitor and model*** is defined by the site-specific PI's which are derived from:

  - ✓ regulatory compliance criteria
  - ✓ performance assessment predictions
  - ✓ need to ***quantify system behavior*** and to ***detect changes affecting radionuclide transport***

(e.g., water contents, hydraulic gradients, flow velocities, contaminant concentrations and fluxes)

Generic Technical Issues

- ***Where to monitor*** is defined by the FEP's scales, system interfaces, and receptors' points of exposure:

  - ✓ facility structures, systems and components (e.g., telltails, concrete curtain walls, drains and sumps)

  - ✓ dynamic interface between facility and surrounding environment

  - ✓ surrounding environmental zone (e.g., pumping wells, springs, and discharge to surface-water bodies)

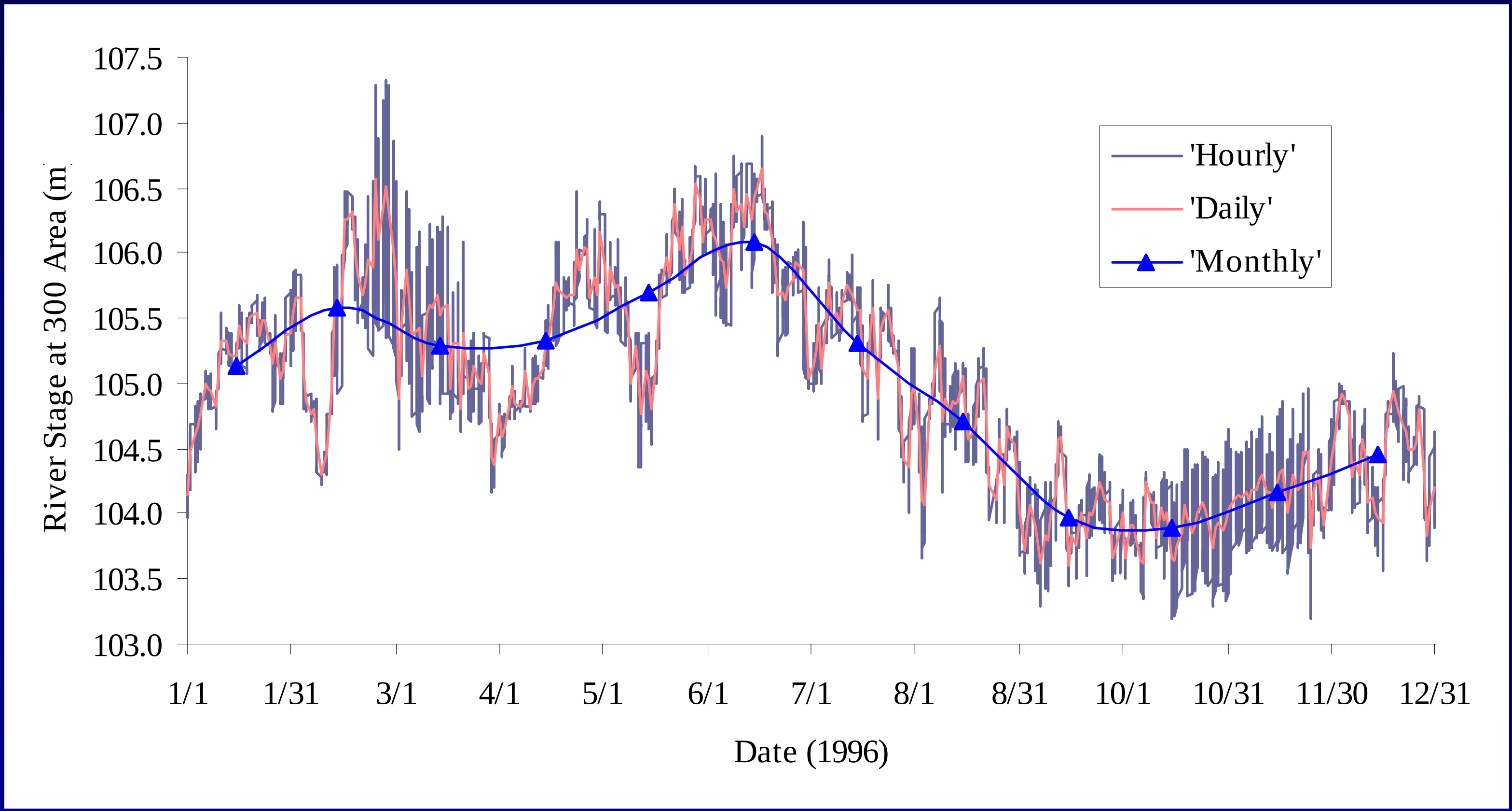
Generic Technical Issues

- ***When to monitor*** is defined by the system behavior (i.e., event and processes' timescales) and PA model assumptions to be tested:

  identify timescales for events and processes of:

  ✓ facility release events
  ✓ dynamic processes in interface zone (e.g., percolation)
  ✓ environmental processes (e.g., unsaturated-saturated zone processes, surface- and ground-water interaction)

Temporal Scales for River-Level Fluctuations



from Meyer et al., 2006

Generic Technical Issues

- ***How to monitor*** relates to the ability to properly select, and capabilities of monitoring systems and instrumentation.

- EPA, NGWA, SSSA, ASTM and USGS guidance exists

- Innovative technologies such as fiber optics and geophysical methods evolve from performance and model analysis criteria (e.g., geochemical indicators and GIS-based indicators)

Opportunities to Build Confidence in Models (after Philip Meyer, PNNL)

Can monitoring strategies be improved by considering uncertainties in parameters, conceptual models, and scenarios?

- maximize probability of detecting contaminants while minimizing the number of monitoring wells
- since model probability is conditioned on observations, monitoring strategies should be designed to obtain observations that improve estimates of model uncertainty
- consider conceptual uncertainty initially in monitoring design
- identify important monitoring locations and data as input to PA models for parameter estimation, model calibration and uncertainty analyses

References

Advanced Environmental Solutions, A Strategy for Ground-Water Monitoring of NRC-Licensed Facilities and Sites, Lexington, SC, 2006

Chien, C.C. et al., Barrier Systems for Environmental Contaminant Containment and Treatment, CRC-Taylor and Francis Group, Boca Raton, FL, 2006

EPA, Performance Monitoring of MNA Remedies for VOCs in Ground Water, EPA/600/R-04/027, Cincinnati, OH, 2004

Meyer, P. et al., Combined Estimation of Hydrogeologic Conceptual Model and Parameter Uncertainty, NUREG/CR-6843, U.S. Nuclear Regulatory Commission, Washington, DC, March 2004

EPA National Air and Radiation Environmental Laboratory Web site http://www.epa.gov/narel for Environmental Radiation Data Reports

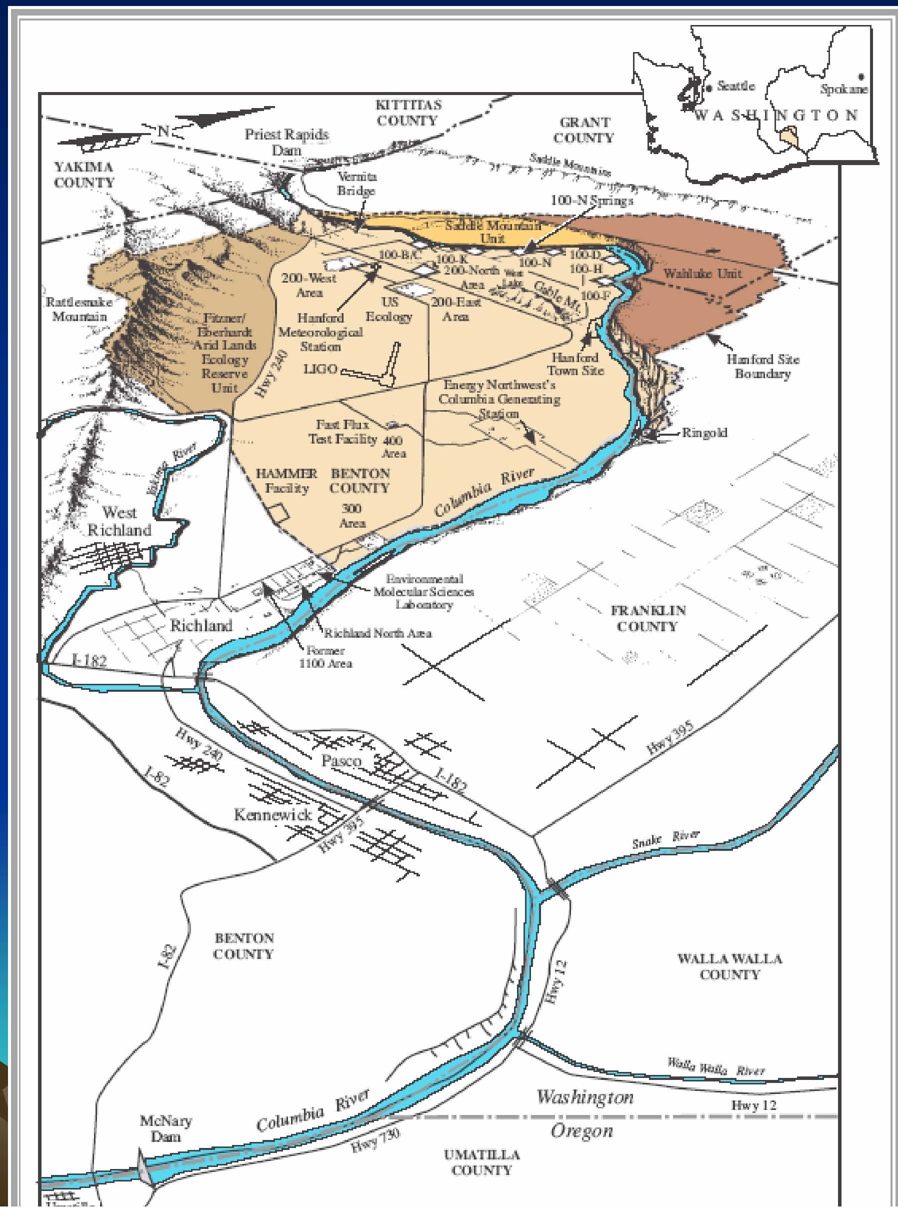
Integrating Modeling and Monitoring to Provide Long-Term Control of Contaminants

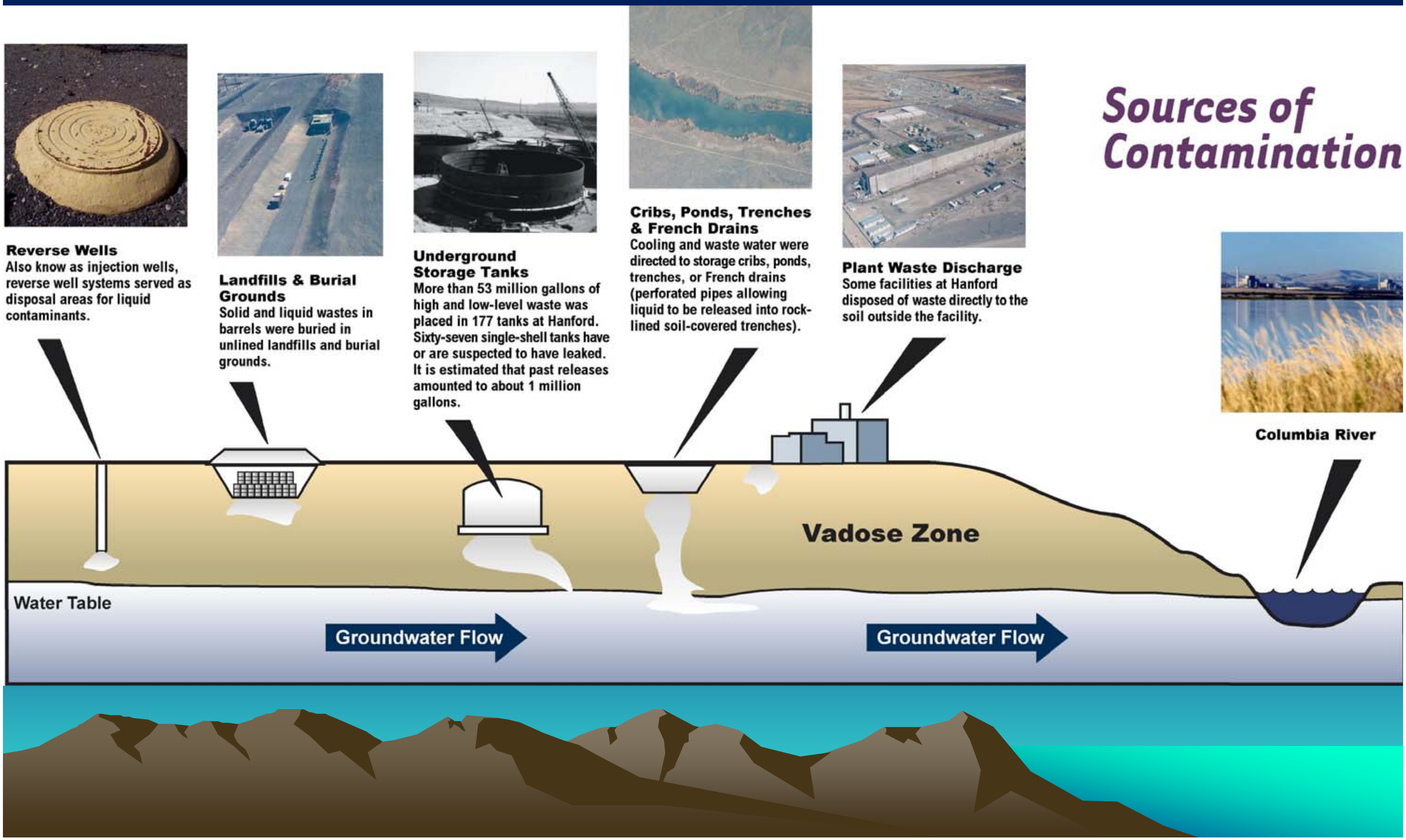
Thomas W. Fogwell, Ph.D., P.E.
Energy Solutions - Fluor Hanford Team
20 September 2006
Advisory Committee on Nuclear Waste Working Group Meeting on Using Monitoring to Build Model Confidence

Outline

- Introduction to Hanford
- Paradigm for remediation showing integration of monitoring with modeling
- Examples of integration of the various parts
- Monitoring methods at Hanford
- Issues to address at Hanford
- Examples of integrated modeling-monitoring approaches

Overview of the Hanford Site




Sources of Contamination
Reverse Wells
Also know as injection wells, reverse well systems served as disposal areas for liquid contaminants.
Landfills & Burial Grounds
Solid and liquid wastes in barrels were buried in unlined landfills and burial grounds.
Underground Storage Tanks
More than 53 million gallons of high and low-level waste was placed in 177 tanks at Hanford. Sixty-seven single-shell tanks have or are suspected to have leaked. It is estimated that past releases amounted to about 1 million gallons.
Cribs, Ponds, Trenches & French Drains
Cooling and waste water were directed to storage cribs, ponds, trenches, or French drains (perforated pipes allowing liquid to be released into rock-lined soil-covered trenches).
Plant Waste Discharge
Some facilities at Hanford disposed of waste directly to the soil outside the facility.
Columbia River
Vadose Zone
Water Table
Groundwater Flow
Groundwater Flow

Hanford Compared to U.S. Nuclear Weapon Complex

- 42% (420 million curies) of 1 billion curies
- 60% (204,000m^3) of high-level waste
- 25% (1200) of waste storage and release sites
- 80% (2100MT) of spent fuel
- 25% (710,000 m^3) of buried solid waste

Remediation Strategies

Activities

Characterization

Remediation

Monitoring

$\Longrightarrow$

Minimize

$\sum$ Costs of all Activities (Present, Probable)

Subject to Constraints from Risks, Regulator, Uncertainties, Agency Requirements, - - -

Answers to Questions

Defining the Problem

Q1. Are there any technical or programmatic reasons why compliance monitoring programs are not designed and compliance monitoring data are not used to support and enhance confidence in models after site characterization has been completed and a site has been licensed?

A1. There has not been an adequate paradigm developed and accepted by the both the regulatory community and the responsible parties to facilitate the use of monitoring data in the models used to evaluate performance.

Defining Opportunities

Q2. Do you know of any specific compliance and other monitoring programs and data at NRC-licensed facilities that could be used to improve models but are not currently used for that purpose?

A2. At Hanford, much more monitoring information could be used to improve models. Many of the sites under NRC pervue are also under RCRA closure requirements. This means the establishment a very prescriptive monitoring program that fails to have a mechanism for improving models.

Q3. What modification in compliance monitoring program design or additional data collection can practically and realistically be instituted so that most use can be made of the monitoring data to improve models?

A3. First, optimizing monitoring automatically entails linking the monitoring with modeling. If monitoring designs were required to be more efficient, thus requiring optimization, then the monitoring automatically becomes linked to modeling. Second, records of decision should be written to accommodate revisions in monitoring as better modeling evolves.

Defining Difficulties/Limitations

Q4. What are the technical and programmatic difficulties and limitations for integrating compliance monitoring programs and modeling at NRC-licensed facilities, with a view to make most use of the monitoring data to increase confidence in model results?

A4. There needs to be a change in the accepted paradigm. The technical pieces of the required paradigm already exist.

Summing Up

Q8. To sum up, do you have specific recommendations on how to improve the integration of compliance monitoring programs and modeling to increase confidence in model results for NRC-licensed facilities?

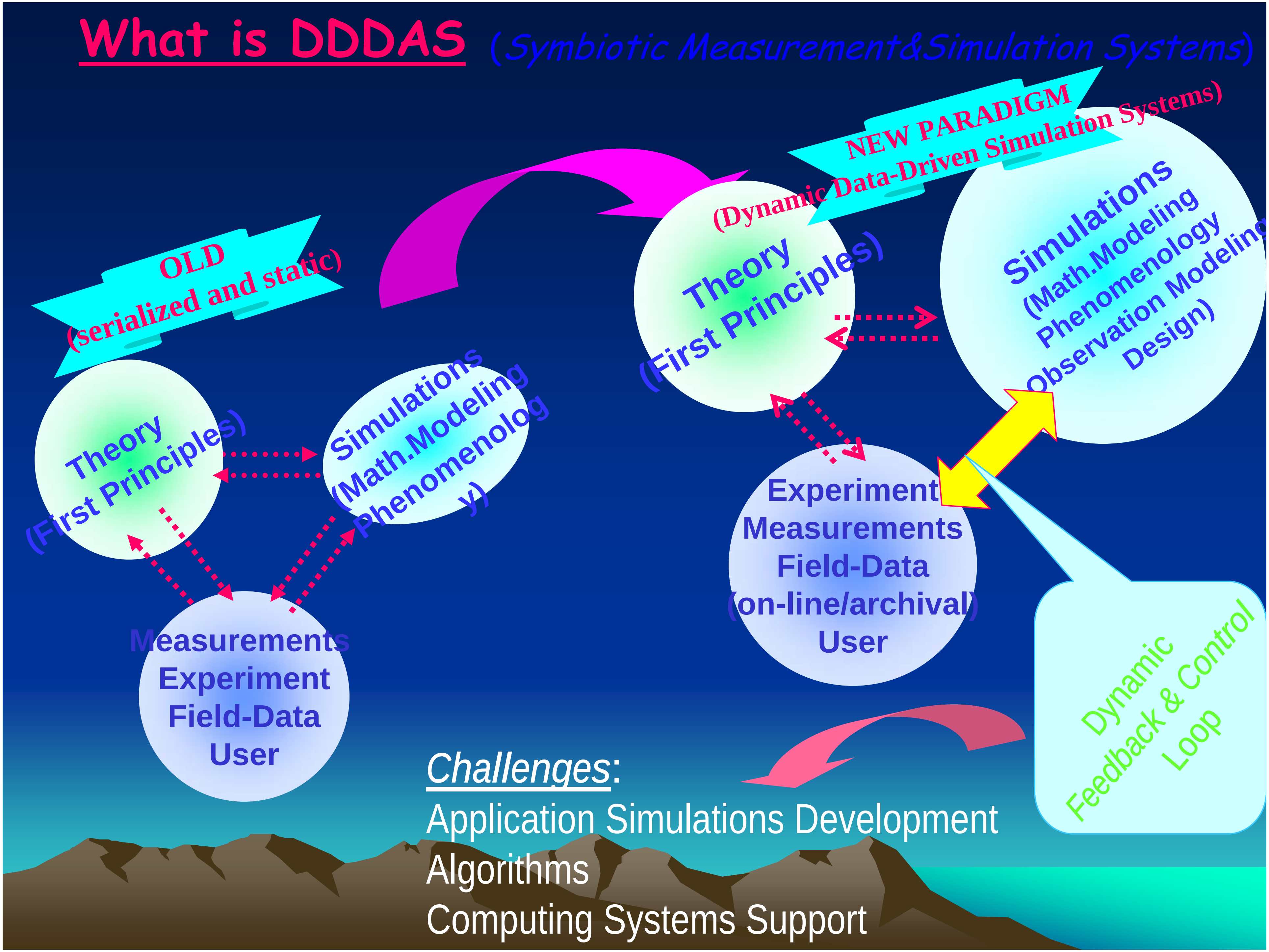
A8. Promulgate requirements to establish this integration as part of acceptable practice.

Q9. To sum up, do you have specific recommendations or suggestions on a path forward?

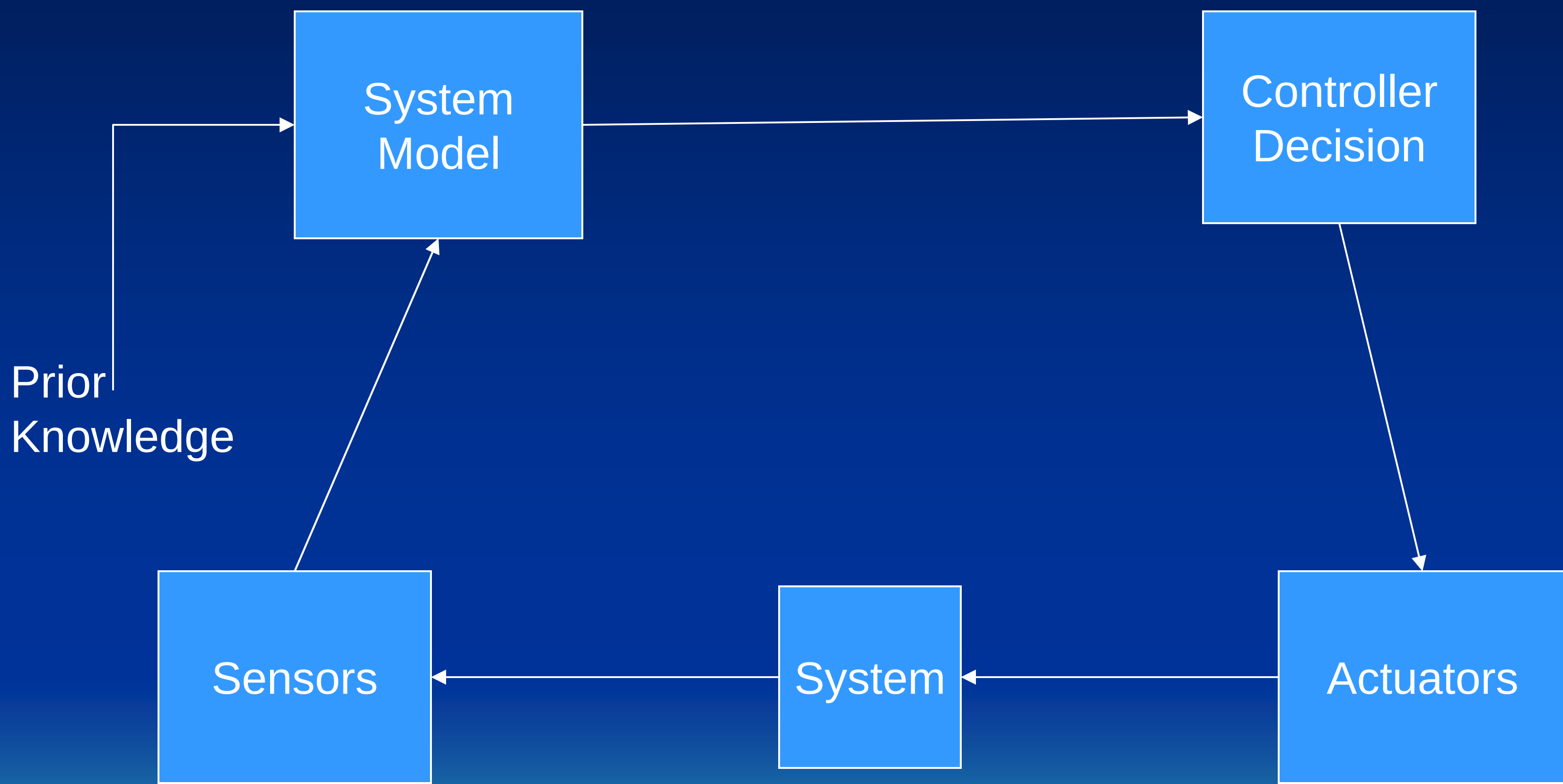
A9. Establish a system control approach with feedback loop as the method for using monitoring data to improve model reliability.

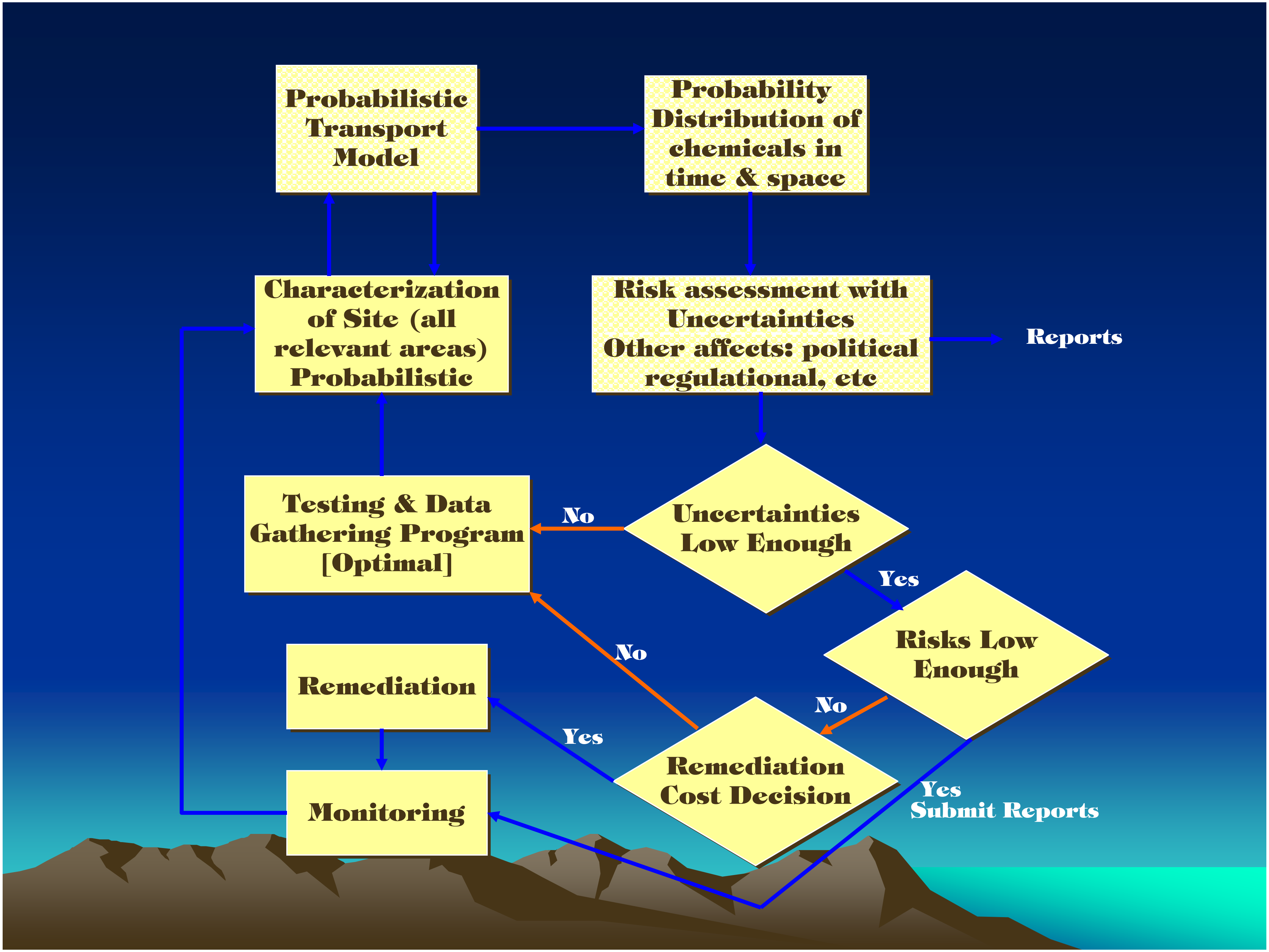
Dynamic Data Driven Application Systems
(DDDAS)

A new paradigm for applications/simulations <u>and</u> measurement methodology


What is DDDAS (Symbiotic Measurement&Simulation Systems)
OLD
(serialized and static)
Theory
(First Principles)
Simulations
(Math.Modeling
Phenomenolog
y)
Measurements
Experiment
Field-Data
User
NEW PARADIGM
(Dynamic Data-Driven Simulation Systems)
Theory
(First Principles)
Simulations
(Math.Modeling
Phenomenology
Observation Modeling
Design)
Experiment
Measurements
Field-Data
(on-line/archival)
User
Dynamic
Feedback & Control
Loop
Challenges:
Application Simulations Development
Algorithms
Computing Systems Support

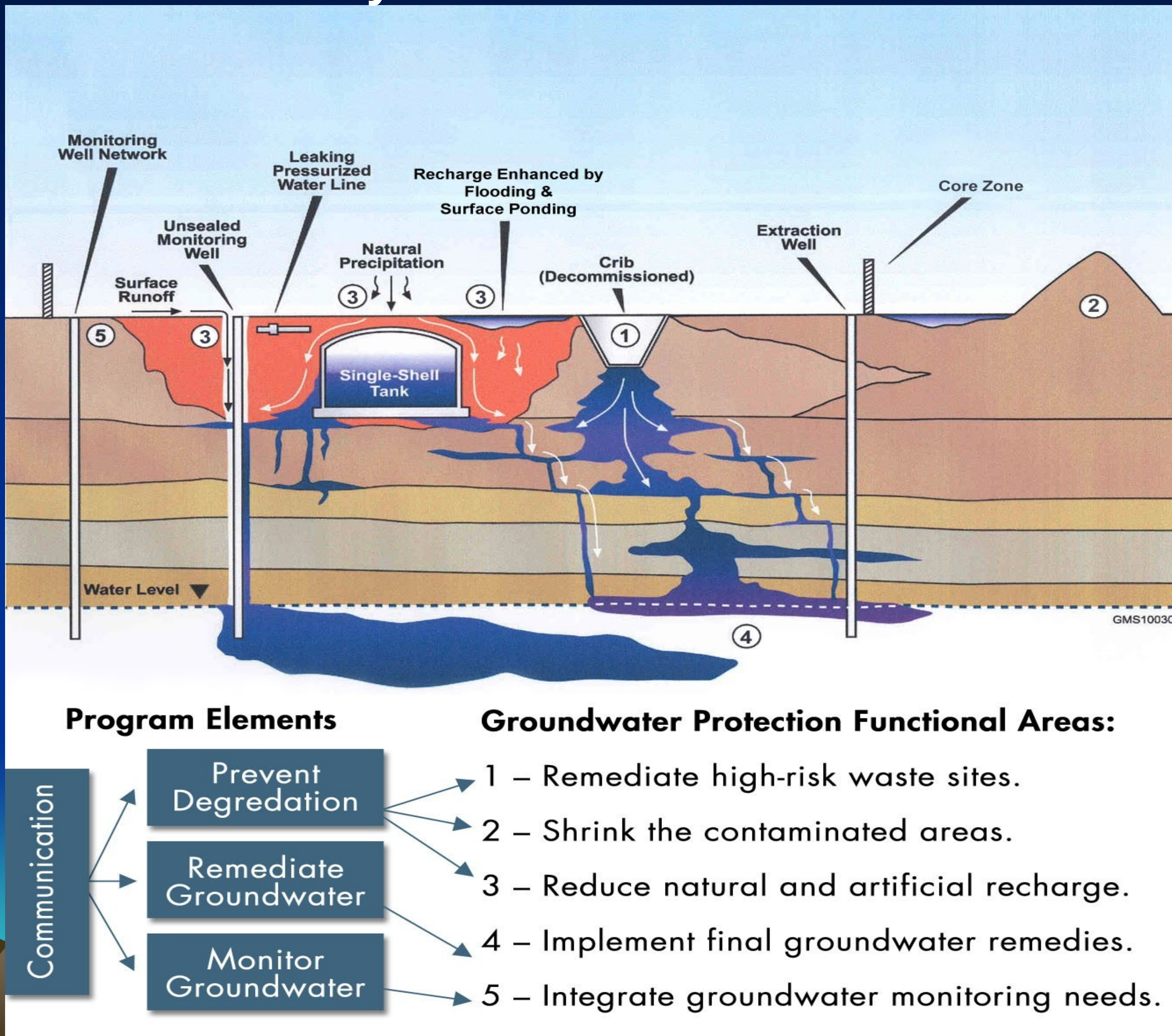
Adaptive Stochastic Control System with Feedback Loop

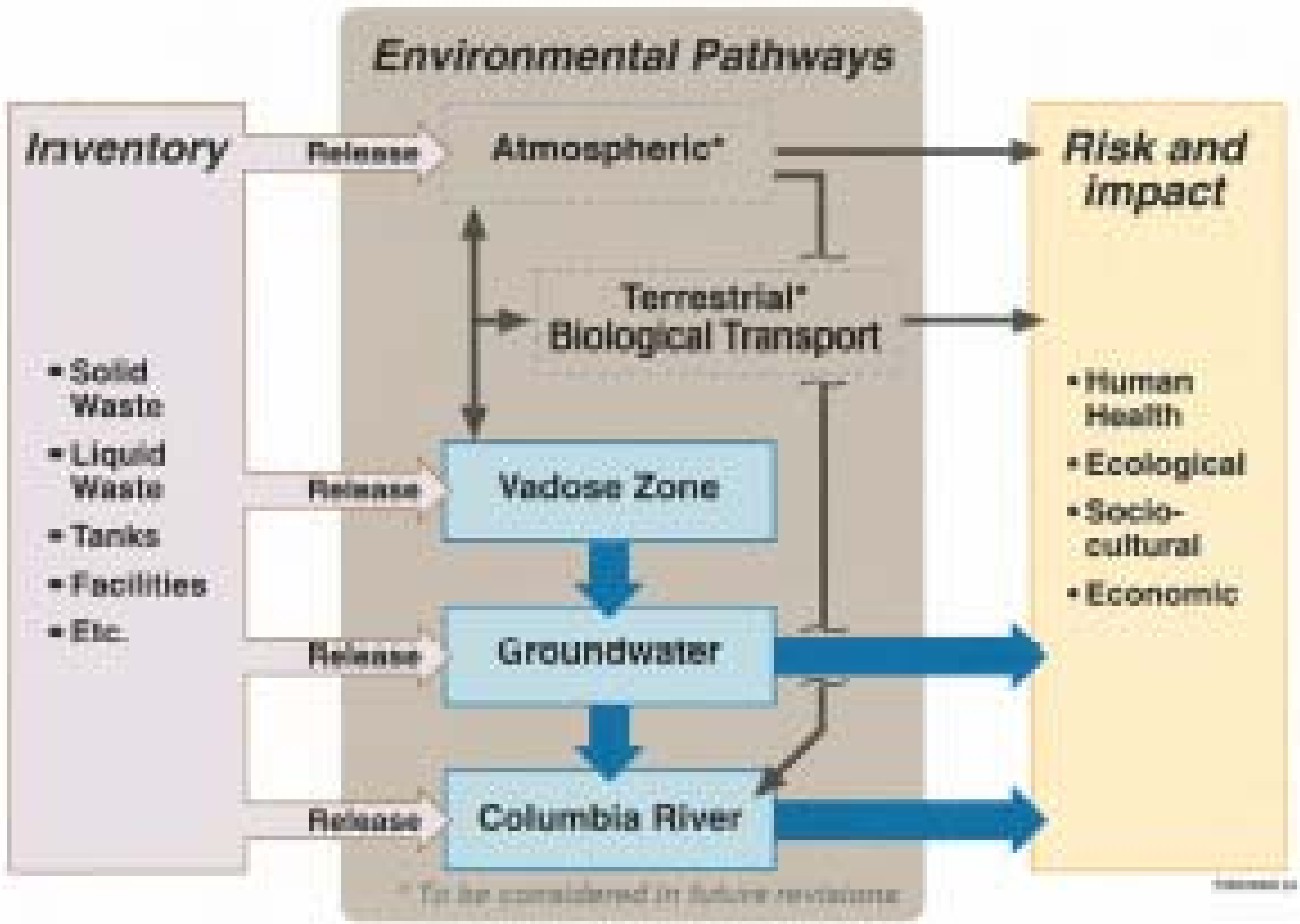


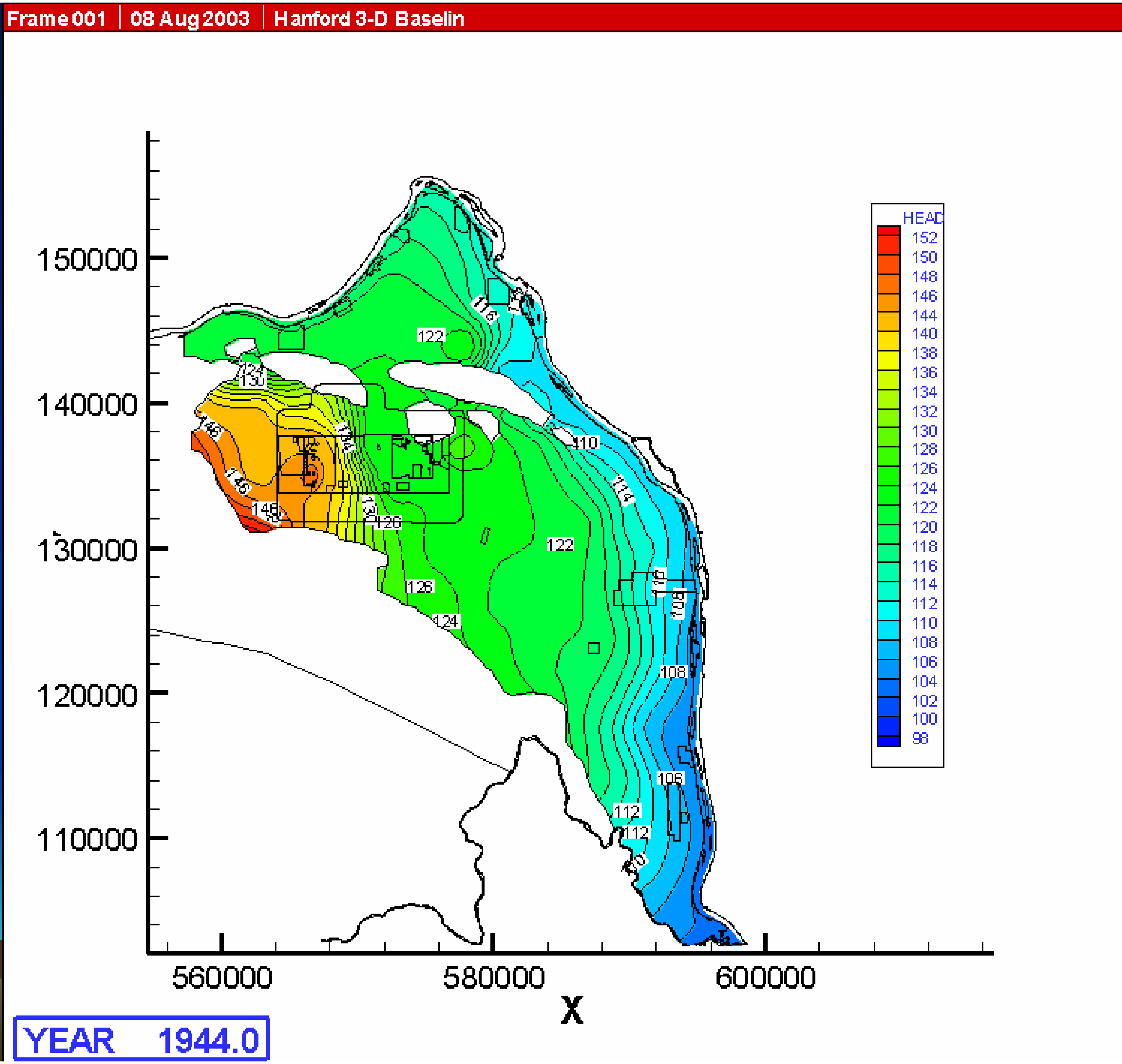


Probabilistic Transport Model
Probability Distribution of chemicals in time & space
Characterization of Site (all relevant areas) Probabilistic
Risk assessment with Uncertainties Other affects: political regulational, etc
Reports
Testing & Data Gathering Program [Optimal]
No
Uncertainties Low Enough
Yes
Risks Low Enough
No
No
Remediation
Yes
Remediation Cost Decision
Yes
Submit Reports
Monitoring

System to be Modeled




Environmental Pathways
Inventory
• Solid Waste
• Liquid Waste
• Tanks
• Facilities
• Etc.
Release
Release
Release
Release
Atmospheric*
Terrestrial* Biological Transport
Vadose Zone
Groundwater
Columbia River
Risk and Impact
• Human Health
• Ecological
• Socio-cultural
• Economic
* To be considered in future revisions


Frame 001
08 Aug 2003
Hanford 3-D Baselin
150000
140000
130000
120000
110000
560000
580000
600000
X
HEAD
152
150
148
146
144
140
138
136
134
132
130
128
126
124
122
120
118
116
114
112
110
108
106
104
102
100
98
YEAR 1944.0

Panel on Decision Tools for Hanford Central Plateau

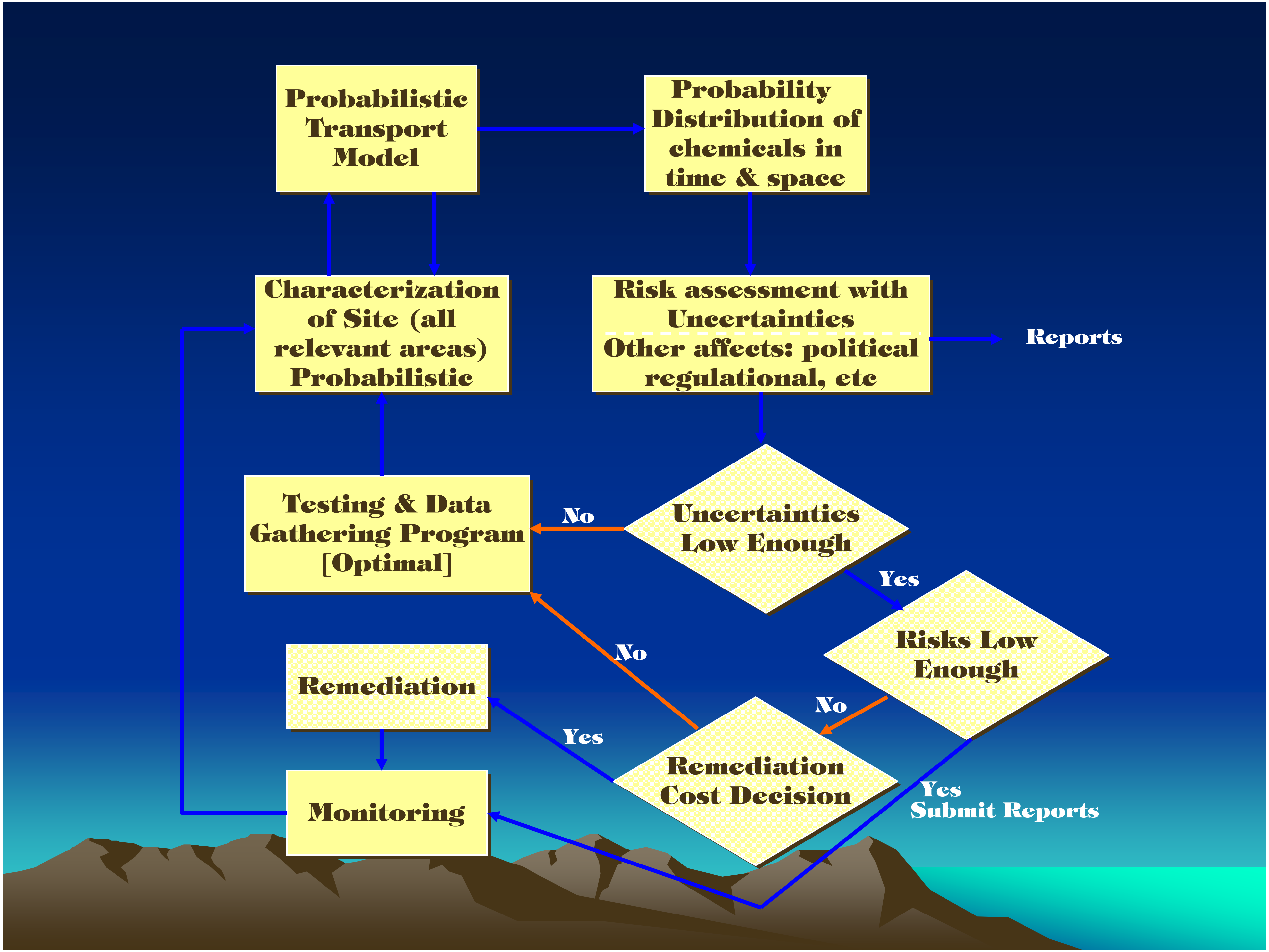
- Michael Celia, Princeton University
- Clint Dawson, University of Texas
- Dennis McLaughlin, MIT
- Shlomo Neuman, University of Arizona
- Dean Oliver, University of Oklahoma

Issues Addressed

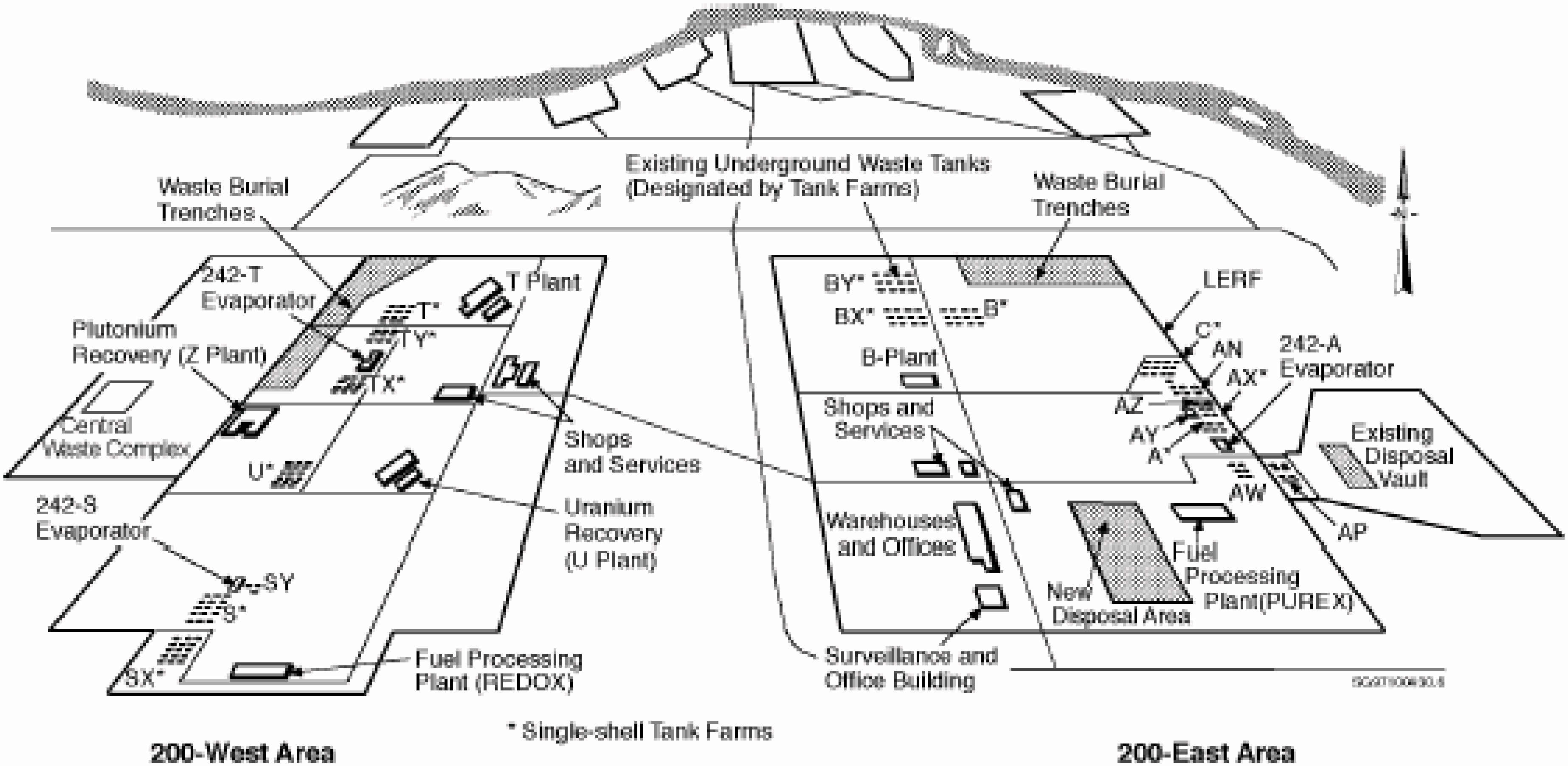
- How should uncertainties be handled? How should they be quantified and conveyed to the reader?
- How should the models be verified and calibrated? What role should history matching play in this process?
- What are the technical specifications for computational codes to be used in the decision process for the operable units?

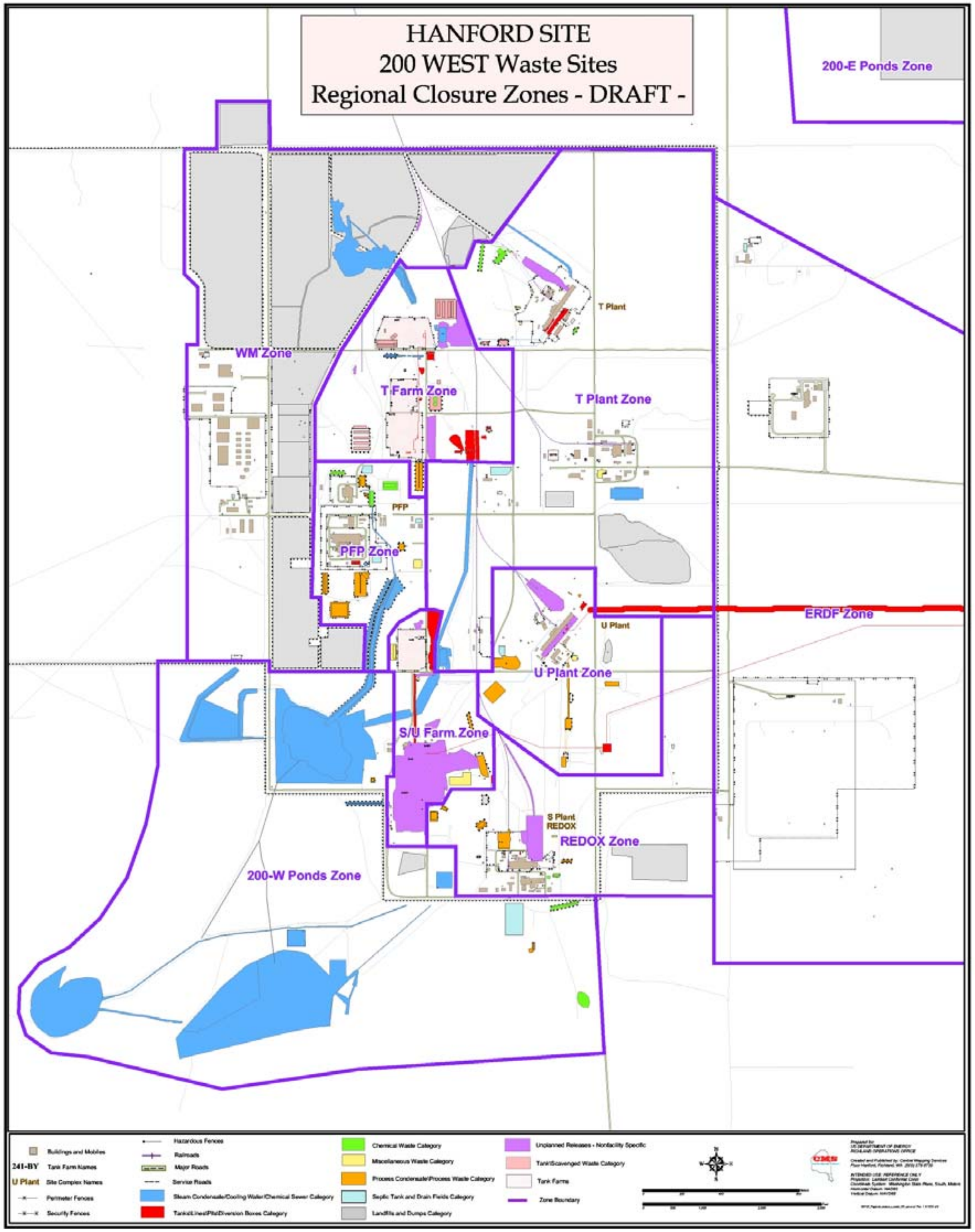
Some Data Issues

- Quantify measurement errors.
- Characterize spatial variability.
- Upscale/downscale data to common support or modeling scales.
- Quantify data and model input uncertainties.
- Investigate the incremental benefit of history matching in the vadose zone.

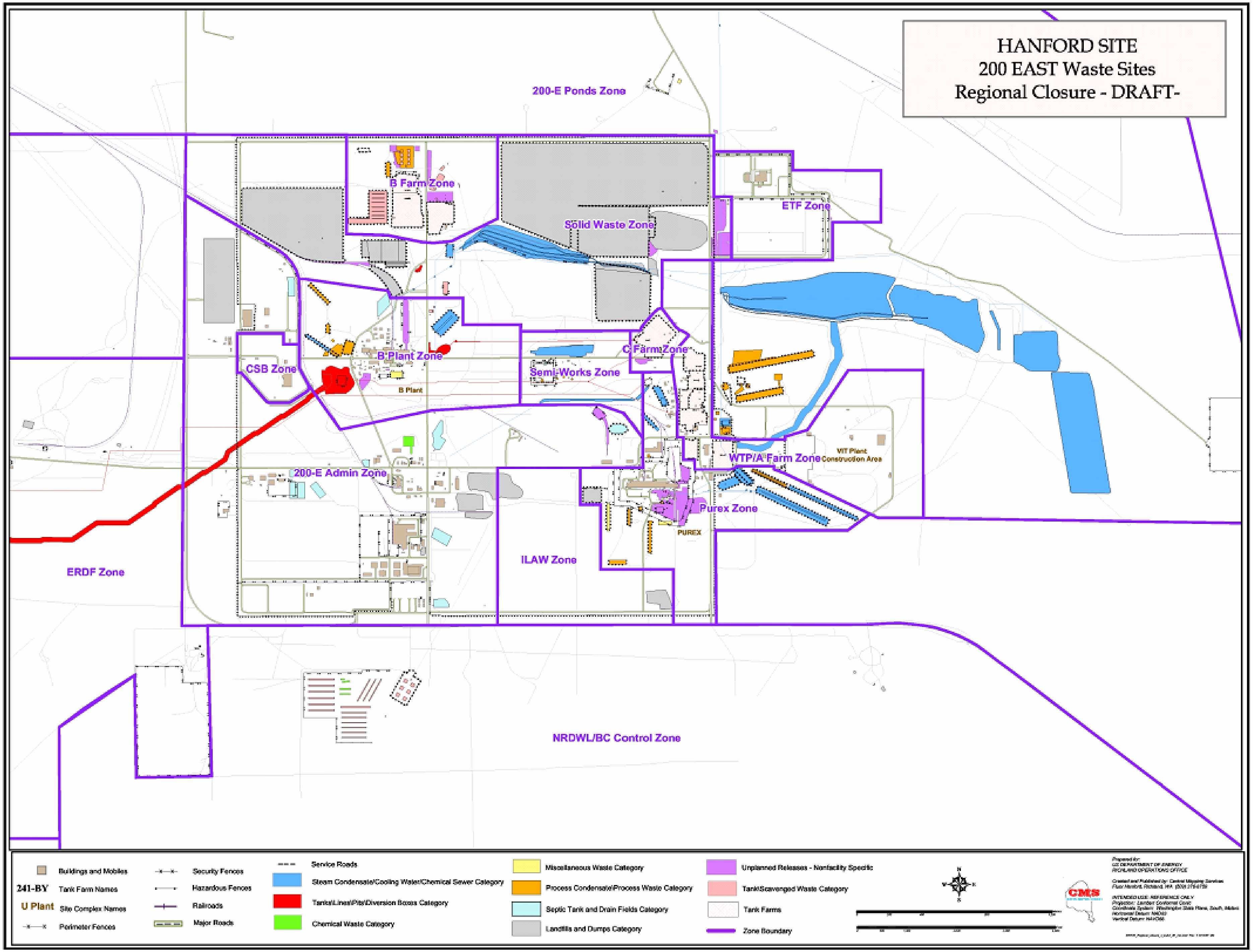

Probabilistic Transport Model
Probability Distribution of chemicals in time & space
Characterization of Site (all relevant areas) Probabilistic
Risk assessment with Uncertainties
Other affects: political regulational, etc
Reports
Testing & Data Gathering Program [Optimal]
No
Uncertainties Low Enough
Yes
Risks Low Enough
No
No
Remediation
Yes
Remediation Cost Decision
Yes
Submit Reports
Monitoring

Central Plateau





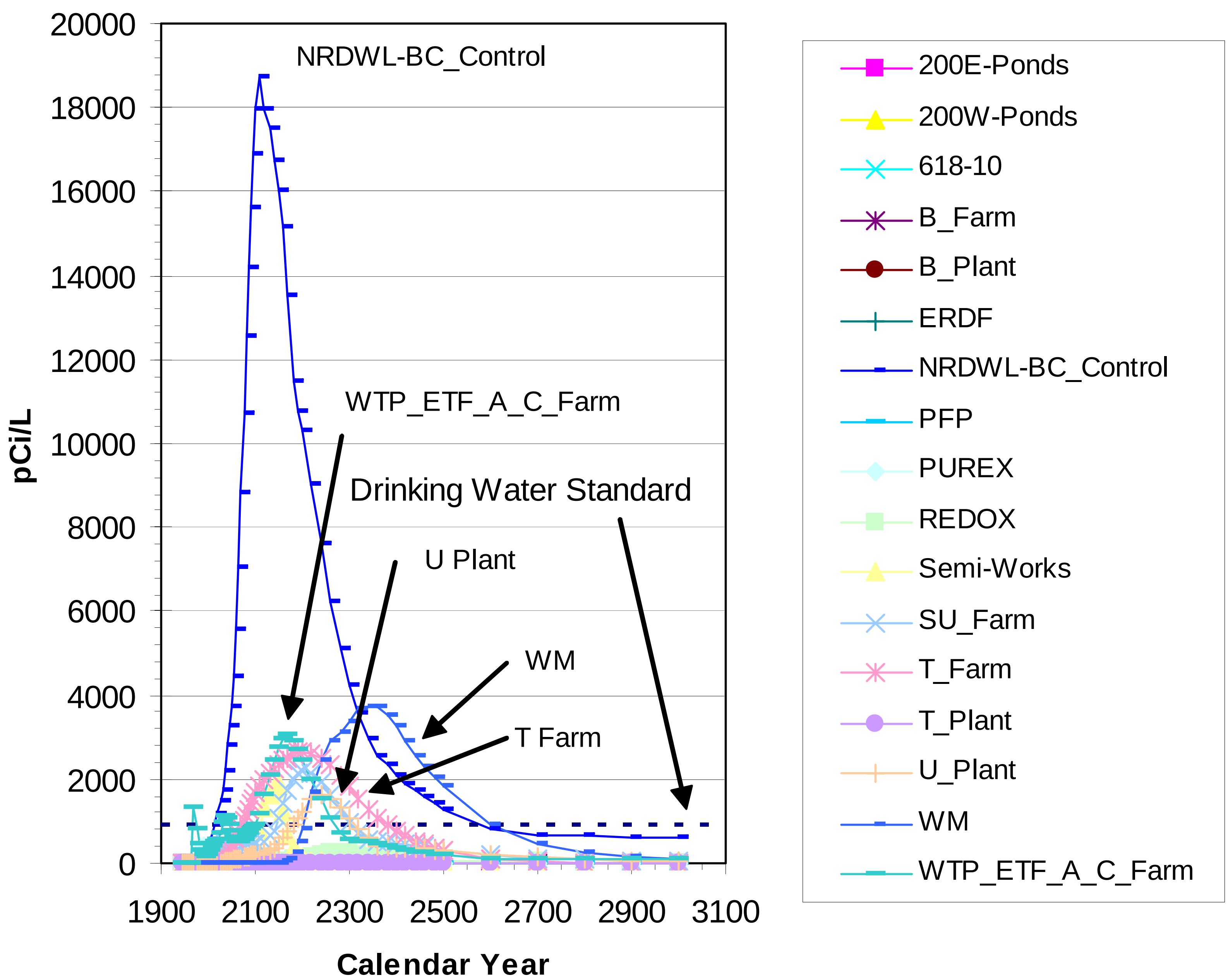
HANFORD SITE
200 WEST Waste Sites
Regional Closure Zones - DRAFT -
200-E Ponds Zone
WM Zone
T Plant
T Farm Zone
T Plant Zone
PFP
PFP Zone
ERDF Zone
U Plant
U Plant Zone
S/U Farm Zone
S Plant
REDOX
REDOX Zone
200-W Ponds Zone
Buildings and Mobiles
241-BY Tank Farm Names
U Plant Site Complex Names
Perimeter Fences
Security Fences
Hazardous Fences
Railroads
Major Roads
Service Roads
Steam Condensate/Cooling Water/Chemical Sewer Category
Tanks/Lines/Pits/Diversion Boxes Category
Chemical Waste Category
Miscellaneous Waste Category
Process Condensate/Process Waste Category
Septic Tank and Drain Fields Category
Landfills and Dumps Category
Unplanned Releases - Nonfacility Specific
Tank/Scavenged Waste Category
Tank Farms
Zone Boundary


HANFORD SITE
200 EAST Waste Sites
Regional Closure - DRAFT-
200-E Ponds Zone
B Farm Zone
Solid Waste Zone
ETF Zone
C Farm Zone
B Plant Zone
CSB Zone
Semi-Works Zone
B Plant
WTP/A Farm Zone
VIT Plant
Construction Area
200-E Admin Zone
Purex Zone
PUREX
ILAW Zone
ERDF Zone
NRDWL/BC Control Zone
Buildings and Mobiles
241-BY
Tank Farm Names
U Plant
Site Complex Names
Perimeter Fences
Security Fences
Hazardous Fences
Railroads
Major Roads
Service Roads
Steam Condensate/Cooling Water/Chemical Sewer Category
Tanks/Lines/Pits/Diversion Boxes Category
Chemical Waste Category
Miscellaneous Waste Category
Process Condensate/Process Waste Category
Septic Tank and Drain Fields Category
Landfills and Dumps Category
Unplanned Releases - Nonfacility Specific
Tank/Scavenged Waste Category
Tank Farms
Zone Boundary
CMS

Preliminary Regional Closure Zone Priorities

CLOSURE ZONE See Figures 1-1 through 1-3)	Number of Locations Requiring Closure[1]	Future Groundwater Contamination Concerns	Intrusion Concerns (TRU Waste Residuals)	Radiological Cleanup Operations Concerns
Zone does not support Hanford cleanup operations				
U Plant Zone	103	^{99}Tc, U, ^{129}I	U	-
Non Radioactive Disposal Waste Landfill and BC Cribs (NRDWL/BC) Control Zone	37	^{99}Tc, ^{129}I	-	-
PUREX Zone	224	^{129}I, H_3	Pu	Pu, Cs, Sr
Plutonium Finishing Plant (PFP) Zone	133	Pu, CCl_4	Pu	Pu
C Farm Zone	53	^{99}Tc	Pu	Pu, Cs, Sr
B Farm Zone	119	^{99}Tc, U, ^{129}I	Pu	Pu, Cs, Sr
T Farm Zone	144	^{3}H, ^{99}Tc, ^{129}I	Pu	Pu, Cs, Sr
618-10 & 11 Zone	4	^{3}H	-	Pu, Cs, Sr
Fast Flux Test Facility Zone	90	-	-	-
Semi-Works Zone	48	-	Pu	Pu, Cs, Sr
200 West Ponds Zone	37	U	Pu	-
Zone supports Hanford cleanup operations & opportunities exist to alter plans and allow earlier cleanup				
B Plant Zone[4]	205	^{90}Sr, ^{137}Cs, Pu	-	Cs, Sr
East Ponds Zone[5]	72	^{99}Tc, ^{90}Sr, ^{129}I	-	-
Zone supports Hanford cleanup operations				
Reduction Oxidation (REDOX) Zone[6]	141	^{129}I, ^{3}H	Pu	Pu, Cs, Sr
T Plant Zone	184	^{3}H, CCl_4	Pu	Pu, Cs, Sr
Waste Management Zone	87	^{99}Tc, U	Pu	Pu
S/U Farms Zone[7]	155	^{99}Tc, U	Pu	Pu, Cs, Sr
Environmental Restoration Disposal Facility (ERDF)	64	-	-	-
Waste Treatment Plant and A Farm (WTP/A Farm) Zone	234	^{3}H, ^{99}Tc	Pu	Pu, Cs, Sr
Solid Waste Zone[8]	48	-	Pu	Pu
Immobilized Low Activity Waste (ILAW) Zone	3	^{99}Tc, U, ^{129}I	-	-
200 East Administrative Zone	145	-	-	-
200 Area Effluent Treatment Facility (ETF) Zone	11	-	-	-
Canister Storage Building (CSB) Zone	13	-	-	-

Tc-99 at Zone Boundary with no Covers

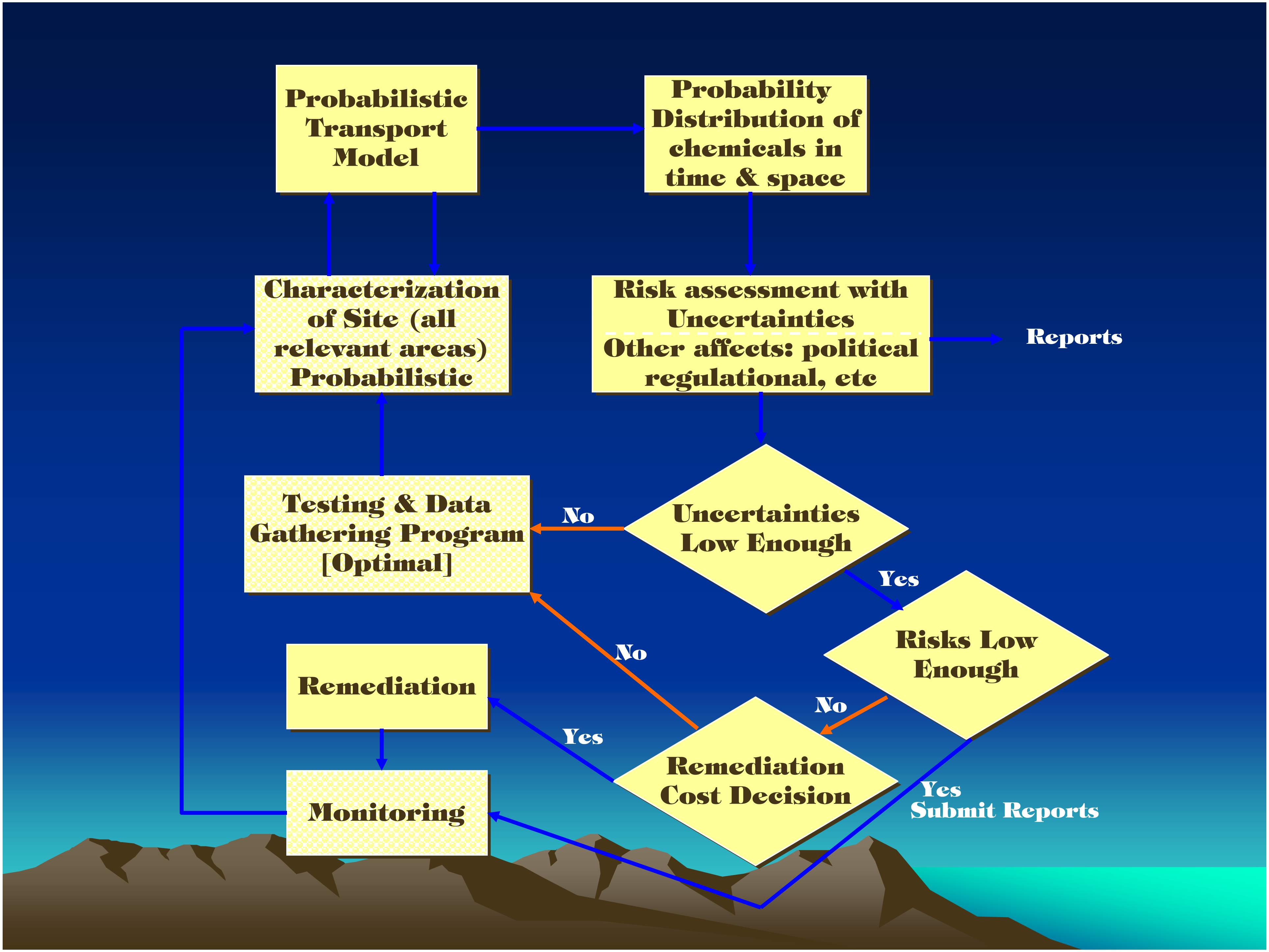


Future Remediation technologies (integrated point of view)

- Removal and disposal actions
  - Moving contaminated material
    - Phyto-remediation of strontium-90
  - Vitrification of wastes
  - Grouting of wastes
  - Excavation of waste and removal of materials to WIPP
  - Pump and treat groundwater
    - Increase capacity with EC Soil vapor extraction
    - Six-phase heating Enhanced volitalization of chlorinated hydrocarbons

Remediation technologies (integrated point of view)

- Immobilization of contaminants left in place
  - Sequestration of contaminants through a chemically reactive zone
    - ISRM
    - Near shore strontium-90 infiltration barrier
    - Micron-sized elemental iron injection
  - direct application of reacting chemicals
    - Calcium polysulfide injection
    - Bio-reduction of chromium
    - Polyphosphate injection for uranium
    - Bio-degradation of carbon tetrachloride
  - Reduce or eliminate water flux to groundwater
    - Caps on landfills (enhanced design capabilities)
    - Desiccation


Probabilistic Transport Model
Probability Distribution of chemicals in time & space
Characterization of Site (all relevant areas) Probabilistic
Risk assessment with Uncertainties
Other affects: political regulational, etc
Reports
Testing & Data Gathering Program [Optimal]
No
Uncertainties Low Enough
Yes
Risks Low Enough
No
Remediation
No
Yes
Remediation Cost Decision
Yes
Submit Reports
Monitoring

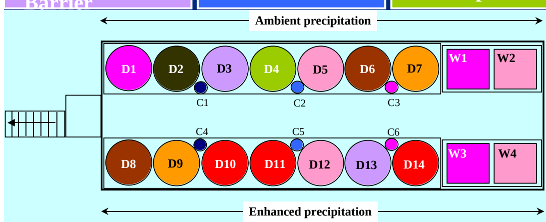
Types of Conditions Needing VZ Instrumentation for Characterization & Monitoring

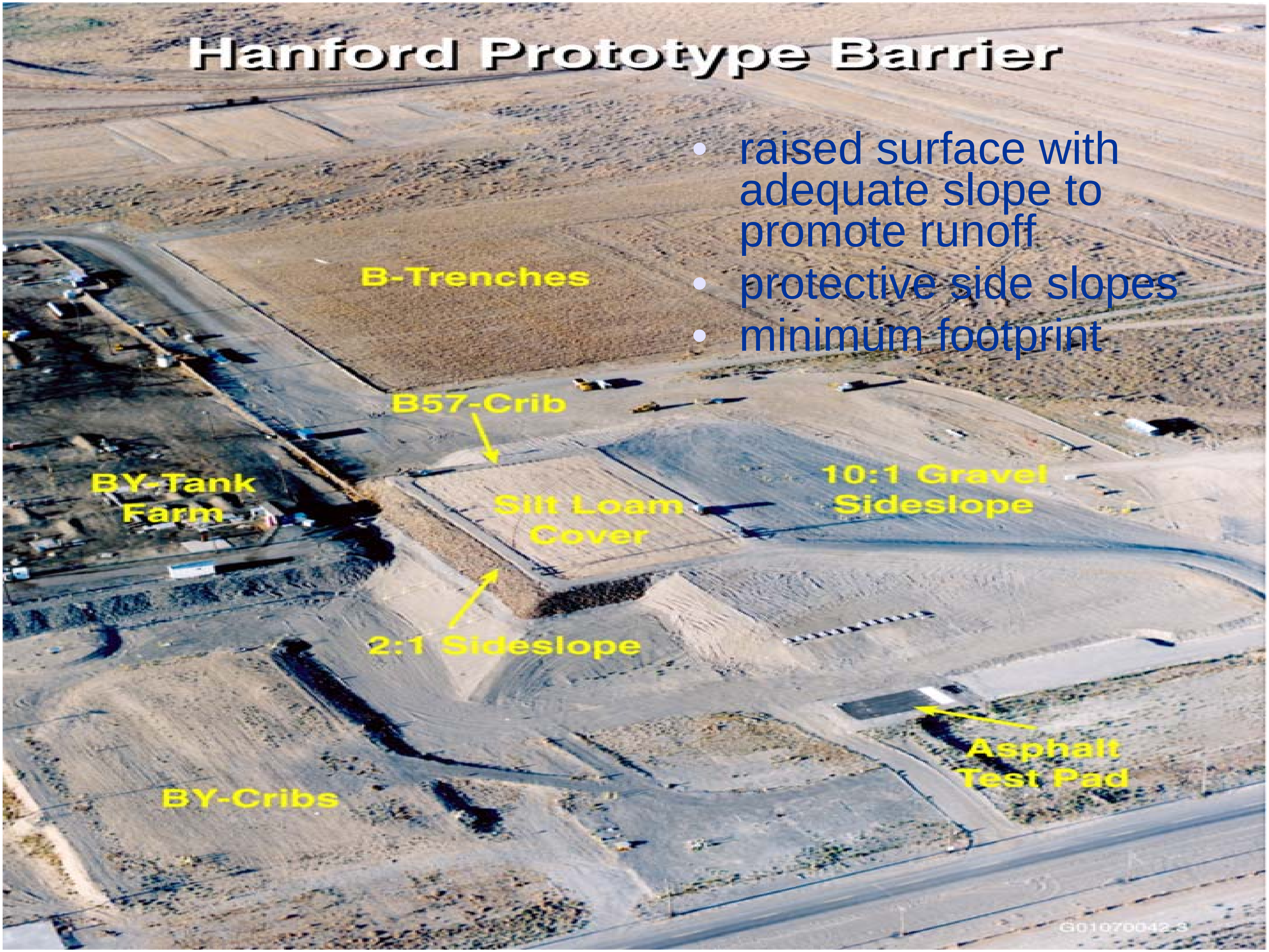
- Waste Sites (Cribs and Trenches)
- Tank Farm Sites
- Canyon Buildings (Reactor buildings)
- Disposal Facilities (ERDF and IDF)
- Liquid Effluent Retention Facilities
- Low-Level Burial Grounds

Field Lysimeter Test Facility (October 2003)

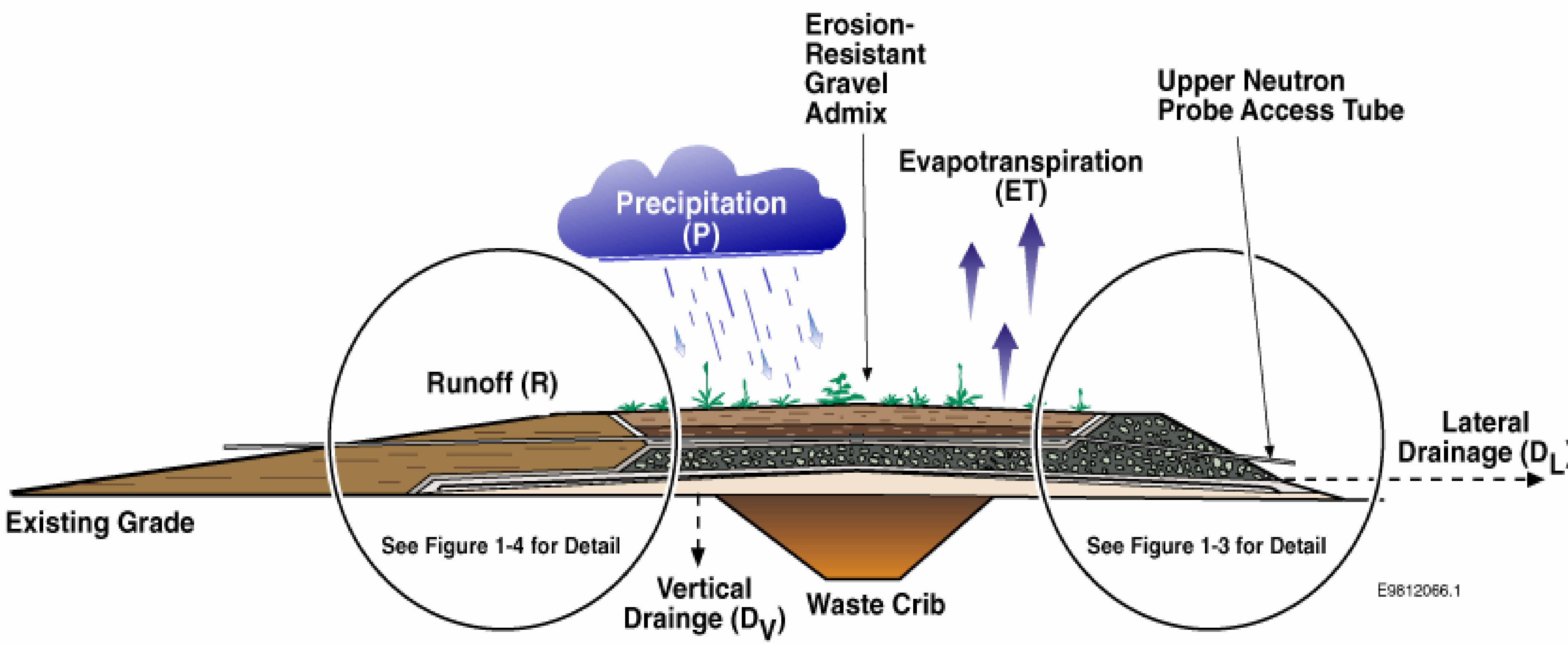
- New Test Matrix

Hanford Barrier	Gravel Mulch	Basalt Sideslope	Hanford Barrier w/Dune Sand	Modified RCRA Subtitle C Cover
Eroded Hanford Barrier	Pitrun Gravel	Sandy Gravel Sideslope	Sand Dune Migration	Glass WasteForm Tests




Hanford Prototype Barrier
• raised surface with adequate slope to promote runoff
• protective side slopes
• minimum footprint
B-Trenches
B57-Crib
BY-Tank Farm
Silt Loam Cover
10:1 Gravel Sideslope
2:1 Sideslope
BY-Cribs
Asphalt Test Pad

Prototype Surface Barrier
(vertical cross-section)



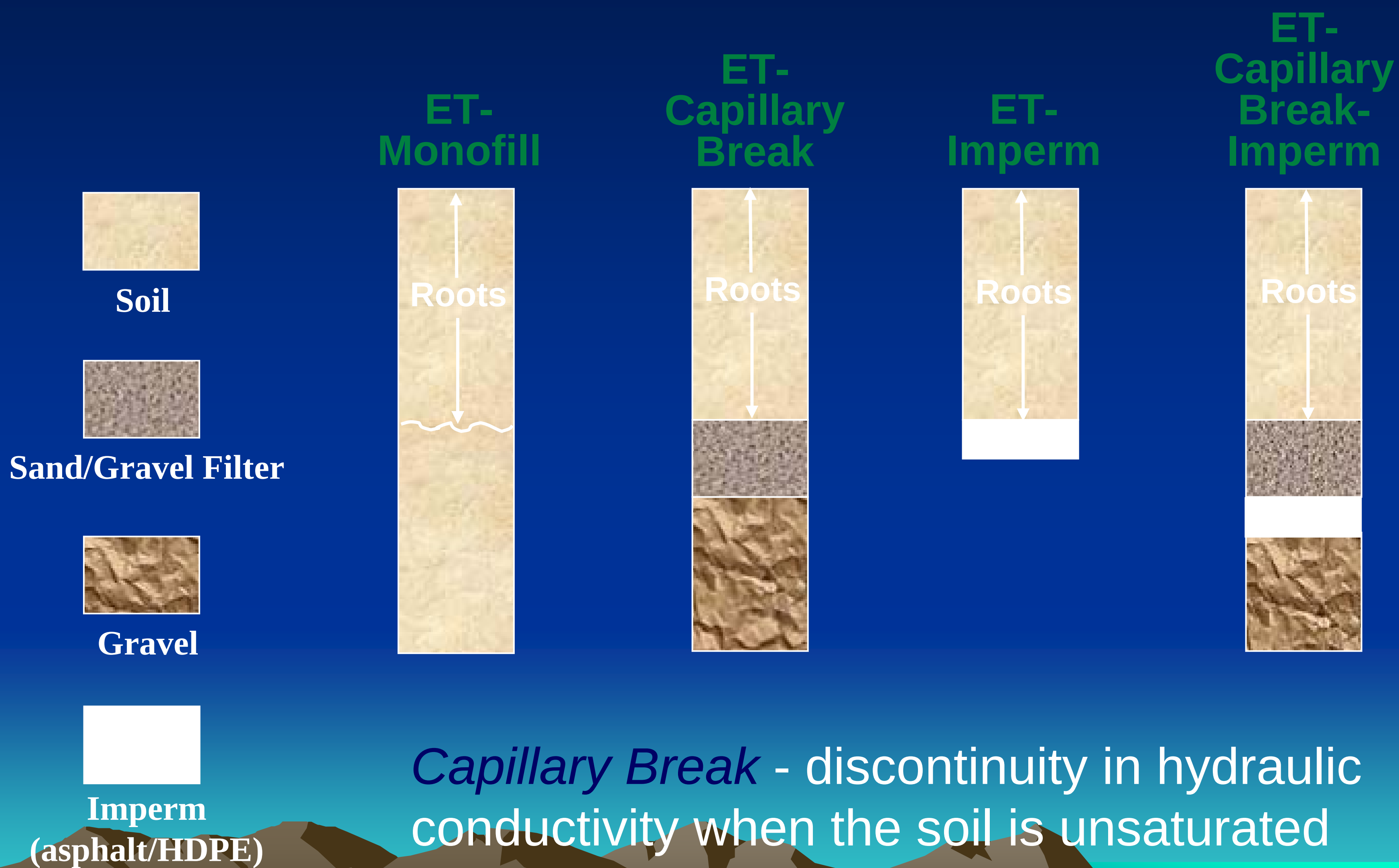
Current Monitoring Scope

– Water balance monitoring

– Vegetation and animal use surveys

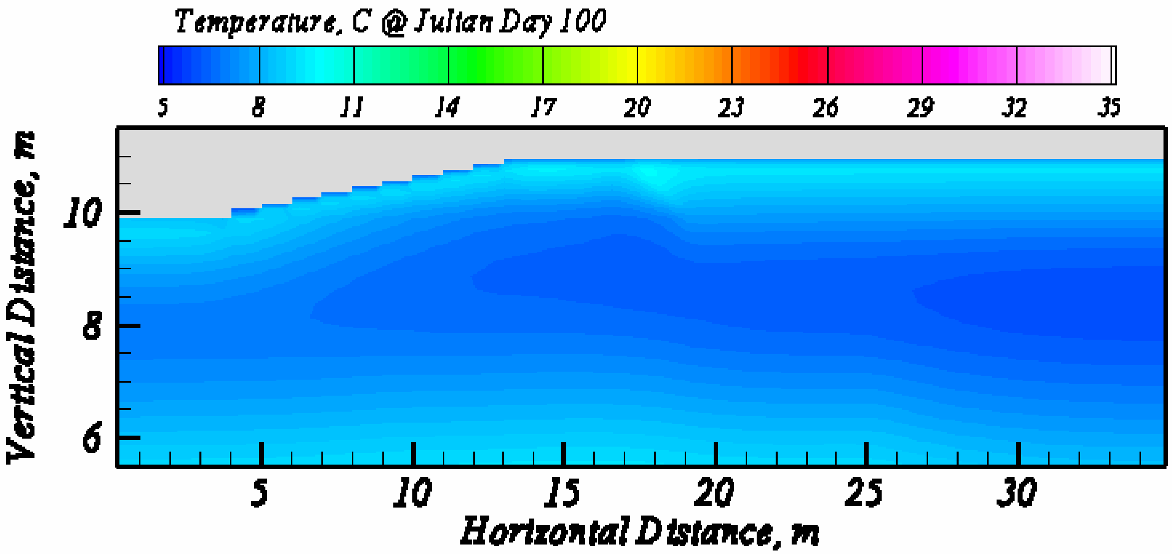
– Stability surveys
  - settlement
  - surface topography
  - riprap side slope stability

Example Designs for ET Covers

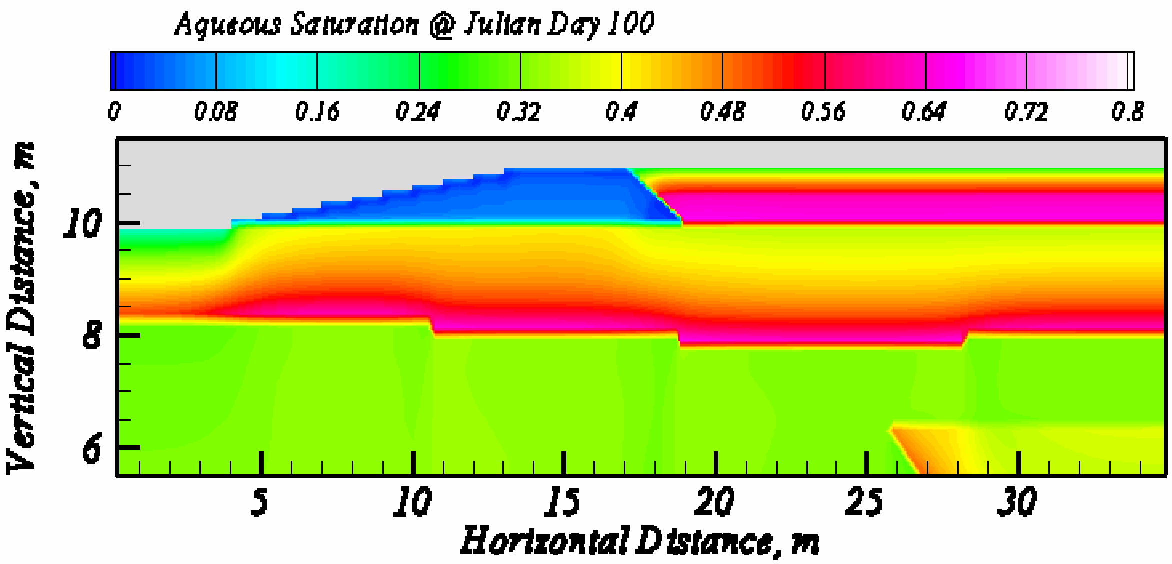


Capillary Break - discontinuity in hydraulic conductivity when the soil is unsaturated

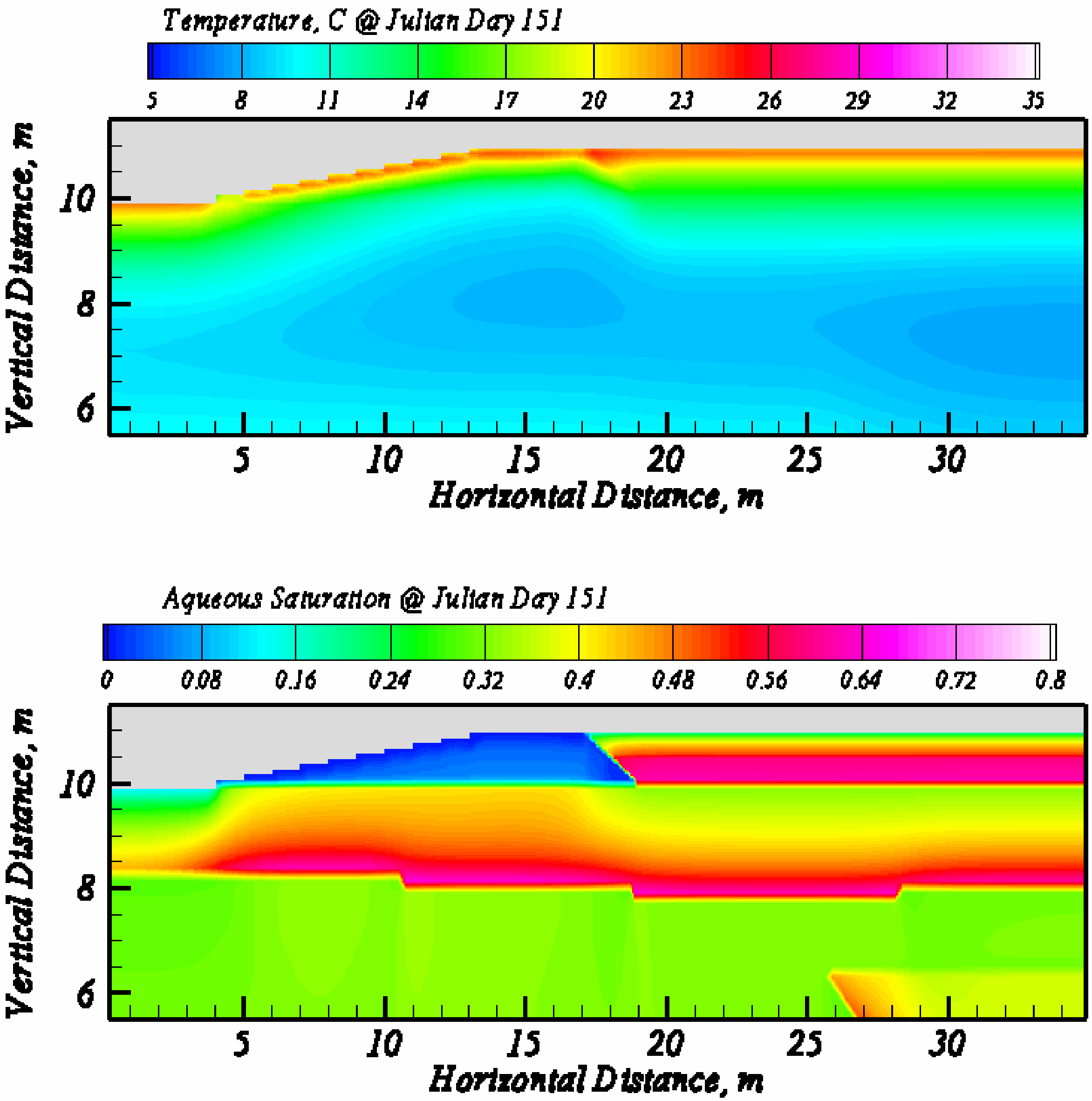
- – e.g., Silt loam/ sand; Sand/gravel; Gravel/silt loam

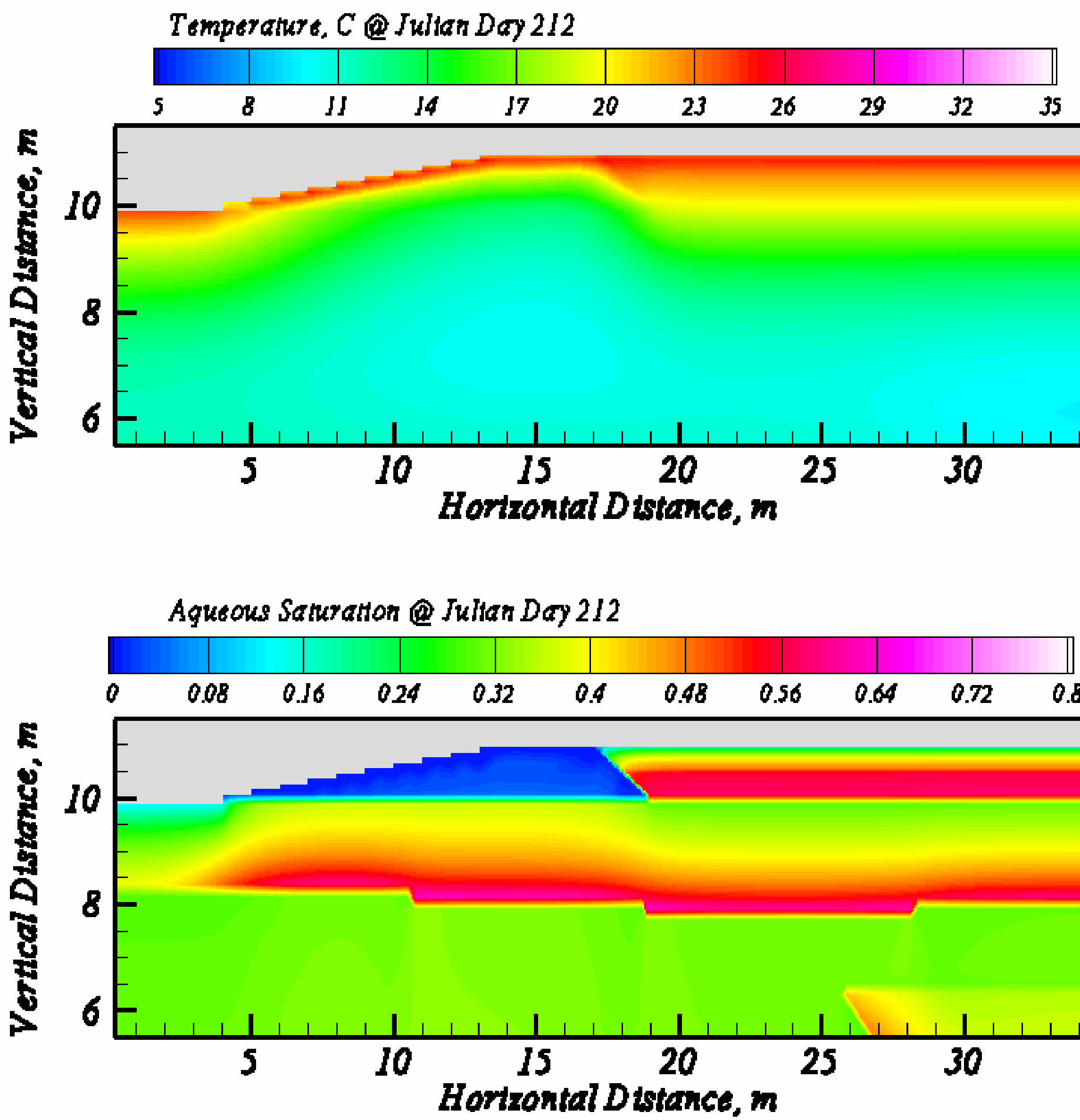


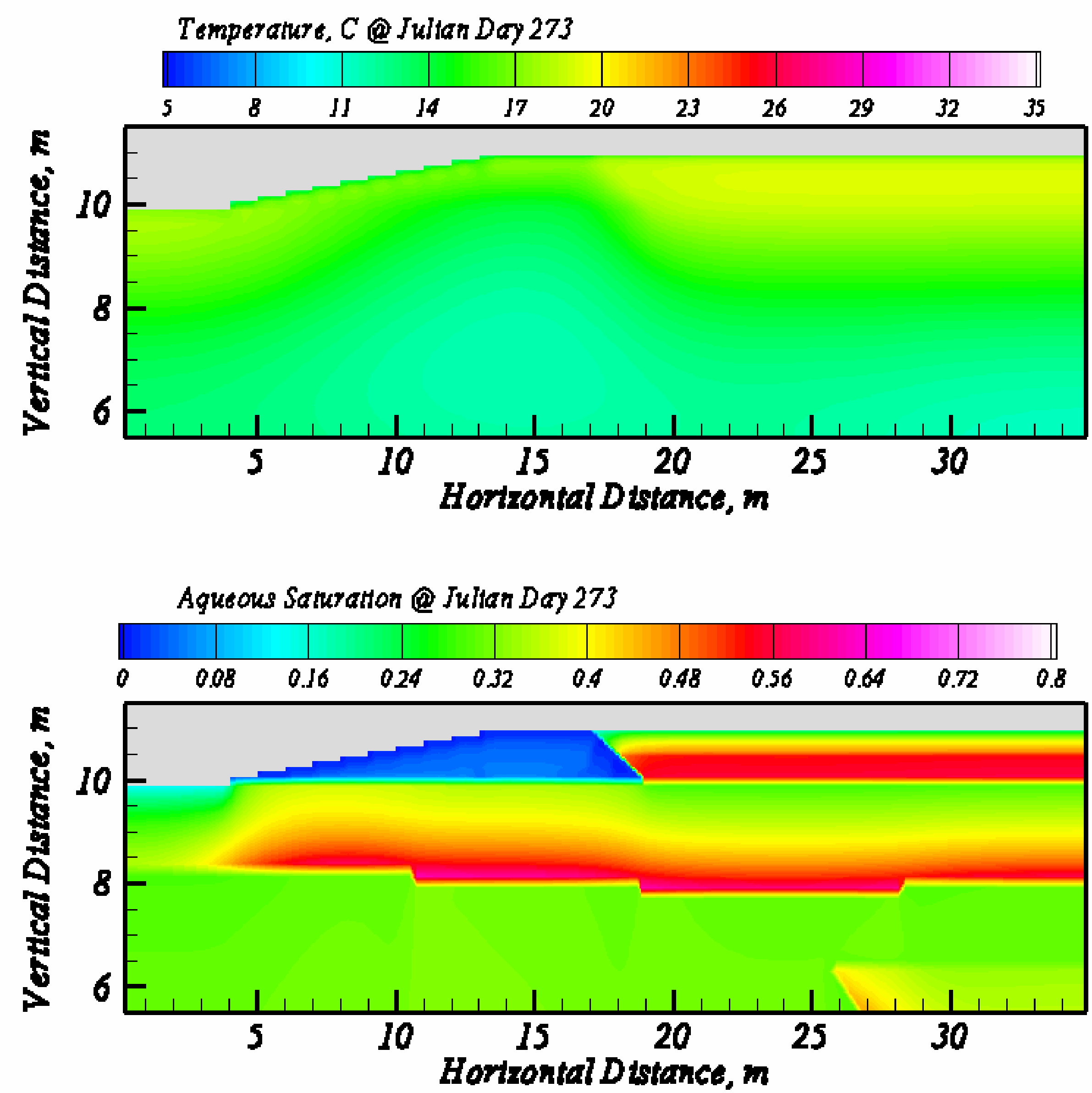
Temperature, C @ Julian Day 100
5 8 11 14 17 20 23 26 29 32 35
Vertical Distance, m
6 8 10
5 10 15 20 25 30
Horizontal Distance, m



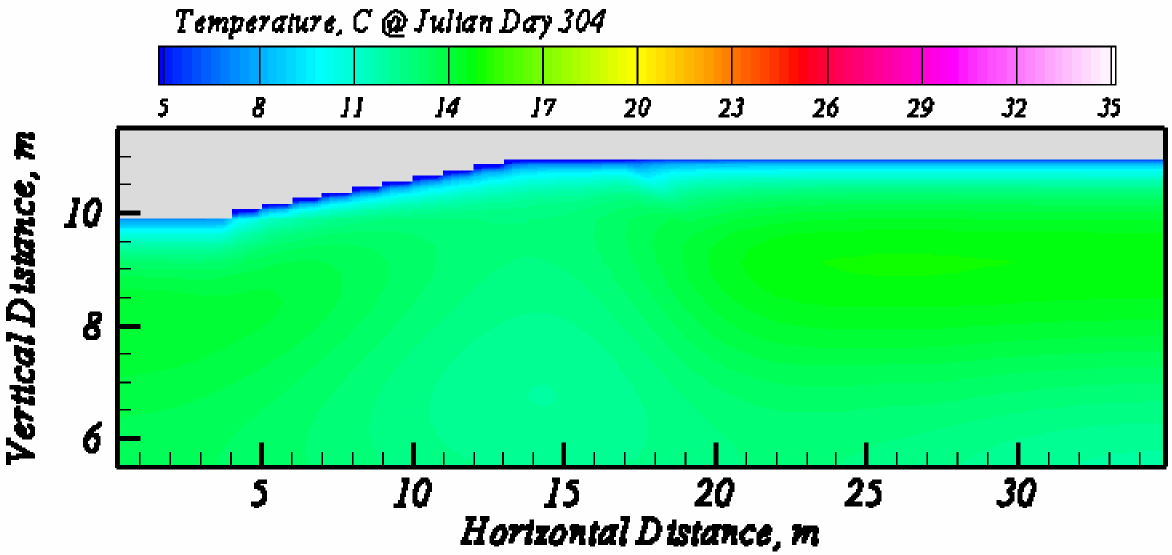
Aqueous Saturation @ Julian Day 100
0 0.08 0.16 0.24 0.32 0.4 0.48 0.56 0.64 0.72 0.8
Vertical Distance, m
6 8 10
5 10 15 20 25 30
Horizontal Distance, m

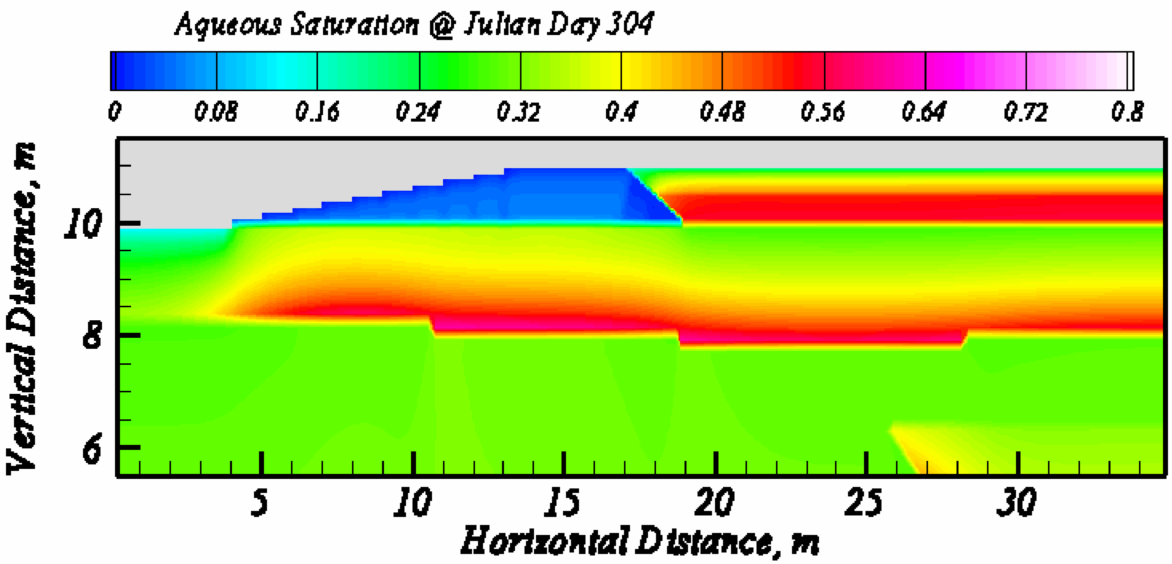

Temperature, C @ Julian Day 151
5
8
11
14
17
20
23
26
29
32
35
Vertical Distance, m
10
8
6
5
10
15
20
25
30
Horizontal Distance, m
Aqueous Saturation @ Julian Day 151
0
0.08
0.16
0.24
0.32
0.4
0.48
0.56
0.64
0.72
0.8
Vertical Distance, m
10
8
6
5
10
15
20
25
30
Horizontal Distance, m

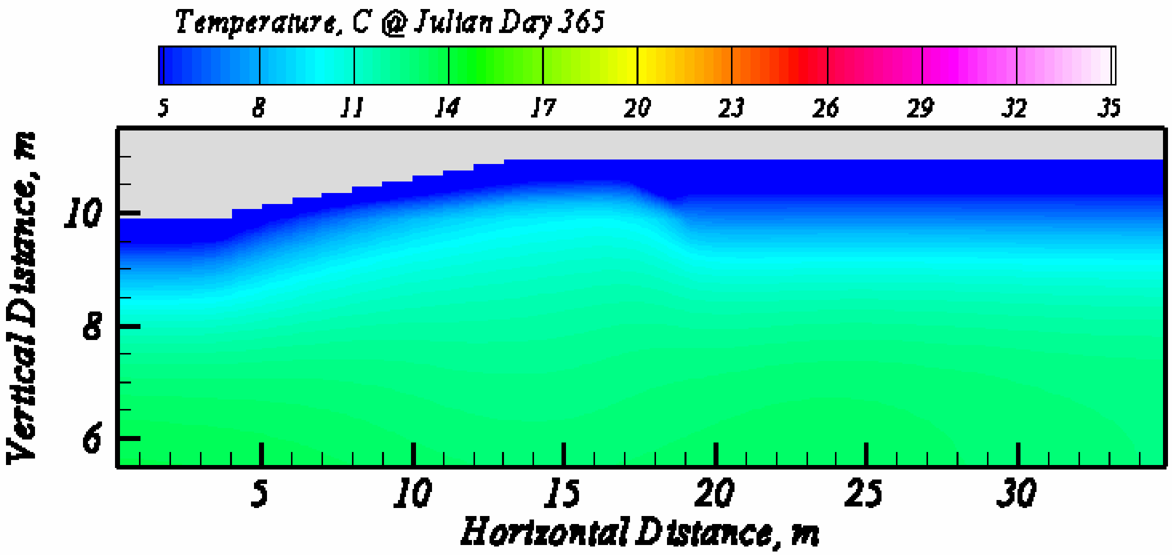

Temperature, C @ Julian Day 212
5
8
11
14
17
20
23
26
29
32
35
Vertical Distance, m
10
8
6
5
10
15
20
25
30
Horizontal Distance, m
Aqueous Saturation @ Julian Day 212
0
0.08
0.16
0.24
0.32
0.4
0.48
0.56
0.64
0.72
0.8
Vertical Distance, m
10
8
6
5
10
15
20
25
30
Horizontal Distance, m

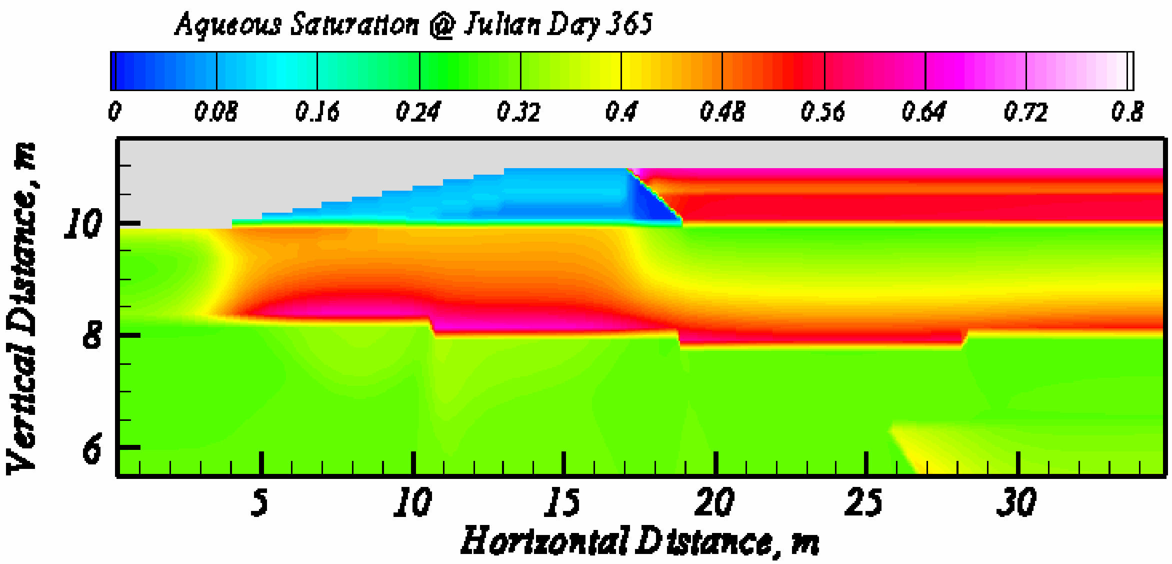


Temperature, C @ Julian Day 273
5 8 11 14 17 20 23 26 29 32 35
Vertical Distance, m
6 8 10
5 10 15 20 25 30
Horizontal Distance, m
Aqueous Saturation @ Julian Day 273
0 0.08 0.16 0.24 0.32 0.4 0.48 0.56 0.64 0.72 0.8
Vertical Distance, m
6 8 10
5 10 15 20 25 30
Horizontal Distance, m


Temperature, C @ Julian Day 304
5
8
11
14
17
20
23
26
29
32
35
Vertical Distance, m
10
8
6
5
10
15
20
25
30
Horizontal Distance, m


Aqueous Saturation @ Julian Day 304
0
0.08
0.16
0.24
0.32
0.4
0.48
0.56
0.64
0.72
0.8
Vertical Distance, m
10
8
6
5
10
15
20
25
30
Horizontal Distance, m


Temperature, C @ Julian Day 365
5
8
11
14
17
20
23
26
29
32
35
Vertical Distance, m
10
8
6
5
10
15
20
25
30
Horizontal Distance, m


Aqueous Saturation @ Julian Day 365
0
0.08
0.16
0.24
0.32
0.4
0.48
0.56
0.64
0.72
0.8
Vertical Distance, m
10
8
6
5
10
15
20
25
30
Horizontal Distance, m


Environmental Restoration Disposal Facility
E0009040.1

VZ Monitoring Technologies
Quantities to Measure

- Moisture change
  - Neutron Probes
  - Time Domain Reflectometry [TDR]
  - Thermocouple Psychrometer
  - Electromagnetic Induction [EMI]
  - Electrical Resistivity Tomography [ERT]
  - Fiber optic cable
  - Flux measurements with SP

Moisture Sampling Methods

- Suction Lysimeter
- Absorbent Pads
- Sodium Iodide Gamma Detector
- Basin Lysimeter
- Associated Chemical Analyses

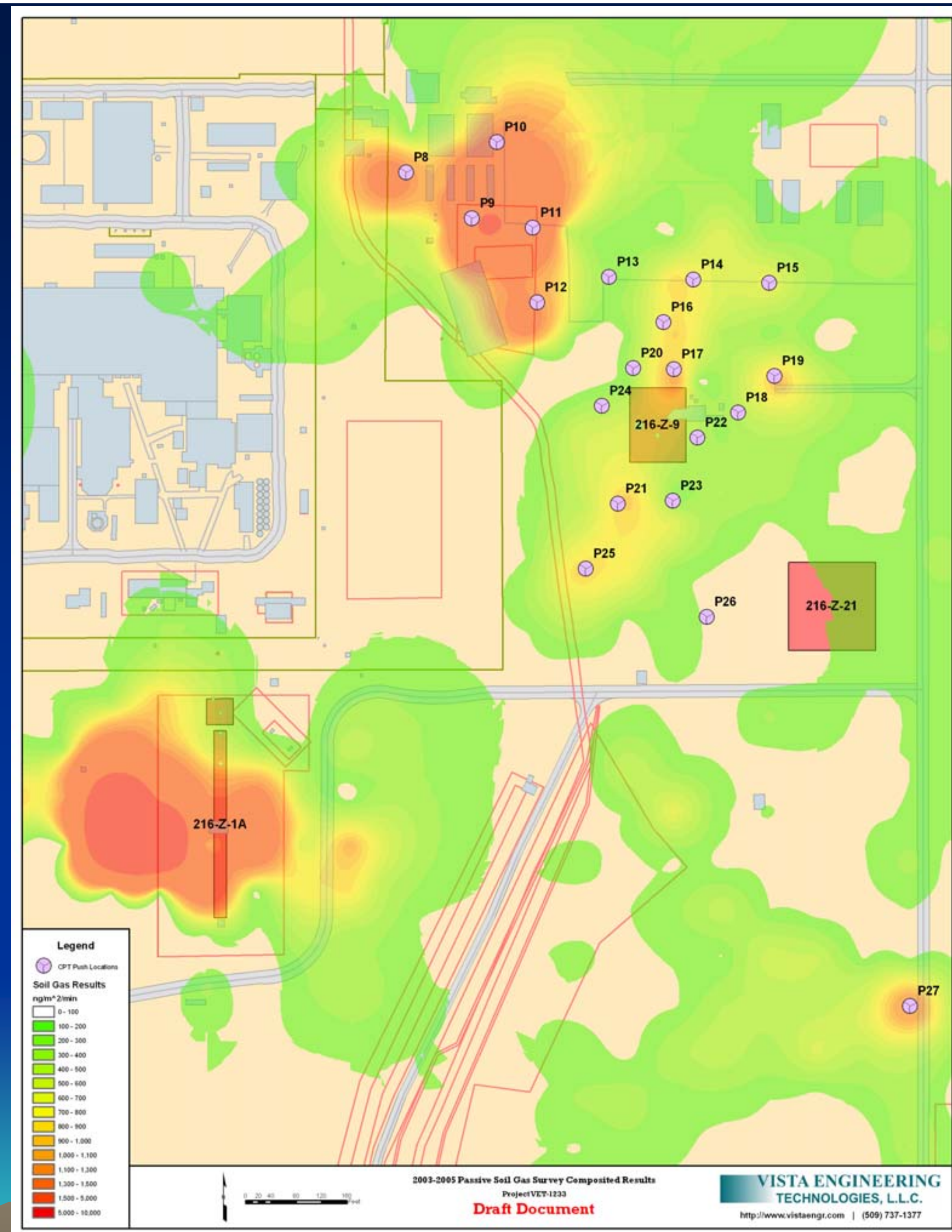
Trends in developing technologies

- More volume integrating
- Better sensitivity
- Better remote sensing [less intrusive]

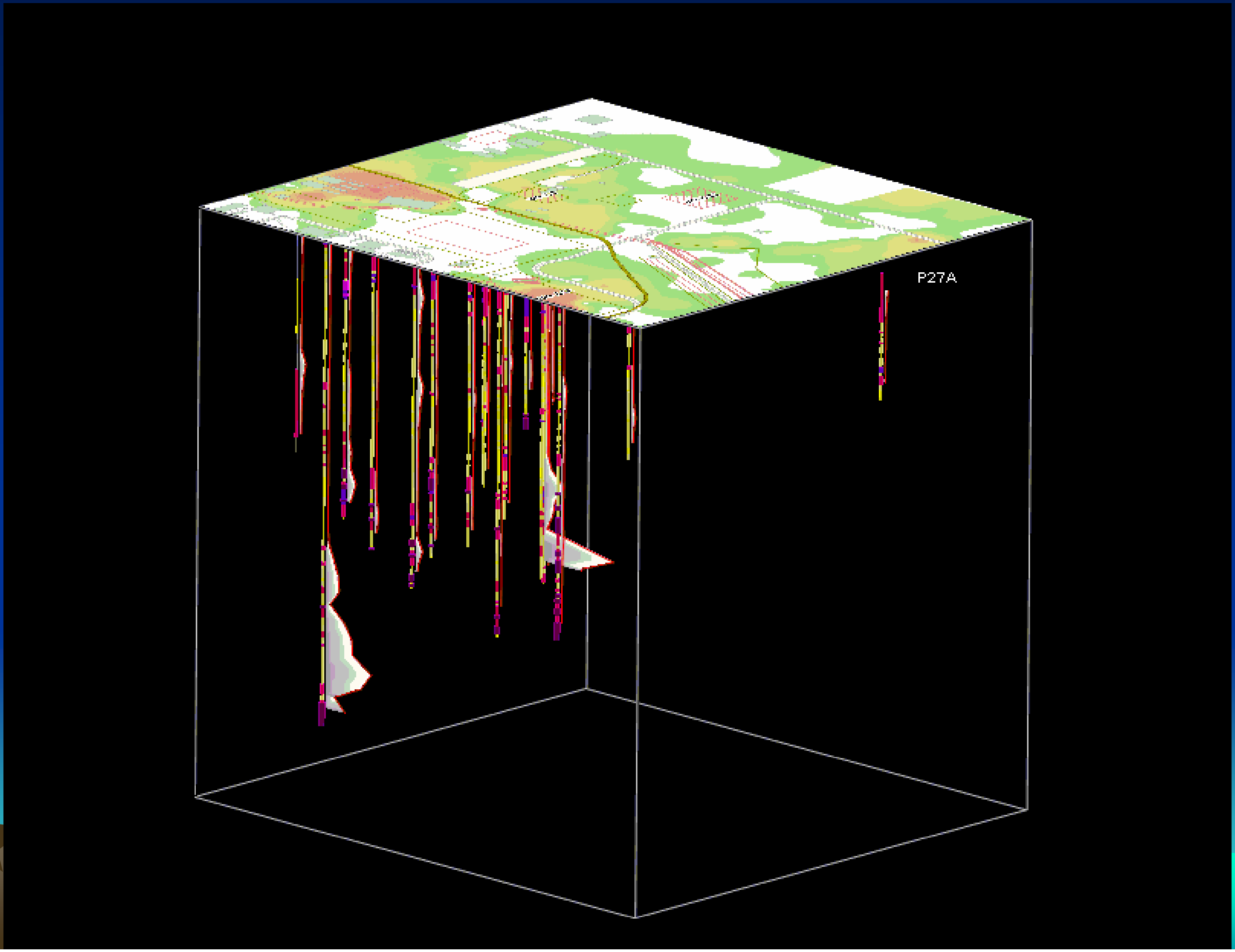
CPT Investigation at 216-Z-9 of Carbon Tetrachloride

20 Locations

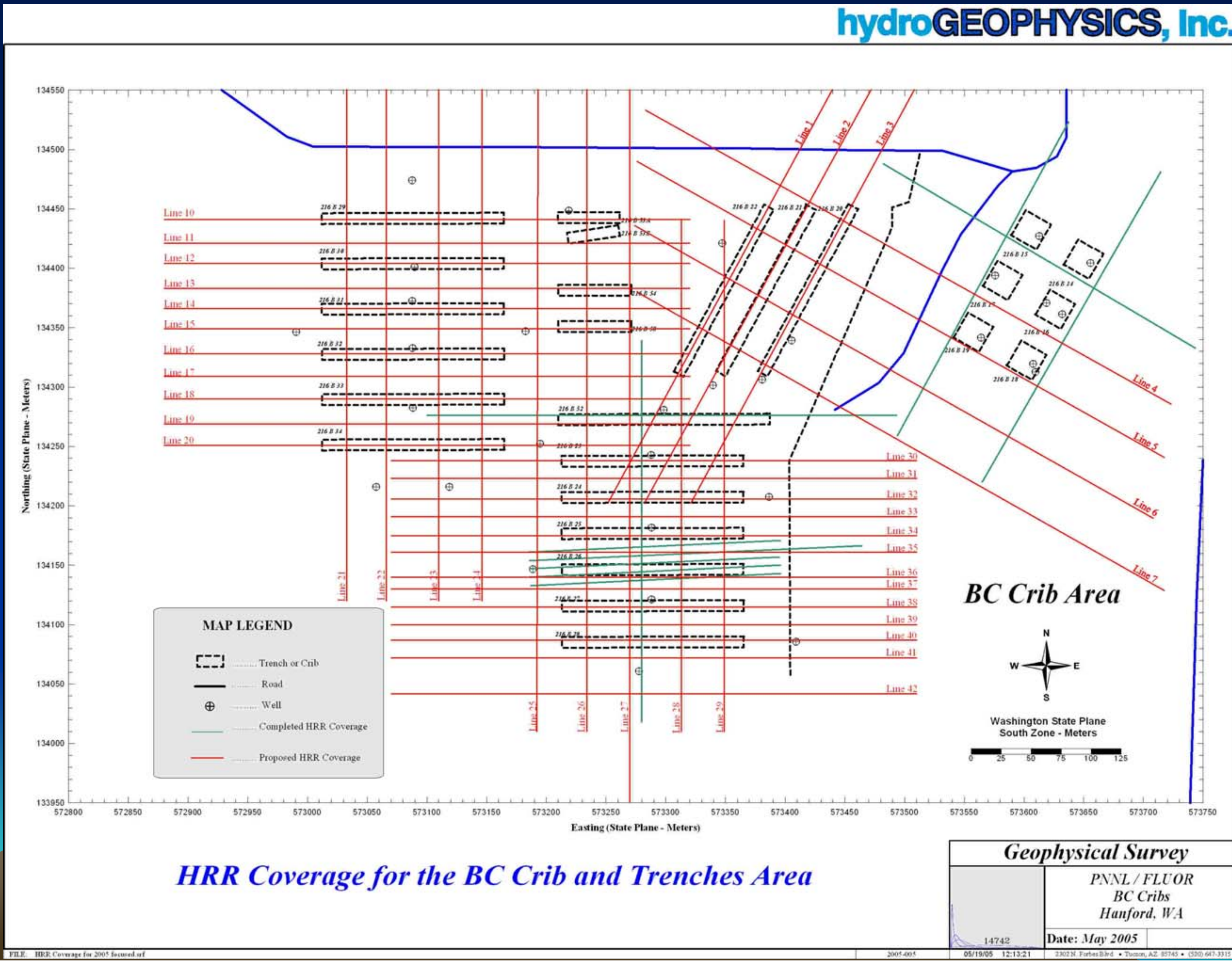
Tip and Sleeve Stress
Total Gamma
Resistivity
Active Soil Gas
Soil Sampling
DNAPL Ribbon Samplers

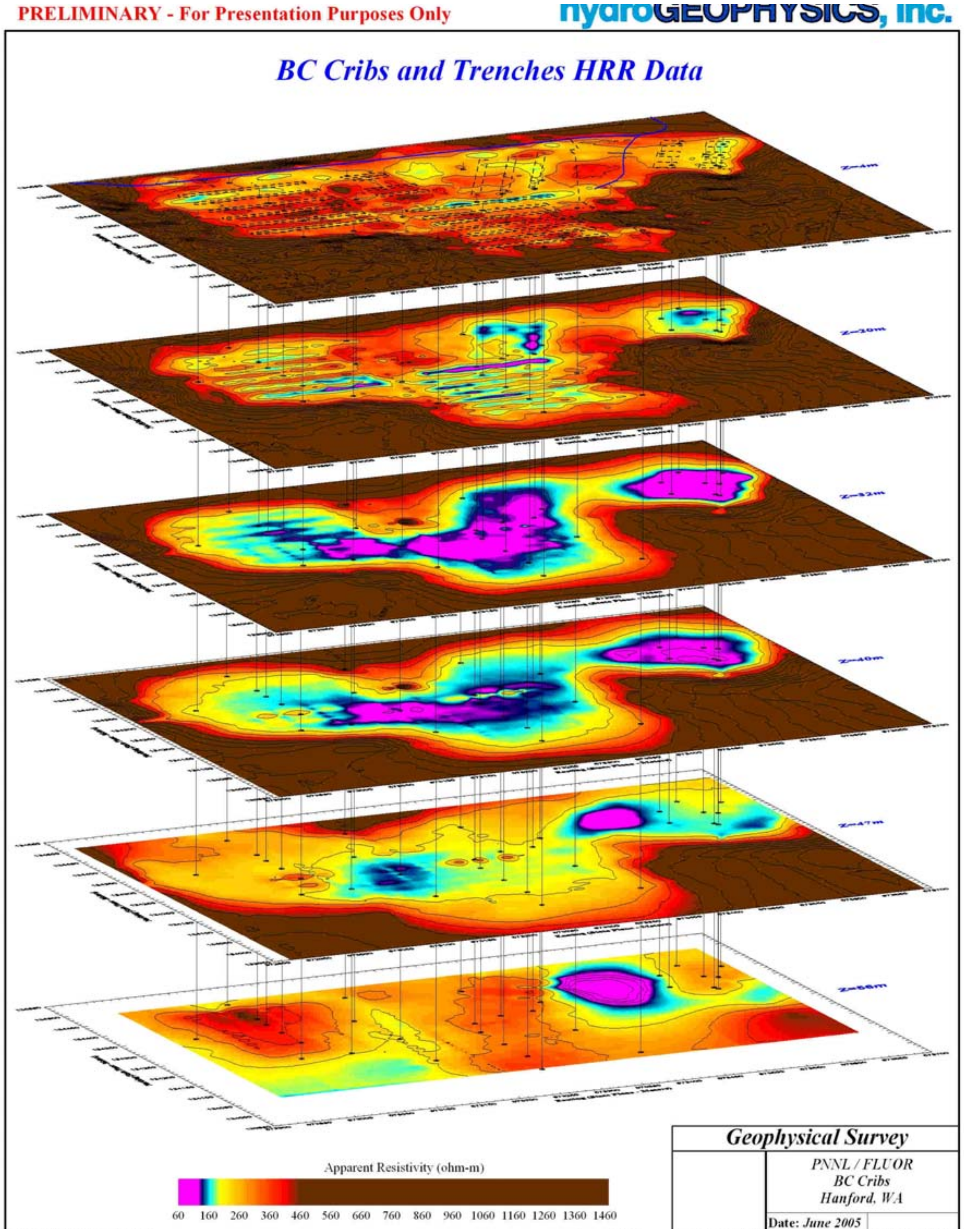


Active Soil Gas Measurements



High Resolution Resistivity

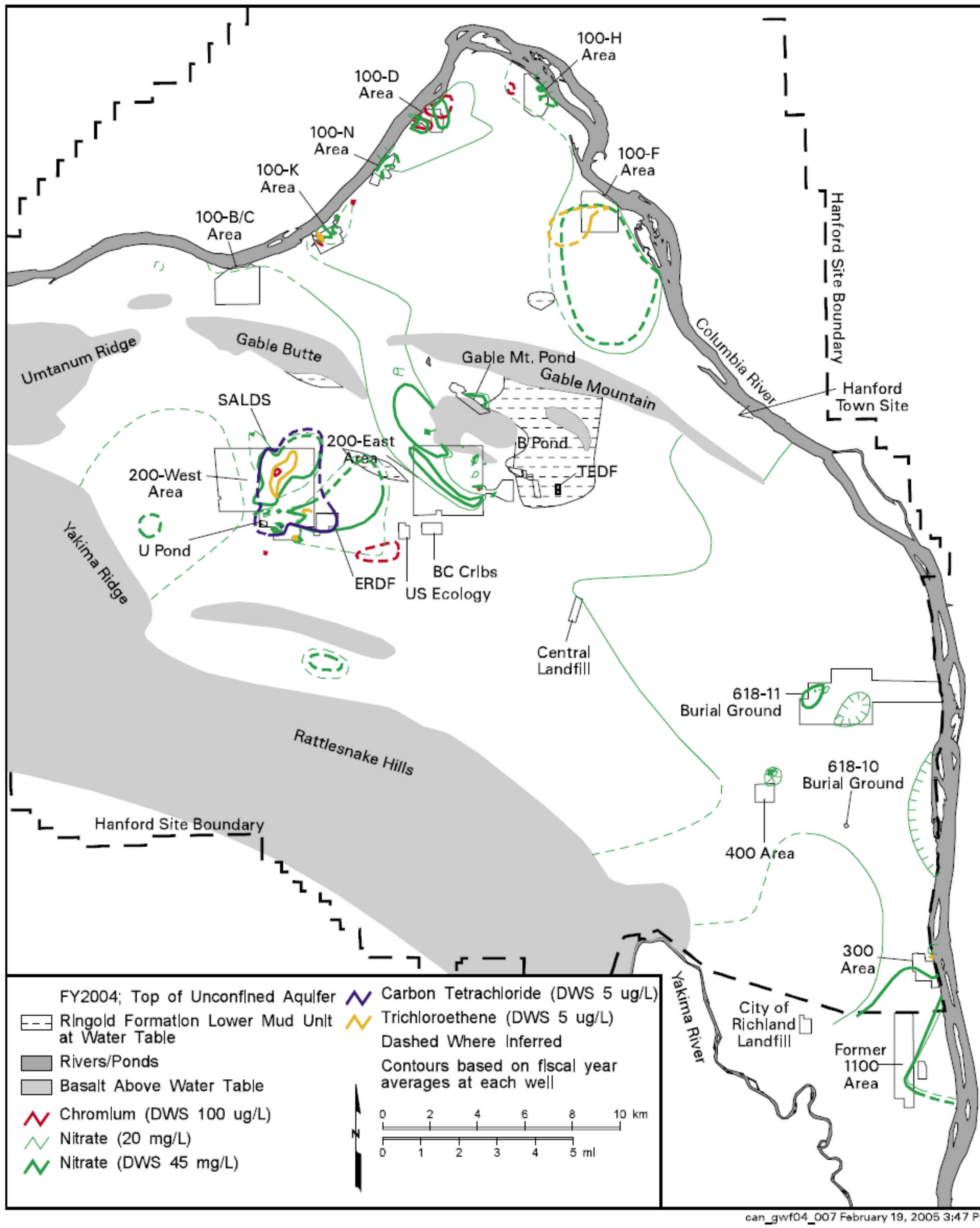



PRELIMINARY - For Presentation Purposes Only
hydroGEOPHYSICS, Inc.
BC Cribs and Trenches HRR Data
Apparent Resistivity (ohm-m)
60 160 260 360 460 560 660 760 860 960 1060 1160 1260 1360 1460
Geophysical Survey
PNNL / FLUOR
BC Cribs
Hanford, WA
Date: June 2005

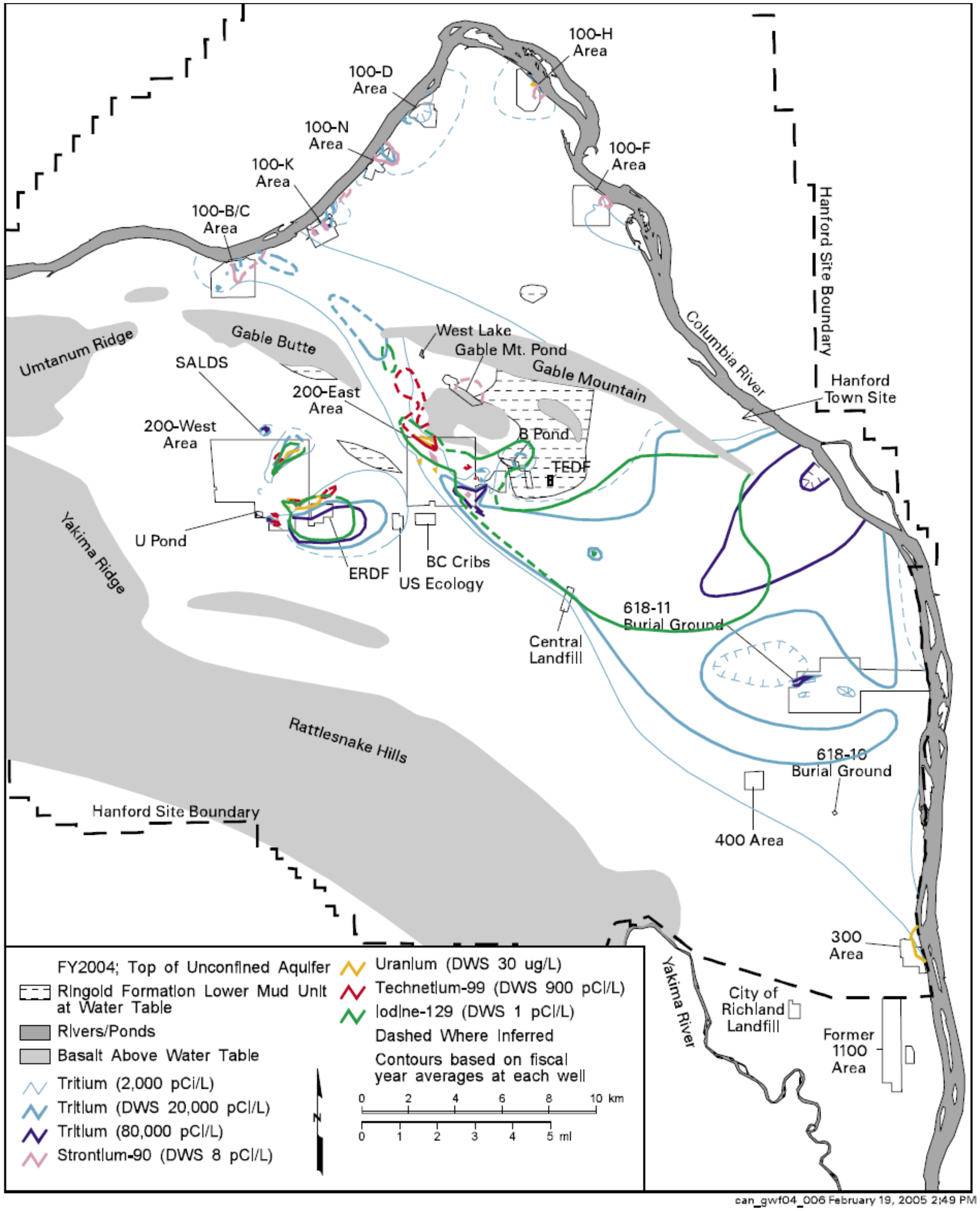
Review of Geophysical Techniques to Define the Spatial Distribution of Subsurface Properties or Contaminants

Technology	Characterization Target	Use Platform	State of Development	Relative Cost	DataSource
Surface ground penetrating radar (GPR)	DNAPL, LNAPL, hydrocarbons, conductive inorganic plumes	Surface	Commercial – widely available 1.• Sisson and Lu Site 2.• Clastic Dike Site	Medium	http://vadose.pnl.gov/; http://fate.clu-in.org/gpr_main.asp; http://costperformance.org/monitoring/#38; Knight 2001; Olhoeft 1992; Sneddon et al. 2002; Guy et al. 2000
Cross-borehole radar tomography	Conductive inorganic plumes	Borehole	Commercial – limited 1.• Sisson and Lu Site	Medium to High	Majer et al. 2001
Seismic reflection amplitude vs. offset (AVO)	DNAPL	Surface	Emerging – research 1.• 200 West CT plume 2.• Savannah River Site	Medium	http://www.clu-in.org/conf/tio/geophysical_121201/chp_3.pdf;
Time domain electromagnetics (TDEM)	Conductive inorganic plumes	Surface	Commercial – widely available	Low	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-1802/c-4.pdf; McNeill 1994
Terrain conductivity (a frequency domain electromagnetics [FDEM] method)	Conductive inorganic plumes	Surface	Commercial – widely available	Low	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-1802/c-4.pdf; McNeill 1990
DC resistivity soundings and profiling	Moisture/conductive plumes	Surface	Commercial – widely available	Low to Medium	http://www.hydrogeophysics.com; http://vadose.pnl.gov (Barnett et al. 2002); http://www.epareachit.org

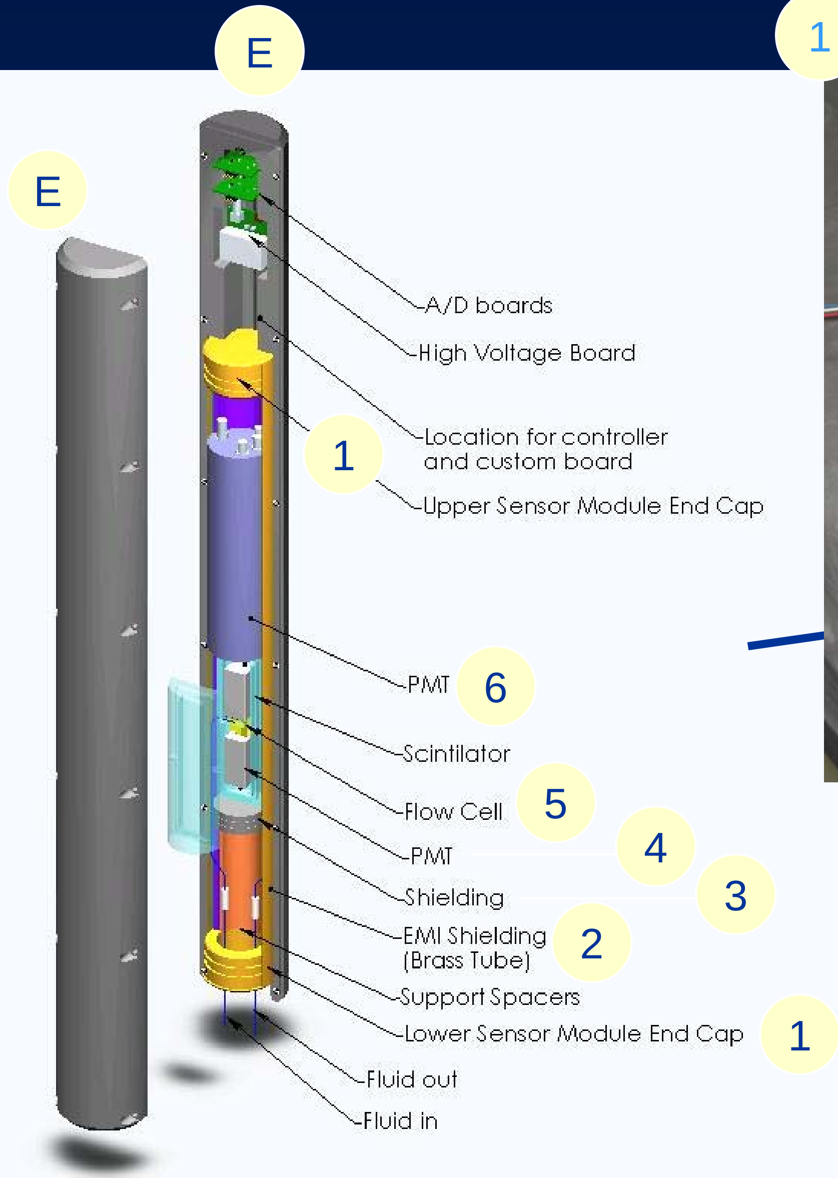
Technology	Characterization Target	Use Platform	State of Development	Relative Cost	DataSource
3D resistivity imaging (including high resolution resistivity [HRR] and HRR-steel casing resistivity technology)	Moisture/conductive plumes	Surface and borehole	Commercial – widely available 1.• Mock Tank (223-E) 2.• Sisson and Lu Site 3.• BC cribs and trenches	Medium to High - $200K - 50 acres (60 m depth)	http://vadose.pnl.gov; Ward and Gee 2000; Barnett et al. 2002
Electrical resistivity tomography (ERT)	Moisture/conductive plumes	Borehole	Commercial – widely available 1.• Mock Tank (223-E)	Medium to High	http://vadose.pnl.gov; Ward and Gee 2000; Barnett et al. 2002
Electrical impedance tomography	Moisture/conductive plumes	Borehole	Emerging – research 1.• Mock Tank (223-E)	Medium to High	http://vadose.pnl.gov; Ramirez et. al. 1998
Complex resistivity (including spectral induced polarization)	Organic contaminants and inorganic contaminants	Surface and/or cross-borehole	Emerging – deployed 1.• A-14 Outfall at SRS 2.• Hill Air Force Base	Medium to High	Morgan and Lesmes 2004; Brown et. al. 2003; EPA 1998; Versteeg 1997
Equipotential and mise-a-la-masse	Moisture/Conductive Plumes and Organic Contaminants	Surface and borehole	Commercial – widely available 1.• Mock Tank (223-E) 2.• Sisson and Lu Site	Medium to High	http://www.clu-in.org/programs/21m2/spotlight/080304.pdf; Barnett et al. 2002
Self potential	Metallic constituents	Surface or	Commercial – limited	Medium - Can be	Versteeg 1997



This map shows the distribution of hazardous chemicals in groundwater at concentrations above drinking water standards during FY 2004 at the top of the unconfined aquifer.



This map shows the distribution of radionuclides in groundwater at concentrations above drinking water standards during FY 2004 at the top of the unconfined aquifer.



Tc-99 Sensor Module

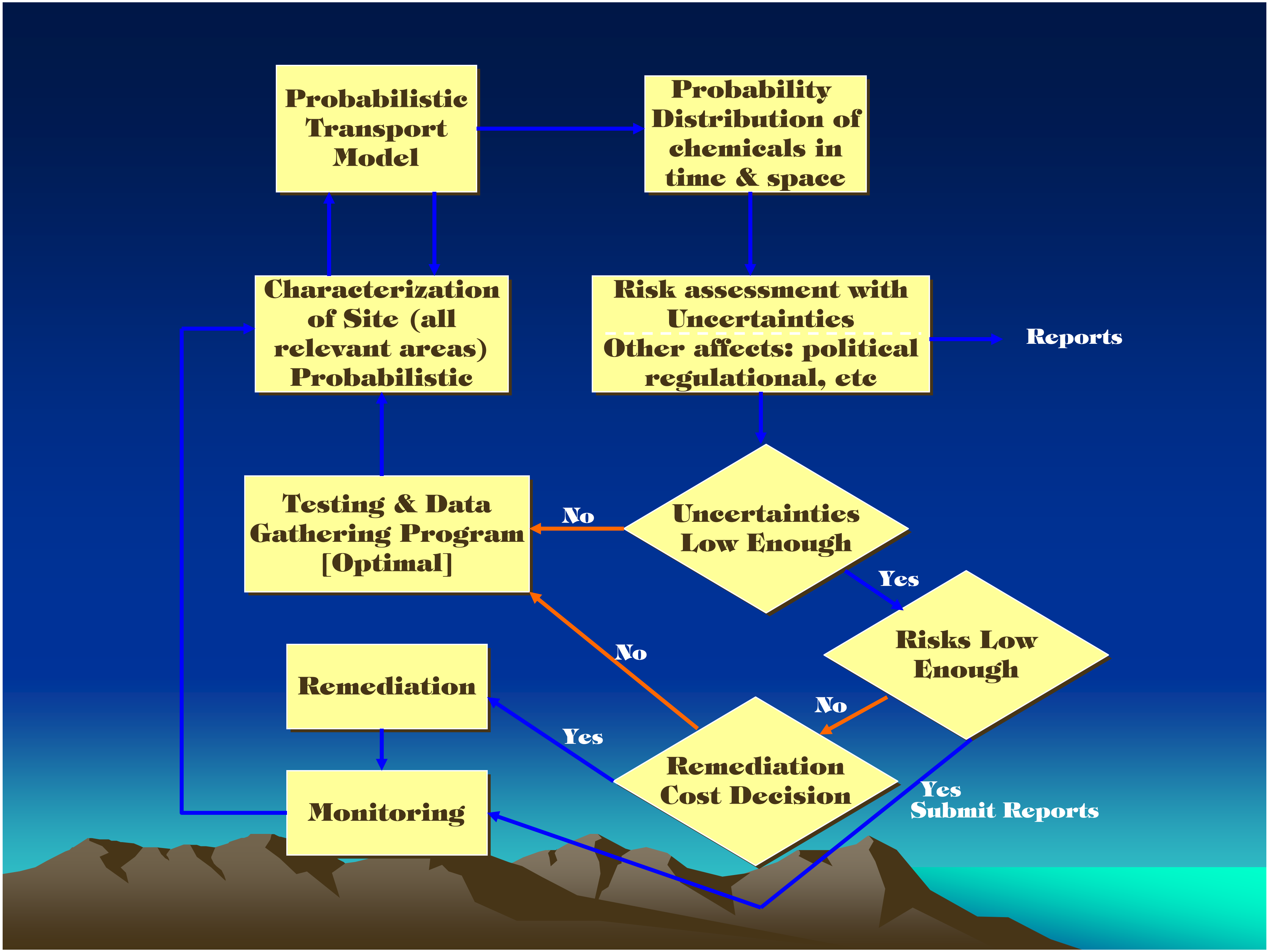
Key:
E – Sensor module enclosure
1 – Sensor module end cap
2 – Light tight, EMF shield
3 – Lead shielding
4 – Tc-99 sensing PMT
5 – Sensor cell
6 – Anti-coincidence PMT
7 – Spacers

Remote Chromium Sensor at 100-D

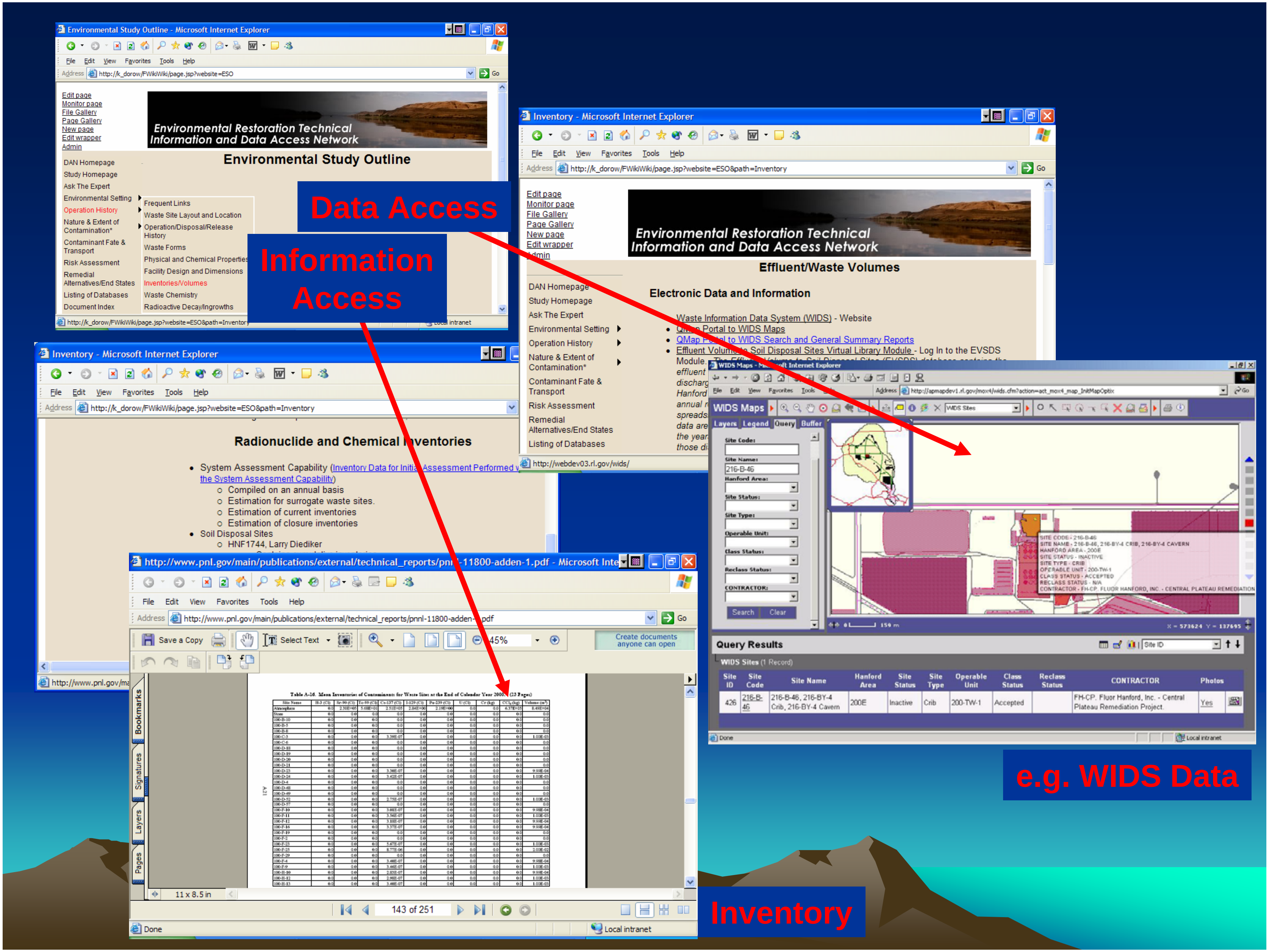
Enhanced Access Penetrometer System (EAPS)

Future Monitoring

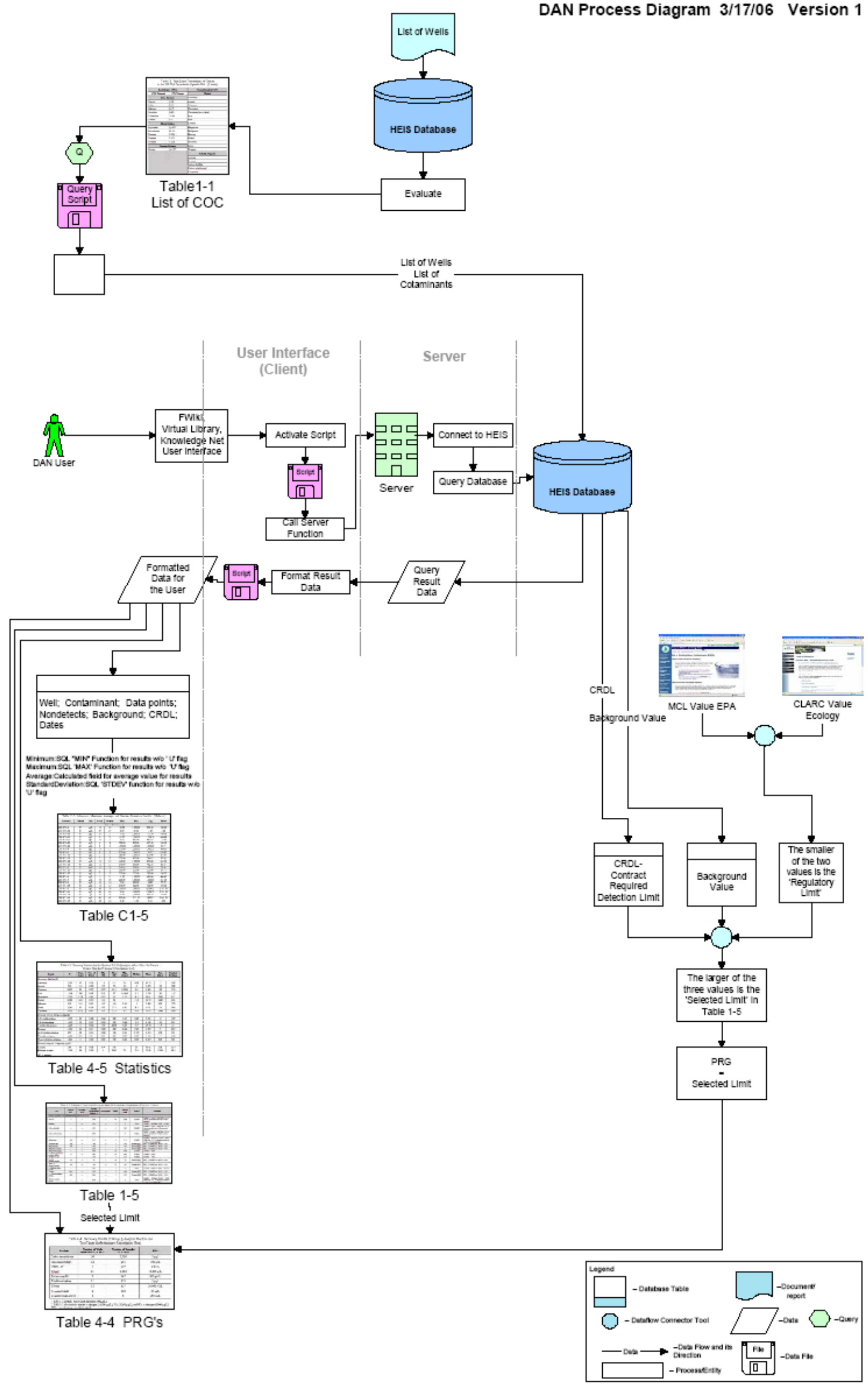
- Beneath TSDs (lysimeters, tubes, etc.) (during operations)
- Liquid retention ponds (mass balance approaches)
- Caps and barriers (integrity, survey methods, etc.) (after closure)
- Protection and monitoring for rapidly decaying constituents
- Continued characterization
- Groundwater Monitoring



Probabilistic Transport Model
Probability Distribution of chemicals in time & space
Characterization of Site (all relevant areas) Probabilistic
Risk assessment with Uncertainties
Other affects: political regulational, etc
Reports
Testing & Data Gathering Program [Optimal]
No
Uncertainties Low Enough
Yes
Risks Low Enough
No
No
Remediation
Yes
Remediation Cost Decision
Yes
Submit Reports
Monitoring


Environmental Study Outline - Microsoft Internet Explorer
Environmental Restoration Technical Information and Data Access Network
Environmental Study Outline
DAN Homepage
Study Homepage
Ask The Expert
Environmental Setting
Operation History
Nature & Extent of Contamination*
Contaminant Fate & Transport
Risk Assessment
Remedial Alternatives/End States
Listing of Databases
Document Index
Frequent Links
Waste Site Layout and Location
Operation/Disposal/Release History
Waste Forms
Physical and Chemical Properties
Facility Design and Dimensions
Inventories/Volumes
Waste Chemistry
Radioactive Decay/Ingrowths
Data Access
Information Access
Inventory - Microsoft Internet Explorer
Effluent/Waste Volumes
Electronic Data and Information
Waste Information Data System (WIDS) - Website
QMap Portal to WIDS Maps
QMap Portal to WIDS Search and General Summary Reports
Effluent Volumes to Soil Disposal Sites Virtual Library Module - Log In to the EVSDS
Radionuclide and Chemical Inventories
System Assessment Capability (Inventory Data for Initial Assessment Performed with the System Assessment Capability)
Compiled on an annual basis
Estimation for surrogate waste sites.
Estimation of current inventories
Estimation of closure inventories
Soil Disposal Sites
HNF1744, Larry Diediker
http://www.pnl.gov/main/publications/external/technical_reports/pnnl-11800-adden-1.pdf - Microsoft Internet Explorer
Table A-16. Mean Inventories of Contaminants for Waste Sites at the End of Calendar Year 2000 (23 Pages)
143 of 251
WIDS Maps - Microsoft Internet Explorer
WIDS Maps
Query Results
WIDS Sites (1 Record)
Site ID | Site Code | Site Name | Hanford Area | Site Status | Site Type | Operable Unit | Class Status | Reclass Status | CONTRACTOR | Photos
426 | 216-B-46 | 216-B-46, 216-BY-4 Crib, 216-BY-4 Cavern | 200E | Inactive | Crib | 200-TW-1 | Accepted | | FH-CP, Fluor Hanford, Inc. - Central Plateau Remediation Project | Yes
e.g. WIDS Data
Inventory

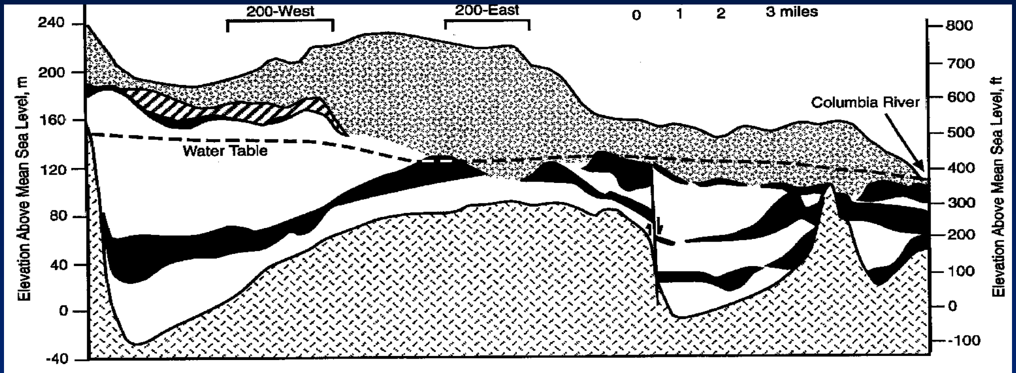
DAN Process Diagram 3/17/06 Version 1



Identified Technology Needs Relative to Contaminant Migration

- Characterization Issues
- Transport Issues
- Risk Issues
- Monitoring Issues
- Cost Issues (Better Remediation Technologies)
- Dissemination Issues

Characterization Issues



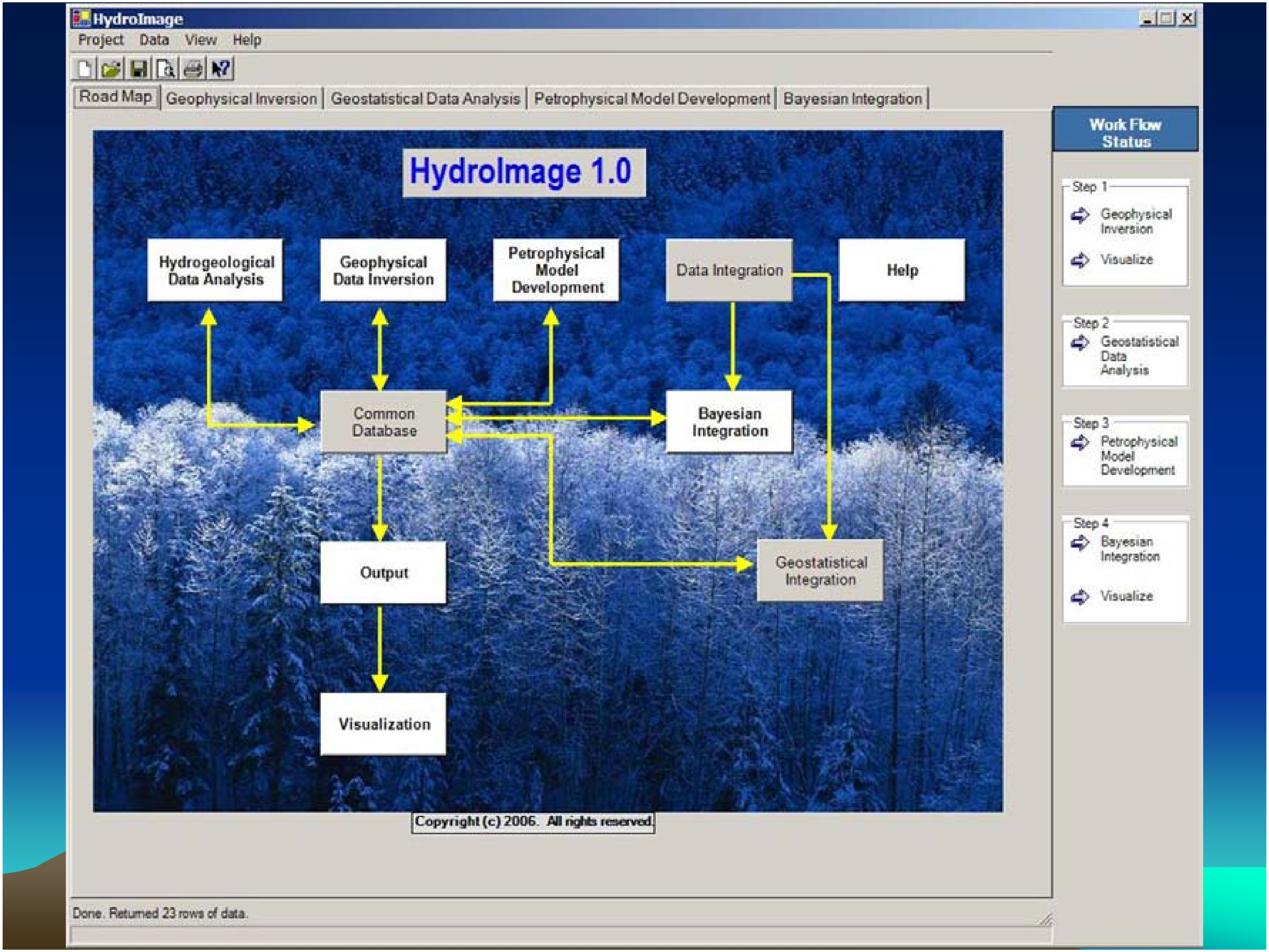
- Technetium – 99 – Difficult to analyze in radiation samples. Transport properties.
- Uranium – Transport properties. Chemical speciation.
- Carbon Tetrachloride – Inventory. Phase? Movement with water or without. Degradation questions. Transport properties.
- Access to locations in groundwater – limits numbers of samples and increases costs.
- Non-intrusive hydro-geological characterization of larger areas.
- Scaling issues.
- Data integration, consistency, and presentation

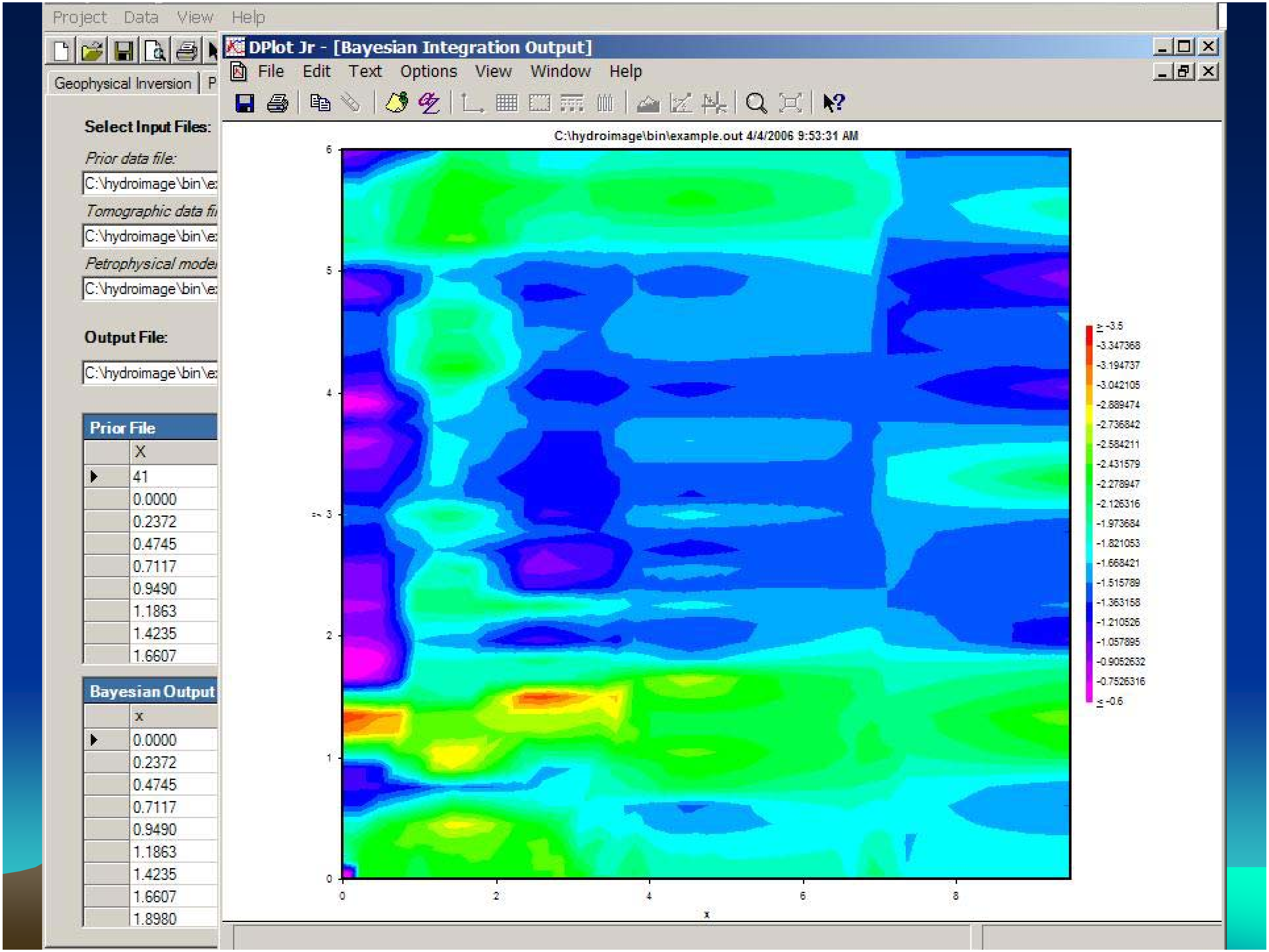
Monitoring Issues

- Optimization strategies for monitoring
- Unsaturated zone monitoring (better methodology).
  - What types of monitoring
  - Types of instrumentation, detection methods, etc.
- Monitoring in long-term stewardship mode. Feedback to modeling.
- Reduce monitoring costs.

Example: HydroImage, A User-friendly Hydrogeophysical Characterization Software Package

Integrates continuous geophysical data with limited borehole data to estimate hydrogeological parameters of interest in the subsurface was developed. The software package can be used to significantly enhance site conceptual models and improve design and operation of remediation systems.


HydroImage
Project Data View Help
Road Map
Geophysical Inversion
Geostatistical Data Analysis
Petrophysical Model Development
Bayesian Integration
HydroImage 1.0
Hydrogeological Data Analysis
Geophysical Data Inversion
Petrophysical Model Development
Data Integration
Help
Common Database
Bayesian Integration
Output
Geostatistical Integration
Visualization
Copyright (c) 2006. All rights reserved.
Work Flow Status
Step 1
Geophysical Inversion
Visualize
Step 2
Geostatistical Data Analysis
Step 3
Petrophysical Model Development
Step 4
Bayesian Integration
Visualize
Done. Returned 23 rows of data.



Project Data View Help
Geophysical Inversion
Select Input Files:
Prior data file:
C:\hydroimage\bin\e
Tomographic data fi
C:\hydroimage\bin\e
Petrophysical mode
C:\hydroimage\bin\e
Output File:
C:\hydroimage\bin\e
Prior File
X
41
0.0000
0.2372
0.4745
0.7117
0.9490
1.1863
1.4235
1.6607
Bayesian Output
x
0.0000
0.2372
0.4745
0.7117
0.9490
1.1863
1.4235
1.6607
1.8980
DPlot Jr - [Bayesian Integration Output]
File Edit Text Options View Window Help
C:\hydroimage\bin\example.out 4/4/2006 9:53:31 AM
≥ -3.5
-3.347368
-3.194737
-3.042105
-2.889474
-2.736842
-2.584211
-2.431579
-2.278947
-2.126316
-1.973684
-1.821053
-1.668421
-1.515789
-1.363158
-1.210526
-1.057895
-0.9052632
-0.7526316
≤ -0.6
0
2
4
6
8
x
0
1
2
3
4
5
6

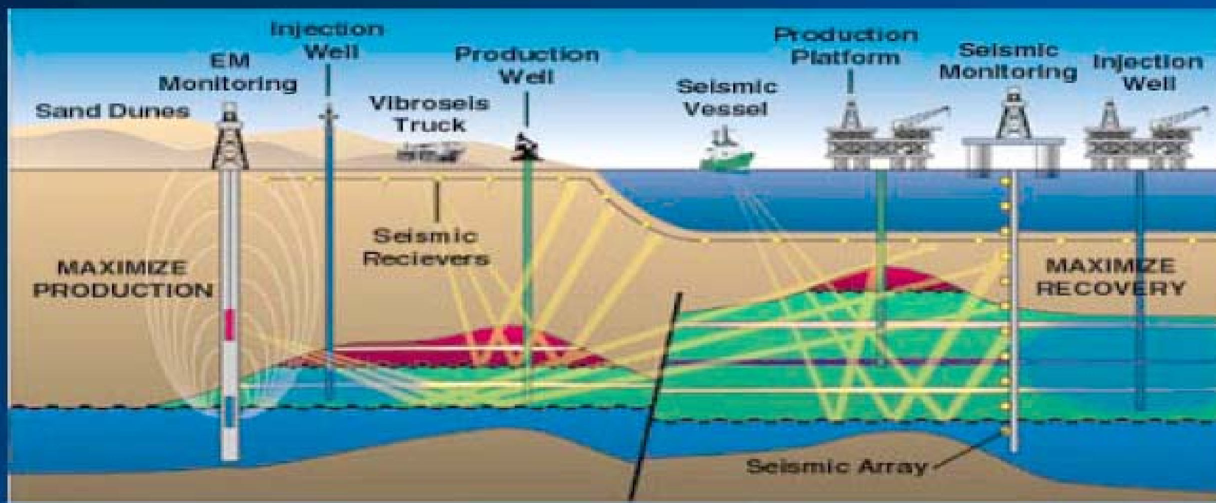
Computational Environments for Integration of Geophysics and Reservoir Simulation

An overview of the NSF/ITR projects:

The Data Intense Challenge: The Instrumented Oil Field of the Future (2001-2005)

Data Driven Simulation of the Subsurface: Optimization and Uncertainty Estimation (2004-2007)

The Instrumented Oil Field



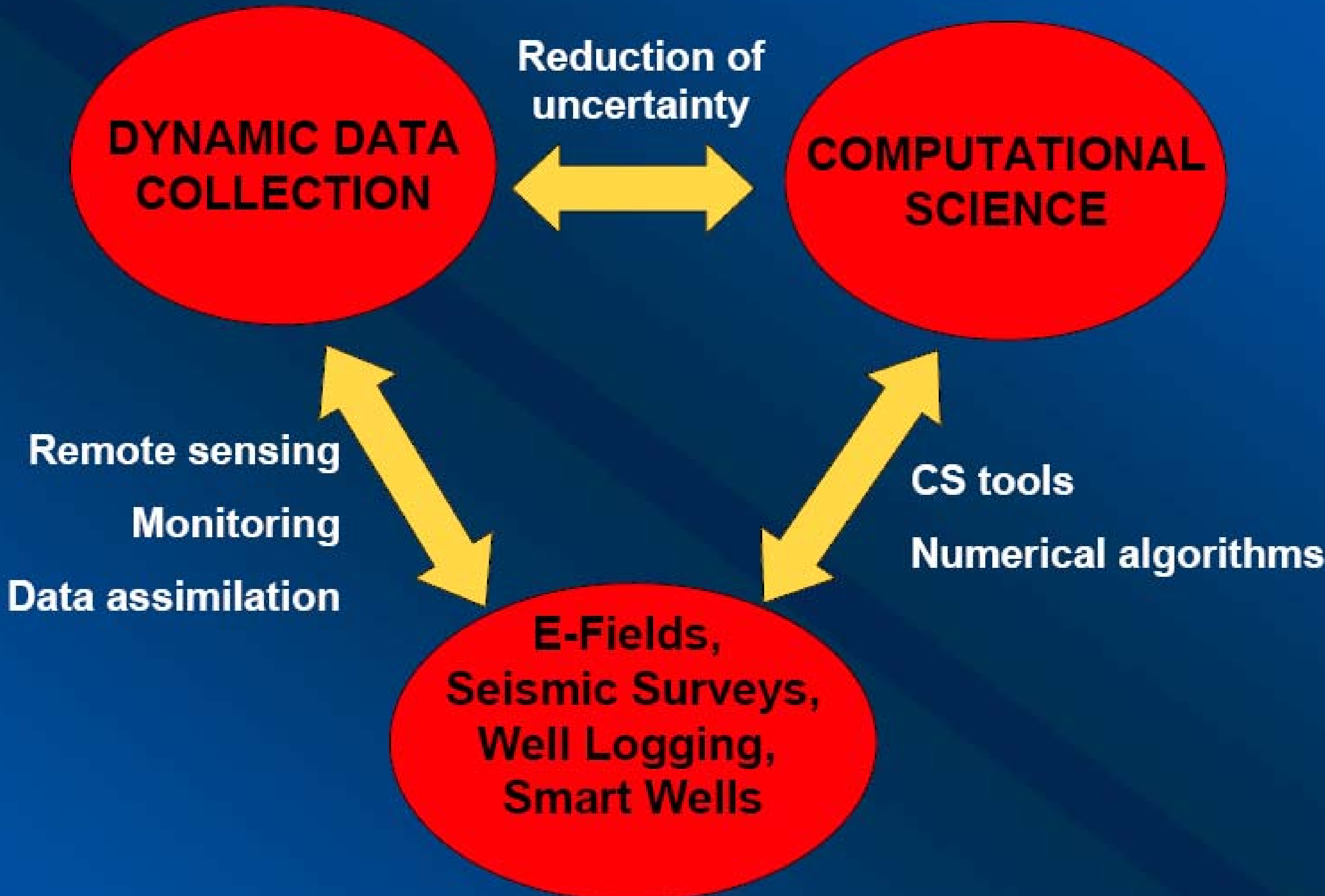
Model Driven

Assimilate data & reservoir properties into the evolving reservoir model

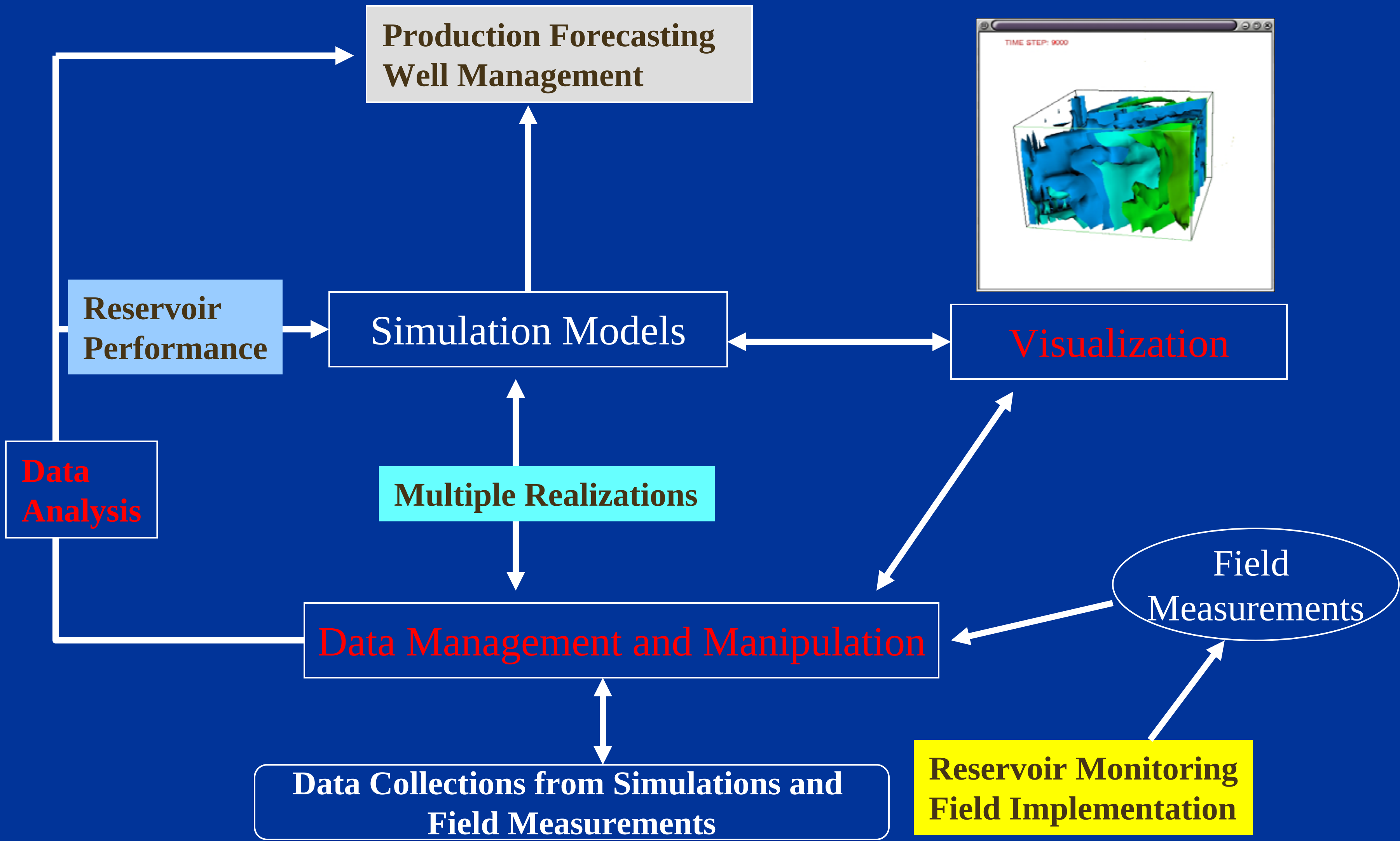
Detect and track changes in reservoir changes during production

Data Driven

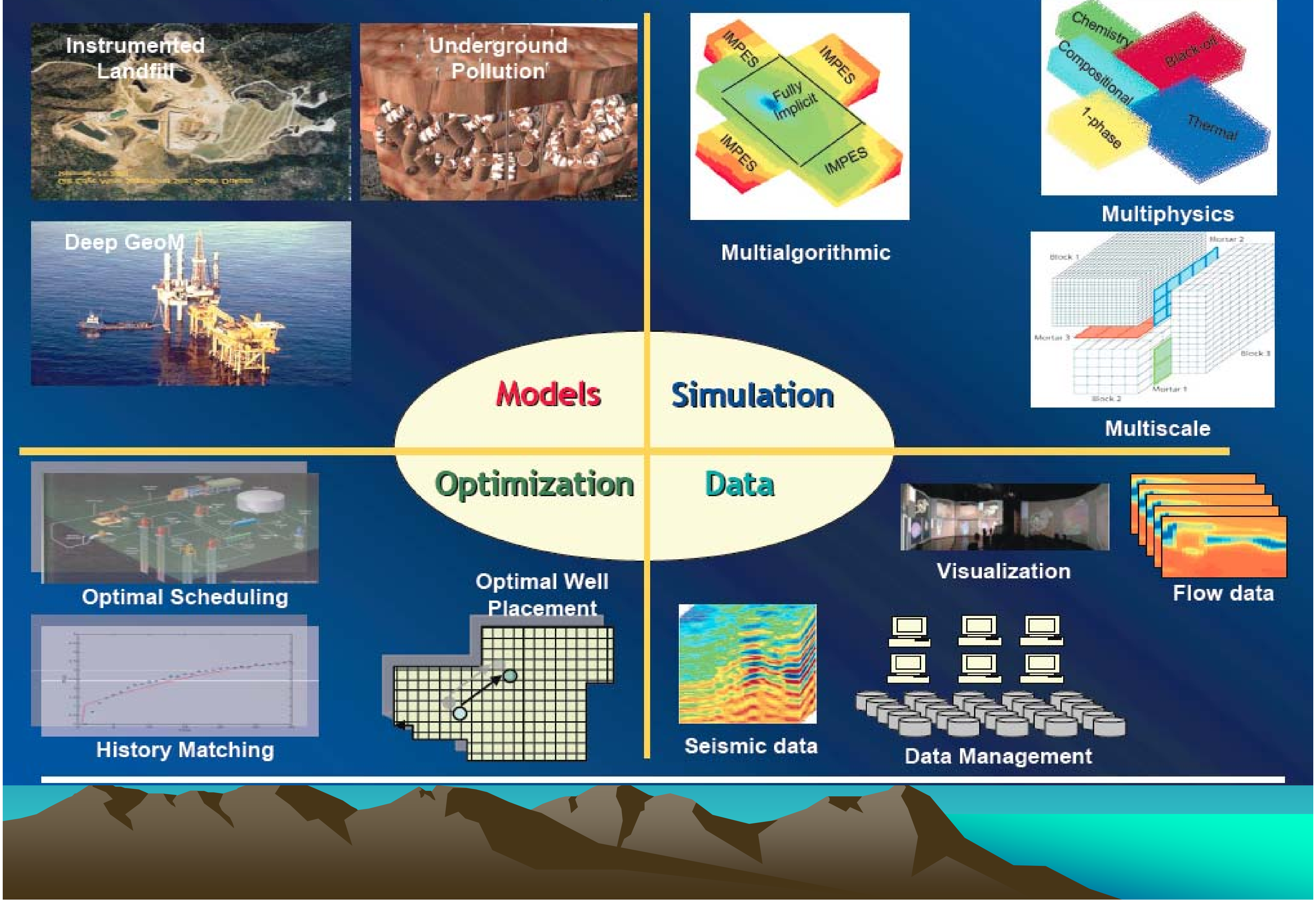
DDDAS: Integration of Data, Models, and IT



Economic Modeling and Well Management

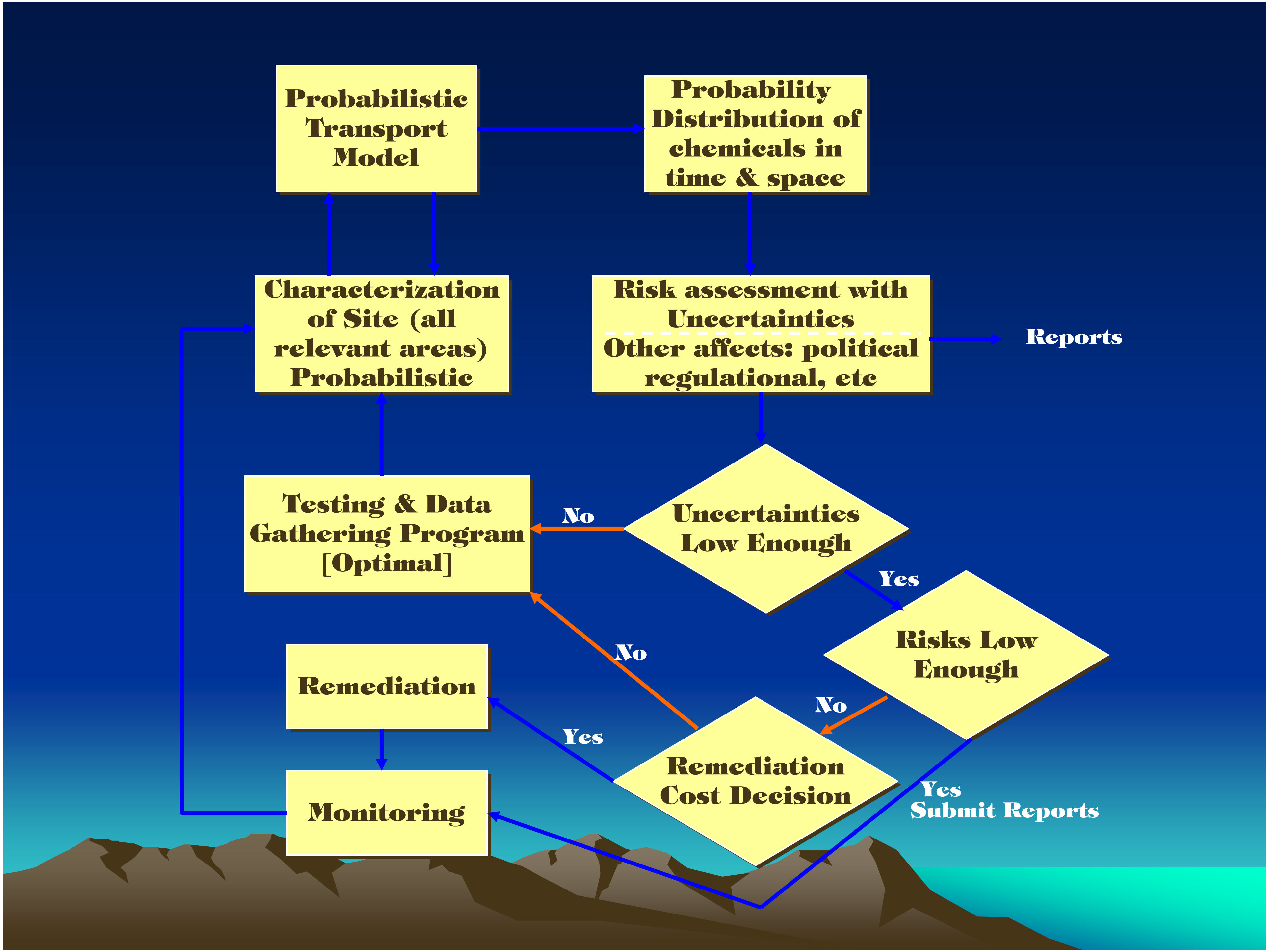


Accomplishments



Two More Examples

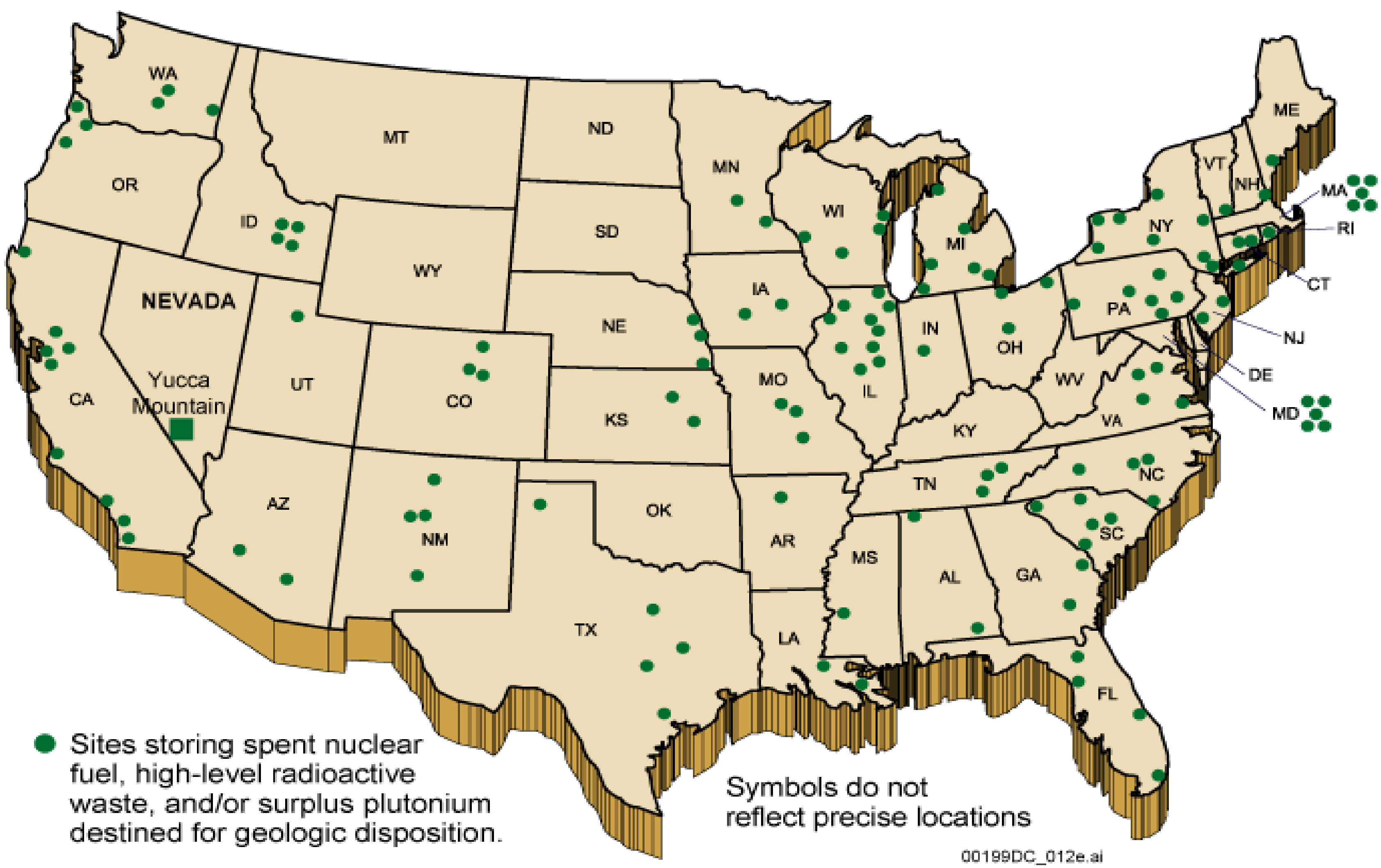
- Collaboration between INEL and PNNL: End goal is to be able to click on a location or well and bring up geophysical (surface and borehole), as well as grain size distributions and estimated hydraulic properties etc.
- SAIC's automated knowledge management and production integration system.


Probabilistic Transport Model
Probability Distribution of chemicals in time & space
Characterization of Site (all relevant areas) Probabilistic
Risk assessment with Uncertainties
Other affects: political regulational, etc
Reports
Testing & Data Gathering Program [Optimal]
No
Uncertainties Low Enough
Yes
Risks Low Enough
No
No
Remediation
Yes
Remediation Cost Decision
Yes
Submit Reports
Monitoring

Future Development Efforts for Analysis of Contaminant Migration

- Better characterization of chromium source in D-Area
- Mapping of top of basalt for better flow direction determination
- Analyze abiotic degradation potential for carbon tetrachloride
- Develop fingerprinting methods for isotope source identification
- Develop better characterization methods
- Develop better conceptual model of the Hanford Site (Simulations)
- Develop better data retrieval and analysis methods
- Continue developing instrumentation and monitoring technology
- Reduce price of instrumentation and deployment of monitoring technology
- Increase reliability of instrumentation and monitoring technology
- Allow current designs to incorporate future technology
- Directions in future technologies deployment (redundancy, developing standards, less intrusive)
- Integrate Modeling and Monitoring to provide long-term control of contaminants

U.S. Locations of Sites



Evaluation of Subsurface Radionuclide Transport at Commercial Nuclear Power Production Facilities

Todd C. Rasmussen
The University of Georgia

James S. Bollinger
Savannah River National Laboratory

ANSI/ANS-2.13-1979

American Nuclear Society

evaluation of surface-water supplies for nuclear power sites

an American National Standard

ANSI/ANS-2.13-1979

published by the
American Nuclear Society
555 North Kensington Avenue
La Grange Park, Illinois 60525 USA

ANSI/ANS-2.9-1980

American Nuclear Society

evaluation of ground water supply for nuclear power sites

an American National Standard

published by the
American Nuclear Society
555 North Kensington Avenue
La Grange Park, Illinois 60525 USA

ANSI/ANS-2.17-1980

American Nuclear Society

evaluation of radionuclide transport in ground water for nuclear power sites

an American National Standard

ANSI/ANS-2.17-1980

published by the
American Nuclear Society
555 North Kensington Avenue
La Grange Park, Illinois 60525 USA




Preliminary Outline

Foreword

1. Scope and Purpose

2. Definitions

3. Assessment Methodology
   - Features, Events, and Processes
   - Data Collection and Storage
   - Incorporating Uncertainty
   - Assessment Updating

4. Site Investigations
   - Regional Environment
   - Site Characteristics
   - Facilities Characterization

5. Flow and Transport Modeling
   - Model Specification
   - Domain Specification
   - Analytical Method Specification

6. Monitoring Program
   - Monitoring Objectives
   - Monitoring Methods

7. Corrective Action
   - Response Threshold Definition
   - Alternatives Response Specification
   - Performance Evaluation

References

Current Plans

- Long-term (multi-year) process
- Incorporate extensive peer review and commenting prior to approval
- Solicit input and feedback from the technical and regulated communities
- Please contact the authors with information sources and experiences