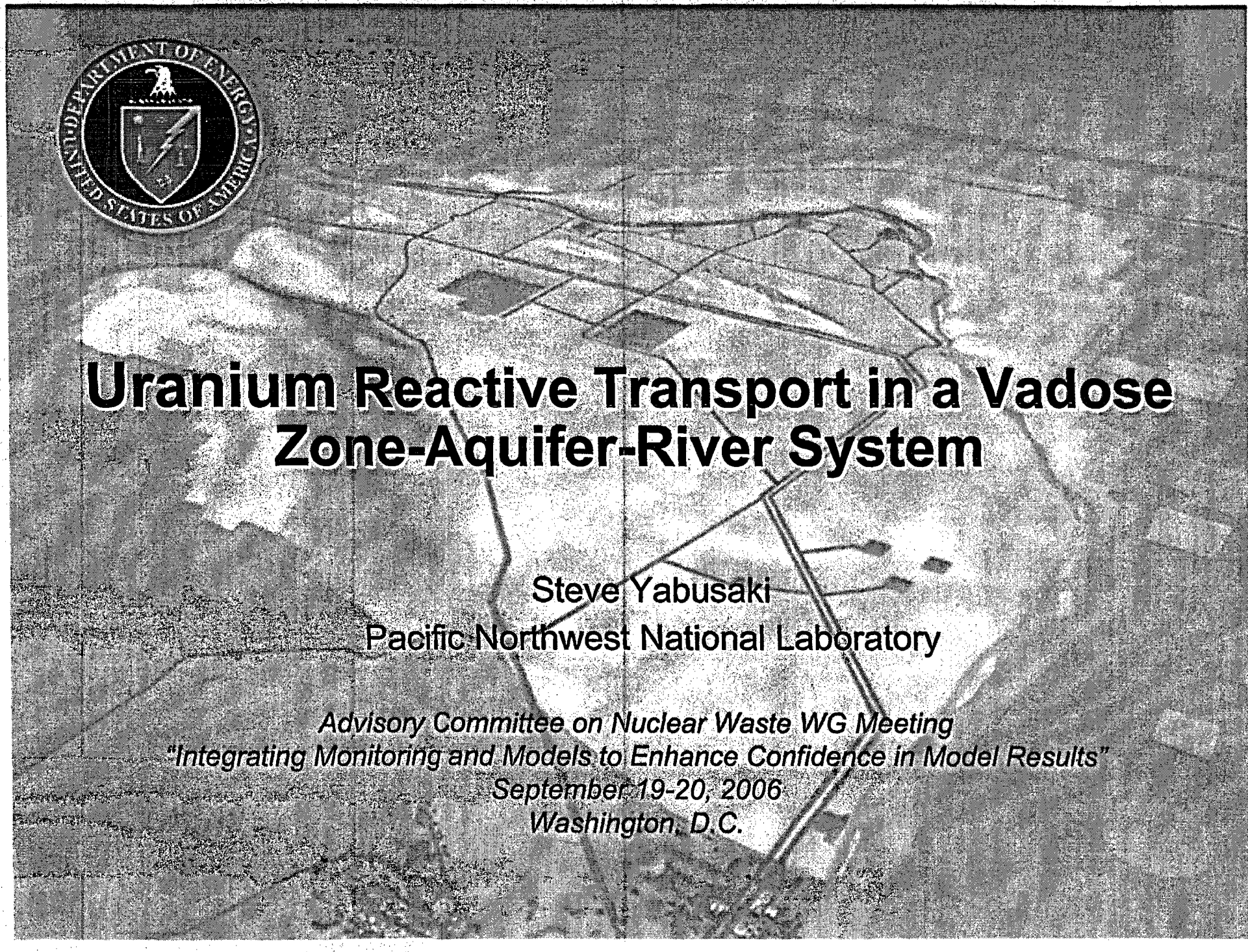


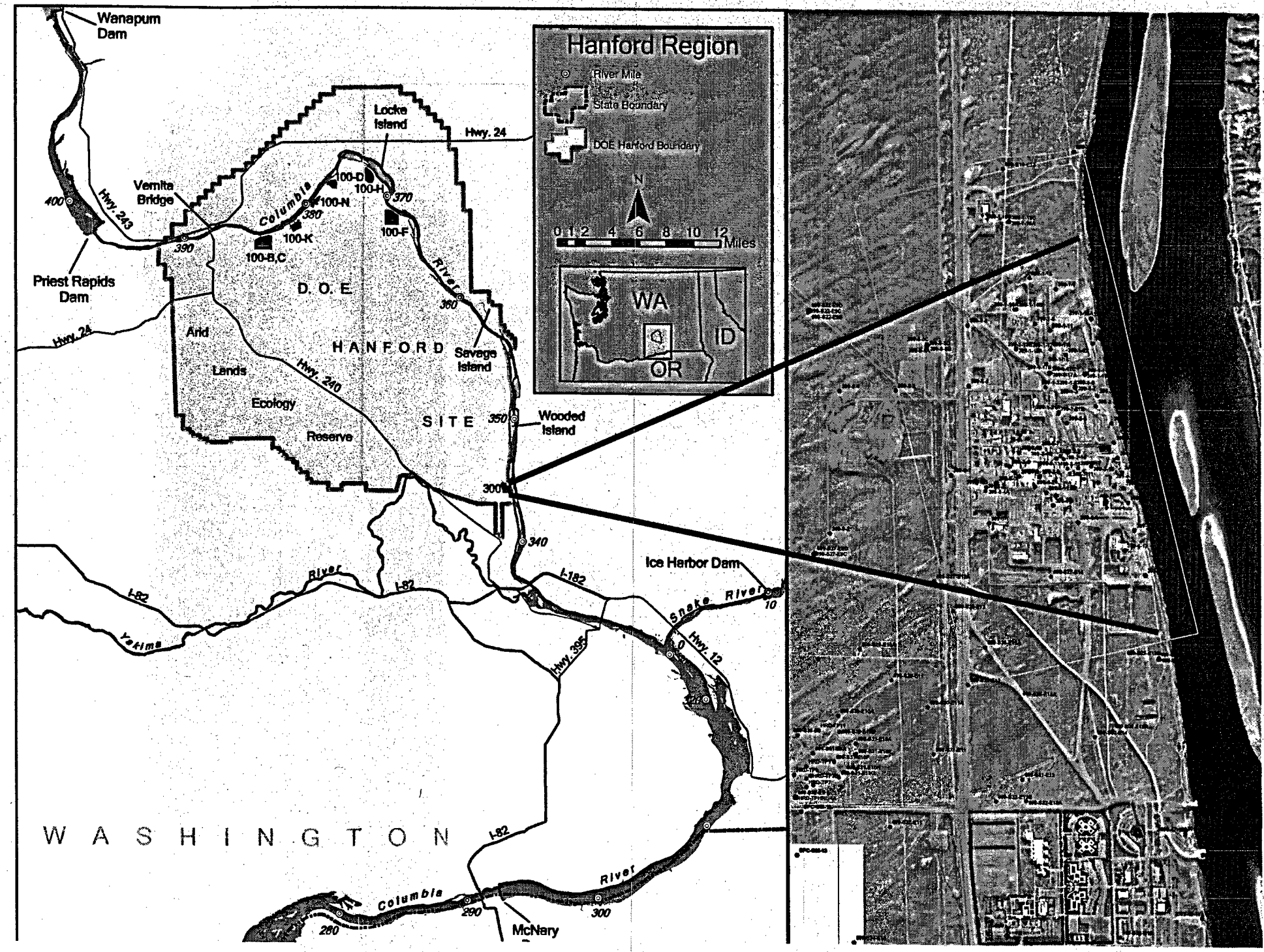
Uranium Reactive Transport in a Vadose Zone-Aquifer-River System

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.

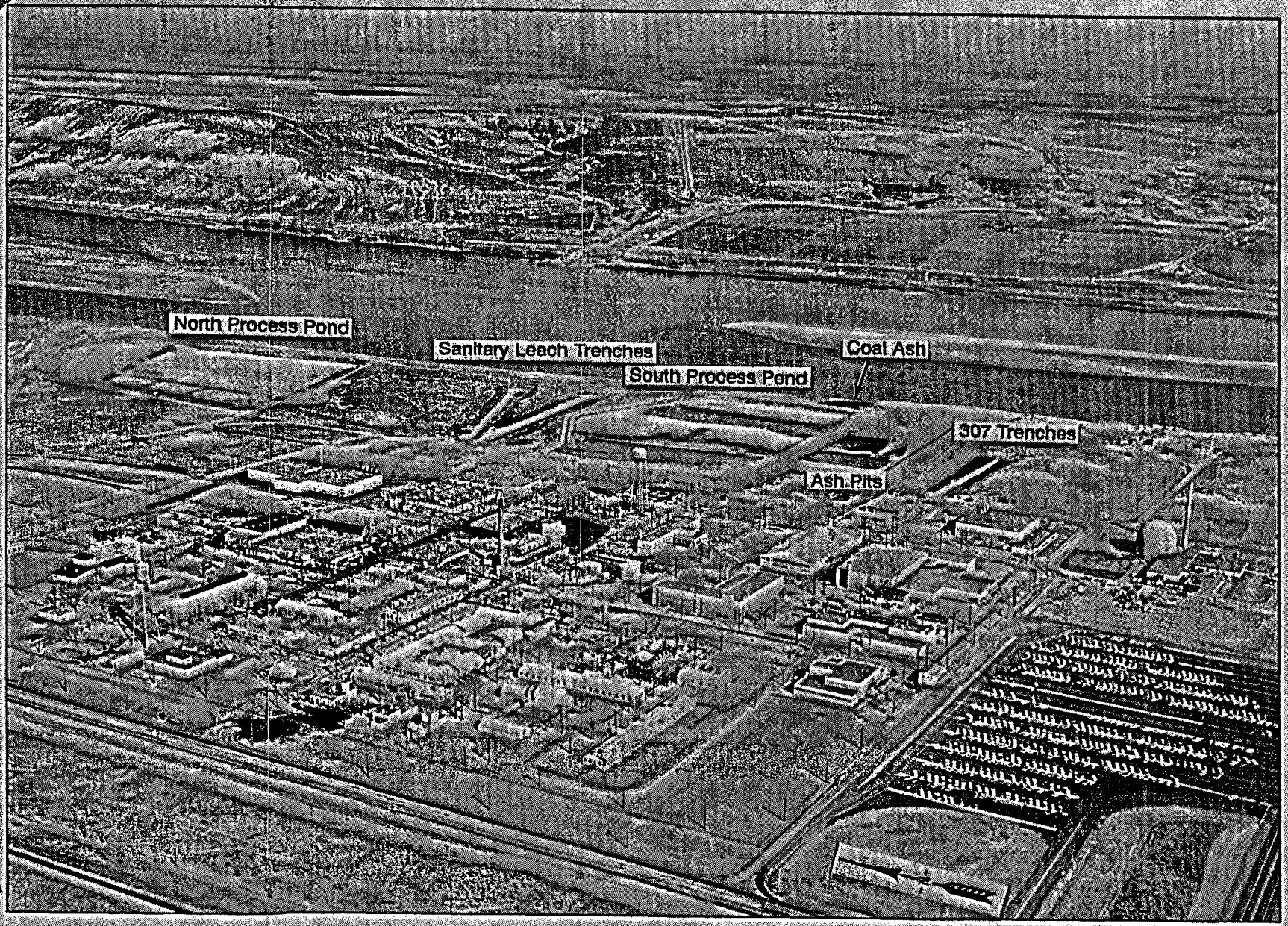
General Themes

- Monitoring and modeling should be consistent with the scales of the controlling processes
- Modeling and geophysics can add value
  - sampling scheme design
  - 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
Hwy. 243
Hwy. 24
Locke Island
Hwy. 24
100-D
100-H
100-N
100-K
100-F
100-B,C
Columbia River
D. O. E.
HANFORD
SITE
Arid Lands Ecology Reserve
Hwy. 240
Savage Island
Wooded Island
Ice Harbor Dam
I-182
Snake River
Hwy. 12
Hwy. 395
I-82
Yakima River
I-82
Columbia River
McNary
WASHINGTON
400
390
380
370
360
350
340
300
290
280
10


399-1-6
399-1-14A
399-1-14B
399-1-10A
399-8-3
399-1-4
399-1-11
399-1-13B
399-1-12
399-1-15
399-1-13A
399-1-22
399-1-19
399-1-17B
399-1-17C
399-1-17A
399-8-1
399-1-2
399-1-8
399-1-9
399-1-7
399-1-3
399-2-
399-1-21A
399-1-21B
399-2-4
399-3-7

Hanford 300 Area in 1962



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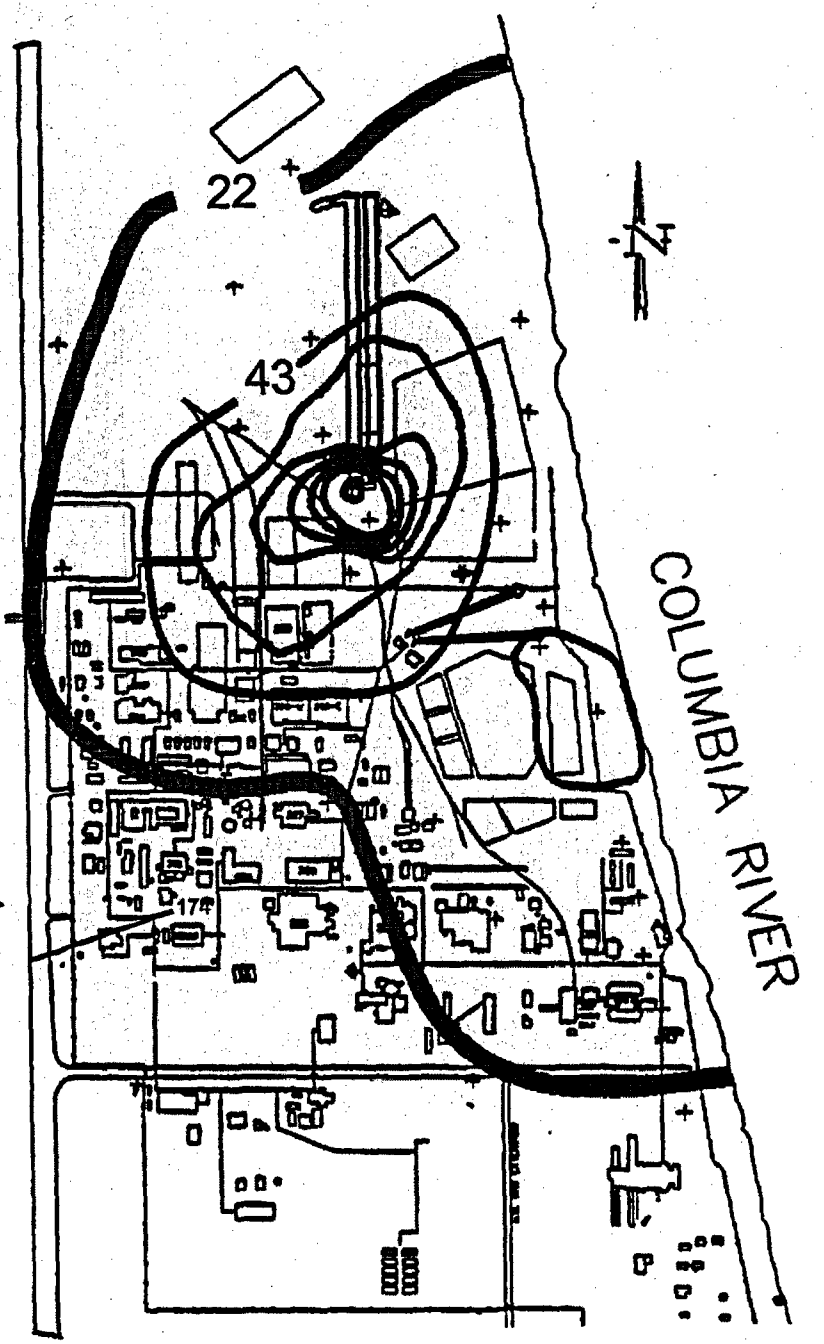
Operational History and Inventory of 300 Area Process Ponds

- 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
- 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
  - 10 m to water table
  - Uranium plumes tracked in the Columbia River in 1957 and 1962

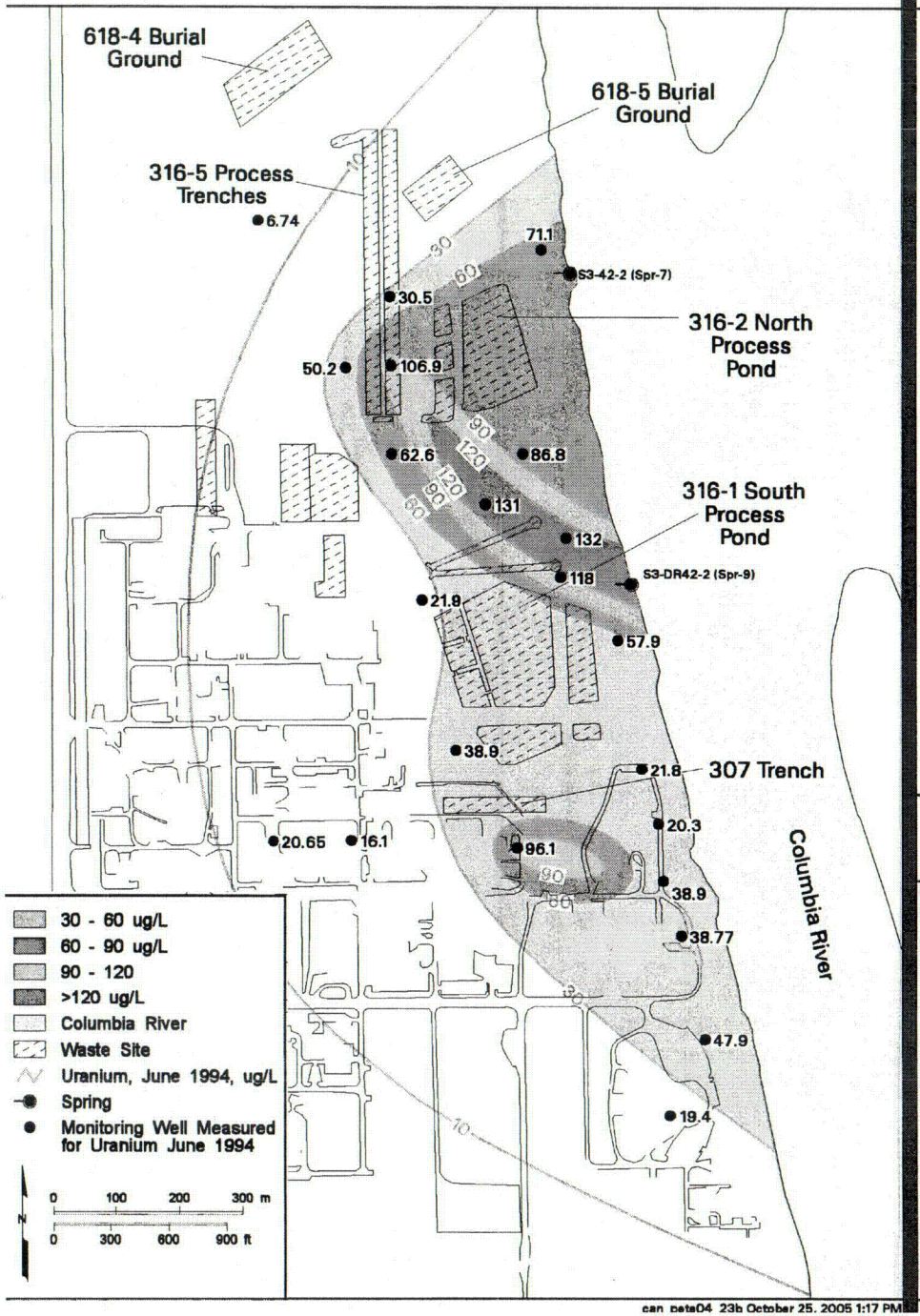
1990 Uranium Plume

- 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



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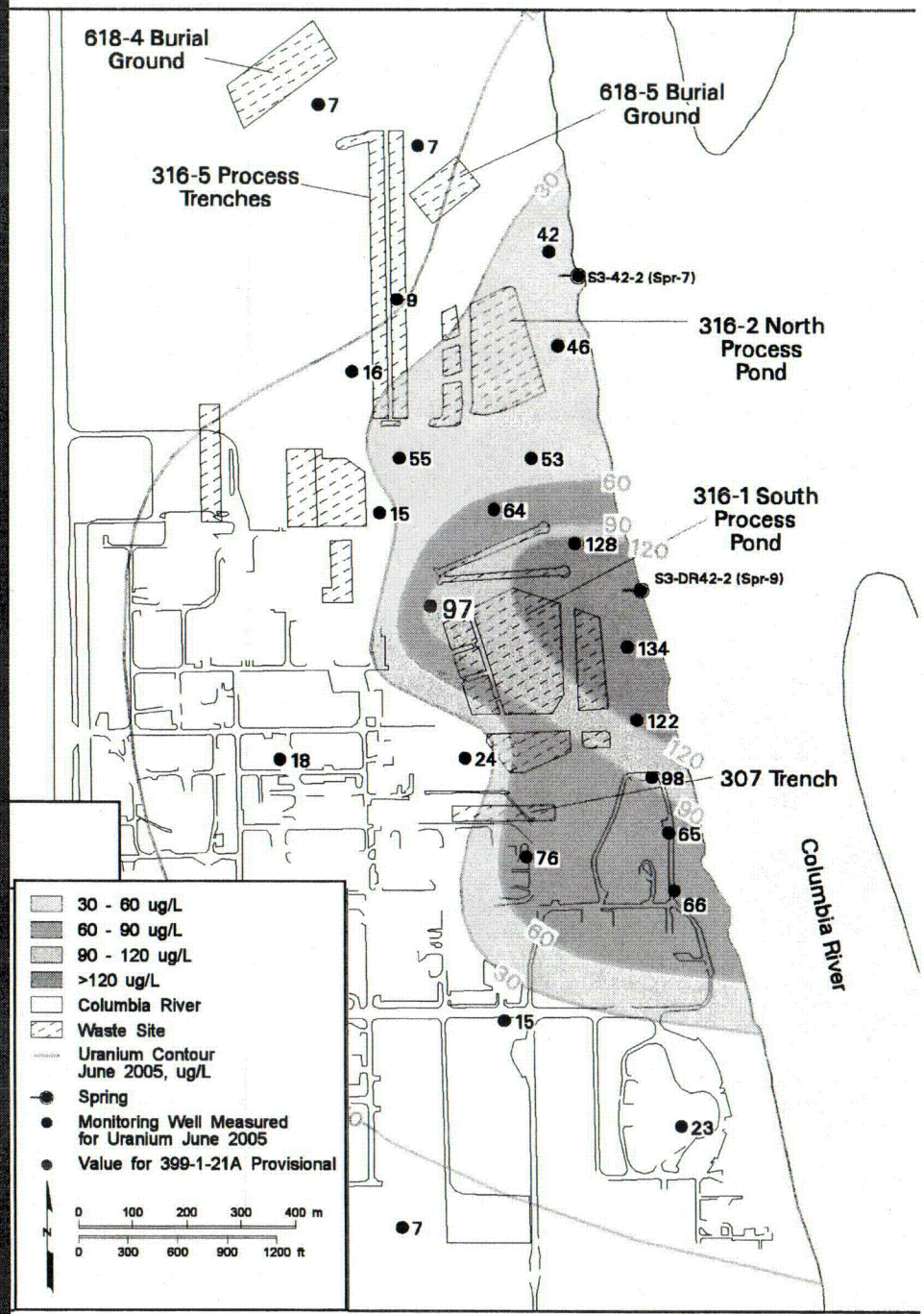
Shaded 300 Area Uranium, June 2005



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1993 Conceptual Model

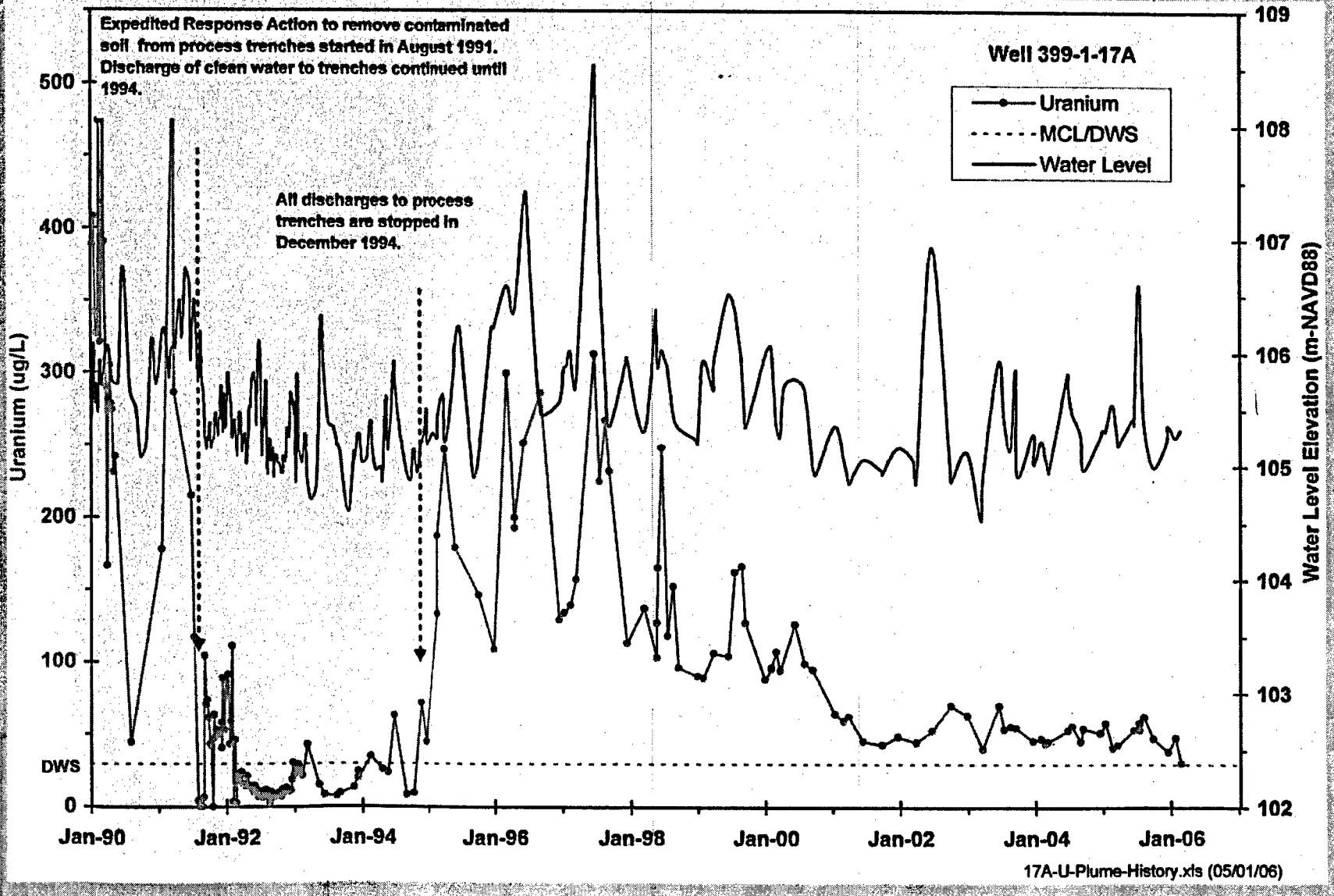
Modeling Assumptions in Phase I Remedial Investigation (1994)

- 3-D saturated unconfined aquifer; **vadose zone not modeled**
  - Spatially distributed hydraulic conductivity (4 hydrofacies types)
  - Flow field driven by **monthly** changes in river stage fluctuations
  - Uranium mobility controlled by **constant K_d**
  - Natural flushing predicted to largely decrease U to < 20 ug/L by 2018

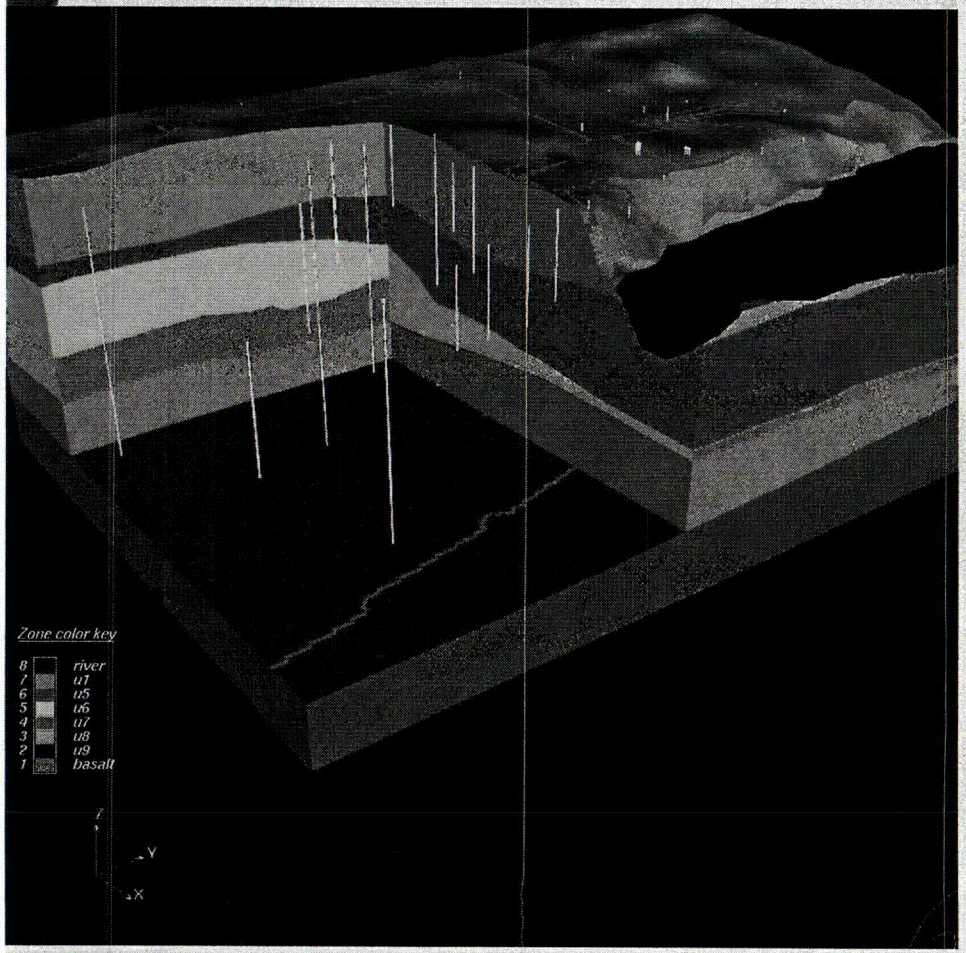
Prediction Update for U < 20 ug/L in RI/FS (1995)

- "Refinement" of Phase I RI estimate: **3 to 10 years** from late 1993 to meet standard
- Analytical model assumptions
  - Steady-state saturated flow
  - Constant hydraulic conductivity: 1830 m/day
  - Constant hydraulic gradient: 5×10^{-4}
  - 500 m travel distance from process trenches to Columbia River
  - Uranium mobility controlled by "best estimate" constant K_d ~ 1 to 2 mL/g
- No interaction between aquifer and river
- No interaction between aquifer and vadose zone

Aquifer Water Levels and Uranium Concentrations

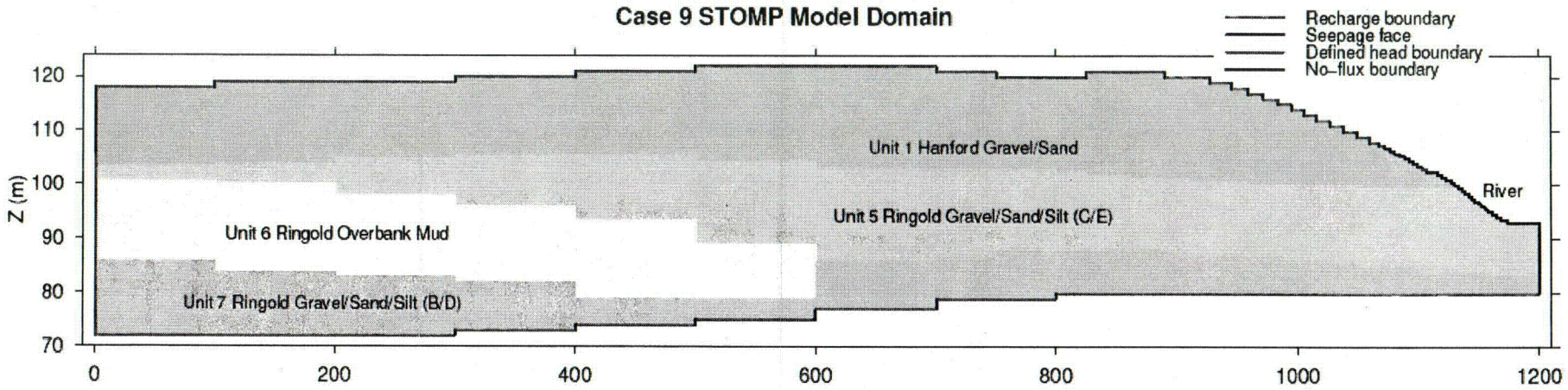


Flow and Transport: Vadose Zone – Aquifer – River System

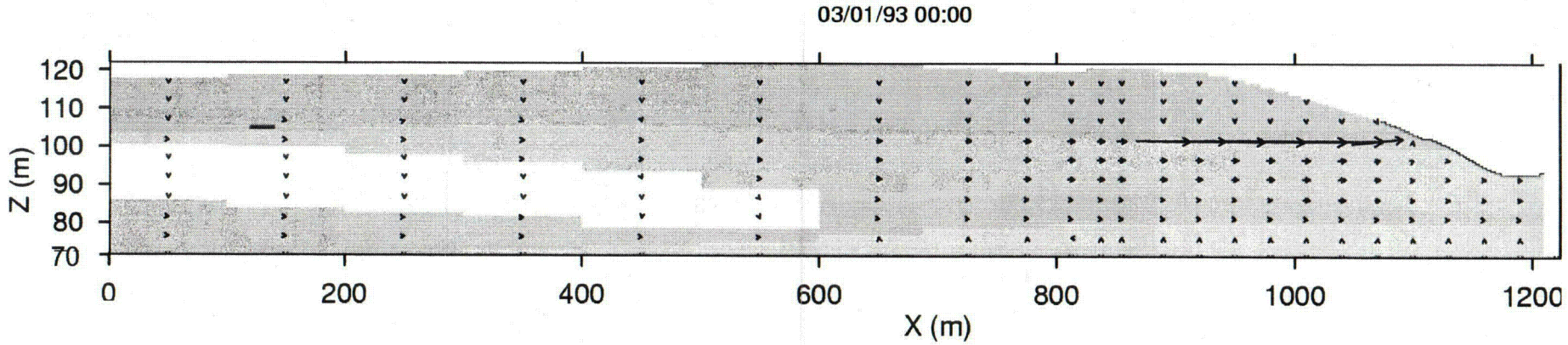


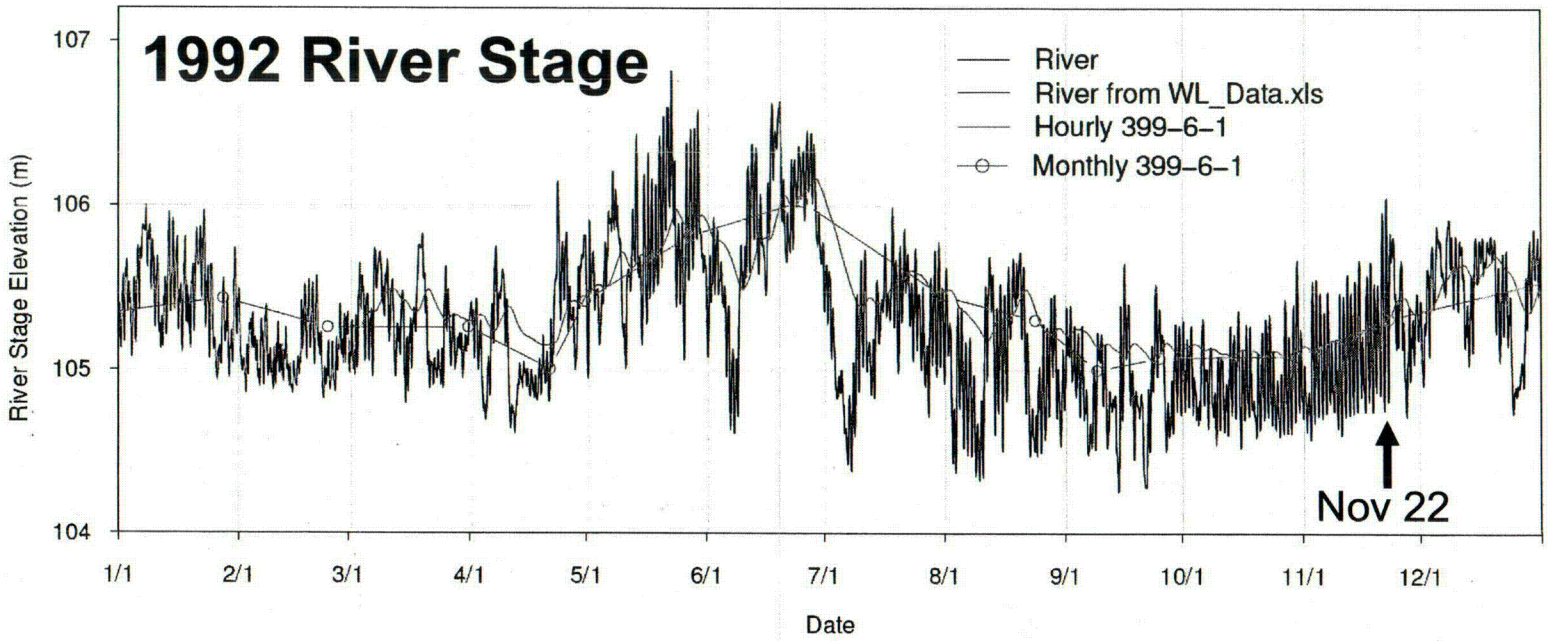
- 2-D and 3-D modeling
- Most current hydrogeology
- Flow and transport driven by hourly river stage fluctuations
- Investigate dynamics of riverbank storage and fluxes across aquifer - river interface
- Investigate release of uranium from contaminated vadose zone sediments due to water table fluctuations

Flow and Transport: Vadose Zone – Aquifer – River System

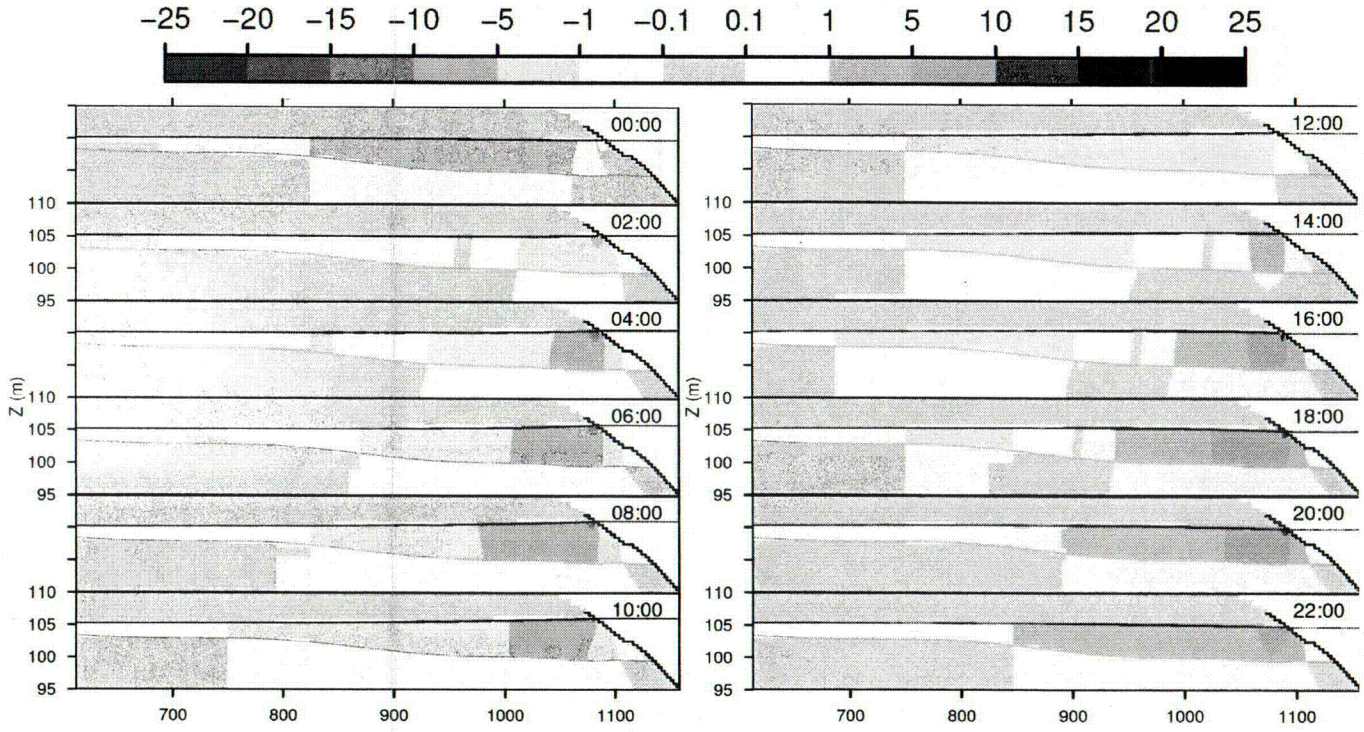


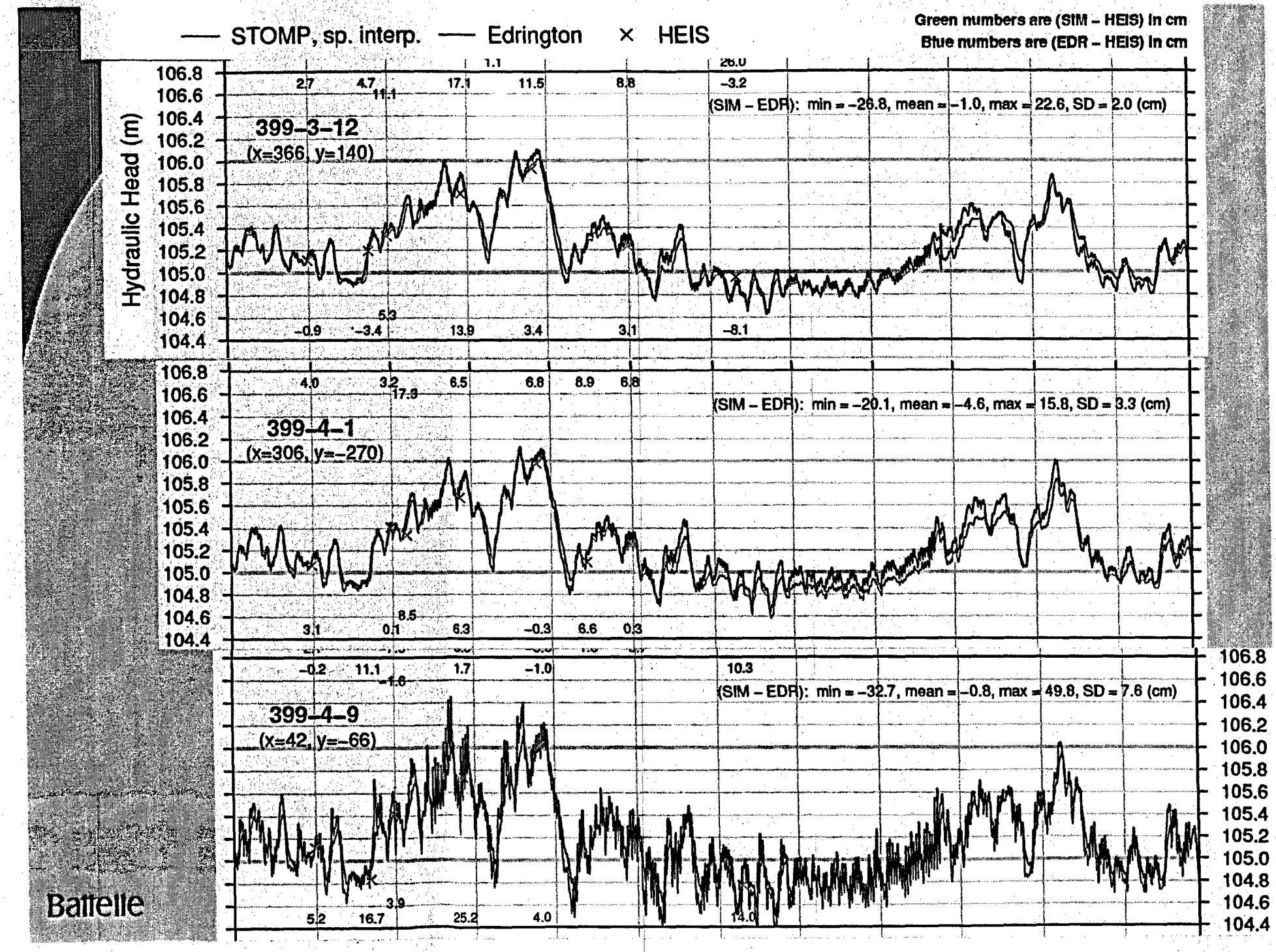
Material	K_l[(a)] (m d^{-1})	ϕ[(b)]	ψ[(c)] (cm)	λ[(d)]	θ_r[(e)]
U1, Hanford Gravel/Sand	1500	0.25	23.04	0.7465	0.1471
U5, Ringold Gravel/Sand/Silt (C/E)	150	0.18	71.31	0.5193	0.1299
U6, Ringold Overbank Mud	0.01	0.18	71.31	0.5193	0.1299
U7, Ringold Gravel/Sand/Silt (B/D)	43	0.18	71.31	0.5193	0.1299
U8,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




— 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 = 8.3 (cm)
399-4-9
(x=42, y=–66)
(SIM – EDR): min = –32.7, mean = –0.8, max = 49.8, SD = 7.6 (cm)
106.8
106.6
106.4
106.2
106.0
105.8
105.6
105.4
105.2
105.0
104.8
104.6
104.4
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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

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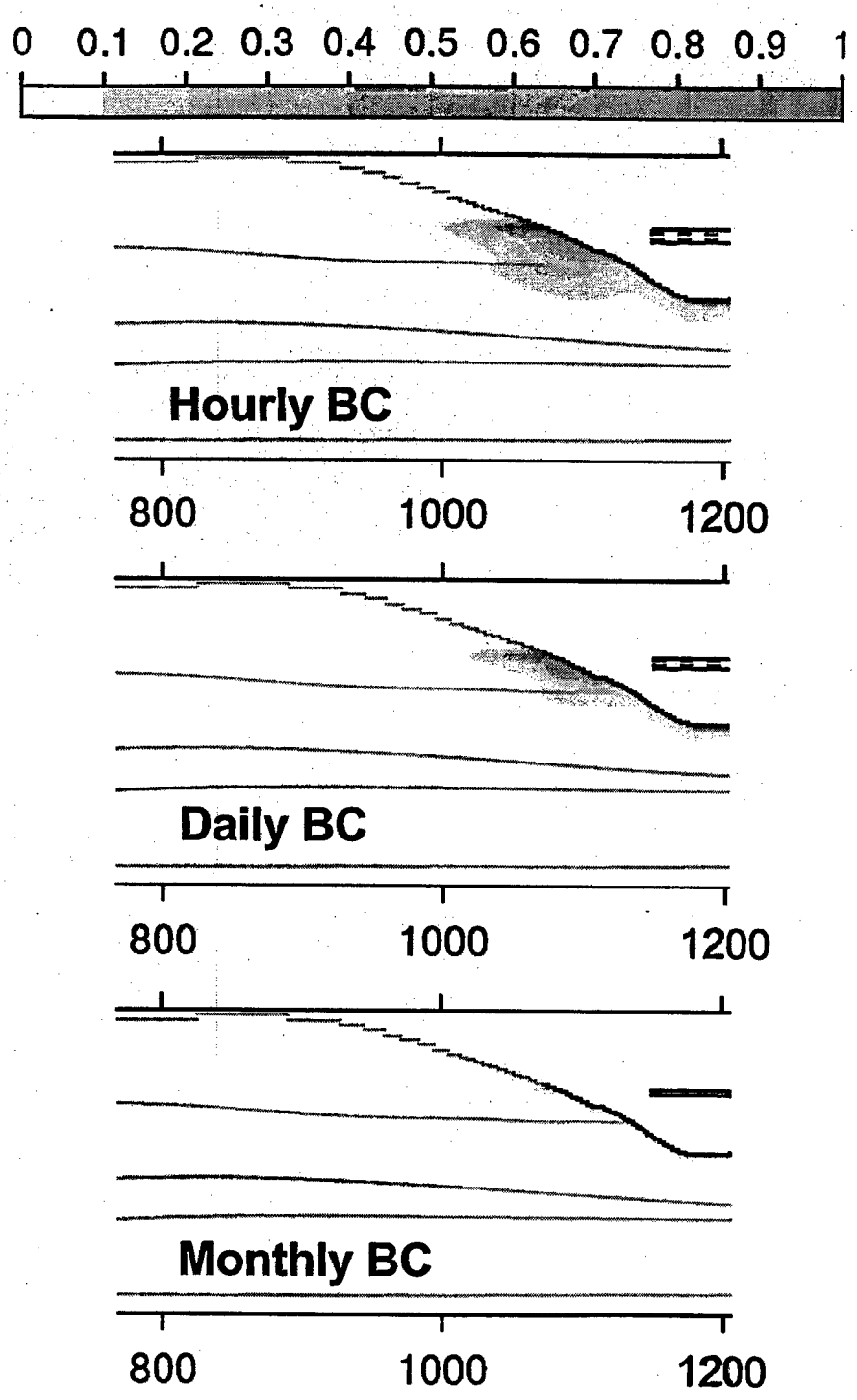
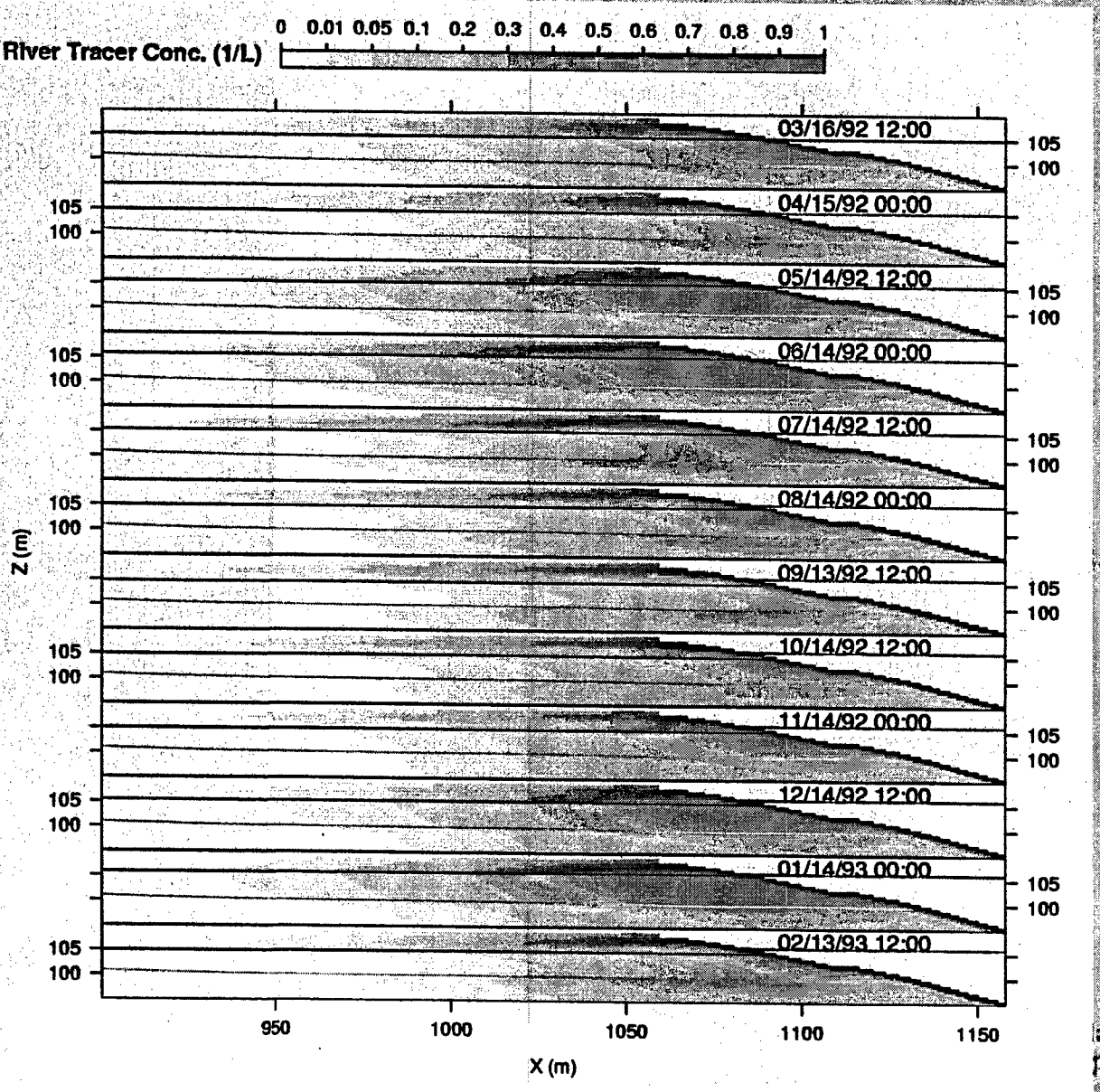


Seasonal Variation in Mixing Zone



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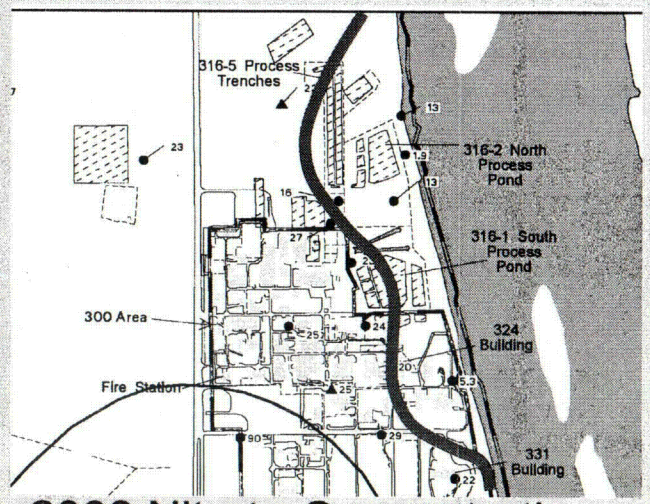
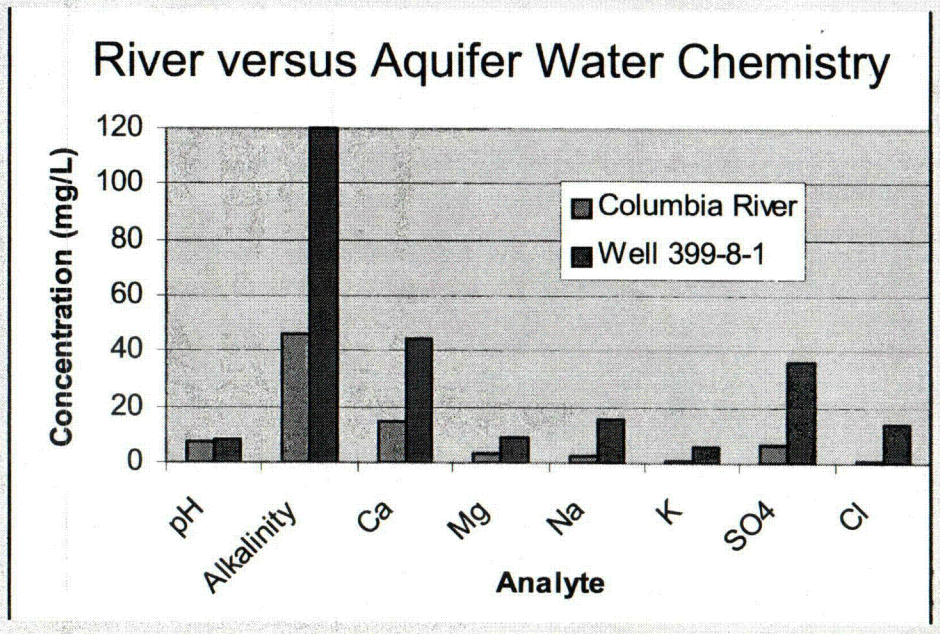
partment of Energy

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
- High pore velocity observed: 10 m/d pore velocity (Cline et al. 1985)



2002 Nitrate Concentration



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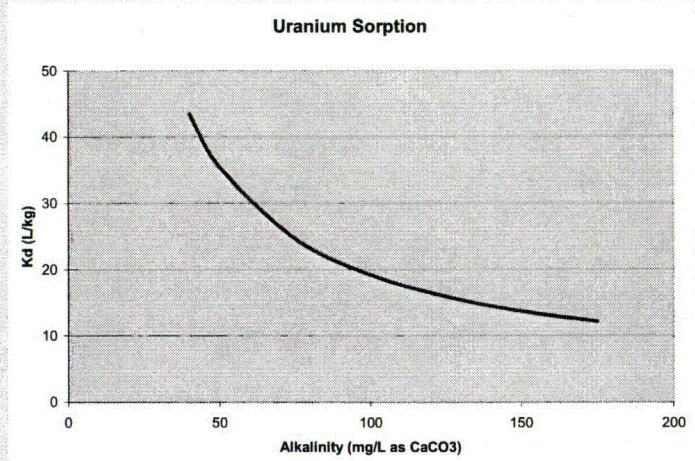
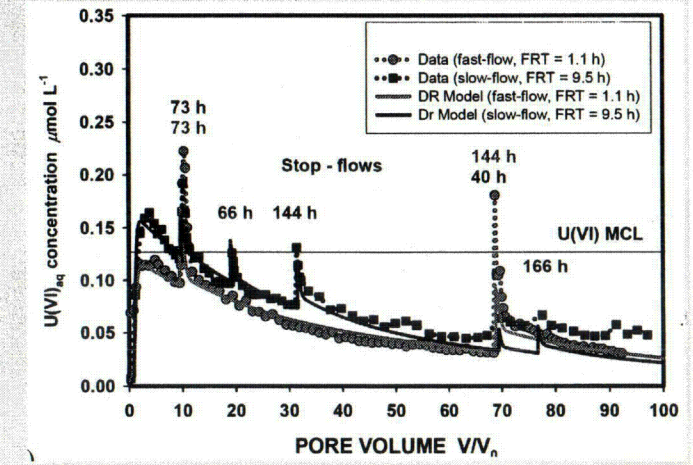
Uranium Geochemistry

- 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 Batch Studies

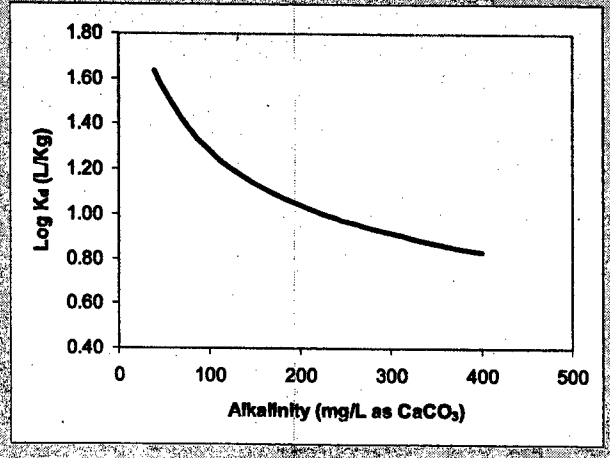
- Performed by Jim Davis, USGS
- Preliminary three-reaction generalized composite surface complexation model
  - accounts for bicarbonate concentration, sediment surface area, and aqueous U(VI) complexation (21 reactions)
  - 1 strong site and 2 weak site reactions:

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

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

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

  - The total site density of 3.84 umoles/m^2 is comprised of a strong site density of 1.344 nmoles/m^2 and a weak site density of 3.839 umoles/m^2
- Kd vs alkalinity



Uranium Aqueous Complexes

Reaction	log ß* (I = 0)[a]
$UO_2^{2+} + H_2O \Leftrightarrow UO_2OH^+ + H^+$	-5.25
$UO_2^{2+} + 2H_2O \Leftrightarrow UO_2(OH)_{2,aq} + 2H^+$	-12.15
$UO_2^{2+} + 3H_2O \Leftrightarrow UO_2(OH)_3^- + 3H^+$	-20.25
$UO_2^{2+} + 4H_2O \Leftrightarrow UO_2(OH)_4^{2-} + 4H^+$	-32.4
$2UO_2^{2+} + H_2O \Leftrightarrow (UO_2)_2OH^{3+} + H^+$	-2.70
$2UO_2^{2+} + 2H_2O \Leftrightarrow (UO_2)_2(OH)_2^{2+} + 2H^+$	-5.62
$3UO_2^{2+} + 4H_2O \Leftrightarrow (UO_2)_3(OH)_4^{2+} + 4H^+$	-11.90
$3UO_2^{2+} + 5H_2O \Leftrightarrow (UO_2)_3(OH)_5^+ + 5H^+$	-15.55
$3UO_2^{2+} + 7H_2O \Leftrightarrow (UO_2)_3(OH)_7^- + 7H^+$	-32.20
$4UO_2^{2+} + 7H_2O \Leftrightarrow (UO_2)_4(OH)_7^+ + 7H^+$	-21.9
$UO_2^{2+} + CO_3^{2-} \Leftrightarrow UO_2CO_3(aq)$	9.94
$UO_2^{2+} + 2CO_3^{2-} \Leftrightarrow UO_2(CO_3)_2^{2-}$	16.61
$UO_2^{2+} + 3CO_3^{2-} \Leftrightarrow UO_2(CO_3)_3^{4-}$	21.84
$2UO_2^{2+} + CO_3^{2-} + 3H_2O \Leftrightarrow (UO_2)_2CO_3(OH)_3^- + 3H^+$	-0.855
$Ca^{2+} + UO_2^{2+} + 3CO_3^{2-} \Leftrightarrow CaUO_2(CO_3)_3^{2-}$	25.4[b]
$2Ca^{2+} + UO_2^{2+} + 3CO_3^{2-} \Leftrightarrow Ca_2UO_2(CO_3)_3$ (aq)	30.55[b]
$UO_2^{2+} + NO_3^- \Leftrightarrow UO_2NO_3^+$	0.3
$UO_2^{2+} + Cl^- \Leftrightarrow UO_2Cl^+$	0.17
$UO_2^{2+} + 2Cl^- \Leftrightarrow UO_2Cl_2(aq)$	-1.1
$UO_2^{2+} + SO_4^{2-} \Leftrightarrow UO_2SO_4(aq)$	3.15
$UO_2^{2+} + 2SO_4^{2-} \Leftrightarrow UO_2(SO_4)_2^{2-}$	4.14

a) Values from Guillaumont *et al.* (2003), unless otherwise indicated.
b) Bernhard *et al.* (2001)

Uranium Column Studies

- Performed by Chongxuan Liu, PNNL
- Saturated column experiments exhibit uranium kinetics
- Multisite model with different reaction rates and/or diffusive mass transfer rates (Culver et al., 1997):

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

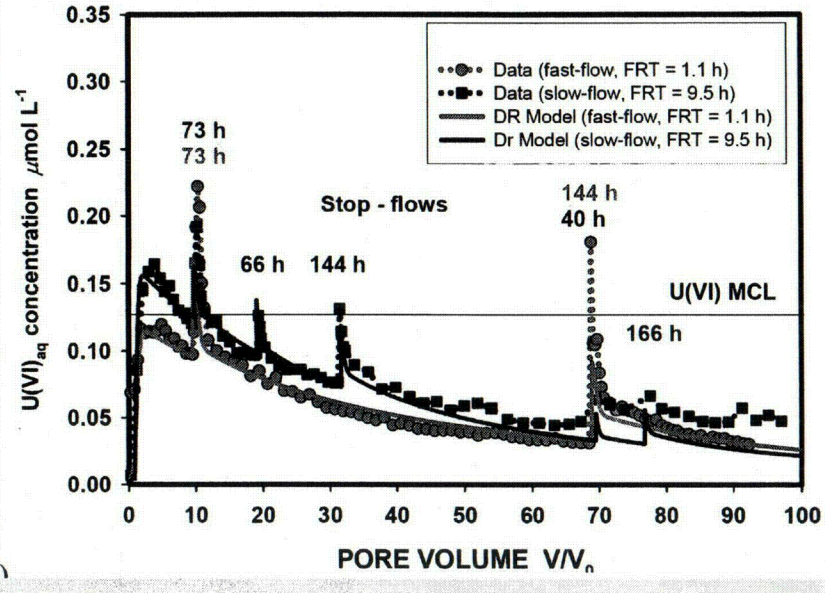
- Distributed rate parameters were assumed to follow the Gamma statistical distribution (two parameters):

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

- The multisite kinetic model was integrated into the advection-dispersion equation:

$$\theta \frac{\partial C}{\partial t} + \rho_b \frac{\partial S}{\partial t} = \theta D \frac{\partial^2 C}{\partial x^2} - \theta v \frac{\partial C}{\partial x}$$

U(VI) Breakthrough Curve



Field-Based Reactive Transport Modeling

Account for full sediment size distribution

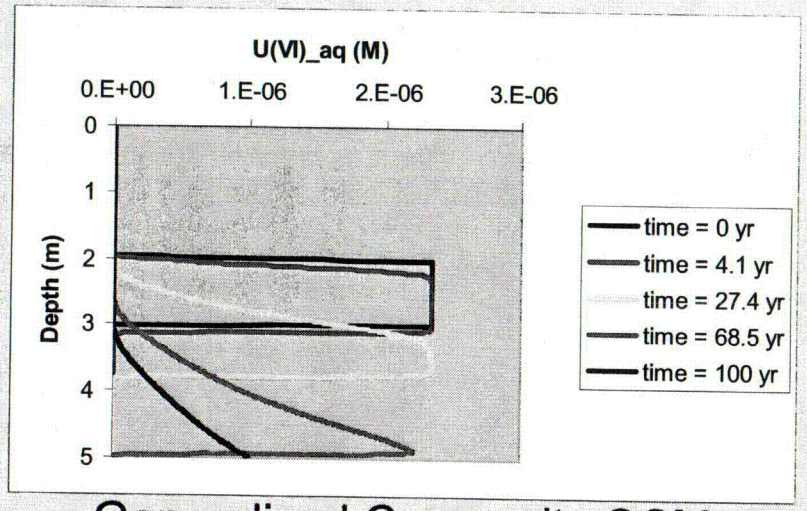
- < 2 mm size fraction in the lab studies
  - Specific surface area: 27.2 m^2/g
  - 8% of total sediment
- Preliminary assumption: gravels are unreactive
  - apportion 8% of the 2.06 kg/L field bulk density for surface complexation

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

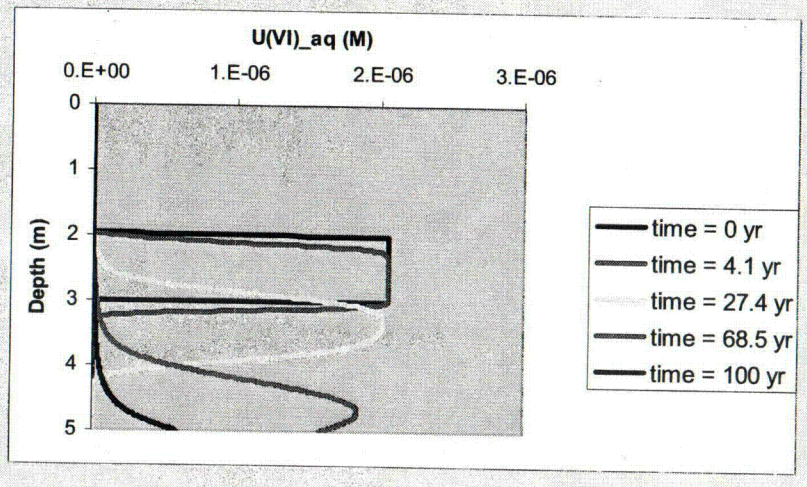
Unsaturated Flow Model Parameters	Value	Units
Horizontal Hydraulic Conductivity	1500	m/d
Vertical Hydraulic Conductivity	150	m/d
Air entry pressure	23.04	cm
Brooks-Corey λ	0.7465	
Residual Saturation	0.1471	
Relative Permeability Method	Burdine	
Porosity	0.25	
Bulk Density	2.06	Kg/L
Recharge Rate	60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

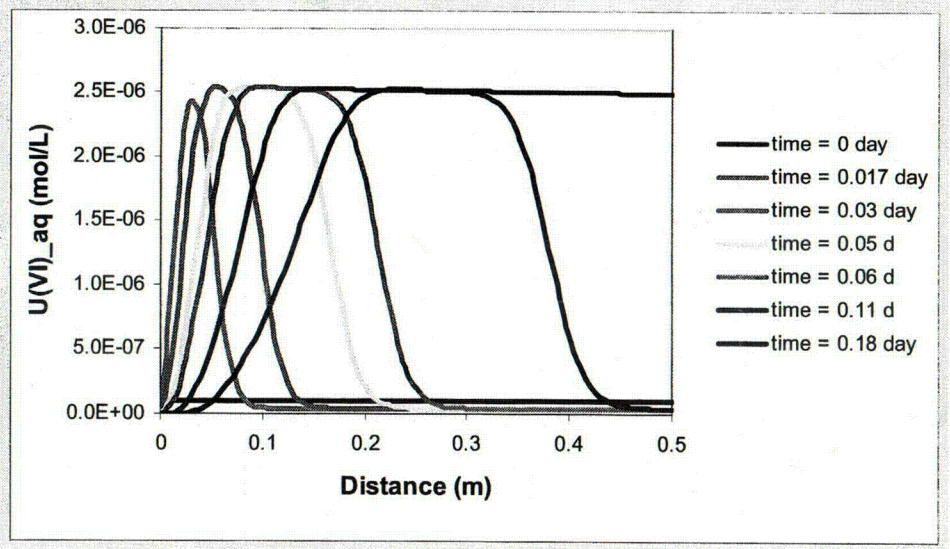
1-D Aquifer-River Interactions

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



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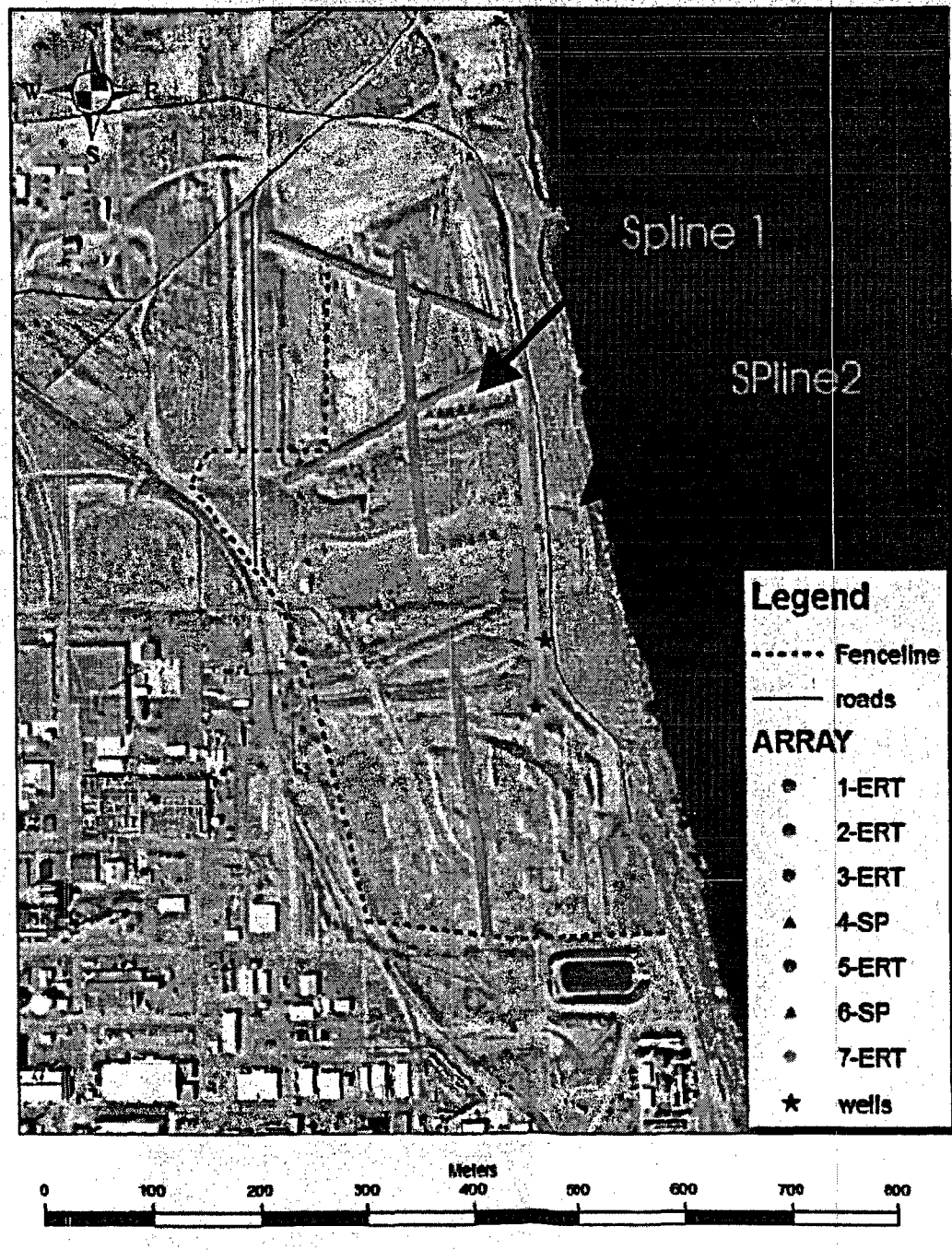
Modeling Summary

- 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



Geophysical Characterization

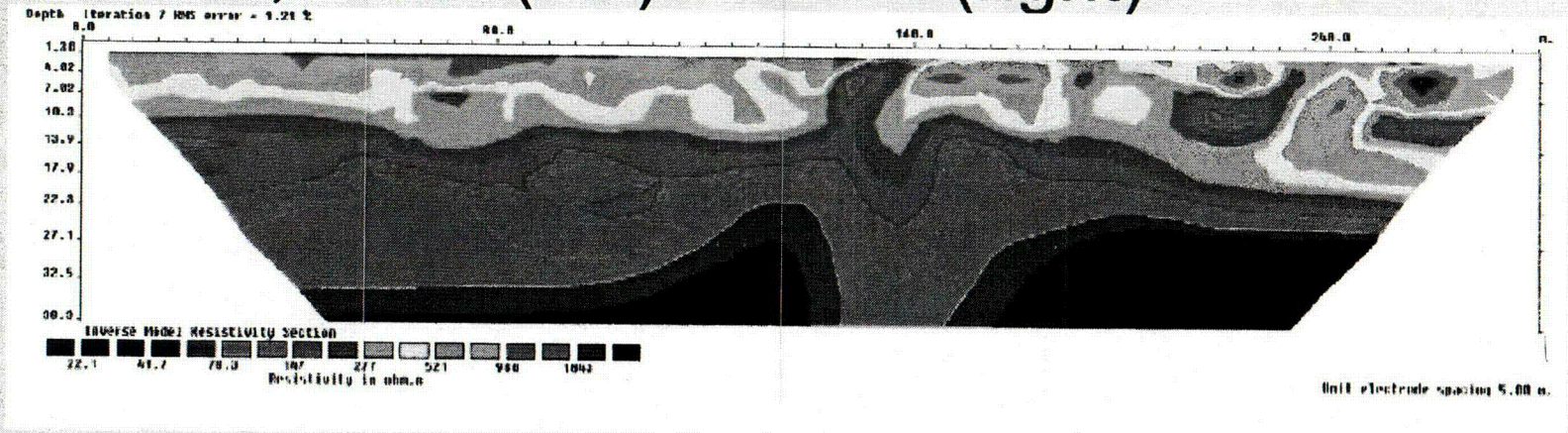
- Performed by Andy Ward (PNNL) and Roelof Versteeg (INL)
- March 2006: successful test of single ERT and SP lines
- August 2006: Full grids of SP, ERT-Complex Resistivity electrodes

Preliminary Resistivity Plots

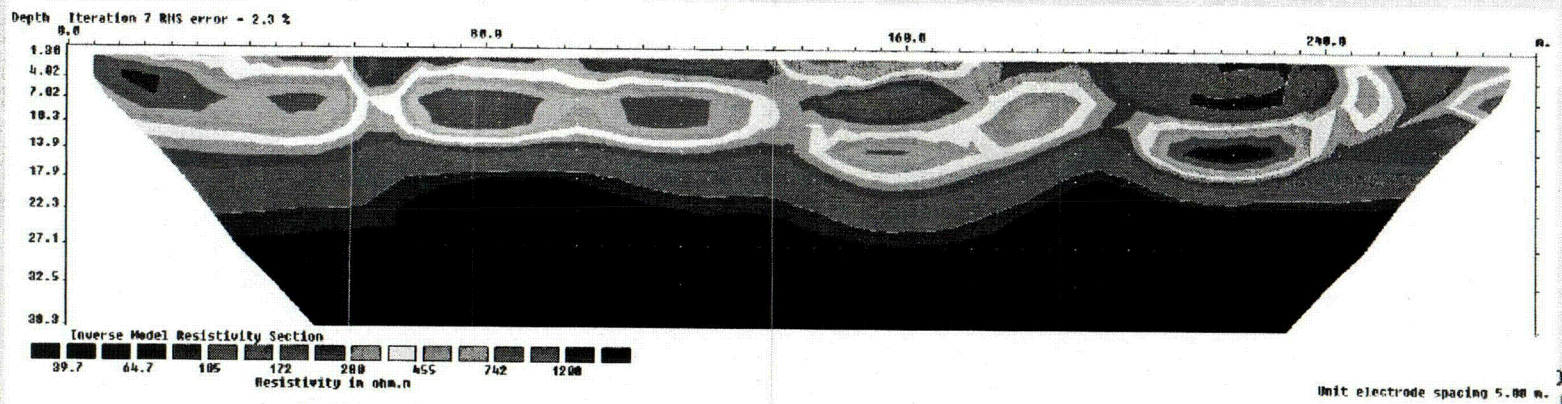
North Process Pond

(high resistance ~ coarse unsaturated sediment)

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



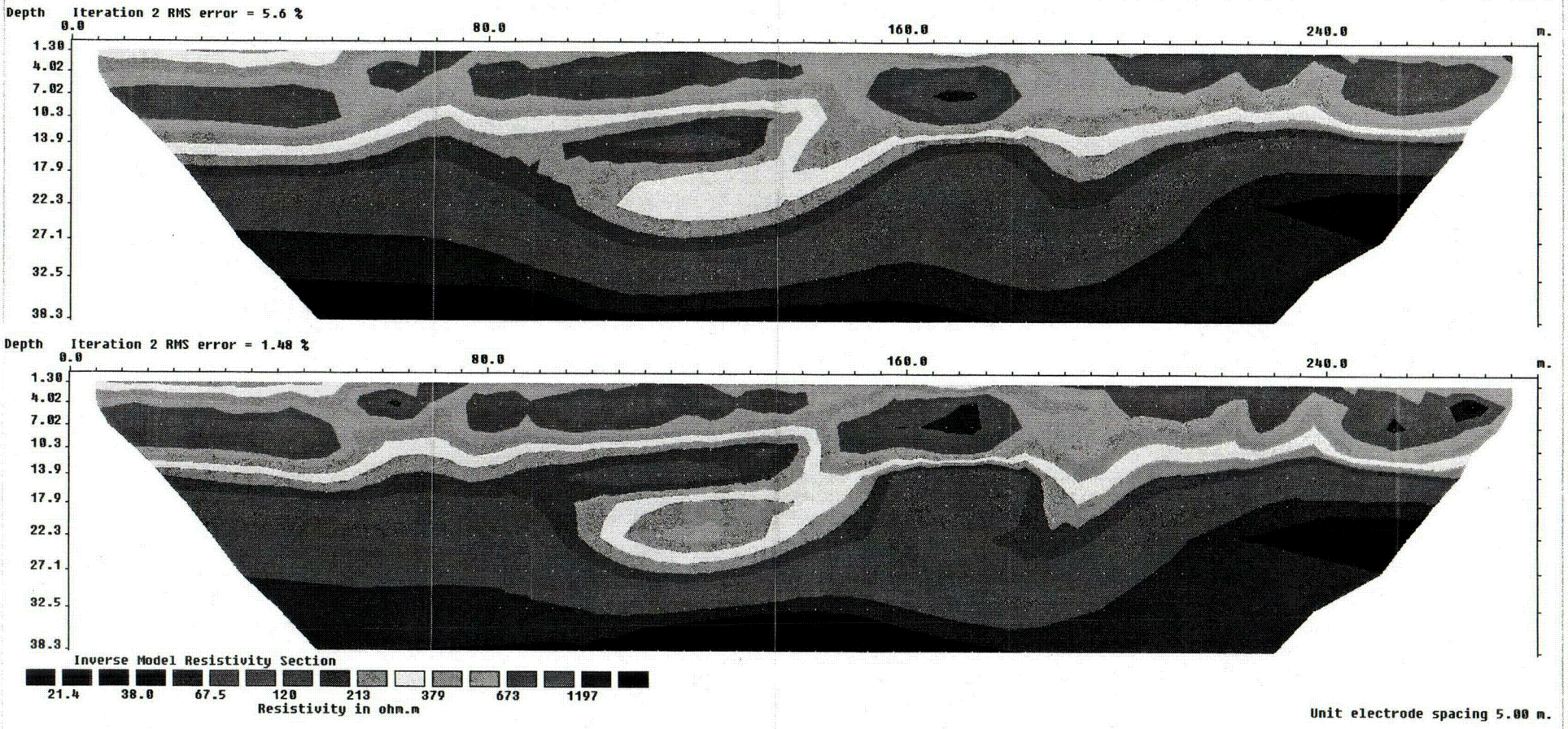
- Line 3, west (left) to east (right)



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 and 60 ERT electrodes
- 30 m spacing
- Screening/Scoping for final grid specification

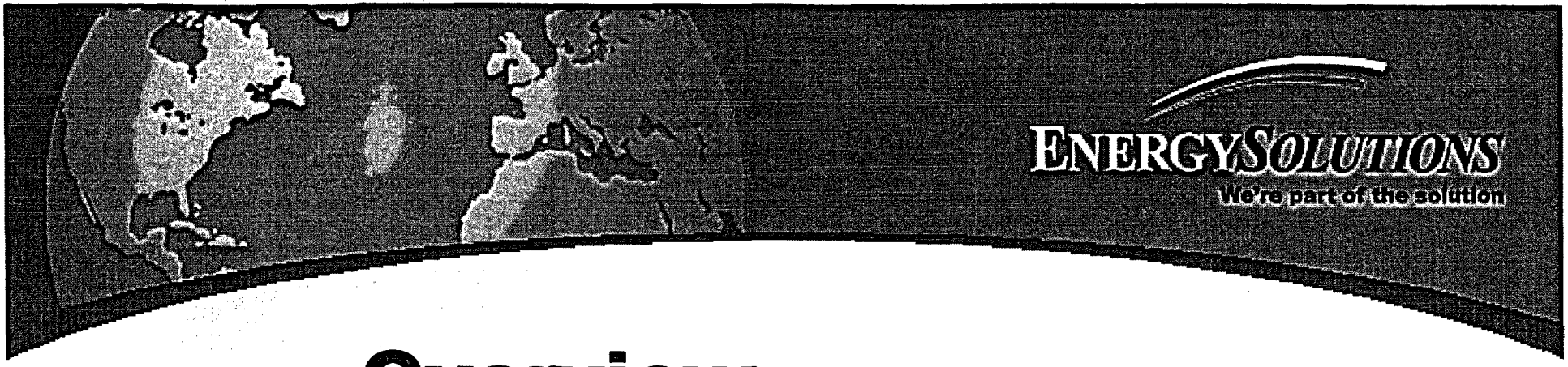
Battelle

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
- Full Grid Deployment
  - 120 SP electrodes
  - 60 ERT/Complex Resistivity electrodes
  - 300 Area flow behavior
- Next Steps
  - Use borehole logs and depth to water to interpret layers in terms of lithology
  - SP survey analyzed with hourly water level to identify groundwater flow field
  - Complex resistivity for material property distribution
  - Identification of permanent electrode locations

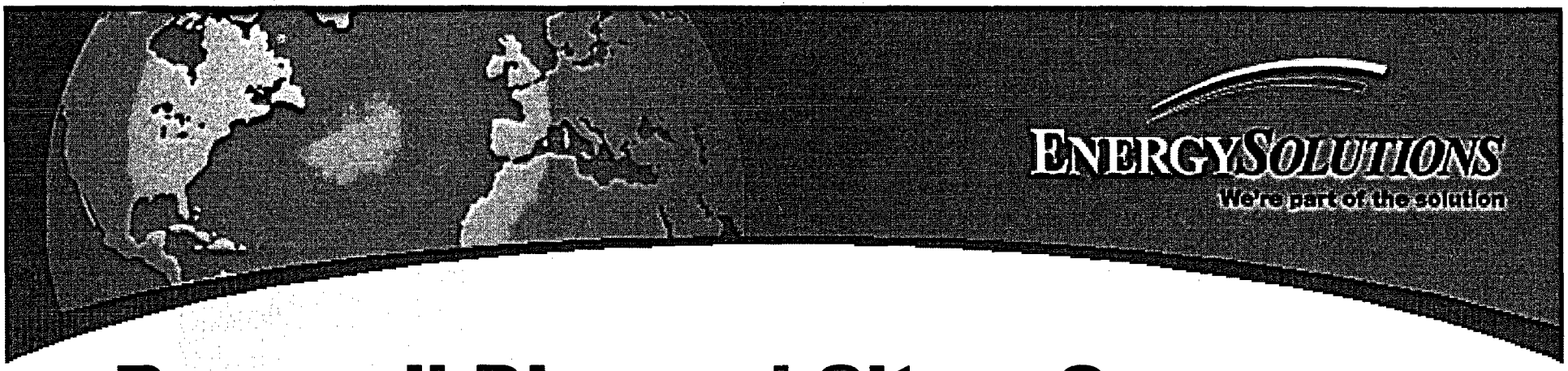
Role of Models in Demonstration, Compliance with Licensing Requirements

presented to the ACNW
September 19, 2006
by Vernon Ichimura



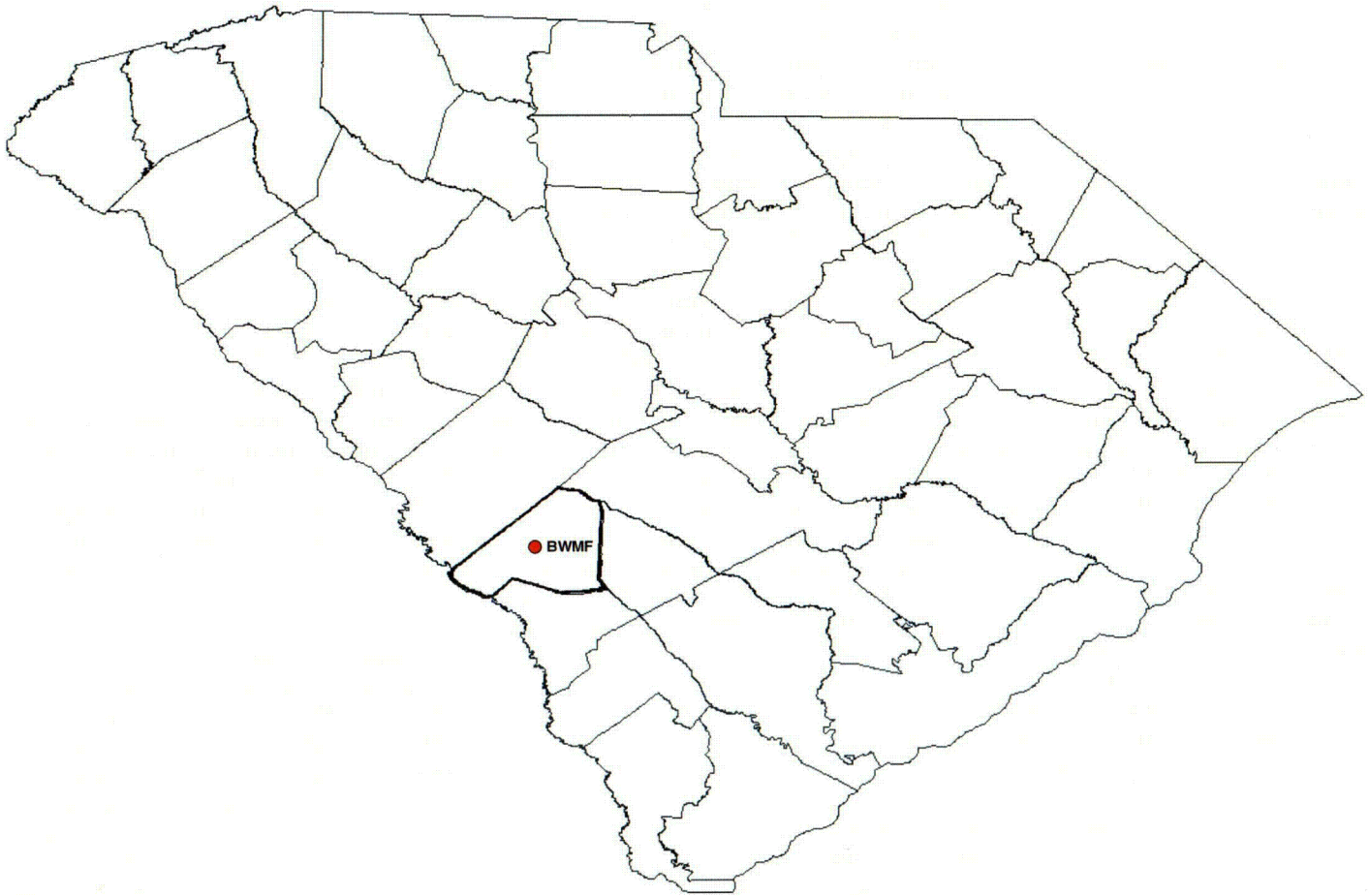
Overview

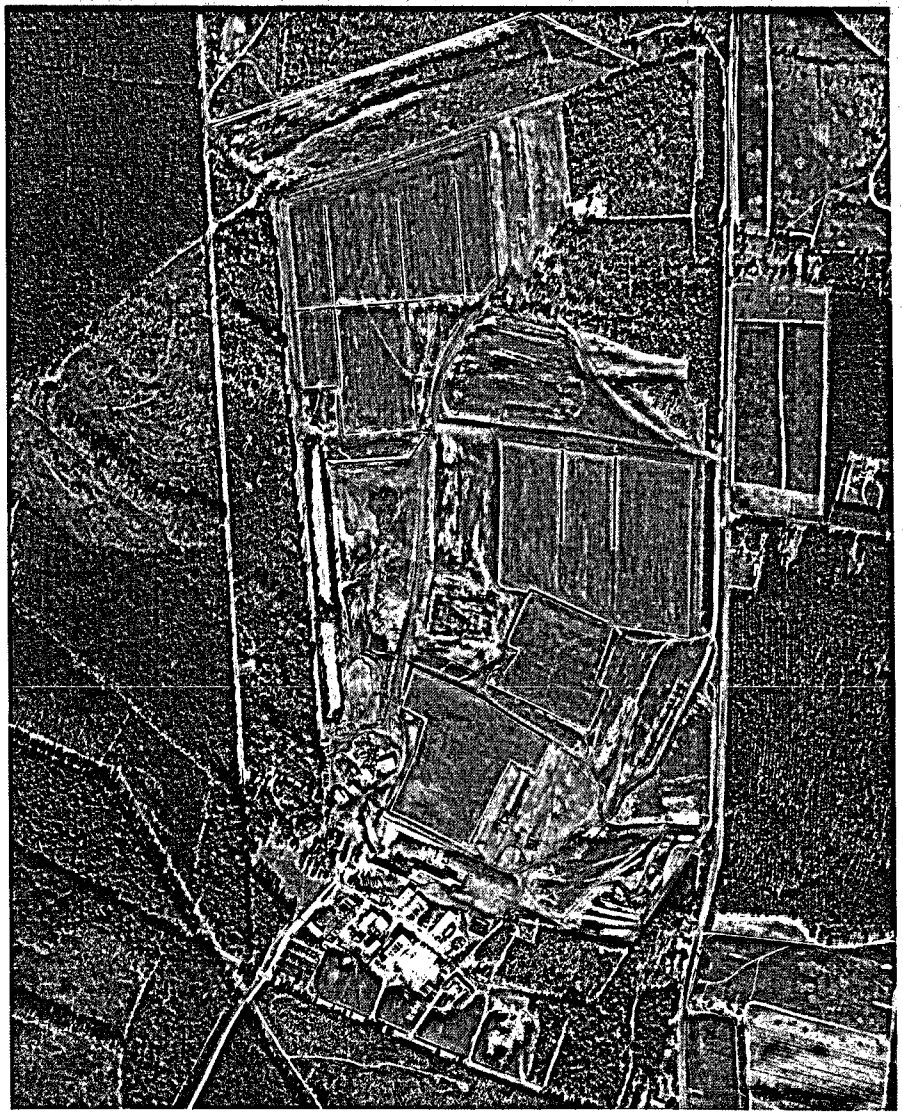
- Barnwell Disposal Site
- Review of Regulation
- Focus on Measurement
- Use of Models

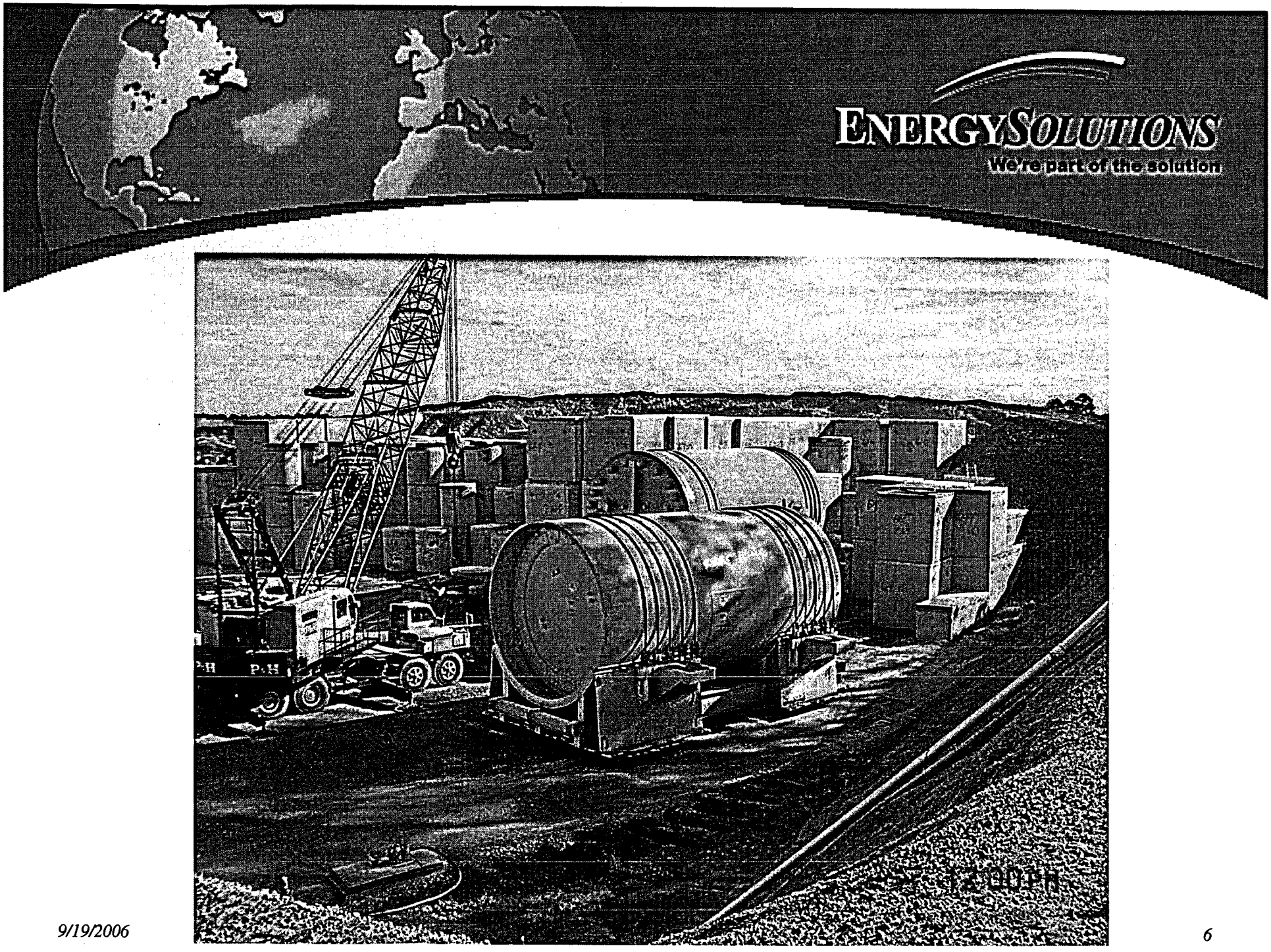


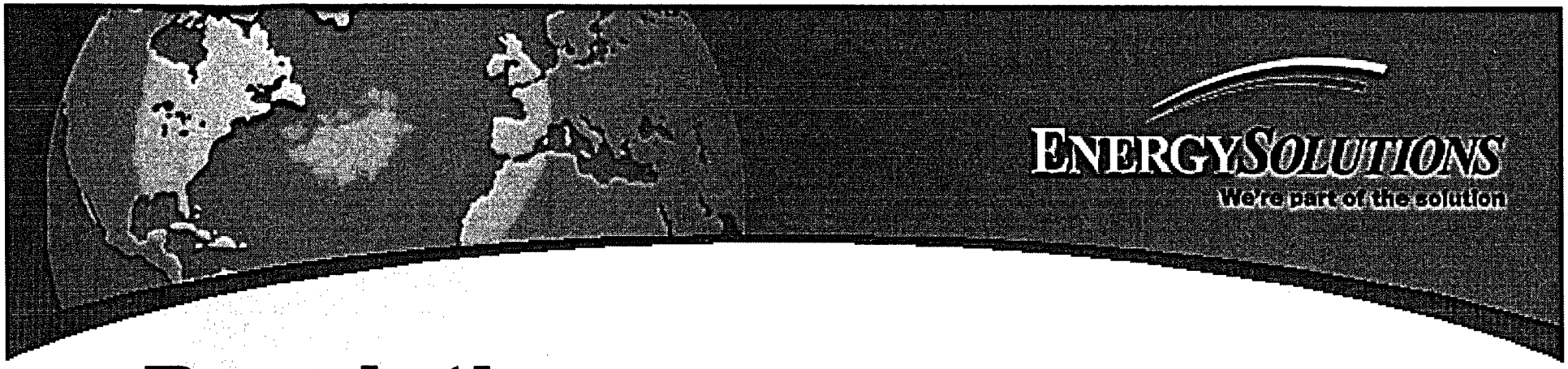
Barnwell Disposal Site -- Summary

- 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



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

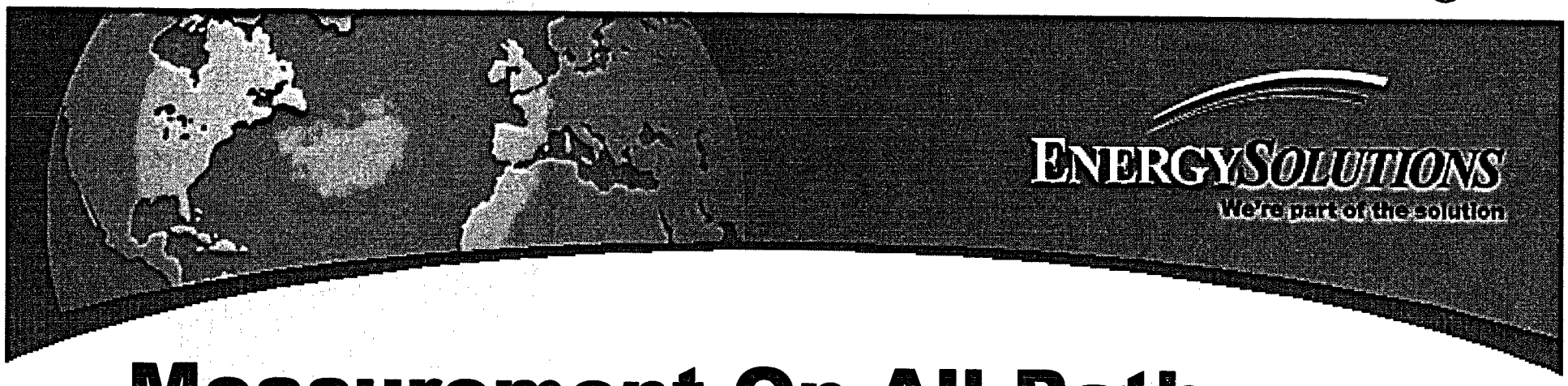
- Real dose to workers
- In 2005 – Average Annual Dose to a Radiation Workers was 241 millirems

Environment

- Hypothetical 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.

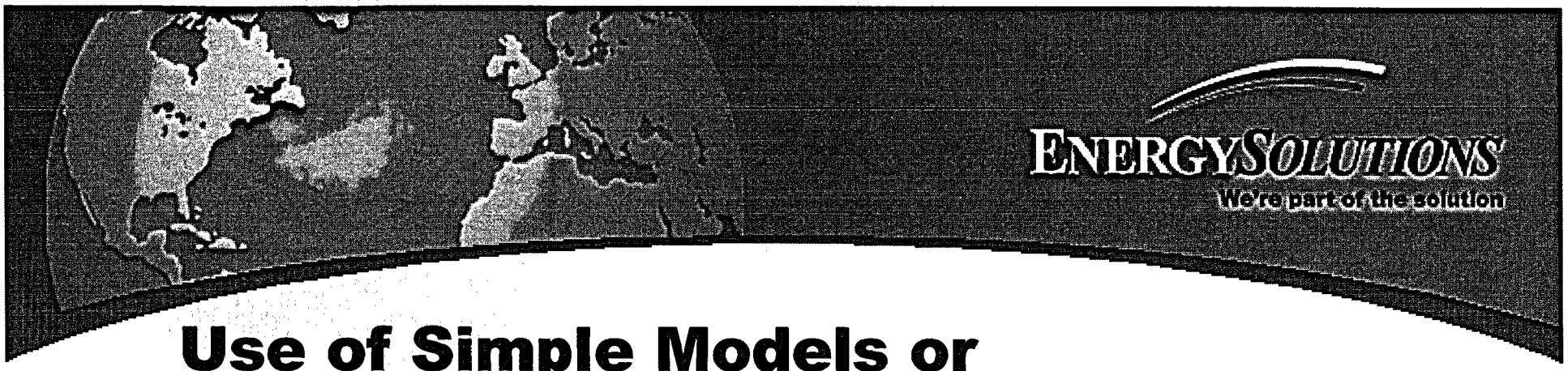
Focus on Measurement

- 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



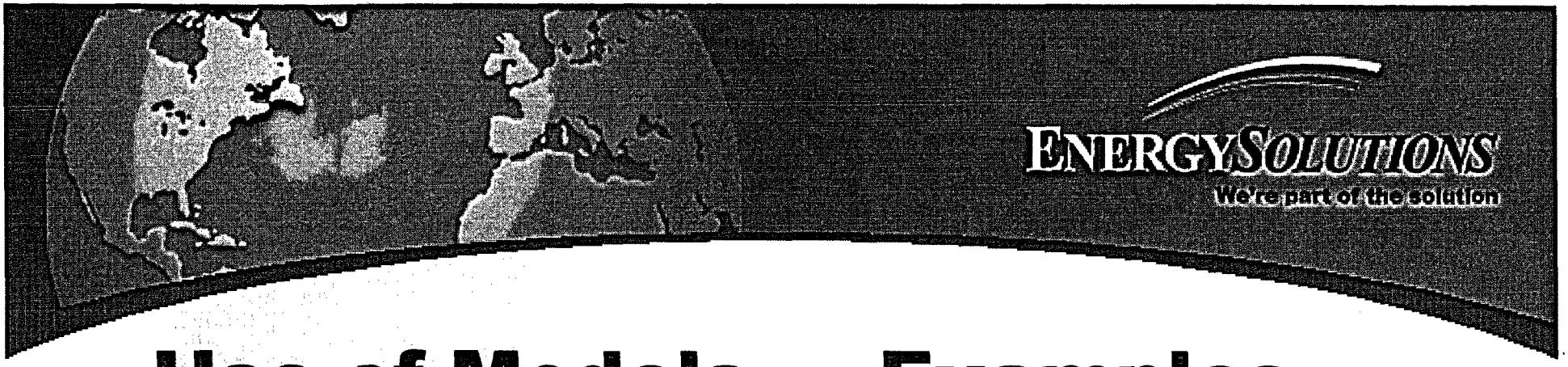
Measurement On All Pathways

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



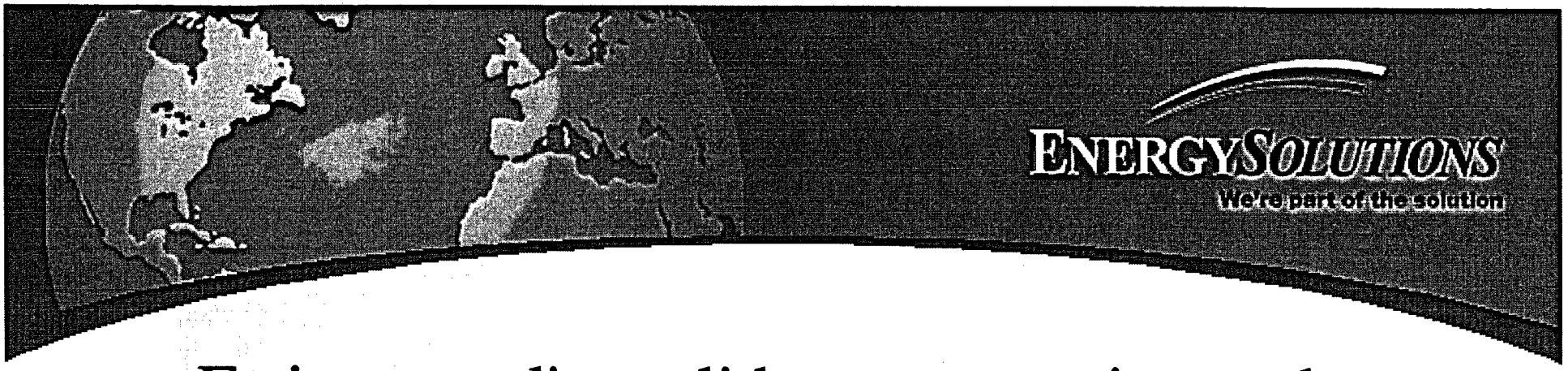
Use of Simple Models or Well Documented Models Which Have Been Checked

- 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



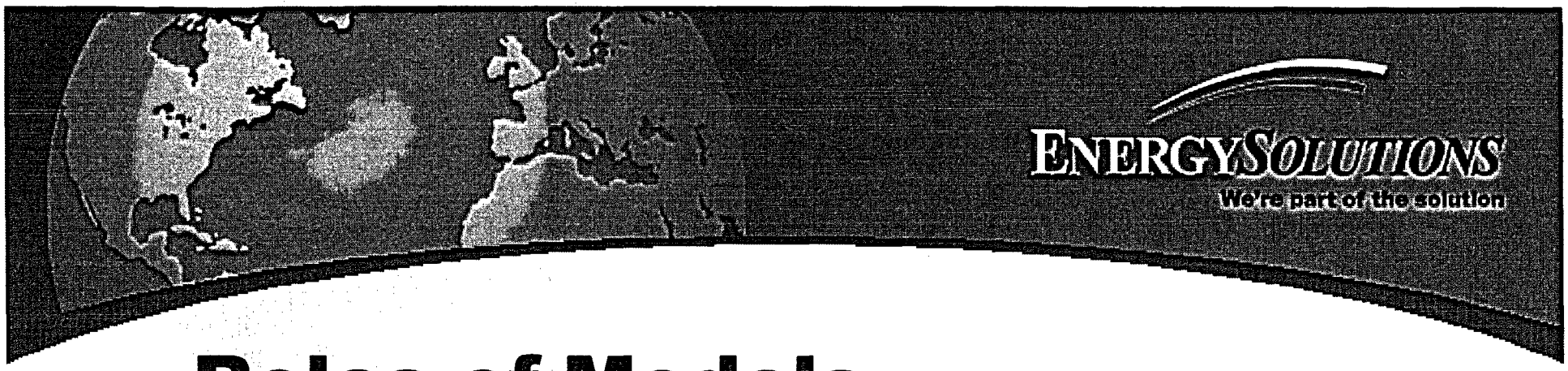
Use of Models - - Examples

- 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

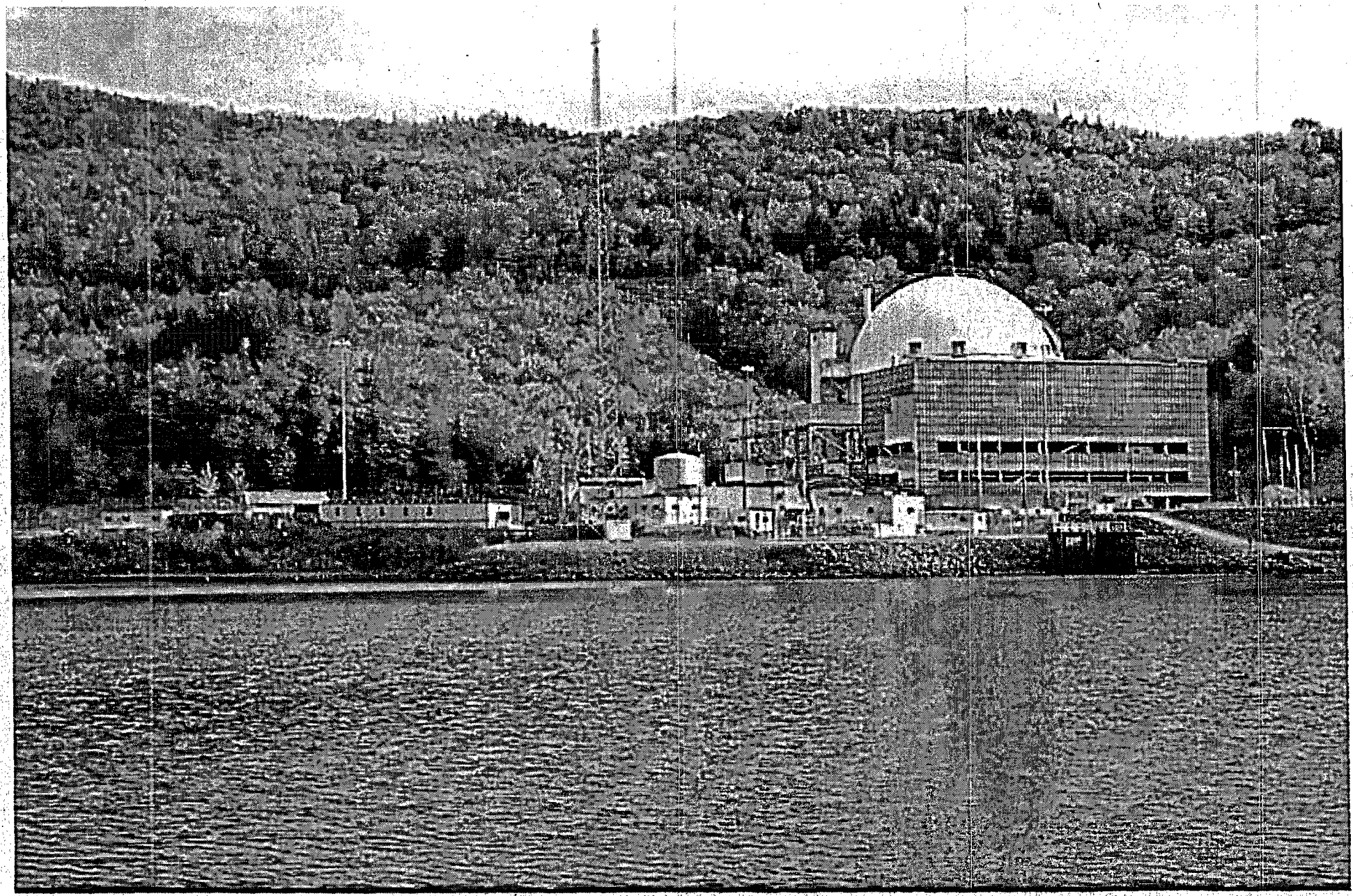
Groundwater Monitoring in Support of License Termination at Yankee Nuclear Power Station

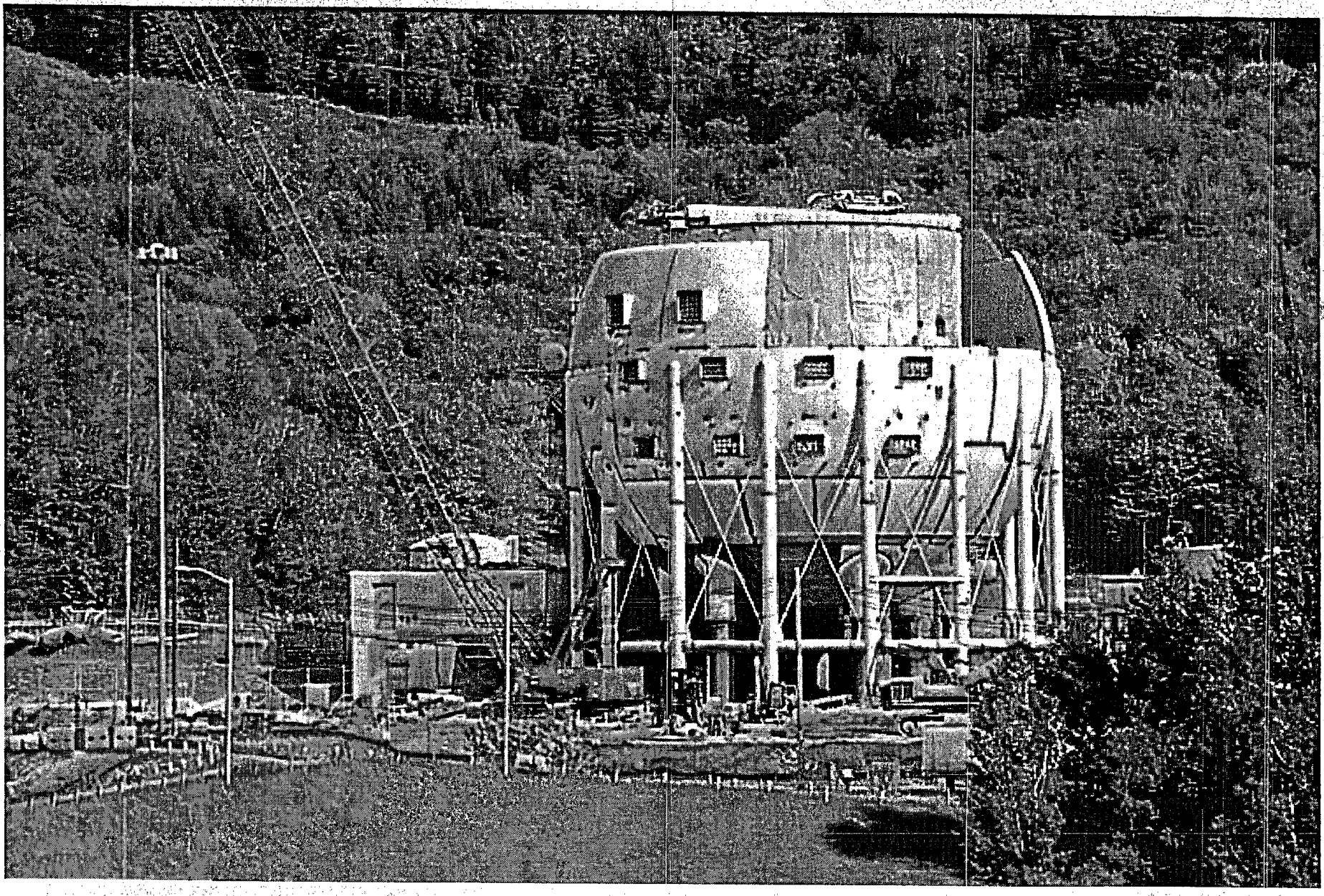
Advisory Committee on Nuclear Waste
U.S. Nuclear Regulatory Commission
Rockville, MD, September 19 & 20, 2006

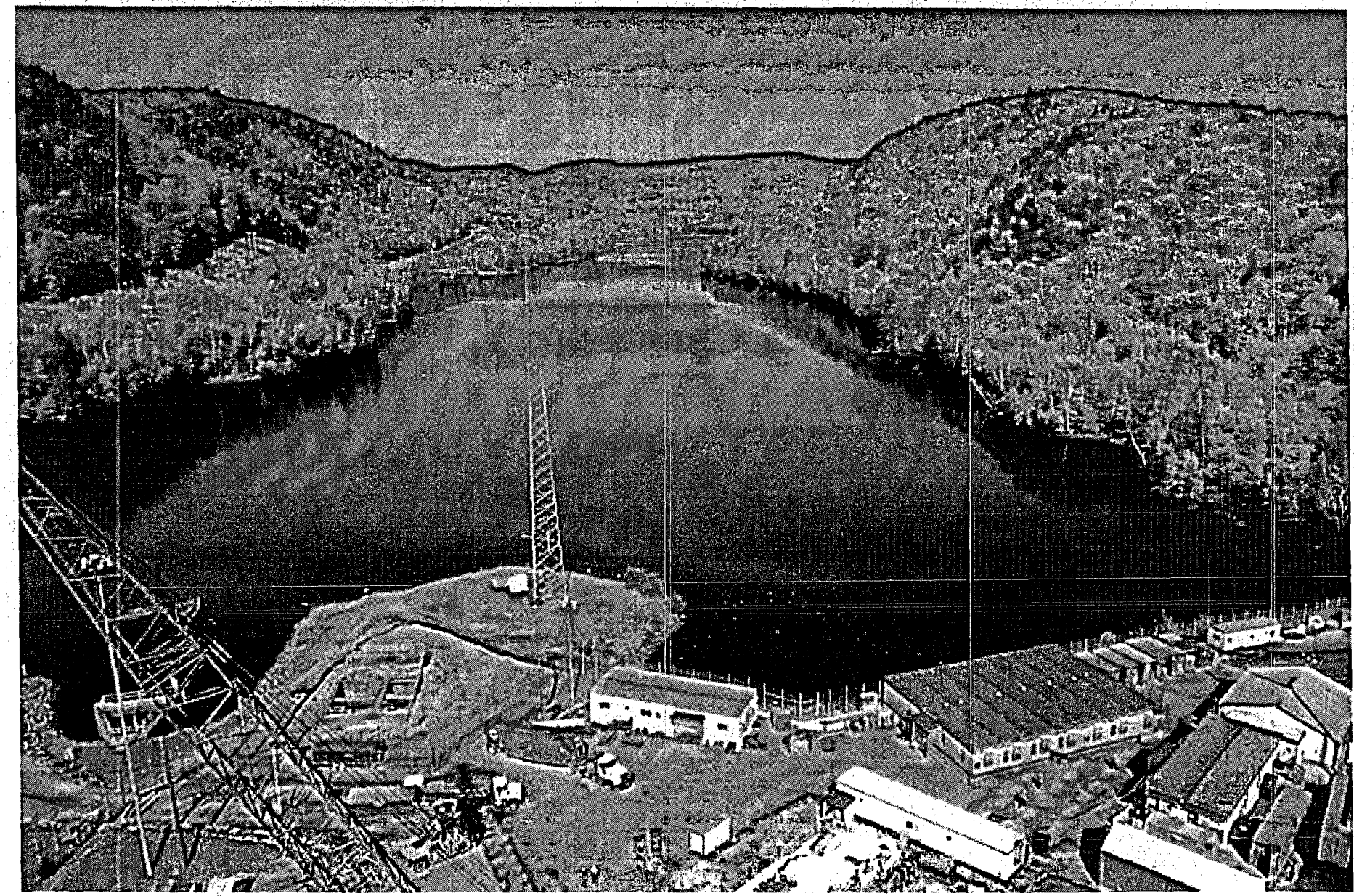
Dave Scott, Project Hydrogeologist, Radiation Safety & Control Services, Inc.
Greg Babineu, Yankee Atomic Electric Company
Eric Darois, CHP, Radiation Safety & Control Services, Inc.

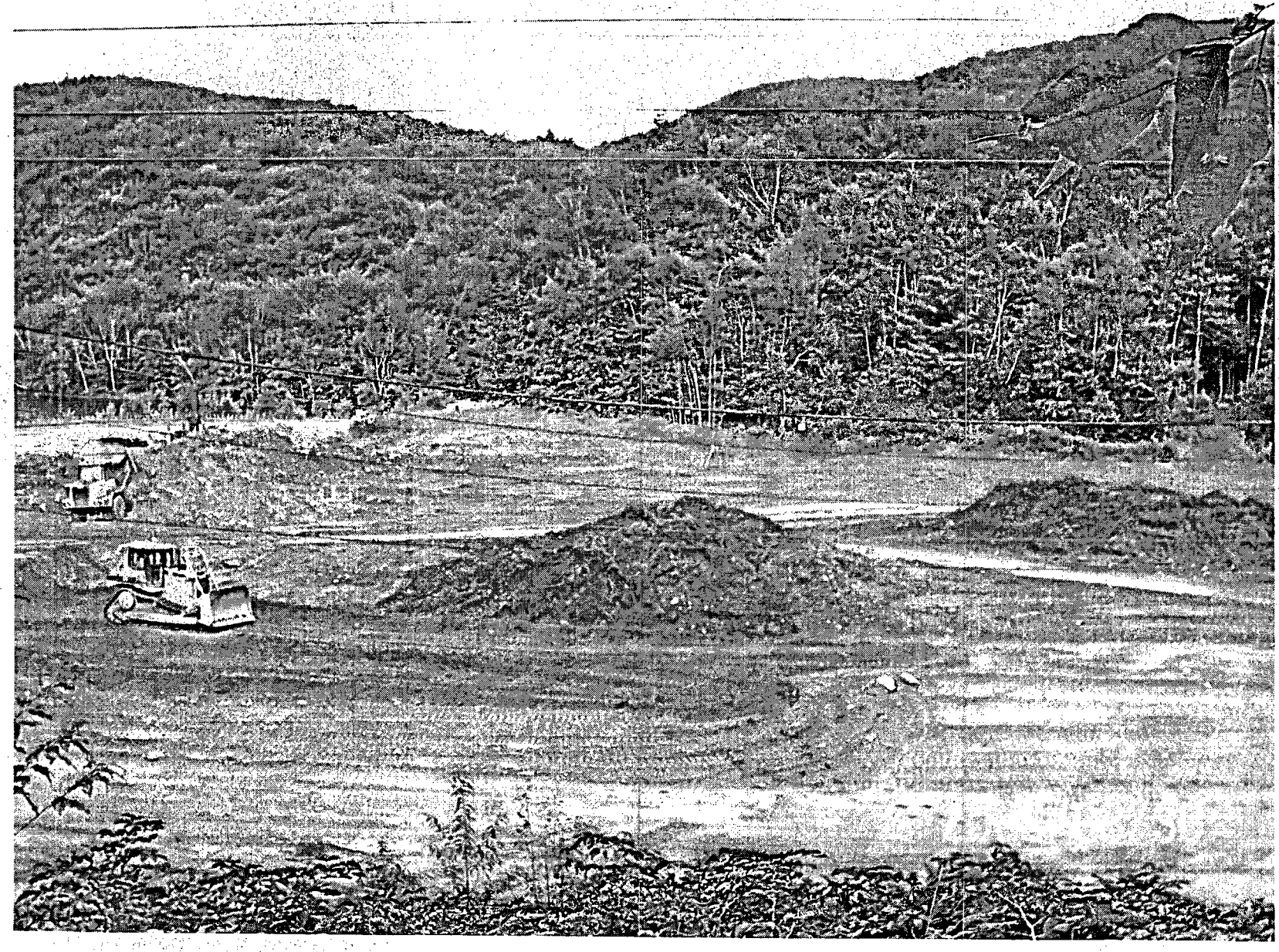
YR Operational History

- 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









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

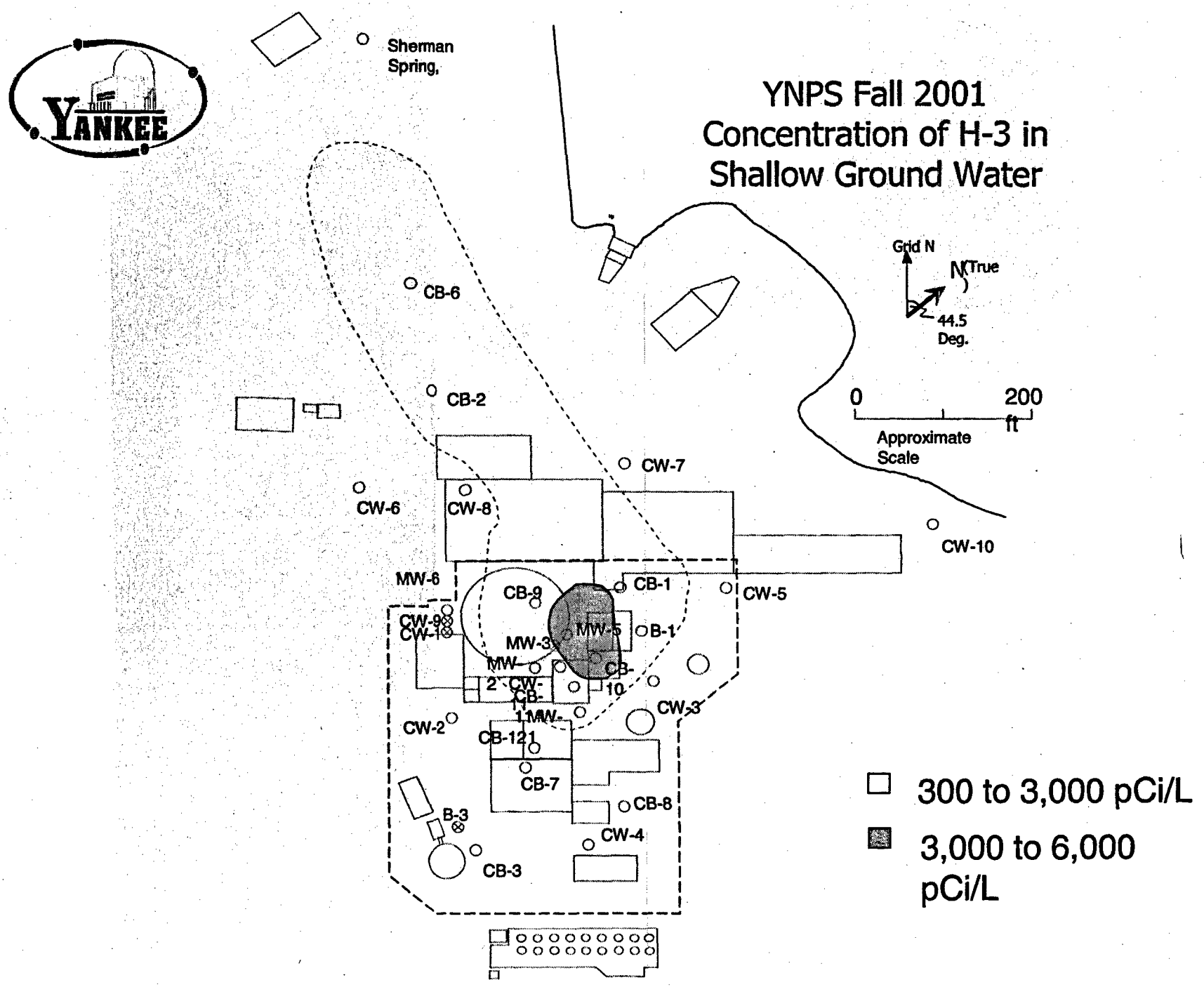
- All Pathways TEDE < 25 Millirem/yr (10 CFR 20.1402), and Residual Radioactivity ALARA
- H-3 Concentration in Resident Farmer's Well Less Than 20,000 pCi/L
  - Average yield of well serving family of four: 1323 m^3/yr (0.665 gpm)
- Other GW Contaminants Less Than Limits Defined in LTP License Condition

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


YANKEE
Sherman Spring
YNPS Fall 2001
Concentration of H-3 in
Shallow Ground Water
Grid N
N (True)
44.5 Deg.
0
200
ft
Approximate Scale
CB-6
CB-2
CW-7
CW-6
CW-8
CW-10
MW-6
CB-9
CB-1
CW-5
CW-9
CW-1
MW-5
B-1
MW-3
MW-2
CW-11
CB-10
CB-11
MW-1
CW-3
CW-2
CB-12
CB-7
CB-8
B-3
CW-4
CB-3
300 to 3,000 pCi/L
3,000 to 6,000 pCi/L

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

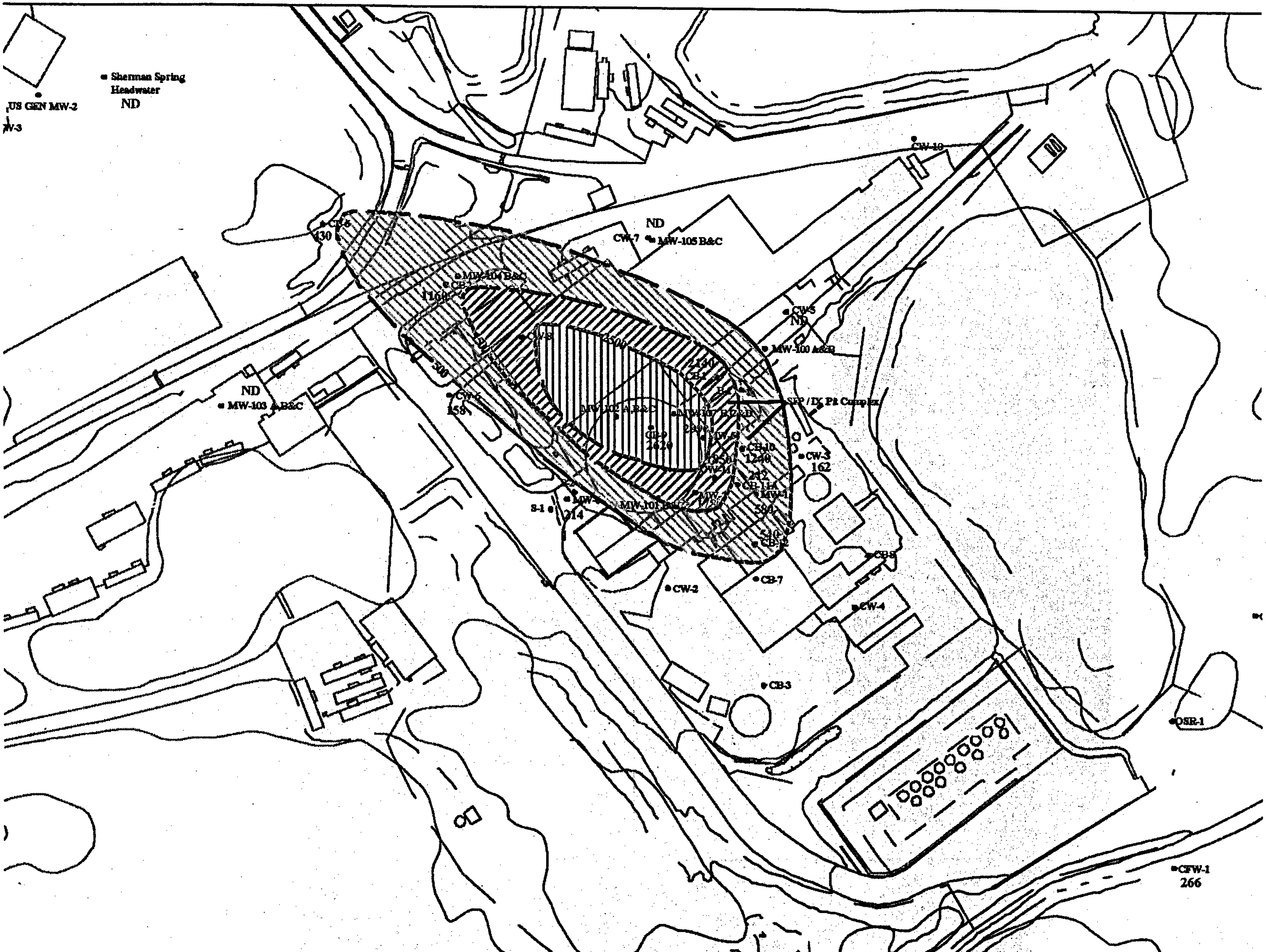
- Established monitoring program that included:
  - Suites of radionuclide analytes determined by location, based on HSA and LTP
  - New locations for wells based on site geology
    - Intermediate depth sand lenses (30 -100 feet)
    - Bedrock (some as deep as 300 feet)
    - Multiple wells at same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

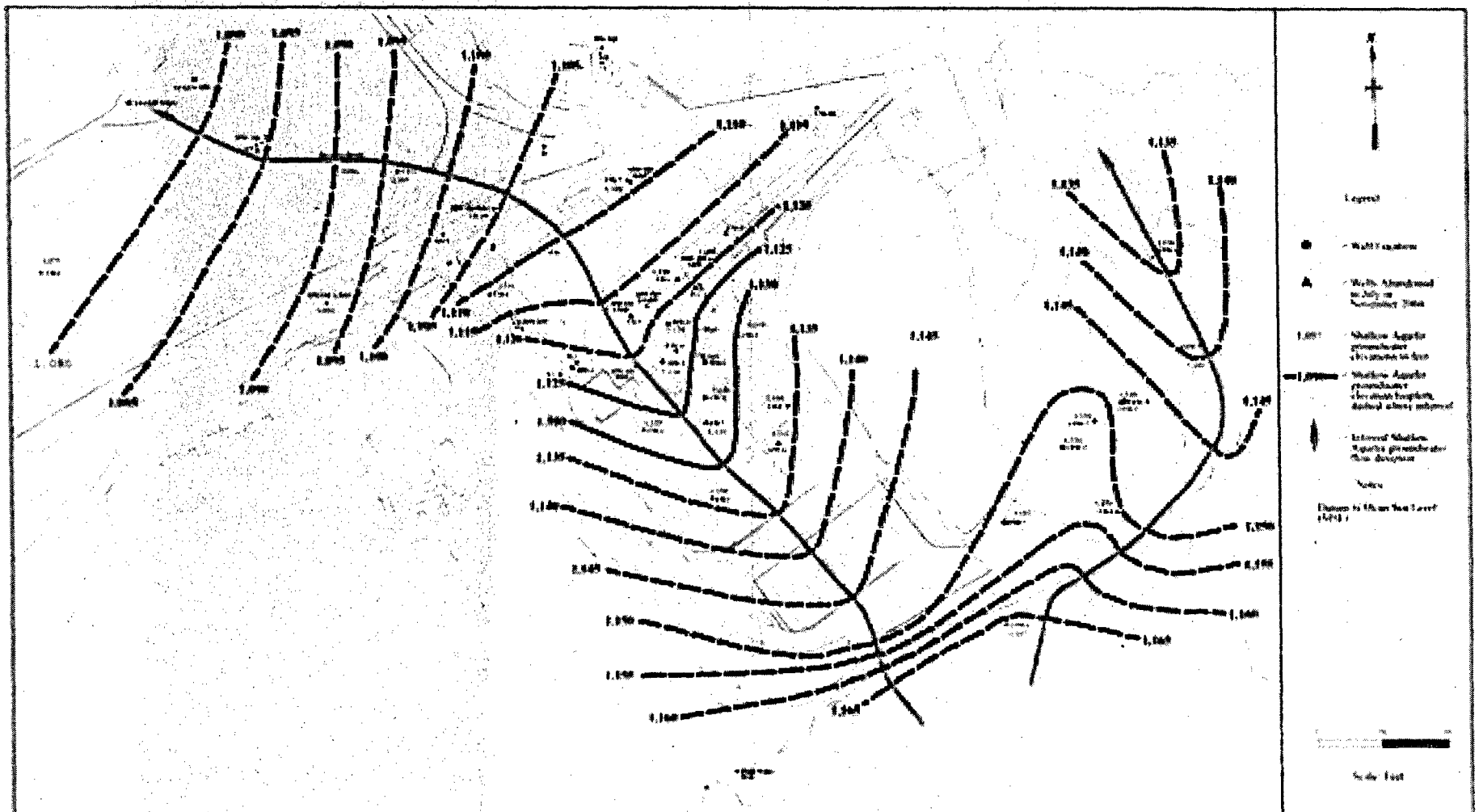
2003 MW Drilling Program

- 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

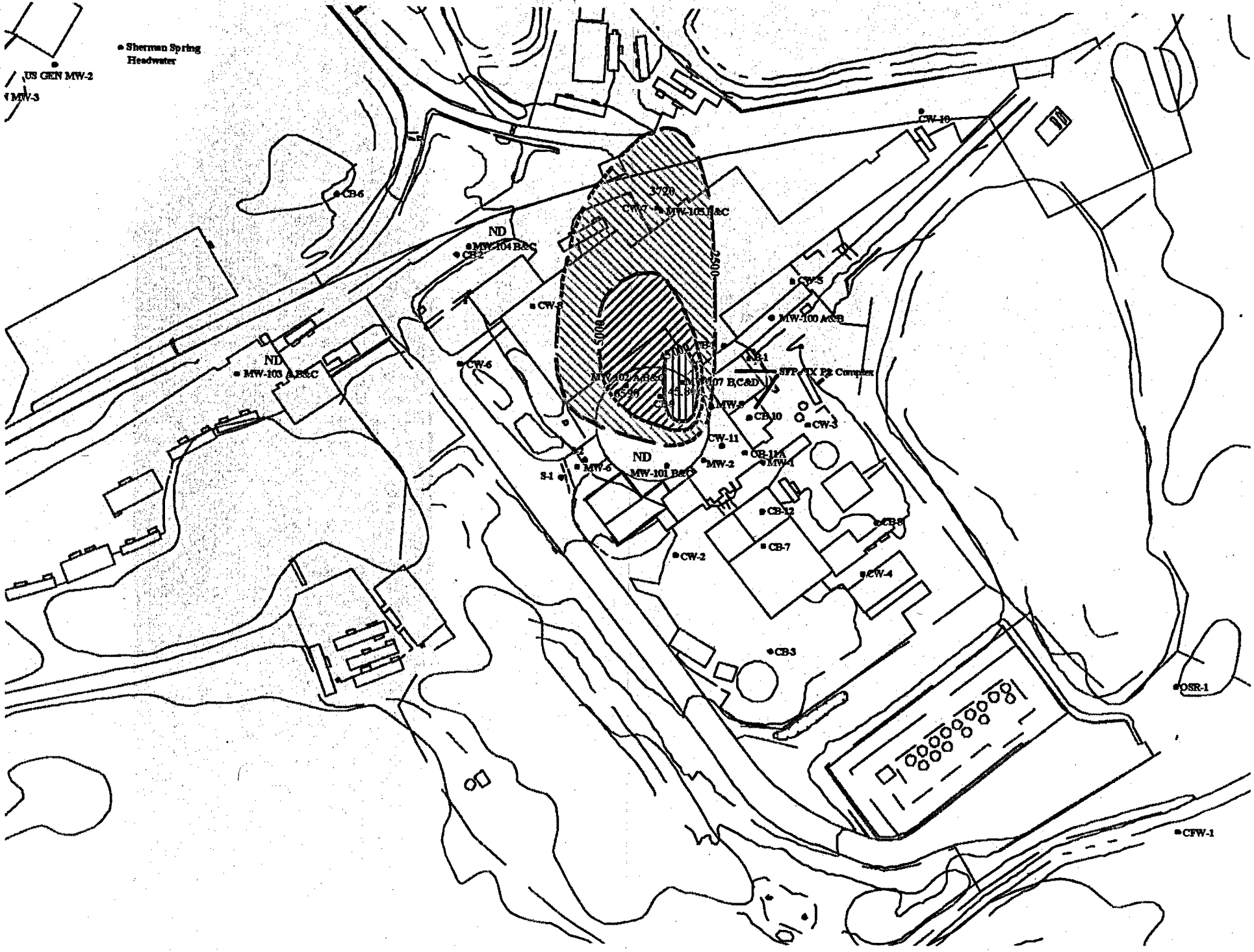
Results of 2003 Investigation

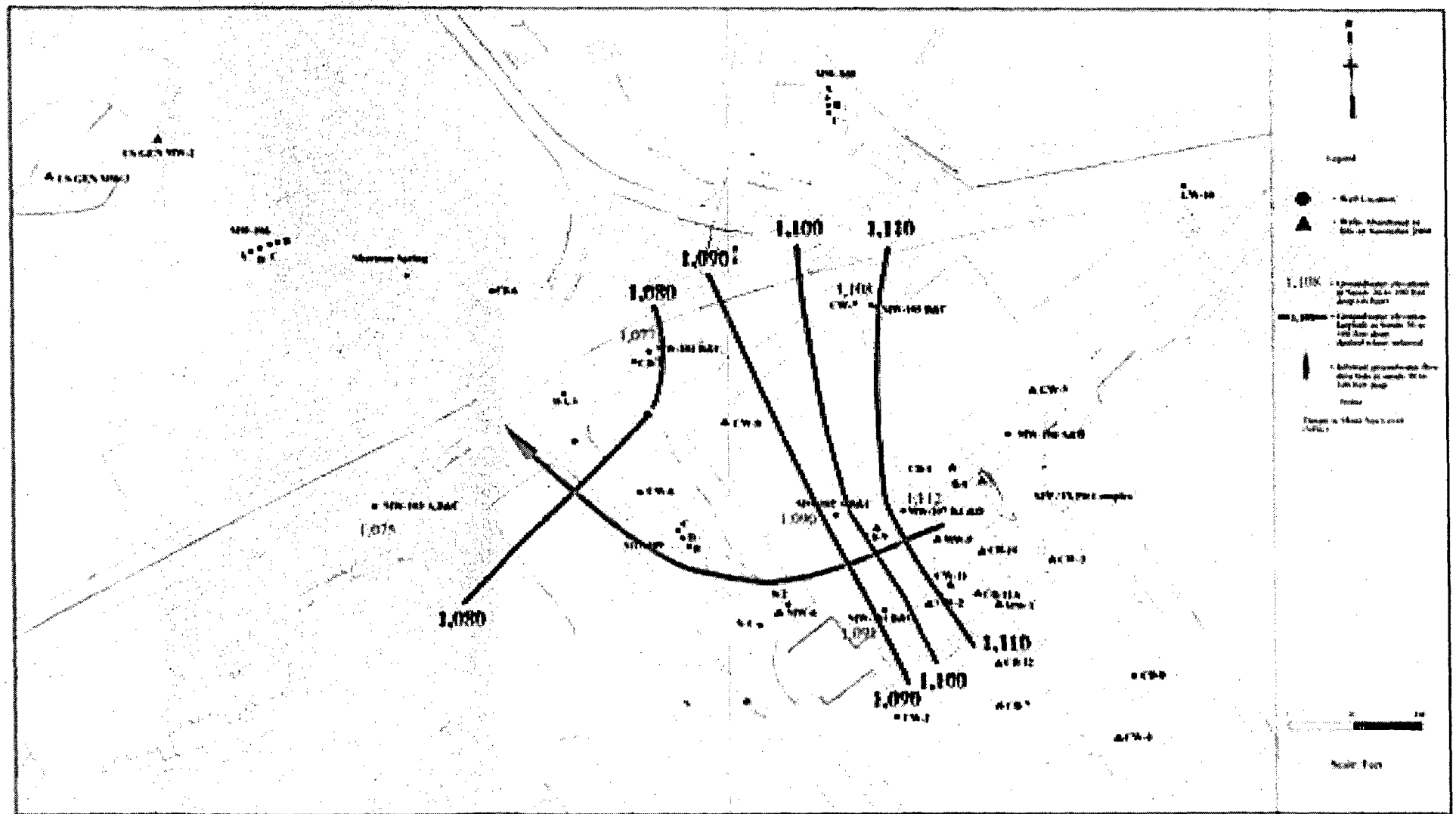
- Tritium only plant-related radionuclide in GW
- One H-3 plume in shallow (outwash) aquifer
  - Maximum concentration ~ 3,500 pCi/L
  - Aligned with direction of shallow GW flow (NW)
- A second H-3 plume in deeper sand lenses
  - Maximum concentration ~ 45,000 pCi/L
  - Direction of deeper GW flow toward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


Sherman Spring
Headwater
ND
US GEN MW-2
ND
CW-7
MW-105 B&C
CW-10
130
MW-104 B&C
1160
CW-8
2500
2140
CW-5
ND
MW-100 A&B
SFP / IX Pit Complex
500
158
ND
MW-103 A B&C
MW-102 A,B&C
CB-9
2620
CB-10
1240
CW-3
162
CB-11A
MW-1
580
540
CB-12
S-1
214
MW-101 B&C
CW-2
CB-7
CB-8
CW-4
CB-3
OSR-1
CFW-1
266



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

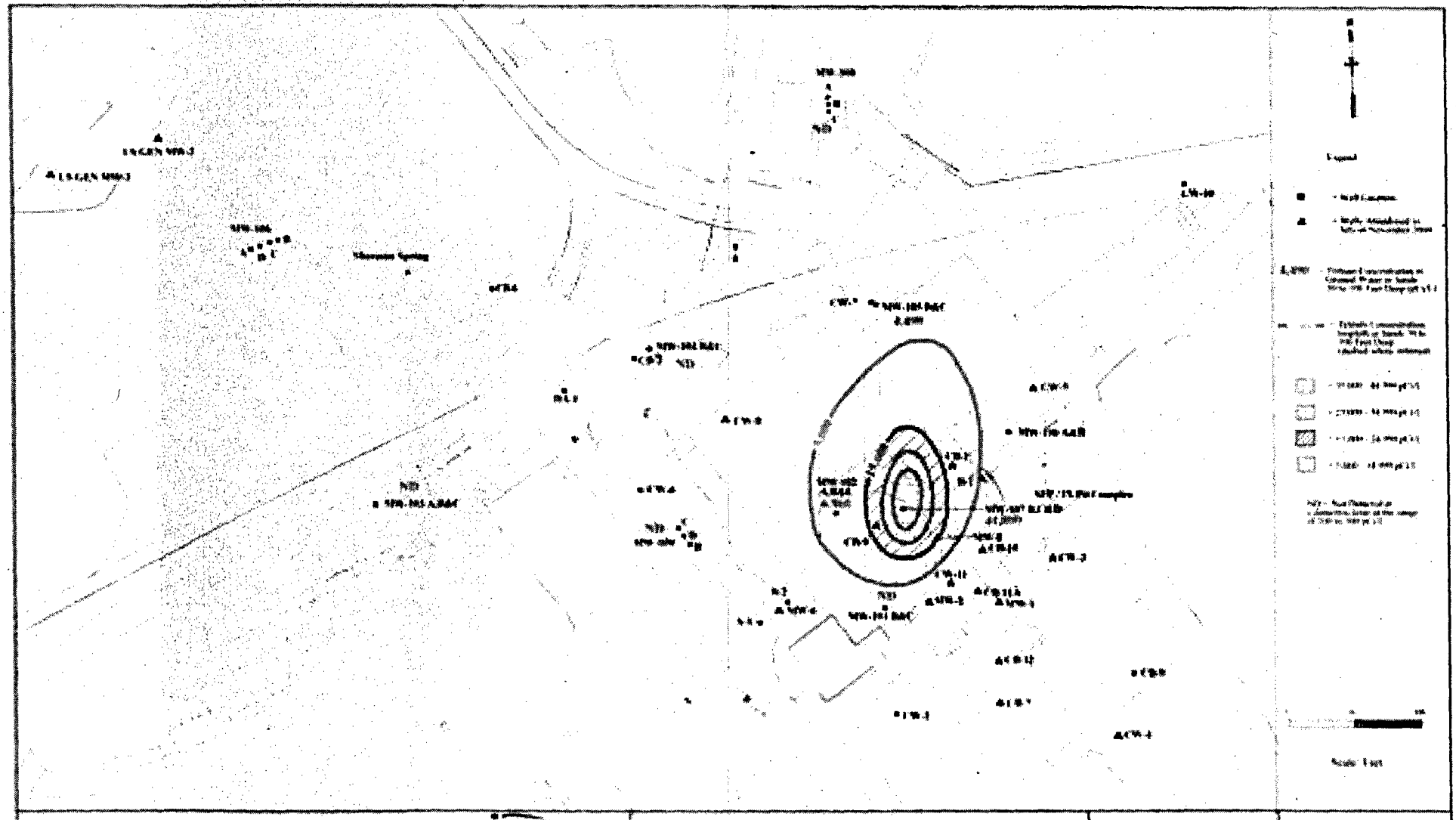

Sherman Spring Headwater
US GEN MW-2
MW-3
CB-6
ND
MW-104 B&C
CW-1
CW-8
MW-105 B&C
3720
2500
5000
CW-5
CW-9
MW-100 A&B
ND
MW-103 A,B&C
CW-6
MW-102 A&B&C
MW-107 B,C&D
SFP-1/IX Pit Complex
MW-8
CB-10
CW-3
CW-11
CB-11A
MW-1
MW-2
ND
MW-101 B&C
MW-6
S-1
CB-12
CB-8
CB-7
CW-2
CW-4
CB-3
OSR-1
CFW-1



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

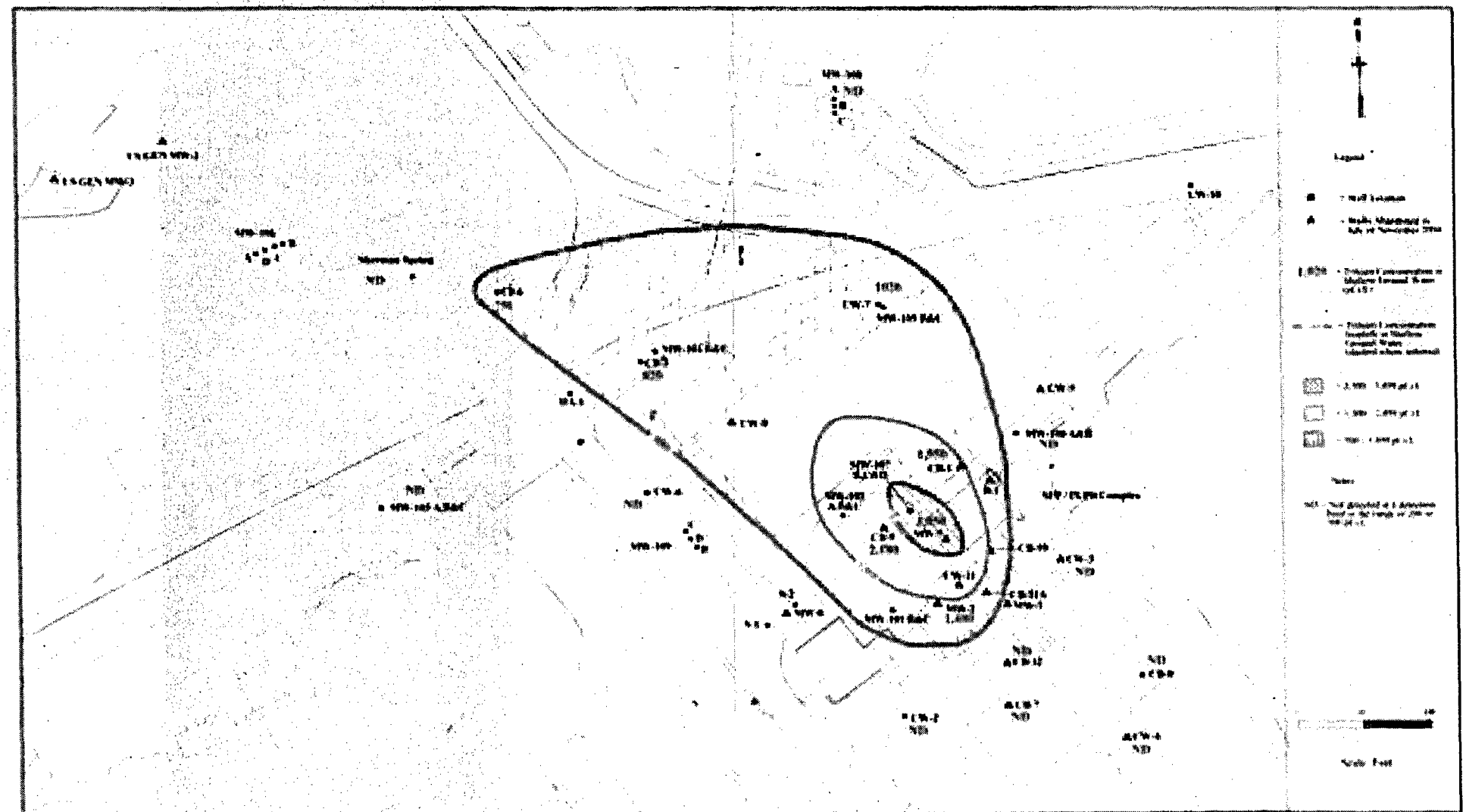
- 10 Additional Monitoring Wells Installed by Rotosonic Method
  - 2 into shallow outwash aquifer
  - 5 into deeper sand lenses interlayered within underlying lodgement till
  - 3 into bedrock
- Well Locations Chosen to Bound the Shallow and Deeper H-3 Plumes
- Studied Interconnectivity Between Aquifers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



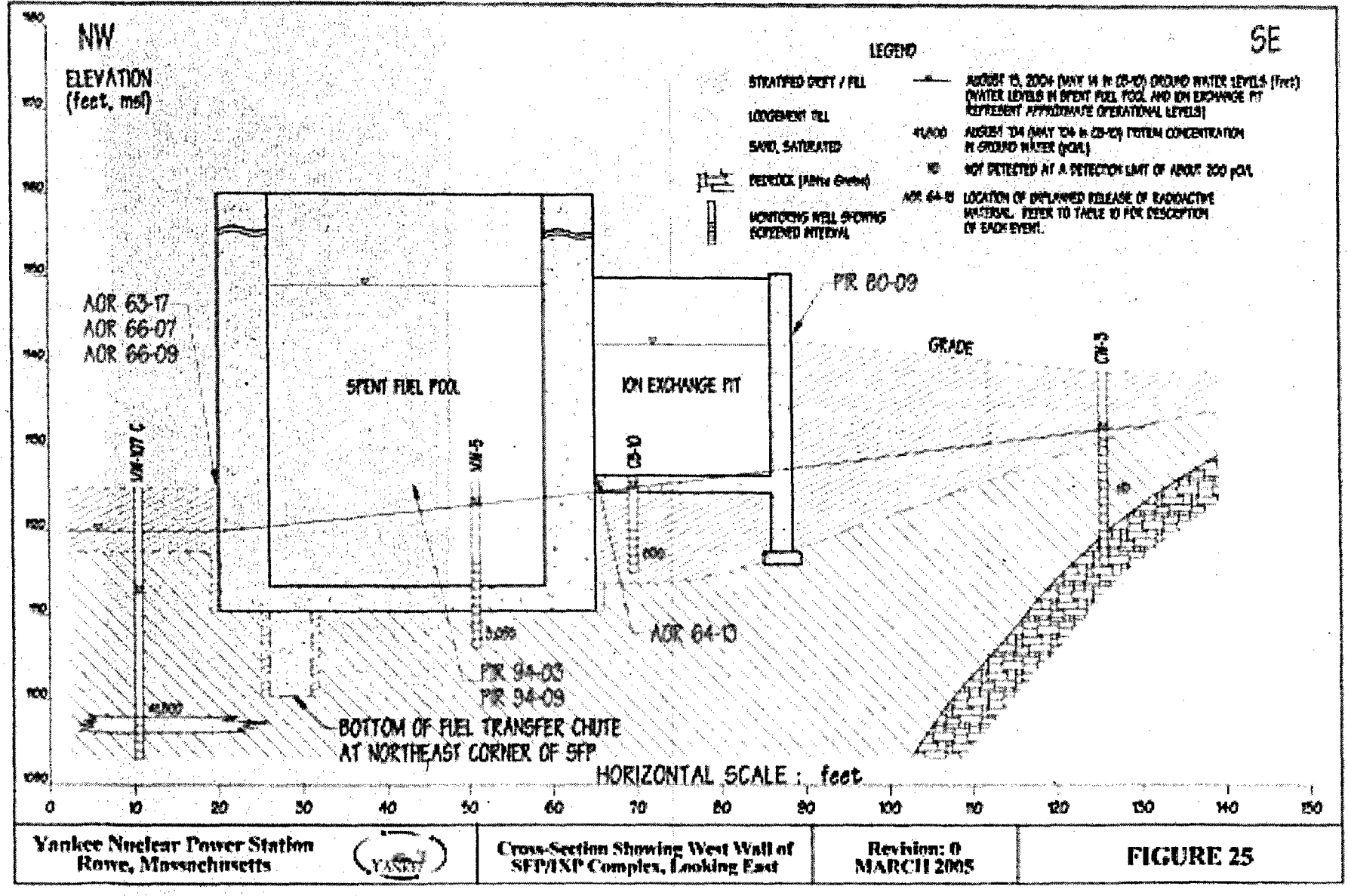
Yankee Nuclear Power Station Rowe, Massachusetts	YANKEE	Tritium in the Shallow Aquifer (less than 25 feet deep) in August 2004	Revision: 1 MARCH 2005	FIGURE 33

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

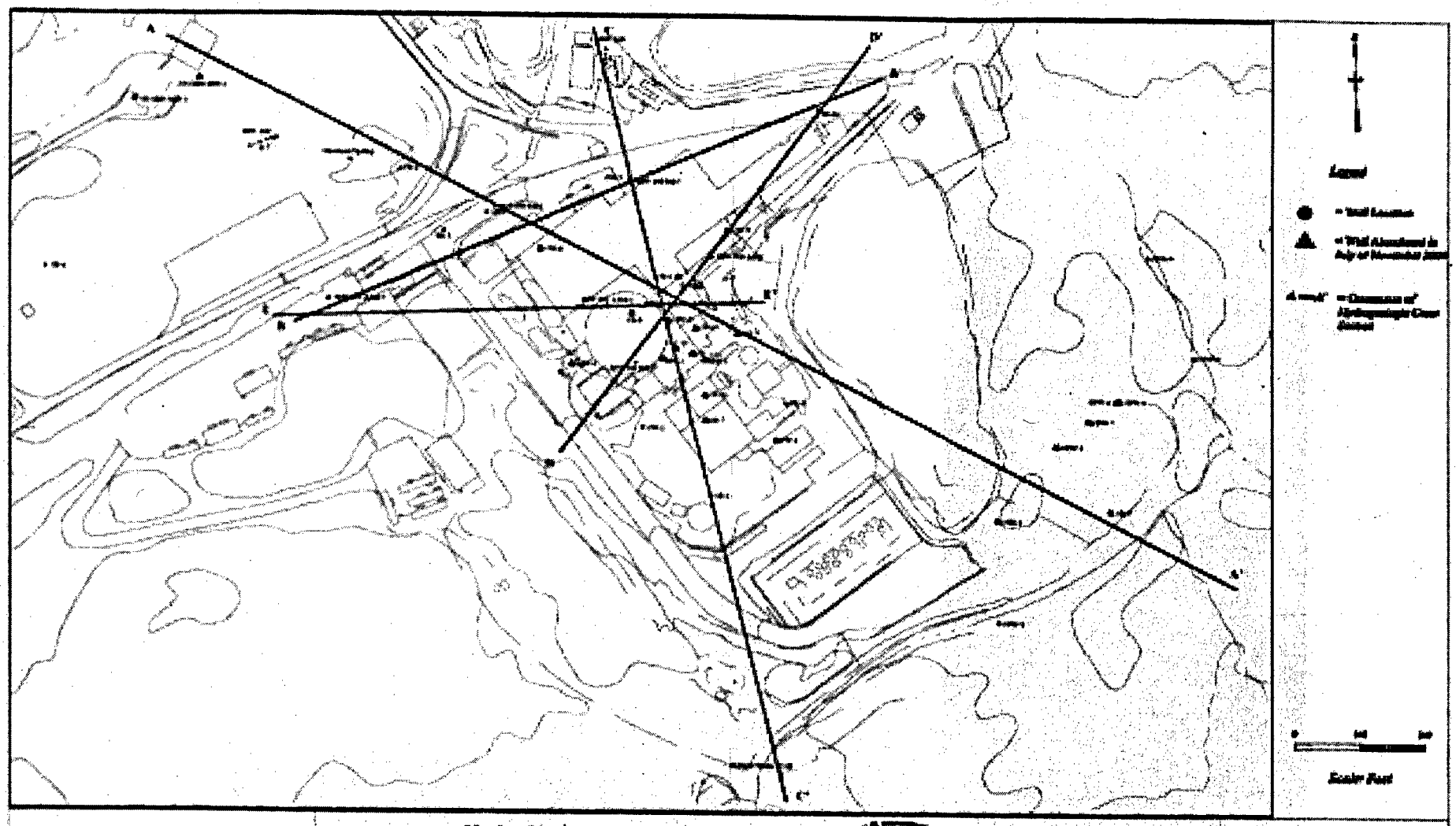
Contaminant Transport Mechanisms

- 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



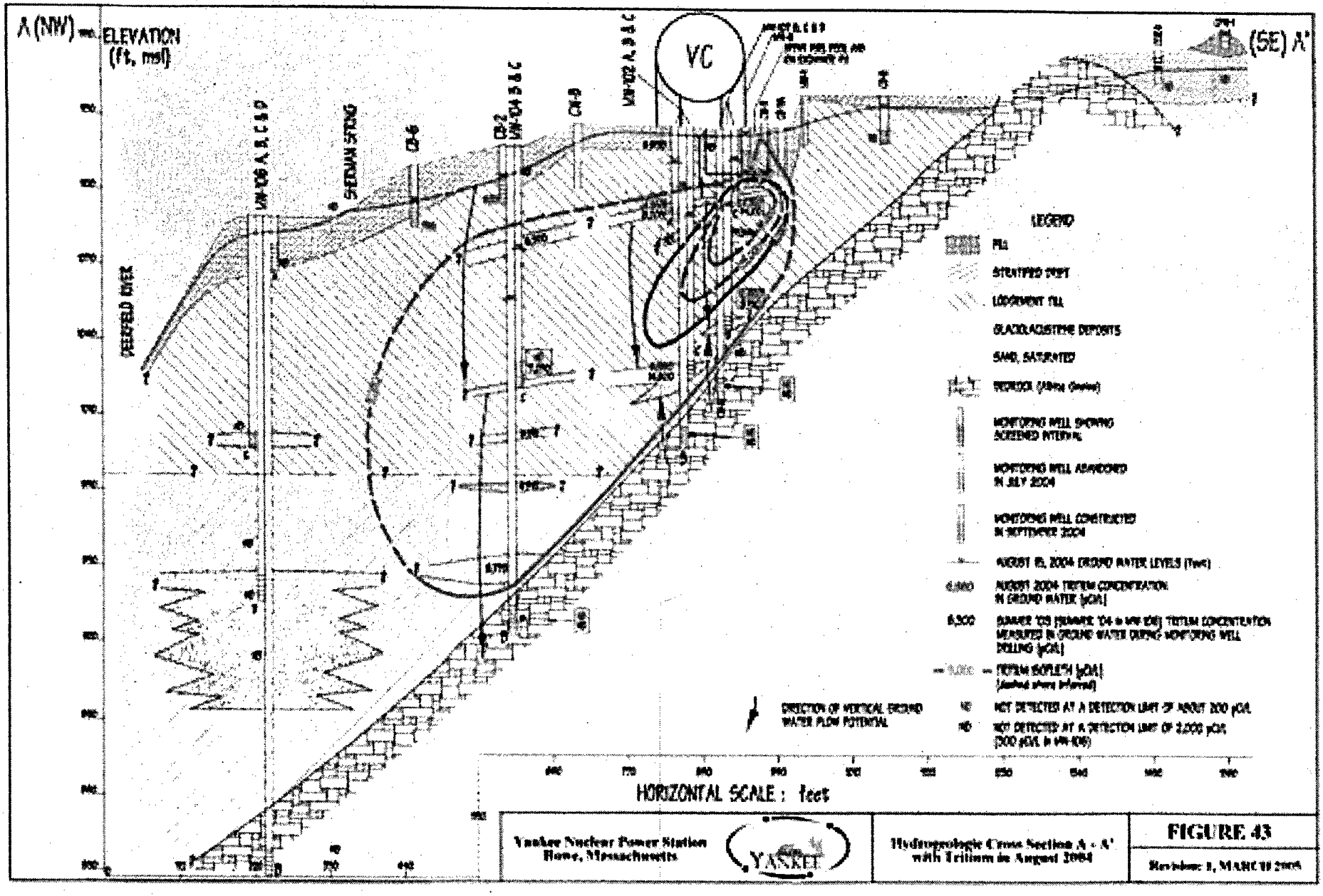
Yankee Nuclear Power Station

Location of Cross Sections

Date: February 2005

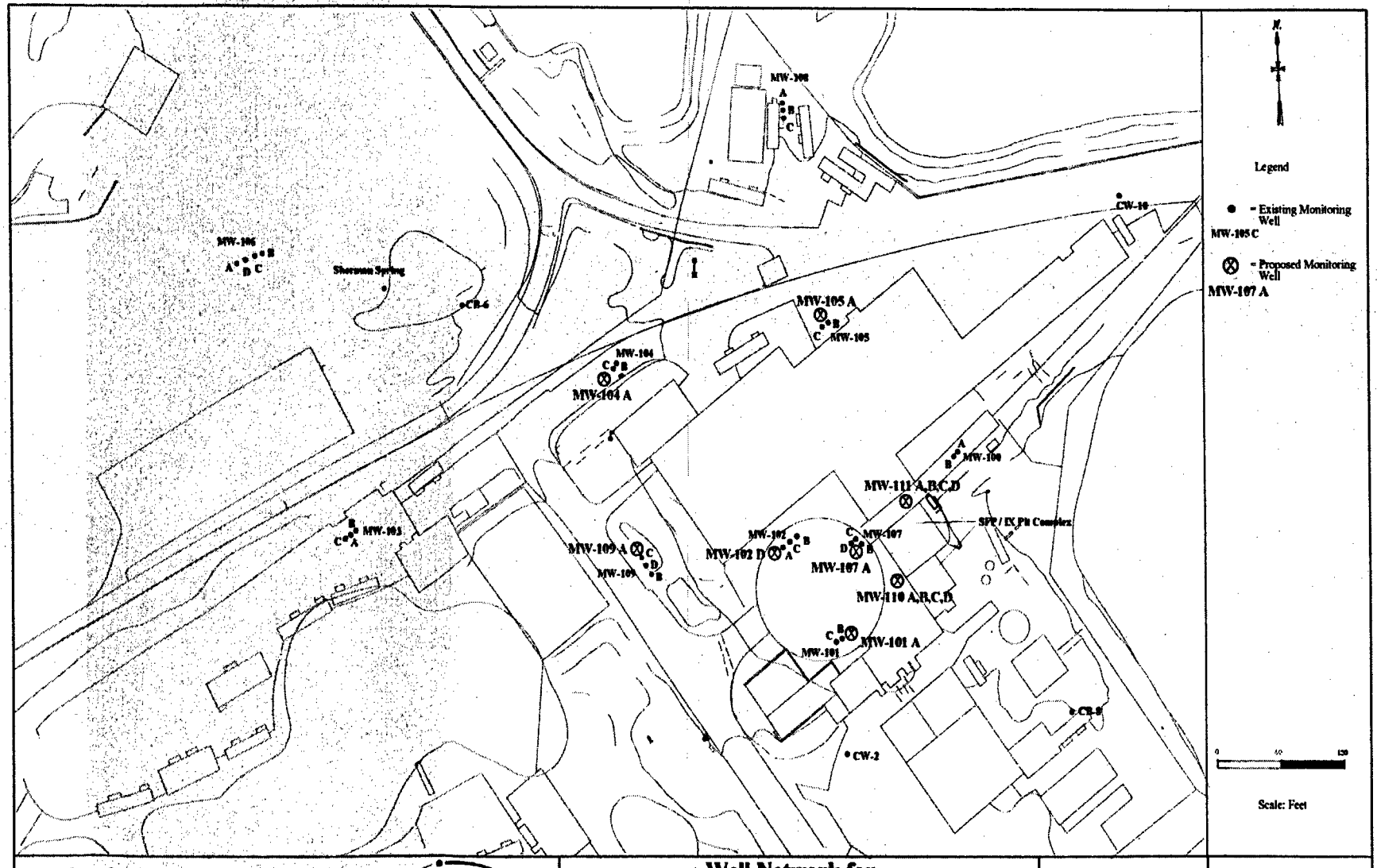
Revision: 1

Figure: 7


A (NW)
ELEVATION (ft, msl)
(SE) A'
VC
SHERMAN SPRING
CB-6
CB-2
CB-9
DEERFIELD RIVER
LEGEND
FILL
STRATIFIED DRIFT
LODGMENT TILL
GLACIOLACUSTRINE DEPOSITS
SAND, SATURATED
MONITORING WELL SHOWING SCREENED INTERVAL
MONITORING WELL ABANDONED IN JULY 2004
MONITORING WELL CONSTRUCTED IN SEPTEMBER 2004
AUGUST 16, 2004 GROUND WATER LEVELS (Feet)
AUGUST 2004 TRITIUM CONCENTRATION IN GROUND WATER (pCi/L)
SUMMER '03 (SUMMER '04 at MW-106) TRITIUM CONCENTRATION MEASURED IN GROUND WATER DURING MONITORING WELL DRILLING (pCi/L)
TRITIUM ISOPLETH (pCi/L) (dashed where inferred)
DIRECTION OF VERTICAL GROUND WATER FLOW POTENTIAL
ND NOT DETECTED AT A DETECTION LIMIT OF ABOUT 200 pCi/L
ND NOT DETECTED AT A DETECTION LIMIT OF 2,000 pCi/L (500 pCi/L in MW-106)
HORIZONTAL SCALE : feet
Yankee Nuclear Power Station
Rowe, Massachusetts
YANKEE
Hydrogeologic Cross Section A - A' with Tritium in August 2004
FIGURE 43
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?