Decision Making for Closure of Contaminated Groundwater Sites

Remediation Technology Symposium

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Presented by

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MALCOLM PIRNIE

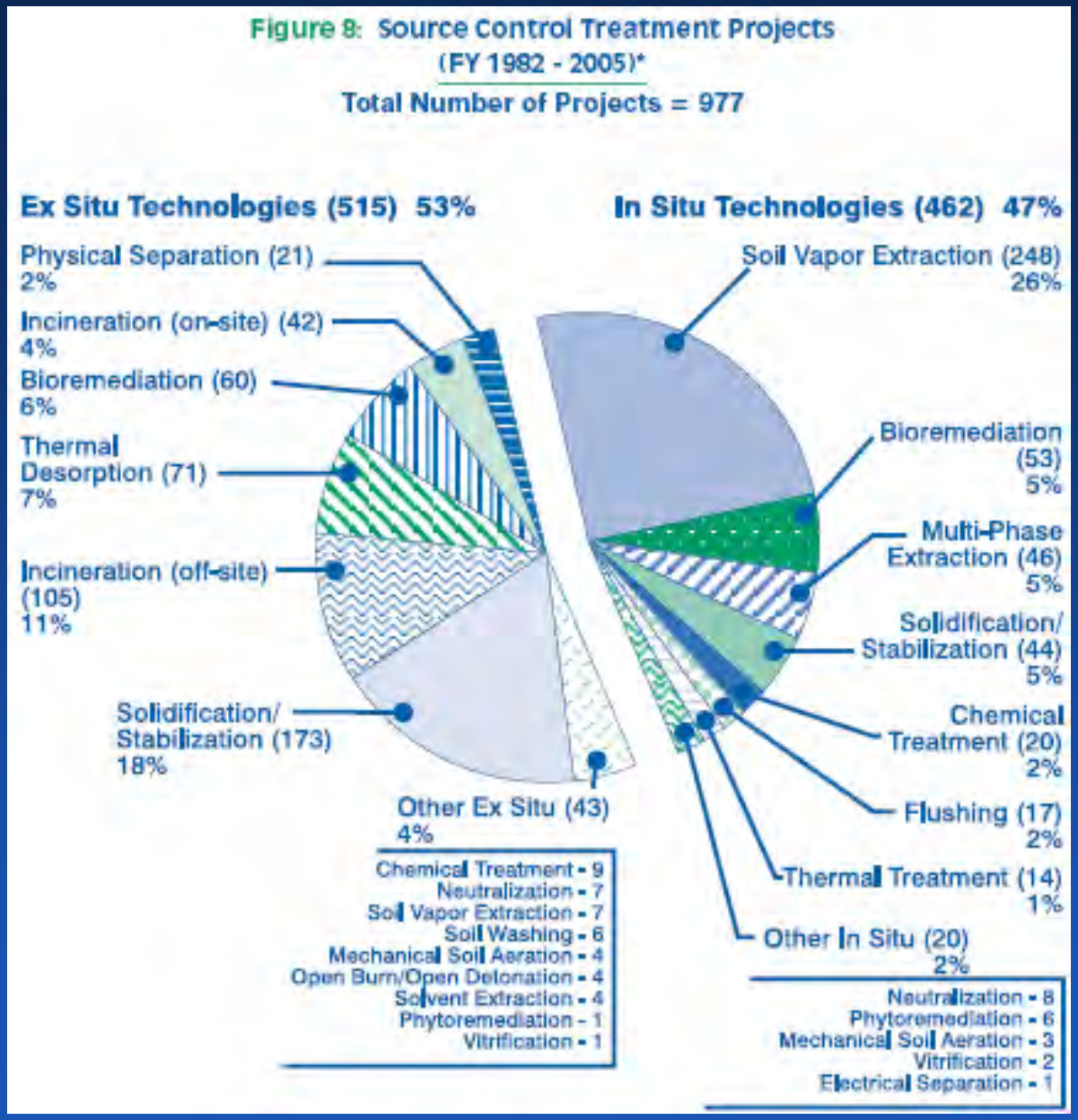
Soil and Groundwater Remediation: The Context for Decision Making

- Soil and groundwater contamination significant worldwide problem
  - In U.S., expenditures exceed $6 billion per year
  - Life cycle cost estimates up to $1 trillion dollars
- Significant progress in site cleanup over last 25 years in US
  - Over 57% of all Superfund sites have completed close-out reports (CORs, EPA-542-R-03-009)
  - Many LUST closures
  - Closures of “low risk” sites nationwide
  - Advances in science and technology in site characterization, remediation technologies, risk assessment

Magnitude of DNAPL Challenge

- Estimated number of DNAPL groundwater sites nationwide: More than 30,000
  - 3,000 to 4,000 DoD and DOE sites with chlorinated solvents
  - 1,500 NPL sites with up to 60% DNAPL
  - 25,000 dry cleaner sites
  - 1,500 gas manufacturing plants
  - ~ 200 wood treating facilities
  - 2,000 – 3,000 RCRA corrective action sites with DNAPL

NRC, *Contaminants in the Subsurface: Source Zone Assessment and Remediation*, 2005.

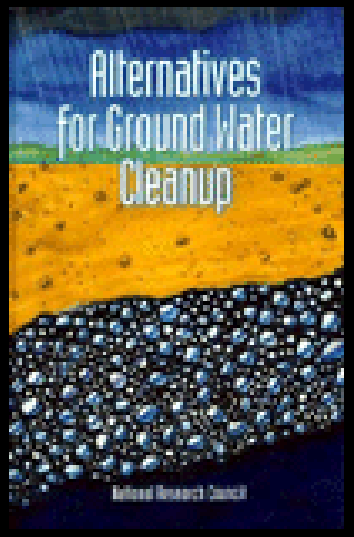


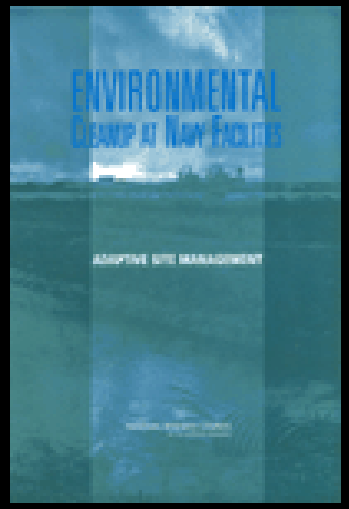
EPA, *Treatment Technologies for Site Cleanup: Annual Status Report*, 2007, EPA-542-R-07-012.

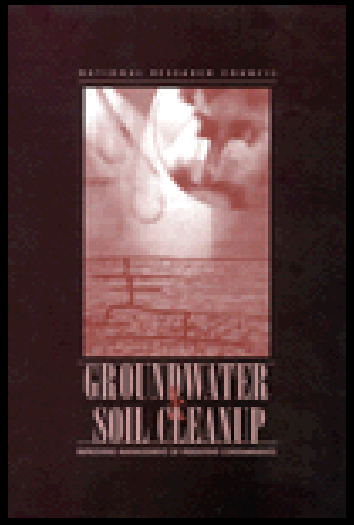
Soil and Groundwater Remediation: The Context for Decision Making

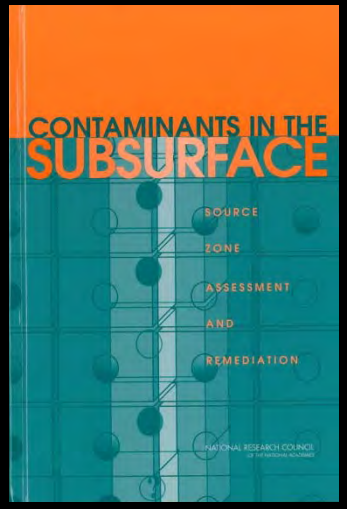
- Numerous technical and institutional challenges remain before closure can be achieved
  - Optimization of pump and treat systems
  - Source removal to the “Extent Practicable”
  - Achieving ARARs or restoration in “reasonable” time frames (e.g., DNAPL sites)
  - Reliability, sustainability and time-frames for MNA
  - Protectiveness of long-term institutional controls
  - Liability risks resulting from residual contamination
  - New contaminants (e.g.,1,4-dioxane, perchlorate) or lowered cleanup targets (e.g., arsenic, TCE, perchlorate, hexavalent chromium) and reopening of closed sites

Groundwater Remediation Issues: Focus of Several EPA and NRC Reports









EPA, 2004, *DNAPL Remediation: Selected Projects Approaching Regulatory Closure*

EPA, 2003, *The DNAPL Remediation Challenge: Is There a Case for Source Depletion?*

Environment Agency, 2003, *Illustrated Handbook of DNAPL Transport and Fate in the Subsurface*

ITRC, 2002, *DNAPL Source Reduction: Facing the Challenge*

EPA Source Depletion Report, 2003

EPA/600/R-03/143
December 2003

The DNAPL Remediation Challenge:
Is There a Case for Source Depletion?

by

Expert Panel on DNAPL Remediation

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Key Findings and Recommendations from these Reports - NRC, 1994

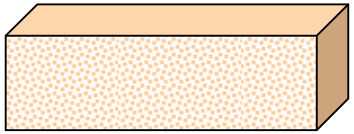
- “Theoretically, restoration of contaminated groundwater to drinking water standards is possible” - however, technically complex and significant obstacles to cleanup
  - Physical heterogeneity
  - Presence of NAPLs
  - Contaminants in inaccessible regions
  - Sorption
  - Difficulties in characterizing the subsurface

Key Findings and Recommendations from these Reports –NRC 2005

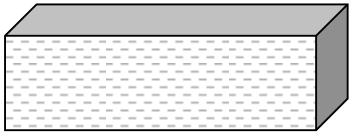
- Cleanup of subsurface source areas poses significant challenges
- "*Future work should attempt to determine the full range of conditions under which these technologies can be successfully applied*"
- Panel recommended "source remediation protocol" to enable managers to make critical decisions on source remediation *"thereby accomplishing a more beneficial distribution of resources"*

Hydrogeologic Settings: A Taxonomy

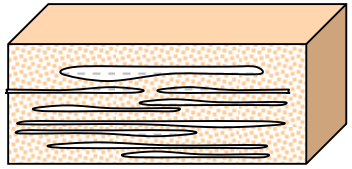
(I) Granular Media with Mild Heterogeneity and Moderate to High Permeability
(e.g. eolian sands)



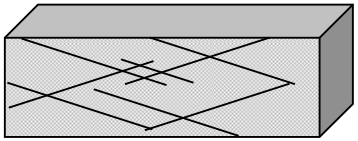
(II) Granular Media with Mild Heterogeneity and Low Permeability
(e.g. lacustrine clay)



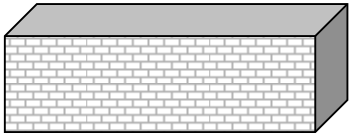
(III) Granular Media With Moderate to High Heterogeneity
(e.g. deltaic deposition)



(IV) Fracture Media with Low Matrix Porosity
(e.g.crystalline rock)



(V) Fracture Media with High Matrix Porosity
(e.g.limestone, sandstone
or fractured clays, including Karst)



National Research Council, *Contaminants in the Subsurface*, National Academy Press, 2005.

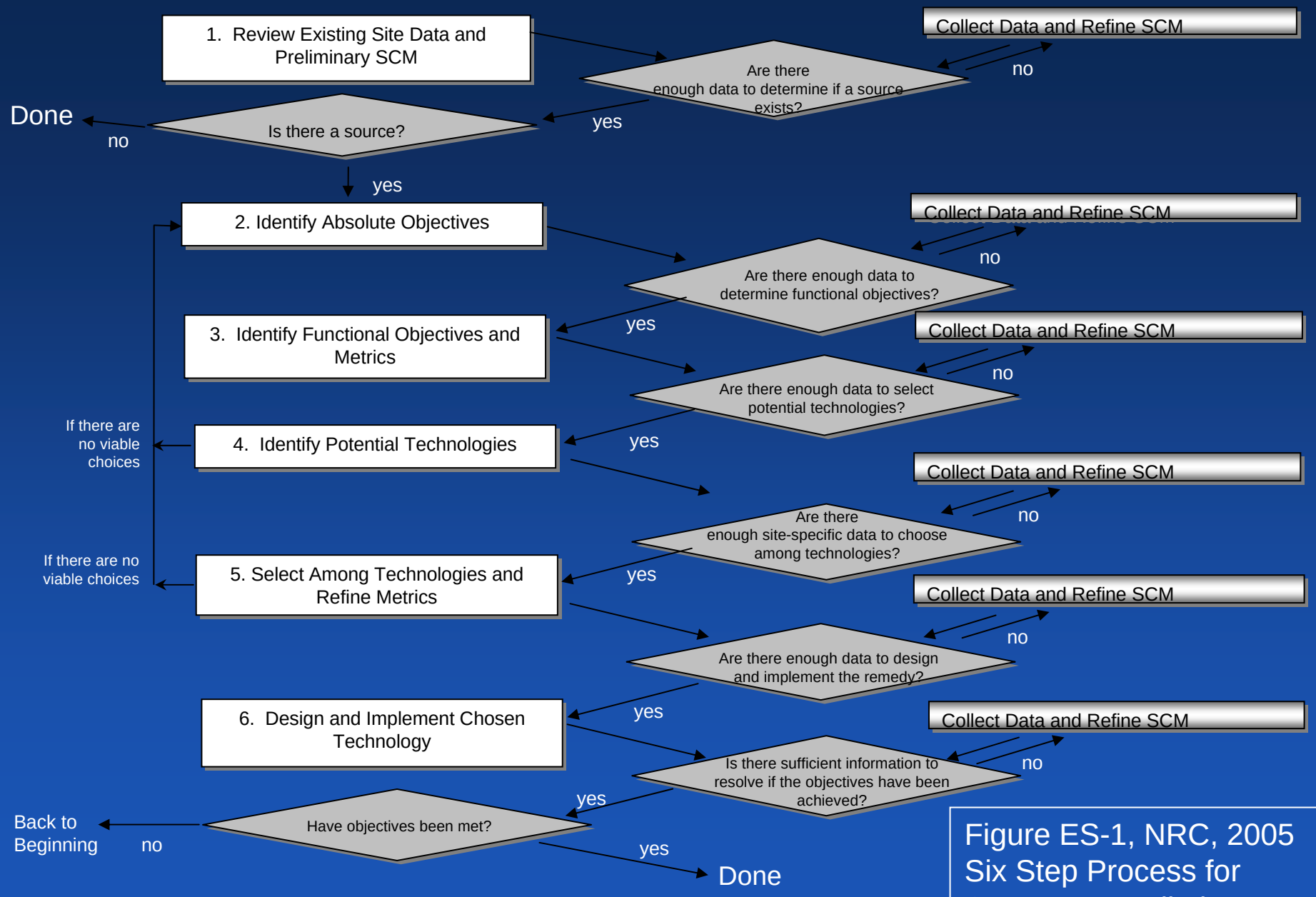


Figure ES-1, NRC, 2005 Six Step Process for Source Remediation

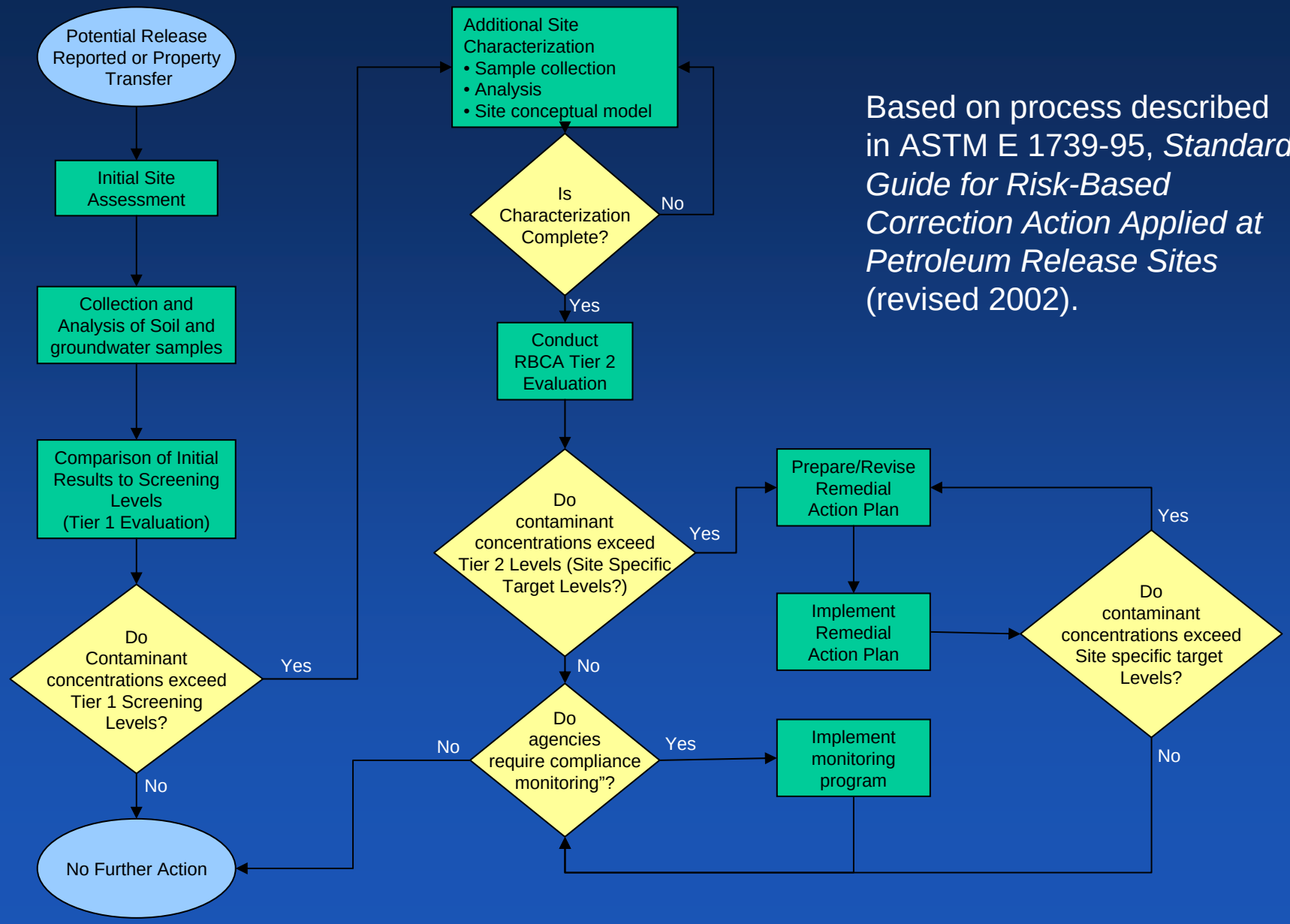
Decision Making at Contaminated Groundwater Sites – A Complex Process

- Scientific and technical Issues
- Regulatory challenges
- Public stakeholder preferences
- Land use options
- Balancing desire for restoration with technical and economic constraints

Life Cycle of a Contaminated Site: Key Decisions

- Discovery – reporting
- Regulatory decision – resource allocation
- Decision on investigation strategy – developing the Conceptual Site Model (CSM)
- Establishing Remedial Action Objectives (RAOs) and Point(s) of Compliance (POC) (e.g., ARAR process)
- Defining “acceptable timeframe”
- Remedy selection
- Performance assessment
- Technical Impracticability (TI)
- Closure

Simplified RBCA Flowchart



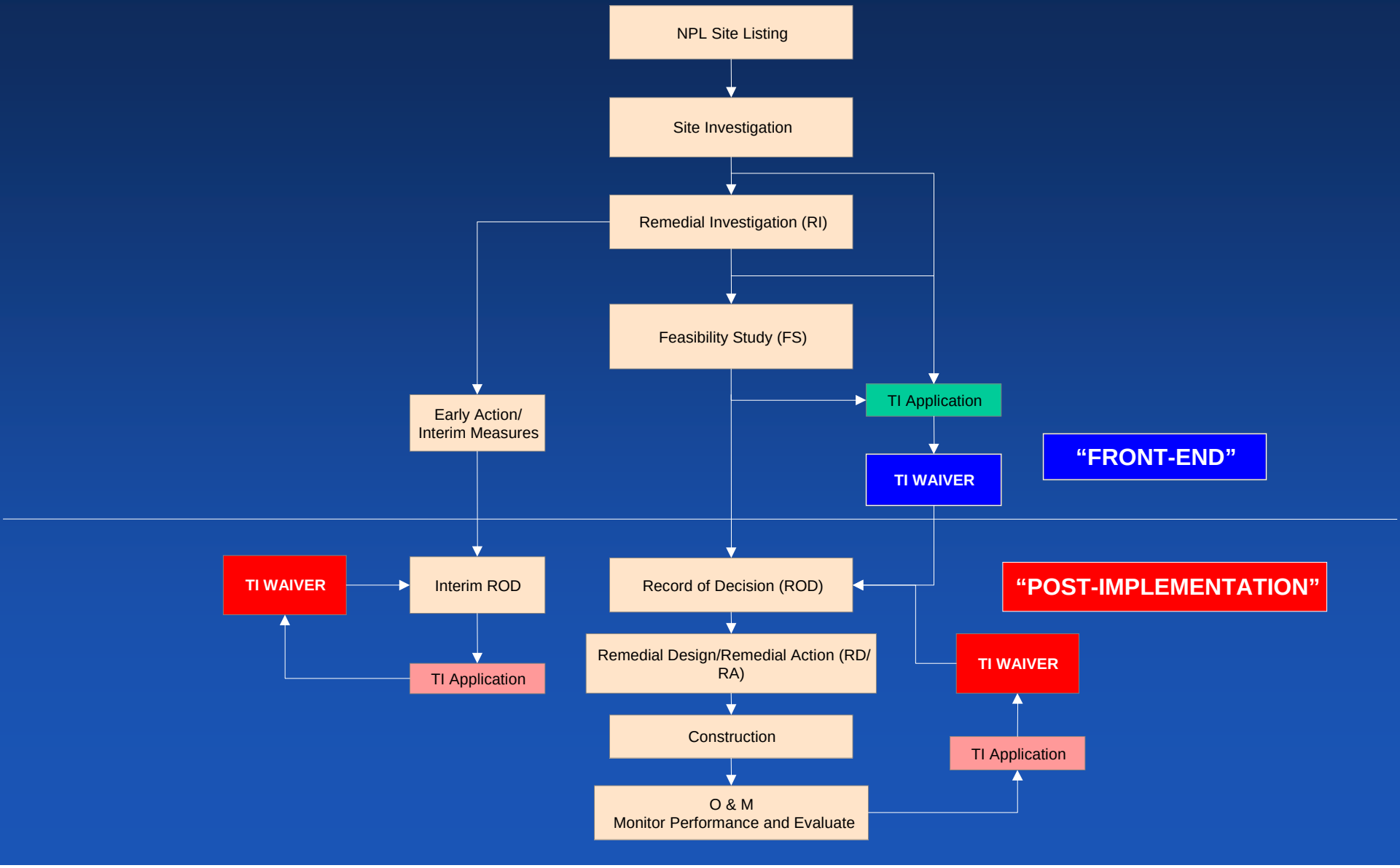
Based on process described in ASTM E 1739-95, *Standard Guide for Risk-Based Correction Action Applied at Petroleum Release Sites* (revised 2002).

Remedy Selection Criteria: The National Contingency Plan (NCP) Model

- Overall protection of human health and the environment
- Compliance with ARARs
- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume
- Short-term effectiveness
- Implementability
- Cost
- State Acceptance
- Community Acceptance

EPA 540/G-89/004, OSWER Directive 9355.3-01, 1988.

TI Waivers in the CERCLA Process



Remedy Selection: Other Potential Factors

- Residuals and by-product formation/control
- Process and mechanical reliability
- Ease of operation/control/implementation
- Permitting
- Public acceptability
- Life cycle costs in undiscounted dollars
- Sustainability metrics

Technical Limitations to Cleanup of Contaminated Groundwater

- Physical heterogeneity
  - Consolidated geologies
- Presence of NAPLs
  - Location and remediation
- Contaminants in inaccessible regions
  - Matrix diffusion
  - Low permeability zones
- Sorption
- Difficulties in characterizing the subsurface

Regulatory Initiatives Recognizing Technical Limitations

- TI Waivers -1993 Guidance – CERCLA – Waivers of ARARs
- Determination of TI - RCRA – e.g., alternative concentration limits (ACLs)
- Containment Zones - Region 2, RWQCB in California
- New Jersey – “Classification Exception Area”- alternative cleanup levels
- Groundwater Classification strategies – e.g., Illinois, Georgia,
- Incorporation of TI concepts in statutes, regulations – at least seven other states
- “To the extent practical” often included in regulatory language – e.g., LUST regulations
- However, none of these initiatives necessarily accelerates closure (e.g., five-year reviews, reopener process); goal remains restoration at many sites

Other Approaches to Alternative End-Points for Remedy Selection

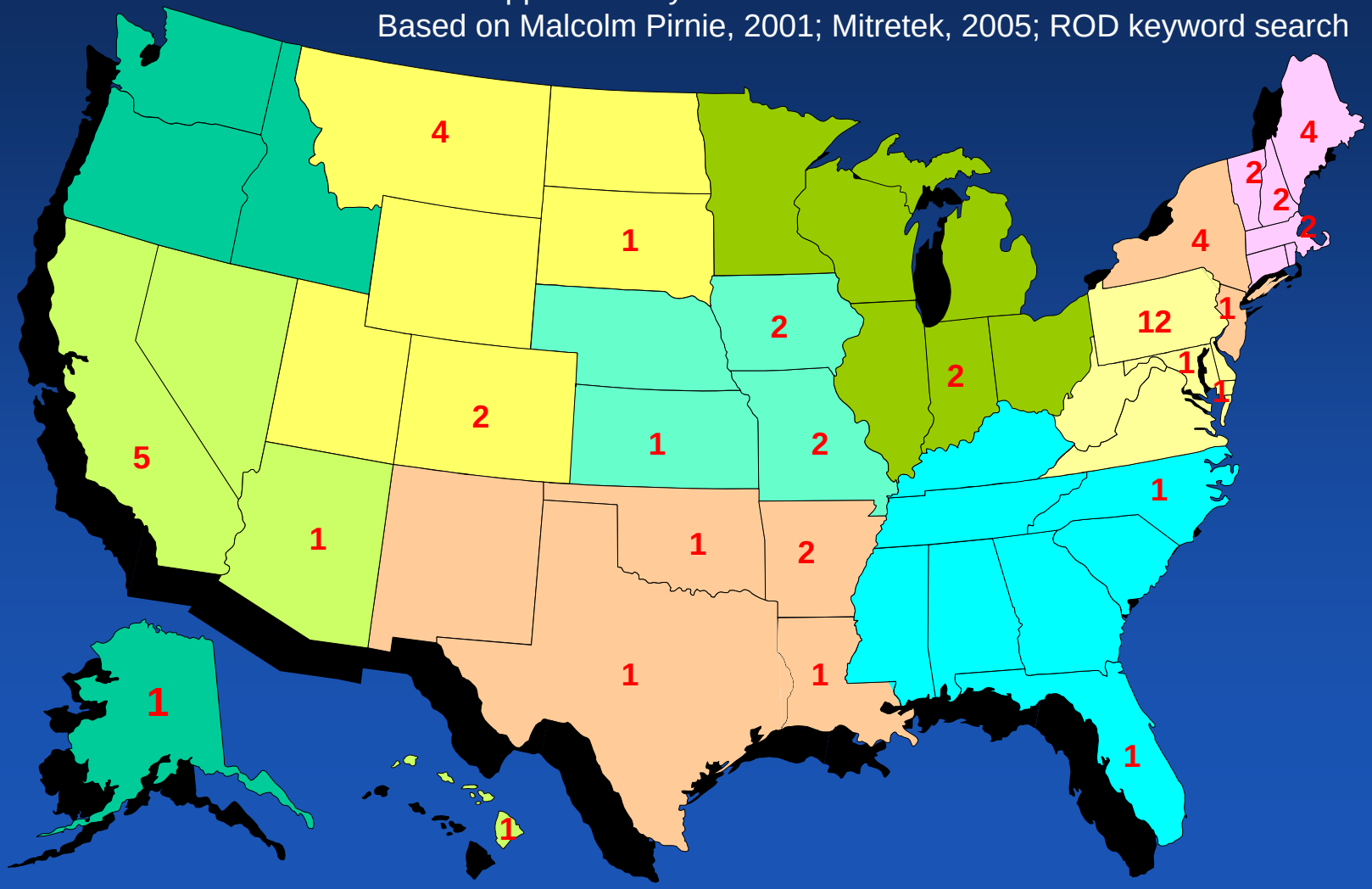
- Alternative points of compliance, planes or boundaries of compliance also widely used
- Negotiated settlements
- An interim remedy strategy
- Implicit acceptance of long timeframes (e.g., greater than 100 years), given particular circumstances of the site

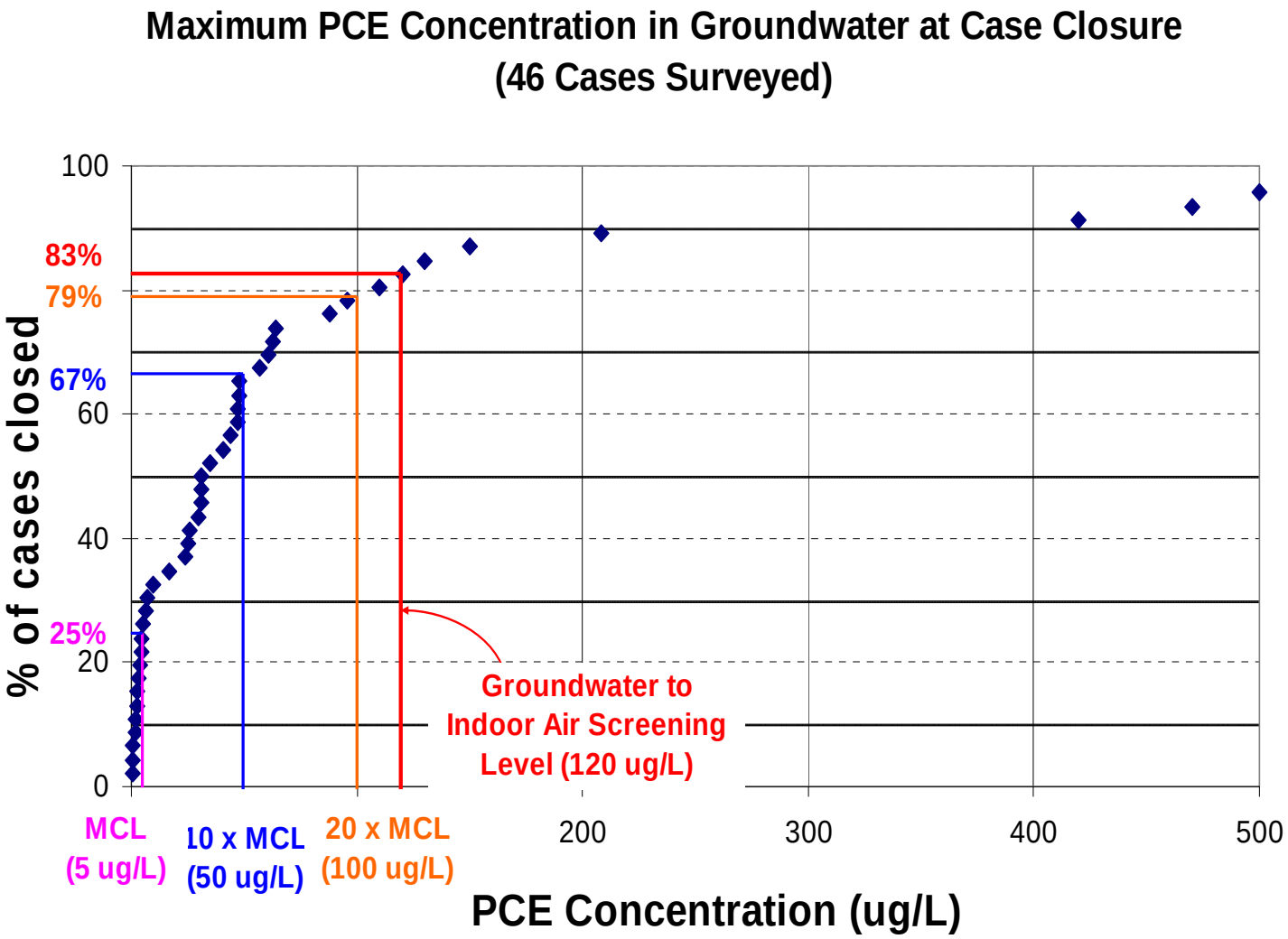
TI Waivers – One of Six Types of ARAR Waivers

Greater Risk to Health and the Environment	→ **Where remedy results in greater risk**
Equivalent Standard of Performance Waiver	→ **Where remedies result in equal benefit**
Interim Measure Waiver	→ **Where remedies will be later implemented**
Inconsistent Application of State Standard Waiver	→ **Where a state standard has not been consistently implemented**
Fund Balancing Waiver	→ **Where money would be better spent elsewhere**
Technical Impracticability Waiver	→ **Where compliance with ARARs is "technically impracticable from an engineering perspective, within a *reasonable* timeframe"**

Locations of Groundwater TI Waivers

Total is approximately 59 sites as of 2007
Based on Malcolm Pirnie, 2001; Mitretek, 2005; ROD keyword search





Source: Survey of cases closed in Region 2 (SF Bay Water Board) from 2002 through early 2007. The closure actions predate the draft low-threat closure criteria and in some cases vapor-intrusion ESLs.

Alec Naugle, RWQCB, CA, GRA Site Closure Strategies Symposium, Concord, CA, February 20, 2008.

Drivers for Site Closure with Minimal Residual Contamination

- Regulatory requirements – Protection of human health and environment
- Eliminating a non-productive cost
- Land value – Economic development
- Long term legal and financial liability (e.g., trespass, NRD claims, toxic torts)

Strategies to Accelerate Closure

- Triad methodology
- Aggressive source depletion technologies (e.g., thermal)
- Molecular biological tools to accelerate transition to MNA where appropriate
- Risk assessment – closure of low risk sites
- Groundwater classification – restricted potable use – other land use controls (LUCs)

Technologies for Source Depletion

- Investment in numerous source depletion technologies
  - Thermal (steam, ERH)
  - Surfactant Flushing (SEAR)
  - Chemical Oxidation
  - In-Situ Bioremediation
- EPA, ITRC evaluation of source remediation options
- EPA's Technology Innovation Program – CLU-IN
- Numerous full scale examples of "significant" source depletion (e.g., Fort Lewis)
- However, continued barriers to embrace source zone depletion because of uncertainties in benefits compared to costs

Status of Development and Deployment of Source Remediation Technologies

Technology	Pilot Studies	Full Scale	Predictive Models	Sufficient Cost Data	At Least One Site Closure	More than Two Vendors
Water Floods	Y	Y	Y	Y	N	Y
Surfactants/Cosolvents	Y	Y	Y	Y	N	Y
Air Sparging	Y	N	N	N	N	Y
Steam Injection	Y	Y	Y	Y	Y	Y
Electrical Resistance	Y	Y	Y	Y	Y	Y
Conductive Heating	Y	**Y**	Y	N	N	N
Chem Ox	Y	Y	Y	Y	Y	Y
ZVI/Clay	Y	**Y**	N	N	N	N
Biodegradation	Y	**Y**	N	**Y**	N	Y
Combination - Co Solvent with Biodegradation	Y	N	N	N	N	N
Combination - Thermal with Chemical Oxidation	Y	N	N	N	Y	N

Note: Y = yes, meets criteria; N = no, it does not meet criteria (EPA,2003, updated).

New Performance Metrics

- EPA Expert Panel on DNAPL Remediation (2003, EPA/600/R-03/143)
  - Is there a case for source depletion?
  - Consideration of mass flux and mass discharge as new metrics
  - Partial source depletion a potentially viable option
  - Still great uncertainties in predicting benefits and costs
- NRC Study of Source Zone Assessment and Remediation (NRC, 2005)
  - Specify absolute and functional objectives at the CSM stage

Control Plane and Source Strength

$$M_d = \Sigma J_i A_i$$

J_i = Local mass flux (ML^2T^{-1})

q_i = Local Darcy flux (LT^{-1})

C_i = Local conc. (ML^{-3})

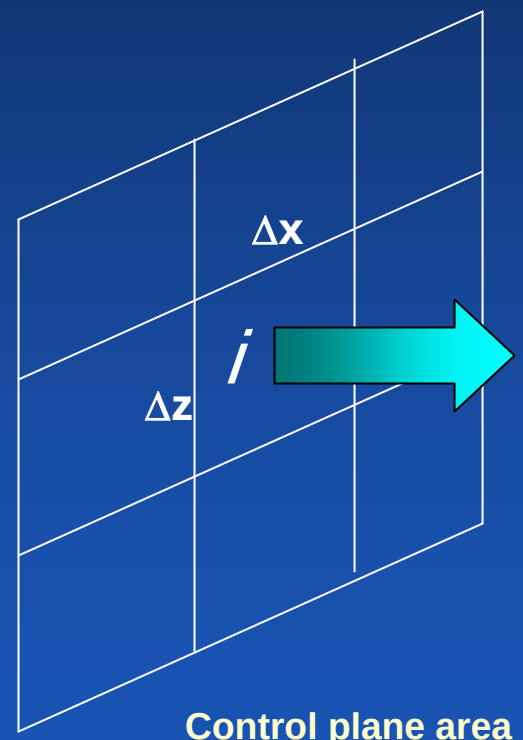
A_i = Area of element i (L^2)

M_d = *Source strength* (MT^{-1})

K_s = Satd. Hyd. Cond (LT^{-1})

j = Hydraulic gradient (-)

Control Plane (CP)



$A_i = \Delta x \, \Delta z$

$J_i = q_i C_i$

$q_i = -K_s j$

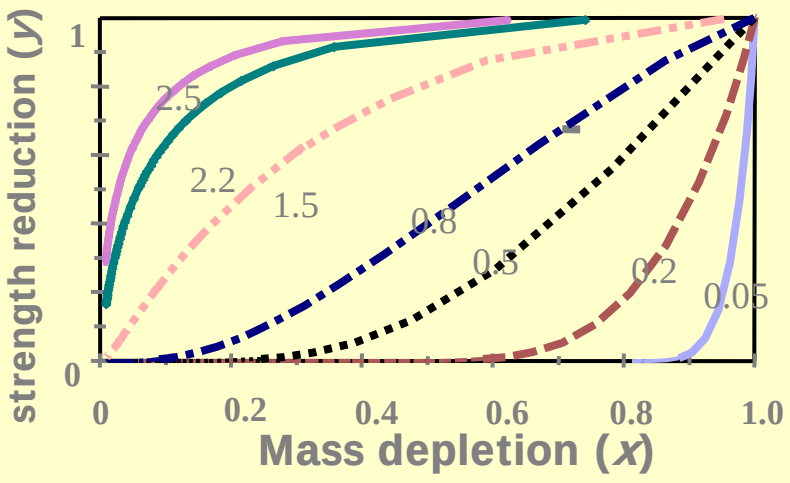
Control plane area should be just large enough to completely inscribe the dissolved plume width

Source Strength Reduction by Mass Depletion in Unconsolidated, Heterogeneous Media

- Low efficiency (small *1/b*) for homogeneous media (e.g., Borden AFB)
- Higher efficiency (larger *1/b*) for heterogeneous media (Dover AFB)
- Higher efficiency for negative correlation between permeability & DNAPL content

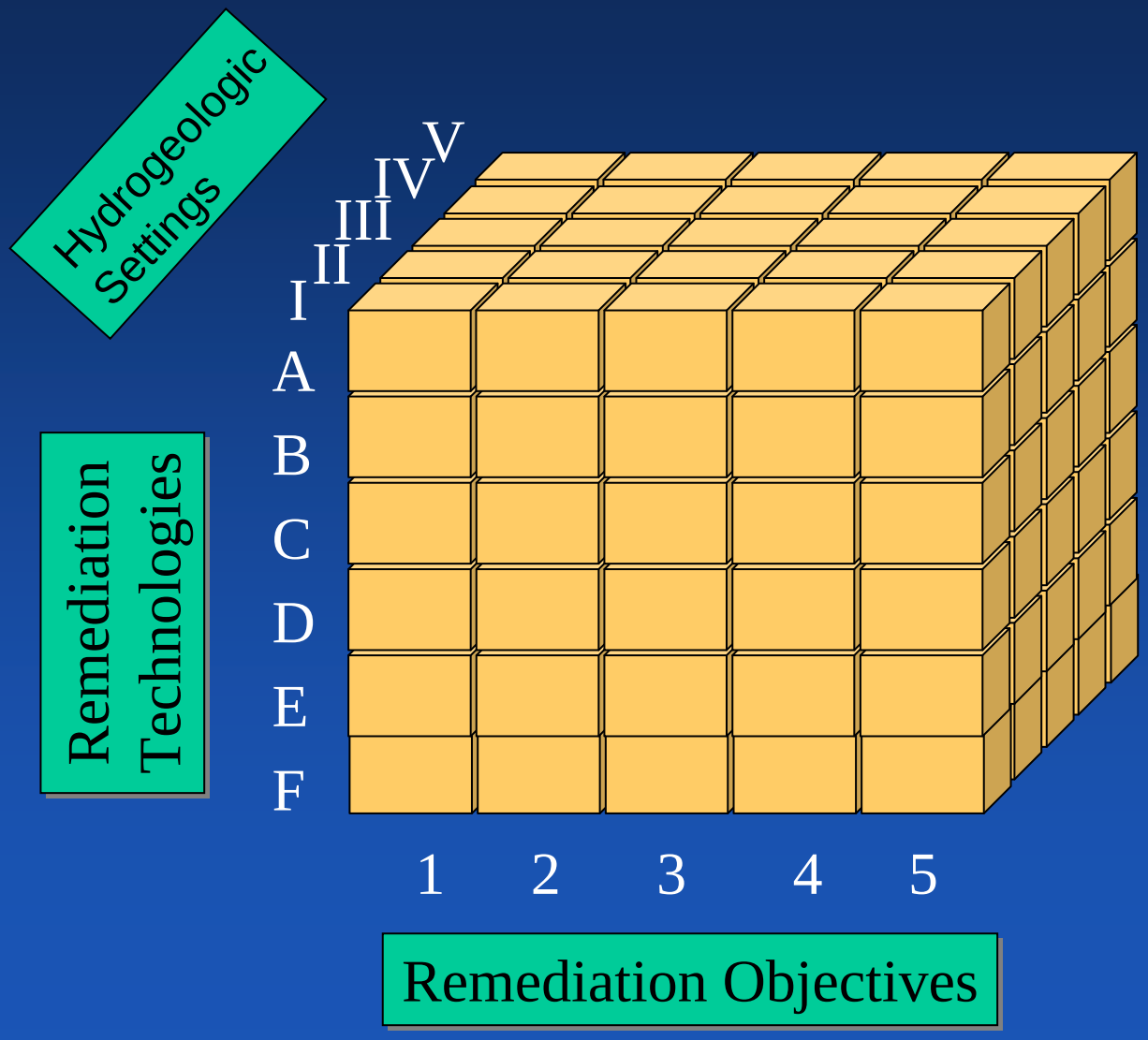
$$y = x^{1/\beta}$$

$$\beta > 0$$

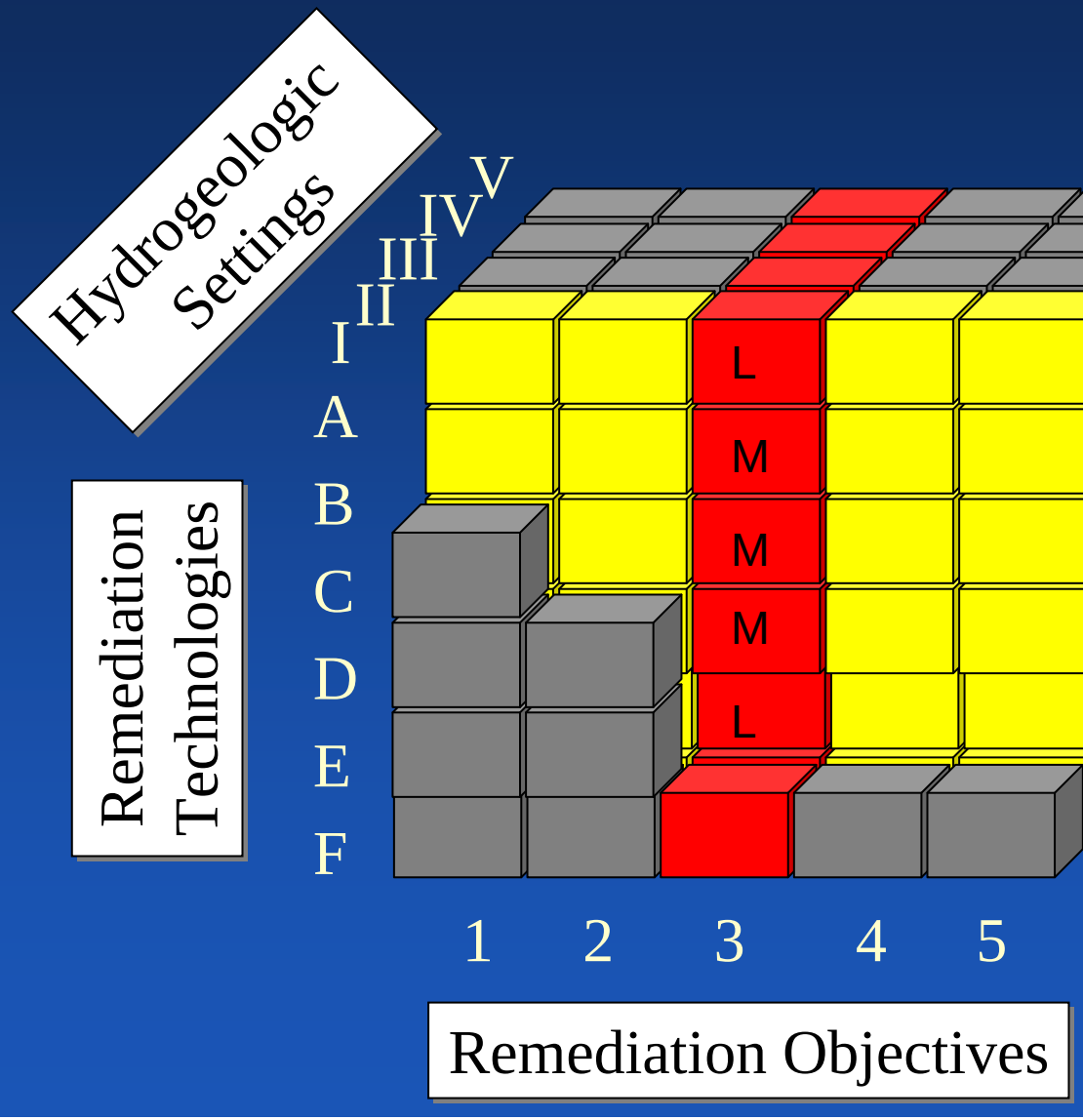


(Rao, 2002)

Conceptual Framework for NRC 2005 Report



Select Potential Technologies



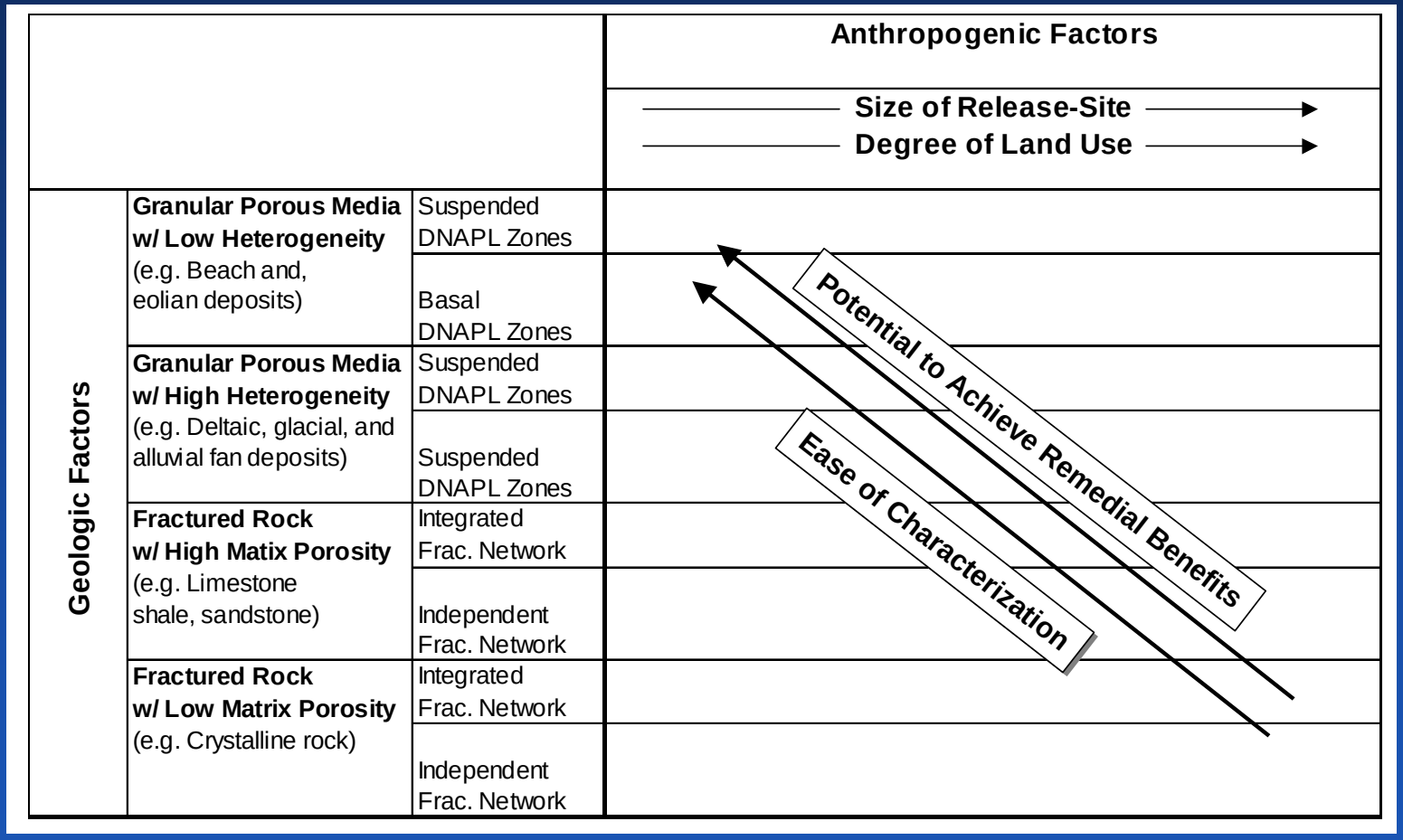
Barriers to Closure

- The Source Depletion decision – balancing capital costs with O&M costs
  - Quantifying the benefits
- Lack of accurate modeling tools to predict times to achieve RAOs
- Subsurface complexities and long term secondary sources
  - Low permeable zones in unconsolidated media as diffusion sources
  - Matrix diffusion in consolidated media
- Lack of consensus on “reasonable timeframe”
- TI strategies not a closure strategy – may reduce costs

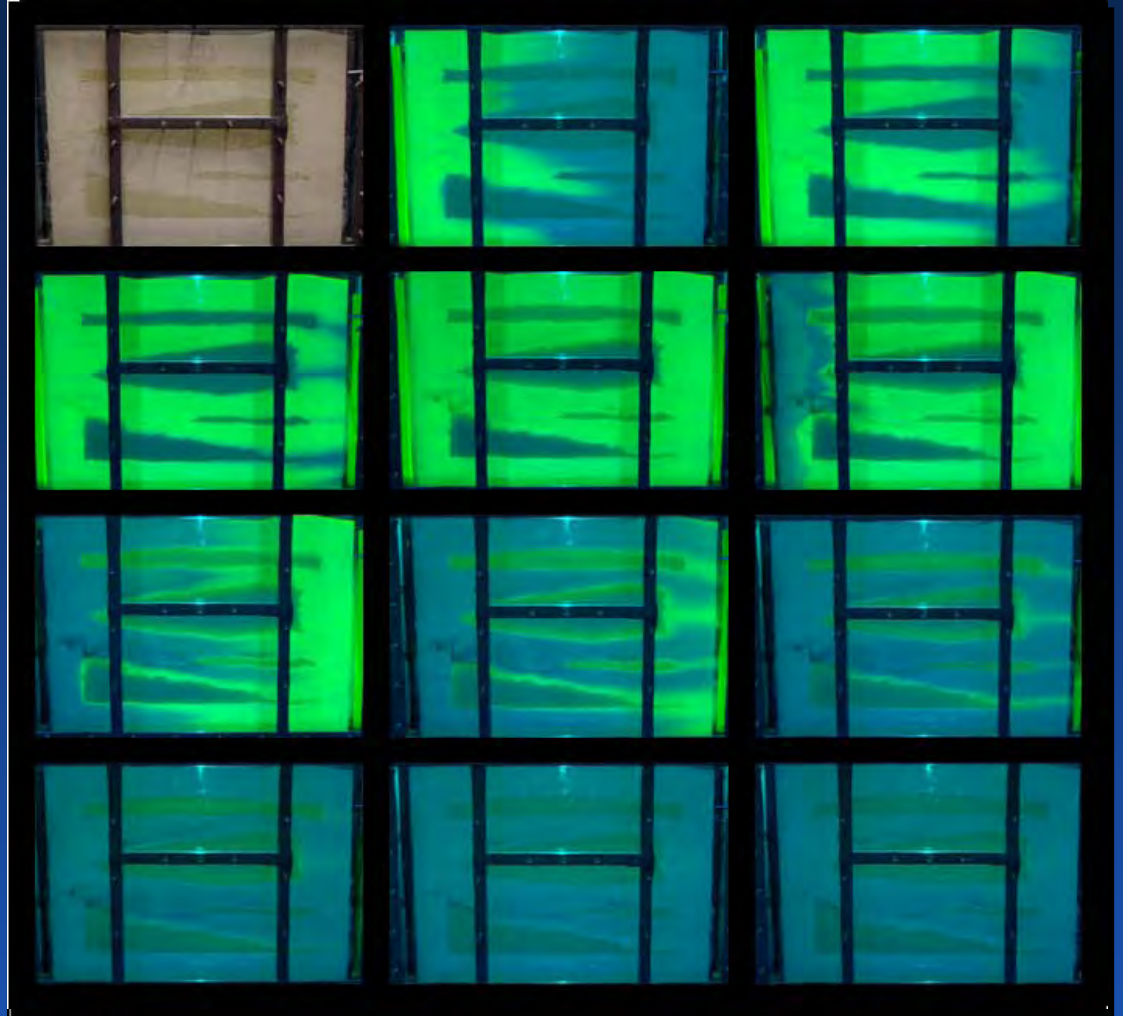
Strategies to Overcome Barriers to Closure

- Improved decision making for remedy selection – modeling tools that account for technical limitations
- Definition of “Extent Practicable”
  - Consider combined remedies (physical, chemical, biological)
  - Partial source depletion, containment, waivers, and MNA
  - Assess residual risk if contamination remains
- Assess “reasonable timeframe” and consider lengthening timeframe
- Use of new diagnostic tools to accelerate transition to MNA, closure
  - Isotopes, microbial probes, mass flux

Example: Qualitative Approach to Decision Making



U.S. EPA, 2003. *The DNAPL Remediation Challenge: Is There a Case for Source Depletion?* Expert Panel.



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Frequently Asked Questions Regarding the Management of Chlorinated Solvents in Soils and Groundwater

November 2007

Tom Sale, Charles Newell, Hans Stroo,
Robert Hinchee, and Paul Johnson

An Adaptive Management Decision Model Evolving at Contaminated Groundwater Sites *(see NRC, 2003, Adaptive Site Management)*

- Innovative contracting strategies by owners (e.g., PBC, GFPR)
- Modeling tools to provide more realistic predictions of time to achieve RAOs
- Continued full scale testing of in-situ technologies where mass removal is achievable – use mass removal as key metric
- Definition of “extent practicable” through independent verification of performance of in-situ technologies
- Consideration of sustainability metrics in remedy selection and closure strategies
- A comprehensive risk analysis as basis for closure of more sites
- Recognition of some fraction of sites that will be legacy sites with long term institutional controls (e.g., DOE sites)

End of Presentation

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