Innovative Remediation of Light Non-Aqueous Phase Liquids (LNAPL): Development of a Conceptual Site Model Leading to a Sustainable Remedial Design

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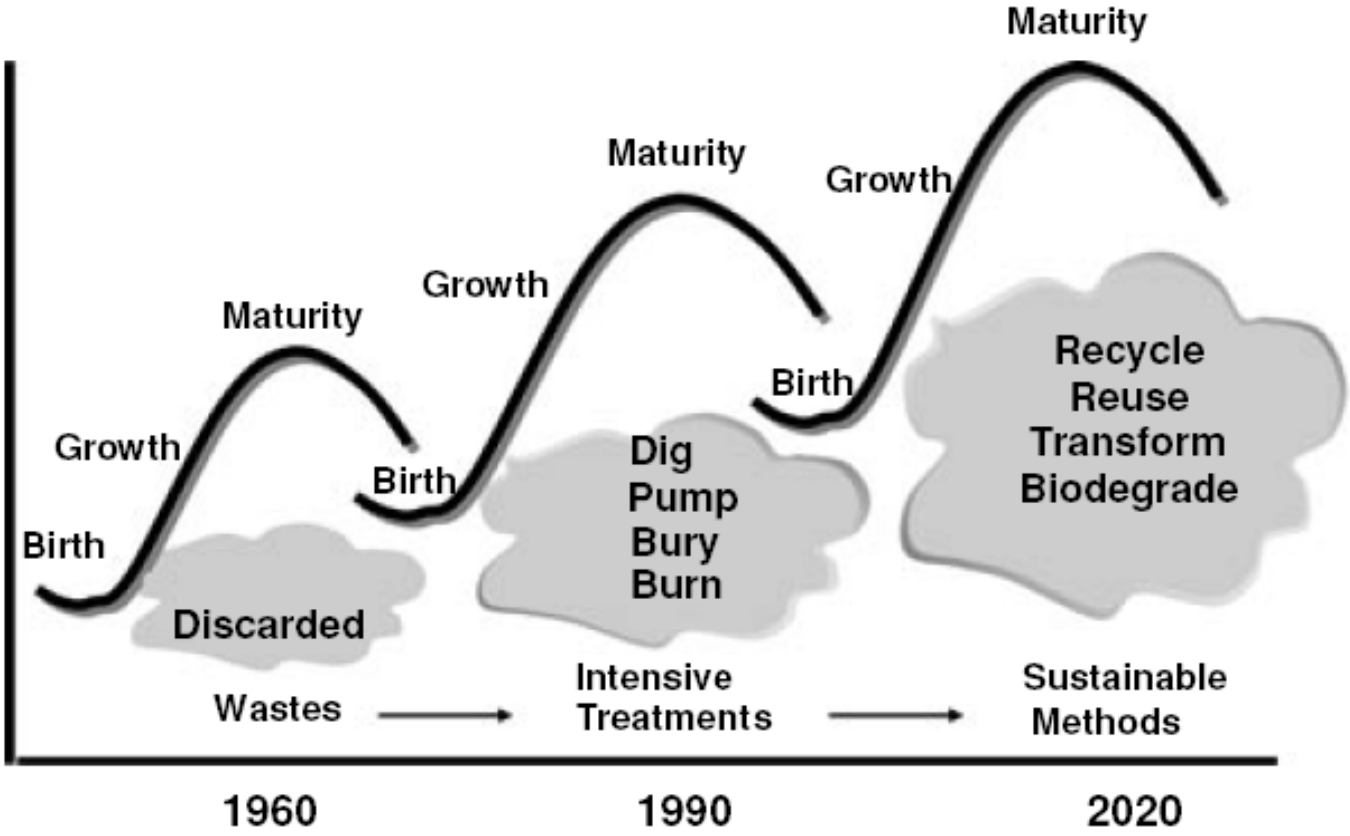
Presentation Agenda & Context

- Primarily US-based documentation used today to relate remediation and LNAPL
- American Society for Testing and Materials (ASTM) standard guidance is internationally developed and applied
- Basic concepts apply internationally – but yet Innovative!
  - *Conceptual Site Model (CSM)*
  - *Risk-based approach designed for LNAPL management & remediation leading to a LCSM*
- Compliant to France's February 2007 guidelines and policies

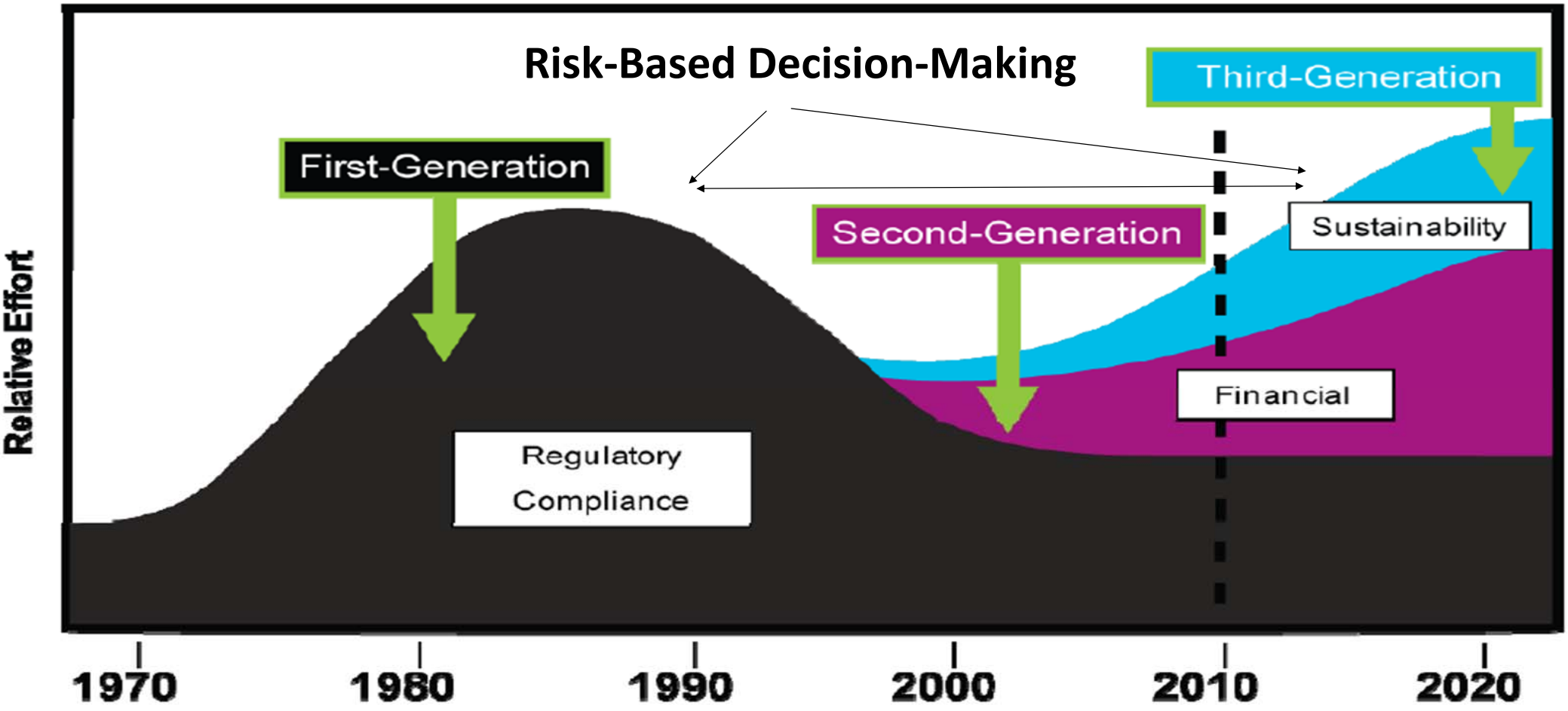
Evolution of Green & Sustainable Remediation



2009, Ellis, D.E., et al – ***Sustainable Remediation White Paper***

Integrating Sustainable Principles, Practices, and Metrics Into Remediation Projects

Evolution of Green & Sustainable Remediation



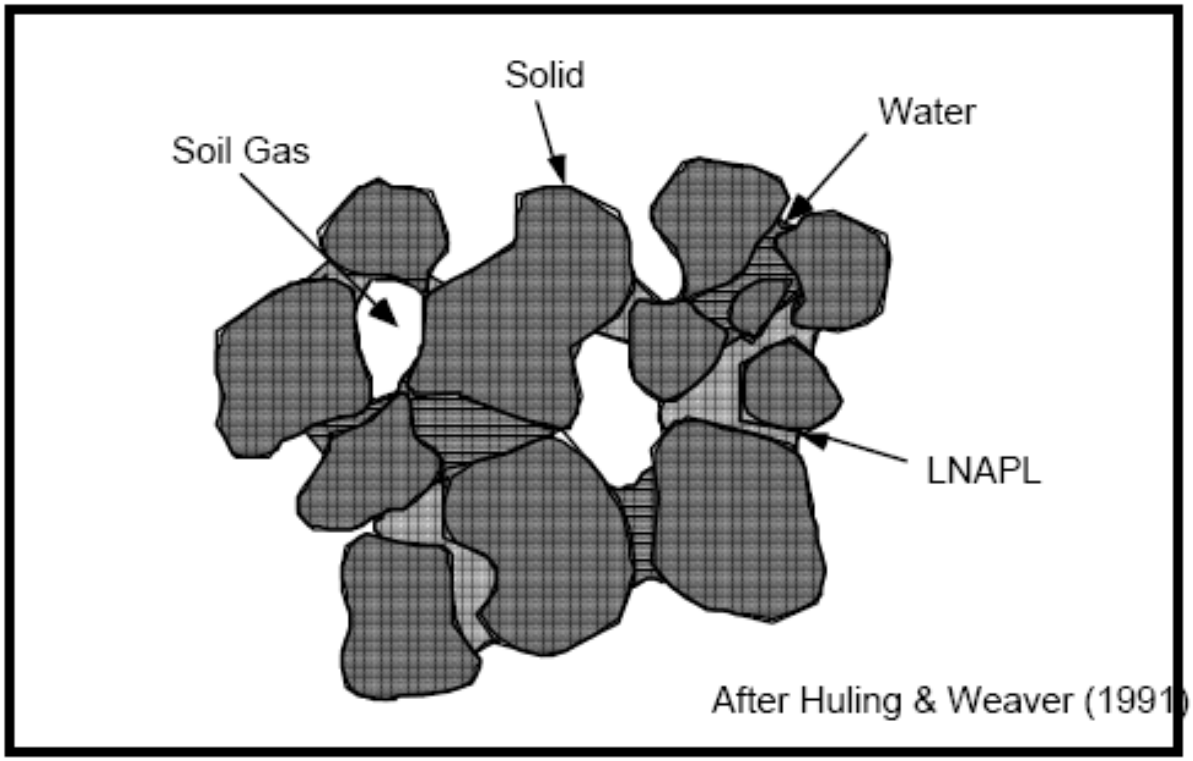
Third Generation activities add business value and build community assets

Light Non-Aqueous Phase Liquids (LNAPL)

- Non-aqueous phase liquids (NAPLs) are hydrocarbons that exist as a separate, immiscible phase when in contact with water and/or air
  - *Differences in the physical and chemical properties of water and NAPL result in the formation of a physical interface between the liquids which prevents the two fluids from mixing.*
- Non-aqueous phase liquids are typically classified as either:
  - *LNAPLs (light non-aqueous phase liquids) have densities <H_2O*
  - *DNAPLs (dense non-aqueous phase liquids) have densities >H_2O*

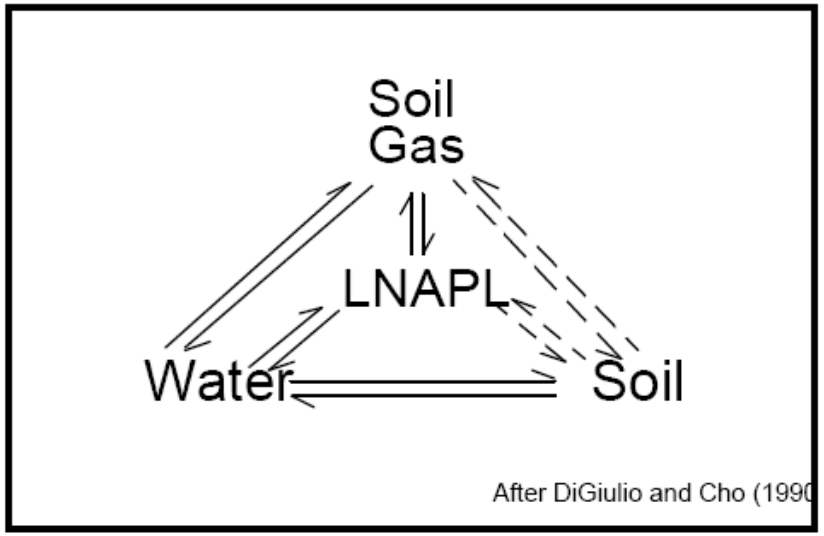
LNAPL Concerns

- NAPL-related contaminants may be present in the aqueous, solid, and NAPL phases



LNAPL Concerns

- LNAPL affects groundwater quality at many polluted sites, and particularly petroleum product release sites
  - *The presence of* significant *LNAPL represents* potential *long-term sources for continuing contamination*
- Phase distribution affects
  - *Migration*
  - *Partitioning*
  - *Exposure pathways*
  - *Receptor risks*



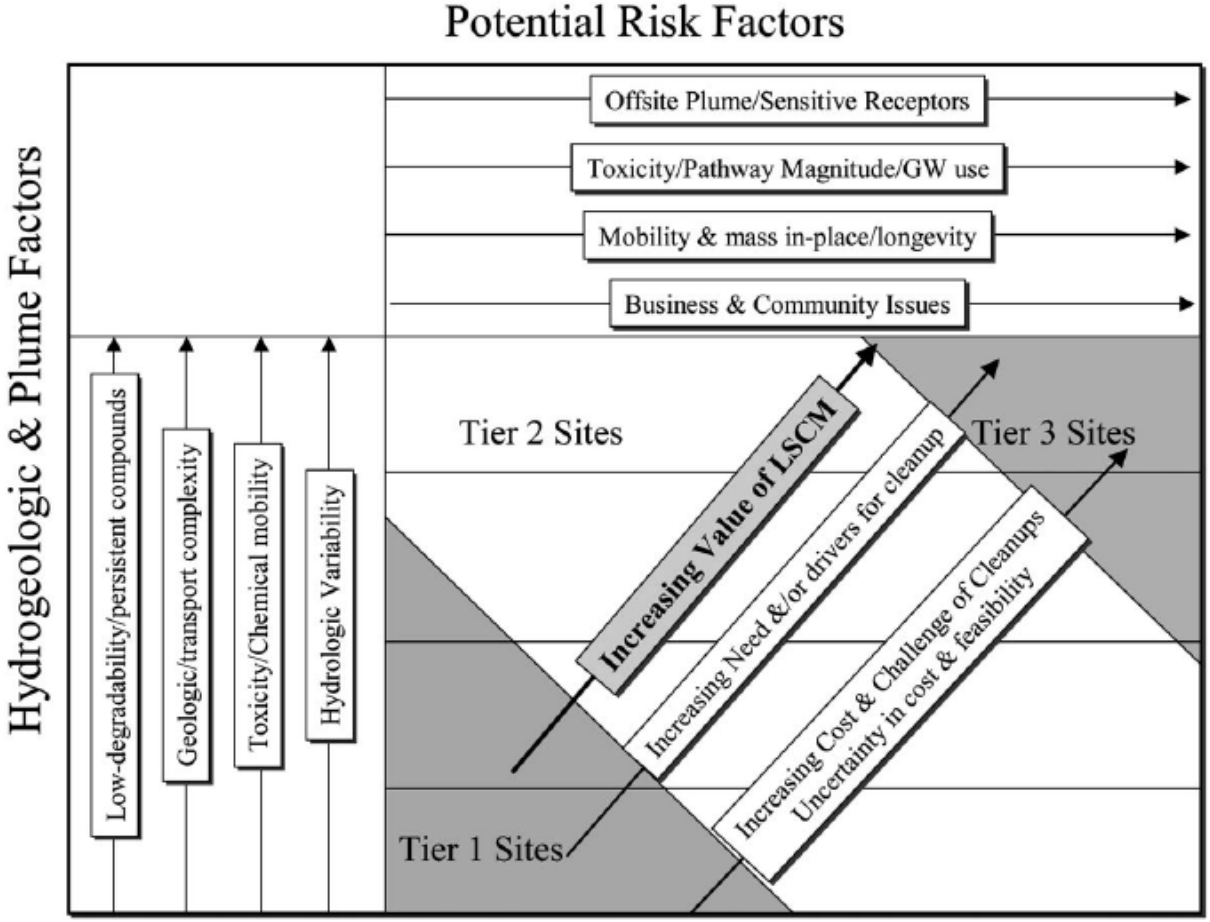
LNAPL + Conceptual Site Model (CSM) = LCSM

Additional elements evaluated and incorporated into the preliminary LCSM remediation design

- Sensitivities associated with working potentially working in and amongst surrounding community areas
- Evaluations of utilities and sensitive areas (which may constrain the design of the system)
- Inventories of operational and safety procedures and concerns at the remediation engineering facilities (source area and off-site)

Understandings of infrastructure complexities must be complete as possible in order to develop proper remedial design – no surprises!

ASTM E-2531-06 – LCSM Risk Matrix



NOTE 1—This is an example list that is not exhaustive, the boundary between tiers is subjective and based on user judgment.
NOTE 2—(Concept after Sale 2002. (Ref 3))

Key concept – *LNAPL Transmissivity*

- LNAPL transmissivity = rate at which a volume of LNAPL, such as oil, will flow through a unit width of porous material, such as soil, for a unit gradient
- Measurements of LNAPL transmissivity desired
  - *key goal of good assessment work → remediation success*
- Various methodologies exist to measure transmissivity
  - *baildown tests, recovery data, soil core and tracer test analyses, etc*
- No consensus exists today on standard methodologies

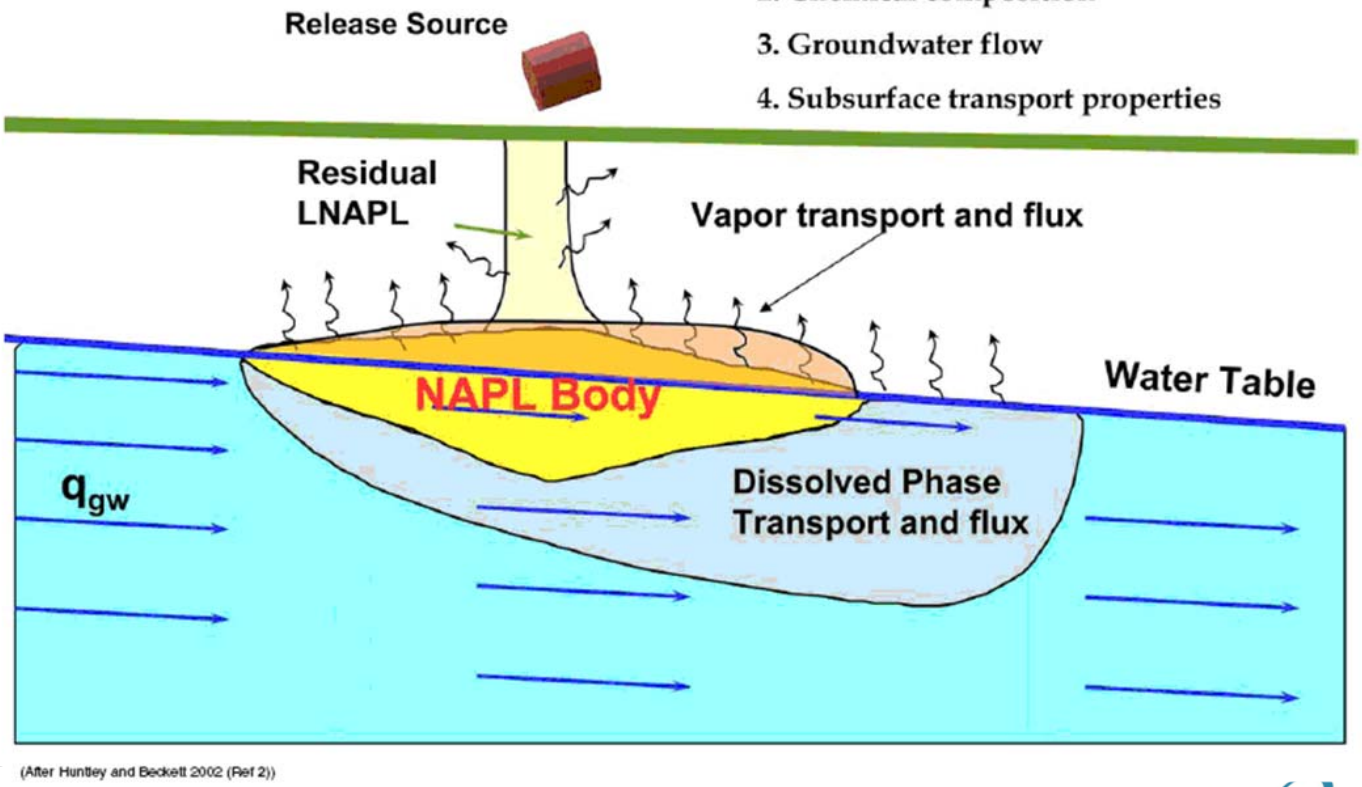
ASTM E-2531-06

Standard Guide for Development of Conceptual Site Models and Remediation Strategies for Light Nonaqueous-Phase Liquids Released to the Subsurface

*- **LCSM***

Aspects of the LNAPL to be described in the LCSM:

1. Geometry of the LNAPL body
2. Chemical composition
3. Groundwater flow
4. Subsurface transport properties



(After Huntley and Beckett 2002 (Ref 2))

LNAPL and the Conceptual Site Model (LCSM)

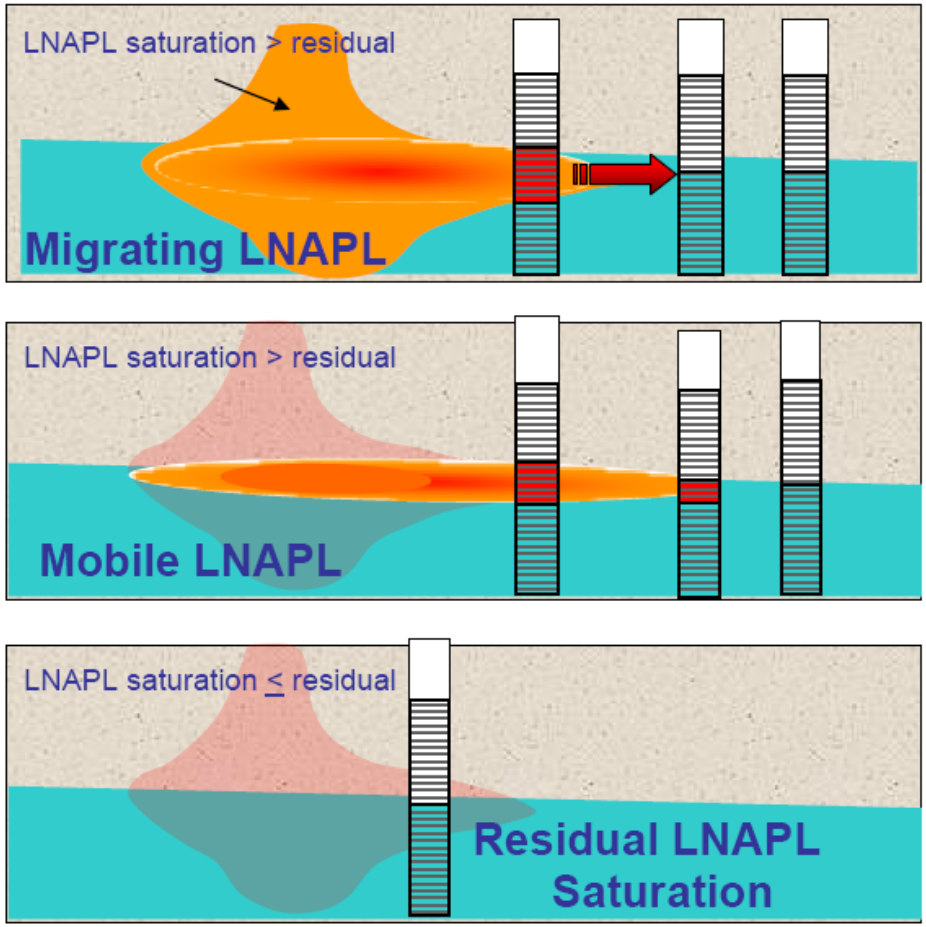
Key factors to successful execution of a LNAPL remediation project

- Develop a robust conceptual and realistic understanding of –
  - LNAPL occurrence, mobility and recoverability
  - LNAPL constituents partitioning to dissolved- & vapor-phases
  - Mechanisms of dissolved- & vapor-phase transport in the subsurface

These understandings build up the Conceptual Site Model (CSM)

- CSM guides remedial design work
  - Important communication tool with project management, regulators, community, and other stakeholders

LNAPL and the Conceptual Site Model (LCSM)



Develop LNAPL understanding:

- Migrating / Mobile
- Residual saturation

Assess recoverability

Many times the thickness of residual LNAPL is the cleanup goal

Evaluate exposure risks

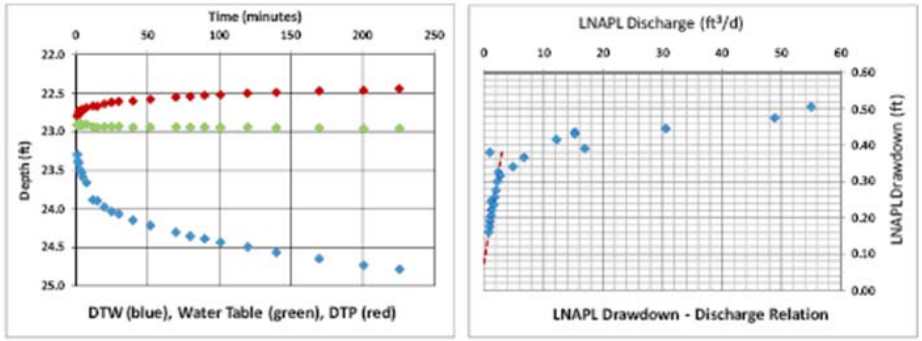
- Determine cleanup goals

Additional LNAPL guidance under development

"Evaluating LNAPL Transmissivity" –work-in-progress as emerging up-to-date ASTM standard technical guidance

- The ASTM guidance will provide data collection and analysis methodologies related to estimating LNAPL transmissivity for the three following methods:
  - ***LNAPL baildown tests***
  - ***LNAPL field tests***
  - ***Recovery system data***

Baildown Tests



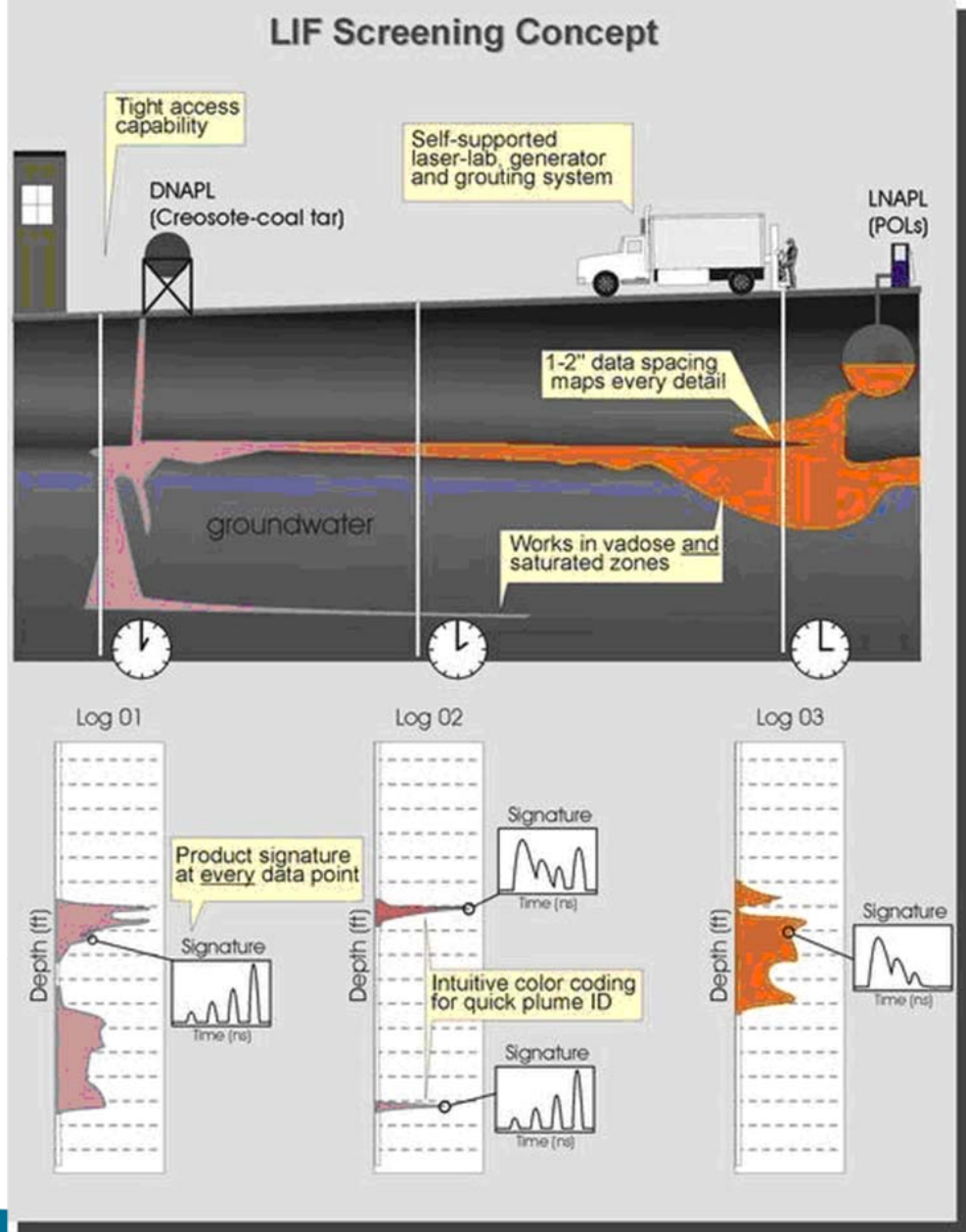
Example Data from Beckett and Lyverse (2002)

- Baildown test data are used to estimate a LNAPL transmissivity value based on measurement of LNAPL drawdown and recharge to the well as a function of time
- Identify possible LNAPL conditions (unconfined, confined, or perched hydro/geologic conditions)
- Typically evaluate these data in spreadsheet models

In-situ testing

Cone penetration testing (CPT)

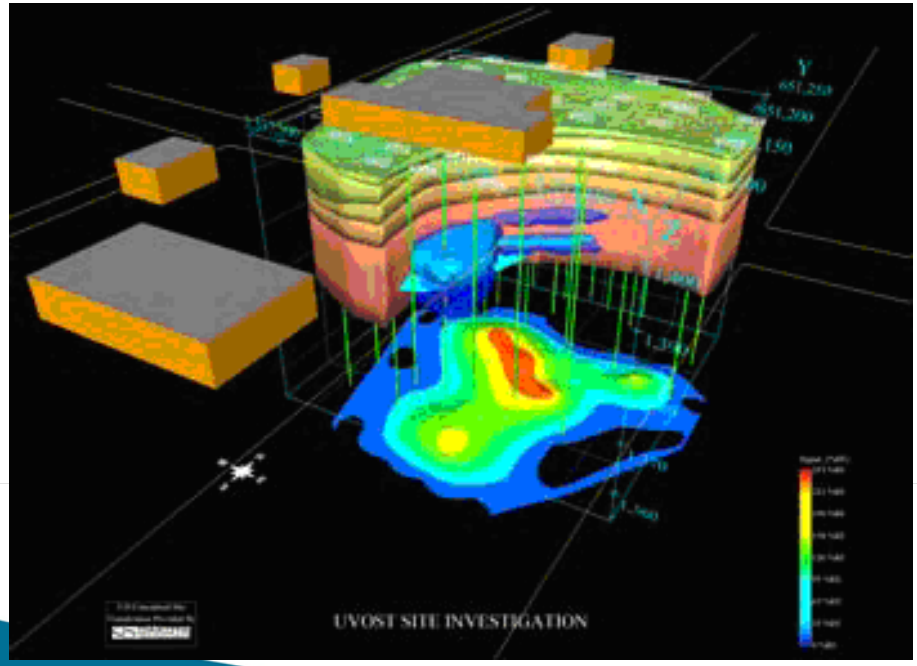
- Geotechnical soil bearing capacity
- Laser-Induced Fluorescence (LIF)
- soil conductivity/resistivity
- video cameras

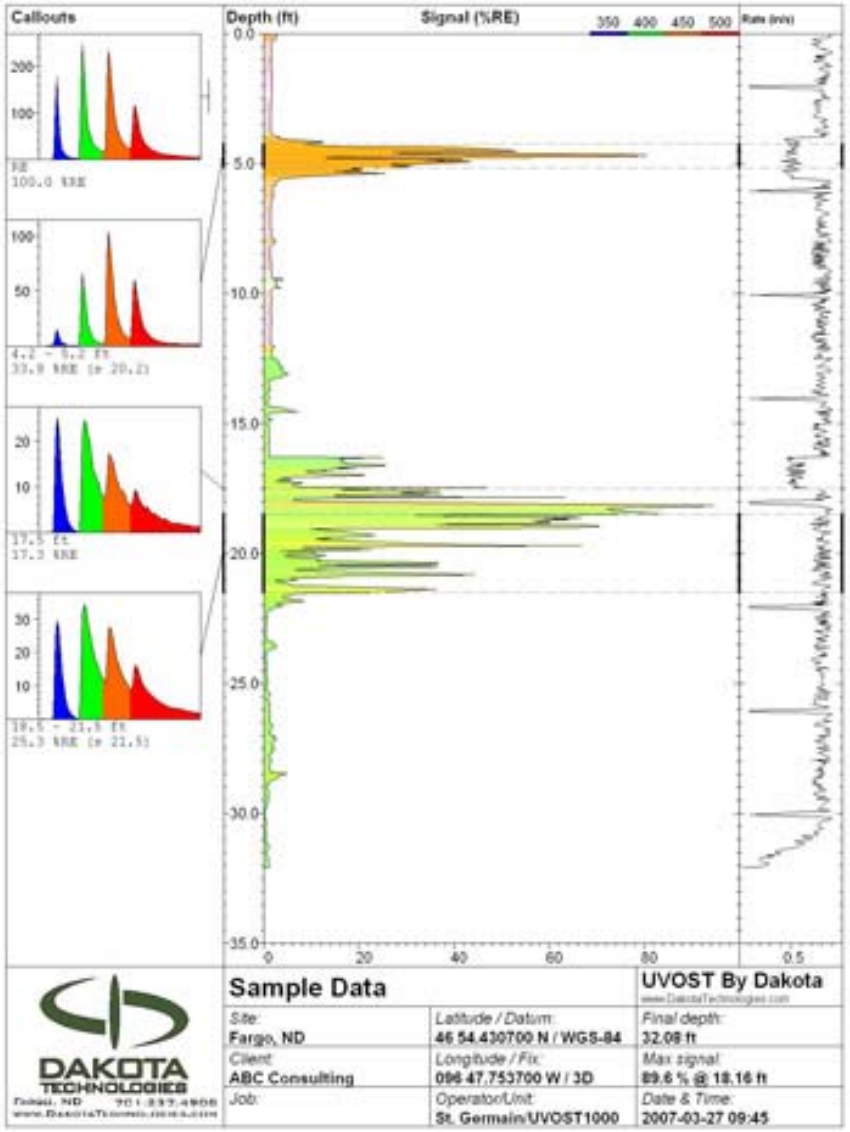


In-situ testing

Advanced MIP techniques:

- UVOST (ultra-violet optical screening tool)





Recovery System Data – spreadsheets / models

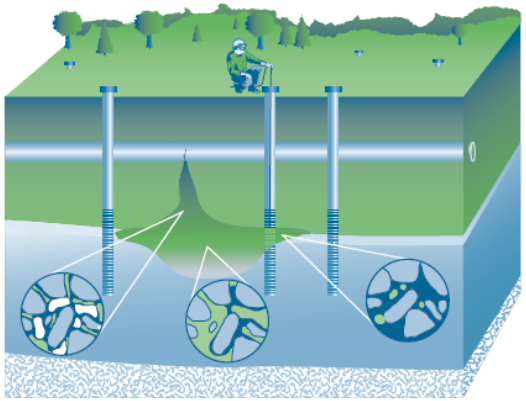
American Petroleum Institute (API)

- ***Distribution and Recovery of Petroleum Hydrocarbon Liquids in Porous Media***
  - *API Publication 4760 Guidance*
  - *Includes **Charbeneau spreadsheet** analysis tool (2007)*
- ***Interactive LNAPL Guide*** (API 2006)
- ***LNAPL Distribution and Recovery Model*** (LDRM)
  - API & University of Texas 2005

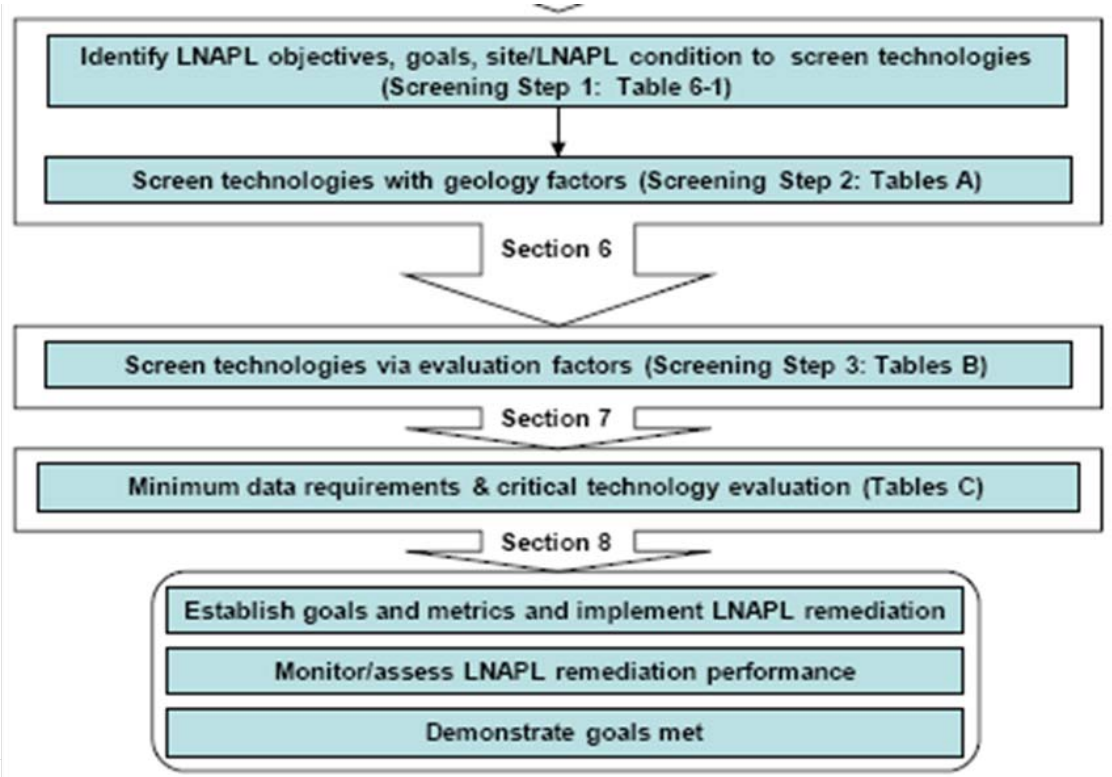
Recovery System – ITRC Evaluation Process

Technical/Regulatory Guidance

Evaluating LNAPL Remedial Technologies for Achieving Project Goals



December 2009



Evaluating LNAPL Remedial Technologies for Achieving Project Goals

LNAPL technology	Advantages	Disadvantages[a]	Applicable geology (fine, coarse)[b]	Applicable to unsaturated zone, saturated zone[c]	Applicable type of LNAPL[d]	LNAPL remedial objective type (saturation, composition)[e]	Potential time frame[f]	Appendix A reference table numbers
Excavation	100% removal, time frame	Accessibility, depth limitations, cost, waste disposal	F, C	U + S	LV, LS, HV, HS	**Sat** + Comp	V. short	A-1.x
Physical or hydraulic containment (barrier wall, French drain, slurry wall)	Source control, mitigation of downgradient risk	Hydraulic control required, site management, cost, depth and geologic limitations	F, C	S	LV, LS, HV, HS	**Sat** + Comp	V. long	A-2.x
In situ soil mixing (stabilization)	Time frame, source control	Accessibility, required homogeneity, depth limitations, cost, long-term residual management	F, C	U + S	LV, LS, HV, HS	**Sat** + Comp	V. short to short	A-3.x
Natural source zone depletion	No disruption, implementable, low carbon footprint	Time frame, containment	F, C	U + S	HV, HS	Sat + **Comp**	V. long	A-4.x
Air sparging/soil vapor extraction	Proven, implementable, vapor control	Does not treat heavy-end LNAPLs/low-permeability soils, off-gas vapor management	C	U + S	HV, HS	Sat + **Comp**	Short to medium	A-5.x
LNAPL skimming	Proven, implementable	Time frame, limited to mobile LNAPL, ROI[g]	F, C	S	LV, LS, HV, HS	**Sat**	Long to v. long	A-6.x
Bioslurping/ enhanced fluid recovery	Proven, implementable, vapor control	Time frame, limited to mobile LNAPL, ROI	F, C	U + S	LV, LS, HV, HS	Sat + **Comp**	Long to v. long	A-7.x
Dual-pump liquid extraction	Proven, implementable, hydraulic control	Time frame, limited to mobile LNAPL, ROI	C	S	LV, LS, HV, HS, > residual	**Sat**	Long to v. long	A-8.x
Multiphase extraction (dual pump)	Proven, implementable, hydraulic control	Generated fluids treatment	C	S	LV, LS, HV, HS, > residual	**Sat** + Comp	Medium	A-9.x

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Multiphase extraction (single pump)	Proven, implementable, hydraulic control, vapor control	Generated fluids treatment	C	U + S	LV, LS, HV, HS, > residual	**Sat** + Comp	Medium	A-10.x
Water flooding (incl. hot water flooding)	Proven, implementable	Capital equipment, hydraulic control required, homogeneity, flood sweep efficiency[h]	C	S	LV, LS, HV, HS, > residual	**Sat**	Short	A-11.x
In situ chemical oxidation	Time frame, source removal	Rate-limited hydraulic control required, by-products, cost, vapor generation, rebound, accessibility/spacing homogeneity, MNO_2 crusting	C	U (ozone oxidant) + S	HV, HS	**Comp**	V. short to short	A-12.x
Surfactant-enhanced subsurface remediation	Time frame, source removal	Hydraulic control required, by-products, cost, dissolved COCs[i] treatment, required homogeneity, water treatment, access	C	S	LV, LS, HV, HS	**Sat + Comp**	V. short to short	A-13.x
Cosolvent flushing	Time frame, source removal	Hydraulic control required, by-products, cost, vapor generation, access, sweep efficiency	C	S	LV, LS, HV, HS	**Sat + Comp**	V. short to short	A-14.x
Steam/hot-air injection	Time frame, source removal, proven, implementable	Hydraulic control required, capital equipment, cost, required homogeneity, vapor generation, access, sweep efficiency	C	U + S	LV, LS, HV, HS	**Sat + Comp**	V. short	A-15.x
Radio-frequency heating	Time frame, source removal, proven, implementable	Hydraulic control required, by-products, cost, vapor generation, access	F	U + S	LV, LS, HV, HS	**Sat** + Comp	V. short	A-16.x

Summary: LNAPL Sustainable Remediation

- Requires key understandings about the occurrence, distribution, and mobility of the LNAPL
- Develops information towards environmental and human health risk analyses
- Past practices have provided misleading and unrealistic LNAPL recoverability expectations
- When key factors are not clearly delineated, the designed corrective action may result in unsuccessful remedial designs and system performance

Summary: LNAPL Sustainable Remediation

- A program of meaningful field data collection and testing methods along with the LCSM approach and modeling -
  - *refines the understanding of site conditions*
  - *characterizes subsurface LNAPL and ground water fate and transport*
  - *technical impracticability of LNAPL removal*
- The LNAPL Conceptual Site Model (LCSM) approach -
  - *evaluates remedial alternatives and sustainable options for each remedy*
  - *defines design parameters for the selected remedial option or options*
  - *contributes a major role to develop remedial goals, objectives and risk-based end points for the selected remediation approach*

Merci pour votre attention

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