Starting Soon: LNAPLs Training – Part 3 of 3

Poll Question

- Light Non-Aqueous Phase Liquid (LNAPL) Site Management: LCSM Evolution, Decision Process, and Remedial Technologies (LNAPL-3, 2018) - https://lnapl-3.itrcweb.org/
- Download PowerPoint file
  - Clu-in training page at https://clu-in.org/conf/itrc/LNAPL-3/
  - Under "Download Training Materials"
- Download information for reference during class
  - Figure 1.1 (from the LNAPL-3 guidance document)
- Using Adobe Connect
  - Related Links (on right)
    - Select name of link
    - Click "Browse To"
  - Full Screen button near top of page
- Follow ITRC

Welcome – Thanks for Joining this ITRC Training Class

Based on ITRC Guidance Document:

Light Non-Aqueous Phase Liquid (LNAPL) Site Management: LCSM Evolution, Decision Process, and Remedial Technologies (LNAPL-3, 2018)

3-Part Training Series: Connecting the Science to Managing Sites

Part 1: Understanding LNAPL Behavior in the Subsurface

Part 2: LNAPL Conceptual Site Models and the LNAPL Decision Process

Part 3: Using LNAPL Science, the LCSM, and LNAPL Goals to Select an LNAPL Remedial Technology

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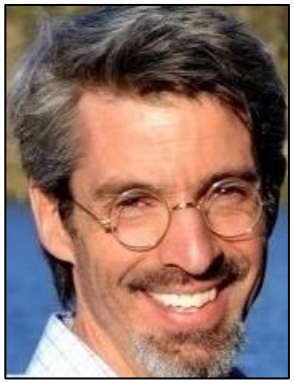

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Read trainer bios at
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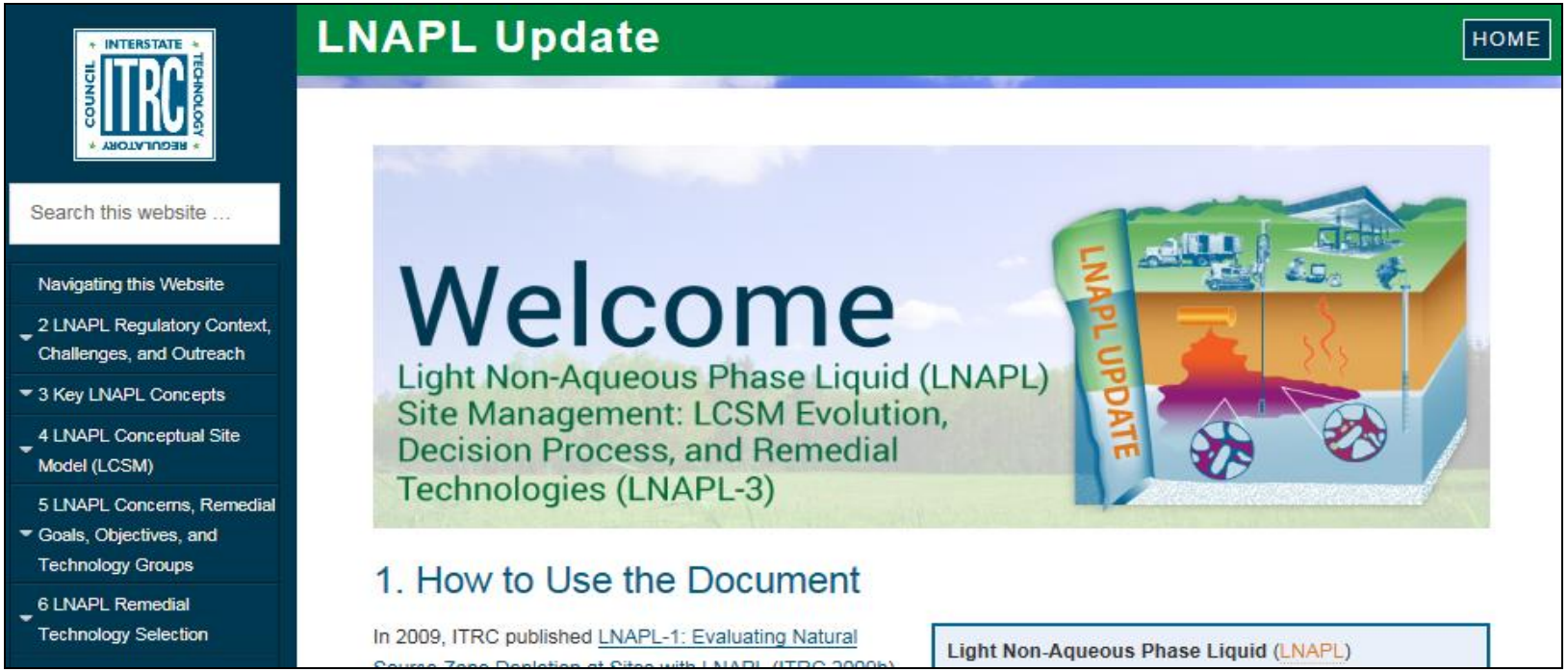


- Expansion of LNAPL Key Concepts
- Development of a LNAPL Conceptual Site Model (LCSM) Section
- Emphasis on identifying SMART goals
- Expansion of Transmissivity (Tn) and Natural Source Zone Depletion (NSZD) via Appendices

LNAPL Part 1 and 2 Summary

LNAPL Science: Key to Improving Decision-making

- Use LNAPL science and its application to make good decisions at your site
- Develop LCSM for LNAPL concern identification and establish appropriate LNAPL remedial goals and objectives

It is important to use your LCSM to help select remedial technology to achieve goals

Learning Objectives
3-Part Training Series

Part 1	▶ Use LNAPL science to your advantage and apply at your sites
Part 2	▶ Develop LNAPL Conceptual Site Model (LCSM) for LNAPL concern identification ▶ Inform stakeholders about the decision-making process
Part 3	▶ Select remedial technologies to achieve objectives ▶ Prepare for transition between LNAPL strategies or technologies as the site moves through investigation, cleanup, and beyond ▶ "SMART"-ly measure progress toward an identified technology-specific endpoint

ITRC 3-Part Online Training Leads to YOUR Action

Part 1:
Connect Science to LNAPL Site Management

(Section 3)

Part 2:
Build Your LNAPL Conceptual Site Model

(Sections 4 and 5)

TODAY

Part 3:
Select / Implement LNAPL Remedies

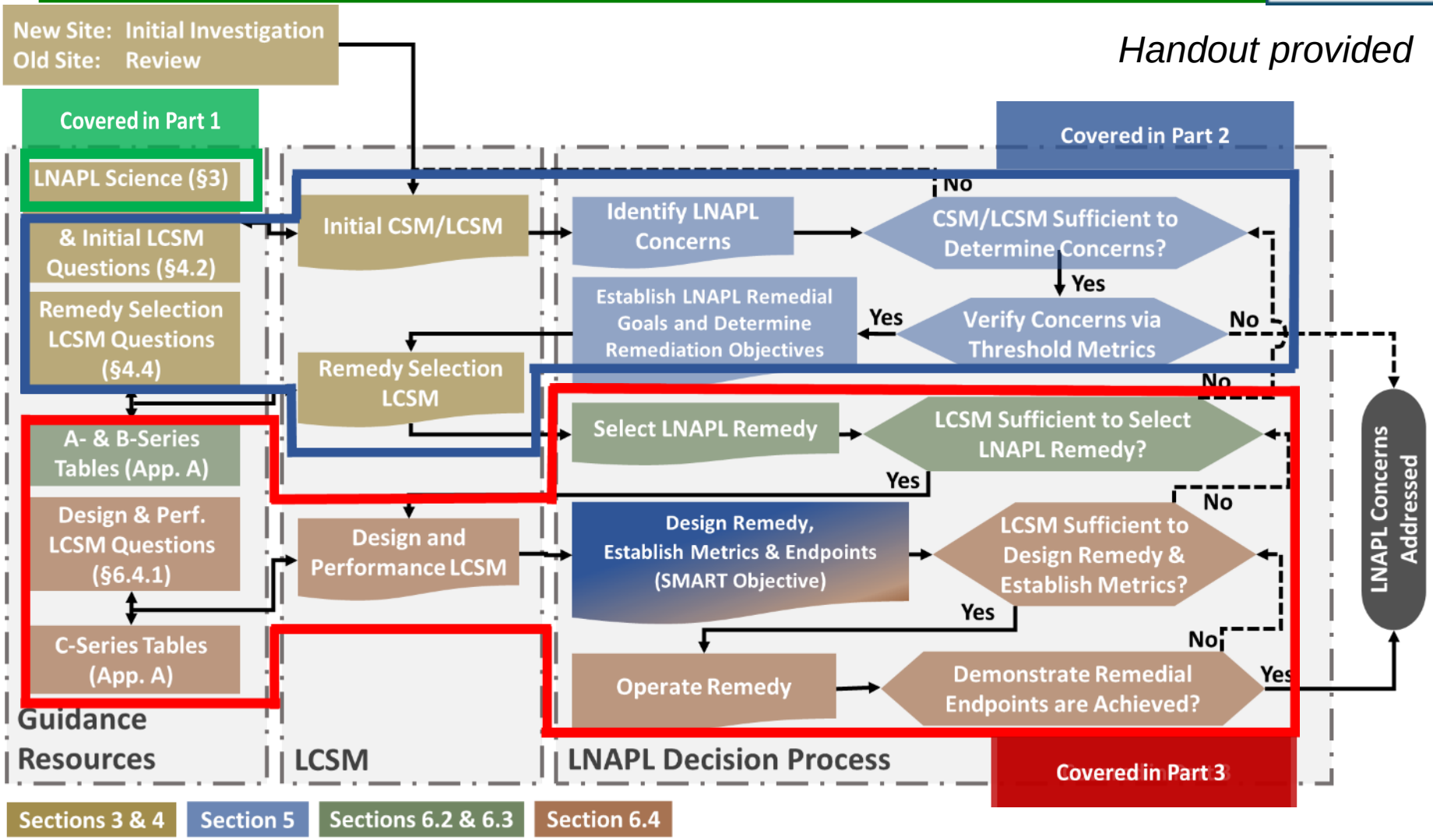
(Section 6)

YOU
Apply knowledge at your LNAPL sites

Based on the ITRC LNAPL-3 Document: LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies

LNAPL Remediation Process and Evolution of the LCSM – Related to the Training Courses

Handout provided



ITRC LNAPL-3, Figure 1-1

LNAPL Remediation Technology Groups

Poll Question

- **Learning Objective:**
  Understand:
  - What the LNAPL remediation technology groups are,
  - Why they've been grouped, and
  - How site goals and objectives influence the selection of a technology group

Many Technologies Available
(ITRC LNAPL-3 Guidance Table 6.1)

21 LNAPL remedial technologies addressed:

- Excavation
- Skimming
- Vacuum Enhanced Skimming
- Total Liquid Extraction
- Multi-Phase Extraction
- Water/hot water flooding
- Surfactant-enhanced subsurface remediation
- Cosolvent flushing
- Steam Injection
- Thermal conduction heating
- Electrical resistance heating
- In-situ smoldering
- Air sparging/ soil vapor extraction
- Biosparging/bioventing
- In-situ chemical oxidation
- Enhanced anaerobic biodegradation
- Natural source zone depletion
- Activated carbon
- Phytotechnology
- Physical or hydraulic containment
- In-situ soil mixing (stabilization)

Key Point: Who ya gonna call?

Not Included in Technology Tables

- Manual Bailing
- Absorbent Socks
- Periodic or Short-term Vacuum Truck Events
- Passive Skimmers

Guidance Technology Series Tables

- Guidance Appendix A
- A table series (Tables A, B, and C) for each of the 21 LNAPL remediation technologies
  - A-series – general technology information
  - B-series – evaluation factors
  - C-series – technical implementation considerations
- For a technology, the A, B, and C tables are presented on consecutive pages
- Key literature references presented in the tables

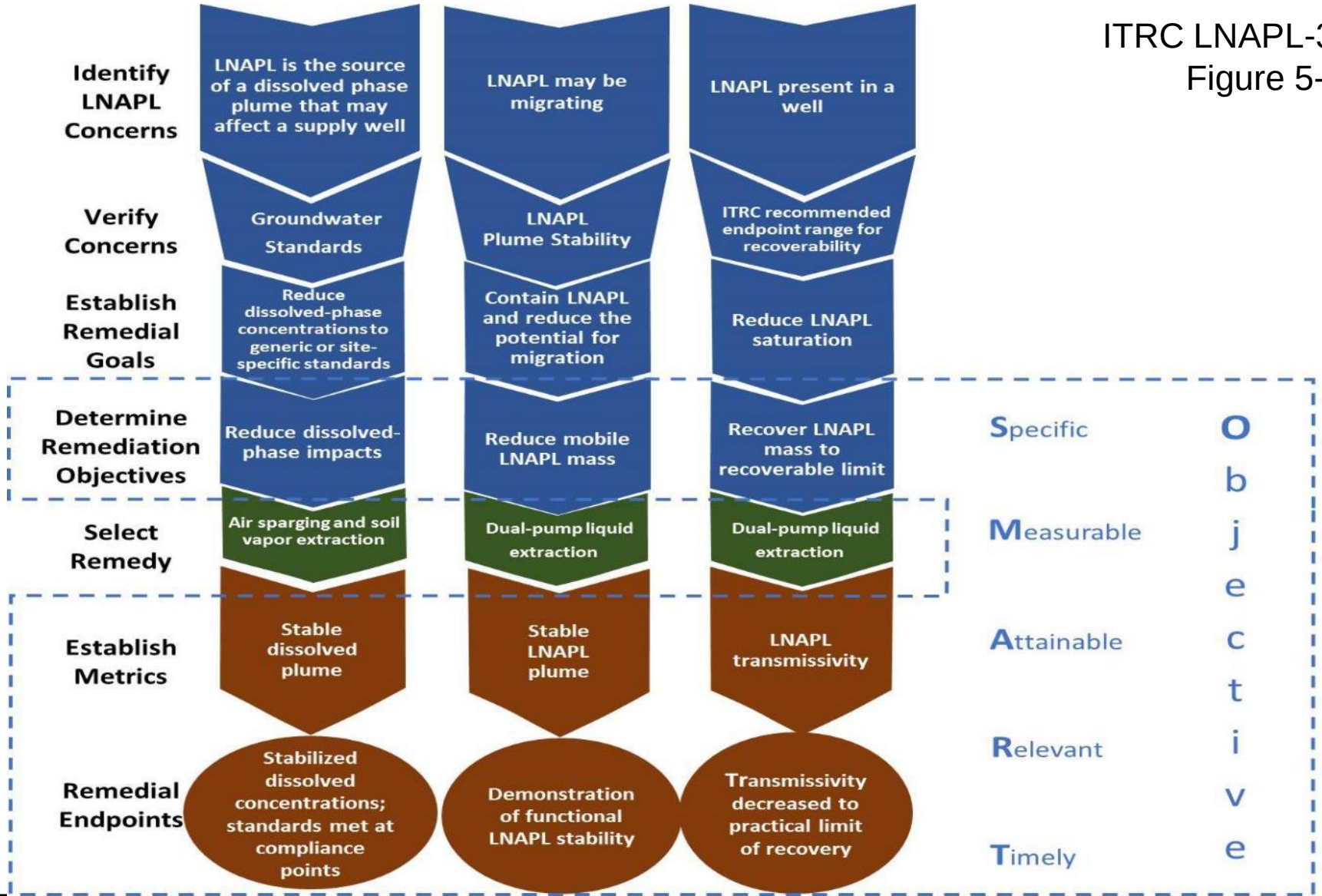
Key Point: Appendix A presents typical technology applicability to site conditions as concluded by the LNAPL Team. This doesn't mean you can't apply the technology in a setting different than what is presented.

Linkage Between Remedial Goals and Remedial Objectives

- "Saturation Goal" – LNAPL mass recovery/control Objective
  - ***Reduce*** LNAPL saturation by recovering LNAPL
  - ***Stop*** LNAPL migration by containing LNAPL
- "Composition Goal" – LNAPL phase change Objective
  - ***Change*** LNAPL characteristics by phase change
- "Aesthetic Goal" – LNAPL Saturation or Composition goals

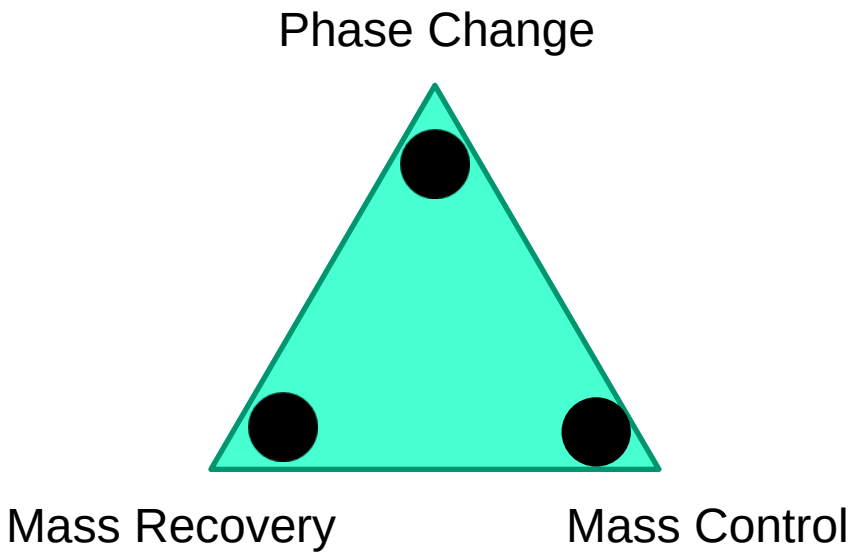
ITRC LNAPL Management Strategy

ITRC LNAPL-3, Figure 5-2



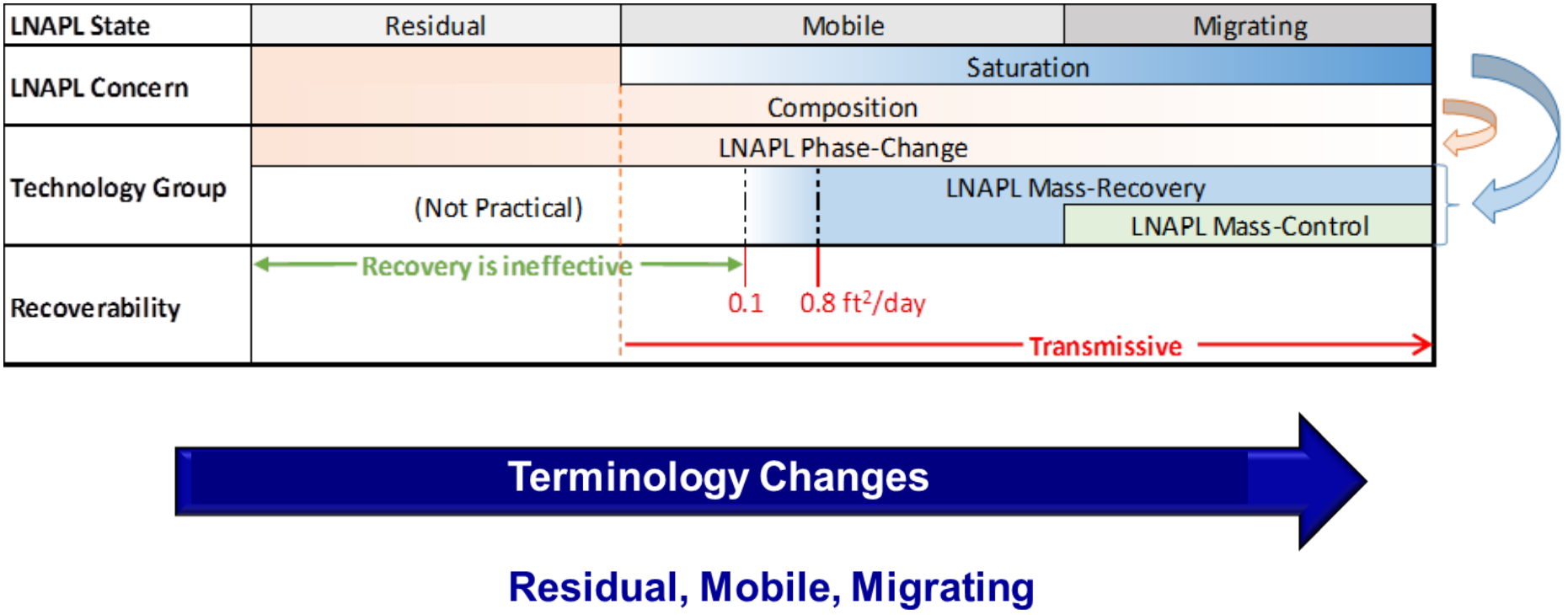
Remedial Technology Groups

- **Mass Control**
- **Mass Recovery**
- **Phase Change**



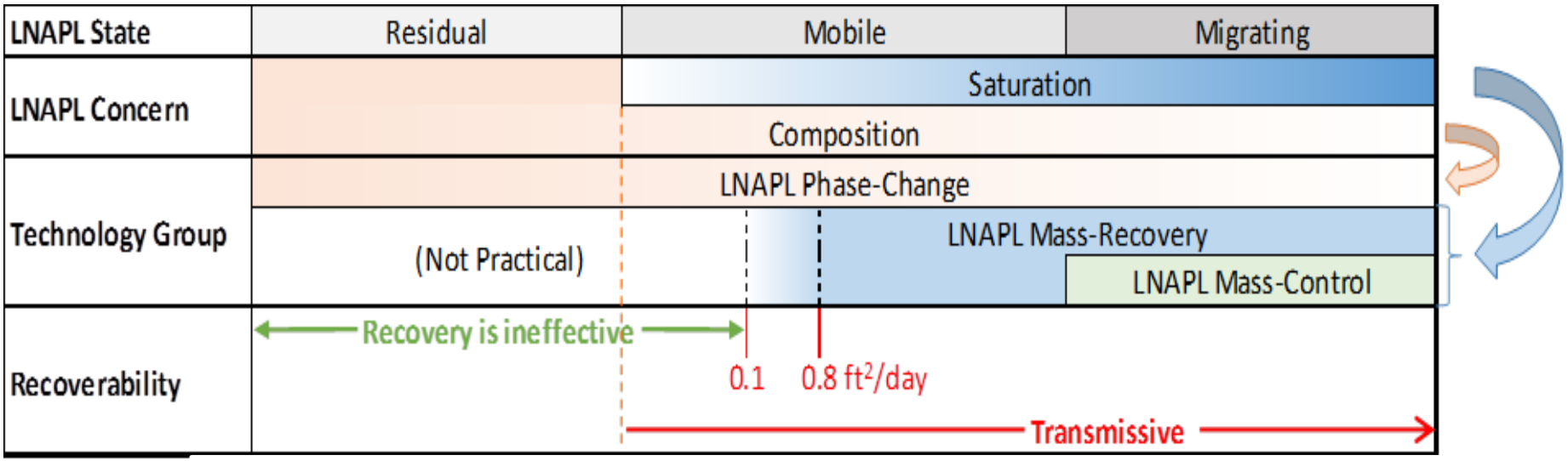
Key Point: Simplify the selection of technology

The Name Game & General Technology Group Applicability



ITRC LNAPL-3, Figure 5-3

Sequenced Technology Deployment - "Treatment Train"



4. Natural Source Zone Depletion | **3. Phase Change** | **2. Mass Recovery** | **1. Mass Control**

ITRC LNAPL-3, Figure 5-3

Treatment Trains

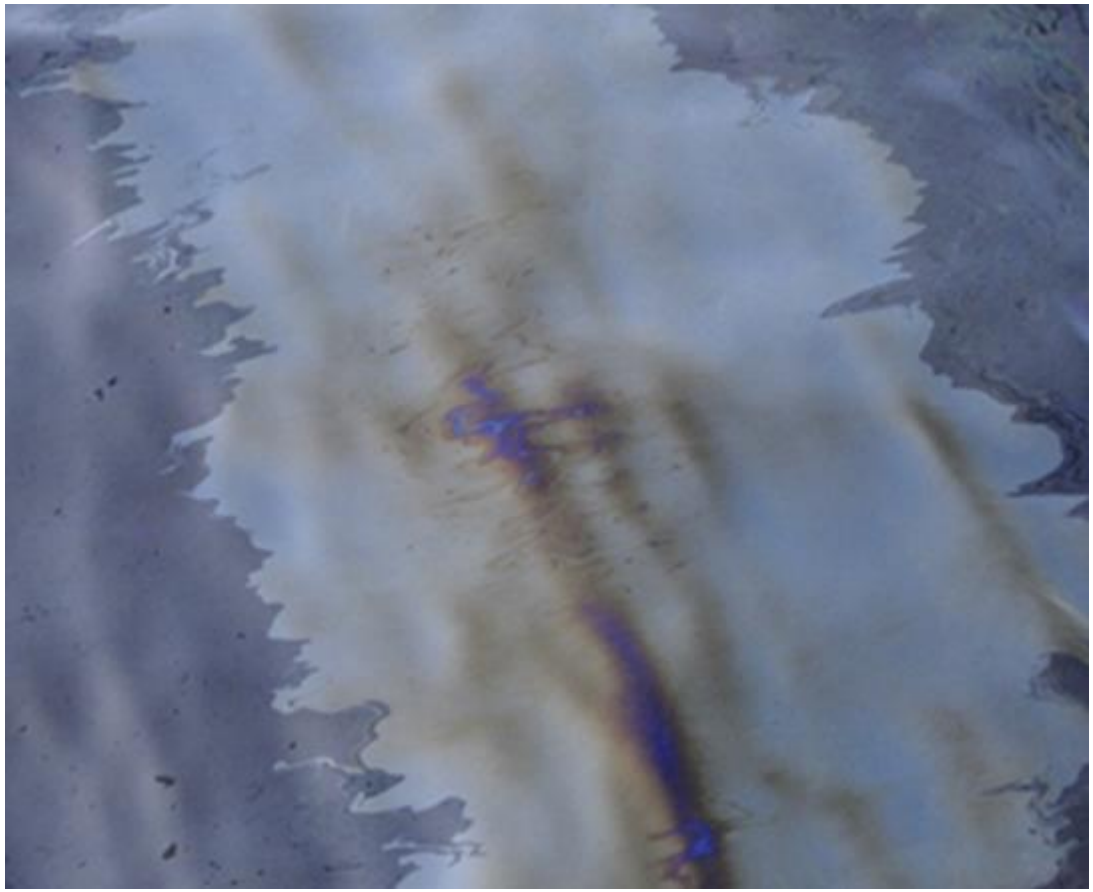
Good

- When planned with SMART objectives, metrics for transition, and endpoints
- Orderly implementation

Bad

- Unplanned, lack specific SMART objectives, metrics for transition, and endpoints
- “Throwing” more technologies at the problem

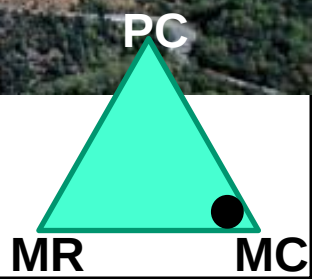
LNAPL Aesthetic (or combination)



ITRC LNAPL-3, Figure S-1

LNAPL Mass Control

Dam the LNAPL!



Saturation Goal

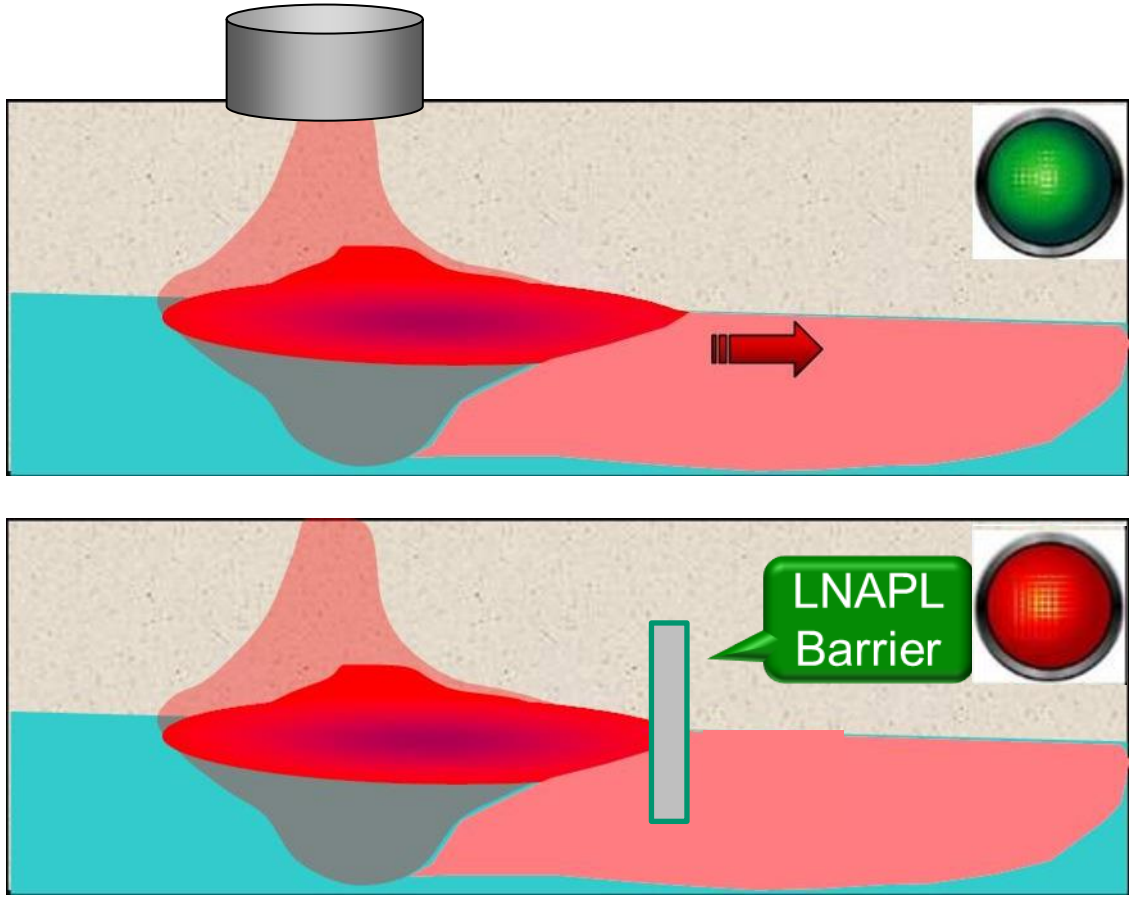
LNAPL Concern	LNAPL Remedial Goal	Remediation Objective
Migration	Terminate LNAPL body migration	Stop LNAPL migration by physical barrier

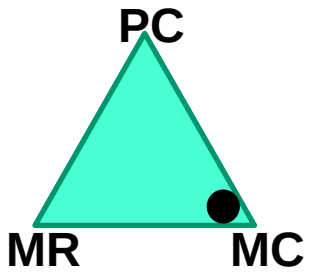
Key Point: Limit mobility or eliminate migration through physical barriers (binding or containment)

Think Barriers

Uncontrolled

Controlled

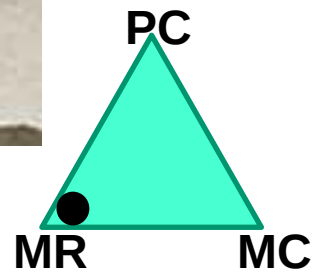




Key Point: Mass control technologies block LNAPL from affecting the surrounding soil, groundwater and/or surface

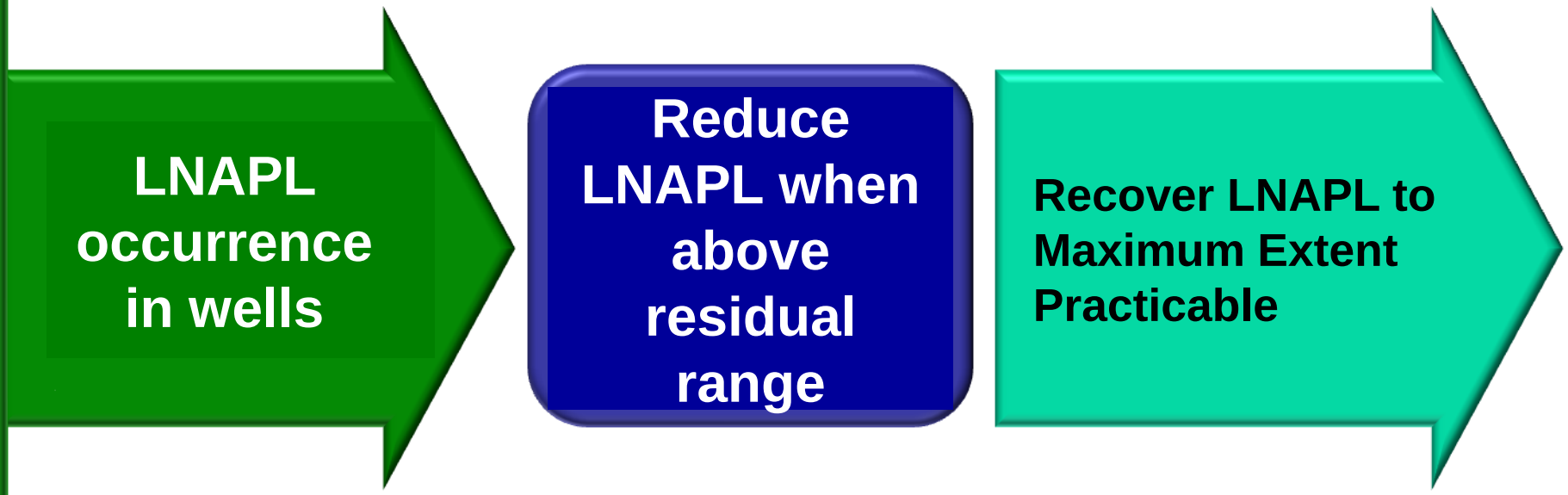
LNAPL Mass Recovery

Think removal as bulk liquid…



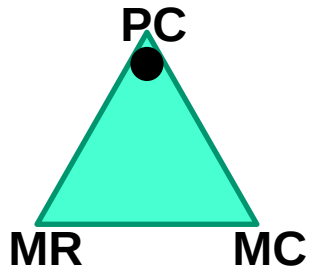
Saturation Goal

LNAPL Concern	LNAPL Remedial Goal	Remediation Objective



Key Point: Reduce mobility and potential for migration by changing LNAPL saturation through mass recovery

LNAPL Phase Change



Composition Goal

LNAPL Phase Change

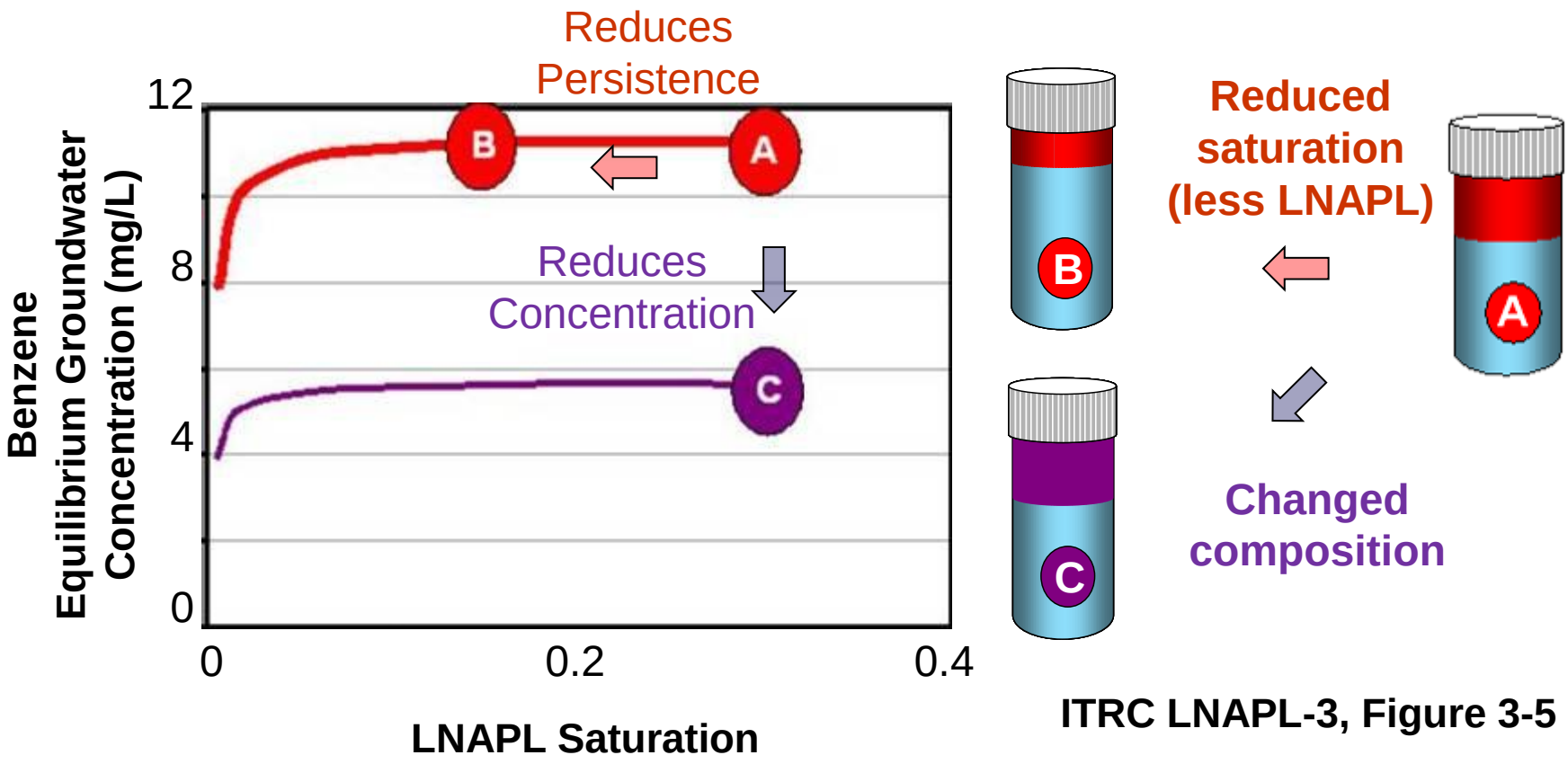
LNAPL Concern	LNAPL Remedial Goal	Remediation Objective
Risk via Vapor Intrusion	Reduce concentrations	Deplete volatile or soluble constituent concentration in LNAPL

Key Point: Reduce soil vapor or groundwater risk by removing risk-driving constituent(s) from LNAPL

LNAPL Composition

- Modified by increasing rates of volatilization and dissolution from LNAPL body – phase change from liquid to vapor phase or liquid to dissolved phase
- Example technologies
  - Soil vapor extraction, or in combination:
    - Air sparging
    - Heating
    - Steam injection
  - Enhanced aerobic biodegradation
  - Enhanced anaerobic biodegradation
  - In-situ chemical oxidation

Contrast Between Composition And Saturation Goals



ITRC LNAPL-3, Figure 3-5

Key Point: Abatement of dissolved or vapor concentration is dependent on change in composition (mole fraction) and not saturation (unless almost all LNAPL is removed)

Knowledge Check

Poll Question

What are the three technology groups?

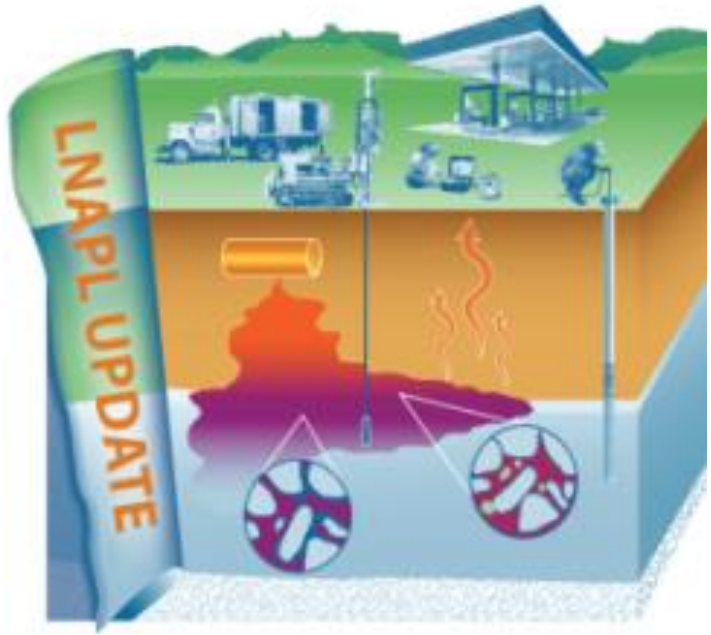
A. Unconfined, Perched, and Confined
B. Mass Control, Mass Recovery, and Phase Change
C. Air Sparging, Skimming, and Excavation
D. Aesthetics, Saturation, and Composition

Technology Groups Overview Takeaways

- Select your Remedial Goals - Saturation or Composition based
- Determine your Remedial Objectives (vapor abatement, remove mobile LNAPL)
- Select your technology from the 3 technology groups
- The 3 groups are:
  - Mass Control
  - Mass Recovery
  - Phase Change
- Sequence your technology deployment and use the “treatment train”

Poll Question

Natural Source Zone Depletion

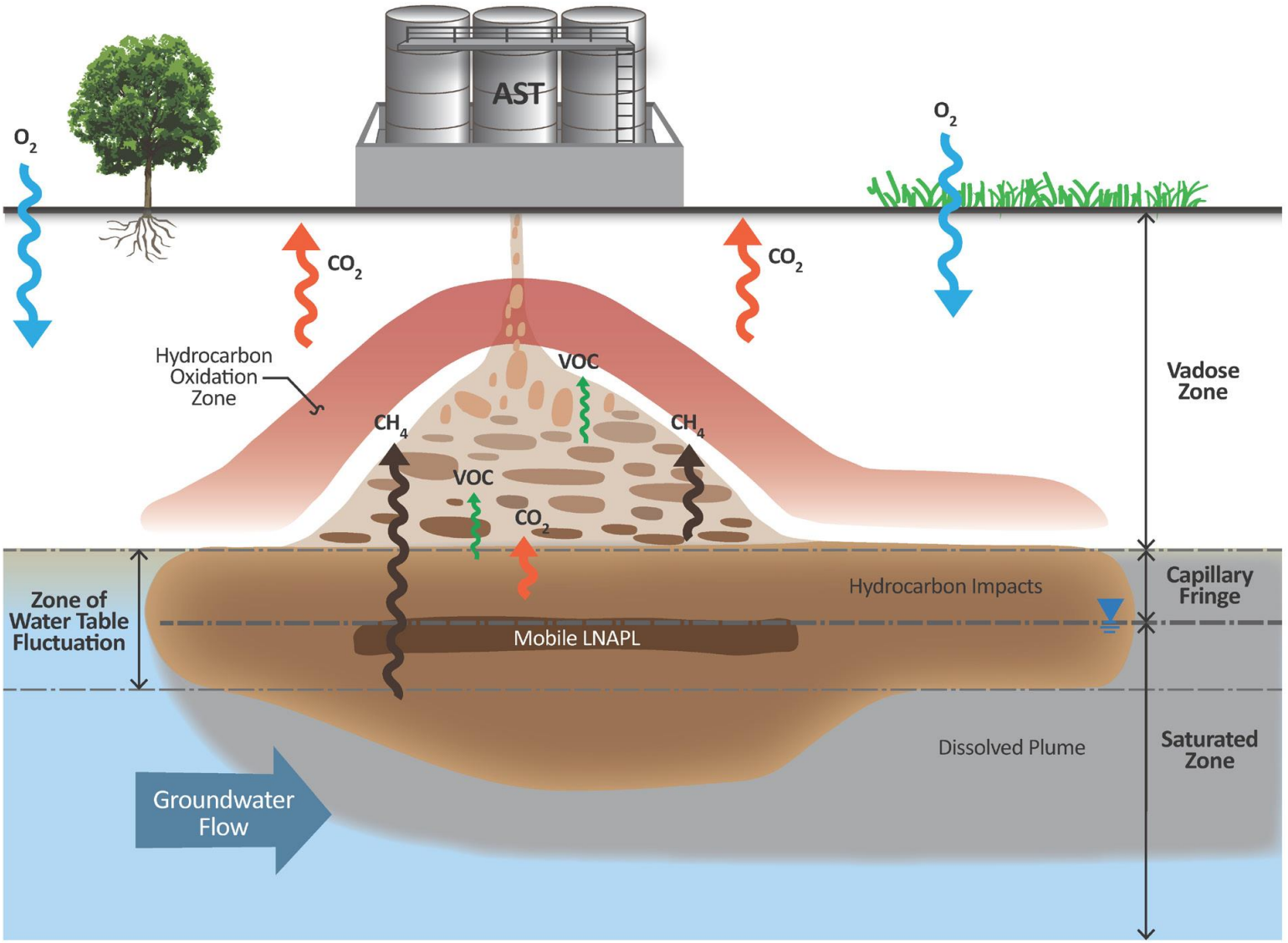


- Mass Control
- Mass Recovery
- **Phase Change**
  - **NSZD**

NSZD Learning Objectives

- NSZD processes and importance
  - It occurs subsurface at most sites and results in LNAPL mass losses
- Incorporate natural source zone depletion (NSZD) into your LCSM
  - There are various measurement methods to suit varied site conditions
- Consider NSZD as a remediation alternative
  - It is an effective, accepted, and sustainable option for low risk sites

Conceptualization of NSZD

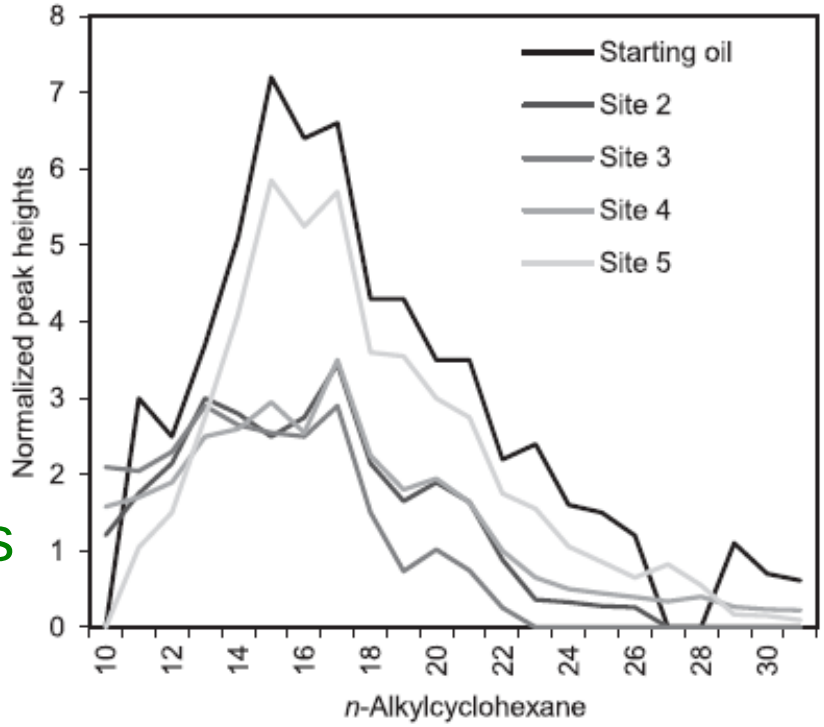


(with permission from API, 2017, http://www.techstreet.com/standards/api-publ-4784?product_id=1984357)

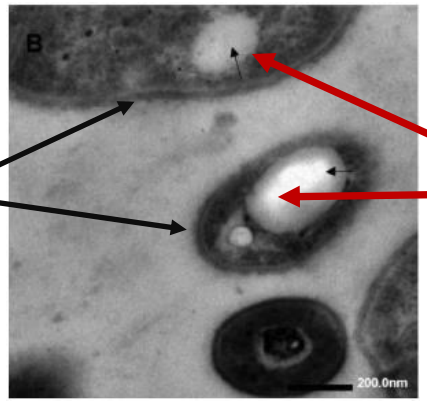
LNAPL-3, Appendix B, Section 2

Key Aspects of NSZD

- Rates are a bulk measure
  - Appear to be zero-order (constant)
- Direct biodegradation
  - Oil-contact microbiology
  - Observing significant losses of longer chain compounds



(Warren et. al., 2014)



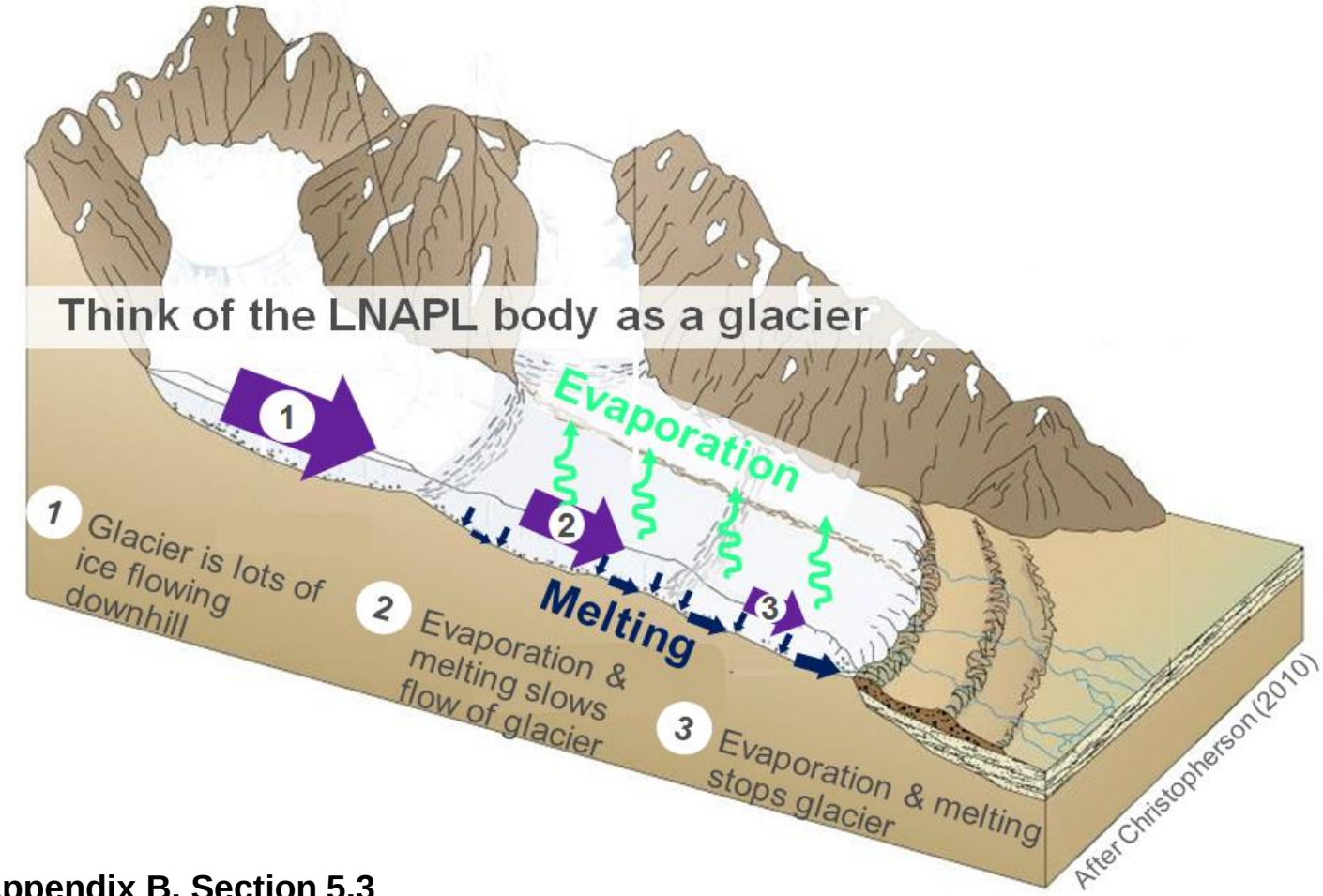
Pseudomonas

Intracellular n-octadecane inclusions

(Transmission electron microscopy from Hua et. al., 2014)

Using NSZD for Decision Making

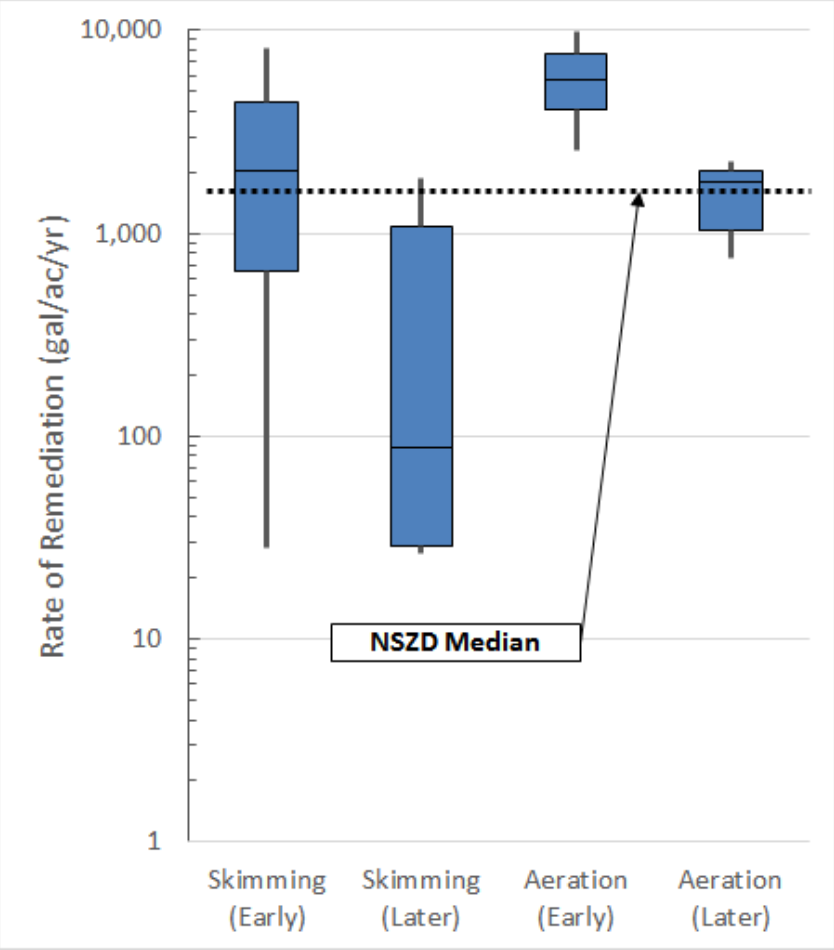
- LNAPL body stability evaluation



LNAPL-3, Appendix B, Section 5.3

Using NSZD for Decision Making

- Practicability of recovery
- Endpoint metric for active LNAPL remediation
- Benchmark for enhanced-NSZD remedy design
  - Aeration
  - Enhanced anaerobic
  - Heating

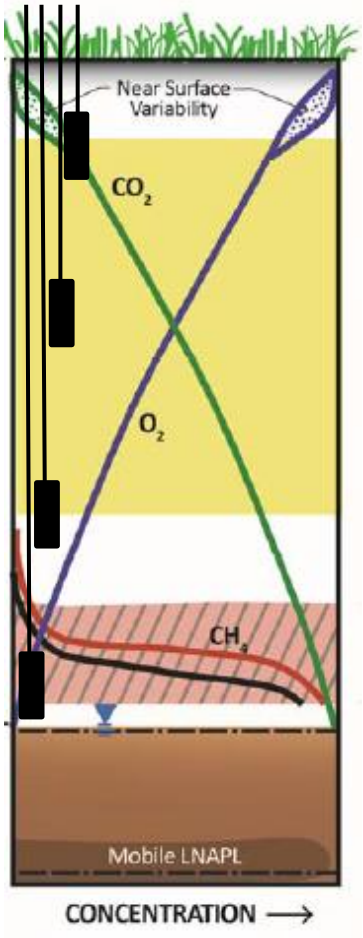


(Median NSZD rate from Garg et al., 2017. System data modified from Palaia, T. 2016. Natural source zone depletion rate assessment. Applied NAPL Science Review 6.)

LNAPL-3, Appendix B, Section 5.3

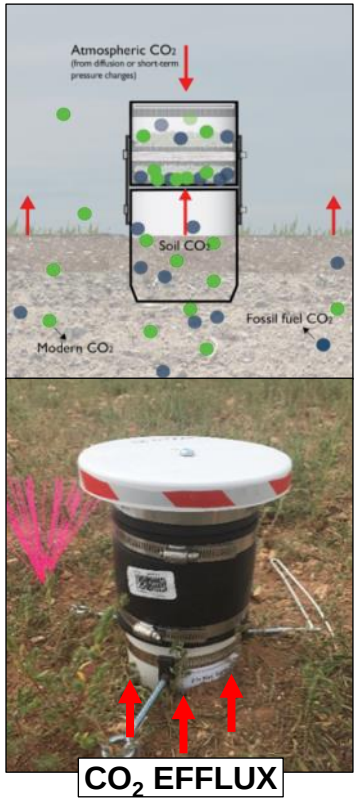
Four Methods to Measure NSZD

1. Gradient Method



(from API, 2017, http://www.techstreet.com/standards/api-publ-4784?product_id=19843

2. Passive Flux Trap

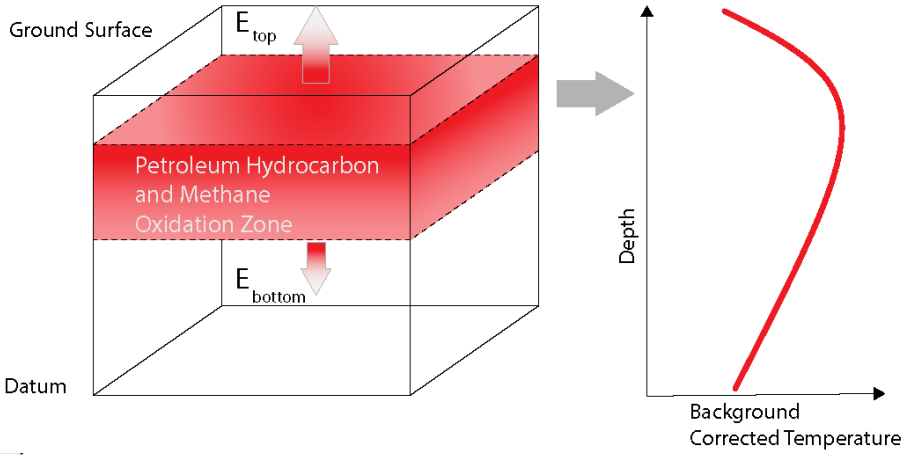


(from E-Flux, LLC, 2017, http://soilgasflux.com/main/home.php)

3. Dynamic Closed Chamber

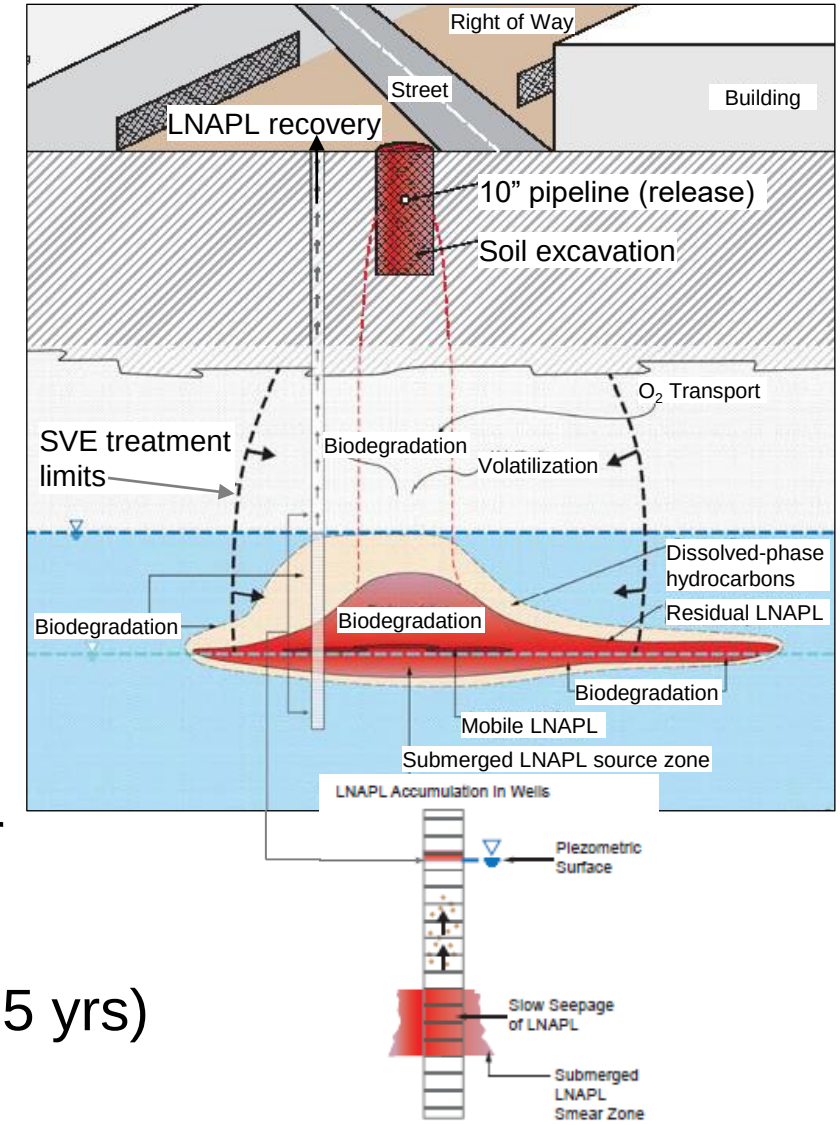
(from API, 2017, http://www.techstreet.com/standards/api-publ-4784?product_id=1984357)

4. Biogenic Heat



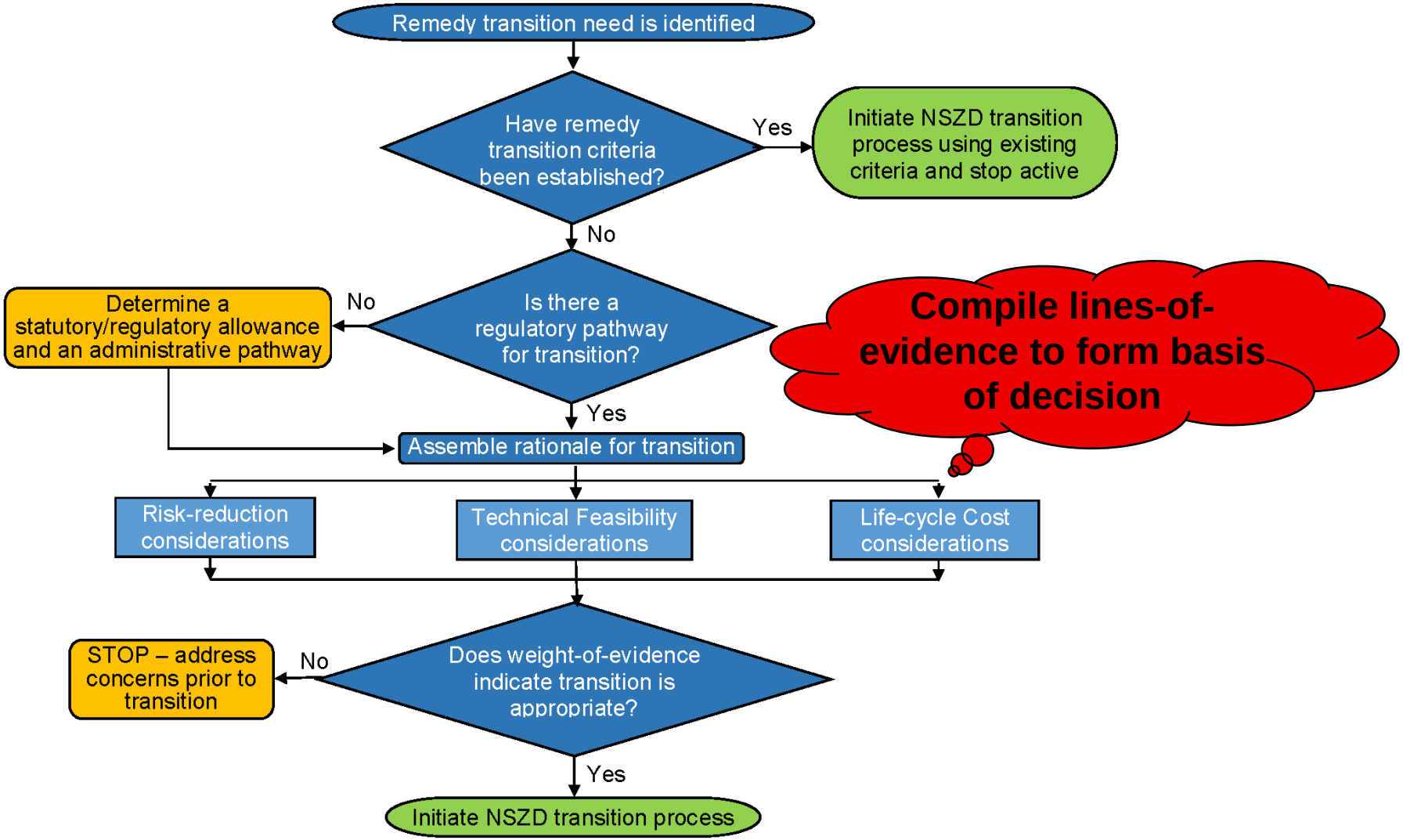
Case Study - Transition from LNAPL Fluid Recovery to NSZD

- Jet fuel pipeline release
- Silt and clay overly silty, fine-grained sand
- Submerged LNAPL
- Historical remedial actions
  - Partial source excavation
  - LNAPL skimming
    - 10,000 gals removed (~10 yrs), <100 gallons/yr
  - SVE system
    - 9,600 gallons removed (~5 yrs)



LNAPL-3, Appendix B, Section 5.3.1

Transition Decision Logic



LNAPL-3, Appendix B, Figure NSZD-15

Case Study – Decision Logic to NSZD

Risk-reduction	Technical Feasibility	Life-cycle Cost
No threat of LNAPL nor dissolved plume migration	Active remediation was effective, but NSZD is now most effective (1,000 vs 100 gals/yr)	None needed.
Industrial land use and no receptors	Impractical LNAPL recovery, T ~ 0.05 ft^2/day	
Groundwater is within a legally enforced use area	LNAPL and dissolved plumes are stable	


Passive Flux Trap Method Use

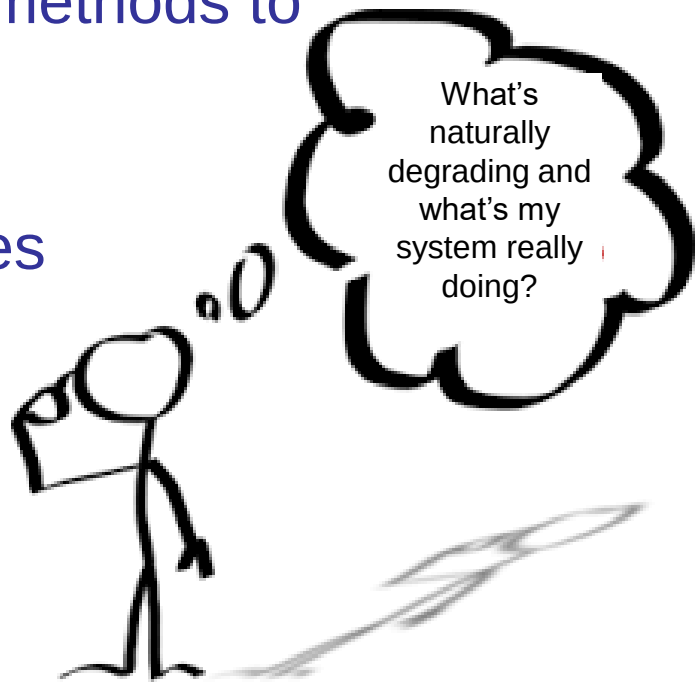
INITIATE NSZD TRANSITION


Chamber Method Use

NSZD - Summary

Poll Question

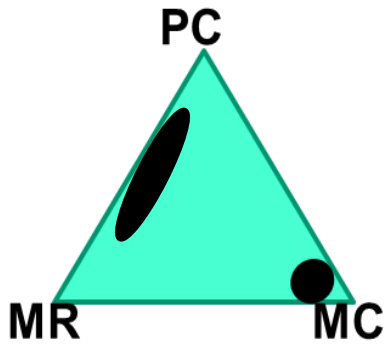
- Natural source zone depletion (NSZD) occurs subsurface at most sites
  - Changes LNAPL composition and reduces saturation
  - Incorporate it into your LCSM
- There are various measurement methods to suit varied site conditions
- It is an effective, accepted, and sustainable option for low risk sites
- It is a viable remedial alternative as a stand-alone or transition remedy



LNAPL Remedial Technology Groups

- **Mass Control** - Contain LNAPL at a defined boundary (e.g. to protect a receptor)
- **Mass Recovery** - Abate LNAPL body migration / mobility by removal of LNAPL mass
- **Phase Change** - Abate unacceptable contaminants emanating from the LNAPL source

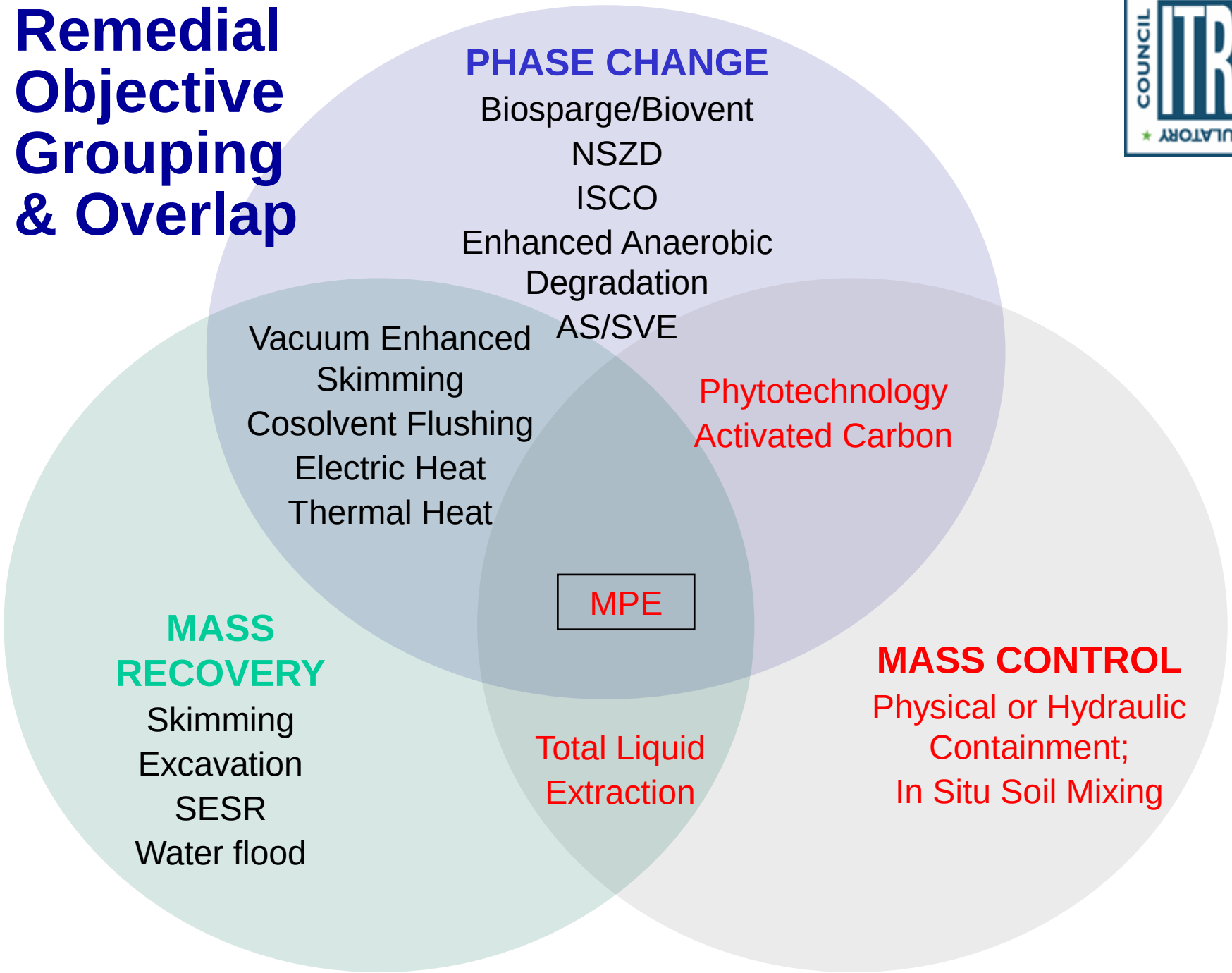
Technologies (i.e. processes) sometimes overlap into two groups.



21 Technologies (2018) – Name Change and Added

1. Excavation
2. Skimming
3. Vacuum enhanced skimming (LNAPL & vapor)
4. Total liquid extraction (LNAPL & water)
5. Multi-phase extraction (LNAPL, water, & vapor)
6. Water/hot water flooding
7. Surfactant-enhanced subsurface remediation
8. Cosolvent flushing
9. Steam injection
10. Electrical resistance heating
11. Air sparging/soil vapor extraction (AS/SVE)
12. In-situ chemical oxidation
13. Natural source zone depletion (NSZD)
14. Physical or hydraulic containment
15. In-situ soil mixing (stabilization)
16. Thermal conduction heating
17. In-situ smoldering
18. Biosparging/bioventing
19. Enhanced anaerobic biodegradation
20. Activated carbon
21. Phytotechnology

Remedial Objective Grouping & Overlap

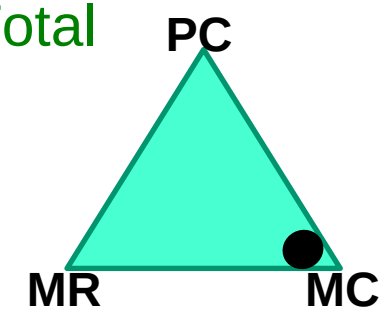


LNAPL Remedial Technology Groups

- **Mass Control – examples of Goals**
  - **Contain LNAPL at a defined boundary**
- **Mass Recovery**
- **Phase Change**

Mass Control Technologies

- Physical containment or Hydraulic containment
  - Sheet piles
  - French drain
  - Slurry wall
  - Groundwater extraction
  - Trenches
  - Permeable absorptive barrier
- In situ soil mixing (stabilization)
  - Also: Phytotechnology, Activated Carbon, Total Liquid Extraction
- **Refer to Tables 6.1, 6.2, 6.3 & Appendix A**



Performance Metrics for Mass Control Technologies

See Tables 5.2 and 6.3 for additional metrics

- No first LNAPL occurrence in down gradient sentinel well
- LNAPL body footprint stabilized based on long-term monitoring (quarterly, semi-annual, annual monitoring)

Photo of barrier wall

Example: A LNAPL Plume is migrating toward a river

		Guidance Document
Concern	LNAPL migrating into a river	Table 5.1
Goal	• Saturation based • Stop the LNAPL migration	Table 5.1
Remedy Selection LCSM	Review or Update the LCSM to Select a Remedy	Section 4.4

Example continued: A LNAPL Plume is migrating toward a river

Guidance Document

"SMART" Objective

Stop the migration using physical barrier

Table 5.1 Sections 5.3 & 5.6

Group of Technologies

- MASS CONTROL NEEDED
- List of technologies
  - Physical or hydraulic containment
  - In Situ soil mixing
  - Also:
    - Total liquid extraction
    - Phytotechnology
    - MPE
- Align with the site conditions
- Further technology details needed

Table 5.1

Table 6.3

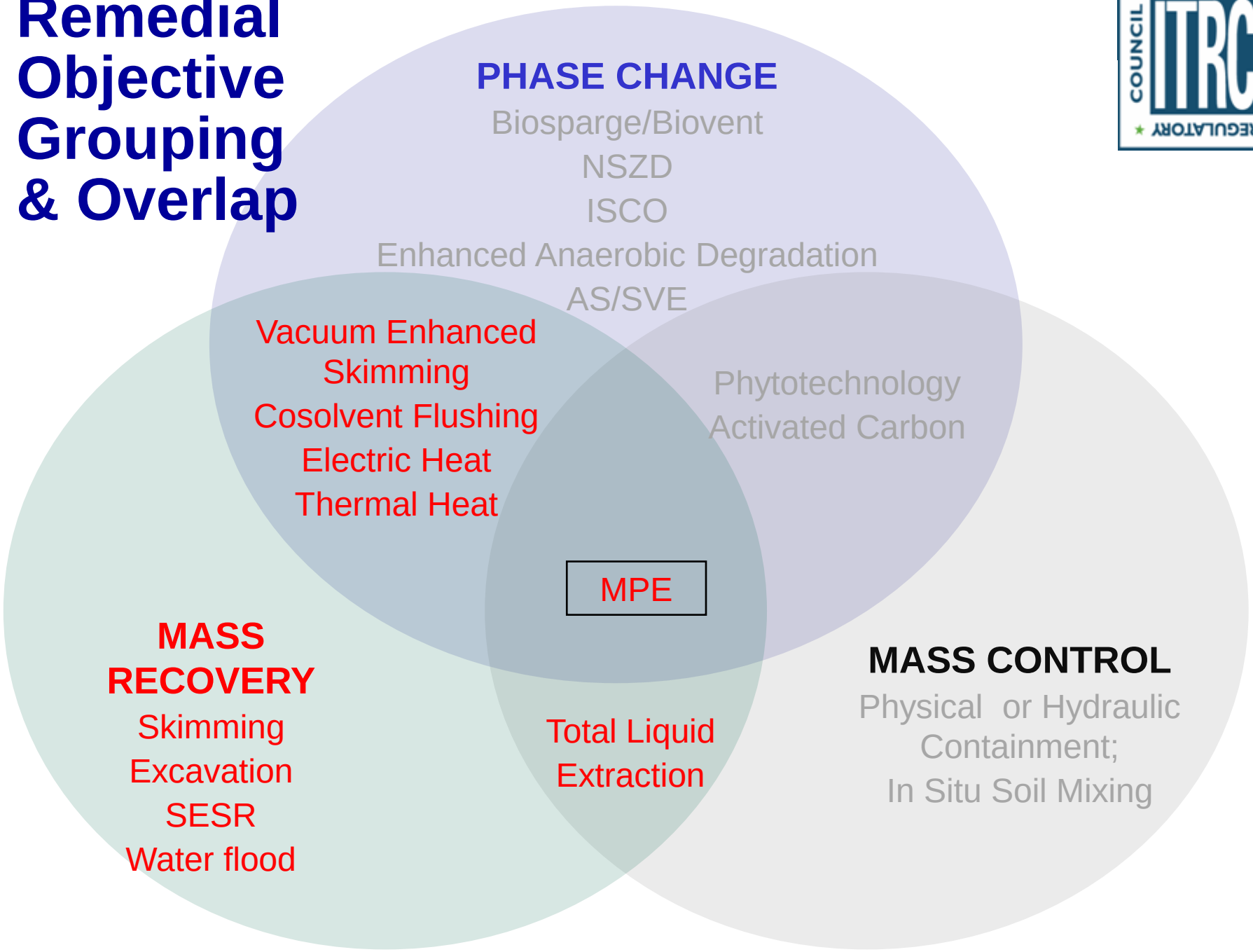
Appendix A

Example continued: A LNAPL Plume is migrating toward a river

Guidance Document

Design & Performance LCSM	• Design and engineer the technology to meet Goals • Evaluate Performance and Set Metrics	Table 6.3 Section 6.4.1
Example Performance Metrics	• No first LNAPL occurrence in down gradient well • LNAPL body footprint stabilized • No sheens detected in river	Tables 5.2 & 6.3

Remedial Objective Grouping & Overlap



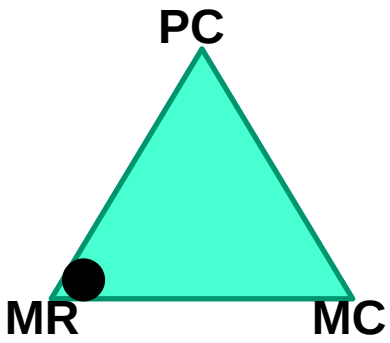
LNAPL Remedial Technology Groups

- Mass Control
- **Mass Recovery**
  - **Examples of SMART Objectives**
    - **Recover LNAPL to a practicable limit**
    - **LNAPL transmissivity**
- Phase Change

Mass Recovery Technologies

- (Simple) Fluid Recovery
  - Skimming
  - Total Liquid Extraction; formerly dual-pump liquid extraction
  - Vacuum enhanced skimming; or vacuum enhanced fluid recovery
  - Multi-phase extraction (MPE)
- Excavation

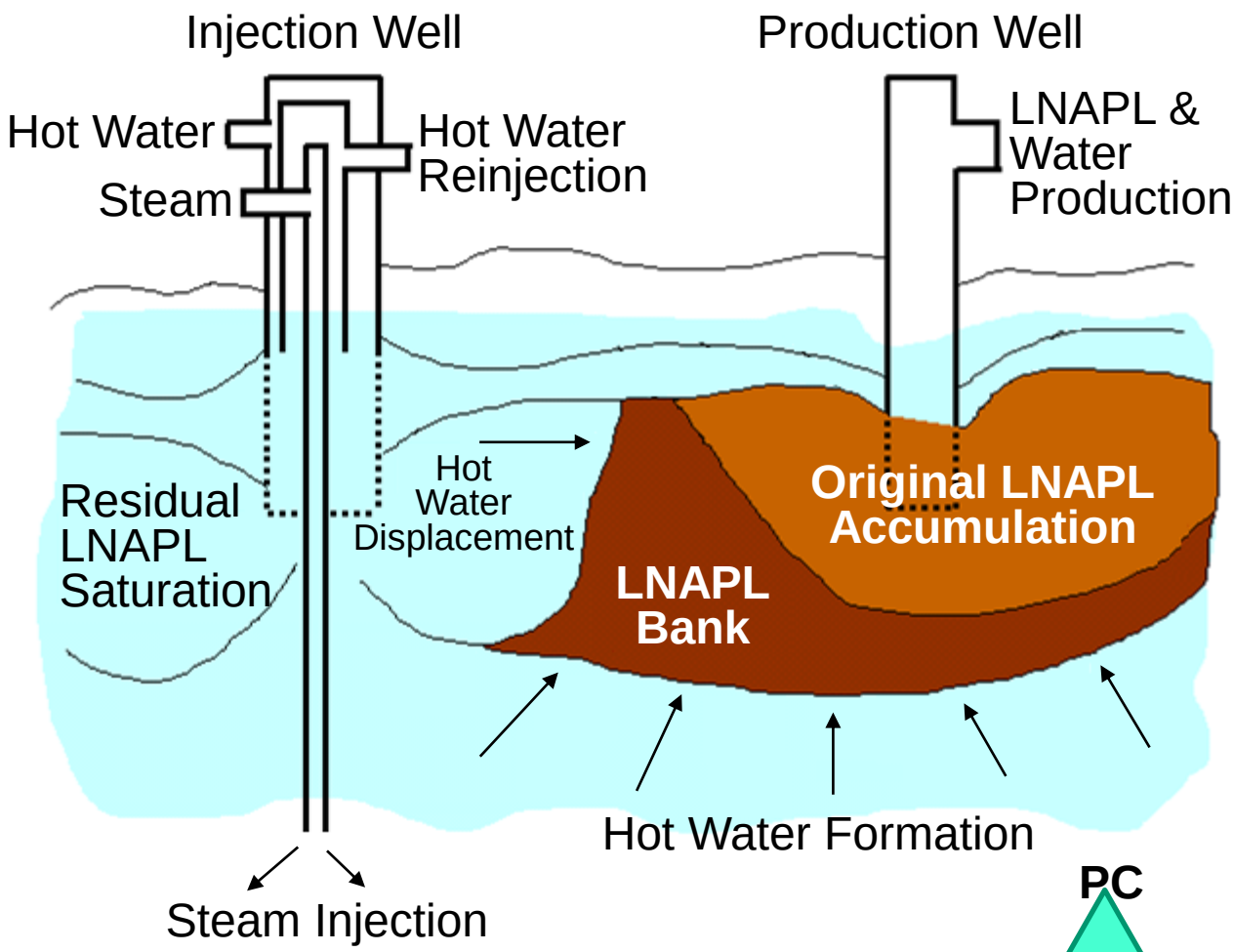
- **Refer to Tables 6.1, 6.2, 6.3 & Appendix A**



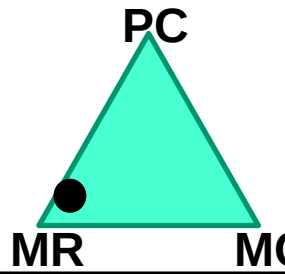
(Hot) Water Flooding – A physical technology

Refer to Tables 6.1, 6.2, 6.3 & Appendix A

- Increases groundwater gradient across LNAPL
- Decreases LNAPL viscosity (hot)



Source www.frtr.gov

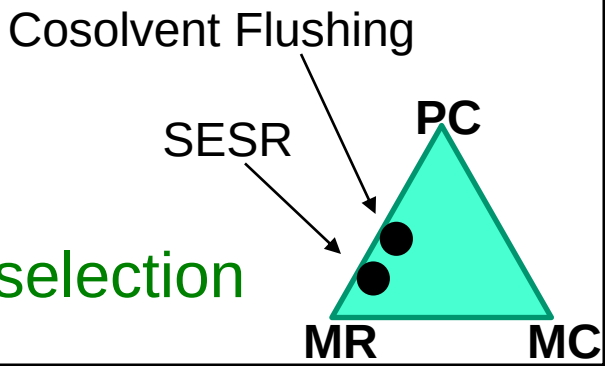


Surfactant Enhanced Subsurface Remediation (SESR) & Cosolvent Flushing

Refer to Tables 6.1, 6.2, 6.3 & Appendix A

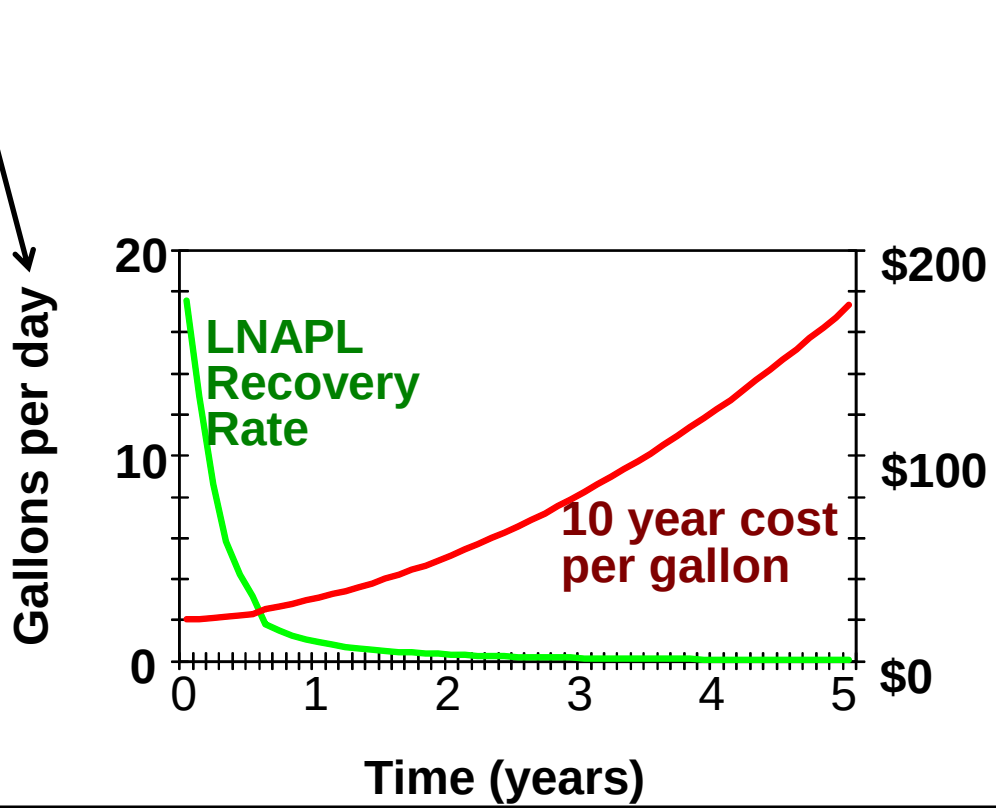
Photo: Gold Crew

- Advantages
  - Short time frame
  - SESR Safety
  - Cosolvent can reduce some LNAPLs to very low saturations
- Disadvantages
  - Single fluid waste stream complex to treat
  - Permitting
- Engineering
  - Injection ROI (sweep volume)
  - LNAPL fluid properties and injectant selection

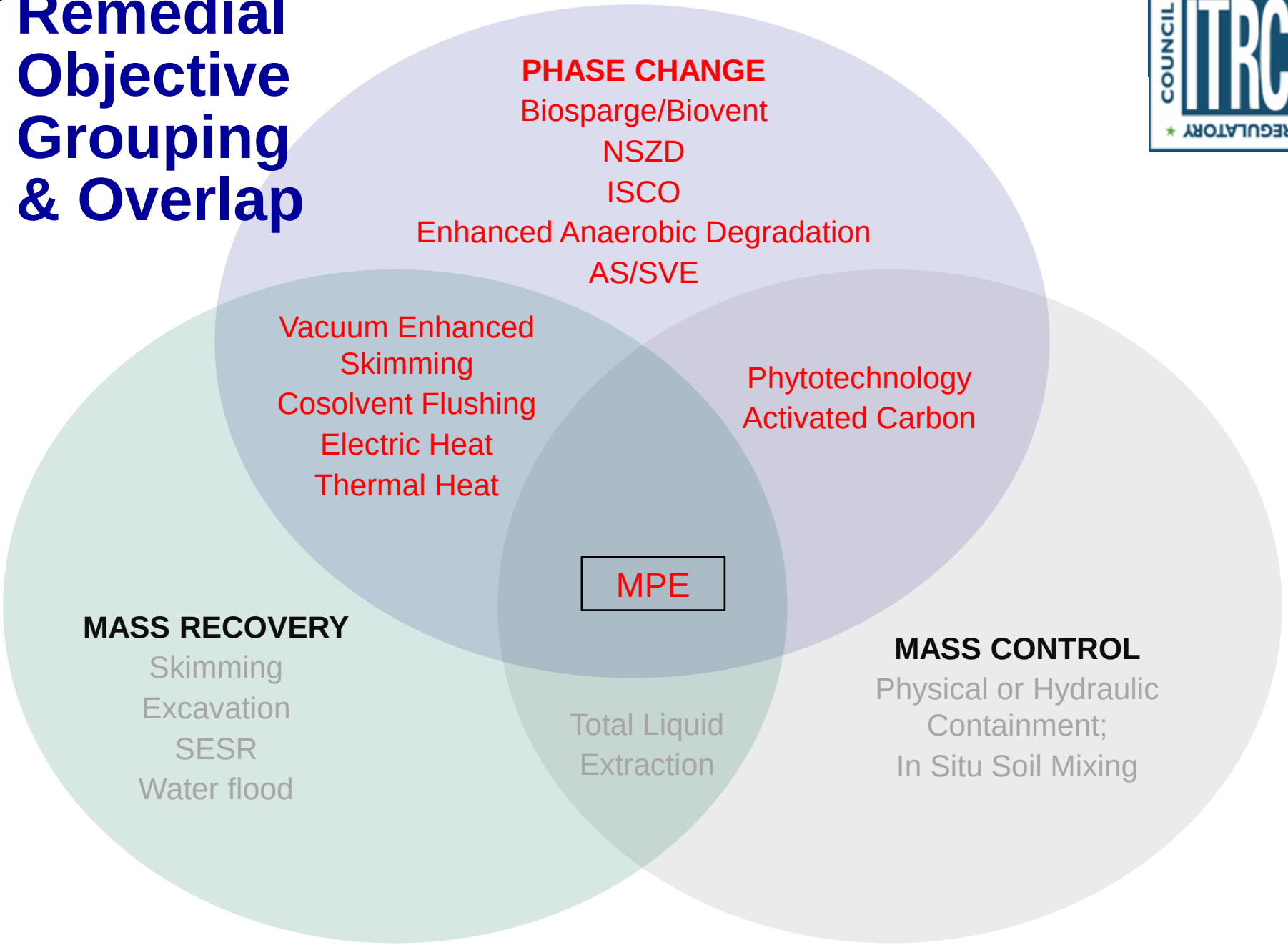


Examples of Performance Metrics

- LNAPL transmissivity
  - Reduction of transmissivity over time to assess performance
- Asymptotic recovery
- Dollars per gallon of LNAPL removed

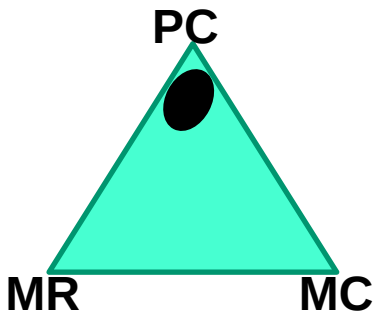


Remedial Objective Grouping & Overlap



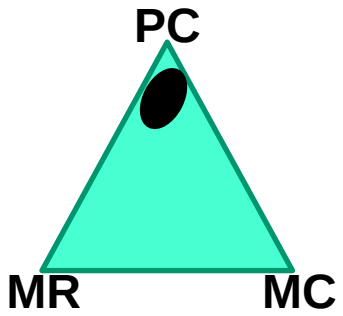
LNAPL Remedial Technology Groups

- Mass Control
- Mass Recovery
- **Phase Change – examples of Goals**
  - Abate unacceptable vapor concentrations by depletion of volatiles from LNAPL
  - Reduce dissolved constituents at point of compliance by sufficient depletion of soluble constituents from LNAPL



Phase Change Technologies

- **Ambient**
  - Natural Source Zone Depletion (NSZD)
  - AS/SVE
  - Biosparging and bioventing
  - MPE; Phytotechnology
- **Refer to Tables 6.1, 6.2, 6.3 & Appendix A**



Other Ambient Phase Change: Air Sparging/Soil Vapor Extraction;

- Volatilizes LNAPL
- Promotes Aerobic Biodegradation
- Refer to Tables 6.1, 6.2, 6.3 & Appendix A

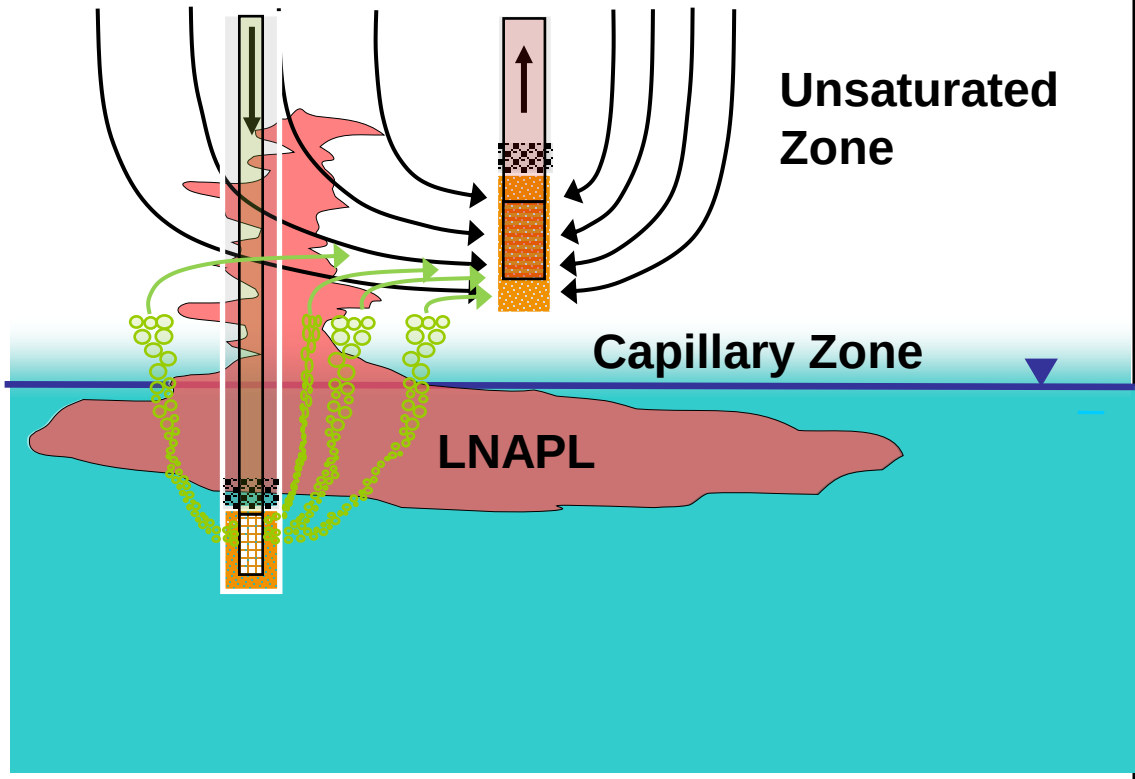
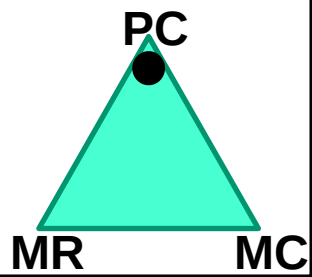


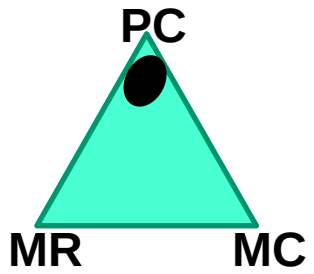
Image source: ITRC LNAPL classroom training: 2015



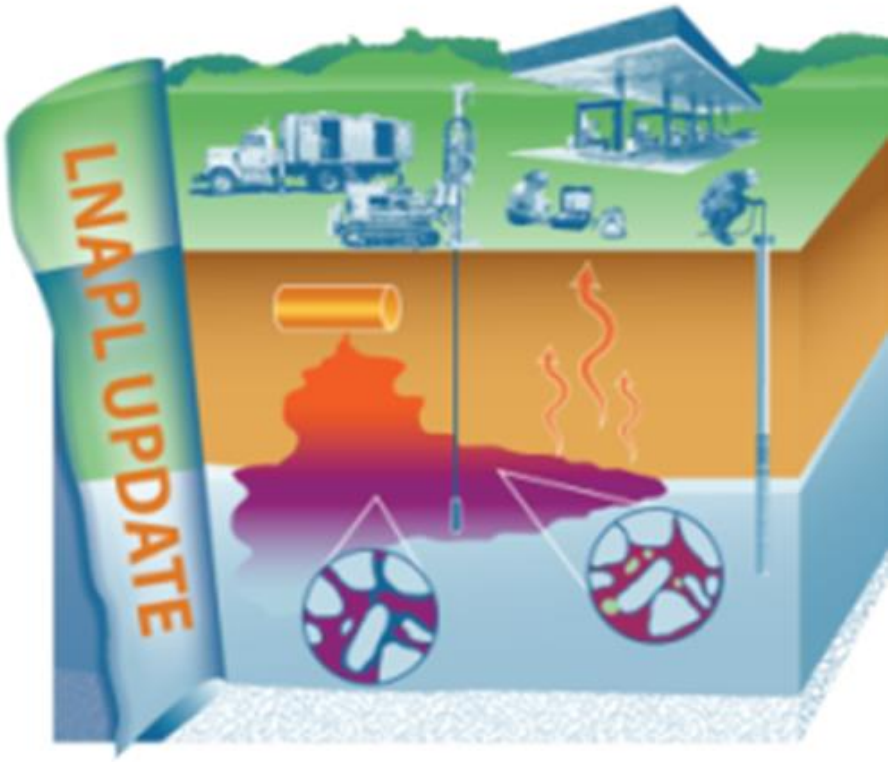
Performance Metrics for Phase Change Technologies

See Tables 5.2 and 6.3 for additional metrics

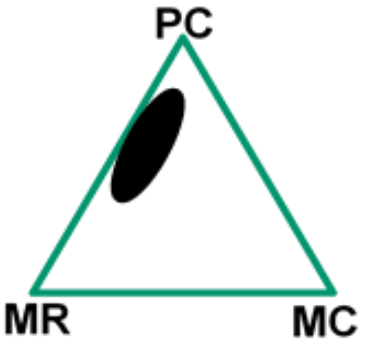
- Dissolved phase concentration is stable or decreasing
- Soil concentrations stable or decreasing; endpoint reached when reduced to regulatory limits.
- Asymptotic performance of the recovery system
- Volatile or soluble constituents reduced to risk-based standards



In Situ Thermal Technologies

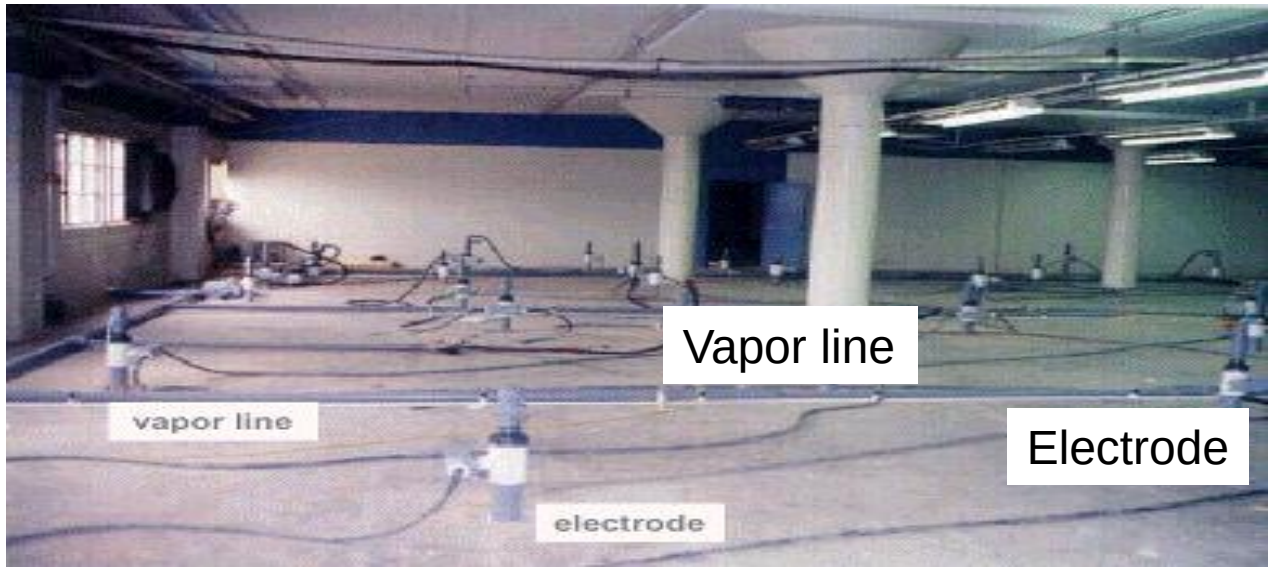


- Mass Control
- **Mass Recovery**
- **Phase Change**



Heating Technologies

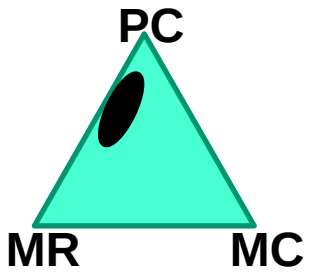
Steam / Hot Air Injection



Others

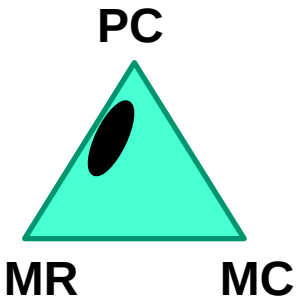
- **In Situ Smoldering (primarily combustion)**
- **Thermal Conduction Heating**
- **Electrical Resistance Heating**

Image source: http://hillafb.hgl.com



In Situ Thermal Technologies

- Increases LNAPL volatility
- Reduces LNAPL viscosity
- SVE for recovery of volatilized LNAPL
- Hydraulic recovery of mobilized LNAPL
- Better in low groundwater velocity settings (<heat loss)



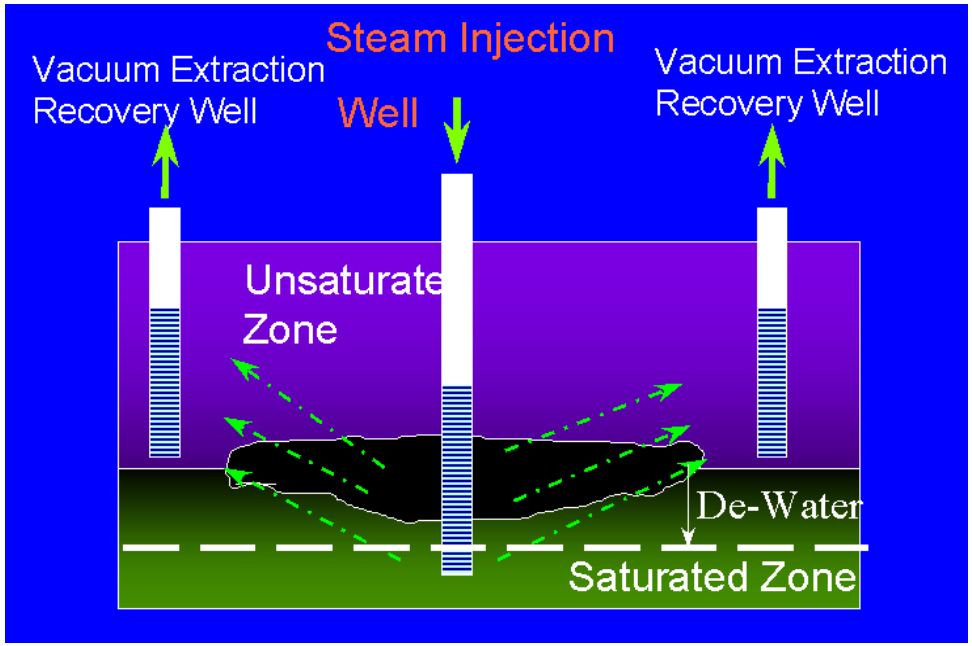
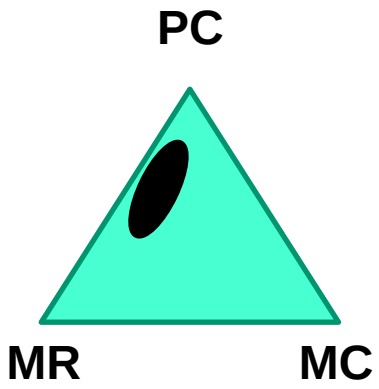


Image source: http://hillafb.hgl.com/steam

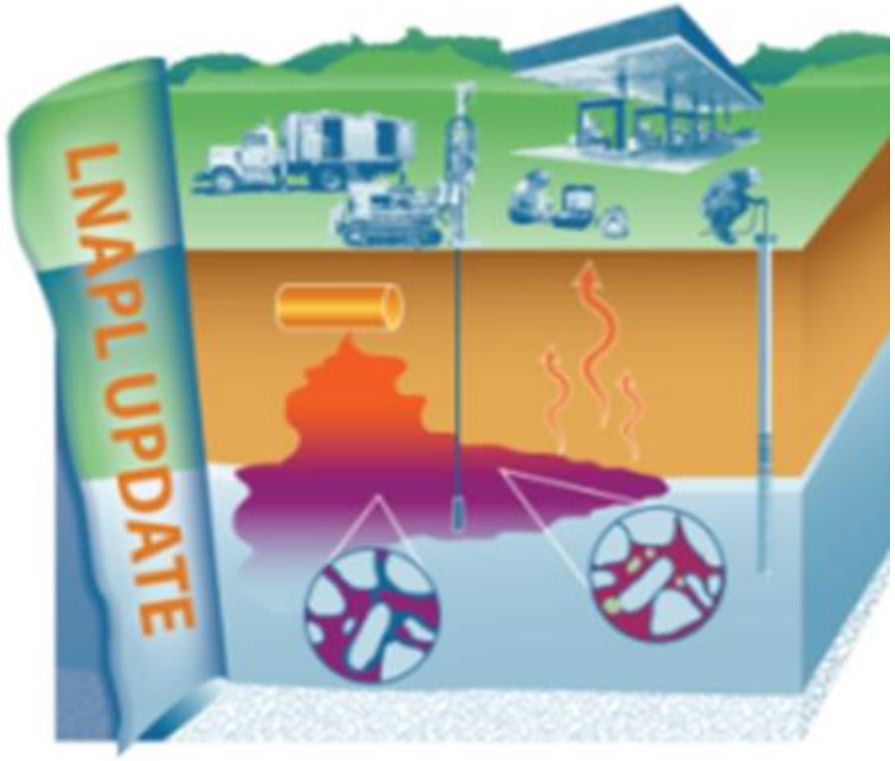
In Situ Thermal Technologies Metrics

- LNAPL transmissivity
- Soil concentration at regulatory standard
- Dissolved phase concentration at regulatory standard
- Cost per unit volume removed
- Asymptotic mass removal
- Also refer to Tables 5.2 and 6.3



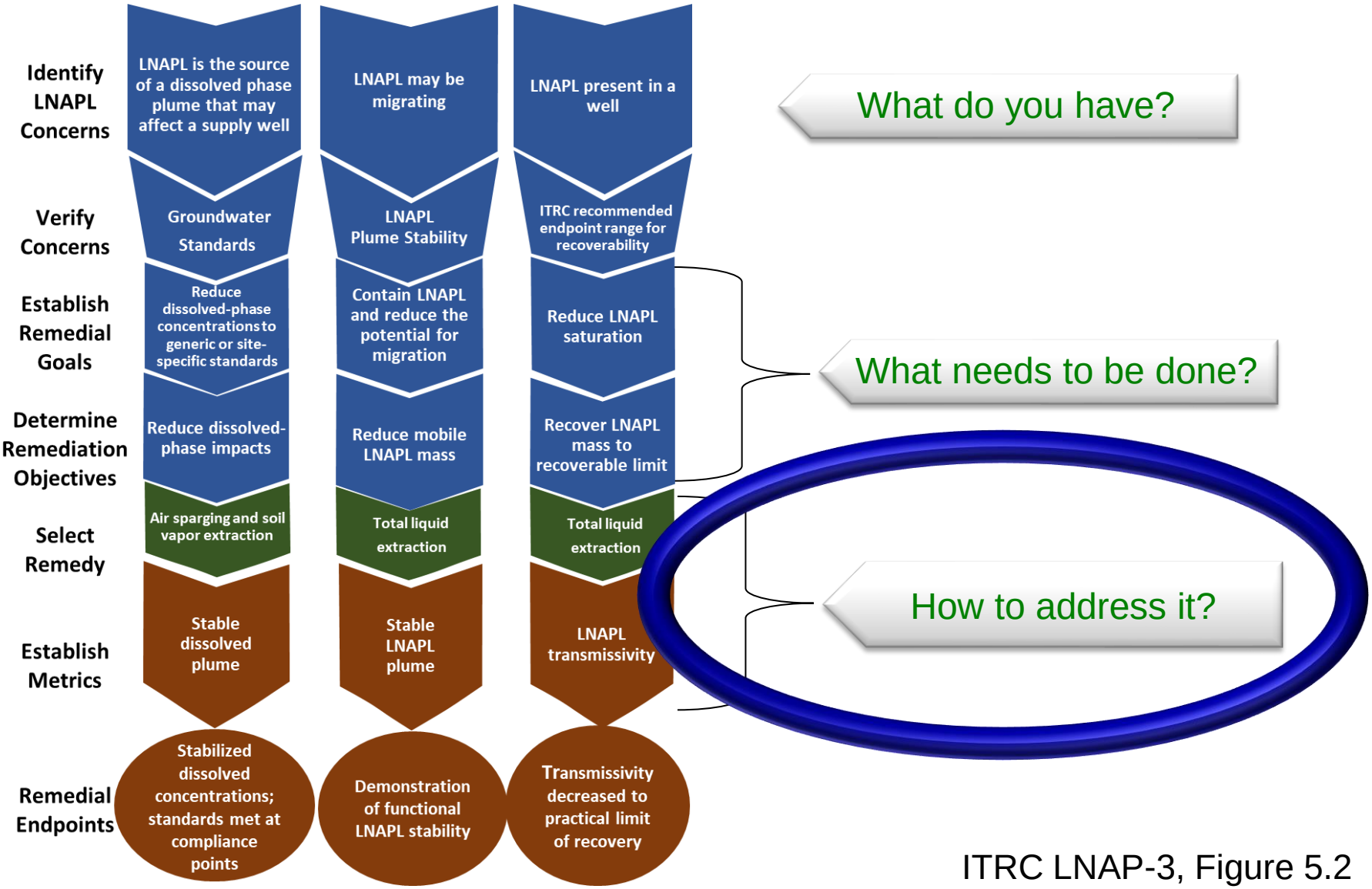
Q&A Break

Follow ITRC



- 1st Question and Answer Break

ITRC LNAPL Management Strategy



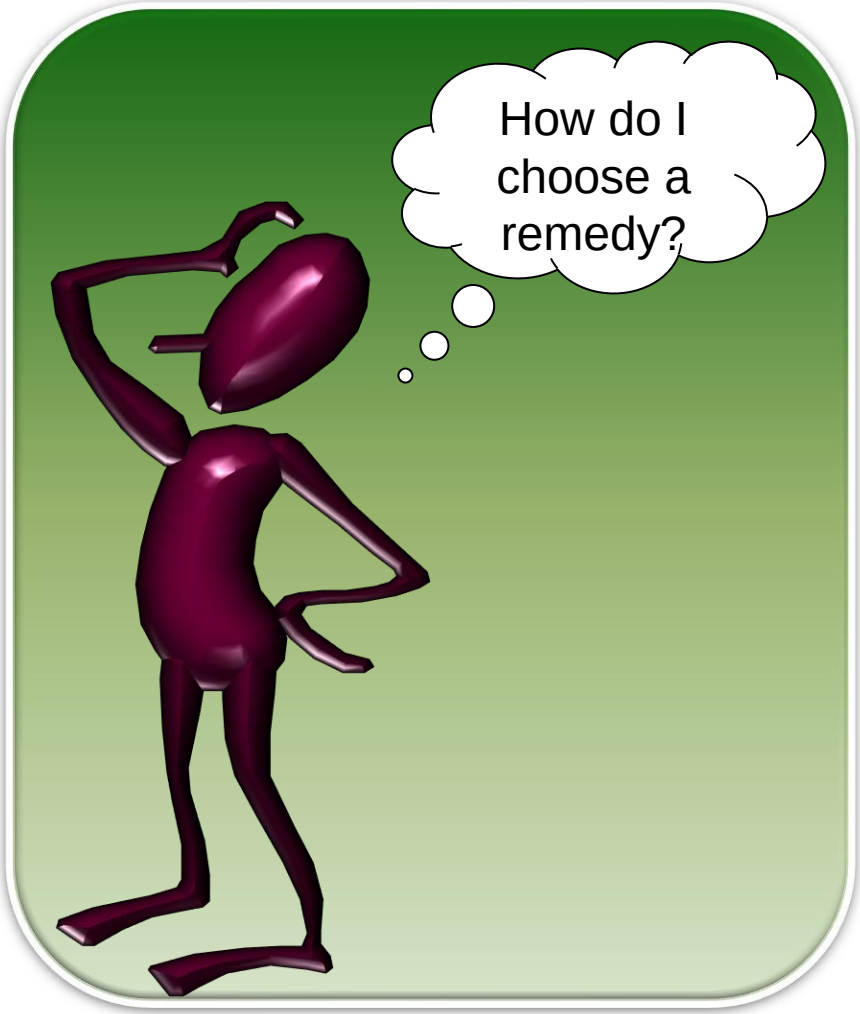
ITRC LNAP-3, Figure 5.2

LNAPL Remediation Technology Selection

Objectives

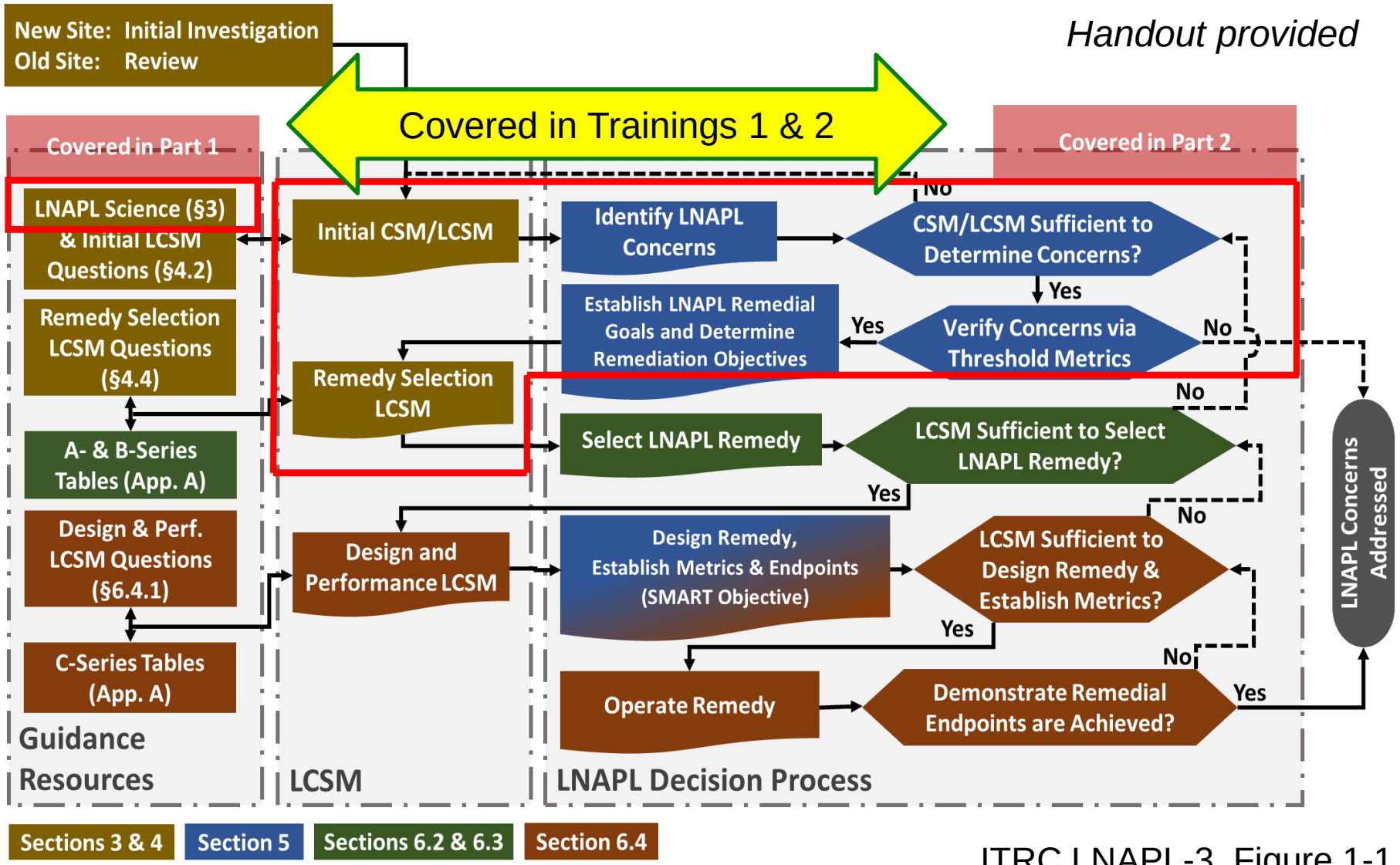
Learning Objectives:

- Learn about the Technology Selection Process
- Apply Remedy Selection Process to a real site



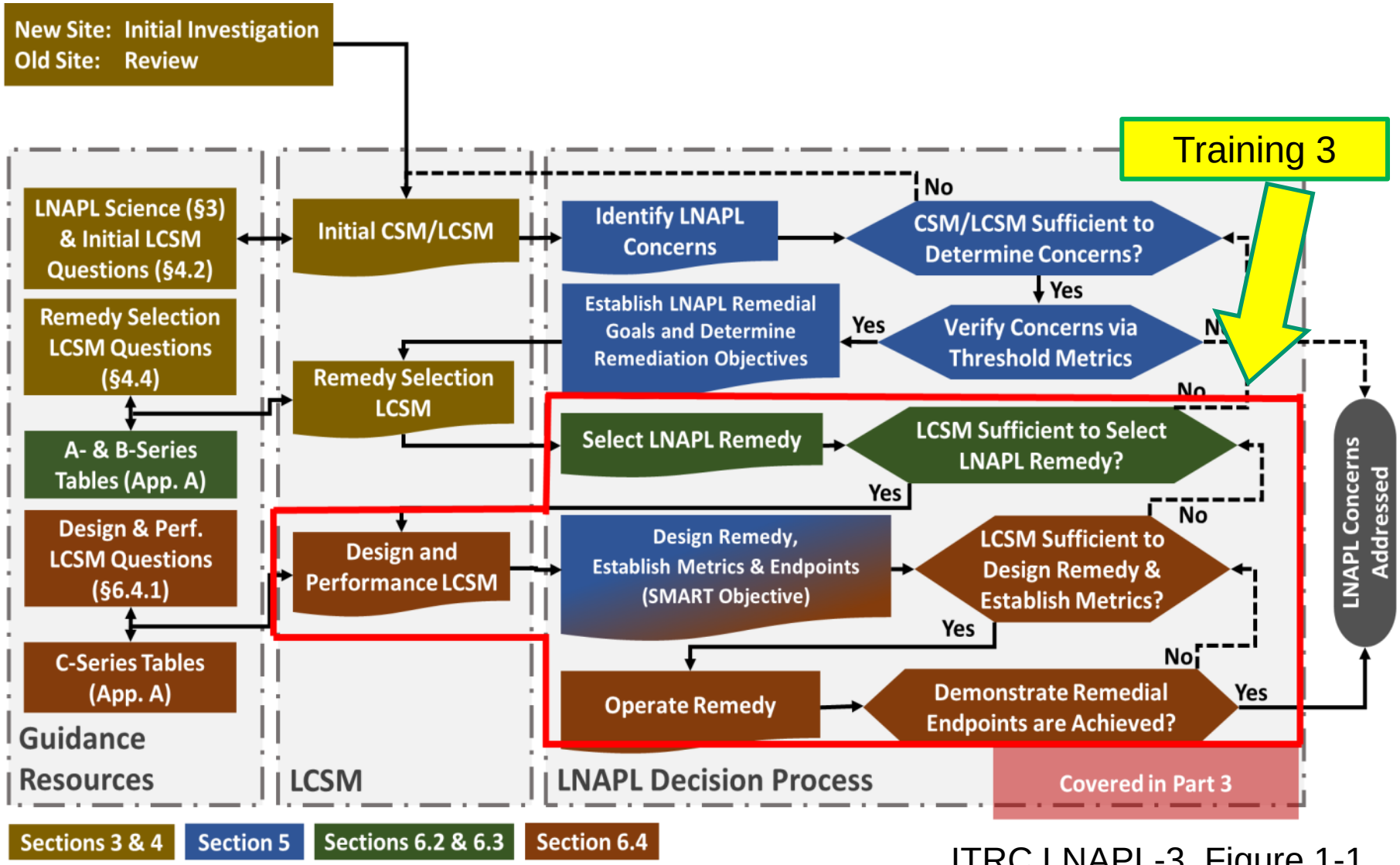
Guidance Process Flow Diagram
Sections 4 and 5

Handout provided



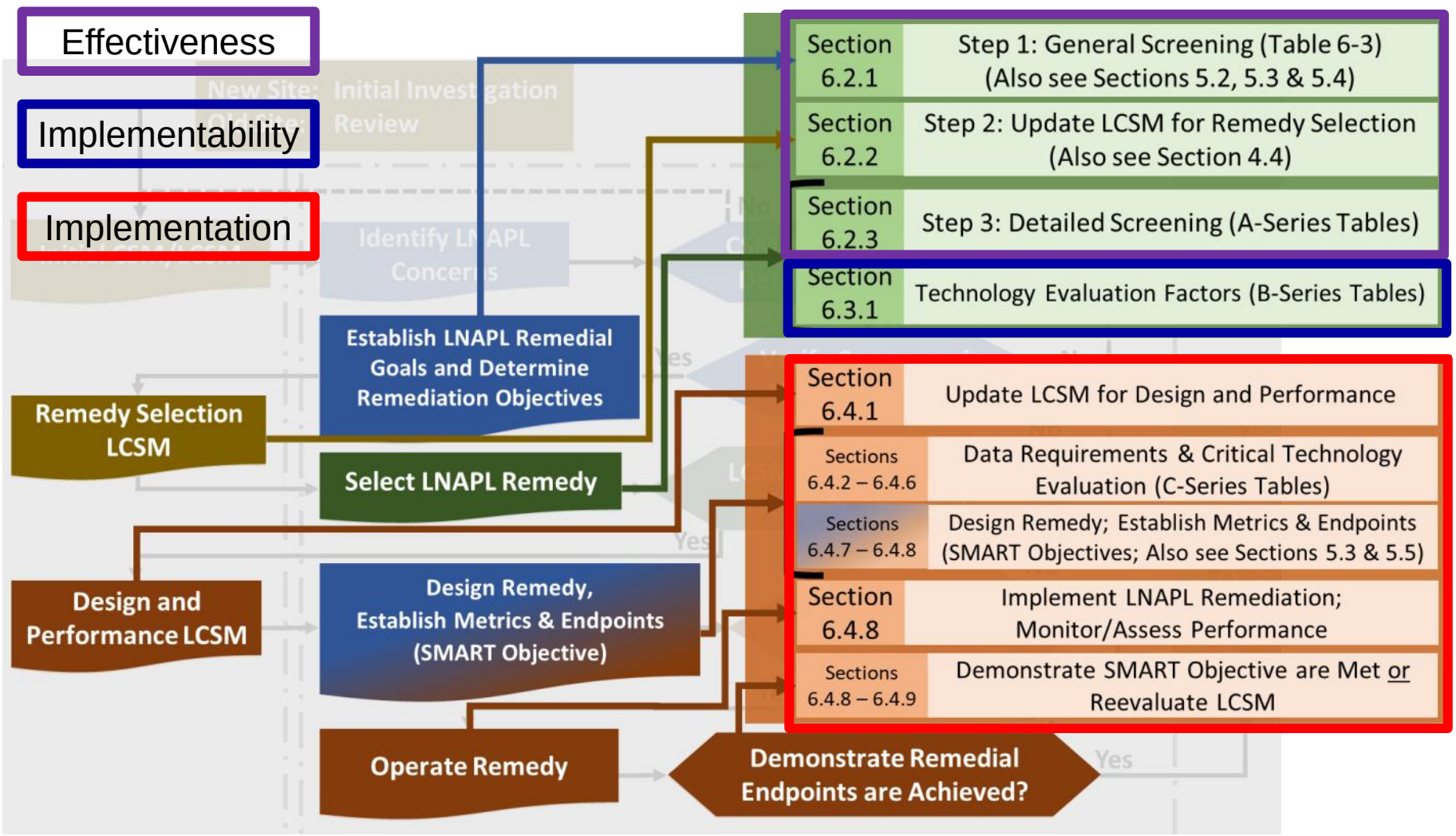
ITRC LNAPL-3, Figure 1-1

Guidance Process Flow Diagram
Section 6



ITRC LNAPL-3, Figure 1-1

Guidance Process Flow Diagram: Figure 6-1



ITRC LNAPL-3, Figure 6-1

Technology Tables - Appendix A

Guidance Document Appendix A

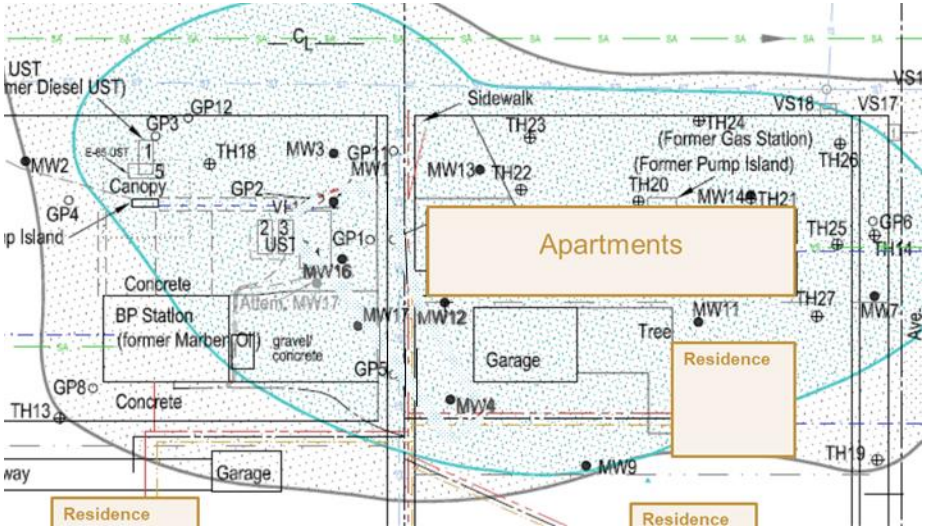
- 3 different types of tables for each of the 21 technologies
- Called the A-, B-, and C-series tables
  - A-series – general information and applicable geologic conditions
  - B-series – evaluation factors to consider
  - C-series – technical implementation consideration
- Key literature references presented in the tables

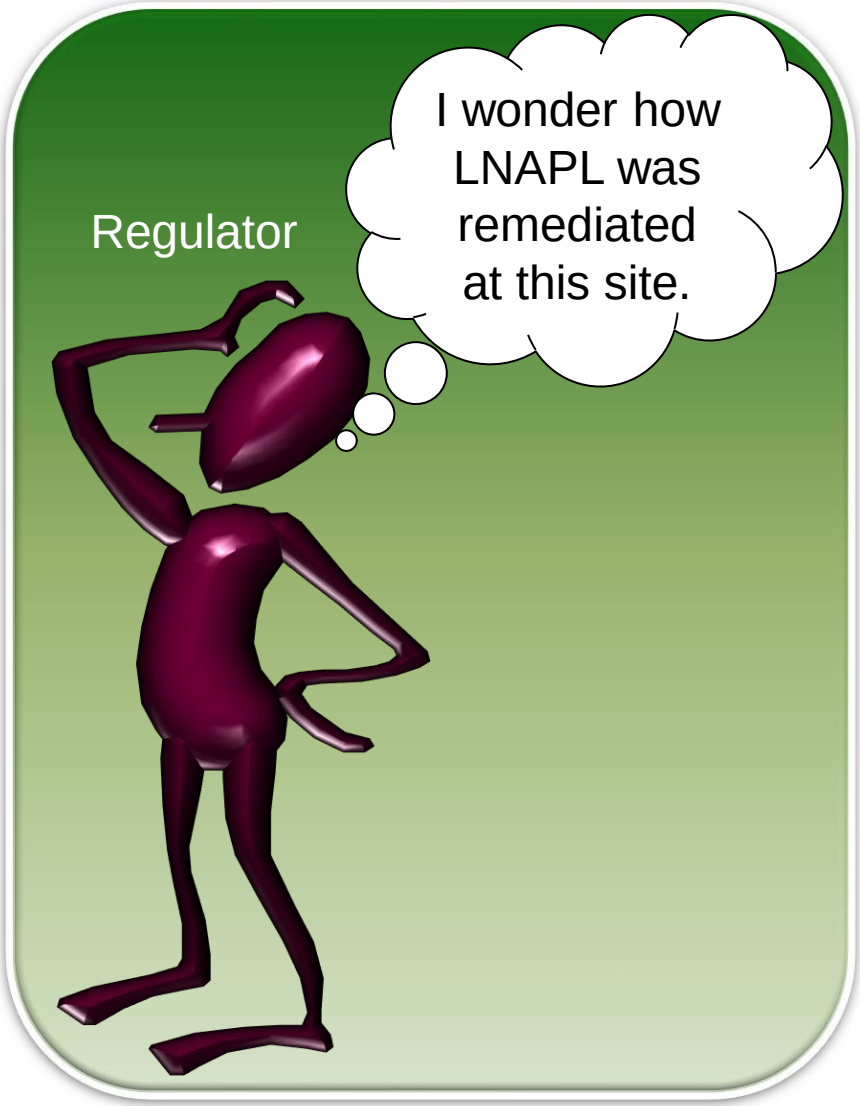
Key Point: Appendix A presents typical technology applicability to site conditions as concluded by the LNAPL Team. This doesn't mean you can't apply the technology in a setting different.

Case Study - LNAPL Remedial Technology Selection

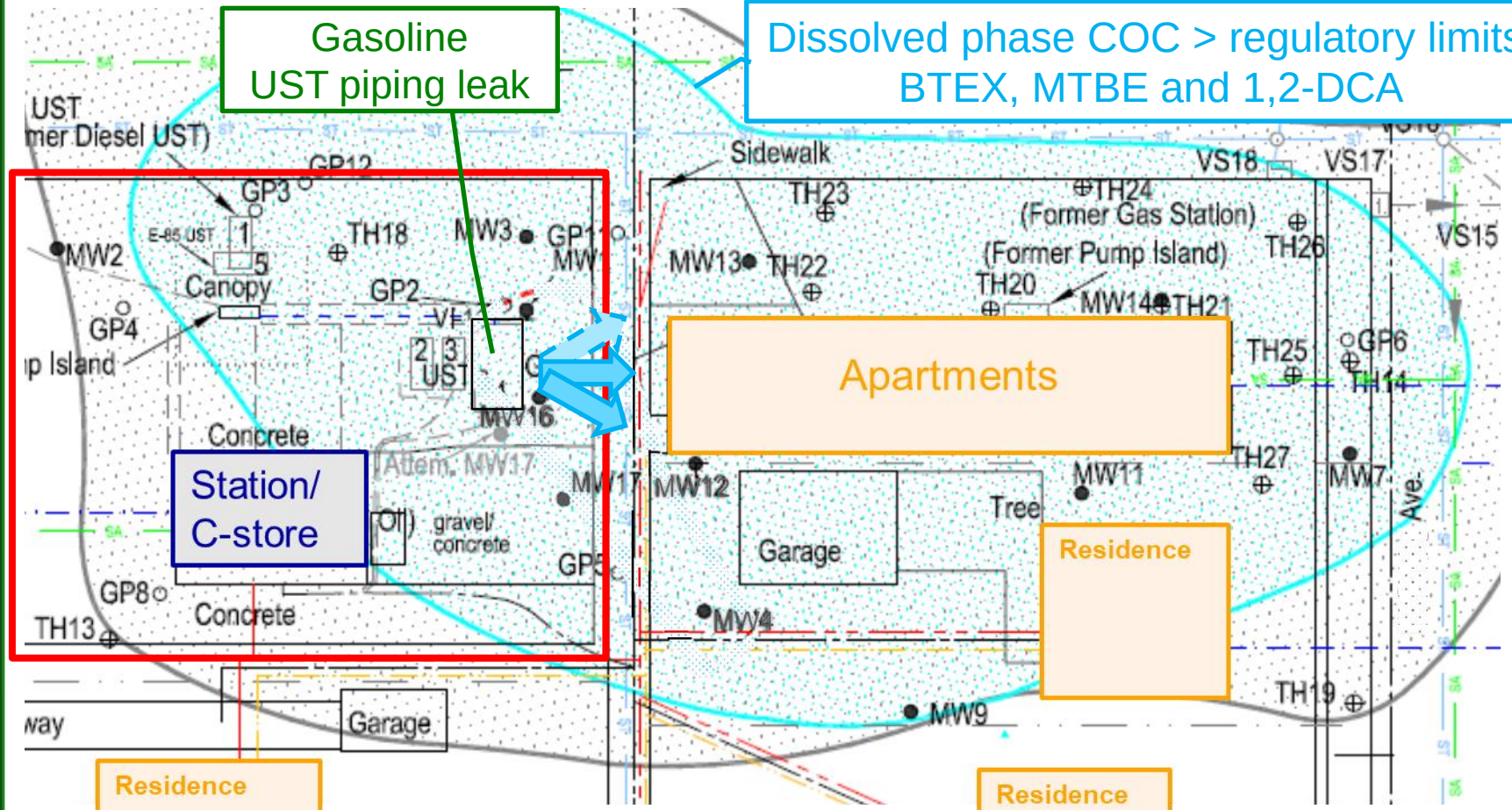
Learning Objectives:

- Learn the Technology Selection Process
- Apply Remedy Selection Process to a real site



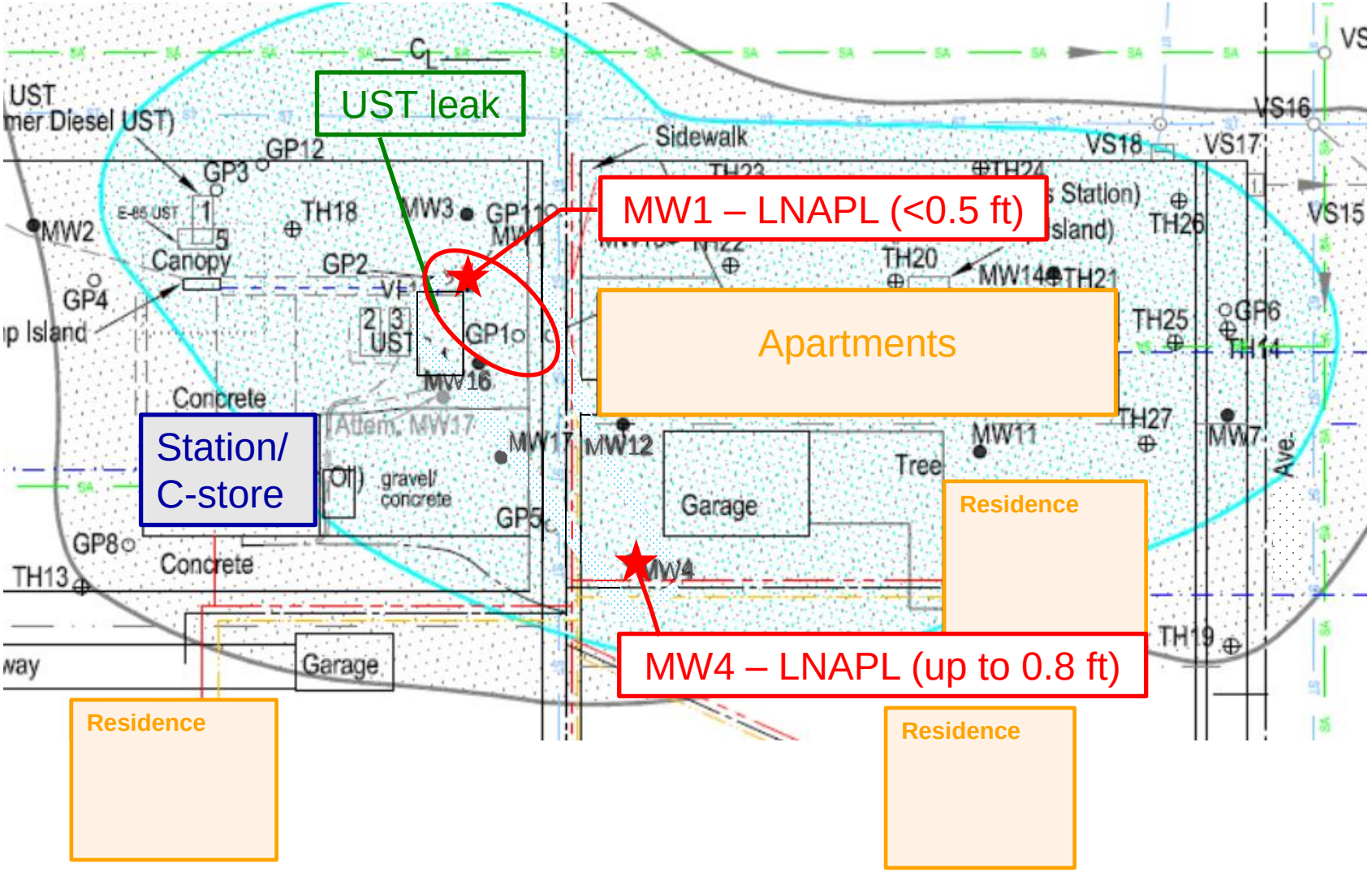


Case Study: LCSM

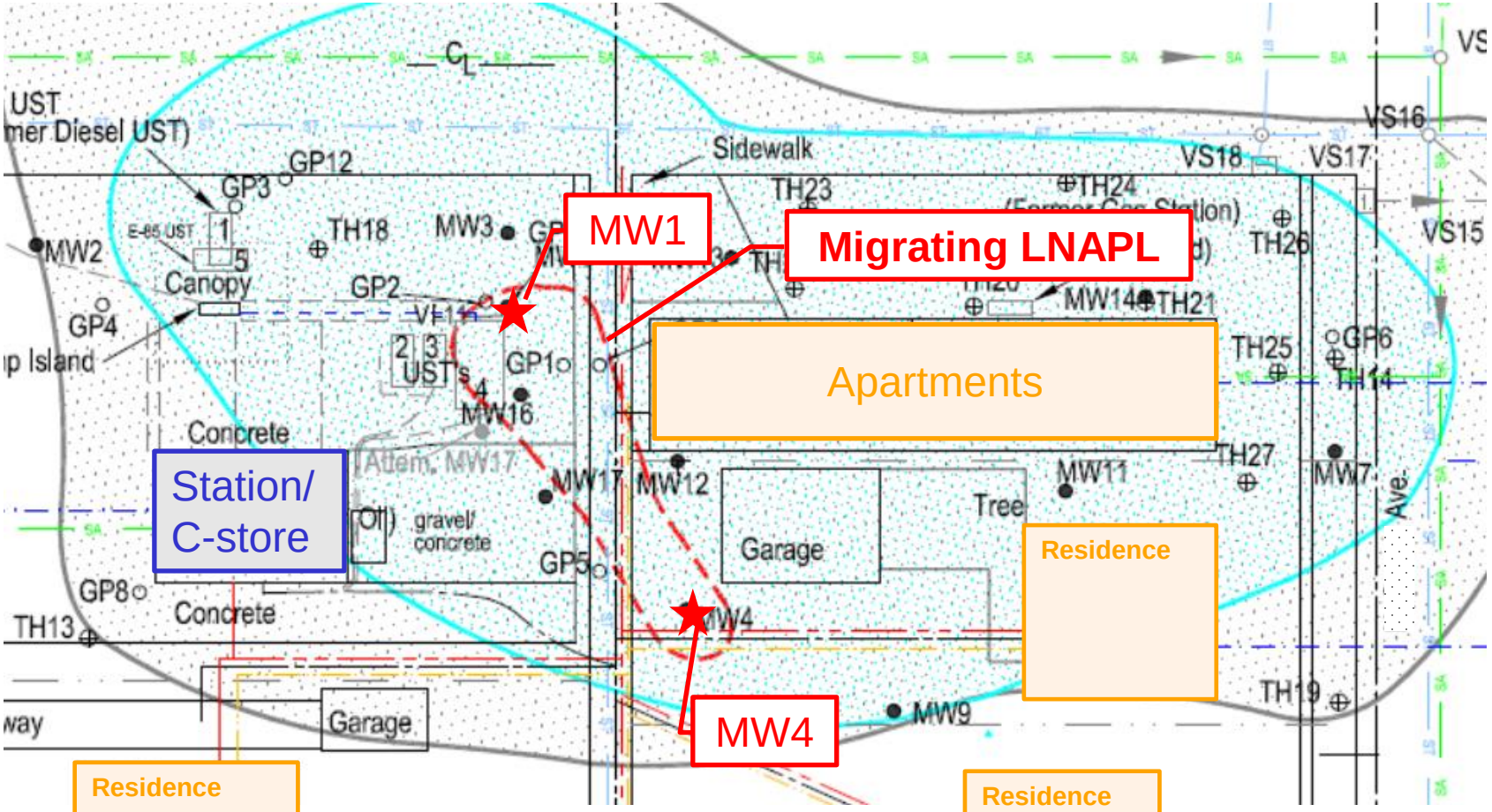


- Water table ~5-6 ft bsg (+/- 2.5 ft)
- Groundwater flow: E & SE; also NE
- Residential area

Case Study: LCSM

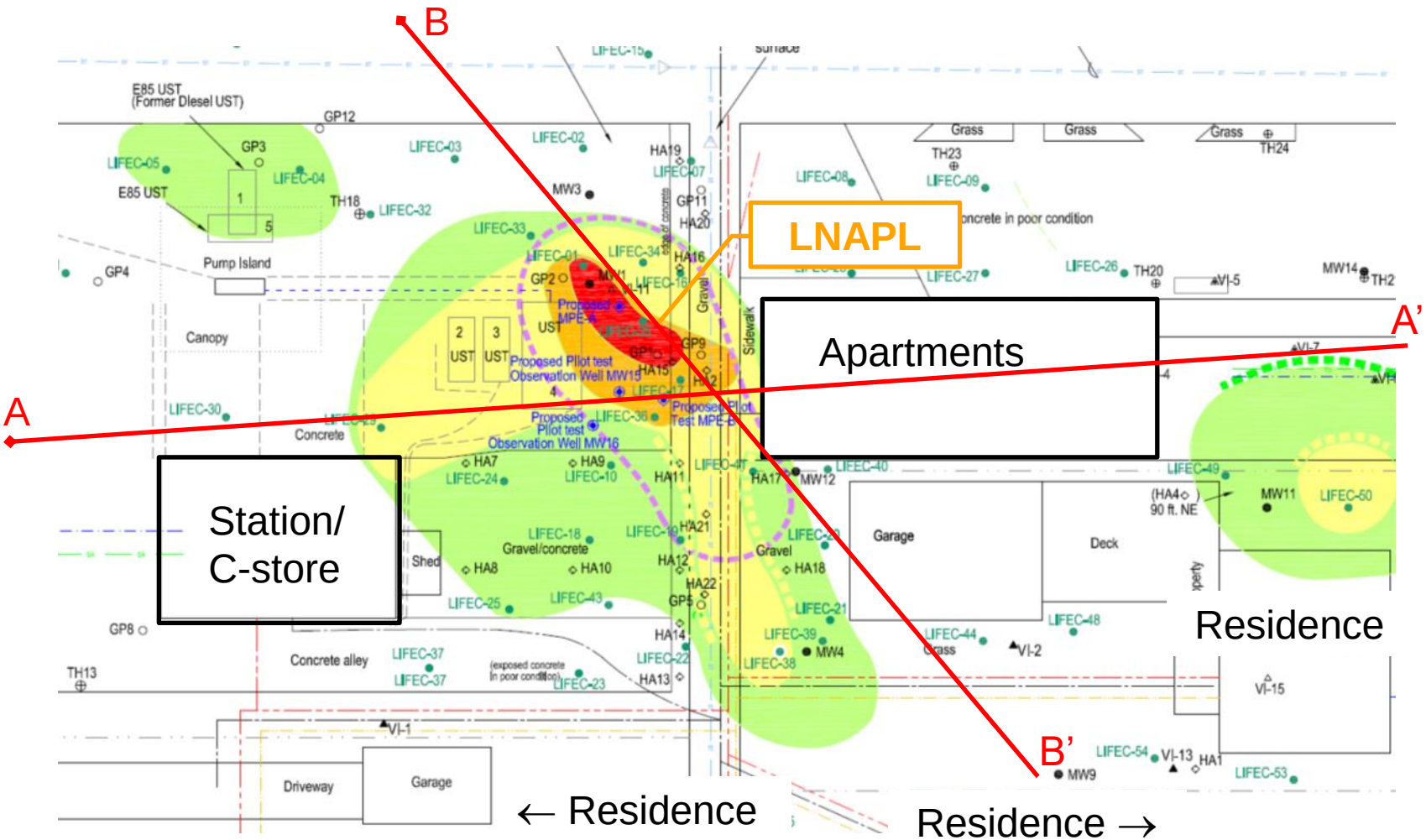


Case Study: LCSM

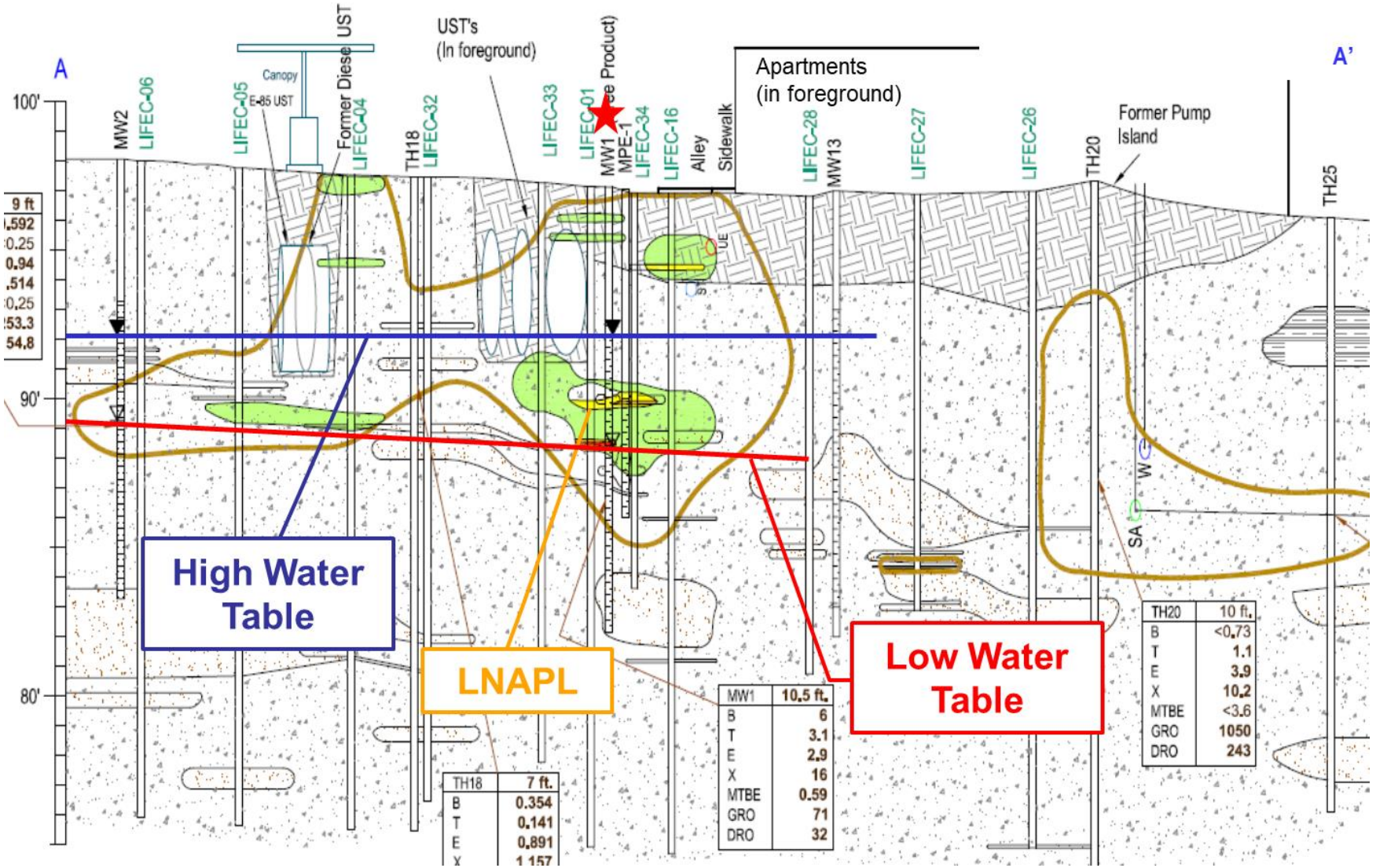


- Potential vapor intrusion at adjacent apartments
- Potential risks to residences (basements/sump pumps)

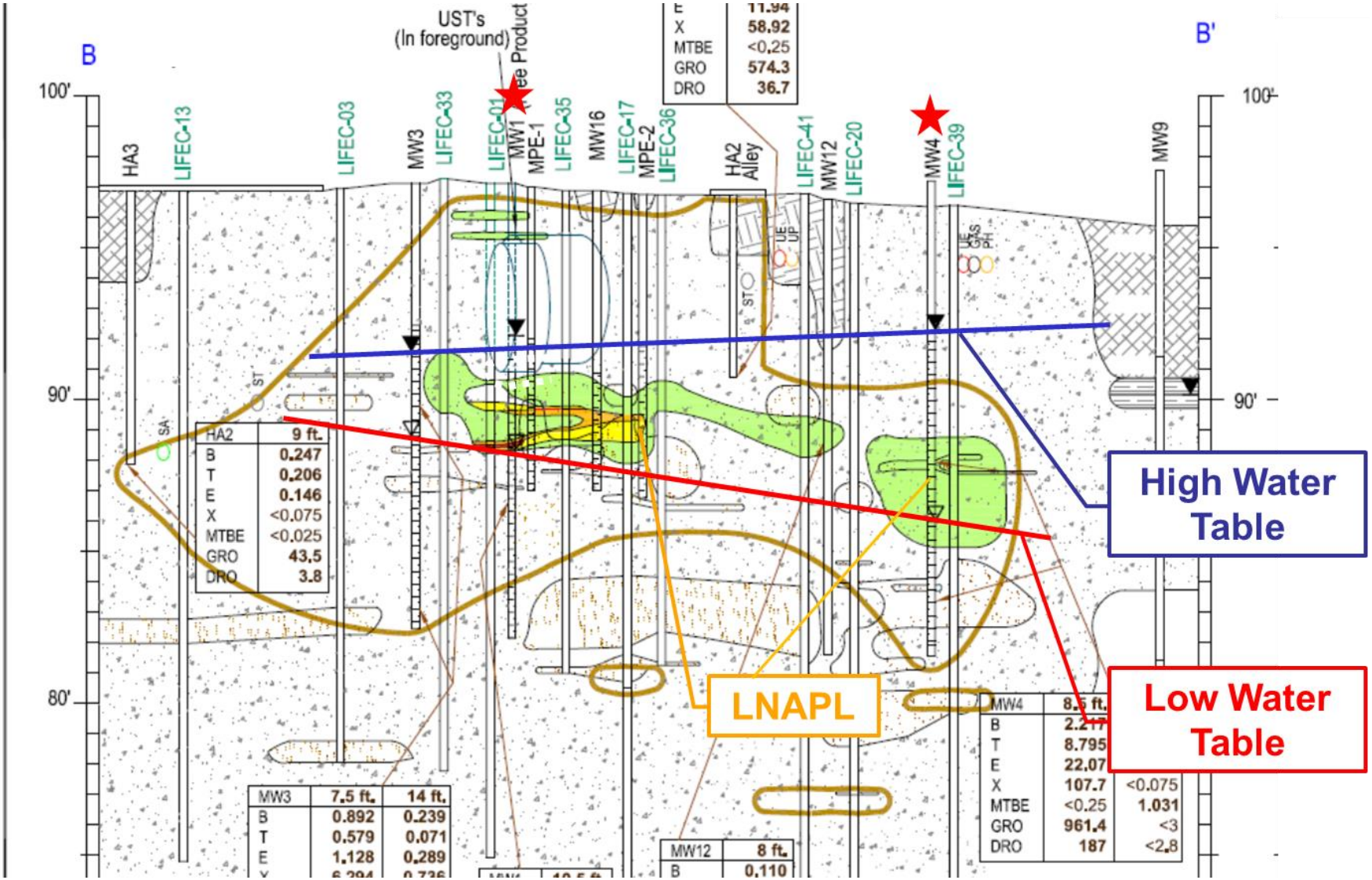
Case Study: Cross-section Plan View



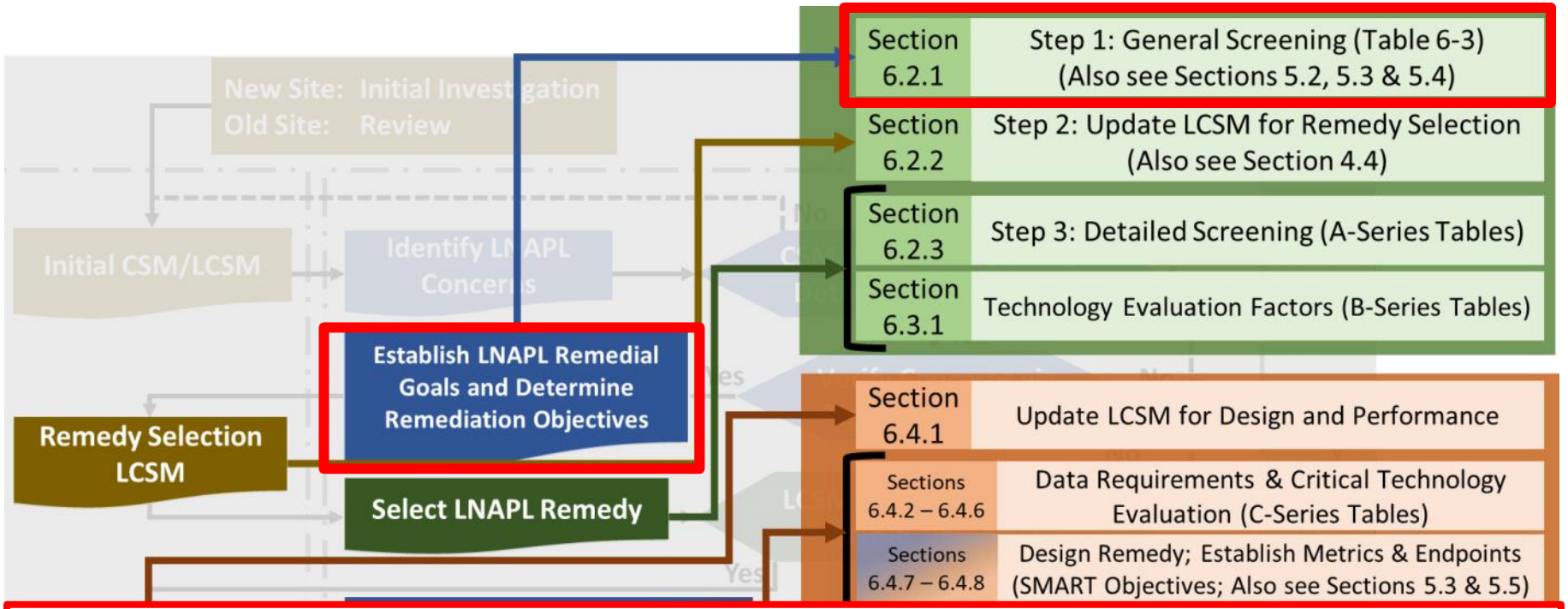
Case Study: Cross Section A-A'



Case Study: Cross Section B-B'



Case Study: Step 1 - General Screening



Goal: Identify a subset of possible LNAPL technologies

- LNAPL concerns, remedial goals, remediation objectives *(LNAPL Trainings 1 & 2)*
- Table 6-3

Case Study: Site LNAPL Concerns

- LNAPL migrated SE during low groundwater elevations
- Large dissolved plume above regulatory limits
  - COC: BTEX, MTBE and 1,2-DCA
- Vapor plume
  - Potential vapor intrusion at adjacent apartments
  - Potential risks for residences (basements/sump pumps)

**Site moved to aggressive site status by Agency

Knowledge Check

Poll Question

- Which concern would you consider to be the highest priority for this site?

  A. Migrating LNAPL

  B. Large dissolved plume above regulatory limits (COCs: BTEX, MTBE, 1,2-DCA)

  C. Vapor plume/vapor intrusion risks to off-site properties

Case Study: Site LNAPL Concerns

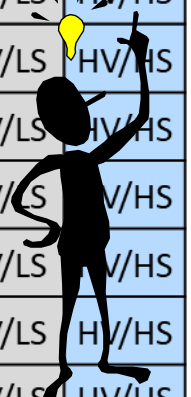
- LNAPL migrated SE during low groundwater elevations
- Large dissolved plume above regulatory limits
  - COC: BTEX, MTBE and 1,2-DCA
- Vapor plume
  - Potential vapor intrusion at adjacent apartments
  - Potential risks for residences (basements/sump pumps)

**Site moved to aggressive site status by Agency

Case Study: Step 1 – Goals, Objectives & Table 6-3

Table 6.3 Preliminary screening matrix

LNAPL remedial goal	LNAPL remediation objective	Technology group	Potentially useful LNAPL technology	Applicable Site Conditions: Geology (a)		Zone (b)		LNAPL type (c)	
LNAPL saturation-based remedial objectives									
Terminate LNAPL body migration and reduce potential for LNAPL migration	Abate LNAPL body migration by sufficient physical removal of mobile LNAPL mass	LNAPL mass recovery	●Excavation	F	C	U	S	LV/LS	HV/HS
			●Skimming		C		S	LV/LS	HV/HS
			●Vacuum enhanced skimming	F	C	U	S	LV/LS	HV/HS
			●Total liquid extraction		C		S	LV/LS	HV/HS
			●MPE	(F)	C	U	S	LV/LS	HV/HS
	Stop LNAPL migration by physical barrier	LNAPL mass control	●Phytotechnology	F	C	U	S	LV/LS	HV/HS
			●Physical containment	F	C		S	LV/LS	HV/HS
			●In situ soil mixing	F	C	U	S	LV/LS	HV/HS
Reduce LNAPL saturation when LNAPL is within residual range	Recover LNAPL to practicable limit	LNAPL mass recovery	●Excavation	F	C	U	S	LV/LS	HV/HS
			●Skimming		C		S	LV/LS	HV/HS
			●Vacuum enhanced skimming	F	C	U	S	LV/LS	HV/HS
			●Total liquid extraction		C		S	LV/LS	HV/HS
			●MPE	(F)	C	U	S	LV/LS	HV/HS



Case Study: Table 6-3 Geologic Factors

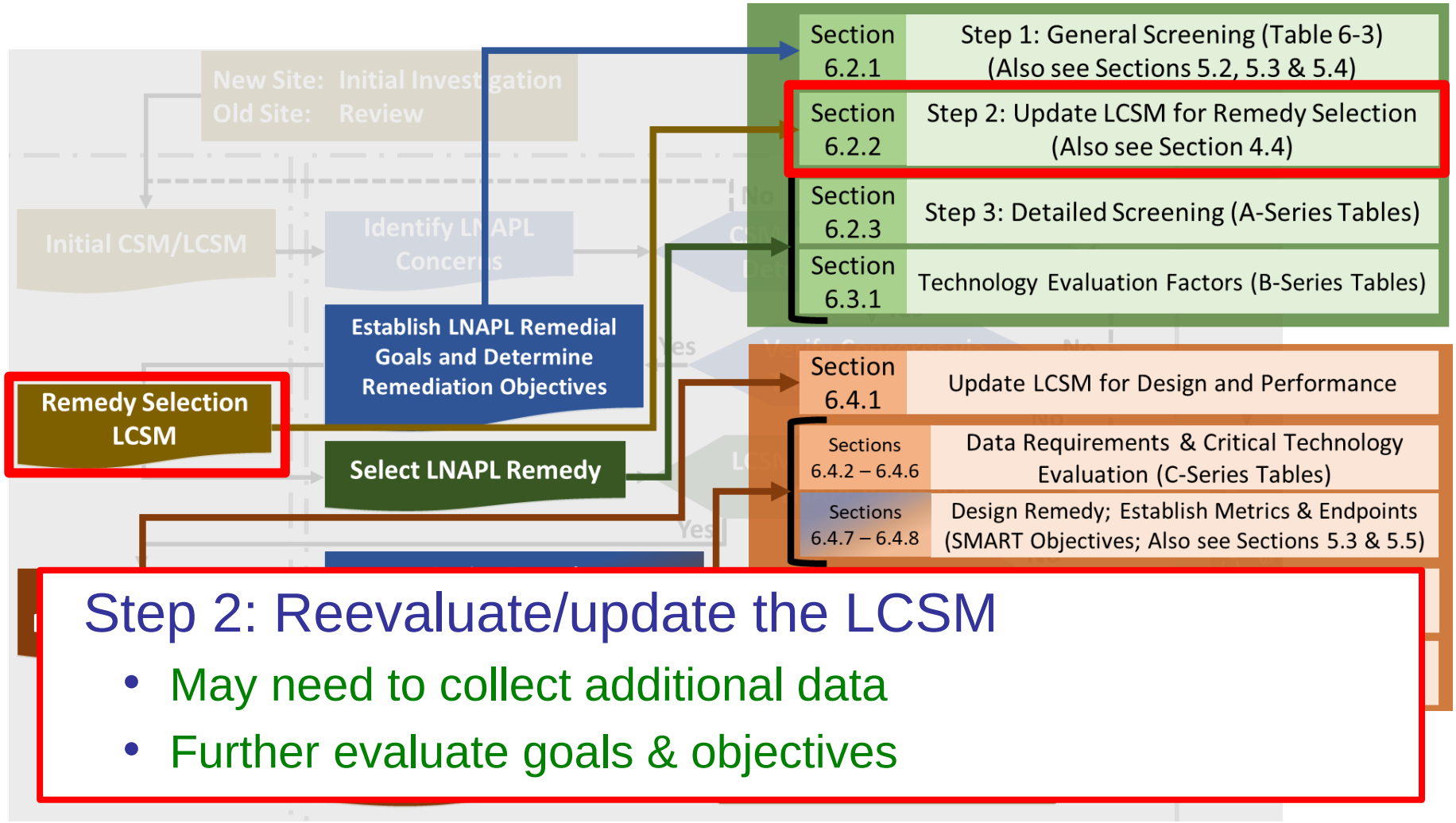
Table 6.3 Preliminary screening matrix

LNAPL remedial goal	LNAPL remediation objective	Technology group	Potentially useful LNAPL technology	Applicable Site Conditions: Geology (a)		Zone (b)		LNAPL type (c)	
LNAPL saturation-based remedial objectives									
Terminate LNAPL body migration and reduce potential for LNAPL migration	Abate LNAPL body migration by sufficient physical removal of mobile LNAPL mass	LNAPL mass recovery	●Excavation	F	C	U	S	LV/LS	HV/HS
			●~~Skimming~~		C		S	LV/LS	HV/HS
			●Vacuum enhanced skimming	F	C	U	S	LV/LS	HV/HS
			●~~Total liquid extraction~~		C		S	LV/LS	HV/HS
			●MPE	(F)	C	U	S	LV/LS	HV/HS

- Geology
  - Fine grained soils (F)
  - Coarse grained soils (C)
- Zone
  - Unsaturated zone (U)
  - Saturated zone (S)
- LNAPL type
  - Low Volatility/Low Solubility (LV/LS)
  - High Volatility/High Solubility (HV/HS)

ITRC LNAPL-3, Section 6.2.1

Case Study: Step 2 – Update LCSM

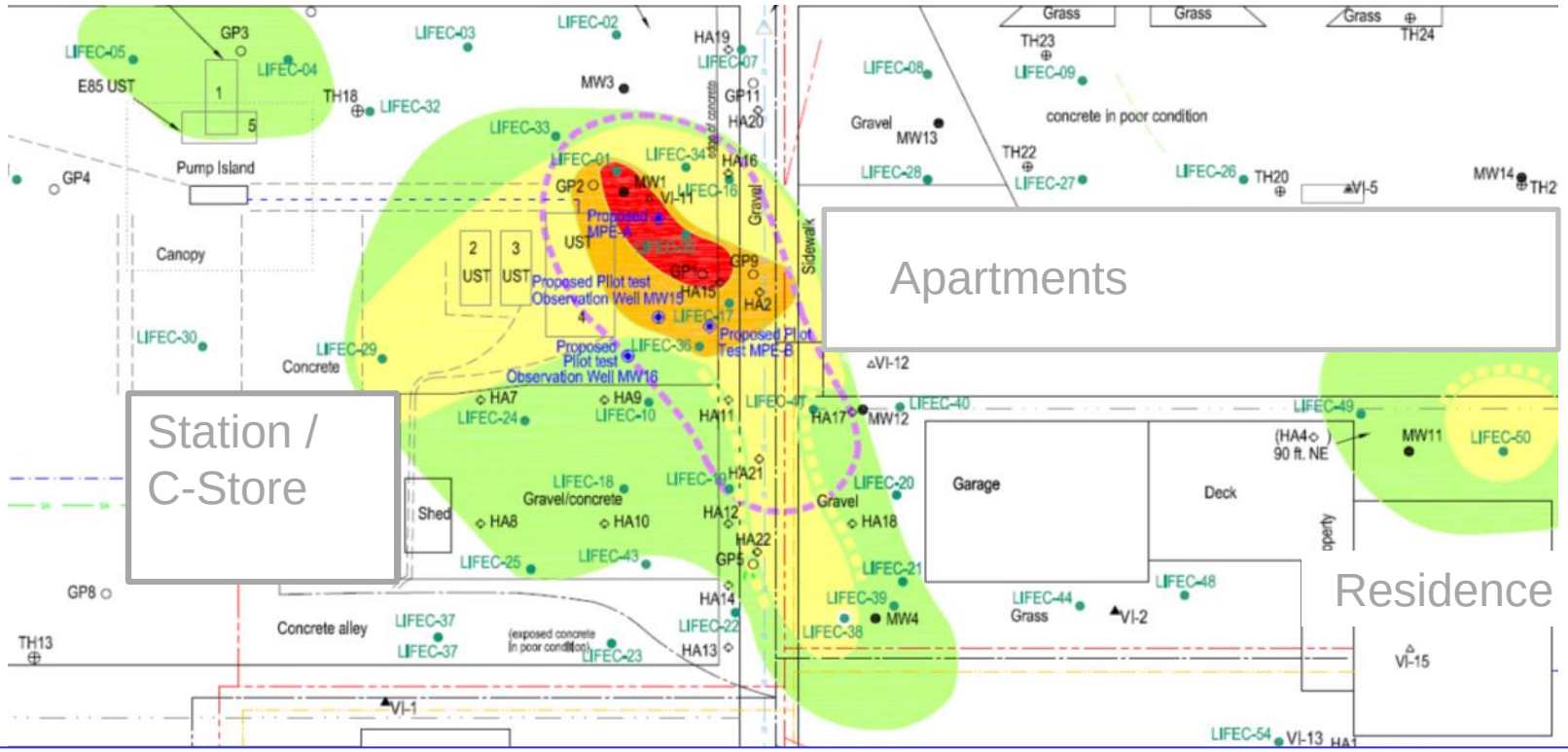


Step 2: Reevaluate/update the LCSM

- May need to collect additional data
- Further evaluate goals & objectives

ITRC LNAPL-3, Section 6.2.2

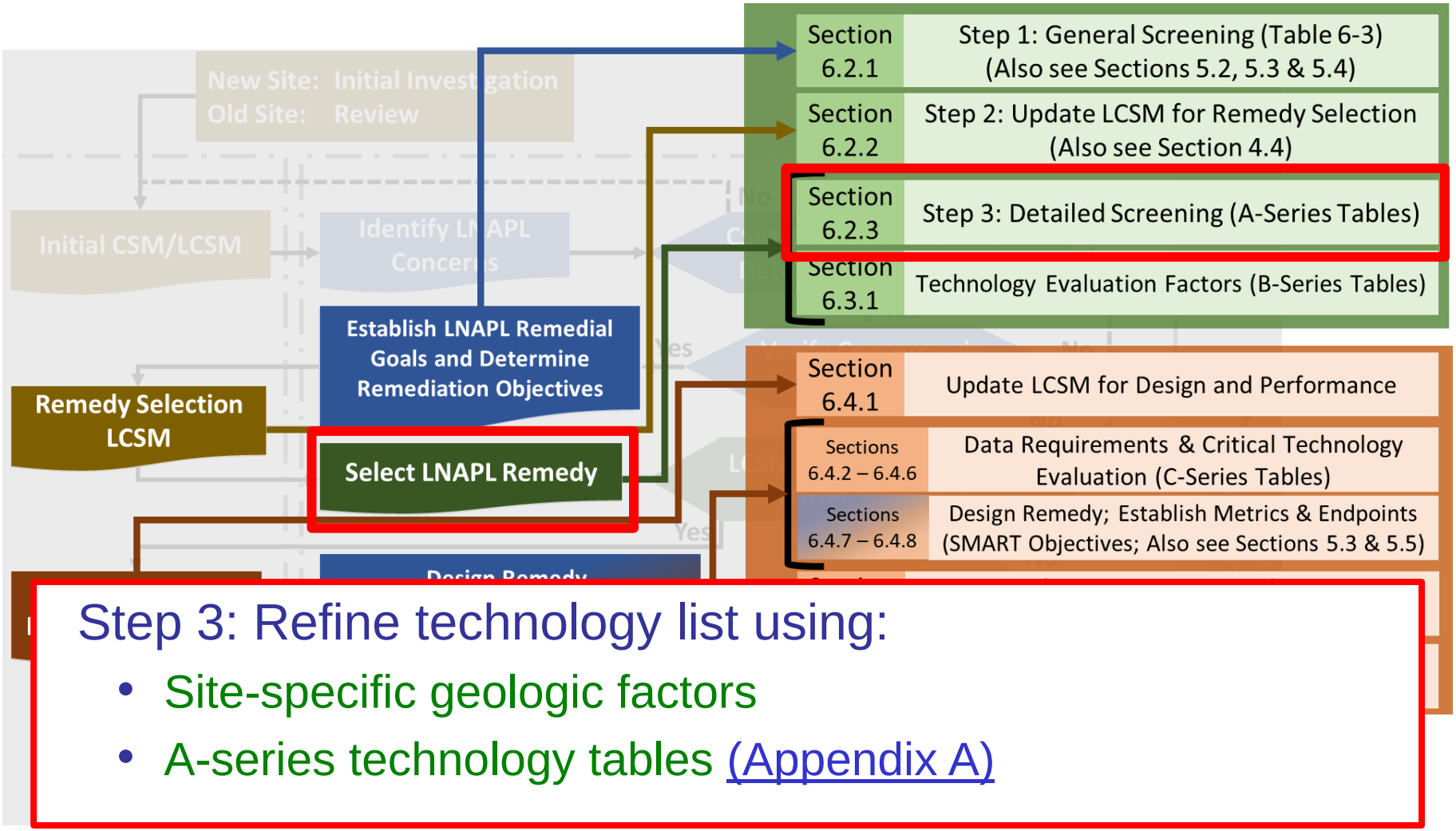
Case Study: Step 2 – Update LCSM



No additional field work:

- LIF data already collected at the site
- LNAPL source below the water table
- Low permeability soils at the site

Case Study: Step 3 – Detailed Screening



Step 3: Refine technology list using:

- Site-specific geologic factors
- A-series technology tables (Appendix A)

Case Study: Step 3 - Geologic Screening

Table A-3.A. Vacuum-enhanced skimming

Technology	Vacuum-enhanced skimming	LNAPL & vapor are the fluids removed. LNAPL drawdown and vacuum induce an..	
Remediation process	Physical mass recovery	Yes (primary)	1.Skimming removes liquid LNAPL from saturated zone and perched LNAPL zones. 2. Induced vacuum extracts LNAPL vapors from…
	Phase change	Yes (secondary)	The induced vacuum volatilizes and evaporates the LNAPL.
	In situ destruction	Yes (secondary)	Infiltration of oxygenated air from the surface enhances in situ aerobic
	Stabilization/ binding	No	
Objective applicability	LNAPL saturation	Yes	Vacuum-enhanced skimming reduces LNAPL saturations.
	LNAPL composition	Yes	Vacuum-enhanced skimming reduces the volatile constituent fraction
Applicable LNAPL type	All LNAPL types, although better suited to less viscous LNAPLs (e.g., gasoline, kerosene).		
Geologic factors	Unsaturated zone	Permeability	More effective in higher-permeability materials where vapor flow is…
		Grain size	More applicable to sands and gravels but can also be applied in…
		Heterogeneity	In heterogeneous soils, vacuum extracts LNAPL from preferential…
		Consolidation	Not typically a factor.
	Saturated zone	Permeability	Can achieve faster LNAPL removal and lower LNAPL saturations in higher-permeability materials.
		Grain size	More applicable to sands and gravels but can also be applied in silts and clays.
		Heterogeneity	Fractured bedrock and heterogeneous soils will induce preferential flow. More applicable to perched LNAPL and unconfined LNAPL…
		Consolidation	Not typically a factor.

Case Study: Step 3 – Geologic Screening (A-2-A Skimming)

Excerpt from Table A.3.A. Vacuum-Enhanced Skimming

Geologic factors	Saturated zone	Permeability	Can achieve faster LNAPL removal and lower LNAPL saturations in higher-permeability materials.

Site Geologic factors

- Saturated zone impacts
- LNAPL in higher permeable lenses
- Mainly lower permeable soils
- Heterogeneous soil profile

Technology Short List

excavation

~~skimming~~

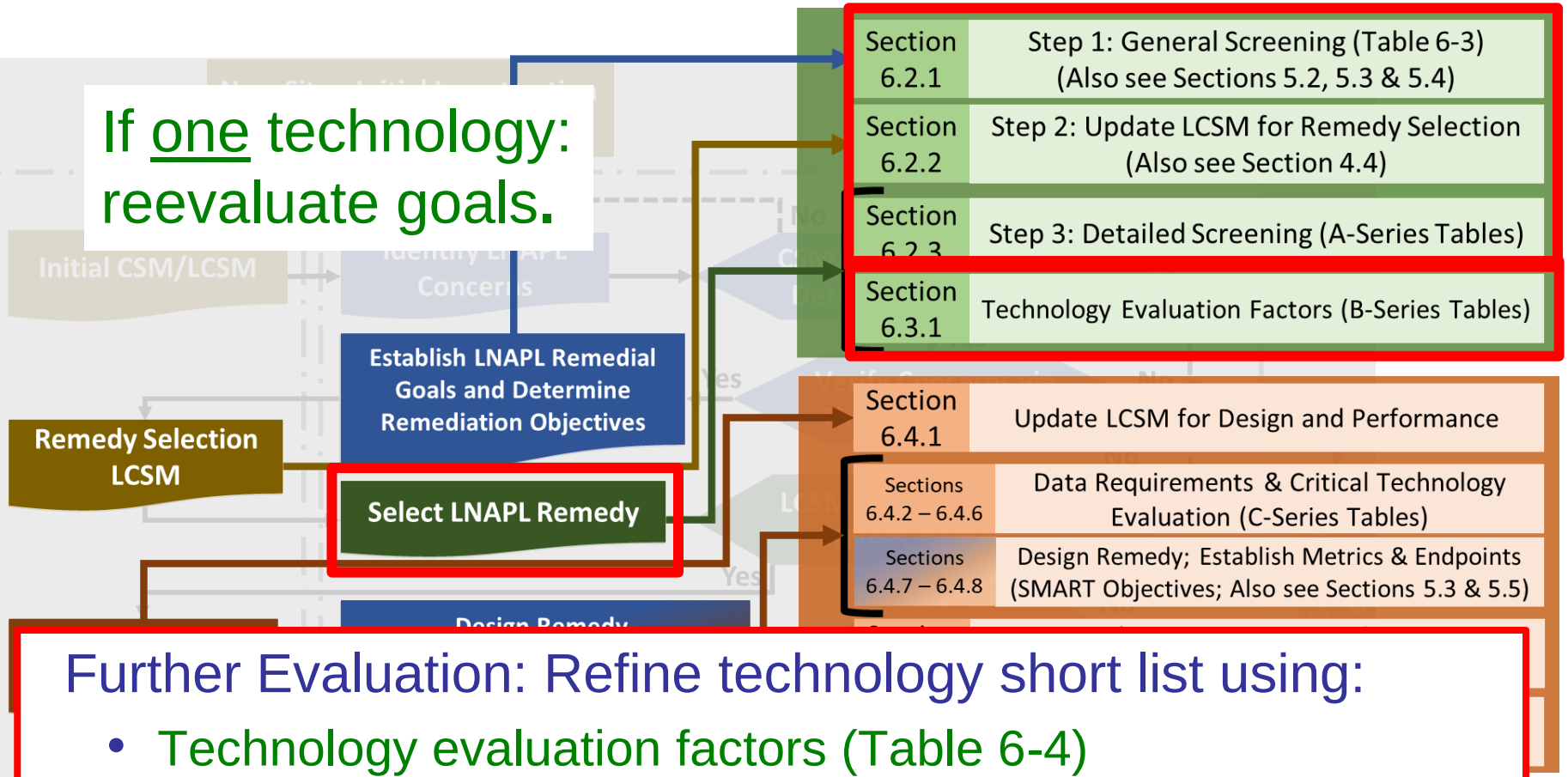
~~vacuum enhanced skimming~~

~~total liquid extraction~~

multi-phase extraction

Case Study: Technology Evaluation Factors

If one technology: reevaluate goals.



Further Evaluation: Refine technology short list using:

- Technology evaluation factors (Table 6-4)
- B-series tables

ITRC LNAPL-3, Section 6.3.1

Case Study: Table 6-4 Evaluation Factors

- Remedial time frame
- Safety
- Waste stream generation and management
- Community concerns
- Environmental factors
- Site restrictions
- LNAPL body size
- Cost
- Other

- Review factors
- Rank top 4-6 factors
- Review “B-series” tables

Case Study: Table 6-4 Evaluation Factors

Example from Table 6-4. Evaluation Factors

Site Restrictions	**Defined**	Physical, logistical or legal obstacles to system deployment at the site (e.g., building locations, high-traffic areas, small property size, noise ordinances…or nearby sensitive receptors, such as schools, day cares, hospitals, etc.)
	Impact	Site restrictions and limitations impact the implementation of some technologies more than others, due to equipment size, degree of surface disruption, etc. At sites with more potential physical, logistical, or legal site restrictions, the physically larger, more “disruptive” technologies may be less feasible to implement.

Case Study: Evaluation Factors

- Remedial Time Frame
  - Priority cleanup site by regulatory agency
- Site restrictions
  - No sewer connections
  - No 3-phase power nearby
  - Many underground utilities
- Waste Stream Management
  - Cannot handle large waste water volume
- Safety
  - Small site
  - Active gas station
  - Adjacent to highway & residential area/apartments

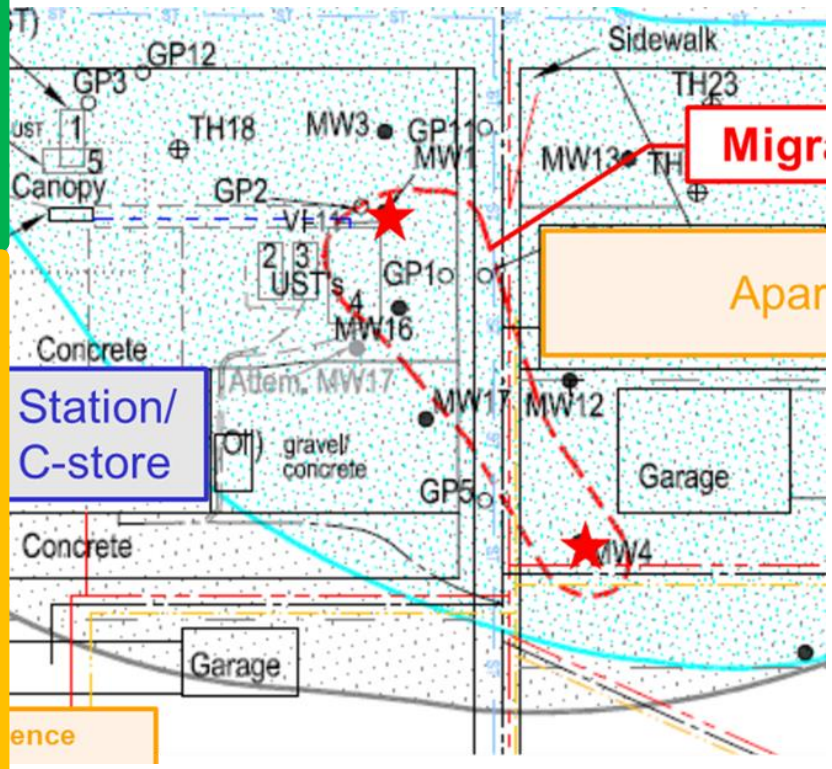
Case Study: B-Series Table – Excavation

Technology: Excavation		
Site Restrictions	**Concern**	High
	Discussion	Disruptive technology. Physical space, and logistical demands significant. Often excavation is infeasible due to site improvements, buildings, structures, roads, etc. Due to the use of large, heavy equipment and the need…

Photo: WCEC

Case Study: Evaluation Factor Screening

Evaluation Factors	Excavation (A-1.B)	Multi-Phase Extraction (A-5.B)
Remedial Time Frame	Low	Moderate
Site Restrictions	*High*	Moderate
Waste Stream Management	*Moderate to High*	Moderate
Safety	Moderate	Moderate

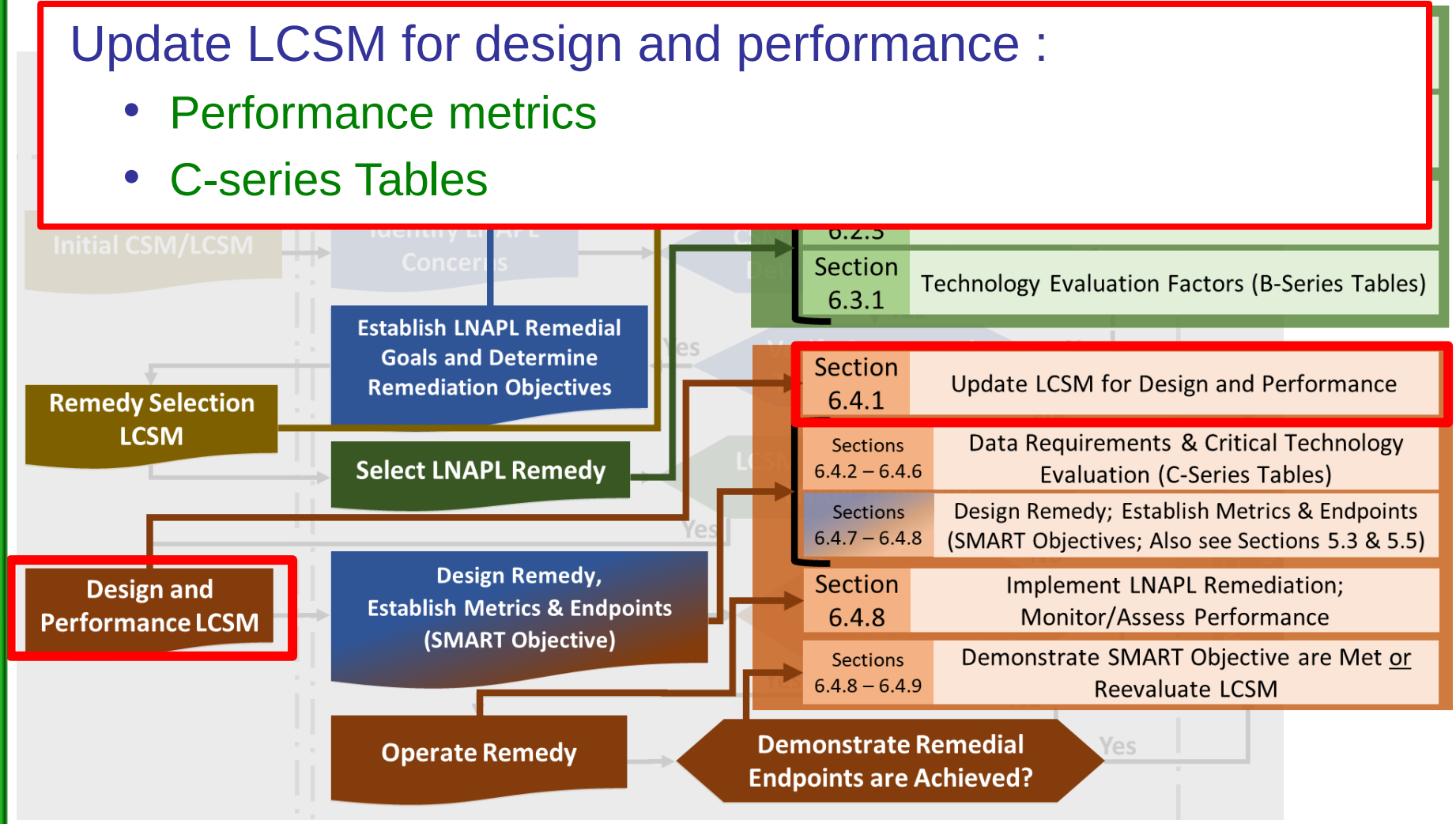


- Small site
- Active tank basin
- Apartment building
- Alley with utilities
- Offsite garage

Case Study: LCSM Update

Update LCSM for design and performance :

- Performance metrics
- C-series Tables



ITRC LNAPL-3, Section 6.4.1

Case Study: Design and Performance LCSM Update

Table A-5-C Technical implementation considerations for MPE

Full-scale design	Number of extraction wells	Determine number of required MPE wells necessary to achieve adequate zone of LNAPL recovery...
	Conveyance piping	Determine locations, lengths, materials for all horizontal conveyance piping to/from MPE wells...
	GW ROC	Establish groundwater ROI/ROC for different groundwater pumping rates. For continuous...
	LNAPL ROC	Establish LNAPL ROI/ROC for different LNAPL...
Performance metrics	GW and LNAPL recovery rates and volumes	Basic system performance monitoring
	Cumulative GW/ LNAPL recovery	
	LNAPL recovery cost metric	Cost per gallon of LNAPL recovered

Case Study: Design and Performance LCSM Update

Section 6.4.1 Design and Performance LCSM

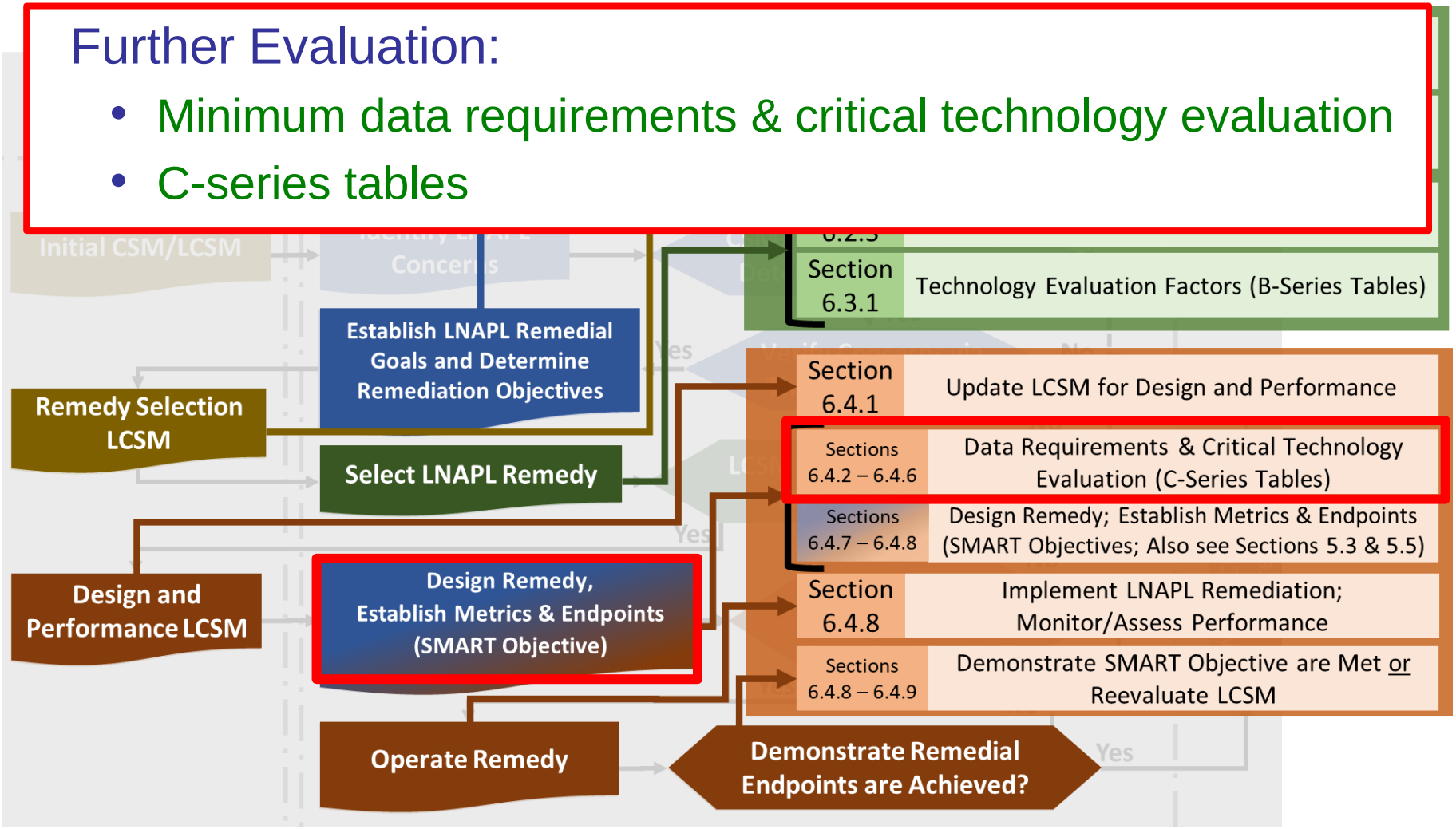
1. What are the conditions to be created by the selected technology(s) that will accelerate LNAPL depletion?

2. What conditions will demonstrate the desired LNAPL changes?

Case Study: Data Requirements

Further Evaluation:

- Minimum data requirements & critical technology evaluation
- C-series tables



ITRC LNAPL-3, Section 6.4

Section 6 – Minimum Data Requirements and Critical Considerations For Technology Evaluation

Table A-5-C. Technical implementation considerations for MPE		
Data requirements	Site-Specific data for technology evaluation	Hydraulic conductivity/transmissivity; LNAPL conductivity/transmissivity; LNAPL characteristics, power availability…
	Bench-scale testing	N/A
	Pilot-scale testing	GW and LNAPL ROC; GW and LNAPL recovery rate, volume & influent concentrations; vacuum and flow...
	Full-scale design	Number of extraction wells; conveyance piping; GW and LNAPL ROC; and LNAPL emulsification issues.
	Performance metrics	GW/LNAPL recovery rates and volumes; system uptime vs downtime; cumulative GW/LNAPL recovery…

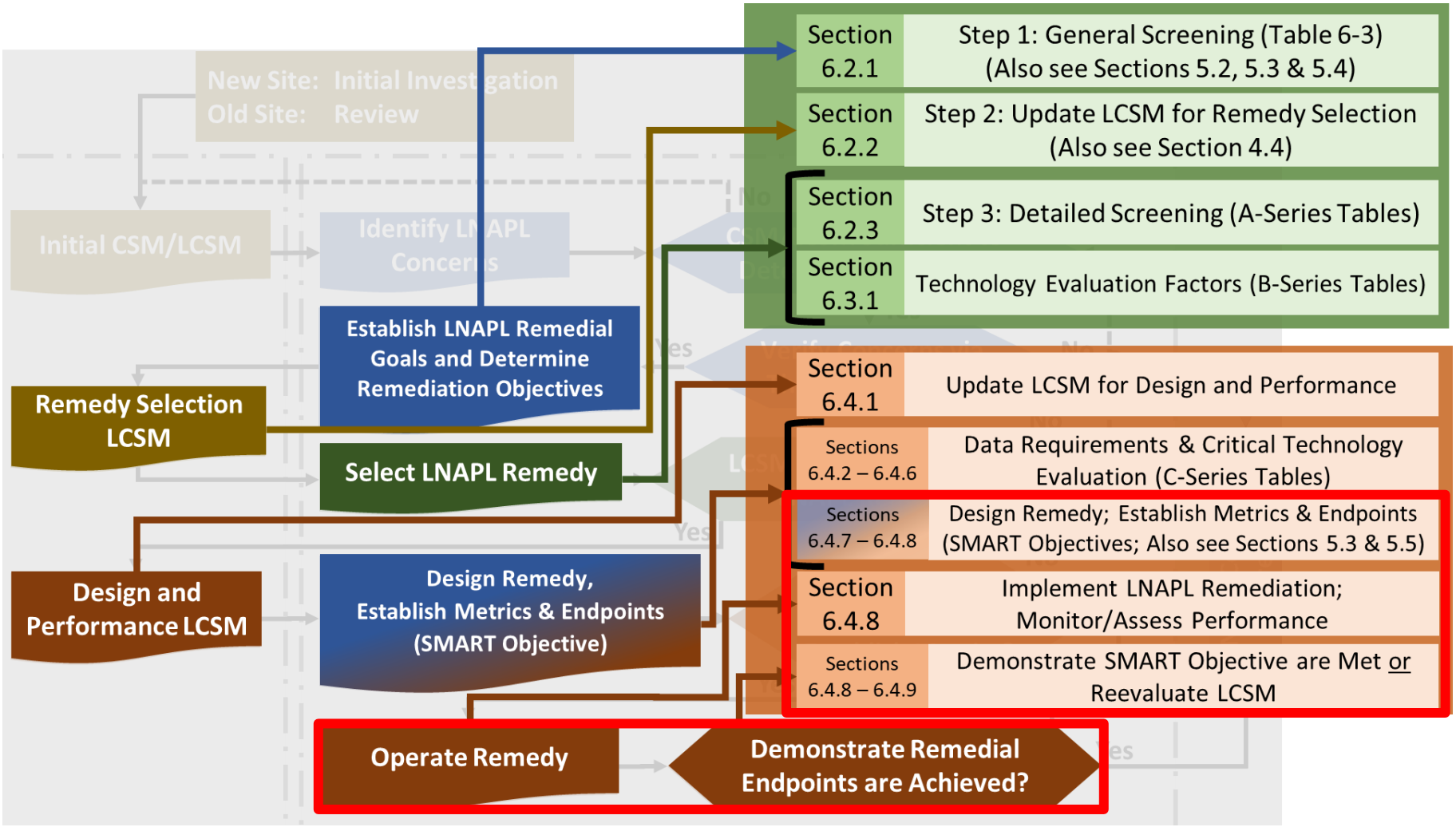
- Determine minimum data requirements
- Further evaluate considering critical technology evaluation
- If no technology can be determined, reevaluate the objectives or goals.

Case Study: Implementation Consideration

	Multi-Phase Extraction (A-5.C)
Site Specific Data for Technology Evaluation	Hydraulic conductivity/ transmissivity, LNAPL conductivity/ transmissivity, power availability
Pilot Testing	GW & LNAPL radius of influence (ROI), recovery rates
Full-Scale Design	Number of extraction wells, conveyance piping

Photo: WCEC

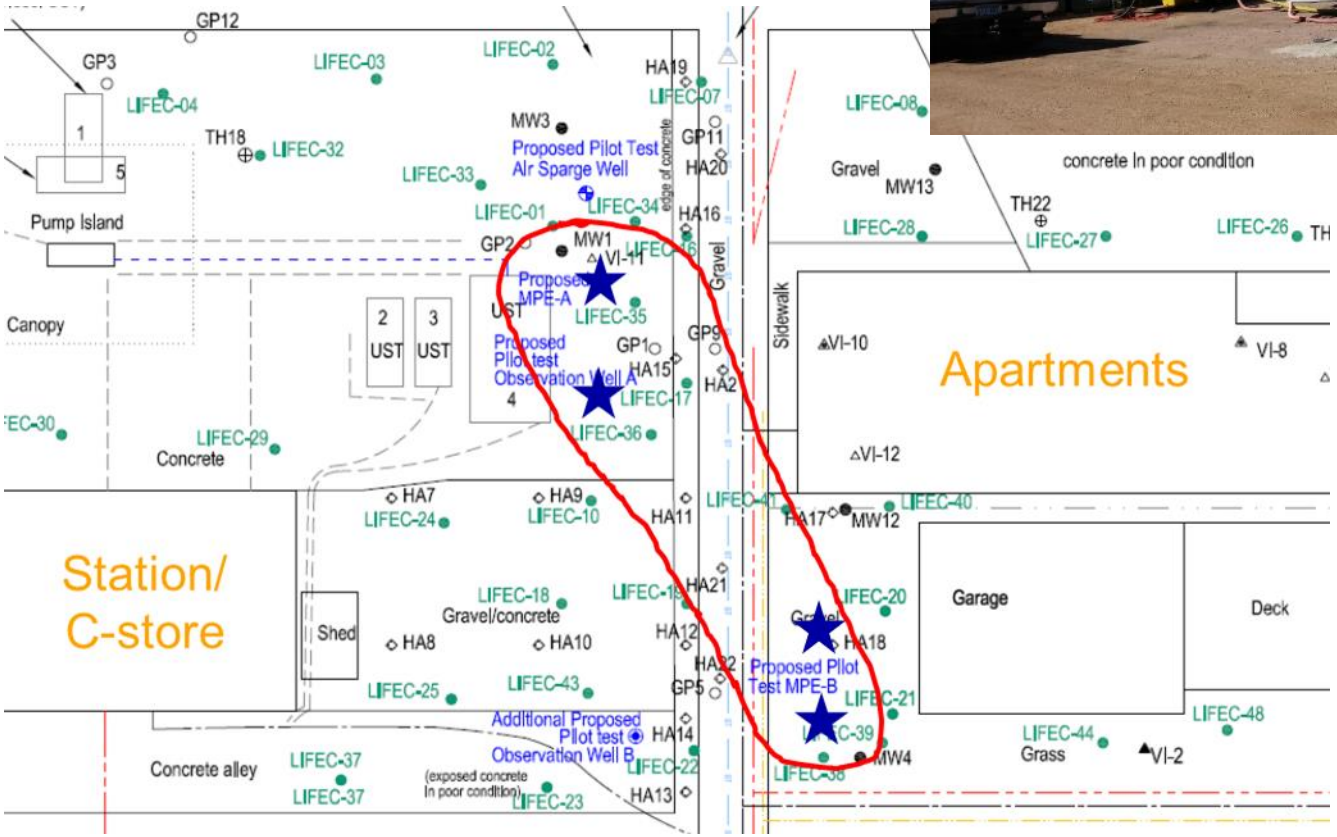
Case Study: Implement Remediation and Monitor Performance



ITRC LNAPL-3, Section 6.4

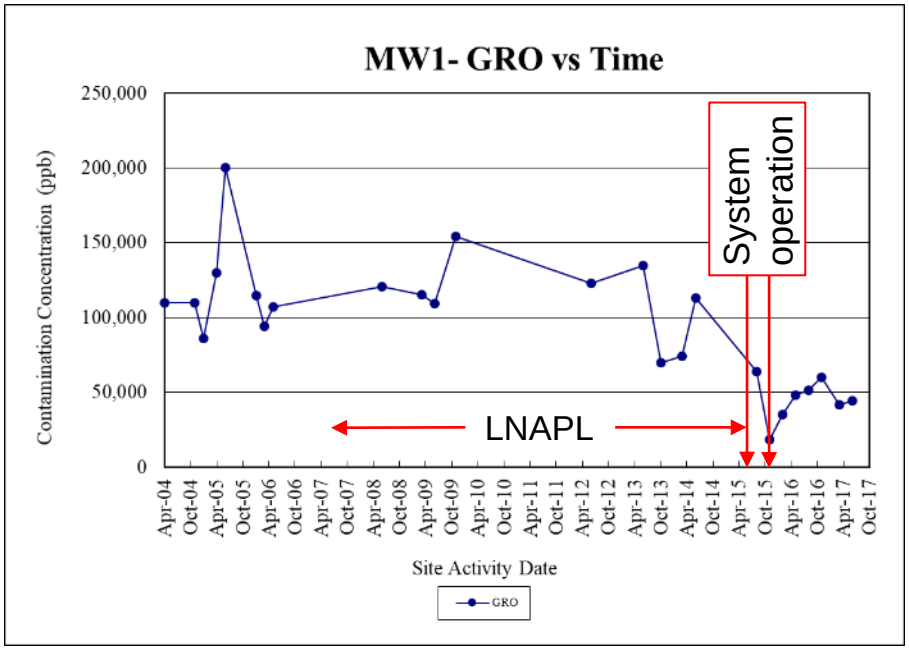
Case Study: Implementation and Performance Metrics

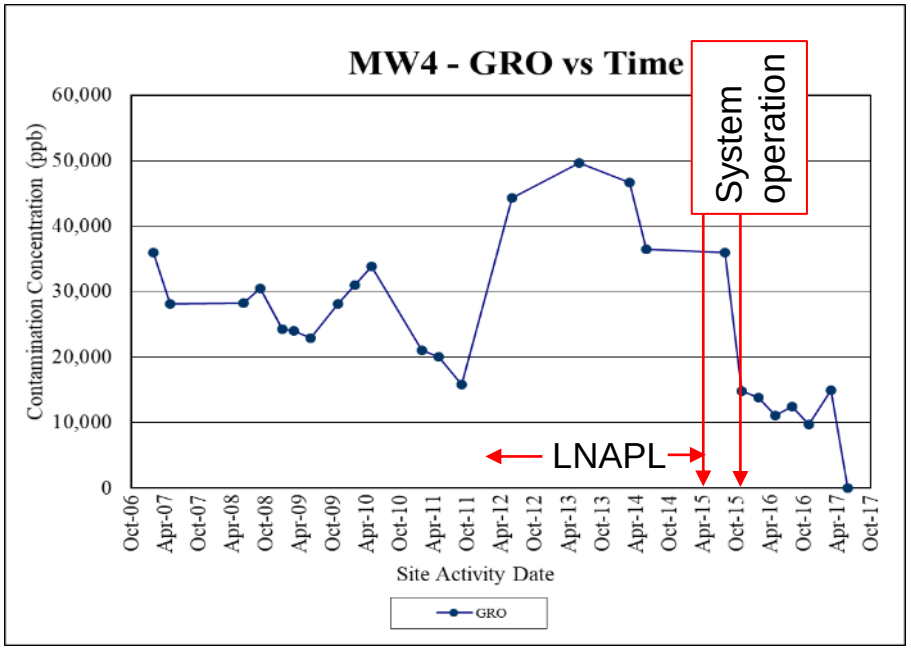
★ MPE wells
— Migrating LNAPL



Case Study: Performance Evaluation

Gasoline range organics (GRO) concentrations





Technology Selection - Take Aways

- Need a robust LCSM
- Decide concerns/goals upfront
- The technology selection framework is systematic
- Repeat process for each concern/goal
- Use technology that overlaps with multiple concerns/goals
- Sequence the technologies as appropriate
- Establish performance metrics to know success

Knowledge Check

Poll Question

- During the technology remediation selection process, when should the LCSM be reevaluated? (Chose all that apply.)
  - A. An LCSM should be developed prior to starting the remedy selection process
  - B. During the preliminary screening process
  - C. After further screening with the evaluation factors
  - D. After remediation, if unsuccessful

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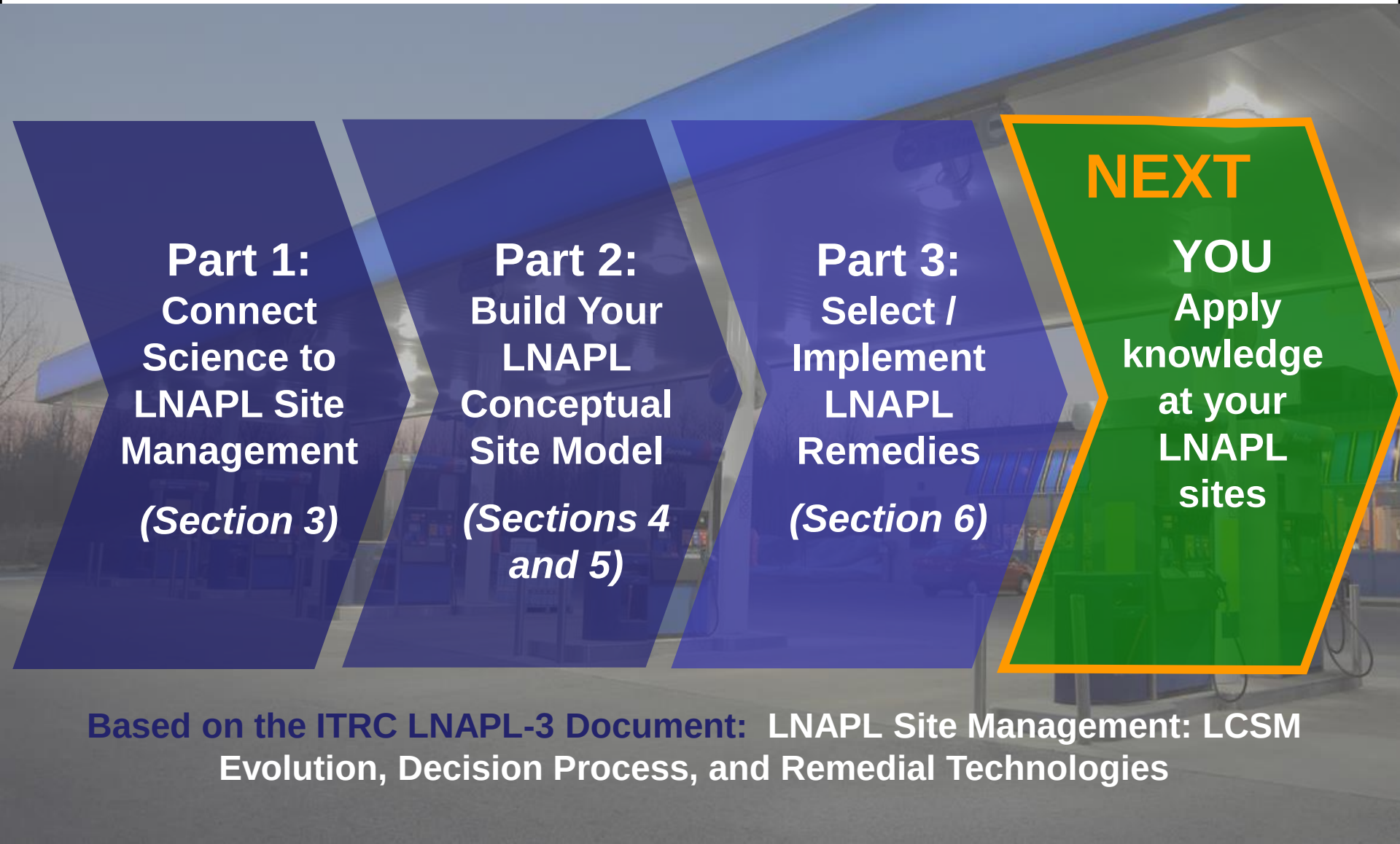


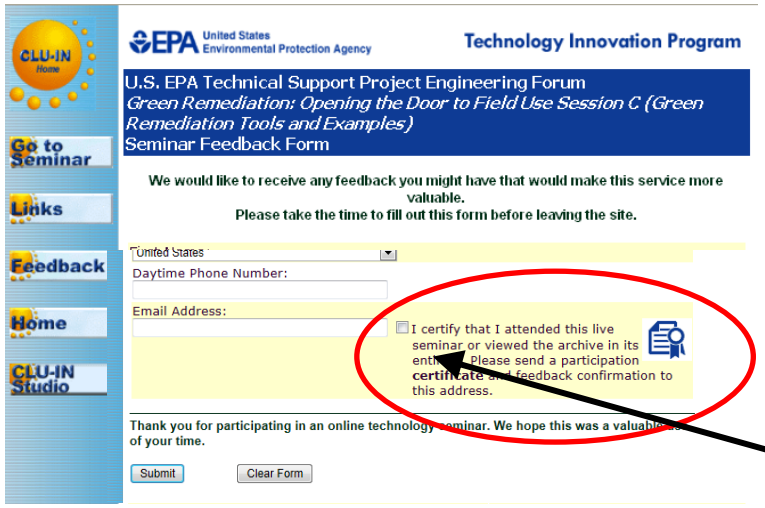
Based on the ITRC LNAPL-3 Document: LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies

Thank You

Follow ITRC

Poll Question

- **2nd question and answer break**
- **Links to additional resources**
  - http://www.clu-in.org/conf/itrc/LNAPL-3/resource.cfm
- **Feedback form – *please* complete**
  - http://www.clu-in.org/conf/itrc/LNAPL-3/feedback.cfm



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