LNAPL CONCEPTUAL SITE MODEL (LCSM) DEVELOPMENT – MENU OF OPTIONS

	Potential Parameters/Considerations	Potential Evaluation Methods	Discussion
LNAPL Body Delineation/ Characterization	1. LNAPL body geometry: horizontal/ vertical extents, position relative to water table 2. Relative intensity of impacts (hot spots)	1. Installation of wells/borings, laser-induced flourescence (LIF), resistivity 2. Soil sampling (TPH, LNAPL saturations), groundwater sampling, LIF, resistivity	
Geology/ Hydrogeology	1. General Stratigraphy 2. Impacted Soil Types 3. Hydraulic Gradients 4. LNAPL Gradient 5. Hydraulic Conductivity	1,2. Field screening of soil borings, laboratory grain size analysis 3,4. Well gauging 5. Slug tests, pumping tests, laboratory testing	
LNAPL Physical/ Chemical Properties	1. LNAPL viscosity 2. LNAPL specific gravity 3. LNAPL type/age 4. LNAPL chemical composition	1,2. Laboratory physical property testing 3. Laboratory forensic testing/fingerprinting 4. Laboratory chemical analytical testing	
Dissolved and Vapor Phase Impacts	1. Groundwater concentrations of LNAPL constituents 2. Soil gas concentrations of LNAPL constituents 3. Soil gas explosivity	1. Groundwater sampling/laboratory testing 2. Soil gas sampling/laboratory testing 3. Field screening of well headspace and/or soil gas samples using handheld lower explosive limit (LEL) meter	1. Focus on wells without LNAPL. The potential benefit of sampling groundwater under LNAPL should be weighed against the risk of obtaining LNAPL-contaminated samples (LNAPL presence may not be readily apparent in a groundwater sample). 2. The need for soil gas sampling and the potential parameter list can be screened based on the volatility of the LNAPL and/or specific constituents (e.g., test for constituents with Henry's law constant > $1e^{-5}$ atm-m^3/mol and vapor pressure > 0.05 Torr)
LNAPL Mobility	1. Age of LNAPL body 2. Soil TPH concentrations 3. LNAPL saturations and residual saturations 4. LNAPL transmissivity 5. Recovery system performance 6. Dissolved phase trends *Typically involves a weight of evidence approach where multiple lines of evidence are considered (due to the complexity of multi-phase flow in the subsurface and the technical limitations of the potential evaluation methods).	2. Comparison against appropriate C_{res} value or conversion of TPH concentrations to saturations and comparison to typical residual saturation values (see ASTM E2531-06) 3. Soil core sampling and laboratory petrophysical testing (e.g., pore fluid saturation testing, water drive testing) 4. Field LNAPL baildown testing, pumping tests, field dye tracer testing (see ASTM E2856-11) 5. LNAPL recovery system cumulative recovery/ recovery rate plots, decline curve analysis 6. Groundwater concentration trends of LNAPL parameters	1. Older LNAPL is less likely to be mobile 2,3. LNAPL saturations exceeding residual levels provide a line of evidence of LNAPL mobility 4. LNAPL transmissivity > 0.8 ft^2/day provides a line of evidence of LNAPL mobility (see ASTM E2856-11) 5. Poor recovery system performance may provide strong evidence that remaining LNAPL is at residual levels/immobile (if the system has been effectively implemented and operated) 6. Dissolved phase trends provide an indication of the state of the LNAPL body (e.g., stable dissolved phase trends = stable LNAPL)
LNAPL Migration	1. LNAPL body expansion and migration *LNAPL migration differs from the LNAPL mobility consideration above in that is only considers the potential for LNAPL mobility around the perimeter of an LNAPL body (i.e., its ability to migrate or expand into areas that are not already impacted).	1. One or more LNAPL mobility lines of evidence indicates potential mobility along LNAPL body perimeter 2. LNAPL observations in sentry wells installed in clean soil 3. Estimate critical LNAPL head (pore entry displacement pressure) at LNAPL periphery	3. Critical LNAPL head (pore entry displacement pressure) exceeded at LNAPL periphery represents a potential for LNAPL body expansion/ migration
LNAPL Recoverability	1. Potential LNAPL recovery rates 2. Fraction of LNAPL body that may be recoverable *Most of the potential evaluation methods listed above for LNAPL mobility will also provide evidence relating to the potential recoverability of the LNAPL.	1. LNAPL recovery pilot results, LNAPL transmissivity estimation, full-scale LNAPL recovery system performance 2. Comparison of LNAPL saturations and residual saturations	1. LNAPL recovery may be considered technically practicable where LNAPL recovery rates exceed a minimum level and/or where LNAPL transmissivity > 0.8 ft^2/day 2. Regardless of the technical practicability of LNAPL recovery, any recovery activity will only have a significant effect on an LNAPL body where LNAPL saturations significantly exceed residual levels (i.e., significant recoverable fraction)
Potential Remedial Drivers	1. Risk (compositional concerns) 2. LNAPL mobility/migration (saturation concerns) 3. Non-risk (non-technical) factors such as aesthetic (e.g., visual, olfactory), regulatory or other considerations (e.g., property transaction condition)	1. Will vary from comparison of existing site data to generic criteria, to quantitative human health and ecological risk assessment (depending on complexity of site and magnitude of potential risks) 2. See LNAPL mobility and LNAPL migration lines of evidence and approaches above 3. Review applicable LNAPL regulations 3. Establish site goals	

NOTES:

The “menu” provided above presents potential elements of an LCSM, potential evaluation methods and potential metrics (where applicable). The need to quantify specific items above should be based on a preliminary consideration of site-specific goals and site complexity. *It will not be necessary to quantify all items above at all sites.*

Table C-1 of ITRC’s Technical Regulatory Document entitled Evaluating LNAPL Remedial Technologies for Achieving Project Goals provides more detail on LCSM components and presents a three level tiered approach to LCSM development based on increasing levels of site complexity

Table X4.1 of ASTM Standard E2531-6 provides detailed information on LNAPL site data collection methods and their applicability

LNAPL Compositional Concerns (potential exposure/risk issues):
- Explosive hazards (vapor accumulation in confined spaces/ utilities, open excavations)
- Dissolved-phase concentrations (migration toward surface water bodies or groundwater supply wells)
- Vapor-phase concentrations (vapor intrusion/long-term exposure risk)
- Direct contact or ingestion

EVALUATE LNAPL CONCERNS FROM LCSM

LNAPL Concerns = Remedial Drivers

Compositional Concerns
Risk-based drivers such as unacceptable levels of dissolved or vapor-phase impacts

Saturation Concerns
Drivers relating to the mitigation of LNAPL migration and/or reduction of LNAPL mobility

LNAPL Saturation Concerns (mobility and migration issues)
- Potential for LNAPL to spread and create new or increased risk (migration toward surface water, property boundary, underground utilities)
- Aesthetic/Nuisance issues

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Risk: Are unacceptable dissolved phase, vapor phase or direct contact exposures associated with the LNAPL under any use scenarios?

Yes → Do feasible options exist to mitigate unacceptable risk through compositional change? (9)

Yes → Can institutional/engineering controls provide effective risk mitigation? (10)

Yes → **Cost-Benefit** Is there potential benefit to partial treatment/removal that outweighs costs? (5)

Yes → Implement treatment/removal action (6)

No → No Further Action

Migration: Is LNAPL migrating or potentially migrating (i.e., mobile along perimeter)? (2)

Yes → Do feasible options exist to mitigate migration through LNAPL recovery or mass control?

Yes → Implement LNAPL Recovery Remedy (6)

Mobility: Is LNAPL potentially mobile within stable LNAPL perimeter? (3)

Yes → **Recoverability**: Is LNAPL readily recoverable? (4)

Yes → **Cost-Benefit** Will potential benefit of LNAPL recovery outweigh costs? (5)

Yes → Implement LNAPL Recovery Remedy (6)

Are controls required? (7)

Yes → Implement Controls

No → Implement Long-Term Stewardship/ Monitoring Plan (**as required**) (8)

No Further Action

(#) NOTES

LNAPL Remedial Decision Tree

1 The LCSM may identify both risk and mobility/migration issues at a given site. Consequently, compositional change techniques (to mitigate risk) and saturation reduction techniques (to mitigate mobility/migration concerns) may represent concurrent considerations that may require independent remedies.

2 Migration is only likely to be occurring where releases are active or shortly after cessation where a LNAPL gradient/head is present. Due to the complexity of multi-phase flow in porous media and the limitations of available assessment methods, LNAPL migration potential should be evaluated using multiple lines of evidence (see LCSM Menu – Page 1)

3 LNAPL Mobility – Is LNAPL present at saturations exceeding residual values? Example lines of evidence listed in LCSM Menu – Page 1.

4 The presence of readily recoverable LNAPL as defined by transmissivity > 0.8 ft^2/day does not necessarily indicate that a significant fraction of an LNAPL body would be beneficially affected through LNAPL recovery. An understanding of the fraction of the LNAPL body that may be recoverable is necessary in order to establish a realistic expectation of the actual benefit of any LNAPL recovery activity and a determination of whether the LNAPL body is “readily recoverable.”

5 The potential benefit of LNAPL remediation should be weighed against the potential costs in terms of the associated expenditure of financial and natural resources, the risks involved in implementation, and the contamination potentially resulting from the remedial action (i.e., sustainability considerations). For situations where LNAPL bodies are stable with no associated risk, the net environmental benefit of active engineered LNAPL remedial systems should be scrutinized. In these cases, it is highly unlikely that LNAPL recovery will effect enough of the LNAPL body to result in a significant level of risk reduction over natural source zone depletion (NSZD) alone.

6 Establish LNAPL recovery objectives and science-based achievable/measureable LNAPL recovery end-points prior to implementing LNAPL remediation (e.g., reduction of LNAPL transmissivity to less than 0.8 ft^2/day to meet a saturation objective).

7 Considering the significant technical limitations of LNAPL mass recovery or compositional change, engineering and/or institutional controls should be considered in conjunction with or in lieu of remedial action.

8 Perform any necessary monitoring to confirm LNAPL remedial goals are/were met.

9 LNAPL compositional change remediation is implemented to reduce the concentration or mole fraction of specific compounds in LNAPL that contribute to dissolved and or vapor phase concerns (i.e., air sparging and soil vapor extraction to reduce the mole fraction of benzene in LNAPL). Phase change technologies can be used to target immobile LNAPL, unlike conventional LNAPL mass recovery technologies such as LNAPL skimming. Examples of compositional change techniques may include air sparging, enhanced biodegradation, in situ thermal treatment, and in-situ chemical oxidation. Some phase change remedial technologies will accomplish both LNAPL mass recovery (saturation objective) and compositional change objectives simultaneously.

10 Examples of potentially effective removal actions include excavation with off-site disposal, excavation with ex-situ thermal treatment and in-situ thermal treatment (e.g., electrical resistance heating with high vacuum extraction).

LNAPL Remedial Decision Tree Notes