LNAPL Conceptual Site Model (LCSM) Data Collection Parameter Can be Considered Sections in a Report	Tools	Direct or Indirect Measurement?	ASTM Reference	Other Guidance and Publications	Notes:
Site Setting					
Current and Future Land use and Zoning	See ASTM CSM	NA	E1527-05; E1528-06		
Receptor location	See ASTM CSM	NA	E1527-05; E1528-06		
Groundwater Classification / Use	See ASTM CSM	NA	E1527-05; E1528-06		
Utility location	See ASTM CSM	NA	E1527-05; E1528-06		
Site History (past remediation, release scenario)	See ASTM CSM	NA	E1527-05; E1528-06		
Geology/Hydrogeology					
Subsurface Stratigraphy					Obtained through soil borings, test pits, continuous core logging, CPT or others.
	Soil borings with visual logging	Direct	D1452-09		Obtained through visual observation.
	Cone Penetrometer Tool (CPT)	Indirect	D 3441 (2004); D 5778	ISSMGE	High resolution soil profiling tool utilizing three measures of soil texture, tip-stress, sleeve friction and pore pressure.
	Electrical Conductivity (EC)	Indirect		Geoprobe 2008 SOP (http://geoprobe.com/ec-electrical-conductivity)	Provides an indication of fine grained content based on differences in quartz sand and clay mineral conductivity.
	Hydraulic Profiling Tool (HPT)				Provides a relative log of soil permeability to water.
	Geophysical borehole	Indirect	D5753-05		More Widely Used in Fractured Rock.
	Capillary pressure	Direct			Specific analysis used for LNAPL and soil gas distribution and transport.
	Moisture Content	Direct and Indirect		Infiltration Guidance	The degree of water saturation in pores affects soil gas transport.
	Native organic content	Direct			
	Secondary porosity (macropores)	Direct			Visual documentation of a specific feature that affects LNAPL distribution.

		Laboratory grain size distribution	Direct	D422; D4464		Direct and consistent measure of soil texture.
Hydraulic Conductivity						Identifies magnitude of potential water transport and can be scaled to other fluids if needed.
		Slug Test	Direct	D4043, D4104, D4044, D5912, and D5785	Butler (1998)	Hydraulic conductivity (K) representative of zone close to well, good for assessing spatial variability of K; inexpensive; don't have to treat contaminated water, may be difficult in higher conductivity formations.
		Laboratory Core Sample	Direct	D5084; D5856, and D2434	Leach and others (1988); Dustman and others (1992)	D5084 appropriate for undisturbed cores; D5856 appropriate for laboratory compacted samples, impact of secondary porosity such as wormholes and fractures may be lost. Sample small, hence K may not be representative of aquifer conditions; however K may be useful for spatial variability; cores taken from soil borings yield vertical K, while horizontal is more significant; don't have to handle contaminated water; may not be practical information with high fraction of cobbles; and inexpensive.
		Grain Size Inferred	Indirect	D422; D4464	Shepherd. R. G. 1989. Correlations of permeability and Grain Size. Ground Water. Vol. 27, No 5. pp. 633-638; Cronican. A.E., and M.M. Gribb. 2004. Hydraulic Conductivity Prediction for Sandy Soils. Ground Water. Vol. 42, No 3. PP 459-464; and Odonj. J. 2007. Evaluation of Empirical formulae for determining hydraulic conductivity based on grain size analysis. Journal of American Science. Vol. 3. No 3. pp. 54-60.	Combined with empirical equations allows for estimate of soil conductivity. Not the most accurate method; will not reflect the effect of secondary porosity such as fractures worm or root hole and structure; inexpensive.
		Geoprobe HPT/CPT inferred	Indirect	D6391-11	http://geoprobe.com/literature/hpt-sop Lee, D. D., Elsworth D, and Hryciw, R, 2008. "Hydraulic conductivity measurement from on-the-fly uCPT Sounding and from VisCPT." Journal of Geotechnical and	Not very accurate K measure (order of magnitude estimate); point measure; high spatial resolution of K; good for assessing K spatial variability; inexpensive (by-product of site assessment).

					Geoenvironmental Engineering. Vol. 134, No. 12, pp. 1720-1729.	
		Pump test	Direct	D4043; D4105; D4106; D5270	Kruseman, G.P., and de Ridder, N.A., 1994. Analysis and Evaluation of Pumping Test Data, Publication 47, International Institute for Land Reclamation and Improvement; and Walton, W. C., 1987. Groundwater Pumping Tests: Design and Analysis, Lewis Publishers, Inc., Chelsea, MI.	Indirect may be more appropriate since pumping test measures transmissivity. Most recommended measure of K; but K is "averaged" over a large zone; Yields other aquifer parameter specific storage (yield); requires multiple wells; expensive; time consuming; normally relatively easy to analyze, however, boundary conditions may complicate analysis; in fractured media interpretation of observation well data may be complicated
Related Aquifer Description (Single aquifer, none, multiple aquifers) &					Heath (1987); Fetter (2001); Freeze and Cherry (1979)	Obtained through comparison of water/LNAPL elevations to lithology. Longer-term monitoring data recommended.
Hydrogeologic condition for Groundwater (unconfined, confined, perched)		Published reports	NA	D653-11; D6106-97; D6030-96		Worthwhile to review prior to and post site characterization.
		Soil borings	Direct	*Ibid.*		Interpreted from visual soil boring logs.
Potential Migration Pathways (GW, LNAPL, Vapor)		Assessed from combinations of multiple tools	NA	(E2531-06)	API (2004/ Interactive LNAPL Guide); Johnson, Lundegard & Liu (2006)	Interpreted from multiple references in Site Setting and observations.
Groundwater/Surface water interaction (incl. tidal)		Transducer or other continuous fluid level survey	NA		Urish and Ozbilgin (1989); Urish and McKenna (2004)	Compare fluid levels during stress periods (e.g., pumping, tidal and/or seasonal changes.
Longer-term monitoring (historical changes in GW levels, Surface water effects, precipitation effects)		Assessed from combinations of multiple tools	NA	D6000-96	USEPA (1992; RCRA Ground-Water Monitoring); USEPA (2009) 530/R-09/007	Evaluated based on historical data trends combined with future site setting.

LNAPL Delineation (includes mobile and residual LNAPL)						
		Soil borings	Direct	ASTM D1452 - 09 Standard Practice for Soil Exploration and Sampling by Auger Borings D1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils D1587 Practice for Thin-Walled Tube Geotechnical Sampling of Soils D4220 Practice for Preserving and Transporting Soil Samples D6286 - 98(2006) Standard Guide for Selection of Drilling Methods for Environmental Site Characterization D6282 Guide for Direct Push Soil Sampling for Environmental Site Characterizations D6640 Practice for Collection and Handling of Soils Obtained in Core Barrel Samplers for Environmental Investigations D5088 Practice for Decontamination of Field Equipment Used at Waste Sites D5784 Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices	Environmental Response Team (ERT), US EPA. Soil Sampling, SOP No. 2012	
		PID (above and below the WT)	Indirect	ASTM D4547 - 09	Environmental Response Team (ERT), US EPA. Photoionization Detector (PID) HNU , SOP No. 2114	
		Core sample LNAPL saturations (e.g., Dean Stark)	Direct	None	API RP40, Recommended Practices for Core Analysis, Second Edition, Feb. 1998	Direct measure of LNAPL saturation in soil cores.
		Shake test	Direct	None		Consists of shaking soil with tap water in a vial and looking for sheen/non-aqueous phase liquid. Does not differentiate between mobile and residual hydrocarbon.
		Olfactory from soil samples	Indirect	None		Qualitative and not standardized.

		Soil vapor measurements	Direct/Indirect	ASTM D5314-92		Qualitative indicator of LNAPL impacts for volatile and semi-volatile hydrocarbons.
		Laser Induced Fluorescence	Indirect	D6187-97(2010)	Aldstadt et al. (2002); DOE (2002); Kram et al. (2004); Kram and Keller (2004a, 2004b)	Qualitative indicator of LNAPL containing poly aromatic hydrocarbons.
		Membrane Interface Probe	Indirect	D7352-07(2012)		Qualitative indicator of LNAPL impacts for volatile and semi-volatile hydrocarbons.
		Ultraviolet Core Photography	Indirect	D2008-12		Qualitative indicator of LNAPL containing poly aromatic hydrocarbons.
		Dye Tests	Indirect	None		Similar to shake test except petrophyllic dye is used.
		CO_2 concentrations in unsaturated zone	Indirect	ASTM D5314-92		Indirect measure of hydrocarbon degradation may have interference with natural soil respiration.
		TPH/COC analytical results from soil samples	Direct	E1739-95(2010)e1; E1943-98(2010)		Concentrations can be compared to theoretical CSAT or converted to LNAPL saturation numbers given other soil characteristics.
		TPH/COC dissolved-phase concentrations	Indirect	E1739-95(2010)e1; E1943-98(2010)		Concentrations can be compared to expected values of effective solubility.
		Electromagnetic surveys	Indirect	E1912-98(2004)		Infrequently applied, requires site specific confirmation.
		Resistivity	Indirect	E1912-98(2004)		Infrequently applied, require site specific confirmation.
Dissolved-phase / Vapor-phase						
Dissolved phase occurrence						
		COC dissolved phase concentrations	Indirect	ASTM E 1943; ASTM E594 - 96(2011); ASTM D7500 - 10		Also consider seasonal variations.
		LNAPL occurrence	Direct	ASTM D 95		Dean Stark
		Low-Flow sampling	Indirect	ASTM D6771-02	EPA, 1996. EPA/540/S-95/504	Low-flow (minimal drawdown) Groundwater sampling procedures
		No Purge sampling	Indirect	ASTM D4448 - 01(2007)	Cal EPA, 1997. File No. 1123.64	Utilization of Non-Purge Approach for Sampling of Monitoring Wells Impacted by Petroleum Hydrocarbons, BTEX, and MTBE.

	Passive/diffusion sampling	Indirect	ASTM D4448 - 01(2007)	Vroblesky & Hyde (1997); http://pubs.usgs.gov/fs/fs-088-00/	
	Direct Push groundwater sampling	Indirect	ASTM D6282-98; ASTM D6001-98(2002); ASTM D6724-04; ASTM D6725-01	EPA 540/R-04/005	
	Pre-packed screen wells	Indirect	ASTM D5092-02; ASTM D6725-02	EPA 540/R-04/005	
	CPT/MIP	Indirect	ASTM D6187 - 97(2010)	EPA 540/R-04/005	
	Semi-permeable Membrane Devices (SPMDs)	Indirect	ASTM D4448 - 01(2007)		
	Vertical characterization	Indirect	None		
	Integral Pumping Tests	Indirect	None		
	Fingerprinting	Indirect	ASTM D3328-06; ASTM D5739-06		
	Isotope Analyses	Indirect	None	US EPA (2005a)	EPA/600/R-04/1790, January 2005
Dissolved Phase Stability					
	Temporal trends	Indirect	ASTM D1943-98		
	Mass Flux				
	Spatial trends	Indirect	ASTM D1943-98		Qualitative analyses only.
	LNAPL Delineation Component	Indirect	None (E2531-06)		
	NSZD component	Indirect	None (E2531-06)		MNA parameters include: (O2, NO3, Fe+2, SO4, CH4).
Vapor Phase Occurrence	Direct soil gas monitoring in the vadose zone	Indirect	ASTM D5314 - 92(2006)	EPA/510/B-97/001	VOCs analysis for soil gas versus indoor air. EPA Methods TO-15 (Summa canister) vs. TO-17 (absorbent tube). An important consideration is to select the appropriate sample size. Too Large of a sample in finer grained or high moisture content soils may mix soil gas from a larger depth interval than desired including atmospheric air.
	PID/FID in vadose zone	Indirect	ASTM D5314 - 92(2006)		
	CO2/CH4/O2 profiles in vadose zone over LNAPL	Indirect	ASTM 1945-96	ITRC (2009); EPA/510/B-97/001	
	Active soil gas sampling	Indirect	ASTM D7663-12	EPA/510/B-97/001	

	Passive soil gas sampling	Indirect	ASTM D7758-11	EPA/600/R-00/091; EPA/600/R-98/095; EPA/510/B-97/001	
	Direct-push probe sampling	Indirect	ASTM D6725-01	EPA/510/B-97/001	
	Compound-specific stable isotope analysis (CSIA)	Indirect	ASTM D5739-95		
	Syringe sampling	Indirect	ASTM D7663-12	EPA/510/B-97/001	
	Discrete-interval sampling tools (vertical characterization)	Indirect	ASTM D7663-12; ASTM D7758-11	EPA/510/B-97/001	
	Dual Tube Sampling Systems	Indirect	ASTM D5314 - 92(2006)		
LNAPL Chemical/Physical Properties					
LNAPL Type					
	History/Site Knowledge/Release Knowledge	Indirect	E2247-08; E1912-98(2004); E1527-05; E1903-11; E2205/E2205M-02(2009)e1		Site history may reduce the range of LNAPL type likely occurring.
	Inference from GW and Soil Samples	Indirect	E1912-98(2004)		Specific COCs and relative concentrations may indicate the minimum expected source concentration.
	LNAPL Gas Chromatography	Direct	D7753-12		Direct measure of LNAPL composition, quality is based on the GC/FID standard or use of Mass Spectrometry.
	Analytical compositional analyses	Direct	None		Relative COC concentrations can be used to assess dissolved or vapor phase concentration maximums.
	Biomarkers	Indirect	None		Used to assess the degree of LNAPL degradation.
	Distillation	Direct	None		Qualitative measure of LNAPL composition.
	PIANO analyses	Direct	None		Gasoline range specific compositional and weathering analysis.

LNAPL Physical Characteristics (density, viscosity, interfacial tensions) - Where mobile LNAPL exists					
	Published values	Indirect	None	API 1628; API 4682; API 4731; http://www.etc-cte.ec.gc.ca/databases/OilProperties/oil_prop_e.html; Mercer & Cohen (1990)	Typically the density and viscosity of refined products varies within a small range and references can be used with reasonable error.
	Analyzed at one temperature	Direct	D1481; D445	a/a	Provides confirmation of the published values and reduces error.
	Multiple temperature analysis	Direct	D1481; D445	a/a	Allows for specific value estimation at aquifer temperature.
LNAPL Recoverability					
Extent of mobile LNAPL					
	Gauging data	Direct	ASTM D5092-90 Standard practice for design and installation of ground water monitoring wells in aquifers. D5784 Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices	Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells, EPA160014-891034, March 1991 RCRA GROUND-WATER MONITORING, DRAFT TECHNICAL GUIDANCE, OFFICE OF SOLID WASTE, U.S. EPA, NOVEMBER 1992 Environmental Response Team (ERT), US EPA. Monitor Well Installation, SOP No. 2048 Environmental Response Team (ERT), US EPA. Monitor Well Development, SOP No. 2044	Most consistent method to identify where mobile LNAPL exists.
Magnitude of LNAPL mobility					
	Pilot test data	Direct	E2856-12		Results in and LNAPL transmissivity value or a specific recovery rate for drawdown induced/existing gradient.
	Recovery data	Direct	E2856-12		
	Manual Skimming data	Direct	E2856-12	API 4760	
	Frequency of LNAPL detection in wells	Indirect	E2856-12		
	Tracer tests	Indirect	E2856-12	Sale and others (2007)	

	Baildown tests	Direct	E2856-12	API LNAPL Transmissivity Workbook	
Residual LNAPL					Shake Test and Paint Filter tests are not appropriate to differentiate between residual and mobile LNAPL. Residual LNAPL is soil type, LNAPL type dependent and also varies across a given plume from a maximum near the release point to a minimum at the fringe. Residual saturation also varies for saturated and vadose zone conditions.
	Frequency of LNAPL detection in wells	Direct			Wells are the most reliable method of understanding if LNAPL is residual; however they do not quantify residual vs. mobile magnitude.
	Centrifuge Core Testing	Direct		API RP40 (method);	Methods such as the 1000G method likely result in false positives for mobile LNAPL. It is worthwhile to design core testing to be more representative of site conditions. Testing cores for the saturated zone under water rather than in air is more appropriate also lower gradients across the core are likely more appropriate.
	Soil Type Reference	Direct		API RP40 (method); API 4760; Johnstone and Adamski 2005	Historic references that provide absolute values of residual saturation vs. a given soil and oil type such as Mercer and Cohen (1990) are inconsistent with current understanding. Residual saturation within a given soil type varies and is dependent on the saturation history of that core. This behavior represented by the f-factor (Johnstone and Adamski 2005).
	Water Flood Testing	Indirect			This is a new test that induces gradients that better represent site conditions. The tests are longer in duration and higher cost than centrifuge.
LNAPL Body Stability					
Document, no on-going release	Document release history				
Stable footprint in terms of LNAPL body extent (Strong reliance on additional components)					
	Stable dissolved/vapor phase center of mass	Indirect	E1943-98; (E2531-06)	API 2004; API 4715;EPA/540/5-95/500; EPA/542/R/04/011; API Bulletin No. 9, No. 18; ITRC 2009a, ITRC 2009b; Mace et al., 1997; Rice et al., 1995	Stability of other phases is anecdotal evidence for LNAPL body stability.

		Visual documentation of sheens or lack thereof on nearby surface water-bodies, soil banks, or ground surface	Indirect	(E2531-06)		
		Document release history; Historical Gauging Data	Indirect	(E2531-06)		Historical gauging data may show declining rate of lateral spreading; long-term non-detections of LNAPL at sentinel well(s) supports stability determination.
		Quantify resistance to flow, Remedial efforts and entry pressure head	Indirect	(E2531-06)	API Bulletin No. 9; API Publ 4760, Mayer and Hassanizadeh, American Geophysical Union, Water Resource Monograph 17	
		Quantify migration potential, LNAPL seepage velocity, LNAPL transmissivity, LNAPL gradient vs. NSZD rate	Indirect	ASTM 2012 LNAPL Transmissivity	API 2004; API 4711; API 4760; ITRC 2009a, ITRC 2009b	LNAPL transmissivity and air-LNAPL gradients decline with lateral spreading, smearing, and chemical weathering over time.
		Quantify LNAPL body losses	Indirect	(E2531-06)	Mahler et al, 2013?;	Rates of LNAPL mass depletion eventually balance and then overcome rates of lateral spreading; facilitated by resistance at the leading edge.
		Statistical trend analysis	Indirect	E1943-98		
		Changes in LNAPL composition	Indirect	(E2531-06)	ITRC 2009a; Lundegard and Johnson, 2006	Changes in degree of weathering indicate ageing of existing LNAPL or addition of a newer release and/or mixing.
		Current LNAPL Source Zone Mass Loss (mass Flux)	Direct		Johnson et al., 2006 ; ITRC, 2009 Lundegard and Johnson, 2006	Qualitative confirmation of LNAPL dissolution to groundwater/volatilization to vadose zone.
Natural Degradation Processes						
		Future Site Setting	Indirect	None (E2531-06)	Johnson et al., 2006 ; ITRC, 2009	Qualitative confirmation of LNAPL dissolution to groundwater/volatilization to vadose zone.
		Future Chemical Physical properties	Indirect	E1943-98; (E2531-06)	Johnson et al., 2006 ; ITRC, 2009	Qualitative confirmation of biodegradation of dissolved LNAPL body mass.
		Future Plume Stability	Indirect	E2531-06	Johnson et al., 2006 ; ITRC, 2009	Qualitative confirmation biodegradation of volatilized LNAPL body mass.
		Future Dissolved Phase	Indirect	D7833-12	NRC, 2000; ITRC, 2009	Measure changes in dissolved phase COC concentrations over time.

		NSZD Soil Gas Gradient Method	Indirect	None	Johnson et al., 2006, Millington & Quirk, 1961 API 2017	Semi-quantitative: Assign literature value based on soil type.
		NSZD CO_2 Efflux Trap Method	Indirect	None	McCoy et al., 2014, API 2017	Quantitative determination of total mass loss via stoichiometric conversion of CO_2 flux above LNAPL body. Based on a passive soil gas flux trap.
		NSZD CO_2 Efflux Chamber Method	Indirect	None	Sihota et al., 2011, API 2017	Quantitative determination of total mass loss via stoichiometric conversion of CO_2 flux above LNAPL body. Based on a dynamic closed chamber.
		NSZD Biogenic Heat Method	Indirect	None	Sweeney and Ririe, 2014 Warren and Bekins, 2015, and Stockwell, 2015	Quantitative determination of total mass loss via thermodynamic conversion of heat flux above LNAPL body. Based on subsurface temperature monitoring.
		LNAPL Compositional Change	Direct	None (emerging)	Garg et al., 2017	Trend change in COC content of LNAPL over time to estimate chemical-specific NSZD rate
		Respiration Testing	Indirect	None	AFCEE, 1992	Estimate biodegradation rate via oxygen utilization rates.