State of Texas

Document on Light Phase Non-aqueous Phase Liquids (LNAPLs)

Draft April 2004

2.0 NAPL Assessment and Management Requirements for TRRP

NAPL can present various concerns depending on the characteristics of the NAPL and site conditions. Typically, NAPL is of regulatory concern because it may be:

- A safety hazard,
- A source of explosive or toxic vapor accumulations in surface or subsurface structures,
- Toxic to human or ecological receptors,
- A source for dissolved COCs in groundwater or surface water, and/or
- The cause of a nuisance condition or aesthetic impairment.

In short, NAPL represents a COC source area that must be properly assessed and managed in order for the person to demonstrate compliance with Remedy Standard A or B (see TCEQ guidance document *Application of Remedy Standards A and B* (RG-366/TRRP-13) for general information on Remedy Standards A and B).

> In this guidance, "NAPL management" includes NAPL recovery and control. "NAPL recovery" encompasses both NAPL removal and decontamination. Removal of NAPL by liquid-phase extraction is an example of NAPL recovery. Other examples of NAPL recovery include phase-change remedial strategies such as volatilization of the NAPL and extraction of the vapors (removal) or solubilization of the NAPL and in-situ biodegradation of the dissolved COCs (decontamination).

Table 1 lists the rule provisions that are applicable to NAPL with regard to particular situations and in terms of Remedy Standard A and B. *Under Remedy Standard A, NAPL recovery is the only NAPL management option*. Under Remedy Standard B, NAPL may be recovered and/or controlled, depending on the situation.

It should be noted that, in some instances, the rule provisions cited in Table 1 may not mention NAPL directly. In those instances, the provision is general and as such encompasses NAPL since NAPL is comprised of one or more COCs and represents a potential COC source area.

The remainder of this section discusses NAPL management requirements in the sequence presented in Table 1.

2.1 NAPL Release Abatement and Hazard Mitigation

Upon discovery of a release, immediate actions should be taken by the person to stop further release of the NAPL from the primary source (*e.g.*, tank, pipeline, *etc*.) and to mitigate any hazards stemming from the NAPL such as fire hazards, or other safety concerns. Table 1 includes NAPL release abatement and hazard mitigation for completeness, but these topics are not further discussed by this guidance as it is presumed those actions have been taken prior to the application of TRRP to the project. Section §350.1 sets the expectation that such actions will be taken and clarifies that nothing in TRRP prevents interim actions from being taken to abate releases and mitigate hazards.

Table 1. NAPL Assessment and Management Provisions

	NAPL Assessment or Management Provision	Remedy Standard A[1]	Remedy Standard B
	Abate the NAPL release and mitigate immediate hazards	§350.1	§350.1
	Assess for NAPL presence, extent, and distribution, NAPL management triggers, and as required for design of a response action	§350.51(a) and (b)	§350.51(a) and (b)
NAPL Management Triggers	**Abate explosive conditions resulting from NAPL via NAPL recovery, or control as interim measure**	§350.31(c)	§350.31(c)
	Stabilize expanding NAPL zone by recovery or control	§350.33(f)(4)(F)(iii)(II), §350.37(d), §350.74(i)(2)(A), §350.75(i)(10)	§350.33(f)(4)(F)(iii)(II), §350.37(d), §350.74(i)(2)(A), §350.75(i)(10)
	Abate aesthetic impacts or nuisance conditions resulting from NAPL with recovery or control[2]	§350.74(f)(3) and §350.74 (i)	§350.74(f)(3) and §350.74 (i)
	Manage NAPL that represents a PCL exceedance[3]		
	Recover or prevent exposure[4] to NAPL in soil via control	§350.31(b) and §350.32(a)-(b)	§350.33(b)
	Recover NAPL in contact with Class 1 groundwater [2, 5, 6]	§350.31(b), §350.32(a)-(b) §350.74(f)(3)	§350.33(b), §350.33(f)(2), §350.33 (f)(3), §350.33(f)(4)(E), §350.74(f)(3)
	Recover or prevent exposure to NAPL in contact with Class 2 groundwater via control[5, 7]	§350.31(b), §350.32(a)-(b) §350.74(f)(3)	§350.33(b), §350.33(f)(2), §350.33(f)(4)(E), §350.74(f)(3)
	Recover or prevent exposure to NAPL in contact with Class 3 groundwater via control[5, 7]	§350.31(b), §350.32(a)-(b) §350.74(f)(3)	§350.33(b), §350.33(f)(2), §350.33(f)(4)(E), §350.74(f)(3)
	Recover NAPL in contact with surface water[2] and recover NAPL in the surface water sediment.	§350.74(h)(6)(A), §350.74(h)(6)(C), §350.74(i)	§350.74(h)(6)(A), §350.74(h)(6)(C), §350.74(i)

PCL = protective concentration level PMZ= plume management zone WCU = waste control unit

Footnotes:

1. Under Remedy Standard A, only NAPL recovery is allowed as final NAPL management objective. Controls may be applied only under Remedy Standard B.
2. Recovery of NAPL is required if the NAPL is in contact with Class 1 groundwater or surface water, or within the surface water sediment, unless the person demonstrates NAPL recovery is technically impracticable or in the case of surface water and sediment, that NAPL recovery will have a significant and highly disproportionate effect on ecological receptors. A control must be applied if NAPL is not recovered.
3. NAPL is generally inferred to exceed a PCL
4. Includes cross-media exposure (e.g., toxic vapors from NAPL-to-air, leachate from NAPL in soil to groundwater)
5. Possible WCU exclusion for recovery (§350.33(f)(2).
6. If full recovery is technically impracticable, then submit TI demonstration and control NAPL within PMZ (§350.33(f)(3).
7. PMZ may be directly proposed or pursued via a technical impracticability demonstration for Class 2 and 3 groundwater. If control, control NAPL within PMZ (§350.33(f)(4)).

2.2 NAPL Assessment

The nature and degree of COCs in a source area must be reliably characterized [§350.51(b)]. NAPL assessment is detailed in Section 4.0. In general, the goal of the NAPL assessment is to identify any NAPL present and to sufficiently characterize it such that an appropriate NAPL management strategy is employed.

2.3 Explosive Condition Prohibitions

Section 350.31(c) requires the person to abate and prevent the accumulations of explosive vapors in surface or subsurface structures. The potential for NAPL to generate explosive vapors in surface and subsurface structures must be evaluated. If NAPL generates or will generate explosive conditions in surface or subsurface structures, then NAPL must be addressed such that explosive vapor generation is mitigated. TRRP considers explosive vapors to be of a general concern for basements, buildings, storm sewers, and subsurface manways or other surface or subsurface structures in proximity to NAPL. If explosive vapors are encountered, immediately notify and coordinate with the proper officials, and all appropriate actions should be taken to protect human health and safety.

Although not an explicit requirement in the rule, because explosive conditions can result in catastrophic and deadly outcomes, the regulatory preference is that the volatile hazard be mitigated by recovering the volatile fraction of the NAPL in the NAPL zone rather than relying solely on a control such as a vapor barrier or vapor suppression system. However, such control measures may need to be put in place immediately as an interim measure. Recovery of the volatile fraction will result in a permanent mitigation of the hazard and may be more cost effective because no constant and aggressive explosive vapor-monitoring program is warranted once the volatile hazard is eliminated.

2.4 NAPL Zone Expansion Prohibitions

In order to satisfy Remedy Standard A or B, NAPL cannot continue to migrate. If the NAPL zone is expanding, then the NAPL must be managed to prevent any further migration. Sections §350.33(f)(4)(F)(iii)(II), §350.37(d), §350.74(i)(2)(A), and §350.75(i)(10) collectively speak to the goal that NAPL not be allowed to spread.

Specifically, §350.33(f)(4)(F)(iii)(II) requires that groundwater source areas (*e.g.*, NAPL) within a plume management zone (PMZ) not be allowed to expand vertically and/or horizontally. If NAPL is not allowed to expand within a PMZ, then NAPL cannot be allowed to expand in more restrictive situations (*e.g.*, no PMZ).

Section 350.37(d) prohibits affecting currently unaffected groundwater-bearing units (GWBU). Therefore, if NAPL is not already in contact with a GWBU, then it cannot be allowed to migrate until it comes in contact with a GWBU. This includes continued vertical NAPL migration from shallower GWBUs to deeper GWBUs.

Section 350.75(i)(10) requires that a PCL ($Soil_{Res}$) be established for residual saturation (*i.e.*, the NAPL saturation above which NAPL may be mobile). A COC concentration in excess of the theoretical residual saturation limit PCL suggests that sufficient NAPL may be present to result in expansion of the NAPL zone. In such an instance, the person should assess whether the NAPL is in fact present, and if so, whether the NAPL is expanding. For Tier 1, the $Soil_{Res}$ PCL is 10,000 mg/kg. However, under Tier 2, this value can be adjusted to reflect the characteristics of the NAPL and geologic medium. Appendix 1 and Tools 1 and 2 in Appendix 2 provide guidance and information for evaluating the residual saturation limit.

2.5 Nuisance or Aesthetic Abatement Requirements

TRRP contains nuisance and aesthetics provisions that factor into the assessment. With regard to odor or other nuisance conditions, the person should be proactive in addressing those but, in general, TCEQ typically will not focus on such matters unless there is a complaint made to the TCEQ about the matter. Exceptions are where COC concentrations present objectionable characteristics (*e.g.*, taste or odor) in Class 1 or Class 2 groundwater when there is a threat to a drinking water well or when there are no drinking water alternatives other than that Class 2 groundwater [§350.74(f)(3)]. When NAPL is in contact with Class 1 or Class 2 groundwater in those certain situations it will be considered to present an objectionable characteristic (*e.g.*, taste or odor) until proven otherwise, and must be proactively addressed.

TRRP prohibits leaving NAPL pools or mobile NAPL, sludges, or concentrations of COCs that compromise the physical integrity of the soil such that it is not able to bear the loads associated with normal surface use of the affected property (§350.74(i)(2)). This is a general provision that applies to any COC that is a liquid at standard temperature and pressure at a concentration greater than 10,000 mg/kg in the soil zone (*i.e.*, extending from ground surface to a depth of 10 feet below ground surface). Therefore, if the critical soil PCL and COC concentration are greater than 10,000 mg/kg in the upper 10 feet of the soil column, then assess for the presence of NAPL. If NAPL is present in that 10-foot soil interval in excess of residual saturation, then a response action is required.

Also, there are certain applicable aesthetic-based requirements for NAPL affecting surface waters. At a minimum, there cannot be any residues (such as NAPL) in amounts that produce a visible film of oil or globules of grease on the surface or coat the banks or bottoms of the water course. See Section 3.5 of TCEQ guidance document *Determining PCLs for Surface Water and Sediment* (RG-366/TRRP-24) for further information.

2.6 NAPL Represents a PCL Exceedance

If any of the above NAPL requirements do not trigger a response action for NAPL at an affected property, then this provision typically will trigger those actions. If the representative concentration of a COC exceeds a PCL, then a response action in accord with Remedy Standard A and B is required. Such a response action is triggered by TRRP in order to protect against current and future exposures. Since NAPL is comprised of one or more COCs, NAPL inherently represents a PCL exceedance. Therefore, if NAPL is present in soil, or in contact with groundwater or surface water, NAPL must be recovered and/or controlled. The only exception is if the NAPL is:

- non-toxic for direct contact (if located within the surface soil),
- not causing COC concentrations in air or groundwater to exceed PCLs,
- not expanding,
- not creating a nuisance or aesthetic impact, and
- is not in contact with Class 1 or Class 2 groundwater meeting the conditions of §350.74(f)(3)(B) and (C), or surface water.

An example of an exception might be a food grade mineral oil NAPL present in subsurface soil at residual concentrations in clay overlying Class 3 groundwater. In this case, NAPL would not typically trigger a response action.

Table 1 lists the general performance requirements for NAPL in soil, and for NAPL in contact with groundwater and surface water.

2.6.1 NAPL in Soil

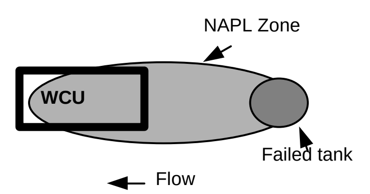
If NAPL is present in the soil (vadose zone), then the NAPLs may be recovered or controlled, provided the person can impose the institutional control that is required for a control remedy. See TCEQ guidance document *Institutional Controls* (RG-366/TRRP-16) for information on institutional controls. The NAPL control must allow critical PCLs in other environmental media to be met (*e.g.*, if the NAPL is sourcing a dissolved PCLE zone, then the control must allow the critical groundwater PCLs to be met at the applicable point of exposure).

2.6.2 NAPL in Contact with Groundwater

If NAPL is in contact with groundwater, there is less flexibility to use a control remedy for the NAPL. Class 1 groundwater is to be restored to critical PCLs. Therefore, NAPL in contact with Class 1 groundwater must be recovered. The only potential exception is if the NAPL is beneath a waste control unit (WCU). A WCU is discussed in more detail later. NAPL can only be left in contact with Class 1 groundwater or where recovery is proved to be technically impracticable. In that instance, a PMZ must be established for the NAPL and any associated dissolved PCLE zone.

The general groundwater response objective for NAPL in contact with Class 2 or Class 3 groundwater is recovery of the NAPL and compliance with critical PCLs. However, there are three exceptions. The first recovery exception is if the NAPL is beneath a WCU. The second recovery exception is if TCEQ approves the establishment of a PMZ. Within a PMZ, the NAPL must be recovered to the extent practicable [§350.33(f)(4)(E)] (i.e., meaning that complete NAPL recovery may not be required). The third recovery exception is for non-toxic NAPL. For Class 2 groundwater situations where §350.74(f)(3)(B) or (C) (see Section 2.5) are not applicable and for Class 3 groundwater, non-toxic NAPL is not required to be recovered unless some degree of recovery is needed to stabilize an expanding NAPL zone, address an explosive condition, or address other aesthetic or nuisance issues [§350.74(I)].

2.6.2.1 Waste Control Units. No groundwater points of exposure are considered to exist within the footprint of a WCU [§350.33(f)(2)]. Hence, there is not a groundwater response objective for NAPL in contact with Class 1, 2 or 3 groundwater beneath a WCU. The groundwater response objectives for NAPL discussed in Section 2.6.2 apply at and beyond the perimeter of the WCU as projected down into the groundwater. In the example presented in Figure 3, NAPL recovery is only required for the portion of the NAPL that is present outside the perimeter of the WCU, unless NAPL recovery beneath the WCU is the only action that will allow groundwater response objectives to be met beyond the perimeter of the WCU. See TCEQ guidance document *Soil and Groundwater Response Objectives* (RG-366/TRRP-29) for information on WCUs.



- Groundwater response objective to recover NAPL such that critical PCLs are met is not applicable within WCU boundary
- Groundwater response objectives to recover NAPL such that critical PCLs are met applies beyond WCU boundary
- WCU is applicable for Class 1, 2 and 3 groundwater and must be proposed in a response action plan for TCEQ approval

Figure 3. Map view of NAPL groundwater PCLE zone extending beneath a waste control unit.

2.6.2.2 Plume Management Zone. Within a PMZ, the groundwater response objectives for NAPL in contact with groundwater are modified from complete recovery to recover NAPL to the "extent practicable." Therefore, NAPL recovery requirements are reduced within a PMZ relative to an affected property where a PMZ is not established. The performance criteria of "to the extent practicable" is addressed in §350.33(f)(4)(E) in the rule as generally:

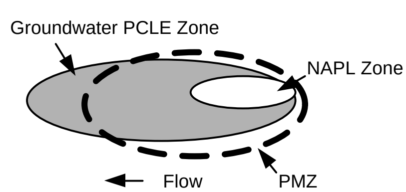
- readily recoverable NAPLs have been recovered,
- NAPLs do not generate explosive conditions in surface or subsurface structures,
- NAPLs will not discharge to ground surface, surface waters, structures or other groundwater-bearing units,
- natural conditions (residual or stable NAPL zone) or operation of a containment system prevent NAPL zone expansion, and
- critical groundwater PCLs can be met at the alternate point(s) of exposure.

The agency may use any or all of these criteria, or other relevant and appropriate criteria to determine whether NAPL has been recovered to the extent practicable for any given affected property. The NAPL recovery endpoint should be consistent with the response action objectives for the affected property.

A common criterion in evaluating recovery to the extent practicable will be consideration of whether the "readily recoverable" NAPL have been recovered and whether the remaining NAPL will result in any unacceptable situations. In some instances, all of the NAPL may be readily recoverable. In other instances, none of the NAPL may be readily recoverable. Section 3.0 provides guidance for evaluating the "readily recoverable" threshold. In general, only conventional recovery technologies such as liquid phase extraction or soil vapor extraction need be considered. The criterion "readily recoverable NAPLs have been recovered" is not a mandatory requirement, but a criterion that may be warranted on a site-specific basis. Generally, preference for use of that criterion will be when:

- the NAPL zone is expanding,
- the NAPL zone is sourcing an expanding dissolved-phase PCLE zone, or
- a PMZ is established for the NAPL zone via a TI demonstration.

In the example presented in Figure 4, NAPL is contained within the limit of the PMZ. Therefore, the NAPL must be recovered only to the extent practicable. Any NAPL present beyond the limit of the approved PMZ must be addressed under the NAPL groundwater response objectives discussed in Section 2.6.2. See TCEQ guidance document *Application of Remedy Standards A and B* (R6-366/TRRP-28) for additional information on PMZs.

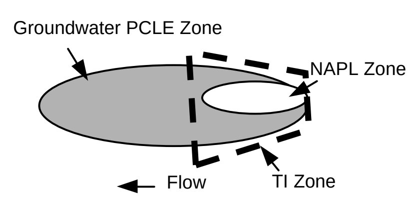


- Within PMZ, groundwater response objective to recover NAPLs such that critical PCLs are met is modified to recovery of NAPL "to the extent practicable"
- Beyond PMZ, groundwater response objective to recover NAPL such that critical PCLs are met applies
- A PMZ must be proposed in a response action plan for TCEQ approval

Figure 4. Map view of dissolved-phase and NAPL groundwater PCLE zone and limit of PMZ.

2.6.2.3 Technical Impracticability. A TI demonstration is applicable to NAPL in any environmental medium, although it is only specifically discussed in the rule in the context of groundwater [§350.33(f)(3)]. However, a TI demonstration is only warranted when there is a rule requirement to recover all NAPL and NAPL recovery is not practicable. In general, NAPL recovery is required for two different conditions. The first condition is that the response objective for NAPL is limited to recovery. Examples of this are NAPL in contact with Class 1 groundwater, or NAPL in contact with Class 2 or Class 3 groundwater and a proposed PMZ is not approved by the TCEQ. The second condition is where NAPL control is an otherwise acceptable management option, but the person cannot obtain the consent from the landowner to impose the required institutional control for a control remedy. For groundwater, if the TI demonstration is approved by TCEQ, a PMZ must be established (§350.33(f)(3)(E)) and NAPLs must be managed in accordance with §350.33(f)(4)(E) as discussed above in Section 2.6.2.2.

Figure 5 illustrates the result of applying of a TI demonstration. The area covered by the TI demonstration is referred to as a TI zone. Within the TI zone, the NAPL is recovered to the "extent practicable." However, if for some reason the NAPL extended beyond the limit of the approved TI zone, then that NAPL present beyond the limit of the TI zone would have to be recovered to meet the groundwater response objective for NAPL discussed in Section 2.6.2. An institutional control must be filed for the TI zone. Examples of what may constitute a sufficient level of TI demonstration for particular situations are presented in Appendix 4 of this document.



- Within TI zone, groundwater response objective to recover NAPLs such that critical PCLs are met is modified to recovery of NAPL "to the extent practicable"
- Beyond TI zone, groundwater response objective to recover NAPL such that critical PCLs are met applies
- TI demonstration must be submitted within response action plan for TCEQ approval

Figure 5. Map view of dissolved-phase and NAPL groundwater PCLE zone with designated TI zone.

2.6.3 NAPL in Contact with Surface Water and NAPL in the Surface Water Sediment

NAPL can represent a toxic level to the biota in a surface water body and associated sediment. NAPL that is in contact with surface water and NAPL in the sediment in the bed of a surface water body must be recovered. Additionally, aesthetic considerations are also of concern as discussed earlier. The only two exceptions are if a demonstration is made that it is technically impracticable to recover the NAPL, or if a determination is made that recovery of the NAPL, from the bed of the surface water body for example, would have a significant and highly disproportionate impact on ecological receptors. For example, dredging the NAPL may result in net loss of ecological activity further downstream. In either of these two instances, a control generally must be put in place to isolate the NAPL from the surface water and the benthic community.

3.0 NAPL Management Program

This section describes the stepped procedure and requirements for managing occurrences of NAPL. The management process includes NAPL site assessment, identifying NAPL management triggers, developing appropriate NAPL management goals, implementing NAPL management solutions, and demonstrating NAPL management effectiveness. The NAPL management program is organized into the following six Steps:

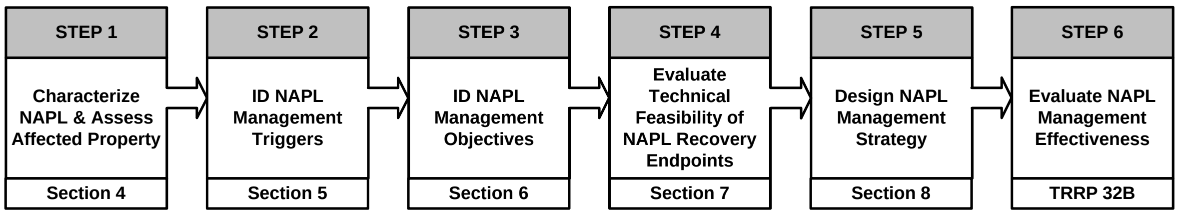


Figure 3-1: Steps of the NAPL Management Program

Each Step of the NAPL Management Program (Figure 3-1) must be followed in sequence. A summary of each NAPL Management Step is given below in this section. Full descriptions of each NAPL Management Step, including logic flow charts and summary tables are provided in the corresponding Section numbers that appear in Figure 3-1.

The flow chart of NAPL Management Steps shown in Figure 3-1 is simplified to illustrate the sequential NAPL management process. Figure 3-2 shows the major logic/decision flow paths for the NAPL management program and serves as a reference for the NAPL management overview.

The NAPL management process is entered into at Step 1 (NAPL Assessment) when historical or field evidence indicates the likely existence of NAPL at the site (see Section 4 for details). The completion of Step 1 takes place after identifying all site-specific NAPL occurrences in the *NAPL Occurrence Matrix* (Table 4.12)

Step 2 (ID NAPL Triggers) is used to determine whether NAPL management is necessary and, if so, which NAPL trigger(s) require(s) attention (see Section 5 for details). The successful completion of Step 2 occurs when all site-specific NAPL Triggers have been identified on the *NAPL Management Triggers Matrix* (Table 5.1). Table 5.1 also indicates triggers that require a *Recovery I* response action or a *Recovery II* response action.

Step 3 (ID NAPL Management Response Actions) is used to determine the appropriate response action(s) (*i.e.*, recovery or control options) at the site (see Section 6 for details). The qualitative “tools” incorporated into Step 3 can facilitate the response action determination. Recovery I NAPL triggers require a recovery response action and Recovery II NAPL triggers may allow a control response action based on the perceived benefits of recovery (Tool 3A) and the availability of institutional controls for the site. Step 3 is completed when all applicable response objective options have been identified in the *NAPL Management Response Action Matrix* (Table 6.1). Sites requiring control-only objectives proceed directly to Step 5.

Step 4 (Technical Feasibility of Recovery/ID Endpoint) may be used in both Recovery I and Recovery II response action options to assist in determining whether a conventional recovery technology is likely to be effective (see Section 7 for details). Step 4 also is used to identify the applicable NAPL Recovery Endpoint in the *NAPL Recovery and Control Endpoints Matrix* (Table

7.1). In all cases, an effective NAPL recovery system should be designed to achieve the recovery endpoint.

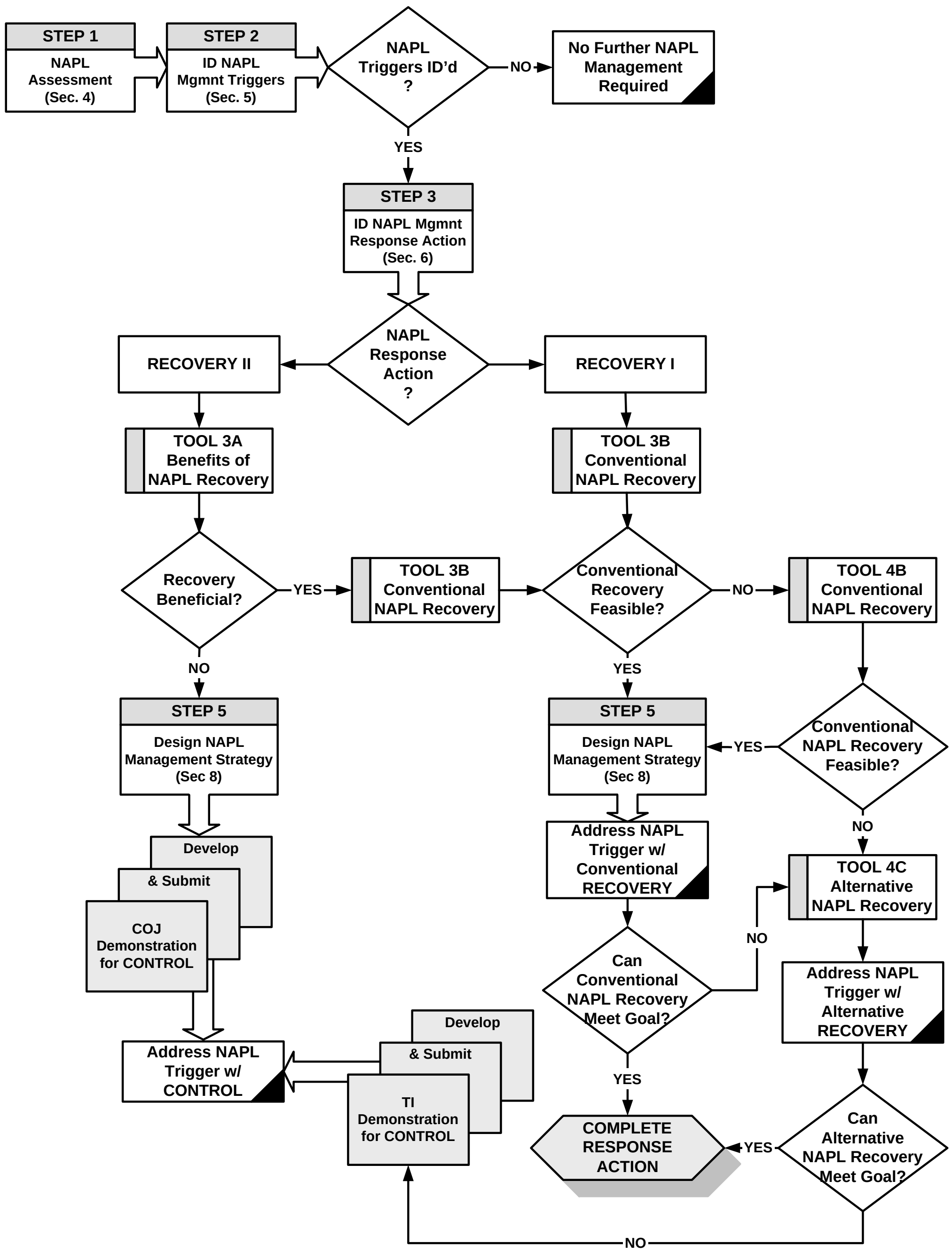


Figure 3-2: Overview of the NAPL Management Program

Step 5 (Develop NAPL Management Strategy) describes the requisite elements necessary to document the development of an effective NAPL recovery or control management strategy. The same elements are required in any proposed NAPL management RAP. Requirements for the *Control Option Justification* and the *Technical Impracticability* demonstrations are described.

Table 3.1 Summary of TRRP 32 NAPL Management Steps

	Topics	Procedure Checklist	NAPL Management Tools
STEP 1 **Characterize NAPL and Assess Affected Property** **(Section 4)**	4.1 Detection of NAPL 4.2 NAPL Composition Methods 4.3 NAPL Assessment LNAPL Assessment 4.4 DNAPL Assessment 4.5 NAPL Occurrence 4.6 NAPL Mobility	❑ Complete NAPL Assessment ❑ Complete *NAPL Occurrence Matrix* (Table 4.12)	• TOOL 1B - Estimate of LNAPL Thickness Method to determine true LNAPL thicknesses • TOOL 1B - Estimate of NAPL Volumes Method to determine NAPL volumes
STEP 2 **Identify NAPL Management Triggers** **(Section 5)**	5.1 Regulatory-Based NAPL Management Triggers 5.2 Risk-Based NAPL Management Triggers	❑ Follow FLOW CHART 2-1 ❑ Complete *NAPL Management Triggers Matrix* (Table 5.1)	
STEP 3 **Identify NAPL Management Response Action** **(Section 6)**	6.1 NAPL Recovery Response Actions 6.2 NAPL Control Response Actions 6.3 NAPL Management TOOL 3A 6.4 NAPL Management TOOL 3B 6.5 Use of Tools with Recovery I Response Action 6.6 Use of Tools with Recovery II Response Action	❑ Follow FLOW CHART 3.1 ❑ Follow FLOW CHART 3.2 for Recovery I ❑ Follow FLOW CHART 3.3 for Recovery II ❑ Complete *NAPL Management Response Action Matrix* (Table 6.1)	• TOOL 3A - Qualitative NAPL Management - Screen necessity for NAPL recovery based on benefits • TOOL 3B - Qualitative NAPL Management Response Action - Screen conventional NAPL recovery based on site characteristics
STEP 4 **Identify NAPL Recovery Endpoints & Evaluate Technical Feasibility** **(Section 7)**	7.1 NAPL Management Response Action Endpoints 7.2 Conventional NAPL Recovery Technologies 7.3 Alternative NAPL Recovery Technologies 7.4 Technical Feasibility Screen for NAPL Recovery Endpoints 7.5 Control Option Justification (COJ) 7.6 Technical Impracticability (TI)	❑ Follow FLOW CHART 4-1 ❑ Complete NAPL Recovery and Control Endpoints Matrix (Table 7.1)	• TOOL 4A - Quantitative Screen for Conventional NAPL Recovery Technologies • TOOL 4B - Quantitative Screen for Total Fluids Petroleum Recovery • TOOL 4C - Alternative Technology Liquid Phase Recoverability
STEP 5 **Develop NAPL Management Strategy** **(Section 8)**	8.1 NAPL Management Response Action Strategy	❑ Follow FLOW CHART 5-1	
STEP 6 **Evaluate NAPL Management Effectiveness**	**See TRRP 32-B**		

Table 3.1 summarizes the process and logic framework for implementing a NAPL management program. Included therein is a summary of the purpose of each NAPL management program Step, and associated NAPL management tools and logic charts. Additionally, a procedure checklist is included to assist in tracking the process through the steps.

The NAPL management strategy that is employed at particular affected properties should be integrated into and support the overall response action for the remediation project. Ultimately, the requirements of Remedy Standards A or B must be met within a reasonable timeframe for the particular circumstances at the affected property. See TCEQ guidance document *Application of Remedy Standards A and B* (RG-366/TRRP-28) for discussion of reasonable timeframe.

3.1 STEP 1: Characterize NAPL and Assess Affected Property

This section provides guidance and methods for effective NAPL assessments. Descriptions of NAPL characterization methods and NAPL behavior are provided to aid in assessing NAPL-affected properties. LNAPL- and DNAPL-specific assessment techniques are discussed.

Upon completion of a NAPL assessment, the person will know or be able to estimate the site-specific NAPL-related attributes summarized in Table 3.2.

Table 3.2: NAPL Assessment Objectives and Site-Specific Attributes

NAPL Assessment Objectives/Attributes	Description	Examples	Section Reference
Presence of NAPL	Assessment techniques for determining the presence of NAPL	NAPL present; NAPL likely present; NAPL not present	4.4 & 4.5
Type of NAPL	Methods for identifying LNAPL compositions	Unknown petroleum NAPL types	4.2
NAPL fluid properties	Fluid - matrix properties useful in predicting NAPL behavior and for planning assessments	Viscosity, volatility, solubility, density, wettability, *etc*.	4.3
NAPL fluid/matrix		Capillary entry pressure, residual saturation, *etc*.	
NAPL-affected media	Assessment of site-specific media affected by NAPL	Soils, GWBUs, surface water, *etc.*	4.4
NAPL occurrence	Nature of the NAPL occurring in affected media	NAPL in vadose zone, NAPL in saturated zone, NAPL in fractured saturated zone, *etc.*	4.6
NAPL mobility	Potential for NAPL zone expansion (observed and theoretical)	NAPL zone expansion monitoring	4.X

3.2 STEP 2: Identify NAPL Management Triggers

NAPL Management Triggers are occurrences of NAPL that prompt a response action under TRRP (see Table 2.1 for specific Rule citations). One or more NAPL Management Triggers can be applicable to an affected property. Based on the results of STEP 1, each NAPL occurrence should be evaluated for all possible applicable NAPL Management Triggers. Descriptions and recognition criteria for each Regulatory- and Risk-Based NAPL Management Trigger are provided and summarized. Table 3.3 summarizes the NAPL Management Trigger groups.

Table 3.3: NAPL Management Triggers

NAPL Management Triggers	Section Reference
• NAPL vapor accumulation is explosive • Expanding NAPL zone • Mobile NAPL within vadose zone • NAPL creates an aesthetic or nuisance condition	5.1
• PCL exceedances • NAPL in contact with groundwater • NAPL in contact with surface water and sediments	5.2

3.3 STEP 3: Identify NAPL Management Objectives

NAPL Management Objectives are the response action goals associated with satisfying each NAPL Management Trigger. Various NAPL Management Objectives are prescribed depending on the NAPL Management Trigger(s) involved and can include response actions ranging from complete to partial NAPL recovery and/or control. Descriptions of NAPL Management Objectives commensurate with each NAPL Management Trigger (from STEP 2) are provided. STEP 3 also includes Qualitative NAPL Management Tools (Tools 3A and 3B) for screening the use of conventional *vs* alternative NAPL recovery technologies and control.

3.4 STEP 4: Determine Endpoints and Evaluate Technical Feasibility

Determine all appropriate NAPL Recovery Endpoints and NAPL Control Endpoints associated with each NAPL Management Objective (from STEP 3). Technical feasibility screening for NAPL recoverability is conducted using Recoverability Tools (Tools 4A, 4B and 4C).

3.5 STEP 5: Develop NAPL Management Strategy

Develop all applicable Technical Impractibility (TI) and Control Option Justification (COJ) demonstrations. Develop Remedial Action Plan (RAP) requirements for a NAPL recovery system and/or control design that is commensurate with addressing the applicable NAPL Recovery and Control Endpoints (STEP 4). The RAP includes system design-based recovery/time frame prediction, system performance monitoring methods, system implementation schedule and tenure, and contingency measures for system performance failure.

3.6 STEP 6: Evaluating NAPL Management Effectiveness

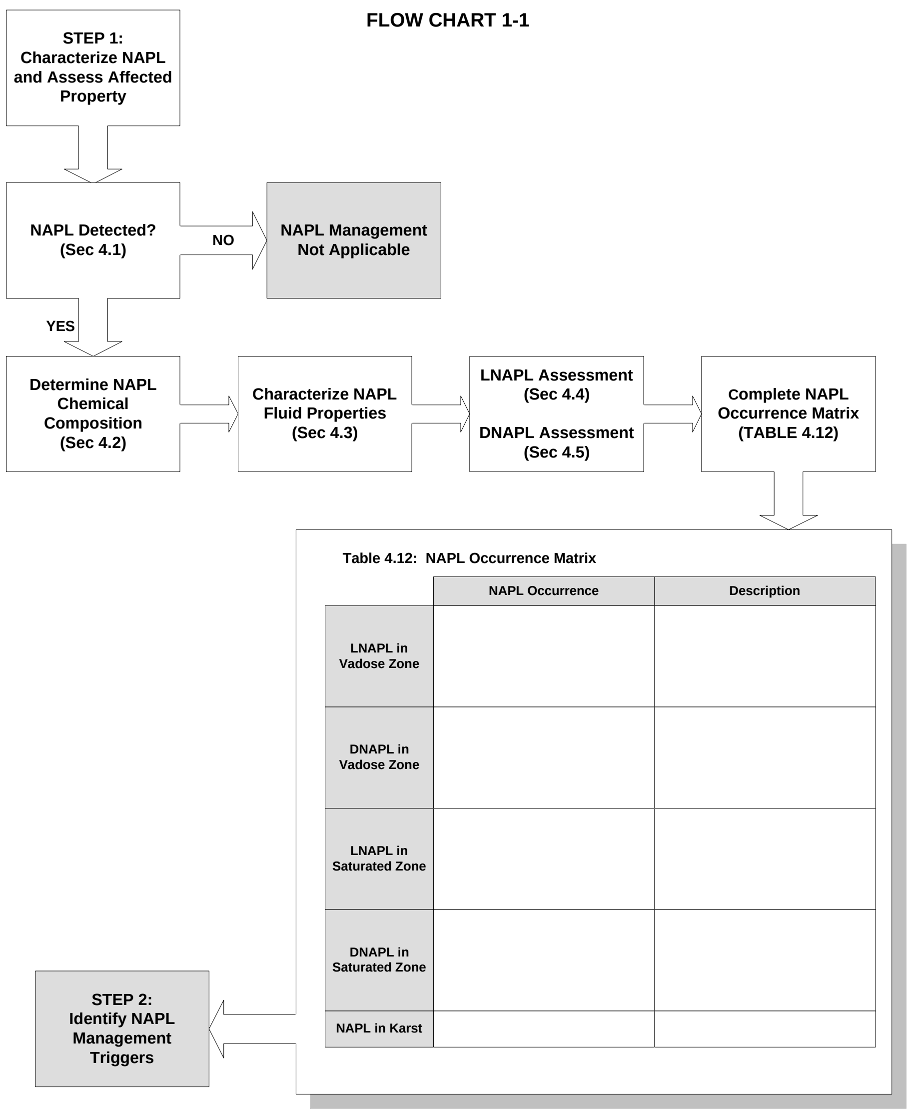
Evaluate and relative effectiveness of the performance of NAPL recovery systems measured against the design-based recovery/time frame prediction. Define the conditions that signal diminished effectiveness of NAPL recovery systems and the likelihood of meeting the NAPL Recovery Endpoint(s). Evaluate other options available to the User when the NAPL recovery system cannot meet the NAPL Recovery Endpoint(s). Guidance on Step 6 is provided in TRRP 32-B.

4.0 STEP 1: Characterize NAPL and Assess Affected Property

The following sections summarize methods applicable to detecting the presence of NAPL in the subsurface, quantifying NAPL physico-chemical properties, and assessment techniques for the distribution and delineation of LNAPL and DNAPL in the subsurface. The results of the NAPL assessment should be presented in an Affected Property Assessment Report (TCEQ Form No. 10325/APAR).

FLOW CHART 1-1 summarizes the STEP 1 procedure and its logic flow. Some assessment steps may be optional.

FLOW CHART 1-1



4.1 Detection of NAPL

As part of the affected property assessment, the presence of NAPLs in the subsurface should be specifically investigated. Areas closest to the original release location may be most likely to yield evidence of the presence of NAPLs. The investigation should consider potential preferential flowpaths, chemical/physical properties of the NAPL and NAPL COCs, as well as geologic conditions that may have controlled the distribution of the NAPLs.

The presence of NAPL in the subsurface may be deduced either with direct evidence, indirect evidence, or both. This section provides guidance on field techniques by which evidence of the presence of NAPL can be collected.

4.1.1 Direct Evidence for the Presence of NAPL

Direct observation of NAPL in the subsurface is the most persuasive indicator for the presence of NAPL in the subsurface. Several field methods can be readily employed during normal assessment operations to check for NAPL.

4.1.1.1 NAPL in borings/monitoring wells. The presence of NAPL accumulations in a well is the best evidence that NAPL is present in the subsurface. For example, presence of NAPL can be detected using bailers, weighted cotton string, pumps, indicator pastes and other methods.

4.1.1.2 NAPL in soils. The presence of NAPL should be evaluated in all soil samples from drilling operations and reported in boring logs. NAPL, if present, should be described in as much detail as possible. Descriptors include color, flowing or non-flowing, and a qualitative saturation estimate (*e.g.*, "… pore space mostly filled with NAPL …", or "… NAPL only in secondary porosity …").

In cases of gross NAPL contamination, a visual inspection of a soil core can confirm that NAPL is present in the subsurface. For example, a soil core that is saturated with oil usually is discernable with unaided eyesight. NAPL that is present in small secondary porosity features or occurs as small globules may be difficult to observe without magnification, particularly if the NAPL is colorless or has a color similar to the soil matrix.

Several field methods can be employed to detect NAPL in soil that is not readily visible. The following tests have been proposed (*e.g.*, Cohen *et al.* (1992); Griffin and Watson (2002), *etc*.) for soil samples:

1) *Unaided visual inspection* – inspect soil samples visually for presence of NAPL.

2) *Organic Volatile Analysis (OVA)* – confine soil sample in sealed jar or plastic bag for a minimum of 15 minutes; open container, insert probe of portable OVA with PID analyzer; test for organic vapors. Concentrations of 100 ppm and greater are indicative of NAPL.

3) *UV fluorescence examination* – place soil sample in a light-restricted container; illuminate sample with a UV light source; many DNAPLs fluoresce.

4) *Soil-water shake test* – place soil sample in jar or plastic bag with water; shake mixture; examine water for presence of NAPL.

5) *Hydrophobic dye with soil-water shake test* – perform soil-water shake test (as above); add hydrophobic dye (*e.g.*, Sudan IV or Red Oil) to water; most NAPLs will become colored with the dye.

6) *Paint filter test* – place soil sample in a filter funnel; add water; allow drainage; examine filter paper for presence of NAPL.

4.1.2 Indirect Evidence for the Presence of NAPL

Confirming the presence of NAPL in the subsurface by direct evidence is not always possible. However, indirect evidence can be used to infer the presence of NAPL at an affected property. The following sections summarize some common indirect techniques.

4.1.2.1 COC concentrations in groundwater. COCs dissolved in groundwater in the immediate vicinity of NAPL source zones can be near the COCs' aqueous solubility limit. However, COC concentrations that high are rarely observed in the field. Two reasons are commonly given to explain this observation: 1) dissolved NAPL COC mixtures can limit each component's solubility and result in a lower *effective solubility* concentration for each respective COC in the mixture, and 2) the typical monitoring well, constructed with a 10 - 20 foot long screen, can intersect groundwater flowlines that do not contact NAPL, resulting in overall dilution of the groundwater flowlines which contain dissolved NAPL.

Effective solubility can be calculated using the following relationship:

$$S_i^e = X_i S_i \tag{4.1}$$

Another indirect indicator of NAPL is the detection of dissolved COCs in groundwater at concentrations greater than 1% of the pure-phase or effective solubility (*e.g.*, USEPA, 1992; Pankow and Cherry, 1996). However, dissolved COC concentrations *less than* 1% does not mean NAPL is not present. A modified version of the rule that considers the presence of multi-component NAPLs was presented by the USEPA (1992).

Table 4.1 lists aqueous solubility values for common COCs. Solubility values for other COCs can be found in TRRP: *Figure 30 TAC §350.73(e).*

Attachment 1 contains an example calculation of determining effective solubility.

4.1.2.2 COC concentrations in soil. When direct visual confirmation of NAPL in soil cannot be made, indirect evidence of NAPL in soil may be developed from COC concentrations. Generally, soil COC concentrations in the percent range (>10,000 mg/kg) are indicative of the presence of NAPL (*e.g.*, Feenstra *et al*., 1991).

Another more exact theoretical method for evaluating NAPL employs a partitioning calculation based on the chemical analyses of soil samples from the saturated zone and the effective solubility concept. This method assumes that all of the COCs in the subsurface are either dissolved in groundwater or adsorbed to soil (assuming dissolved-phase sorption, not the presence of NAPL). By using the concentration of COCs on the soil and the partitioning calculation, a theoretical pore-water concentration of COCs in groundwater is determined. If the theoretical pore-water concentration is greater than the estimated solubility of the organic constituent of interest, then NAPL may be present at the affected property (Feenstra et al., 1991; EPA, 1992).

Table 4.1: Aqueous Solubilities of Common COCs

Chemical of Concern	Solubility* (*mg/L*)	1% Solubility (*mg/L*)
Acenapthene	4.24 E+00	4.24 E-02
Anthracene	4.34 E-02	4.34 E-04
Benzene	1.77 E+03	1.77 E+01
Ethyl benzene	1.69 E+02	1.69 E+00
Methyl *tert*-butyl ether (MTBE)	4.80 E+04	4.8 E+02
Napthalene	3.14 E+01	3.14 E-01
Toluene	5.30 E+02	5.3 E+00
Trichloroethane (1,1,1)	1.33 E+03	1.33 E+01
Trichloroethylene	1.10 E+03	1.10 E+01
6 C aliphatics (TPH)	3.60 E+01	3.6 E-01
> 6 – 8 C aliphatics (TPH)	5.40 E+00	5.4 E-02
> 8 – 10 C aliphatics (TPH)	4.30 E-01	4.3 E-03
> 10 – 12 C aliphatics (TPH)	3.40 E-02	3.4 E-04
> 12 –16 C aliphatics (TPH)	7.60 E-04	7.6 E-06
> 16 – 35 C aliphatics (TPH)	2.50 E-06	2.5 E-08
5 – 7 C aromatics (TPH) – Benzene	1.77 E+03	1.77 E+01
> 7 – 8 C aromatics (TPH) - Toluene	5.30 E+02	5.30 E+00
> 8 – 10 C aromatics (TPH)	6.5 E+01	6.5 E-01
> 10 – 12 C aromatics (TPH)	2.5 E+01	2.5 E-01
> 12 – 16 C aromatics (TPH)	5.8 E+00	5.8 E-02
> 16 – 21 C aromatics (TPH)	6.5 E-01	6.5 E-03
> 21 – 35 C aromatics (TPH)	6.6 E-03	6.6 E-05

*** *from* TRRP; Figure 30 TAC §350.73(e)**

4.2 Determining NAPL Chemical Composition

The determination of the chemical composition of NAPL may be necessary for:

1. determination of composition of unknown NAPL liquid, and
2. determination of fractions of multi-component NAPL liquid mixture (esp., weathered NAPL)

4.2.1 NAPL Analytical Methods

EPA analytical methods are applicable to the determination of *dissolved COCs* found in groundwater, the EPA's methods (EPA SW846) are not applicable to NAPL liquids. Table 4.2 summarizes *NAPL liquid* analytical methods.

TABLE 4.2: NAPL Liquid Chemical Composition Analytical Methods*

	Compound Class	Analytical Methods	Description
LNAPL	Industrial Aromatics & Gasolines	ASTM Test D4420	Finished product by GC
		ASTM Test D6733	Light hydrocarbons common to petroleum refineries, incl. blending stocks (naphthas, reformates, alkylates, *etc.*)
		ASTM Test D4534	Benzene content in some cyclic hydrocarbon products
	Middle Distillates	ASTM Test D3257	Aromatics in mineral spirits & Stoddard Solvents
	Crude Oils	ASTM Test 4534	Benzene content in some cyclic hydrocarbon products

*** Analytical methods are for *immiscible phase liquids* only, <u>*not*</u> dissolved phase in groundwater or NAPL in soils**

4.3 Characterizing NAPL Fluid Properties

Characterization techniques may be used to better understand the physical and chemical properties of NAPL compounds (and their mixtures) for the purpose of developing an effective assessment strategy.

Measurement of the physical and chemical properties of NAPL collected from wells is not necessary at all sites, but may be needed for developing assessment techniques, employing Management and Recoverability Tools, determining the applicability of certain remediation technologies, and designing effective NAPL recovery systems.

4.3.1 NAPL Density

The density (r) of a NAPL is expressed as the liquids mass per volume (M/L^3), most commonly g/cm^3. NAPL density is used to distinguish LNAPL from DNAPL simply by comparing the product's *specific gravity (SG)*, the ratio of NAPL density and density of site water:

$$SG = \frac{r_{NAPL}}{r_{water}} \qquad (4.2)$$

The density of site water also should be determined. The in-situ temperature of all site fluids (NAPL and groundwater) should be obtained. Table 4.3 summarizes acceptable methods for determining NAPL fluid densities.

TABLE 4.3: NAPL Density Test Methods

	Method Description	Method Designation
NAPL Density	Density of product by hydrometer	ASTM Test D 1298
	Density of product by pycnometer	ASTM Test D 1217
	Density of high viscosity product by pycnometer	ASTM Test D 1480 ASTM Test D 1481
	Density of product by digital density meter	ASTM Test D 4052
	Density of crude oils by digital density meter	ASTM Test D 5002

The density of NAPL mixtures (*e.g.*, gasoline, diesel, *etc.*) can change over time as more volatile and soluble components of the mixture fractionate from the NAPL phase.

4.3.2 NAPL Fluid Viscosity

Viscosity is a measure of a fluid's resistance to flow due to internal forces caused by molecular cohesion. Two (2) types of viscosity are used commonly, *absolute* or *dynamic viscosity* (m) having units FT/L^2 , and *kinematic viscosity* (υ) which has units L^2/T. Absolute and kinematic viscosities can be equated using the following relationship:

$$m = n r_{NAPL} \tag{4.3}$$

Fluid density and kinematic viscosity control the rate at which a liquid moves through a permeable geologic formations and can be related to that liquid's hydraulic conductivity (K), the formation's intrinsic permeability (k), and the acceleration due to gravity (g) by the following relationship:

$$K = \frac{k r_{NAPL} g}{m} \tag{4.4}$$

Consequently, NAPLs with high viscosities (thick) have a lower hydraulic conductivity than NAPLs with low viscosities (thin) thus affecting the relative propensity for and rate at which a NAPL can move in the subsurface.

Recommended methods for determining NAPL fluid viscosity are presented in Table 4.4.

TABLE 4.4: NAPL Fluid Viscosity Test Methods

	Method Description	Method Designation
NAPL Fluid Viscosity	Kinematic/dynamic viscosity of product	ASTM Test D 445
	Kinematic viscosity of volatile and reactive liquids	ASTM Test D 4486

4.3.3 NAPL Interfacial Tension and Surface Tension

Liquid *interfacial tension* is a measure of the force (F/L) which develops at the boundary of two (2) immiscible liquids. The magnitude of interfacial tension is defined as the differences between the higher mutual attraction of like molecules in each liquid and the lower degree of molecular attraction occurring across the liquid-liquid interface between different phases. Similarly, s*urface tension* refers to the differences of forces at the boundary of a liquid phase and that liquid's vapor phase (or air).

Interfacial tension, together with a NAPL's wettability, governs the formation and mobility of NAPL globules in the saturated zone. Table 4.5 provides values of interfacial tension for selected NAPLs and water. Typically, the interfacial tension values for DNAPL – water systems range from 20 to 50 dyn/cm.

NAPL existing at a site often is weathered and/or is a mixture, in which case values provided in Table 4.4 may not be accurate and a site-specific value may be needed. Table 4.5 summarizes Agency-recommended test methods for determining interfacial tension and surface tension values. Interfacial tension is strongly influenced by temperature. Interfacial tensions decrease with increases of temperature and it is important to obtain *in situ* fluid temperatures when determining these properties.

TABLE 4.5: Interfacial Tension Values for Selected NAPLs and Water

Chemical of Concern	Interfacial Tension (*dyne/cm @ 20° C*)	Reference
Carbon disulfide	48.4	Dean, 1973
Carbon tetrachloride	45.0	Dean, 1973
Chlorobenzene	37.4	Dean, 1973
Chloroform	32.8	Dean, 1973
Ethylene dibromide	36.5	Mercer and Cohen, 1990
Methylene chloride	28.3	Dean, 1973
Tetrachloroethene	44.4 (@ 25° C)	Mercer and Cohen, 1990
Trichloroethane (1,1,1)	45.0	Mercer and Cohen, 1990
Trichloroethene	34.5 (@ 24° C)	Mercer and Cohen, 1990

TABLE 4.6: Interfacial Tension and Surface Tension Test Methods

	Method Description	Method Designation
Surface Tension & Interfacial Tension	Interfacial tension and surface tension of NAPL by Ring Method (DuNouy)	ASTM Test D 971
	Dynamic surface tension by fast-bubble technique (not suitable for opaque DNAPL)	ASTM Test D 3825
	Surface tension and interfacial tension of mixed solvent and surfactant solutions	ASTM Test D 1331
	Interfacial tension of petroleum-based electrical insulating oils against water by drop-weight method	ASTM Test D 2285

4.3.4 Wettability

Wettability is the affinity of one immiscible liquid phase for a solid surface in the presence of another immiscible liquid phase. The *wetting fluid* is the liquid phase that covers the solid surface preferentially over the *nonwetting fluid*. Wettability is governed by interfacial tension (see Section 4.2.3) of the two liquid phases.

The simplest measure of wettability is the *contact angle* formed by the liquid-liquid interface of two immiscible phases in contact with a solid surface. In the case of the DNAPL-water-aquifer matrix system (*i.e.*, a contaminated site), the DNAPL phase typically is the nonwetting fluid. Here, water wets the surface area of the solid aquifer matrix and occupies the smaller porosity spaces while DNAPL tends to be restricted to larger pore spaces and fractures. However, this DNAPL-water wettability relationship can be reversed if the aquifer matrix is organic. Additionally, the degree of wettability can change over time as the DNAPL and water begin to equilibrate chemically.

Typical values of contact angles for selected NAPLs, water, and solid substrate are provided in Table 4.7

Site-specific occurrences of NAPL can be weathered and/or mixtures on different substrate solids with contact angles that may require determination by analysis. Test methods for determining contact angles and wettability are presented in Table 4.8.

TABLE 4.7: Typical Contact Angles for NAPL – Water – Solid Systems

Chemical of Concern	Substrate	Contact Angle* (° *degrees*)
Carbon tetrachloride	clay	27 - 31
Chlorobenzene	clay	27 - 34
Chloroform	clay	29 - 31
Tetrachloroethene	clay	23 - 48
Tetrachloroethene	fine to coarse sand (Ottawa)	33 - 45
Tetrachloroethene	dolomite	16 – 21

***** Mercer and Cohen, 1990

TABLE 4.8: Wettability Test Methods

	Method Description	Method Designation
Wettability	Contact Angle Method – drop of DNAPL on geologic substrate	Cohen *et al*., 1993
	Amott Method – repetitive imbibition and forced drainage of soil or rock core	Cohen *et al*., 1993
	Amott-Harvey Relative Displacement Method – wettability index using saturated cores	Cohen *et al*., 1993
	USBM Wettability Index – for porous media that can be cut into plugs and centrifuged; more sensitive than Amott Method	Cohen *et al*., 1993

4.3.5 Capillary Pressure

Capillary pressure controls the extent to which a DNAPL released to the subsurface can penetrate downward into a zone of (water) saturation and the extent to which a LNAPL can penetrate upward through a rising or inundating zone of saturation. Consequently, capillary pressure also controls the horizontal component of the shape of a NAPL spill (Mercer and Cohen, 1990).

Capillary pressure is most simply expressed as the difference of the pressure of a NAPL and the pressure of water at a pore opening, or:

$$P_{cap} = P_{NAPL} - P_{H_2O} \tag{4.5}$$

Bear (1979) relates capillary pressure (P_{cap}) to interfacial tension (s), contact angle (f), and pore size radius (r) by the following:

$$P_{cap} = \frac{2s \cos f}{r} \tag{4.6}$$

In order for a nonwetting NAPL to enter a water-saturated pore space the capillary pressure (P_{cap}) must be overcome. This force is the threshold or displacement *entry pressure*. A NAPL that exists in a state that is at or below the entry pressure cannot penetrate vertically into that pore space. Movement of NAPL in such a state is restricted to horizontal migration or no migration at all (*e.g.*, fractures).

4.3.6 Residual Saturation

Residual saturation (S_r) is the fraction of NAPL-filled void-space at which NAPL becomes discontinuous and resistant to mobility by fluid flow due to capillary forces. Factors upon which residual saturation depend include 1) median pore-size distribution, 2) fluid wettability, 3) fluid viscosity and density ratios, 4) fluid interfacial surface tension, 5) gravity/buoyancy forces, and 6) hydraulic gradients (Mercer and Cohen, 1990). NAPL residual saturation can be useful in making estimates of the mass of immobile NAPL in saturated and unsaturated soils.

Residual saturation for a NAPL can differ greatly in the vadose zone as compared to the saturated zone. Typically, a larger void-filled fraction of NAPL is immobilized in the saturated zone than in the vadose zone because 1) the fluid density ratio of NAPL vs air promotes greater drainage in the vadose zone, 2) NAPL in the saturated zone is the nonwetting fluid and tends to be trapped more readily in larger pores, 3) NAPL in the vadose zone is the wetting fluid and tends to spread to adjacent pores leaving less residuum in any given pore.

In the vadose zone, NAPL residual saturation can contribute COCs to leachate in the ^{GW}Soil pathway and can contribute volatile COC vapor to the ^{Air}Soil$_{Inh\text{-}V}$ pathway. In the saturated zone, NAPL residual saturation typically becomes the source zone for dissolved groundwater plumes in the ^{GW}GW pathways and the ^{Air}GW$_{Inh\text{-}V}$ pathway.

Volumetric Retention Capacity (*R*) is a measure of the volume of NAPL (L residual NAPL/m^3 of soil) held in residual saturation per unit volume by the following relationship:

$$R = S_r \cdot h \cdot 1000 \tag{4.7}$$

where h is soil porosity.

Since the value of S_r is depend on so many variables, its determination is not easily predicted and its direct measurement is susceptible to error. The range of S_r values in the vadose zone typically range between 0.10 to 0.20; in the saturated zone the range is 0.15 to 0.50 (Mercer and Cohen, 1990). Empirical values of S_r for various NAPLs and soil types and conditions have been published and appear in Table 4.9, Table 4.10 and Table 4.11.

NAPL at Residual Saturation or Mobile?

If NAPL flows into a monitoring well or boring it is above it's residual saturation fraction at that location in the formation and is classified as a *mobile NAPL* (Mercer and Cohen, 1990).

A precise site-specific determination of S_r or *R* can be difficult and expensive.

TABLE 4.9: Typical Values of LNAPL Residual Saturation in Vadose Zone

NAPL Type	Soil Type	**S_r (% NAPL-filled pore space)** or **R (% NAPL of soil volume)**	Reference
LNAPLs in Vadose (*Unsaturated)* Soils (NAPL – air – water)			
Gasoline	Coarse gravel	R = 2.5	Fussell *et al.*, 1981
	Coarse sand and gravel	R = 4.0	
	Medium to coarse sand	R = 7.5	
	Fine to medium sand	R = 12.5	
	Silt to fine sand	R = 20	
Middle distillates	Coarse gravel	R = 5.0	
	Coarse sand and gravel	R = 8.0	
	Medium to coarse sand	R = 15	
	Fine to medium sand	R = 25	
	Silt to fine sand	R = 40	
Fuel oils	Coarse gravel	R = 10	
	Coarse sand to gravel	R = 16	
	Medium to coarse sand	R = 30	
	Fine to medium sand	R = 50	
	Silt and fine sand	R = 80	
Light oil & gasoline	Soil	S_r = 18	Mercer and Cohen, 1990
Diesel & light fuel oil		S_r = 15	
Lube & heavy fuel oils		S_r = 20	
Gasoline	Coarse sand	S_r = 15 – 19	Hoag and Marley, 1986
	Medium sand	S_r = 12 – 27	
	Fine sand	S_r = 19 – 60	
	Well-graded fine – coarse sand	S_r = 46 – 59	
	Fine sand	S_r = 28.5 ± 1.7	Wilson *et al.*, 1990
Kerosene		S_r = 26.3 ± 2.2	
n-Decane		S_r = 25.9 ± 1.7	
p-Xylene		S_r = 23.3 ± 2.6	
Tetrachloroethene		S_r = 26.4 ± 2.4	

TABLE 4.10: Typical Values of DNAPL Residual Saturation in Vadose Zone

NAPL Type	Soil Type	S_r (% NAPL-filled pore space) or R (% NAPL of soil volume)	Reference
DNAPLs in Vadose (*Unsaturated)* Soils (NAPL – air – water)			
DNAPL	Sandy soils	S_r > 1 – 10	Schwille, 1988
		R > 3 -30	Feenstra and Cherry, 1988
Tetrachloroethene	Fracture with 0.2 mm aperture	R = 0.051 m^{-2}	Schwille, 1988
Trichloroethene	Medium sand	S_r = 20	Mercer and Cohen, 1990
	Fine sand	S_r = 19	
	Fine sand	S_r = 15 – 20	
	Loamy sand	S_r = 8	Cary *et al.*, 1989

TABLE 4.11: Typical Values of DNAPL Residual Saturation in Saturated Zone

NAPL Type	Soil Type	S_r (% NAPL-filled pore space) or R (% NAPL of soil volume)	Reference
DNAPLs in Saturated Soils (NAPL – water)			
DNAPL	Sandy soils	S_r > 2 – 15	Schwille, 1988
		R > 5 – 50	Feenstra and Cherry, 1988
1,1,1 - Trichloroethane	Coarse Ottawa sand	S_r = 15	Mercer and Cohen, 1990
Tetrachloroethene		S_r = 15 – 25	

4.4 LNAPL Assessment Techniques

The behavior and distribution of LNAPL released to the subsurface often may be predicted using knowledge of LNAPL fluid properties (Sec 4.2) and the relevant geology and hydrogeology. The ability to understand the physical behavior of LNAPL in the subsurface is necessary to the completion of an adequate NAPL site assessment.

The LNAPL assessment techniques provided herein are intended for use in property assessments and the development of site conceptual models.

4.4.1 Behavior of LNAPL in the Unsaturated Zone

Upon release to the unsaturated zone, LNAPL migrates principally in the vertical direction by infiltration. In the dry unsaturated environ, LNAPL typically is the wetting fluid (displacing air) and the progress of the LNAPL's downward migration is controlled by gravity and capillary forces.

Lateral spreading can occur in the unsaturated zone when downward migrating LNAPL encounters a finer-grained or relatively impermeable zone whose capillary entry pressure requires additional LNAPL thickness (head) to overcome. LNAPL will then migrate laterally via capillary forces. LNAPL lateral migration will continue on the perching unit until: 1) the LNAPL driving force (perched LNAPL accumulated thickness) diminishes, or 2) the LNAPL driving force increases sufficiently to overcome the capillary entry pressure of the perching unit and the LNAPL resumes its vertical migration through the perching unit, or 3) the perching unit ends in the direction of lateral migration and the LNAPL resumes its vertical migration from the perching unit's edge (*e.g.,* API, 1996; El-Kadi, 1992, *etc.*).

As vertical migration of LNAPL continues within the unsaturated zone it may encounter the increasingly water-wet environ of the *funicular zone* where the fraction of water increases above its residual saturation due to capillary rise from an underlying GWBU or zone of saturation. In the funicular zone, water becomes the wetting fluid and the capillary entry pressure for the lighter-than-water LNAPLs increases significantly. Since the capillary entry pressure of a small water-wet aperture is greater than that of a larger one, vertically migrating LNAPL can penetrate the larger pore spaces of a coarse-grained matrix with less force than it can the smaller pore spaces of a fine-grained matrix (*e.g.*, API, 2003; Whitworth and Hsu, 1999; Fetter, 1993, *etc.*).

If the volume of LNAPL release is small enough and the depth to groundwater is large enough, the extent of LNAPL vertical migration may be such that it cannot reach groundwater and will, instead, be confined to the unsaturated zone at it's residual saturation. Figure 4.1 is an idealized depiction of the distribution of an LNAPL mass in the subsurface that does not reach groundwater.

4.4.2 Assessment Methods for LNAPL in Unsaturated Zone

4.4.3 Behavior of LNAPL about the Capillary Fringe and Saturated Zone

4.4.4 Assessment Methods for LNAPL within the Capillary Fringe

4.4.5 Estimating LNAPL Thickness (NAPL Assessment TOOL 1A)

ATTACHMENT A2.1 has example calculation

4.4.6 Estimating LNAPL Quantities (NAPL Assessment TOOL 1B)

ATTACHMENT A2.2 has example calculation

4.4.7 Spreading Velocity of LNAPL on Water Table (NAPL Assessment TOOL 1C)

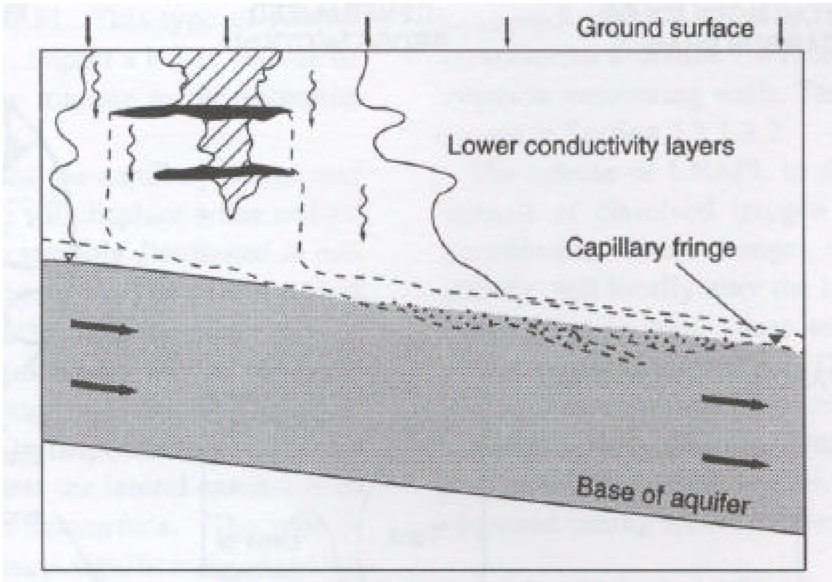


FIGURE 4.1: Idealized distribution of residual LNAPL (striped) in case where LNAPL does not reach groundwater (from API, 1996).

4.5 DNAPL Assessment Techniques

4.5.1 DNAPL Assessment in the Unsaturated Zone

4.5.2 DNAPL Assessment in the Saturated Zone

4.6 Characterizing NAPL Occurrence

Understanding the general behavior of NAPLs in the subsurface is critical to performing a complete assessment of the extent of the NAPL release both in the vadose zone and the saturated zone. The differences in physical and chemical properties between LNAPLs and DNAPLs can result in idiosyncratic behavior of various NAPL substances in the subsurface. Those properties combined with a variety of hydrogeologic conditions lead to a number of generally predictable NAPL occurrences to which standard assessment techniques can be applied.

Conceptual models of various NAPL occurrences are provided, as well as some relevant metrics, for the purpose of assisting in the task of assessing a NAPL release completely enough to permit the site to progress through the stepped NAPL Management decision process without remobilization.

4.6.1 LNAPL or DNAPL in Vadose Zone (*unconsolidated silt/sand/gravel*)

NAPL released to the vadose zone comprised of soil or sediments will migrate vertically and laterally within the unsaturated zone. The degree to which its migration extends is largely a function of the characteristics of the subsurface geomaterial and its heterogeneity. The volume and rate of NAPL released affects the degree of NAPL mobility. Generally, the smaller and slower the NAPL released, and the deeper the vadose zone, then the more likely NAPL will reach its residual saturation (and become immobile) before reaching groundwater.

4.6.2 LNAPL or DNAPL in Unsaturated Fractures

NAPL released into unsaturated fractures, root holes, or other macroporosity features with low primary porosity such as fractured clays or fractured rock will continue to migrate downward through these preferential pathways toward groundwater. However, as the macroporosity features narrow or terminate at depth and capillary forces can prevent further migration. In clay matrices, NAPL trapped in fractures will dissolve into the matrix via a diffusion.

4.6.3 LNAPL in Saturated Zone (*capillary fringe and saturated zone*)

LNAPL that has migrated through the unsaturated zone, or that has been released directly into groundwater (saturated zone), will begin to spread across the top of the saturated zone and also displace some water in the at the top of the saturated zone and penetrate the water table to a depth at which LNAPL head (thickness) reaches equilibrium with interfacial tension forces forming a LNAPL "iceberg." The LNAPL body generally is mobile in the capillary fringe and displaced saturated zone (API, 1996).

4.6.4 DNAPL in Saturated Zone (*unconsolidated silt/sand/gravel*)

Mobile DNAPL that migrated through the vadose zone, or that was released directly into groundwater, and that is mobile in the saturated zone, continues to migrate downward through the saturated zone until DNAPL head (thickness) reaches equilibrium with interfacial tension forces. Sometimes DNAPL will migrate vertically until it encounters a geologic material whose capillary entry pressure cannot be overcome by the DNAPL's head in which case the DNAPL can migrate laterally along the top of that material.

4.6.5 NAPL in Saturated Fractures

NAPL that has moved through secondary porosity features such as fractures or macropores in saturated formations with low primary porosity such as fractured clays or fractured rock.

4.6.6 NAPL in Karst Systems

NAPL which has moved into and through primary porosity features (*i.e.*, solution cavities) and/or secondary porosity features (*e.g.*, fractures) in unsaturated and saturated karst formations.

4.6.7 Completing the NAPL Occurrence Matrix

Upon fulfillment of the NAPL assessment requirements, the *NAPL Occurrence Matrix* (TABLE 4.12) is completed by checking all boxes that are associated with each type of NAPL occurrence encountered during the property assessment.

TABLE 4.12: NAPL Occurrence Matrix

	NAPL Occurrence	Description
LNAPL in Vadose Zone	❑ LNAPL in permeable vadose zone	*LNAPL in unsaturated, unconsolidated silt, sand, and/or gravel*
	❑ LNAPL in impermeable vadose zone	*LNAPL in unsaturated fine-grained soil/sediments*
	❑ LNAPL in unsaturated fractures	*LNAPL in fractures of unsaturated fine-grained soils/sediments*
DNAPL in Vadose Zone	❑ DNAPL in impermeable vadose zone	*DNAPL in unsaturated clayey soil/sediments*
	❑ DNAPL in permeable vadose zone	*DNAPL in unsaturated, unconsolidated silt, sand, and/or gravel*
	❑ DNAPL in unsaturated fractures	*DNAPL in fractures of unsaturated fine-grained soils/sediments*
LNAPL in/on Saturated Zone	❑ LNAPL at water table and/or capillary fringe	*LNAPL in maximally-saturated portion of capillary zone (>90% water-filled porosity) and in water table*
	❑ LNAPL in saturated and fractured soils/sediments	*LNAPL in fractures of saturated fine-grained soils/sediments*
	❑ LNAPL in saturated and fractured rock	*LNAPL in fractures of saturated rock*
DNAPL in Saturated Zone	❑ DNAPL in saturated soils/sediments	*DNAPL in saturated unconsolidated silt, sand, and/or gravel*
	❑ DNAPL in saturated and fractured soils/sediments	*DNAPL in fractures of saturated fine-grained soils/sediments*
	❑ DNAPL in saturated and fractured rock	*DNAPL in fractures of saturated rock*
NAPL in Karst	❑ NAPL in karst	*NAPL in karstic environment, either in unsaturated zone or in GWBU*

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5.0 STEP 2: Identify NAPL Management Triggers

NAPL Management Triggers are occurrences of NAPL that require a response action. Two types of NAPL Management Triggers exist: 1) Regulatory-based Triggers, and 2) Risk-based Triggers. Section 2 provides the TRRP rule citations for each NAPL Management Trigger. This section describes the field occurrence and recognition of each trigger.

The existence of NAPL Management Triggers should be evaluated as part of the assessment process (Step 1; Sec 4). Figure 3-2 places this step in the context of the NAPL Management Program.

Upon completing an appropriate affected property assessment, the person should compare any occurrences of NAPL to the list of NAPL Management Triggers (Table 5.1) to determine if any apply to the occurrence. Each applicable trigger should be identified, as requisite response actions are dependent on the specific triggers identified.

Figure 5-1 summarizes the logic of Step 2.

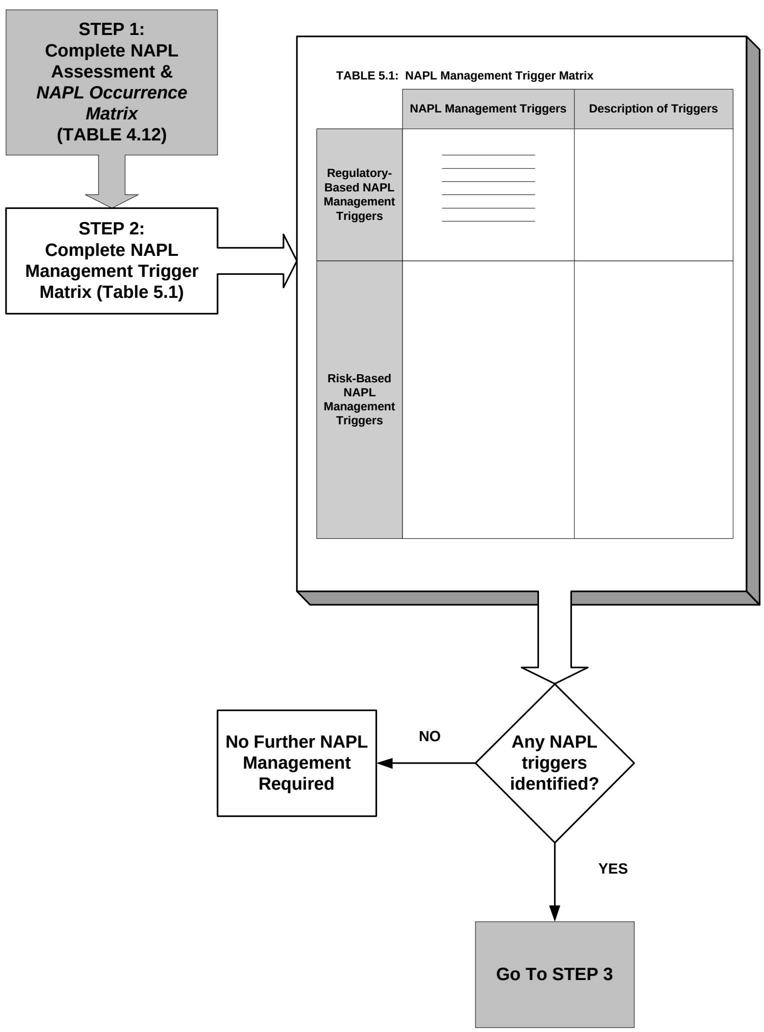


Figure 5-1: Overview of Step 2

5.1 Regulatory-Based NAPL Management Triggers

Regulatory-based NAPL Management Triggers are the typical occurrences of NAPL for which a specific response action is warranted. Three regulatory-based triggers exist and are summarized in Table 5.1.

5.1.1 NAPL Vapor Explosivity

All subsurface NAPL occurrences capable of causing accumulations of volatile vapors that exceed the pure phase or mixture vapor's *25% of Lower Explosive Limit* (LEL) must be removed. Underground utility conduits, basements, buildings, storm sewers and other surface and subsurface structures close to the NAPL source area should receive particular attention for the purpose of ensuring the absence of any explosivity hazard.

Attachment 2 provides methods and protocols for measuring and assessing explosive limits.

5.1.2 NAPL Zone Expansion (Potential or Observed)

Two Regulatory-based NAPL Management Triggers exist: 1) the Expanding NAPL Zone Trigger and 2) the Mobile NAPL in Vadose Zone Trigger. Both of these triggers are related to observed NAPL expansion and/or the presence of potentially mobile NAPL in the unsaturated zone.

5.1.2.1 *Expanding NAPL Zone*. The Expanding NAPL Zone Trigger is applicable when a NAPL zone is observed to be increasing in volume or migrating in any direction.

5.1.2.2 *Mobile NAPL within Vadose Zone*. The Mobile NAPL in Vadose Zone Trigger is applicable when a NAPL zone is observed to have a region of mobile NAPL or has a COC concentration that exceeds its residual saturation (see Step 1; Sec 3).

Instances of observable mobile NAPL include, 1) NAPL appearing in borings, monitoring wells, trenches, or other subsurface discontinuity, 2) a change of NAPL fluid levels in borings, monitoring wells, trenches, or other subsurface discontinuity, or 3) visible NAPL seeps at surface.

The presence of mobile NAPL is inferred when soil concentrations approach or exceed 10,000 mg/kg for NAPL mixtures or pure phases. COC concentrations that exceed their residual saturation concentrations also indicate the presence of mobile NAPL.

5.1.3 NAPL Aesthetic/Nuisance Condition

Aesthetic or nuisance conditions for NAPLs comprise the following circumstances: 1) complaints of taste, odor, or other objectionable characteristics in Class 1 and Class 2 Groundwater, 2) NAPL pools, sludges in the upper 10 feet of the soil column (or at ground surface), or COC concentrations that diminishes a soil's structural integrity or load-bearing capacity associated with current or prospective land use, and 3) visible traces of NAPL in surface water and/or the banks or sediment of surface water bodies.

5.2 Risk-Based NAPL Management Triggers

Risk-based NAPL Management Triggers are those occurrences of NAPL for which the TRRP rules require management in order to prevent exposure to human and ecological receptors at unprotective levels. Risk-based triggers are summarized in Table 5.1.

5.2.1 PCL Exceedances

NAPL accumulations in surface and subsurface soils whose COC concentrations exceed soil PCLs or soil cross-media PCLs require a mitigating response action. The following soil exposure pathway PCLs should be evaluated during the NAPL assessment process for compliance.

5.2.1.1 *Total soil combined PCL exceeded*. The $^{Tot}SOIL_{Comb}$ should be evaluated for all instances of a NAPL release to surface soils.

5.2.1.2 Soil-to-groundwater PCL exceeded. The $^{GW}SOIL$ should be evaluated for all instances of a NAPL release to a surface or subsurface soil.

5.2.1.3 Soil volatilization-to-ambient air PCL exceeded. The $^{Air}SOIL_{Inh\text{-}V}$ should be evaluated for all instances of a NAPL release to a subsurface soil.

5.2.2 NAPL in Contact with Groundwater

NAPL releases that have impacted classifiable groundwater-bearing units constitute NAPL Management Triggers and require a response action.

5.2.2.1 NAPL in contact with Class 1 Groundwater. All NAPL releases that impact Class 1 Groundwaters require NAPL management and response action.

5.2.2.2 NAPL in contact with Class 2 Groundwater. All NAPL releases that impact Class 2 Groundwaters require NAPL management and response action.

5.2.2.3 NAPL in contact with Class 3 Groundwater. All NAPL release that impact Class 3 Groundwaters require NAPL management and response actions.

5.2.3 NAPL in Contact with Surface Water and Sediments

NAPL releases to surface water bodies, sediments lining the banks of surface water bodies, or sediments lining the channels or basins of surface water bodies constitute NAPL Management Triggers and require a response action.

5.2.3.1 NAPL in contact with Surface Water. NAPL impacts to surface water bodies (*e.g.*, streams, creeks, rivers, lakes, ponds, bays, estuaries, wetlands, *etc*.) require NAPL management and response actions.

5.2.3.2 NAPL in or on Sediments. NAPL impacts to sediments associated with surface water bodies (see Section 5.2.3.1) require NAPL management and response actions.

5.3 Complete NAPL Management Trigger Matrix

Upon evaluating for the presence of all Regulatory-Based NAPL Management Triggers (Section 5.1) and all Risk-Based NAPL Management Triggers (Section 5.2), the person should complete the NAPL Management Trigger Matrix (Table 5.1) by checking all applicable triggers.

In the event that no conditions exist that correspond to the NAPL Management Triggers in Table 5.1, no further NAPL management activities are required.

Table 5.1: NAPL Management Trigger Matrix

	NAPL Management Triggers	Description of Triggers
Regulatory-Based NAPL Management Triggers	' NAPL Vapor Accumulation is Explosive	*NAPL vapors accumulate in buildings, utility and other conduits, or other existing structures at levels that are potentially explosive (= 25% LEL)*
	' Expanding NAPL Zone	*NAPL zone is observed to be expanding*
	' Mobile NAPL w/in Unsaturated Zone	*NAPL zone is observably mobile, or is theoretically mobile based on COC concentrations and residual saturation*
	' NAPL Creating an Aesthetic Impact or Causing Nuisance Condition	*NAPL is responsible for objectionable characteristics (*e.g.*, taste, odor, color) resulting in making a natural resource unfit for use*
Risk-Based NAPL Management Triggers	' $^{Tot}Soil_{Comb}$ PCL is Exceeded	*NAPL is present in shallow subsurface soil at concentrations which exceed the applicable* $^{Tot}SOIL_{Comb}$
	' $^{GW}SOIL$ PCL is Exceeded	*NAPL is present in subsurface soil at concentrations which exceed the applicable* $^{GW}SOIL$
	' $^{Air}SOIL_{Inh\text{-}V}$ PCL is Exceeded	*NAPL is present in shallow subsurface or subsurface soil at concentrations which exceed the applicable* $^{Air}SOIL_{Inh\text{-}V}$
	' NAPL in Contact with Class 1 Groundwater	*NAPL has come in actual contact with, or has otherwise directly impacted Class 1 Groundwater*
	' NAPL in Contact with Class 2 Groundwater	*NAPL has come in actual contact with, or otherwise directly impacted Class 2 Groundwater*
	' NAPL in Contact with Class 3 Groundwater	*NAPL has come in actual contact with, or otherwise directly impacted Class 3 Groundwater*
	' NAPL in Contact with Surface Water	*NAPL has come in actual contact with surface water via migration along groundwater-to-surface water interconnectivity, migration in the vadose zone, migration via a surface pathway, or direct release to surface water*
	' NAPL In or On Sediments	*NAPL has impacted surface water (lake, river, stream) sediments via a groundwater pathway, a vadose zone pathway, or a direct release*

6.0 STEP 3: Identify NAPL Management Response Action

NAPL Management Response Action comprises the response actions associated with each of the NAPL Management Triggers described in STEP 2 (Section 5). Each NAPL Management Response Action is associated with a specific NAPL Management Trigger (see Table 5.1). The only NAPL Management Response Actions to be addressed at any given site are those for which any associated NAPL Management Triggers have been identified in STEP 2.

All NAPL Management Response Actions fall into one of two categories:

1. NAPL Recovery
2. NAPL Control

STEP 3 also provides two NAPL Management Tools (TOOL 3A and TOOL 3B) which can be used as *qualitative screens* to facilitate decisions regarding the benefits of NAPL recovery and the potential efficacy of using conventional NAPL recovery at the site. The Qualitative NAPL Management Tools are:

1. TOOL 3A: Screen for Benefits of NAPL Recovery
2. TOOL 3B: Screen for Potential of Conventional NAPL Recovery Technology

The logical context of STEP 3 within the overall NAPL Management Program is shown in Figure 3-2. Figure 6-1 summarizes the process of STEP 3.

6.1 NAPL Recovery Response Actions

NAPL Recovery response actions constitute the following source media decontamination responses:

1. NAPL removal (extraction) from the source media
2. NAPL destruction within the source media (*in situ*)

Two types of NAPL Recovery response actions exist, each of which is applicable to certain NAPL Management Triggers:

1. RECOVERY I, and
2. RECOVERY II

6.1.1 NAPL RECOVERY I Response Action

The NAPL Management RECOVERY I Response Action applies to those NAPL Management Triggers (Table 5.1) for which a *recovery-only* response action is permitted by TRRP rule. RECOVERY I response actions require a decontamination response action and *do not permit a control response action option*.

NAPL Management Triggers for which the RECOVERY I response action apply are summarized in Table 6.1.

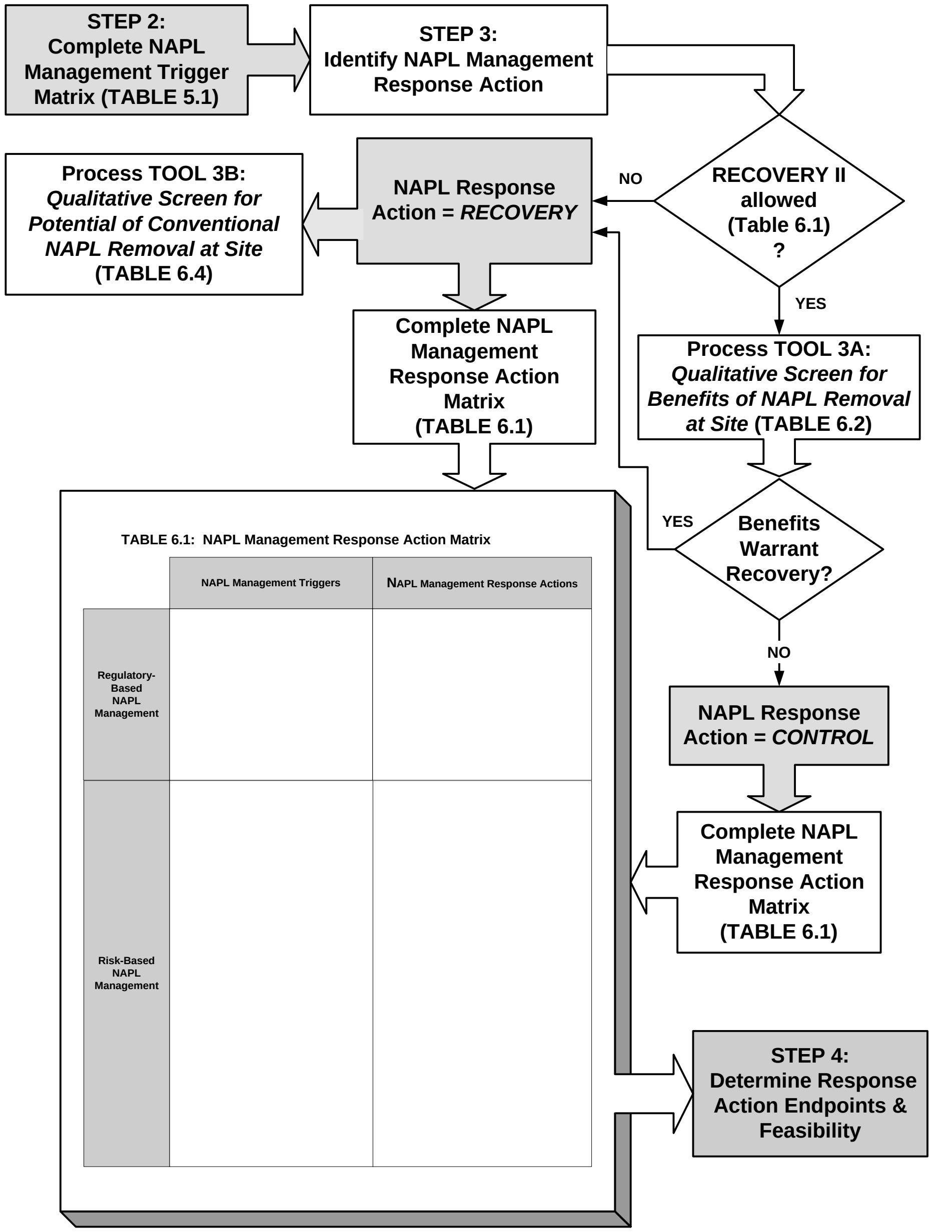


FIGURE 6-1: Overview of Step 3

6.1.2 NAPL RECOVERY II Response Action

The NAPL Management RECOVERY II Response Action applies to all NAPL Management Triggers (Table 5.1) for which the RECOVERY I response action is not required. The RECOVERY II response action may be coupled with, or substituted by the control response action if certain conditions are met. *When the effectiveness of an implemented conventional RECOVERY II response action is sufficiently diminished, a control may be resorted to for completion of the response action.*

NAPL Management Triggers for which the RECOVERY II response action applies are summarized in Table 6.1.

6.2 NAPL Control Response Actions

Use of the NAPL Management Control Response Action may be applicable for certain NAPL Management Triggers that permit a control response action and for which a recovery action response may not be required. However, the use of the control response action where NAPL is in contact with groundwater is predicated upon the establishment of a plume management zone (PMZ). NAPL Management Triggers for which the control response action applies are summarized in Table 6.1.

Table 6.1: NAPL Management Response Action Matrix

	NAPL Management Triggers (*from* TABLE 5.1)	NAPL Management Response Actions
Regulatory-Based NAPL Management	❑ NAPL Vapor Accumulation is *Explosive*	Permanent abatement of NAPL vapor source ❑ Recovery I
	❑ NAPL Zone Expanding (potential or observed mobility)	Arrest NAPL expansion ❑ Recovery II OR ❑ Control Only
	❑ Mobile NAPL in Vadose Zone (potential or observed mobility)	Eliminate mobile NAPL fraction (to residual) ❑ Recovery II OR ❑ Control Only
	❑ NAPL Creating an Aesthetic Impact or Causing Nuisance Condition	Abate NAPL nuisance or aesthetic condition ❑ Recovery II OR ❑ Control Only
Risk-Based NAPL Management	❑ ${}^{Tot}Soil_{Comb}$ PCL Exceeded	Critical PCL met throughout NAPL zone & prevent cross media impact ❑ Recovery II OR ❑ Control Only
	❑ ${}^{GW}Soil$ PCL Exceeded	Critical PCL met throughout NAPL zone & prevent cross media impact ❑ Recovery II OR ❑ Control Only
	❑ ${}^{Air}Soil_{Inh\text{-}V}$ PCL Exceeded	Critical PCL met throughout NAPL zone & prevent cross media impact ❑ Recovery II OR ❑ Control Only
	❑ NAPL in Contact with Class 1 Groundwater	Critical PCL met throughout NAPL zone ❑ Recovery I
	❑ NAPL in Contact with Class 2 Groundwater	Critical PCL met throughout NAPL zone or prevent exposure ❑ Recovery II OR ❑ Control Only (w/PMZ)
	❑ NAPL in Contact with Class 3 Groundwater	Critical PCL met throughout NAPL zone or prevent exposure ❑ Recovery II OR ❑ Control Only (w/PMZ)
	❑ NAPL in Contact with Surface Water	Critical PCL met throughout NAPL zone ❑ Recovery I
	❑ NAPL IN or ON Sediments	Critical PCL met throughout NAPL zone ❑ Recovery I

6.3 Use of Qualitative NAPL Management TOOL 3A (Screen for Benefits of NAPL Recovery)

NAPL Management TOOL 3A (Table 6.2) is a *qualitative screen for evaluating the benefits of NAPL recovery based on the risk posed by site conditions*. TOOL 3A uses qualitative site conditions to estimate the relative benefits of NAPL recovery. Each column and row heading has an associated point value. For each site condition the corresponding column point value is multiplied by that row's point value. For example, for an explosive condition – the point value is 100. *All products are added* to determine a point total. *A point total greater than 100 indicates an unequivocal benefit to recovery*.

Table 6.2: Qualitative NAPL Management TOOL 3A (Screen for Benefits of NAPL Recovery)

SITE CONDITONS FOR NAPL RECOVERY		SIGNIFICANT BENEFIT to NAPL Recovery	REASONABLE BENEFIT to NAPL Recovery	INSIGNIFICANT BENEFIT to NAPL Recovery
	Pts.	5	3	1
Level of Risk	20	Explosive	Exceeds Health/ecological PCLs	None
Potential for Direct Contact (via Excavation) and/or Migration through Utility Conduits	15	Mobile NAPL fraction < 15 ft BGS	NAPL 15 ft – 30 ft BGS	NAPL > 30 ft
Status of NAPL migration	15	Expanding NAPL zone	Stable or trapped NAPL zone	Immobile NAPL zone
Mobile NAPL in Vadose Zone	15	Above *unaffected* Class 1/Class 2 GW	Above *affected* Class 1/Class 2 GW	Above Class 3 GW
Status of Dissolved GW Plume	8	Expanding dissolved phase plume	Stable dissolved phase plume	Shrinking dissolved phase plume
Impact to Site Use	5	Beneficial use of site clearly improved	Potential for improvement in site use	No impact on use
Level of Public Concern	5	High (*e.g.*, pending litigation, significant resource injury, *etc*.)	Moderate (*e.g.*, public notice, multiple affected parties, *etc*.)	None
Potential for Threat to Receptors	3	Receptor currently impacted or in < 2 years travel time	Potential impact to receptor > 2 years travel time	No foreseeable risk to receptors
Urgency of Meeting PCL Goals	3	Rapid clean-up required (*e.g.*, property transfer)	Reasonable time-frame < 15 years clean-up	Reasonable time-frame > 15 years clean-up
Consequence of Failure of Physical Control	3	Significant increase to risk	Potential adverse effect	No adverse consequences

If TOOL 3B (Table 6.2) indicates there is a need to recover NAPL, Table 7.1 (STEP 4) should be consulted to determine the requisite NAPL Recovery Endpoint(s) for each NAPL Management Trigger.

6.4 Use of Qualitative NAPL Management TOOL 3B (Screen for Potential of Conventional NAPL Recovery Technology)

NAPL Management TOOL 3B is a *qualitative screen for the potential use of conventional NAPL recovery technologies based on existing site conditions*. (Table 6.3 summarizes conventional NAPL recovery technologies.)

TABLE 6.3: Example Conventional NAPL Recovery Technologies*

	Conventional Technology	Description
Soil Excavation	Excavate and dispose	Excavate vadose zone (including capillary fringe), dispose soil
	Excavate and treat	Excavate vadose zone (including capillary fringe), treat soil on-site or other location
Liquid-Phase NAPL Recovery	Skimming	LNAPL is removed from surface of water table through purpose-built recovery wells
Multi-Phase NAPL Recovery	Drop-tube entrainment extraction	Single pump w/ drop tube set to recover total fluids (GW/LP/VP)
	Low-vacuum dual phase extraction	Two pumps, w/ submersible pump for GW (GW/LP/VP)
	Two-phase extraction	Single pump with high vacuum (GW/LP/VP)
	Bioslurp	Single pump w/ drop tube at air-liquid interface (GW/LP and/or VP)

*** Conventional NAPL recovery technologies are based on physical removal processes (*i.e.*, hydraulic and vapor phase recovery) GW = Groundwater LP = Liquid Phase VP = Vapor Phase**

TOOL 3B (Table 6.4) is used qualitatively by selecting all applicable site characteristics matrix boxes. A "*weight-of-evidence*" approach is used to determine the relative potential for the efficacy of conventional NAPL recovery technologies by the number of applicable site characteristics in each column.

In this qualitative evaluation, the recovery potential column in which the highest number of applicable site characteristics boxes occur is selected as the most likely forecast for efficacy of conventional recovery. For sites whose recovery potential characteristics are equivocal (*i.e.*, diversity of site characteristics do not point to a single recovery potential level) an appropriate weighting system may be applied to given site characteristics.

NAPL Management TOOL 3B is presented in Table 6.4. Examples of the use of TOOL 3B appear in Attachment 3.

Table 6.4: Qualitative NAPL Management TOOL 3B
(Screen for Potential of Conventional NAPL Recovery Technology)

Site Character	Parameter	CONDITIONS FOR CONVENTIONAL NAPL RECOVERABILITY POTENTIAL IS:		
		LOW POTENTIAL For Conventional NAPL Recovery (Use of Alternative technology necessary)	**MODERATE POTENTIAL** For Conventional NAPL Recovery (Use of Conventional technology possible)	**HIGH POTENTIAL** For Conventional NAPL Recovery (Use of Conventional technology likely)
Remediation Factors	**Depth of NAPL for Excavation (*vadose zone*)**	Deep (NAPL > 15')	Moderate Depth (NAPL is 5' – 15')	Shallow (NAPL < 5')
	Accessibility	Poor (*i.e.*, beneath building)	Moderate (some obstruction)	Good (no obstruction)
Geology	**Soil Type**	Clay / Clayey Silt	Silt / Sandy Silt	Sand to Gravel
	Stratigraphy	Complex geologic site conditions	Moderately complex geologic site conditions	Simple geologic site conditions
NAPL Occurrence	**NAPL Mobility**	Immobile NAPL	Stable NAPL	Mobile NAPL
	Pooled NAPL	NAPL in karst	NAPL below water table	NAPL just on or below water table
	Disseminated NAPL	NAPL in fractures in saturated zone	NAPL in unsaturated fractures	NAPL in unconsolidated vadose materials
Site Hydraulics	**Hydraulic Conductivity**	$K < 10^{-4}$ cm/sec	10^{-4} cm/sec $< K < 10^{-2}$ cm/sec	$K > 10^{-2}$ cm/sec

6.4 Qualitative NAPL Management Tools with RECOVERY I

When evaluating the Qualitative NAPL Management Tools for a RECOVERY I response action (see Table 6.1), the *control option is not an available response action*. The RECOVERY I response action requires recovery. As such, *only TOOL 3B can be used in conjunction with a RECOVERY I response action*.

Use of TOOL 3B with the RECOVERY I response action is used to assist in the qualitative determination of whether a conventional or an alternative NAPL recovery technology may be more appropriate for the general conditions at the site. Figure 3-2 summarizes the logic for use of TOOL 3B with the RECOVERY I response action.

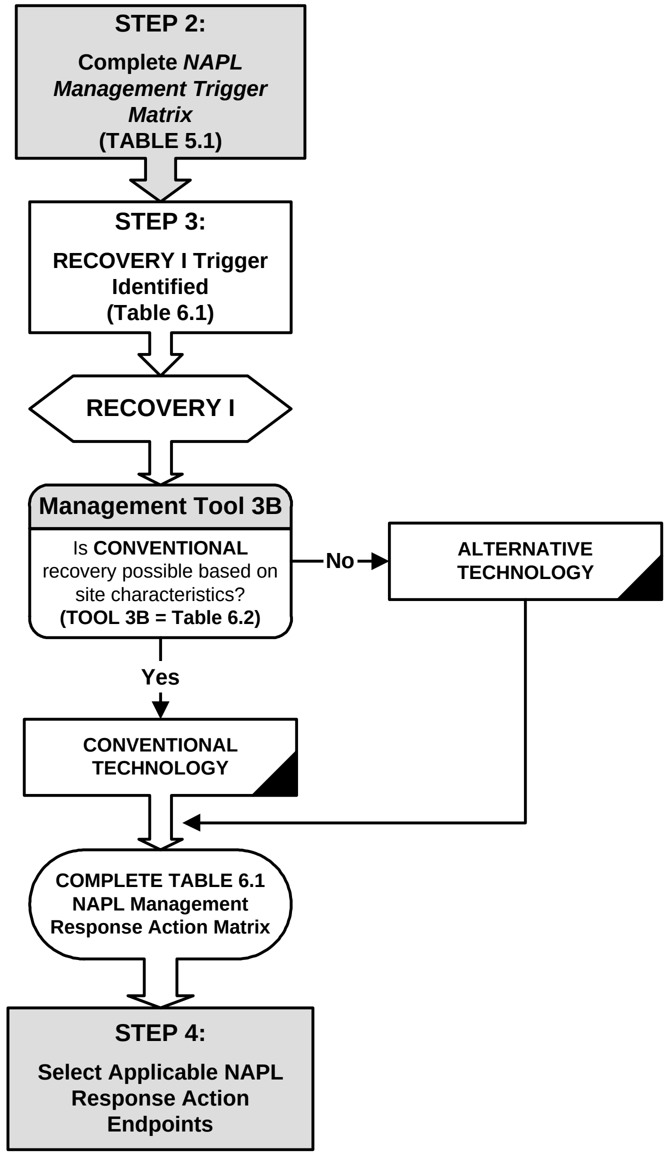


Figure 6-2: Evaluation under RECOVERY I response actions

6.5 Qualitative NAPL Management Tools with RECOVERY II

When evaluating the Qualitative NAPL Management Tools for a RECOVERY II response action (see Table 6.1), *the control option is a potential alternative response action*. The use of a control may be used in conjunction with recovery. However, approval for the *use of a control option as the sole response action is considered only when Qualitative NAPL Management TOOL 3A indicates the benefits of NAPL recovery are not significant and that recovery may not be warranted*.

The use of TOOL 3A and TOOL 3B with the RECOVERY II response action is used to determine qualitatively if 1) a control or control-only option may be appropriate for consideration (TOOL 3A), and 2) a conventional or an alternative NAPL recovery technology may be more appropriate for the general conditions at the site (TOOL 3B). Figure 6-3 summarizes the logic for use of TOOL 3A and TOOL 3B with the RECOVERY II response action.

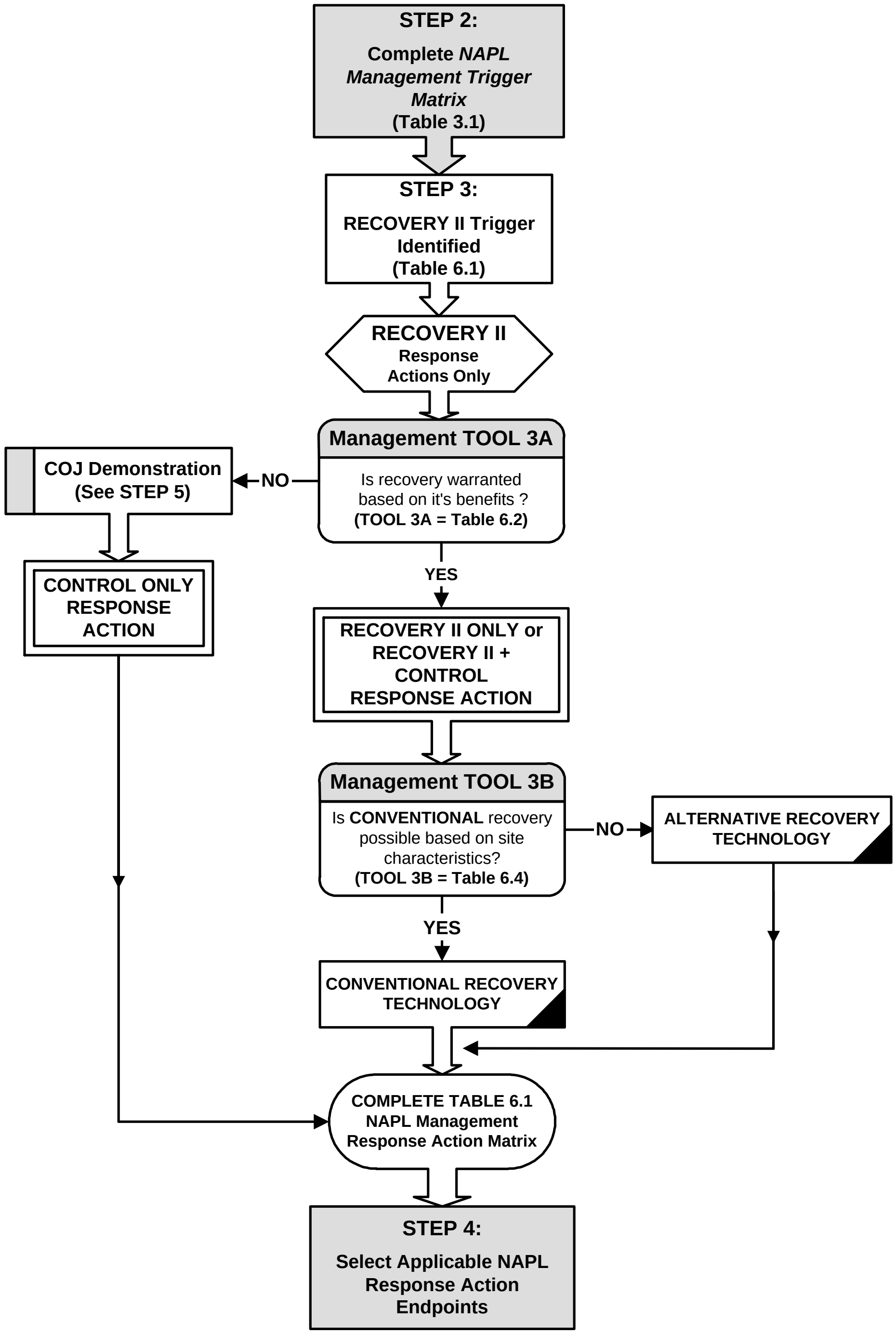


Figure 6-3: Evaluation under RECOVERY II response action

If TOOL 3A indicates that there is an insignificant level of benefit associated with NAPL recovery at the site and that the control-only option is appropriate for consideration as the response action, a *Control Option Justification* (COJ) demonstration must be submitted (see STEP 5 for COJ submittal requirements). The COJ demonstration comprises a detailed discussion of recovery benefits and site conditions items in TOOL 3A and TOOL 3B leading to the conclusion that the control response action is an appropriate option.

6.6 Complete NAPL Management Response Action Matrix

After processing the logic procedures of Figure 6-2 and/or Figure 6-3 the final procedure in STEP 3 is to complete the NAPL Management Response Action Matrix (Table 6.1) by checking a box for each applicable NAPL Management Trigger and all applicable NAPL Management Response Actions.

For example, when the *NAPL in Contact with Class 1 Groundwater* NAPL Management Trigger is identified (and box checked) - and *Critical PCL met throughout NAPL zone* is the NAPL Management Response Action - the *RECOVERY I* box should be checked.

When the *NAPL in Contact with Class 2 Groundwater* NAPL Management Trigger is identified (and box checked) - and *Critical PCL met throughout NAPL zone* is the NAPL Management Response Action, the *RECOVERY II* box <u>or</u> the *Control* box (if appropriate) <u>or</u> both boxes should be checked.

After completion of STEP 3, proceed to STEP 4.

7.0 STEP 4: Select Applicable NAPL Response Action Endpoints

Step 4 is employed for the purpose of specifying what requirements comprise each NAPL Recovery and Control Endpoint subsequent to identifying all applicable NAPL Management Response Actions in Step 3. The NAPL Recovery and Control Matrix (Table 7.1) summarizes the NAPL recovery and control trigger-endpoint details. Step 4 also is used to screen for the technical feasibility of using various NAPL recovery technologies. Step 4 comprises checking all applicable endpoints and completing Table 7.1. The logic procedure of Step 4 is depicted in Figure 7-1.

7.1 NAPL Management Response Action Endpoints

NAPL Management Response Actions comprise two general categories: *recovery* and *control*. NAPL management *endpoints* are the specific response action goals that must be met to eliminate the NAPL site conditions that prompt a NAPL Management Trigger (*see* Step 2). The following sections describe the response actions that comprise each NAPL Management Endpoint. Each NAPL Management Trigger has associated with it at least one NAPL Response Action Endpoint. Table 7.1 summarizes the NAPL trigger-endpoint associations and the endpoint description.

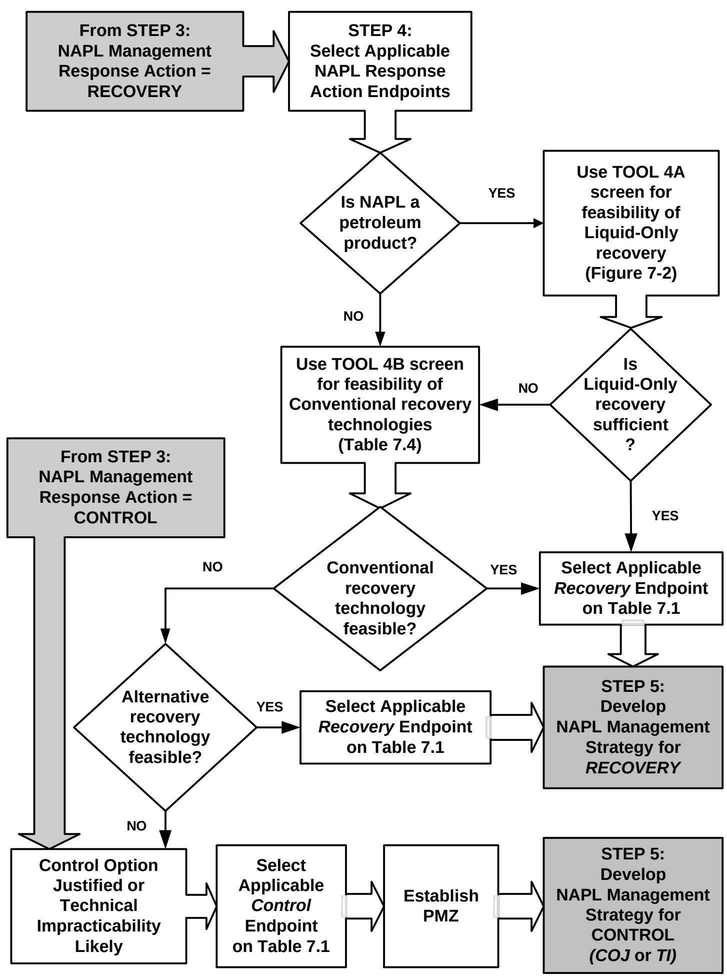


Figure 7-1: Overview of Step 4

Table 7.1: NAPL Recovery and Control Endpoints Matrix

NAPL Management Response Actions (*From STEP 3 ; Table 3.1*)	Interim Control	NAPL Recovery Endpoints*	NAPL Control Endpoints
Regulatory NAPL Management Response Actions			
NAPL Trigger: Explosive Vapor Accumulation ❑ ***Abate NAPL vapor source* permanently**	❑ Immediate abatement & suppression of vapor accumulation	***RECOVERY I ONLY*** *(Section 7.1.1.1)* ❑ Recovery mass of volatile components of NAPL sufficient for permanent vapor abatement	**N/A**
NAPL Trigger: Expanding NAPL Zone ❑ ***Arrest all NAPL Zone expansion*** ❑ ***Prevent NAPL zone expansion beyond PMZ***	❑ Abate expansion	***RECOVERY II*** **(Select one only)** *(Section 7.1.2.1 or 7.1.2.2)* ❑ Recover mobile NAPL fraction (reduce COC concentrations to below residual saturation throughout NAPL zone) ***(w/out PMZ)*** ❑ Recover mobile NAPL fraction sufficient to prevent potential NAPL migration ***(w/PMZ)***	***Control Only w/COJ***** *(Section 7.1.3.1 or 7.1.3.2)* ❑ Physical control prevents NAPL migration
NAPL Trigger: Mobile NAPL w/in vadose zone ❑ ***Eliminate mobile NAPL fraction in vadose zone***	❑ Recover readily recoverable fraction	***RECOVERY II*** *(Section 7.1.2.3)* ❑ Recover NAPL to Residual Saturation	***Control Only w/COJ*** *(Section 7.1.3.3)* ❑ Physical control prevents potential exposure to mobile NAPL
NAPL Trigger: NAPL creating aesthetic or nuisance condition ❑ ***Abate NAPL nuisance or aesthetic condition***	❑ Abate nuisance	***RECOVERY II*** **(***Section 7.1.2.4)* ❑ Recover sufficient NAPL to eliminate nuisance/aesthetic condition at source or point of concern	***Control Only w/COJ*** *(Section 7.1.3.4)* ❑ Physical control eliminates nuisance/ aesthetic condition at source or point of concern

N/A = Control endpoint not available option
*** Endpoints must be consistent with STEP 3 response action(s) – from Table 6.1**
**** COJ = Control Option Justification – see STEP 5**

Table 7.1: NAPL Recovery and Control Endpoints Matrix (Cont.)

NAPL Management Response Actions (*From STEP 3 ; Table 3.1*)	Interim Control	NAPL Recovery Endpoints*	NAPL Control Endpoints
Risk-Based NAPL Management Response Actions			
NAPL Trigger: NAPL in Soil ❑ ***Meet critical soil PCLs throughout NAPL zone or exposure to NAPL and cross-media impact prevented***	**N/A**	***RECOVERY II*** **(select the Critical PCL)** *(Section 7.1.2.3)* ❑ Recover NAPL to: **concentration < $^{Tot}Soil_{Comb}$** ❑ Recover NAPL to: **concentration < $^{GW}Soil$** ❑ Recover NAPL to: **concentration < $^{Air}Soil_{Inh\text{-}V}$**	***Control Only w/COJ***** *(Section 7.1.3.5)* ❑ Physical control prevents exposure to NAPL zone and prevents exposure to unprotective vapors or generation of unprotective leachate
NAPL Trigger: NAPL in Contact w/ Class 1 Groundwater ❑ ***Meet Class 1 groundwater PCL throughout NAPL zone***	**N/A**	***RECOVERY I ONLY*** **(select one only)** *(Section 7.1.1.2)* ❑ Recover all NAPL in contact with groundwater ❑ Remove readily recoverable fraction of NAPL, after which remaining NAPL in source zone is decontaminated via NAPL dissipation within acceptable reasonable timeframe	***Control w/ TI ONLY*** **(select one only)** *(Section 7.1.4.1)* ❑ Soluble NAPL fraction recovered, PMZ for NAPL extent ❑ NAPL isolated with physical control, no mass loading to dissolved PCLE zone
NAPL Trigger: NAPL in Contact w/ Surface Water ❑ ***Meet Surface Water PCL***	**Establish control to prevent further exposure to surface water**	***RECOVERY I ONLY*** *(Section 7.1.1.3)* ❑ Recover NAPL to: **concentration < ^{SW}SW**	**N/A**
NAPL Trigger: NAPL IN or ON Sediments ❑ ***Meet Sediment PCLs throughout NAPL Zone***	**Establish control to isolate sediment exposure to other media**	***RECOVERY I ONLY*** *(Section 7.1.1.4)* ❑ Recover NAPL to: **concentration < ^{Sed}GW** ❑ Recover NAPL to: **concentration < $^{Sed}Soil$** ❑ Recover NAPL to: **concentration < Sed_{eco}**	***Control w/ TI ONLY*** *(Section 7.1.4.2)* ❑ Isolate NAPL-contaminated sediments from surface water bodies and receptors

N/A = Control endpoint not available option
*** Endpoints must be consistent with STEP 3 response action(s) – from Table 6.1**
**** COJ = Control Option Justification – see STEP 5**

TABLE 7.1: NAPL Recovery and Control Endpoints Matrix (Cont.)

NAPL Management Response Actions (*From STEP 3 ; TABLE 3.1*)	Interim Control	NAPL Recovery Endpoints*	NAPL Control Endpoints
Risk-Based NAPL Management Response Actions			
NAPL Trigger: NAPL in Contact w/ Class 2 & Class 3 Groundwater ❑ ***Meet critical Class 2/Class 3 groundwater PCLs within NAPL zone or exposure to NAPL and expanding dissolved PCLE zone prevented***	N/A	***RECOVERY II*** (select one only) *(Section 7.1.2.4)* ❑ Recover all NAPL in contact with groundwater ❑ Recover fraction of NAPL mass to meet PCL (focus on eliminating toxic, volatile and/or soluble components in mixtures) ❑ Recover fraction of NAPL mass such that remaining NAPL dissipation occurs within reasonable timeframe	***Control ONLY w/COJ** (w/PMZ)*** (select one only) *(Section 7.1.3.6)* ❑ For: NAPL causing expanding dissolved PCLE zone - Physical control w/in PMZ to isolate dissipating NAPL mass loading to GW and result in shrinkage or elimination of dissolved PCLE zone ❑ For: NAPL causing expanding dissolved PCLE zone - Physical control w/in PMZ to reduce NAPL mass loading to GW and result in stable or shrinking dissolved PCLE zone ❑ For: NAPL not causing expanding dissolved PCLE zone – Natural containment, PMZ for NAPL source and dissolved PCLE zones
		RECOVERY II + Control (w/PMZ) (select one combination only) *(Section 7.1.5.1)*	
		❑ Recover sufficient NAPL to prevent creation of dissolved PCLE plume	+ PMZ for NAPL extent only
		❑ Recover sufficient NAPL to prevent further expansion of dissolved PCLE zone	+ PMZ for NAPL and dissolved PCLE zone
		❑ Recover sufficient NAPL to create shrinking PCLE zone	+ PMZ for NAPL and dissolved PCLE zone

N/A = Control endpoint not available option
*** Endpoints must be consistent with STEP 3 response action(s) – from Table 6.1**
**** COJ = Control Option Justification – see STEP 5**

7.1.1 NAPL RECOVERY I Only Endpoints

The NAPL RECOVERY I Endpoints are applicable to four NAPL response actions: 1) Permanent abatement of an explosive NAPL vapor source, 2) meeting critical PCLs throughout a NAPL zone in contact with Class I groundwater, 3) meeting surface water PCLs and 4) meeting sediment PCLs (*see* Table 7.1).

The NAPL RECOVERY I Endpoints mean that NAPL recovery is the requirement. In RECOVERY I Endpoint situations, the NAPL Control is permissible as a NAPL response action only after 1) alternative technology recovery has been attempted and 2) a *Technical Impracticability Demonstration* (*see* Step 5) showing that further NAPL recovery is infeasible is accepted by the TCEQ.

7.1.1.1 *Permanently abate NAPL vapor source*. In the situation where an explosive NAPL vapor source must be abated, no compromise or alternative action (*i.e.*, control) is permitted. The endpoint is achieved upon sufficient recovery of the NAPL source responsible for the explosive vapor condition. Sufficient NAPL is recovered when the NAPL Zone is no longer capable of generating an explosive condition. *However, an interim control may be warranted and should be pursued in accordance with §350.1*.

7.1.1.2 *Critical PCL met throughout NAPL zone in contact w/ Class 1 groundwater*. In the case of NAPL in contact with Class 1 groundwater, the most effective NAPL recovery technologies should be utilized and all possible NAPL recovery efforts typically should be expended prior to proposing a control option via a *Technical Impracticability Demonstration* (*see* Step 5). The endpoint is achieved when COC concentrations within the NAPL zone in contact with Class 1 groundwater (including the smear zone, current and historical capillary fringe, *etc.*) are reduced to levels below the PCL.

In the case where PCLs can not be achieved because of technical limitations, implementation of a control option may be proposed via a formal *Technical Impracticability Demonstration* (*see* Step 5).

7.1.1.3 *Meet Surface Water PCL.* In the case of a NAPL-affected surface water body, the Recovery I response action requires that NAPL must be recovered to the extent that the ^{SW}SW PCL is met in the surface water interface.

7.1.1.4 *Meet Sediment PCLs throughout NAPL Zone.* For NAPL-affected sediment associated with surface water bodies and groundwater, the NAPL Recovery I response action requires that NAPL be recovered to the extent that all sediment-related PCLs are met.

7.1.2 NAPL RECOVERY II Endpoints

The NAPL RECOVERY II Endpoints are applicable to the remaining NAPL response actions: 1) eliminating NAPL mobility, 2) abating NAPL nuisance or aesthetic condition, 3) meeting critical PCLs in soil, 4) and meeting critical PCLs in Class 2 and 3 groundwaters (see Table 7.1). NAPL RECOVERY II means that NAPL recovery as a NAPL management response action should be pursued, but *a NAPL control endpoint may be available when TOOL 3A (Table 6.2) an insignificant benefit is associated with NAPL recovery*.

Requirements to satisfying completely the response action goals of the following endpoints may be mitigated by site risk and other factors via a control option using the *Control Option Justification* (*see* Step 5).

7.1.2.1 *Arrest all NAPL zone expansion (NAPL in contact w/ Class 2/3 groundwater, but no PMZ).* The mobile NAPL fraction is recovered to the extent that COC concentrations associated with observed and theoretical NAPL mobility are reduced to levels below that COC's applicable residual saturation concentration throughout the NAPL zone.

7.1.2.2 *Prevent NAPL Zone migration beyond PMZ (NAPL in contact w/ Class 2/3 groundwater with PMZ).* NAPL is recovered to the extent that the mobile NAPL fraction removed is sufficient to prevent NAPL zone expansion.

7.1.2.3 *Eliminate mobile NAPL fraction in vadose zone.* NAPL is recovered to the extent that the mobile fraction is removed to residual concentrations or below, sufficient to prevent further migration of the NAPL zone and threat to a groundwater resource.

7.1.2.4 *Abate NAPL nuisance or aesthetic condition.* NAPL is recovered to the extent that COC concentrations are below a level that eliminates the offending nuisance or aesthetic condition.

7.1.2.3 *Meet critical soil PCLs in NAPL zone.* NAPL is recovered from soil to the extent that COC concentrations meet critical PCLs that insure protection from direct exposure and for all cross-media impacts (*i.e.*, ${}^{Tot}Soil_{Comb}$, ${}^{Air}Soil_{Inh}$, and ${}^{GW}Soil$).

7.1.2.4 *Meet critical groundwater PCLs in NAPL zone contacting Class 2/Class 3 groundwater.* NAPL is recovered to the extent that one (or more) of the following endpoints is satisfied:

1) Recover all NAPL in contact with groundwater,
2) Recover fraction of NAPL sufficient to reduce NAPL zone to below PCLs,
3) Recover fraction of NAPL sufficient to insure remaining NAPL shall dissipate within reasonable timeframe via NAPL dissipation demonstration.

7.1.3 NAPL CONTROL Only (w/COJ) Endpoint

The NAPL CONTROL Only (w/COJ) Endpoint is a permissible NAPL Control Endpoint *only if the NAPL control response action has been determined appropriate* by the following:

1) The NAPL Control Option has been justified after processing the logic in Figure 3-2 in Step 3, *and*
2) A *NAPL Control Option Justification* (COJ) has been accepted by the TCEQ (*see* Step 5).

The NAPL CONTROL Only (w/COJ) Endpoint is applicable to the following NAPL Response Actions: 1) arrest NAPL zone expansion, 2) eliminate mobile NAPL, 3) abate NAPL nuisance or aesthetic condition, 4) meet soil PCLs, and 5) meet critical Class 2/Class 3 groundwater PCLs (see Table 7.1).

7.1.3.1 *Arrest all NAPL Zone expansion.* Install a physical control that effectively prevents any further migration of the NAPL Zone. Acceptance of a COJ demonstration is required prior to implementation of this NAPL Control Option (*see* Step 5) as a formal remedy, but interim actions can be taken to halt continued expansion.

7.1.3.2 *Prevent NAPL Zone migration beyond PMZ (w/PMZ).* Install a physical control that effectively prevents expansion of NAPL Zone beyond the boundary of an established PMZ. Acceptance of a COJ demonstration is required prior to implementation of this NAPL Control Option (*see* Step 5) as a formal remedy, but interim actions can be taken to halt any potential expansion.

7.1.3.3 *Eliminate mobile NAPL in vadose zone.* Install a physical control that effectively prevents potential migration of NAPL to underlying groundwater resources, utility conduits, structures and surface water bodies, and prevents potential direct exposure of NAPL to all receptors. Acceptance of a COJ demonstration is required prior to implementation of this NAPL Control Option (*see* Step 5) as a formal remedy, but interim actions can be taken to halt any expansion.

7.1.3.4 *Abate NAPL nuisance or aesthetic condition.* Install a physical control that effectively eliminates the nuisance or aesthetic condition at the source or point of concern. Acceptance of a COJ demonstration is required prior to implementation of this NAPL Control Option (*see* Step 5) as a formal remedy, but interim actions can be taken to halt any expansion.

7.1.3.5 *Meet critical soil PCLs throughout NAPL zone or exposure to NAPL and cross-media impact prevented.* Install a physical control that effectively prevents exposure to NAPL zone and/or effectively prevents exposure to unprotective levels of vapor-phase COCs and/or generation of unprotective leachate. Acceptance of a COJ demonstration is required prior to implementation of this NAPL Control Option (*see* Step 5).

7.1.3.6 *Meet critical Class 2/Class 3 groundwater PCLs throughout NAPL zone.* Three different NAPL control endpoints are possible are under this NAPL response action: Two possible control endpoints associated with NAPL causing an expanding dissolved COC PCLE zone; one control endpoint associated with NAPL associated with a stable or shrinking dissolved COC PCLE zone. Specifically, the possible associated NAPL control endpoints are:

1. For: Stable NAPL zone causing expanding dissolved COC PCLE zone: Install a physical control within the PMZ that effectively isolates dissipating NAPL mass loading to groundwater and that results in the *shrinkage or elimination* of the dissolved COC PCLE zone.

2. For: Stable NAPL zone causing expanding dissolved COC PCLE zone: Install a physical control within the PMZ that effectively reduces NAPL mass loading to groundwater and that results in a *stable or shrinking* dissolved COC PCLE zone.

3. For: Stable NAPL zone not causing expanding dissolved PCLE zone: Control shrinking or stable dissolved COC PCLE zone from expanding using the Natural Containment (I or II) groundwater control option (*see* TRRP 31).

All NAPL control endpoints above require establishment of a PMZ and the acceptance of a COJ demonstration by the TCEQ prior to implementation of the available NAPL Control Options (see Step 5).

7.1.4 NAPL CONTROL Only (w/TI) Endpoint

The NAPL CONTROL Only (w/TI) Endpoint is a control endpoint *that is applicable only* in two instances:

1. In cases where TRRP requires restoration as the Recovery I response action (*e.g.*, NAPL in contact with Class I groundwater), and

2. In cases where a Control option is available (Recovery II response action), but an Institutional Control but is denied for off-site properties (*e.g.*, NAPL in contact with Class 2/3 groundwater).

Prior to implementing this control endpoint a PMZ must be established and TCEQ acceptance of a formal Technical Impracticability Demonstration is required (see Table 7.1).

The NAPL CONTROL Only (w/TI) Endpoint is applicable to the following NAPL Response Action:

7.1.4.1 ***Meet Class 1 groundwater PCLs throughout NAPL zone.*** Under this NAPL management response action either of two (2) different control endpoints may be afforded upon acceptance of a formal Technical Impracticability Demonstration (see Table 7.1). The endpoints are: 1) recovery of the soluble NAPL fraction associated with a NAPL, and 2) physically control NAPL such that the NAPL Zone is isolated and prevented from any mass loading to a dissolved PCLE zone. Guidance on developing a TI demonstration is provided in Step 5.

7.1.4.2 ***Meet Sediment PCLs throughout NAPL Zone.*** Under Under this NAPL management response a TI Demonstration must be accepted by the TCEQ after which a control option is implemented that is capable of effectively isolating NAPL-contaminated sediments from all groundwater resources and surface water bodies. Guidance on developing a TI demonstration is provided in Step 5.

7.1.5 NAPL RECOVERY II + CONTROL (w/PMZ) Endpoint

The NAPL RECOVERY II + CONTROL (w/PMZ) Endpoint comprises three separate NAPL recovery and control endpoint option *combinations*, any of which may be used so long as the coupled recovery and control endpoints are used in the combinations summarized in Table 7.1 and below.

7.1.5.1 ***Meet Class 2/Class 3 groundwater PCLs.*** Under this NAPL management response action three NAPL recovery + control endpoint options are available:

1. Recover NAPL to prevent creation of dissolved PCLE zone + PMZ for NAPL zone
2. Recover NAPL to prevent further expansion of dissolved PCLE zone + PMZ for NAPL and dissolved PCLE zones
3. Recover NAPL to induce shrinking dissolved PCLE zone + PMZ for NAPL and dissolved PCLE zones

The selection of which one of the above options to implement should be based what is appropriate to the site-specific condition encountered.

7.2 Conventional NAPL Recovery Technologies

Conventional NAPL recovery technologies are considered to be technologies that remove NAPL by exploiting the following physical properties:

1. *Hydraulic* - remove liquid NAPL via direct pumping of NAPL only or NAPL + groundwater.

2. *Vapor phase* - volatilize NAPL by increasing its vapor pressure via reducing pressure (induce vacuum) and removing in vapor phase.

Many conventional NAPL recovery technology configurations exploit both the hydraulic and pneumatic properties of a NAPL and the site conditions by combining technologies and creating effective recovery systems. While conventional NAPL recovery technologies can be effective for DNAPL in the unsaturated zone (vadose or induced), they are most effective for LNAPL recovery in the saturated zone since the pneumatic recovery processes are limited in the deeper saturated zones where DNAPL is more likely to reside.

Table 7.2 summarizes the various conventional NAPL recovery technologies addressed in this document.

Table 7.2: Summary of Conventional NAPL Recovery Technologies

Technology	System Description / Configuration	Recovery Products
Soil Vapor Extraction (SVE)	Extraction well(s) set in vadose zone, one low- (or hi-) vacuum pump recovers volatile NAPL	VP LNAPL and VP DNAPL
Floating LNAPL Extraction (FLE)	LNAPL skimming pump with LNAPL inlet set at water-NAPL interface	LNAPL
Shallow Liquid-Only (Total Fluids) Extraction (SLE)	Single submersible pump set *shallow* in saturated zone	GW + LNAPL (undifferentiated)
Deep Liquid-Only (Total Fluids) Extraction (DLE)	Single submersible pump set *deep* in saturated zone	GW + DNAPL (undifferentiated)
Dual-Pump Liquid Extraction (DPLE)	Two submersible pumps; one set below water table to create groundwater drawdown, second pump set at water-NAPL interface to recover NAPL	GW & LNAPL (separated)
Low-Vacuum Dual Phase Extraction (LVE)	One submersible pump set below water table, one low-vacuum pump with suction-tube set above cone of depression Lo vacuum = 2 – 12 in Hg	GW + LNAPL (undifferentiated) VP LNAPL and VP DNAPL (separated)
Hi-Vacuum Dual Phase Extraction (HVE)	One submersible pump set below water table, one hi-vacuum pump with suction-tube set above cone of depression Hi vacuum = 18 – 26 in Hg	GW + LNAPL and DNAPL (undifferentiated) VP LNAPL and VP DNAPL (separated)
Two-Phase Extraction (*i.e.*, Bioslurp) (TPE)	Single high-vacuum pump, suction-tube set at air-liquid interface; Hi vacuum = 18 – 26 in Hg	GW + LNAPL (undifferentiated) VP LNAPL and VP DNAPL (separated)
GW = groundwater VP = vapor phase LNAPL = light non-aqueous phase liquid DNAPL = dense non-aqueous phase liquid		

7.3 Alternative NAPL Recovery Technologies

Alternative NAPL recovery technologies rely primarily on transforming NAPL chemistry or altering site conditions. A summary of the most common alternative NAPL recovery technologies appears in Table 7.3. However, the list is not a complete one as new technologies are being tested routinely.

Implementation of these technologies generally requires more significant design and testing effort than that typically required for conventional technologies. Pilot testing of alternative NAPL recovery systems often is commensurate with the site-specific engineering design process and may be necessary prior to completing the submitted RAP design. As such, the design process can become technically challenging and requires the involvement of experienced and qualified professionals.

Most of the alternative NAPL recovery technologies

TABLE 7.3: Summary of Alternative NAPL Recovery Technologies

Technology	System Description	Target NAPLs
Soil Flushing	Alcohol, cosolvents, and/or surfactants are flushed through NAPL zone to solublize and mobilize NAPL; flushate and groundwater is recovered via extraction downgradient	DNAPL & LNAPL in saturated zone
***In Situ* Oxidation**	Oxidizing compound (*e.g.*, potassium permanganate, hydrogen peroxide) introduced into the NAPL zone chemically destroys NAPL; system is flushed with water and extracted	DNAPL in saturated zone
Electrical Heating + SVE	Vadose NAPL zone temperature is increased via resistance (Joule) heating, radio frequency heating, or steam heating; NAPL is volatized and mobilized; vapor is removed using soil vapor extraction, which is treated	Volatile & semi-volatile DNAPL & LNAPL in fine-grained (and coarser) vadose zone
Air Sparging + SVE	Air injected in the saturated zone below NAPL zone causes DNAPL to partition into air phase which is transported into vadose zone where vapor is extracted via SVE system and treated	DNAPL in saturated zone
Steam Injection + SVE	Steam is injected into the NAPL zone to vaporize and mobilize NAPL which is recovered by soil vapor extraction system and treated	DNAPL & LNAPL in medium – coarse unsaturated zone
Electrokinetics	A DC electrical field is established in NAPL zone that induces water and NAPL migration to recovery area; NAPL can be made to migrate through a treatment zone	DNAPL in fine-grained soils

7.4 Technical Feasibility Screen for NAPL Recovery Endpoints

The feasibility of using conventional NAPL recovery technologies for a NAPL recovery response action may be evaluated by use of two Quantitative NAPL Recovery Screening Tools. The logic for using the quantitative screening tools is shown in Figure 7-1.

The use of the two quantitative NAPL recovery screening tools is intended to provide decision-making guidance for determining whether a conventional NAPL recovery system may be a more appropriate choice than implementing an alternative NAPL recovery technology for some site conditions. *The Quantitative NAPL Recovery Screening Tools (4A and 4B) are provided as guide and are not intended to replace engineering analysis or design.*

7.4.1 Use of Quantitative NAPL Recovery Screening TOOL 4A (Screen for Liquid Only Petroleum NAPL Recovery)

The Quantitative NAPL Recovery Screening TOOL 4A can be used to determine whether a total-fluids submersible pump recovery system is likely to be effective on a range of petroleum products and hydraulic conductivities at petroleum product NAPL sites. The Quantitative NAPL Recovery Screening TOOL 4A was developed using the numerical model *ARMOS* (ES&T, 1994) is *applicable only to situations that have the following characteristics*:

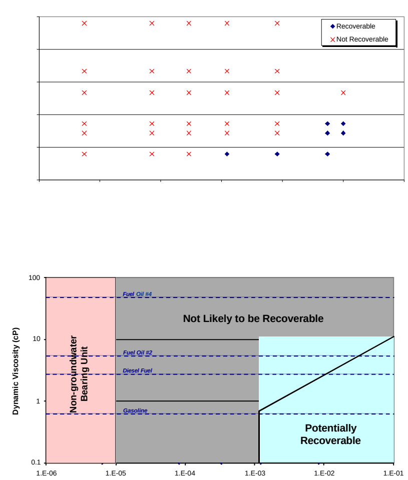
1. petroleum hydrocarbon contamination, *and*
2. a single submersible total-fluids recovery pump, *using*
3. a submersible pump inlet set at depth of 3 feet below static water level.

To use TOOL 4A, select the graph which most closely approximates the true NAPL thickness (*see* Sec 4.4.3) at the site, plot a point that corresponds to the applicable product viscosity and the hydraulic conductivity of the unit in which the NAPL is found. If the plotted point lies within the *Potentially Recoverable* field, then NAPL recovery using the above configuration is technically feasible.

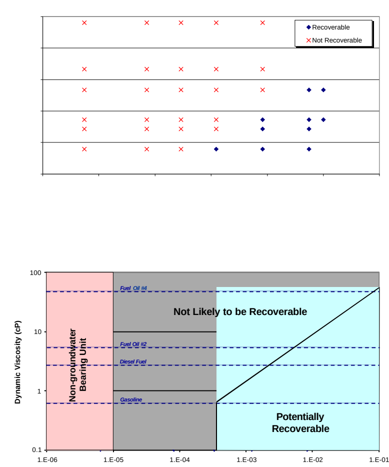
NOTE: *If the system configuration (described above) is implemented and becomes ineffective in removing NAPL prior to satisfying the applicable endpoint(s), conversion to implementation of an alternative NAPL recovery system may be necessary*.

Screening for conventional NAPL recovery at sites with conditions different than those specifically listed above should be performed using Quantitative NAPL Management TOOL 4B (Sec 7.5.2). See Figure 7-1 for the TOOL 4A logic path.

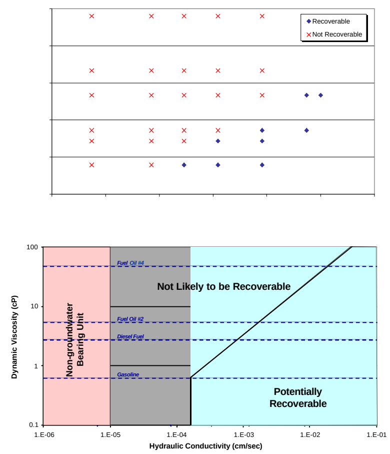
TOOL 4A – Quantitative NAPL Management Screen for Total Fluids Petroleum Recovery



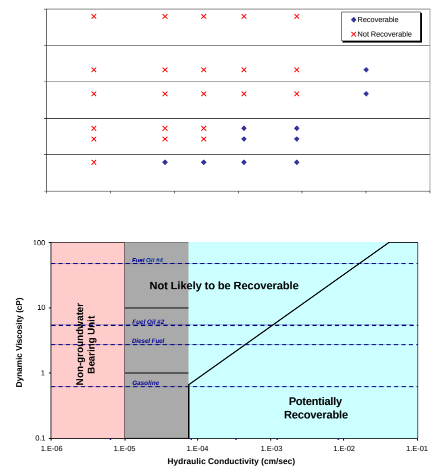
LNAPL Thickness = 0.5 ft



LNAPL Thickness = 1.0 ft



LNAPL Thickness = 2.5 ft



LNAPL Thickness = 5.0 ft

7.4.2 Use of Quantitative NAPL Management Screening TOOL 4B (Screen for Conventional NAPL Recovery Technologies)

Quantitative NAPL Management TOOL 4B (Table 7.4) is used to screen the applicability of conventional NAPL recovery technologies (*see* Table 7.2) for ranges of site-specific conditions. Figure 7-1 shows when to implement TOOL 4B in the context of Step 4 logic.

Use of TOOL 4B begins by finding the row that contains the applicable site-specific NAPL occurrence (from Table 4.12). Next, site-specific values for various parameters and site conditions are matched to the ranges in the column labeled *Condition(s) Favorable for Conventional Recovery* for each NAPL occurrence. When actual site data match a range of values for recovery criterion parameters and site conditions, the next column, *Conventional NAPL Recovery Technologies*, contains one or more corresponding conventional NAPL recovery technologies demonstrated to be successful in recovering NAPL from the same NAPL occurrence.

As illustrated in Figure 7-1, if site conditions for a given NAPL occurrence are outside the range favorable for conventional recovery then consideration must be given for the implementation of an alternative NAPL recovery technology.

The quantitative screen for conventional NAPL recovery technologies (TOOL 4B) is intended for guidance purposes and is not to be used as a replacement for engineering judgement or design.

7.5 Control Option Justification (COJ)

Prior to implementing a NAPL Control Endpoint (Control Only w/COJ) the following should occur: the logic in Figure 7-1 should be followed and lead to a NAPL Control Endpoint and 2) a *Control Option Justification* must be accepted by the TCEQ in the RAP.

Requirements for COJ submittals in the RAP are detailed in Step 5 (Section 8).

TABLE 7.4: TOOL 4B - Quantitative Screen for Conventional NAPL Recovery Technologies

NAPL Occurrence (*from* TABLE 4.12)		Condition(s) Favorable for Conventional Recovery	Conventional NAPL Recovery Technologies
NAPL in Vadose Zone	NAPL in permeable vadose zone	COC vapor pressure > 0.5 mm Hg [1]	SVE
	NAPL in impermeable vadose zone	COC vapor pressure > 0.5 mm Hg [1] Vadose zone air permeability > 10^{-10} cm^2 [1]	SVE
	NAPL in unsaturated fractures		
LNAPL in/on Saturated Zone	LNAPL at water table and/or capillary fringe	10^{-3} cm/sec < K_w < 10^{-5} cm/sec [2] True NAPL thickness > 15 cm [2] NAPL kinematic viscosity < 10 centistoke [2]	Vacuum-enhanced LNAPL recovery
	Petroleum HCs at water table and/or capillary fringe	Use TOOL 4A (Section 7.5.1)	Total fluids extraction
	LNAPL in saturated and fractured soils/sediment		
	LNAPL in saturated and fractured rock		
DNAPL in Saturated Zone	DNAPL in saturated soils and sediments		
	DNAPL in saturated and fractured soils/sediments		
	DNAPL in saturated and fractured		
NAPL in Karst			

(1) USACE, 1995
(2) USACE, 1999

7.6 Technical Impracticability (TI)

Prior to implementing a NAPL Control Endpoint (Control w/TI) the following should occur: the logic in Flow Chart 4-1 should be followed and lead to a NAPL Control Endpoint and 2) a *TI Demonstration* must be accepted by the TCEQ in the RAP.

Requirements for TI Demonstration submittals in the RAP are detailed in Step 5 (Section 8).

7.7 References

ES&T 1994 *Areal Multiphase Organic Simulator for Free Phase Hydrocarbon Migration and Recovery: ARMOS*, ES&T, Blacksburg, Va.

USACE 1995 *Soil Vapor Extraction and Bioventing*, Engineering Manual No. 1110-1-4001, U.S. Army Corps of Engineers, Department of the Army, Washington, DC.

USACE 1999 *Multiphase Extraction*, Engineering Manual No. 1110-1-4010, U.S. Army Corps of Engineers, Department of the Army, Washington, DC.

8.0 STEP 5: Develop NAPL Management Strategy

STEP 5 comprises the final procedure in the NAPL management process prior to implementation of a NAPL recovery and/or control system. Of primary importance to STEP 5 is the description of required elements that are necessary to developing the NAPL management strategy and to the fulfillment of the RAP (under Remedy Standard B and non-SIN sites). Even if TCEQ approval of a RAP is not required and not submitted, it is recommended that this guidance be followed to document the development of the NAPL management strategy and NAPL recovery efforts in the event that a *COJ* or *TI Demonstration* becomes necessary.

A NAPL management strategy is the comprehensive response plan to which all applicable NAPL Management Endpoint(s) at a site are to be satisfied. The NAPL management strategy must address directly each applicable NAPL Management Trigger (Table 5.1) at the site.

The NAPL Management Strategy comprises all NAPL recovery and control endpoints, including engineered designs for recovery and control systems, as well as fulfilling the requirements of COJ and TI demonstrations. Figure 8-1 summarizes the Step 5 process.

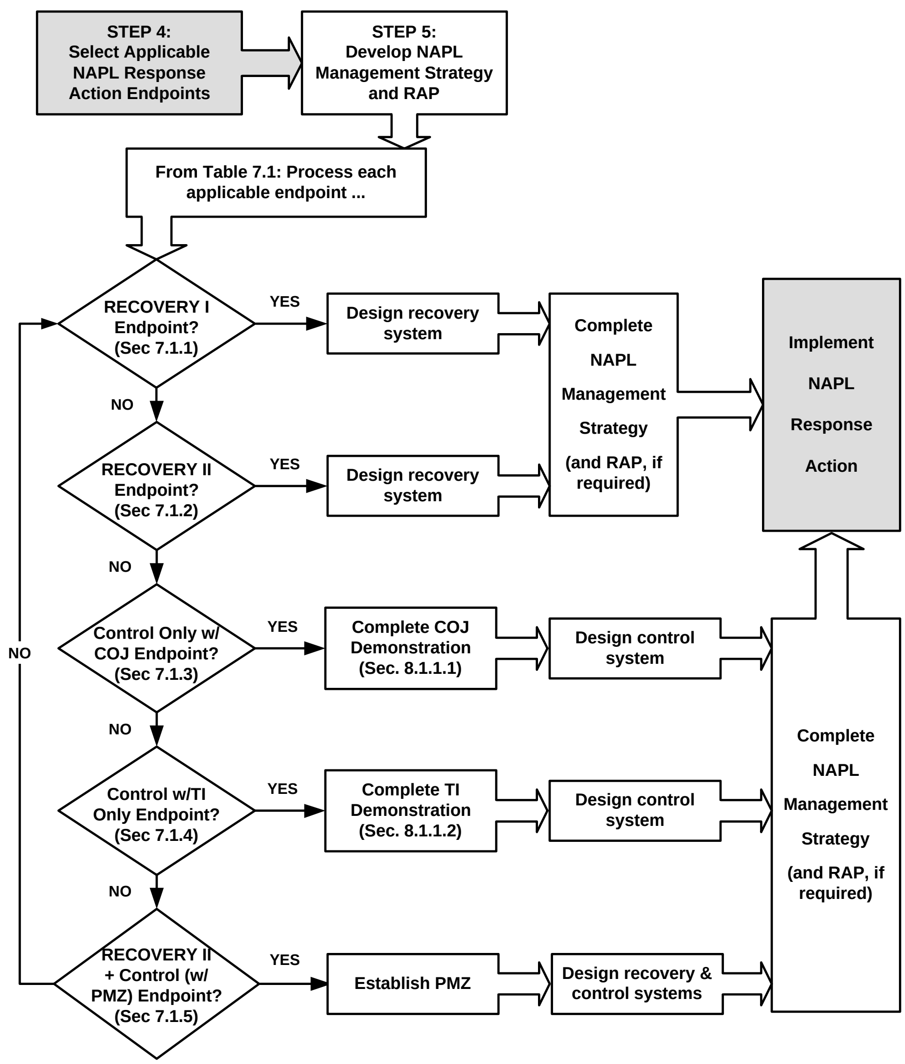


Figure 8-1: Overview of Step 5

8.1 NAPL Management Strategy Plans (& RAPs)

TCEQ approval for Response Action Plans (RAPs) is required for all NAPL Management Response Actions for control and all Remedy Standard B response actions.
A RAP submittal is comprised of four separate and distinct sections: 1) *RAP Objectives*, 2) *RAP Design*, 3) *RAP Performance* and 4) *Implementation Schedule*. The purpose of the RAP is 1) to communicate to the TCEQ the attempted response action, 2) to propose an engineered design for a NAPL recovery or control system, 3) to describe the method by which system performance shall be evaluated, and 4) to transmit to the TCEQ the schedule for implementing the proposed system.

8.1.1 NAPL Response Action Objectives

This section of the RAP submittal comprises the formal declaration of the intended NAPL response action (*i.e.*, recovery and/or control). The declared NAPL response action must correspond to the response action(s) and endpoint(s) selected in Table 7.1 (*NAPL Recovery and Control Endpoints Matrix*) for the subject site. Table 8.1 summarizes the available NAPL response action design options available.

If a NAPL control endpoint is proposed as a response action, a *COJ* or a *TI Demonstration* (as applicable) is included in this section of the RAP for the purpose of establishing the appropriateness of a control option at the site. Details of requirements for the completion of the COJ and TI demonstrations are provided below.

8.1.1.1 ***Control Option Justification (COJ).*** The implementation of a NAPL *Control Only w/COJ* endpoint (see Tables 7.1, 8.1 and 8.2 for applicable response actions) is predicated upon the COJ. Requirements of the COJ include the following:

1. The logic that led to the permissibility of the NAPL *Control Only w/COJ* endpoint using the Qualitative Tools in Step 3 (Figure 3-2), including all site-specific data used in the decision-making process for Qualitative Tools 3A and/or 3B, and/or

2. The logic that lead to the permissibility of the NAPL *Control Only w/COJ* endpoint based on the infeasibility of an existing and effective RECOVERY II response action or field data obtained from an appropriate pilot test.

8.1.1.2 ***Technical Impracticability (TI) Demonstration.*** The implementation of a NAPL *Control w/TI Only* endpoint is applicable to 1) a *Recovery I response action* (see Tables 7.1, 8.1 and 8.2) and 2) a *Recovery II response action for which no institutional control can be obtained*. *The TI Demonstration is the only means by which to obtain flexibility for the use of a control option*. As such, the TI Demonstration requires a technically rigorous analysis and/or a demonstration that an effective engineered NAPL recovery system has become inefficient and whose evaluation leads to a quantitative conclusion that recovery is not, or is no longer feasible. Requirements of the TI Demonstration include the following:

1. A technically rigorous analysis of time-series data collected during the operation of (once) effective engineered recovery system that demonstrates the existing system has become inefficient using system performance evaluation methods provided in Step 6.

2. A technically rigorous analysis of data from an appropriate on-site pilot test and modeling study that demonstrates the endpoint cannot be achieved via recovery efforts alone.

Table 8.1: Components of a TI Demonstration

TI Demonstration Component	Description	Data Requirements
TI Demonstration Applicability	TI Demonstration Applicability pertains only to the inability of meeting RECOVERY I response action endpoints and establishes the site-specific NAPL occurrences for which the demonstration is intended. Applicability extends only to specific COC(s) for which the response action endpoint(s) can be demonstrated to be unachievable. See Section 8.1.1.2 for additional details.	• All applicable NAPL Response Action Endpoints • Applicable COC(s) • All NAPL Occurrences
NAPL Zone Applicability	The NAPL Zone, or portion thereof, for which the TI Demonstration is intended must be fully assessed and delineated.	• Location(s) and map(s) of NAPL Zone(s) • Dimensions of NAPL Zone(s) • Affected GWBUs • PCLE Zone maps for all affected media
Site Conceptual Model	The TI Demonstration must be appropriate to the Site Conceptual Model. The TI must persuasively demonstrate that reverting to a Control Response Action Endpoint will be permanently effective.	• Site geology and hydrology • Observed and theoretical NAPL migration pathways • NAPL source history
Evaluation of Conventional and/or Alternative NAPL Recovery Efforts	The TI Demonstration option is available only after NAPL recovery has been attempted and found to be ineffective, physically or practicably, in meeting the recovery endpoint(s). The TI Demonstration is based on actual system recovery data and operational record.	• Cumulative mass recovered *vs* time data • Concentration reduction *vs* time data • O&M expenditure records

8.1.2 NAPL Management Strategy Design

The NAPL Management Strategy Design includes all design criteria and final (sealed) engineering design plans for any proposed NAPL recovery system and/or proposed NAPL control system. *TCEQ approval of a RAP, when applicable, for NAPL recovery systems is predicated upon the development of an effective design*. Submittal of a NAPL recovery system design deemed to be ineffective can be the basis upon which a proposed RAP is rejected by the TCEQ.

Table 8.2 summarizes the elements of the NAPL Management Strategy design requirements for each NAPL Endpoint. The design elements are applicable to RAP submittals, as well. It is this information upon which TCEQ approval of a proposed design is based. Table 8.3 summarizes the essential elements of a NAPL response action design. These elements should be submitted in a RAP if one is required.

Table 8.2: NAPL Management Strategy Design Section Guidance

NAPL Management Response Action	NAPL Endpoint	NAPL Response Action Procedure
For Regulatory NAPL RECOVERY Endpoints		
Abate NAPL vapor source *permanently*	RECOVERY I Only	Design engineered NAPL recovery system
Arrest NAPL zone expansion	RECOVERY II	
Eliminate mobile NAPL		
Abate NAPL nuisance or aesthetic condition		
For Risk-Based NAPL RECOVERY Endpoints		
Meet Class 1 groundwater PCL throughout NAPL zone	RECOVERY I Only	Select specific endpoint (Table 7.1); design engineered NAPL recovery system
Meet critical soil PCLs throughout NAPL zone or exposure and cross-media impact prevented	RECOVERY II	Determine critical soil PCL (Table 7.1); design engineered NAPL recovery system
Meet critical Class 2/Class 3 groundwater PCLs within NAPL zone or exposure and cross-media impact prevented		Select applicable recovery endpoint (Table 7.1); design engineered NAPL recovery system
For Regulatory NAPL CONTROL Endpoints		
Abate NAPL vapor source *permanently*	**Control Not Permitted for this NAPL Response Action**	
Arrest NAPL zone expansion	Control Only w/COJ	Follow logic in Figure 7-1 to confirm appropriateness of control option; determine applicable NAPL control endpoint (Table 7.1); establish PMZ; develop COJ for acceptance (Sec. 8.1.1.1)
Eliminate mobile NAPL		
Abate NAPL nuisance or aesthetic condition		
For Risk-Based NAPL CONTROL Endpoints		
Meet Class 1 groundwater PCL throughout NAPL zone	Control w/TI Only	Follow logic in Figure 7-1 to confirm appropriateness of control option; determine applicable NAPL control endpoint (Table 7.1); establish PMZ; develop TI for acceptance (Sec. 8.1.1.2)
Meet sediment PCLs throughout NAPL zone		
Meet critical soil PCLs throughout NAPL zone or exposure and cross-media impact prevented	Control Only w/COJ	Follow logic in Figure 7-1 to confirm appropriateness of control option; determine applicable NAPL control endpoint (Table 7.1); design engineered recovery system (if applicable); establish PMZ; develop COJ for acceptance (Sec. 8.1.1.1)
Meet critical Class 2/Class 3 groundwater PCLs within NAPL zone or exposure and cross-media impact prevented	Control Only w/COJ *OR* RECOVERY II + Control (w/PMZ)	
Meet surface water PCLs	**Control Not Permitted for this NAPL Response Action**	

Table 8.3: NAPL Response Action Design

Requisite NAPL response action design elements for each NAPL occurrence
Response Action Diagrams and Component/Equipment Descriptions – complete design drawings for engineered NAPL recovery and/or control systems; description of all associated tests and modeling, assumptions and results; RAER and RACR require *as-built* design/drawings
Plume Management Zone Map – PMZ delineation, GW PCLE, AMPs, all POEs, as applicable

8.1.3 NAPL Response Action Performance Elements

The NAPL response action performance elements include all proposed measures associated with NAPL recovery and control system performance and effectiveness, including effectiveness evaluation methodology, effectiveness monitoring plan and sampling schedule. *TCEQ approval of a RAP, when applicable, for NAPL recovery systems is predicated upon the development of an appropriate NAPL response action performance plan.* Submittal of a NAPL recovery or control system performance plan deemed to be ineffective can be the basis upon which a proposed RAP is rejected by the TCEQ. Table 8.3 summarizes the elements of the NAPL response action performance elements.

Table 8.4: NAPL Response Action Performance Elements

Performance measures used to evaluate progress of a NAPL recovery response action
Performance Measures – methods that clearly demonstrate that response actions can accomplish objectives in reasonable timeframe (see Step 6 for methods)
Results of Effectiveness Measurements – documentation that response action is proceeding in a timely manner; RAER submitted each 3 yrs OR other program-imposed schedule
Description of Potential Problems and Operations and Maintenance (O&M) Program – description of any problems that may occur with, or during, the response action and that may cause response action failure or downtime; demonstration that potential problems have been anticipated; and details of the proposed O&M program and schedule
Contingency Measures – documentation of contingency actions to be taken in the event that any *Potential Problems* (see above) are realized; incl. equipment and assets

8.1.4 NAPL Response Action Implementation Schedule

The NAPL response action implementation schedule details the proposed schedule to which the person shall adhere for implementing the NAPL response action. In the case of phased or compound response actions, the various anticipated response action modules are scheduled separately. Table 8.5 summarizes the NAPL response action implementation schedule elements.

Table 8.5: NAPL Response Action Implementation Schedule

Detailed project schedule of proposed NAPL response action activities
Project Schedule – proposed duration, start/finish dates
Proposed Submittal Schedule – proposed submittal dates for applicable reports or notifications