A Decision-Making Framework for Cleanup of Sites Impacted with Light Non-Aqueous Phase Liquids (LNAPL)

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Notice

This document was developed by the Non-Aqueous Phase Liquid (NAPL) Cleanup Alliance (the Alliance). The Alliance, established in 2001, is one of the six active Action Teams under the Remediation Technologies Development Forum (RTDF). The RTDF was established in 1992 to foster collaboration between the public and private sectors in developing innovative solutions to mutual hazardous waste problems. The NAPL Cleanup Alliance includes representatives from the petroleum industry, federal and state government, and academia who share an interest in pursuing aggressive technologies for removing large-scale non-aqueous phase liquid (NAPL) contamination. The Alliance's work has focused on a number of activities, of which this document is a part, all dedicated to finding more practicable and reasonable ways of cleaning up sites that have been impacted by petroleum hydrocarbons. More information about the Alliance can be found at http://www.rtdf.org.

This document has been prepared as a guide for long-term management of light, non-aqueous phase liquid (LNAPL) at impacted sites. The document has been reviewed by a broad stakeholder group that includes U.S. EPA and state entities. This document is not a U.S. EPA policy, guidance, or regulation. It does not create or impose any legally binding requirements or establish U.S. EPA policy or guidance. The U.S. EPA does not exercise editorial control over the information in this document, and Standards of Ethical Conduct do not permit the Environmental Protection Agency (EPA) to endorse any private sector product or service. The Alliance hopes to disseminate the information in the document through presentations, workshops, Internet seminars, etc., so that it can be made available to all who have a need for such assistance. To further their goals, the Alliance is also conducting pilot projects and preparing training modules, all related to LNAPL management.

Definitions

The following definitions are provided to promote common understanding of the terminology used throughout the document.

- *Long-Term Vision* is the qualitative statement of the ultimate desired situation or condition at the site. Achieving the long-term vision will likely require iterative steps through the LNAPL management process.
- *Goals* represent the specific elements that enable achievement of the long-term vision, representing intermediate steps on the way to the long-term vision. Goals can be short-, intermediate-, or long-term.
- *Endpoints* are the measurable criteria, specifically associated with each goal, which demonstrate progress towards achieving the goal.
- *LNAPL management options* include active or passive technologies for remedial action, and/or engineering or institutional controls. The implementation of the LNAPL management option is the means to achieving the long-term vision.
- *Regulatory requirements* are those actions and specifications that are mandated by the laws and regulations that apply to a particular site, with respect to corrective-action activities (e.g., meeting groundwater or surface- water standards, discharge permits for remedial action systems, local zoning requirements). These regulatory requirements become part of the constraints for the LNAPL Management Plan.
- *LNAPL Management Plan* is the overall decision-making framework for the site.

ACRONYMS

API	American Petroleum Institute
ARAR	Applicable or Relevant and Appropriate Requirements
COC	Chemicals of Concern
CPT	Cone Penetrometer Technology
DNAPL	Dense Non-aqueous Phase Liquid
EPA	Environmental Protection Agency
LIF	Laser Induced Fluorescence
LNAPL	Light Non-aqueous Phase Liquid
LNAST	Light Non-aqueous Screening Tool
MIP	Membrane Interface Probe
MNA	Monitored Natural Attenuation
NAPL	Non-aqueous Phase Liquid
RCRA	Resource Conservation and Recovery Act
ROST	Rapid Optical Screening Tool
RTDF	Remediation Technologies Development Forum
TCEQ	Texas Commission on Environmental Quality
TPH	Total Petroleum Hydrocarbons

Executive Summary

Purpose and Background

A Decision-Making Framework for cleanup of sites impacted with light, non-aqueous phase liquids (LNAPL) has been prepared by the Remediation Technologies Development Forum (RTDF) NAPL Cleanup Alliance to provide a guide to practicable and reasonable approaches for management of LNAPL petroleum hydrocarbons in the subsurface. This unique document describes an innovative consensus-based process to develop a long-term vision for a particular site (e.g., an industrial site for the next 100 years with groundwater standards attained in 125 years), while providing a roadmap that calls for specific goals and endpoints to measure progress during each phase of the LNAPL management project. The major benefit of this innovative approach is the establishment of a practicable vision that is consistent with regulatory requirements and can be attained within a realistic timeframe and a reasonable budget, using a phased, stepwise process. The consensus-based process is designed to support the stakeholder group in developing a common, site-specific understanding of what “realistic timeframes” and “reasonable budgets” will mean for any particular site.

The Decision-Making Framework has been designed for application at sites that are impacted by petroleum hydrocarbons in the subsurface, with special focus on large complex sites, such as operating and closed petroleum refineries, pipelines, shipping terminals, and tank farms. This document strives to provide a framework for making sound, scientifically-based decisions for LNAPL management, which may shorten the cleanup timeline. LNAPL management, which is the focus of this document, represents only a portion of the environmental work ongoing at these sites. However, sound LNAPL management can significantly impact the overall cleanup timeline for the site. Because LNAPL in the subsurface presents complex technical challenges and long-term financial commitments, a phased approach to LNAPL management is recommended. Regulatory concurrence should be sought for the LNAPL management strategy that results from use of the Decision-Making Framework for a particular site.

Key components of the Decision-Making Framework are its flexibility and the iterative nature of the process, where vision and goals are revisited and revised as new data and information are obtained throughout the various steps of the process during each phase of the project. Decisions are made, and revised if necessary, based upon the latest information to ensure the approach maintains its reasonableness and practicability. The Decision-Making Framework, based upon the following definitions, consists of the following steps depicted in Figure ES-1. Each of the major steps is described further in this executive summary and in the noted Sections of the report, 2.0 through 9.0. Key LNAPL management questions asked during each step of the process are shown to the right of the flow chart. The Decision-Making Framework is designed to address sites where imminent hazards are already under control and site managers know that an LNAPL problem exists.

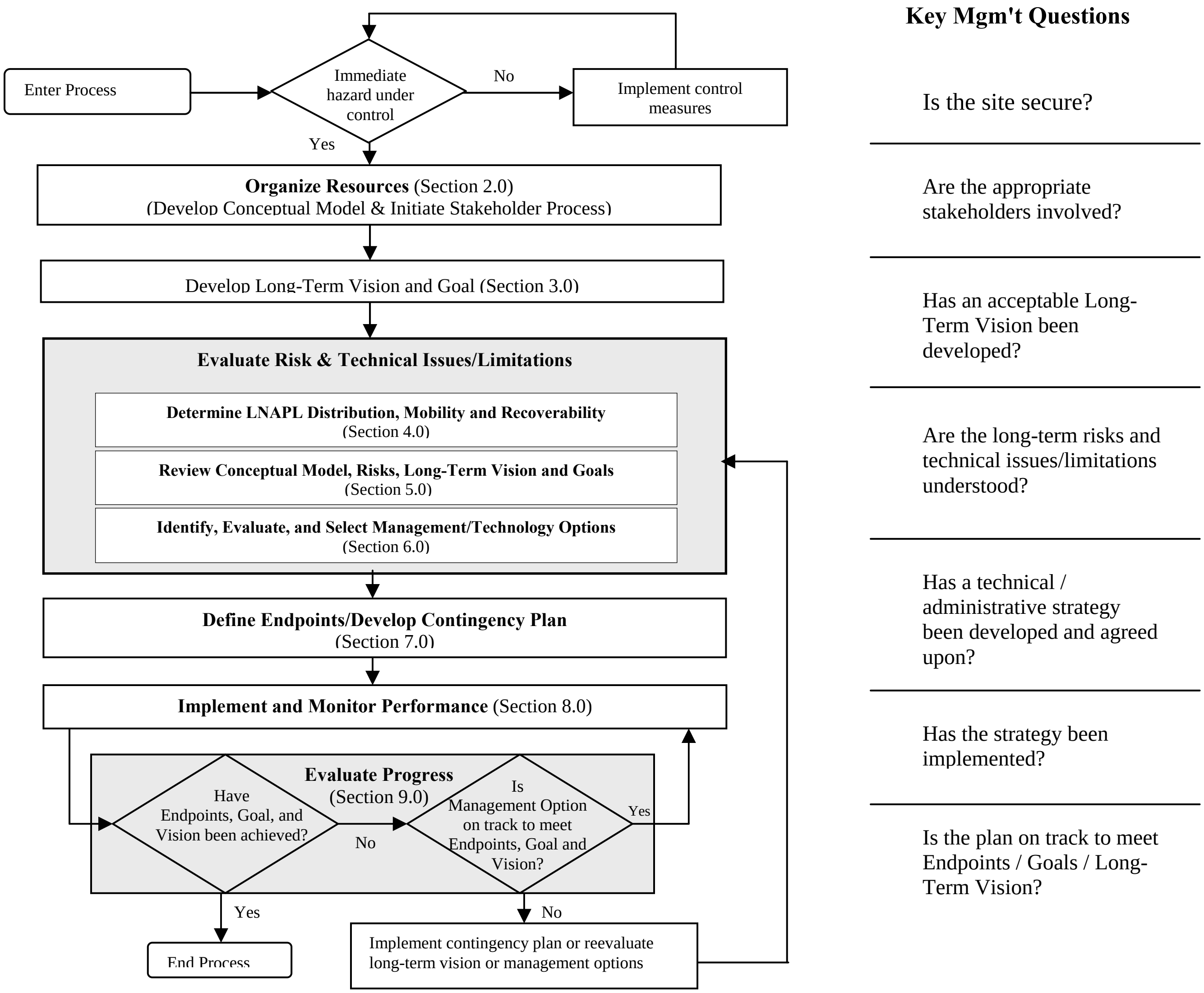

Figure ES-1. NAPL Management Process

Organize Resources

Once it has been recognized that LNAPL is present and must be managed at a site (e.g., based on unacceptable impacts and associated risk, by the owner or operator, a regulatory agency, or community stakeholder) and immediate hazards and risks have been controlled, resources, which include human, financial, and information, should be organized and carefully evaluated. The current state of knowledge is first assessed to provide a foundation for the project. Appendix A contains a “Current Conditions” checklist that may be a useful tool to accomplish this activity. This information can be used to build the conceptual model, which describes potential exposure pathways, including sources of chemicals of concern (COCs), environmental media, and potential receptors under current and potential future activity and land use.

The next activity involves organization of a stakeholder process, where all those who can affect the outcome or can be impacted by the outcome are invited to participate. The stakeholders include the regulatory agency(ies), local government, community members, adjacent landowners and others. This process can be accomplished in a variety of ways, depending upon the needs of the specific site and the culture of the community. Suggestions for organizing the stakeholder process are provided as a series of steps.

Develop the Long-Term Vision and Establish LNAPL Goals

After the stakeholder group is convened, their major focus should be on developing a long-term vision for the site with regard to LNAPL management, incorporating regulatory requirements and other issues, such as land-use considerations. Often it is difficult to obtain consensus on a vision; the process may take some time, as the stakeholder group works together, developing trust and respect for one another's interests. Once a consensus-based, long-term vision has been developed, the responsible party and the regulatory entity should identify and agree to specific, measurable, achievable, cost-effective goals for LNAPL management. Goals should be established for each phase of the project, short-, intermediate-, and long-term. It is not a requirement to establish the goals for multiple phases all at once. The process provides the flexibility to be applied iteratively. However, the stakeholders should consider the long-term vision and how the goal for an interim phase will influence the later phases. The timeline for the various phases of LNAPL management may be tied into various land-use scenarios.

Collect and Analyze Supplemental Data

After establishment of specific goals, the stakeholder group should identify information and data gaps to evaluate whether goals can be attained, given the current understanding of available remedial approaches and technologies. A supplemental investigation may be designed to answer targeted questions that provide specific information needed to assess options for LNAPL management. The major questions to be answered relate to improving understanding of the distribution, mobility, recoverability, characteristics of the LNAPL, regulatory requirements, and potential risks associated with the proposed land use at the site.

Review and Revise Conceptual Model

The conceptual model developed at the beginning of the process, while organizing resources and assessing current conditions, should be reviewed in light of supplemental data collected and analyzed. Included in this review is a re-assessment of the risks and how they may be met by the long-term vision and goals set by the stakeholder group. If significant changes to the conceptual model have been made and/or risks have changed significantly, the long-term vision and goals should be revisited, before management options are identified and evaluated.

Identify, Evaluate, and Select LNAPL Management Options

LNAPL management options should be identified and evaluated based upon the information collected in the early and supplemental phases of investigation, the conceptual model, and risks. The first step involves screening of a broad list of LNAPL management options, which include active and passive technologies, institutional and engineering controls, and combinations thereof. The next step involves detailed evaluation and prioritization of the most promising options based upon a set of criteria agreed to by the stakeholder group. Selection of management options may be contingent upon laboratory or field pilot tests conducted to provide critical information to make the final decision or to optimize implementation of the selected option.

Establish Endpoints and Develop Contingency Plan

The stakeholder group should then identify specific endpoints and timelines for each of the LNAPL management goals, so that progress towards reaching the goals can be measured. Endpoints may be performance-based specific to a management option or may reflect a measurable long-term condition to be attained. Endpoints should be defined with specifics such as sampling method, analytical method, location of measurement, and timeframe for measurements. The more specifically the endpoints are defined, the less likelihood there will be cause for confusion or dissension among the stakeholders.

A contingency plan should also be developed with the assumption that endpoints may not be achieved, management options may not allow you to attain the goals, etc. The contingency plan should be inclusive enough that it details all potential failures and identifies potential solutions, including revisiting of the long-term vision and goals, review of the performance of the management options, and collecting additional data.

Implement and Monitor Performance

Implementation of the LNAPL management strategy will occur in phases as specific goals are addressed and attained. Performance monitoring related to the implementation of a management option is necessary so that progress towards meeting the goal, using endpoints as a measurement tool, can be assessed. After the active phase of LNAPL management is completed, confirmation monitoring will be required to assess whether the goal for LNAPL management, incorporating regulatory requirements and land-use considerations, have been attained and whether the site has reached the point for final closure and the long-term vision has been attained (if this is the final corrective-measures phase).

Evaluate Progress

Revisit the LNAPL Management Plan to assess whether progress towards the endpoints and goals has been made or whether the management option is on track. To evaluate the progress:

- analyze the performance monitoring data to understand the effectiveness of the LNAPL management option;

- perform confirmation monitoring if active NAPL management has been discontinued and review data to confirm that active remediation is no longer required;
- assess whether the goal has been achieved through the measurement of the endpoints and determine if it is necessary to implement a contingency plan. If this is the final goal, has the long-term vision been achieved?

The LNAPL Management Plan is a living document that is updated as circumstances change throughout the NAPL management process. The process is iterative and flexible. The focus during each phase of the process is the specific goal; ultimately activities are targeted towards reaching the long-term vision.

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1.0 Introduction and Objectives

The Decision-Making Framework as applied to a particular site is documented in a consensus-based LNAPL Management Plan, which provides a systematic strategy to attain a long-term vision for that site, recognizing that each specific site will differ in some respects from other similar sites. The long-term vision is achieved through a stepwise process of practical goal setting, using measurable endpoints to evaluate progress.

The types of sites for which the Framework is most appropriately applied include operating and closed petroleum refineries, pipelines, shipping terminals, and tank farms.[1] However, this LNAPL Decision-Making Framework can be utilized for all sites regardless of size.

The materials of interest at these sites include:

- common liquid products directly produced from crude oil (e.g., gasoline, diesel, aviation and other fuels);
- specialized refined oil products (e.g., motor oil or lubricating oils);
- less often, more specialized products, directly or indirectly manufactured from crude oil.

Uncontrolled releases of these petroleum-based materials infiltrate into the soil and, if sufficient quantities have been released, ultimately reach groundwater. Collectively, these oil-based materials do not readily mix with aqueous systems, such as groundwater.[2] Therefore, if a sufficient quantity of these oil-based materials is present, these materials will remain in separate phases. In general, any materials that exhibit these phenomena are known as non-aqueous phase liquids, or NAPL. Typically oil-based materials are less dense, or “lighter” than water; thus the acronym LNAPL. The LNAPL phase can also be the source of specific COCs in the vadose zone and dissolved COCs in the saturated zone. The impact of COCs dissolved in groundwater and present in vadose-zone soil gas present significant challenges to selection and implementation of investigation and remedial measures. These issues are not the subject of this document, but the LNAPL management strategy should take these corrective-action activities into account. The consensus-based process for the development of an LNAPL management strategy outlined in this document is certainly applicable to the development of an overall site corrective-action strategy for all impacts, but the discussion of such an over-arching framework is beyond the scope of this document.

Some regulatory agencies are now recognizing that goals set for these sites may be difficult to achieve within a realistic timeframe. It is also recognized, that at some time

[1] Sites handling relatively small quantities of petroleum products, such as gas stations, which typically have problems that are smaller in scope and also are the subject of federal and state programs focused on underground storage tanks are not the primary audience for this guide. Certain sections of the document may not be appropriate for some sites.
[2] Some fuel additives such as methyl-tert butyl ether and tert-butyl alcohol are more soluble in water than the primary petroleum hydrocarbons and may impact significant quantities of groundwater.

after LNAPL removal is implemented, recovery rate will asymptotically approach zero. Further attempts at removal will become more costly; further removal may be impracticable. A search for a more flexible NAPL management process that considers each site individually is underway in some states, whereas other states regulate within their current laws that specify the same requirements for all sites.

Many states have a non-degradation policy or law for groundwater contamination, which might lead to the conclusion that ultimately all of the LNAPL should be removed from the subsurface. The practical implication of these requirements is that the LNAPL management project may not be completed for a long time; however, the consensus-based process outlined in this document may be useful for structuring the process and progress for getting to completion of the LNAPL management project.

For a variety of reasons, LNAPL in the subsurface presents complex technical challenges to facility owners as well as to federal and state environmental regulatory agencies. For closed sites, after demolition and removal of processing equipment, tanks, and other potential sources of LNAPL releases are completed, the properties and quantity of LNAPL remaining may likely require continued management and evaluation by owners and regulators for years. LNAPL management can dominate the resources associated with the remedial action of a site, both in terms of costs borne by the owner as well as human resources devoted both by the owner and the regulatory agencies. Often LNAPL is of great concern to area residents and local government; proper management of LNAPL can aid in the continued operation of active sites in ways acceptable to the local community, or can speed the re-development or re-use of closed or inactive sites (e.g., a Brownfields property).

These sites typically have significant financial liability and may require long-term LNAPL management to achieve an acceptable long-term vision, which is critical to the LNAPL management process. The issue of long-term financial liability must be considered during the decision-making process. Imagine how difficult it would be today to enforce contracts with parties who might have negotiated agreements one hundred years ago.

The long-term vision will vary from one site to another and may be significantly different for a refining or storage facility that will continue in operation as compared to a facility that is closed and will be redeveloped. The goals to achieve the vision need to be defined in specific and quantifiable terms, so they can be easily measured. Because these sites typically contain very complex groundwater contamination problems, it may be difficult to determine whether a cleanup goal can be achieved at the time a remedial action selection is made. Hence, the recommended approach to reduce uncertainty is to use a flexible, phased approach to site characterization and remedial action, where goals are revisited, and revised if necessary, as more data and information are collected.

The Decision-Making Framework outlines the overall process for reasonable and practicable approaches to LNAPL management and identifies factors to be considered during creation of the LNAPL Management Plan. It provides a tool for developing a scientifically sound LNAPL management strategy for each site pursuant to its unique conditions. The regulatory requirements, future land use, timing to achieve specific site conditions and other factors should all be considered in developing the LNAPL management strategy. There inevitably will be trade-offs between the costs to implement the various LNAPL management options and the timeframes to meet endpoints. The consensus-based process is designed to support the stakeholder group as they define the acceptable trade-offs for a specific site.

The Decision-Making Framework is designed to address sites where some site characterization data have already been collected, where immediate hazards and risks have been controlled, i.e., short-term protectiveness goals have been reached,[3] and where site managers know that an LNAPL problem exists.

The LNAPL management process should be flexible and be designed by the stakeholder group for the site. A variety of approaches may be utilized to achieve the long-term vision through a collaborative process. The primary audiences for the document are the facility owners and operators and the federal and state agencies that regulate them. Other interested parties, such as area residents, community groups, and local government agencies, may also find the concepts and information useful.

The NAPL Decision-Making Framework is shown in the following flow chart (Figure 1). Implementation of the decision-making process at a site may include multiple iterations through goal setting, data collection, and LNAPL-management option selection and implementation. The process must remain flexible and be tailored to meet site-specific needs. Figure 1 attempts to capture a complex process, for which all iterations cannot be identified on a single page. The figure instead provides a typical pathway for the process.

[3] Example short-term protectiveness goals are the RCRA environmental indicators: current human exposures are under control, or do not exist, and existing dissolved-phase plumes of COCs are not expanding above action levels or adversely affecting surface waters.

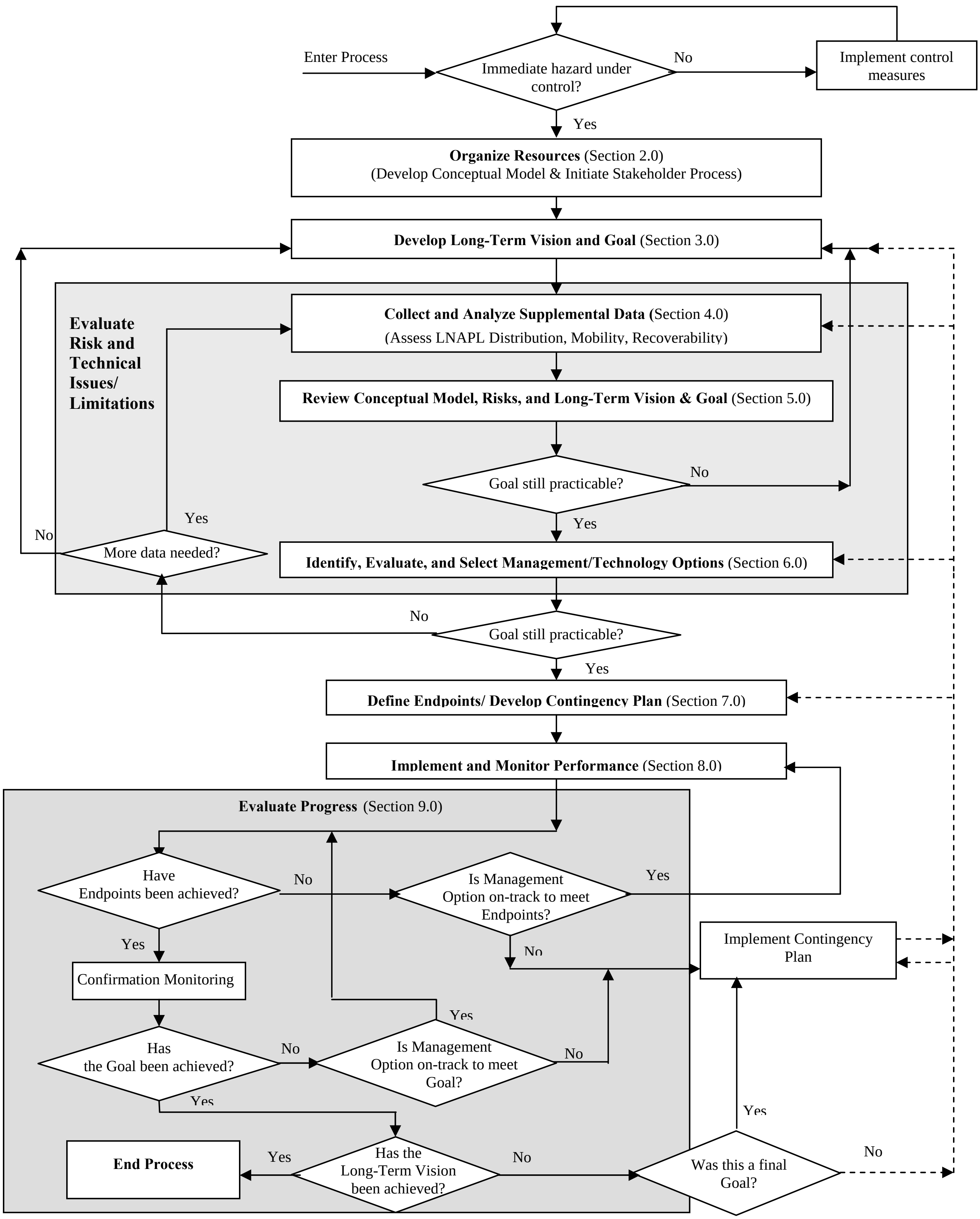

Figure 1. NAPL Management Decision-Making Framework Process

2.0 Organize Resources

The NAPL Decision-Making Framework process begins with the organization of resources, including understanding current conditions, building a conceptual model, and establishing an active stakeholder group.

Over the last twenty years, environmental cleanup of impacted sites across the United States has been fraught with complex regulations, slow progress, elevated costs, distrust and divisiveness among various stakeholders, and litigation. Since the early 1990's, a number of attempts at integrating stakeholder collaboration into the cleanup process have been demonstrated to provide an effective and efficient means to a reasonable and practicable approach to cleanup (FFRDC, 1996; Scrimgeour *et al.*, 1994; Bryan, 1997; Gamman *et al.*, 2001). Each of these efforts developed a process for effective consensus-based decision-making with slight variations on a theme. Each also developed a set of guiding principles, which have many commonalities from one to the next. Each collaborative process should be designed to meet the specific needs and situation of the stakeholders at a particular site.

EXAMPLE STAKEHOLDER PRINCIPLES
(Bryan, 1997)

1. The right stakeholders must be involved.
2. A decision-making process that effectively integrates stakeholders and leads to the resolution of issues must be designed.
3. The process must provide for the collection of information that stakeholders will need to resolve the issues.
4. The process must include an interactive communication program responsive to the needs of all stakeholders.
5. Stakeholders must be involved in identifying and jointly framing the problem.
6. Stakeholders must be involved in developing an Action Plan that integrates technical, regulatory, and stakeholder interests.

Principles developed by the Alliance for LNAPL management include the following:

1. It is important to understand the current regulatory situation, site conditions, and stakeholder interests before beginning preparation of an LNAPL Management Plan.
2. It is recognized that the need for an LNAPL Management Plan will typically occur after preliminary investigation activities at the site have identified an LNAPL problem.

3. Any immediate concerns and hazards have been or are being addressed at the site before beginning preparation of an LNAPL Management Plan.
4. An effective LNAPL Management Plan should be designed to be a "living" document that is used to continuously evaluate new data and the results of remedial actions.
5. All parties understand that for most sites LNAPL may need to be managed for an extended period of time (the mass left behind will control plume longevity and risk); new technologies that may enable more mass recovery and shorter LNAPL management timeframes are being developed and tested.
6. Technical content of the LNAPL Management Plan should contain components, such as measurable endpoints, closure criteria, and points of compliance.
7. Site conditions may change over the course of the implementation of the LNAPL Management Plan.
8. The plan should be flexible to accommodate site changes and to incorporate technological innovations in data collection or remedial technologies.
9. The LNAPL Management Plan should be consistent with the overall remedial action plan for COCs in environmental media at the site.

Specific activities for organization of the necessary resources are described in the following sections.

2.1 Assess Current State of Knowledge

Existing data and other relevant information should be gathered and assessed to provide a common foundation for the members of the stakeholder group who agree to participate in the process. This step could start at any time, and probably will have anyway, by some of the individual entities represented on the stakeholder group. As a practical matter, by the time a facility is judged as needing an LNAPL Management Plan, there is likely to have been a significant amount of data collected from the site, and perhaps from off-site. These data will generally have been obtained by the facility owner/operator and the primary regulatory agencies, with some data possibly available from other sources. Other relevant information, however, such as regional land use plans or zoning requirements, may not yet have been compiled systematically. A detailed "Current Conditions" checklist is located in Appendix A to help the user determine if the types of information typically needed are already available for their site.

The Current Conditions Checklist topics include:

- regulatory requirements,
- LNAPL management program, and
- site conditions (of note in Appendix A is the fact that there should be an assessment of the potential for on-going releases at all refineries, operating or closed).

The checklist may be a resource to begin stakeholder discussions of LNAPL management strategy and decision-making, while also enabling rapid identification of data gaps that must be filled.

2.2 Develop the Conceptual Model

The process of developing the current state of knowledge for the site should include an understanding of the contribution of LNAPL to the potential risks associated with both current and future activities, including consideration of regulatory requirements and land use. In order to develop this understanding, a conceptual model is often used to describe the ways in which human and ecological receptors may be exposed to COCs from a site. The conceptual model is used as a foundation for making calculations of risks to human and ecological receptors. The conceptual model and subsequent risk assessment are often developed as part of the overall corrective-action process for a site; if not, these activities may be considered as part of the LNAPL Management Plan development. Selected references for developing conceptual models and for conducting risk assessments are included in Appendix D.

The conceptual model describes potential exposure pathways, including sources of COCs, environmental media, and potential receptors under current and potential future activity and land use. These exposure pathways account for the movement of COCs from sources to places where receptors may be exposed. The impact of LNAPL on the exposure pathways (e.g., as an on-going contribution of COCs to groundwater or soil vapor or as a direct contact exposure medium in excavations) should be considered in the development of the conceptual model and the LNAPL Management Plan.

The conceptual model should also establish the current interpretation of where LNAPL exists in the subsurface, i.e. the vertical and lateral distribution and the associated properties of the subsurface media containing the LNAPL, and some estimate of the nature and mobility of the LNAPL.

2.3 Organize the Stakeholder Process

A broad spectrum of stakeholders should be invited to participate in the process. Realistically, it may be difficult to obtain a commitment from outside stakeholders. Ideally, members of the active stakeholder group will have agreed to dedicate a sustained commitment of time and effort to create a reasonable and practicable LNAPL Management Plan. Participation by the responsible party and the regulatory agencies is a minimum requirement. Involvement of the appropriate stakeholders at the beginning of the process has been demonstrated to expedite a more efficient collaborative process. The size and complexity of the stakeholder process needs to be proportional to the size and complexity of the problem.

By focusing the stakeholder group’s activities explicitly on the substantive elements of LNAPL management, i.e., specific goals and associated endpoints, greater progress can be made during each phase of the project. With focused direction through a consensus-based process, participants will likely see that individually and collectively their own work has been made more efficient and necessary technical work has been completed cost-effectively on an accelerated schedule.

2.4 Identify Stakeholders

An essential step is to explicitly identify parties (e.g., governmental agencies, community and other organizations, and individuals), and the key individuals associated with the parties that have a stake in the development and implementation of the LNAPL Management Plan. One or more stakeholders interested in developing the LNAPL Management Plan may typically initiate the stakeholder process. It has been demonstrated that for highly contentious issues, the stakeholders may benefit by utilizing an independent resource to convene and facilitate the stakeholder group, so that the process is perceived as fair. When identifying the stakeholders, it is critical to include all who can affect the outcome or can be impacted by the outcome. The stakeholder group should be inclusive, not exclusive. However, all stakeholders may not choose to participate in the process.

After the stakeholders are identified, they should be contacted to: 1) determine their interest in participating in the process of planning LNAPL management at the site and 2) collect information regarding their specific issues, concerns, and interests. A series of questions, such as the following, may be asked:

- What are your expectations about the project?
- What resources will you commit to the project?
- What benefits do you anticipate from participating in the project?
- What other interests do you have related to this project?
- How do you regard the other stakeholders likely to participate in the project?

This activity may be conducted by an independent resource.

To manage the process effectively, it may be useful to group stakeholders into two categories: 1) an active stakeholder group, which typically will include the facility owner/operator, the primary regulatory agencies (EPA and/or the lead state environmental agency, and others, such as a local re-development authority, local/county governmental agencies, civic or neighborhood organizations, and environmental interest groups), and 2) a broader community of other interested, but not active, stakeholders, such as regional businesses, other non-profit organizations, and individuals, which may not have common interests.

2.5 Design, Agree to, and Implement a Consensus-based Process

At the first meeting of the stakeholder group, the need for a consensus-based process should be discussed and agreed upon, and progress made on designing the overall team structure and operational procedures. Some principles and practices for reaching consensus may be considered at this first meeting. There are many techniques for reaching consensus. The choice of the technique in a specific situation will, however, reflect the preferences and prior experiences of the various stakeholders. In addition, the technique should reflect the "culture" of the community. Some communities, for example, may historically have a tradition of major local or county-agency involvement in such matters; in others communities, local and county agencies may not be proactively involved in cleanup decision-making.

Specific actions to be completed during this step in the process follow.

FORMER AMOCO REFINERY, CASPER WYOMING
AN EXAMPLE OF CONSENSUS DECISION-MAKING

A formal collaborative process was established at the former Amoco Refinery in Casper WY to deal with the remedial actions, including but not limited to LNAPL, and future land use for the closed property. In addition to the site owner and the lead regulatory agency, a Joint Powers Board created by the city and county governments was established. While regulatory authority rested solely with the state environmental agency, frequent public meetings of the three parties, coupled with other techniques that included an independent facilitator and independent technical panels, set the stage for a consensus-based decision-making process. This approach provided a mechanism for extensive involvement of a broader stakeholder group in the decision-making process (http://www.bp.casper.com).

- Define a process for appropriate involvement of each of the individual stakeholders. Stakeholder representation is critical to success of the project. It should be recognized that stakeholder participation may change over time.
- Agree upon a decision-making process that satisfies all stakeholder expectations for involvement. Develop ground rules, meeting logistics, meeting schedules, and decision rules if consensus cannot be reached.
- Consider use of third-party assistance (e.g., facilitators for policy issues, fact finders and/or independent panels for technical issues). An independent convener and facilitator have been demonstrated to be particularly effective for contentious projects. A range of resources, such as consultants and academicians, may be available, utilizing support from EPA or the state. Support will vary based upon site and state specifics.
- Provide education and support to ensure that all stakeholders are capable of performing their roles and addressing their interests. This may include staff to support meetings, technical consultants, financial, in-kind and other resources, which may be provided through EPA or the state.
- Address information and data needs to ensure an effective communication program that focuses on common understanding of technical issues, regulatory requirements, etc., both within the group and within the broader stakeholder community.
- Ensure a commitment to consensus. Keep the process open, flexible, and creative to guarantee success. For example, as more data are collected, revisit what has been agreed to in the past to see if new data and new understanding about LNAPL conditions require revision in any element of the LNAPL Management Plan, the long-term vision, or goals previously agreed to, etc. In short, make the consensus process iterative.

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3.0 *Develop the Long-Term Vision and Goals*

The long-term vision for the LNAPL Management Plan is meant to be a qualitative statement of the ultimate desired situation/condition at the site once specific actions are taken and specific goals are accomplished. While the actual wording of the statement may be quite general in tone, the vision itself should be highly site specific. There is no formula or checklist for developing the vision. The vision may be broader than management of LNAPL, but the LNAPL Management Plan is intended to move the site towards achieving the long-term vision.

The long-term vision may focus on, for instance, surface conditions at the site, the impact of the operations at the site or its surroundings, or some other key or essential feature. Developing the long-term vision may almost certainly require the use of consensus-building techniques, both within the stakeholder group and also reflecting the inputs and concerns of the broader stakeholder community. In some cases, the long-term vision may change over time, to reflect new technical information about the site, changes in laws and regulations, proposed land use or other factors. For some cases, such as an operating refinery, it may not be possible to develop a long-term vision. Short-term and intermediate goals can be agreed upon, however, for such a condition.

The adage "Start with the end in mind" is highly relevant in developing the long-term vision. Long-Term Vision statements for LNAPL management for specific parcels of land may vary greatly, depending on regulatory requirements and the future land use for the parcel. If a specific site will continue to be used for industrial purposes, the LNAPL management vision may likely be quite different than where the future use involves recreation. Similarly, if the site is adjacent to a water body, the long-term vision may be different than that for a site in a dry upland location.

THE GUADALUPE OIL FIELD EXAMPLE OF DISPUTE FOLLOWED BY CONSENSUS

(Gamman, 2001)

To provide resolution for a serious environmental dispute between industry and governmental agencies on the environmental impacts of the Guadalupe Oil Field in California, a consensus-based process, was implemented. The process of joint fact-finding, using a neutral, scientific panel to provide technical input, offered a unique opportunity for the disputing parties to cooperatively address information gaps and scientific uncertainty. Together the parties developed a common understanding of the issues and potential solutions, relying heavily upon the expertise of the independent panel. The joint fact-finding process involved the following steps:

- identify key issues,
- identify and select experts,
- define the steps in the process,
- review background information and data gaps,
- fill data gaps and resolve questions,
- develop screening criteria and apply to options,
- define performance evaluation criteria and apply to options.

The consensus-based process turned the situation from a significant dispute to a collaborative effort between the various stakeholders.

Relevant legal and regulatory criteria will almost certainly play a significant role in developing the long-term vision. These may include both quantitative criteria, such as numerical standards, as well as non-quantitative or semi-quantitative criteria, such as the evaluation of the potential utility and cost-effectiveness of various technical alternatives. Overall protection of human health and the environment will be a fundamental criterion for all sites; current and potential future use of groundwater beneath the site will often be a primary concern for most sites.

The process of developing a long-term vision may be difficult and arduous, as often the stakeholder group has members with divergent interests. However, as the group works together over time, members can build trust and respect for each other’s interests and eventually come to consensus on a long-term vision. The timeframe for this process will be very site specific and may range from six months to several years.

The process for developing the long-term vision should remain flexible so that the vision can be revisited by the stakeholder group at key steps in the process.

3.1 Discuss Stakeholder Interests

Key to development of a consensus-based long-term vision is the integration of the interests of the stakeholder group. The stakeholder group may almost certainly consist of individuals or entities with different beliefs, values, culture, tradition, and perceptions, from which their interests arise. Stakeholders typically exhibit their interests as positions, which often appear to be opposing. However, discussion of the underlying interests provides an improved setting for understanding the positions espoused by each of the stakeholders and for identifying areas of common interest. It also helps stakeholders to postpone judgments while learning about others' interests. These are critical steps to determining the common ground upon which the group can base its decisions.

It is important to remember that various stakeholders will typically have some and perhaps many interests in common, but will likely have some unique interests (Table 1).

Table 1. Examples of Typical Stakeholder Interests

Stakeholder	Interests
Facility Owner	• Achieve regulatory compliance • Utilize risk-based techniques • Minimize/eliminate disruption of operations • Minimize costs • Reduce long-term treatment and liabilities
Regulatory Agencies	• Protect human health and the environment, including groundwater resources • Protect groundwater resources • Achieve regulatory compliance • Eliminate off-site impacts to receptors • Involve stakeholders • Maintain reasonable schedule • Obtain reimbursement for oversight costs
Other Stakeholders (Local/county agencies, property owners, special interest groups, etc.)	• Optimize zoning • Maximize tax revenues • Accelerate schedule • Protect human health and the environment • Maximize quality of life • Protect groundwater resources

Often, a critical interest of the various stakeholders is the future land use associated with the LNAPL-impacted property, which has significant implications for the future owner/operator of the site, the agency or agencies with long-term regulatory responsibilities, and the community. In some cases, the original facility owner/operator may have stated intent to continue industrial operations at the facility for an indefinite period into the future; at others, it is clear that the original owner/operator plans to (or even has already) cease industrial operations and has no intention to re-open them. Table 2 provides examples that demonstrate that some stakeholders may have different interests from other stakeholders and that the interests may be highly dependent upon the land-use scenario.

Appendix B, the Potentially Affected Interests Matrix, provides a template that has been utilized by some state regulatory agencies to document stakeholder interests for specific projects.

Table 2. Hypothetical Examples of Stakeholder Interests

Stakeholder	Facility's Future Condition	Interests
Facility Owner	Operating Facility	Integrate LNAPL management and pollution prevention into facility operations
Facility Owner	Property is or will be closed	Identify future land use (e.g., dormant, new industrial, commercial, recreational, mixed use)
Facility Owner	Property is to be transferred to new owner	Minimize future costs and liability, e.g., deed restrictions, contractual obligations
New Facility Owner	Property transferred	Operate/maintain LNAPL recovery systems Minimize costs and liability
Regulatory Agencies	Operating Facility	Eliminate releases and control sources
Regulatory Agencies	Property is or will be closed	Identify future land use Operation/maintenance of LNAPL recovery systems
Other Stakeholders	Operating Facility	Protection of public health and the environment
Other Stakeholders	Property is or will be closed	Optimize future land uses Economic revitalization

3.2 Develop a Common Understanding of the Problem

The stakeholder group should reassess the current state of knowledge for the site (Appendix A Current Conditions Checklist), described in Section 2.1, to develop a common understanding of the problem. By jointly organizing what information is available, seeking out additional information, and resolving any inconsistencies that may exist, the stakeholder group can come to a common understanding of the problem.

This step will include sharing of information on technical, regulatory, and stakeholder issues. Use of a joint fact-finding team (e.g., Guadalupe Oil Field) or an independent scientific panel (e.g., Amoco Casper) may be recommended to expedite understanding of technical issues. The ultimate objective of this step is to develop a common information base for all stakeholders.

3.3 Prepare the Long-Term Vision Statement

On the pathway to creation of the long-term vision, the stakeholder group may choose to craft a joint work statement that captures the varying interests of the group in question.

The example below illustrates opposing positions, underlying interests, and a joint work statement for cleanup of an impacted site where the stakeholder group consists of extremely divergent interests. This joint work statement is the first attempt at consensus and illustrates the opposing interests of the various stakeholders. As the stakeholders work together, they can begin crafting the long-term vision statement for LNAPL management at the site. Such vision statements typically contain specific components that inclusively reflect the broad interests of the group.

HYPOTHETICAL EXAMPLE OF A JOINT WORK STATEMENT FOR AN IMPACTED SITE DEVELOPED BY A DIVERGENT STAKEHOLDER GROUP
(Bryan, 1997)

Divergent stakeholder positions

1. Clean up the site to pristine conditions
2. Clean only the most impacted portions and contain the remainder of the contamination on site.

Underlying interests that support these positions

1. Reduce health risks to zero or near zero, restore the ecological integrity of the site, and/or hold the company accountable for past actions
2. Reduce costs, lower health risks to acceptable standards, and avoid further disturbance to the site.

The Joint Work Statement

How can we

reduce health risks to acceptable levels
protect groundwater resources
restore the ecological integrity of the site
hold the company accountable for past actions

while also

reducing costs and future liabilities
minimizing disruption of operations
achieving regulatory compliance?

Some examples of long-term vision statements include:

- Clean up the site to an industrial-use, risk-based standard;
- Clean up the site to allow future land use as a recreational facility;
- Restore the on-site groundwater quality to state groundwater quality standards.

3.4 Establish LNAPL Management Goals

Goals describe what is needed to obtain the long-term vision. Goals should be reasonable, practical, and as specific as possible. It may be useful to develop goals based on the acronym SMART—Specific, Measurable, Achievable, Results Oriented, and Timebound. A first set of goals, perhaps specifically termed “preliminary” goals, should be developed as early as possible within the stakeholder group.

One or more goals should be developed for each phase of the LNAPL management process and should be revisited as the process unfolds to determine their appropriateness and applicability as new data and other information are collected. For simplicity, it may be preferable to define goal(s) in terms of a single overarching statement. For example, the interim-measures phase, often focused on control of existing and potential sources of LNAPL, may have a specific goal. The longer-term, final corrective-action phase may have yet another specific goal. All goals for all of the phases are not necessarily developed at the same time. However, when developing a goal, the long-term vision should be considered, as well as the influence that intermediate goals may have on subsequent phases. If the LNAPL plume is sufficiently complex, goals and management strategies should be developed separately for various areas of the LNAPL plume.
The goals for each phase and area of the plume will be highly site-specific. Table 3 provides an example of specific goals that might be developed for each phase.

Table 3. Example Goals

Project Phase	**Example Goals**
Interim measures or intermediate-term	Reduce the mobility of on-site LNAPL to a practical limit by the year 2005.
Corrective action or long-term	Achieve risk-based standards at the property boundary by the year 2015.

As more data are collected, the goal may need to be modified to reflect the improved technical understanding of the LNAPL distribution and behavior. Less likely, a goal may need to be shifted in time, for example, from the immediate/short-term protection phase to the interim-measures phase, or vice versa. In addition, as the LNAPL is managed over time, new technologies for investigation, remedial action and containment will be developed. The stakeholder group should continue to revisit the LNAPL management goal in light of these technology innovations and consider updates as necessary. The ability of the process to respond to new data and better understanding of site-specific conditions demonstrates the flexible, iterative nature of the process.

All stakeholders should remember to focus on site-specific factors. The factors may be either technical or non-technical in nature. Examples of such factors include the presence of sensitive habitats such as wetlands, any prior or pending related litigation, the relative role of federal and state environmental issues, specific regional planning goals, or town vs. county jurisdictional matters (e.g., zoning). In addition to site-specific aspects of a particular site, the development of goals should be based on consideration of:

- regulatory requirements
- LNAPL characterization and distribution
- current and future land use
- existing and/or potential receptors

- technology capabilities and limitations, which should be revisited periodically, because technologies continue to develop rapidly
- interactions with other remedial measures at the site
- stakeholder issues, concerns, and interests
- cost
- risk and uncertainty in those risks
- points of compliance
- time frames and schedules to reach the goals.

CACHE CREEK STAKEHOLDER GROUP GOALS*: AN EXAMPLE

In Northern California, a collaborative process was implemented to prepare the Cache Creek Watershed Management Plan. Building upon their common interest of maximizing their quality of life, the stakeholder group developed five overarching goals:

- healthy ecosystem
- integrated water management
- quality recreation
- healthy community
- healthy economy.

Within each goal, they developed a number of specific objectives for which they identified data needs and alternative actions to achieve the objective (www.yolorcd.org/programs/Cache%20Creek).

** These were identified by the stakeholders as goals, but may actually represent interests. Their specific objectives may be the goals described in this document.*

3.5 Document and Communicate the Consensus Process, Long-Term Vision, and LNAPL Management Goals

The process of developing an LNAPL Management Plan needs to be appropriately documented. Depending on the size of the stakeholder group, the documentation process may be relatively informal or highly structured. The formality of the documentation process should be left up to the stakeholder group. As noted earlier, the "culture" of the stakeholder group and the broader community will, in part, determine the nature of the documentation, as well as the communication techniques used. No matter what the details, the responsibility for documentation and communication rests with the stakeholders. Key agreements collectively reached by the stakeholder group (on the long-term vision, goals, endpoints etc.) should be promptly written, circulated in draft among the stakeholder group, formally agreed to, and distributed more broadly to other stakeholders, as appropriate.

If a formal LNAPL Management Plan is prepared it should document the long-term vision, goals, and endpoints by describing who is going to do what, where, and when, thus providing a road map. It should be a living document that can be revisited at various stages of the process. For example, as site assessment and remedial actions are completed during the interim phase, important data and insights may be obtained. These data and insights should be utilized to revisit and revise the goals and long-term vision. At that time, the plan should be modified.

Systematic mechanisms to communicate to the broader community of stakeholders, both directly by traditional means (open meetings, workshops, open houses, etc.) as well as through the media, should be developed and implemented throughout the process. Such techniques are generally familiar to environmental agencies and facility owners or operators, and need not be described in detail here. However, LNAPL conditions and issues may not be as familiar to stakeholders, including the general public, as surface-water and air issues, and there may be a need to explain the unique challenges associated with LNAPL.

4.0 Collect and Analyze Supplemental Data

Targeted data collection can support the evaluation of viable LNAPL management options and the selection of the most appropriate alternative for a particular site.

Current LNAPL recovery efforts often rely on a relatively incomplete or inaccurate understanding of the distribution and behavior of the LNAPL. In addition, the types of data typically collected on environmental projects are often inadequate to quantify LNAPL distribution and behavior for purposes of selecting technologies or institutional controls for LNAPL management. This often results in the installation of ineffective recovery or treatment technologies with limited or inappropriate performance metrics and endpoints that are not clearly defined.

4.1 Objectives and Targets for the Supplemental Investigation

Proven science should be used to quantify the magnitude and behavior of the LNAPL. This approach typically requires the installation of additional sampling locations, the collection of specialized fluid and soil-fluid interaction properties, and the use of generally accepted evaluation tools and methods. An investigation plan that incorporates multiple lines of evidence to develop an understanding of LNAPL at a given site is more likely to be successful than a plan that relies on only one type of data or analysis. The LNAPL investigation is a crucial component of the LNAPL management strategy.

Investigation results are used to:

- provide a more accurate understanding of LNAPL distribution and behavior,
- re-assess the current LNAPL management goal in a context of whether it is still practicable and achievable,
- facilitate the selection of appropriate LNAPL management options (i.e., active or passive technologies, engineering or institutional controls),
- design and test the technology or control system to optimize performance and efficiency,
- provide a means of estimating technology or control-system performance as a benchmark for comparison,
- establish a quantifiable endpoint for shutting off active systems,
- provide an improved understanding of the relationship of LNAPL to the dissolved COCs in the groundwater.

A series of questions need to be answered to define the scope of any supplemental LNAPL investigation.

1. What goal is the investigation intended to support (e.g., LNAPL mobility or mass reduction)?

2. What is the purpose of the data collection and what specific questions are to be answered with the data?
3. What is currently known about the LNAPL distribution and behavior? (Appendix A Checklist).
4. What field-engineering data should be obtained to quantify LNAPL distribution, volume and mobility (e.g., laser-induced fluorescence data, soil core data, LNAPL bail-down tests)?
5. What laboratory data should be obtained to quantify LNAPL distribution volume, and mobility (e.g., fluid properties, soil properties, soil-fluid interaction properties)?
6. What models and calculation methods will be used?
7. What field engineering and test data should be obtained to fill technology-selection data gaps (e.g., pilot tests, treatability tests, geotechnical tests)?
8. What statistical data analysis methods are available to support the selection of endpoints?

The potential exposure pathways for current and future conditions will dictate data needs. As examples, if there are concerns about down-gradient receptors that are users of groundwater, then chemical-component information and the potential for a continuing down-gradient dissolved-phase plume are important data needs. If the LNAPL contains light-end volatile components and the vapor diffusion to indoor-air exposure pathway is of concern due to the locations of buildings, then chemical analyses and vadose-zone soil properties are important data needs.

Data collection will support the evaluation of viable LNAPL management options and the selection of the most appropriate alternative for a particular site. The LNAPL management option evaluation and selection process and the supplemental data collection process are iterative processes that are dependent upon each other. Therefore, it is important that there be an understanding of the potential alternatives available for LNAPL management before designing the data collection process.

The distribution, mobility, recoverability, and characteristics of LNAPL are the key questions to be answered for LNAPL management using a variety of methods described in the following sections.

4.2 LNAPL Distribution

An understanding of the distribution of LNAPL in the subsurface is a fundamental component of any LNAPL management strategy. It is important to recognize that the simplified cartoons of LNAPL pancakes floating on groundwater do not exist in the real world. The LNAPL is typically smeared within the capillary fringe, and because of the water table rise and fall, below the water table. LNAPL shares the pore spaces with the air, and water above the water table and with water below the water table. The saturation with respect to LNAPL defines its distribution. LNAPL saturations typically vary significantly throughout the subsurface. In heterogeneous porous media, common at many sites, the distribution of LNAPL is typically extremely complex. For sites where

LNAPL occurs in bedrock, there are added challenges in developing a complete understanding of the distribution of LNAPL (API, 1999). The heterogeneous nature of the subsurface makes it cost-prohibitive to develop a comprehensive understanding of LNAPL distribution. Therefore, it is recommended that site investigation data be focused on the questions to be answered.

Traditional methods for estimating the distribution of LNAPL in the subsurface include collection of soil cores, installation of soil borings, and installation of groundwater monitoring wells with screened intervals that span the water table, using a variety of drilling techniques, including direct-push methods. Recent applications of geotechnical-engineering methods (e.g., direct-push) with sensor enhancements allow indirect mapping of LNAPL distribution in the subsurface (laser-induced fluorescence [LIF], rapid optical screening tool [ROST™], NAPL Ribbon Sampler, Geo Vis). Monitoring wells or soil borings can provide an indication of whether or not LNAPL exists in soil in a particular area based on visual inspection of cores obtained during drilling and measurement in wells. Observation over a period of time may be necessary to verify that LNAPL is not present in a given area. Permanent monitoring wells may also be useful in recovery efforts, or in field-testing for recoverability, as discussed below. However, monitoring wells and soil borings provide limited information about the pore-scale distribution of LNAPL. The user is directed to http://www.fate.cluin.org and http://www.epareachit.org for more information.

Soil cores can be examined to develop an understanding of the vertical distribution of LNAPL. Field tests for the detection of LNAPL in soils are typically qualitative tests to indicate the presence of NAPL. Simple tests include using a paint filter to increase the visibility of LNAPL or shaking a sample of soil in a jar to see if a separate LNAPL phase results. Other tests that require additional equipment include using hydrophobic dyes to identify LNAPL or a black light to detect fluorescing hydrocarbons (Bedient *et al.*, 1999). Laboratory methods are discussed below (see Section 4.6). A disadvantage of using soil cores to develop an understanding of the distribution of LNAPL in the subsurface is the expense of retrieval and storage of the cores after field and laboratory analyses are complete. Subsurface heterogeneity makes it difficult to interpolate between drilling locations; costs often make it prohibitive to place borings close together at a large site.

Additional information on emerging characterization and monitoring technologies can be found in Appendix D. The primary advantage of the innovative techniques is that they may enable collection of a larger number of data points for estimation of LNAPL distribution than traditional methods, so uncertainty may be reduced. Indirect sensing methods may require confirmation or calibration by more traditional methods, such as monitoring wells and soil cores. However, the quantity of confirmation samples collected by traditional methods should be substantially less than would be required if no innovative technologies were utilized to evaluate LNAPL distribution.

4.3 LNAPL Mobility and Plume Stability

Understanding whether the LNAPL is mobile is important to LNAPL management. In sedimentary regimes, LNAPL in the subsurface is distributed in the pore spaces between the particles. The following discussion focuses on pore-scale mobility. On the plume scale, movement is described in terms of migration or stability, which is described after the pore-scale discussion.

In the saturated zone, water is typically the wetting-fluid (i.e., it forms a continuous layer on, or preferentially wets, the particles) and LNAPL is the non-wetting fluid (i.e., it resides inside the pore spaces and is surrounded by a film of water). In the unsaturated zone, where there is an air phase in addition to the water and the LNAPL, the air is the non-wetting fluid, the water is still typically the wetting fluid, and the LNAPL resides between the two other fluids (Bedient, *et al*., 1999, Charbeneau 2000). The water and the LNAPL have different densities and therefore different pressures in the pore spaces. The difference in the pressure of the two liquids is the capillary pressure, which controls the saturation of LNAPL in the subsurface. As the amount of LNAPL decreases, the pressure decreases and the capacity of the formation to transmit LNAPL decreases. If LNAPL is not continuous from one pore to the next, then LNAPL will not flow from one pore to the next; it will be immobile, which is referred to as the LNAPL residual saturation (API, 1999, Bedient *et al*., 1999, Charbeneau, 2000). At residual saturation, the LNAPL cannot move unless the chemical or physical properties of the LNAPL are altered. Examples of chemical or physical changes that can affect the residual saturation include induced pressure gradients from a soil vapor-extraction system, changes in interfacial tension through the use of surfactants, or reduction in viscosity through the addition of heat (Charbeneau, 2000).

The mobility of LNAPL is a function of its saturation in the subsurface. LNAPL saturation greater than the residual saturation will constitute mobile LNAPL, whereas LNAPL saturation less than residual will constitute immobile LNAPL. Defining the conditions under which the LNAPL at a particular site is or is not mobile is an important step in the management of the LNAPL. In analyzing LNAPL mobility, it is important to understand soil-fluid interaction properties (e.g., capillary pressure and relative permeability), fluid properties (e.g., fluid density, viscosity and interfacial tension), and hydraulic properties (e.g., hydraulic conductivity, water-table fluctuations). The distribution of the LNAPL is also dependent upon specific fluid and soil properties.

If an LNAPL recovery system is operating and the recovery is approaching a low rate, the design, installation, and operating parameters and procedures should be reviewed to determine if the system is operating properly, or any changes in operation should be implemented. If after this review, the system is judged to be operating effectively, then it is likely that the remaining LNAPL is essentially immobile. In the absence of other forces acting on the LNAPL plume (e.g., a recovery or containment system), if the dissolved-phase plume has been adequately characterized and monitored and can be shown to be stable, then the LNAPL plume is likely to be stable (API, 2002).

On a plume scale, LNAPL is often present above residual saturation in the center of the plume and thus could be considered to have inherent mobility. However, that fact is not sufficient to describe the footprint of the entire plume. A study of the LNAPL plume at the fringes may be prudent to understand plume-scale migration of LNAPL. For example, because LNAPL saturation decreases to residual toward the fringe of the plume, the fringe of the plume may be immobile, while the body of the plume is considered to be stable. Temporal variation in plume characteristics should be considered to address variability in measurements, such as variations observed as a result of a fluctuating water table.

On-going LNAPL releases to the surface or subsurface may likely produce a plume that is not stable. It is possible that if the LNAPL plume appears to be stable under current site conditions, the LNAPL may still be mobilized by changes in the hydrologic system, including declining groundwater elevations[4]. The definition of a stable plume may be best presented through multiple lines of field, laboratory, and modeling evidence, while considering temporal variability.

4.4 LNAPL Recoverability

When monitoring wells, recovery wells, or soil borings are installed, a thickness of LNAPL may be observed on the water table. This thickness is the result of LNAPL draining from the surrounding pores into the well or boring (which acts like a large pore in the ground). LNAPL will drain into the borehole, either naturally or due to engineered controls such as a pump, to the extent that it remains mobile in the area of the monitoring well. Once the residual saturation is reached, further recovery by pumping methods will not be possible. The residual saturation is a theoretical endpoint for pumping-based recovery systems that will not likely be achieved on a field-scale. It is likely that there will be more LNAPL remaining in the formation than predicted by the residual saturation (API, 2002). This is because the heterogeneity of the subsurface, inefficiencies in the recovery-well network, and variability in the estimates of residual saturation will result in uncertainties in the predictions for an actual pumping system (U.S. EPA, 1996).

The extent and success of LNAPL recovery is, in large part, defined by the geology, fluid properties, and the technology that is implemented. For fluid flow, e.g., pumping-based systems, recovery is limited by the residual saturation and the influence of the pumping system on groundwater and LNAPL movement to the recovery wells. For technologies such as surfactant washing, steam stripping, and soil vapor extraction, the recovery may be able to address some portion of the residual saturation after mobile LNAPL has been removed. These methods have been designed for enhanced mass recovery. The implementation of these technologies should be considered in the context of potential exposure pathways that result from the LNAPL as a source of dissolved-phase or vapor-phase COCs (API, 2002).

The potential exposure pathways associated with the LNAPL (e.g., vapor-phase COC migration to indoor environments) should be considered in the evaluation of LNAPL recovery technologies. As noted above, some enhanced mass-recovery methods will reduce the potential for dissolved-phase or vapor-phase COCs to continue to migrate away from the LNAPL source. In addition, the potential for the LNAPL management

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[4] A fluctuating water table will contribute to the smearing of LNAPL across the water table and capillary fringe, which may reduce LNAPL saturations, by spreading the LNAPL over a greater thickness and reducing mobility and recoverability.

option to liberate COCs from the LNAPL into other environmental media (e.g., steam stripping will generate vapor-phase COCs) should be considered during the evaluation of LNAPL recovery options, and during the design of a site-specific system.

Typically LNAPL bail-down tests are used to understand the recoverability of LNAPL using pumping systems in wells. The result of the bail-down test is an estimate of the LNAPL conductivity and also the local transmissivity of the formation for LNAPL. The LNAPL recovery rate can be estimated from the transmissivity and a determination made if that rate is acceptable (typically reviewed and approved by the regulatory agency). A bail-down test is conducted by removing all accumulated LNAPL in a well and recording the rate at which LNAPL recharges into the well. Field data are analyzed in similar fashion as groundwater bail-down tests or slug tests, using methods such as the Bouwer-Rice method, Lundy and Zimmerman, or Huntley methods (Huntley, 1997; Lundy and Zimmerman, 1996; BP, 2003; TCEQ, 2003; Charbeneau, 2000; Bedient *et al*., 1999).

Recovery of LNAPL from the subsurface reduces its saturation, making the LNAPL less mobile, but also less recoverable. Therefore as the recovery progresses, it becomes less effective and the actual recovery rate diminishes.

4.5 Field Data Collection

The scope of field data collection should be defined through the series of questions posed in Section 4.1. Quantity and quality of data will be assessed based on the LNAPL management goals to be supported and the potential management options to be considered. If management options are to be pilot tested, the quality and quantity of data that are required should be decided based on the specifications of the pilot test. Methods for estimation of LNAPL distribution, mobility, recoverability, and characteristics are described briefly in Sections 4.2 through 4.4.

4.6 Laboratory Analyses

Laboratory analyses to be performed will vary depending on the management options to be evaluated for a specific site. Some of the more common laboratory data collected include basic fluid and soil properties. There are a number of references that provide recommendations for analytical methods, e.g., API, 1999; API, 2001a; TCEQ, 2003. The methods for each parameter are often updated with newer techniques. It is suggested that the user consult with the regulatory agency and a qualified analytical laboratory to develop a site-specific analytical scope of work.

Laboratory analyses of LNAPL are generally performed to measure the following:

- density
- viscosity
- chemical composition
- surface tension
- LNAPL/water interfacial tension
- source petroleum product (i.e., “finger-print” analysis).

For situations where an LNAPL separate-phase has not been detected in monitoring wells, or there is insufficient LNAPL in the monitoring wells to collect a sample for laboratory analyses, total petroleum hydrocarbon (TPH) measurements or other methods designed to estimate the total concentration of COCs in soil may provide an indication of LNAPL saturation (Bedient *et al.,* 1999).

Laboratory analyses of core samples are generally performed to quantify the following soil properties:

- grain size
- porosity
- bulk density
- hydraulic conductivity
- Atterberg limits (for soil classification)
- undisturbed samples (e.g., soil cores) for
  - — saturation analysis for LNAPL and water, including residual saturation
  - — capillary pressure tests
  - — relative permeability tests.

For more information on laboratory analyses, see BP, 2002; TCEQ, 2003; and API, 1996a.

4.7 Data Interpretation

Data interpretation typically requires the use of multiple lines of evidence to analyze both qualitative and quantitative data to develop an understanding of LNAPL distribution, LNAPL characteristics, and its mobility and potential recoverability.

A credible estimate of the volume of LNAPL remaining in the formation should be developed. However, all estimates of LNAPL volume have large uncertainties due to factors such as heterogeneity of the subsurface, representativeness of the data set, and variability of LNAPL properties, particularly for multiple or old releases. Basic calculation of the volume in the subsurface considers horizontal and vertical distribution of LNAPL and the measured or estimated saturations of LNAPL. It is also important to estimate the fraction of the total LNAPL volume in the subsurface that is mobile. Some of the newer investigation techniques that involve indirect sensing with direct-push methods can produce a three-dimensional interpretation of LNAPL distribution in the subsurface. Based on these measurements, the volume in the subsurface can also be estimated. A discussion of the potential uncertainties in the estimated volume of LNAPL is often helpful to the stakeholder group, while developing a common understanding of the site.

LNAPL saturation for a site can also be estimated from TPH concentrations or can be measured in the laboratory. These can be compared to a residual saturation value, either from the literature (API, 1999) or from laboratory measurements. Caution should be exercised when using literature values because of the potential for large differences between site-specific field measurements and theoretical literature values. If the calculated saturation is below the residual saturation, there is not likely a mobile LNAPL phase and the LNAPL is likely not recoverable using fluid-pumping methods (TCEQ, 2003; API, 1999; Mercer and Cohen, 1990). The TCEQ 2003 guidance includes a set of LNAPL recoverability graphs. The information required to use the graphs includes the type of LNAPL, an estimate of the aquifer hydraulic conductivity, and an estimate of the LNAPL thickness. The graphs show regions where LNAPL is likely recoverable and where LNAPL is likely not readily recoverable. The graphs were developed using model simulations and an assumption of a dual-pump system where LNAPL and groundwater are recovered simultaneously. The user is cautioned to ensure that the assumptions detailed in the TCEQ 2003 reference are applicable to the site before using the results of the graphs.

It may also be useful to understand the natural attenuation of LNAPL. The chemical composition and "finger print" analyses can be used to understand the volatile and dissolution losses for LNAPL distribution to develop estimates of the loss rates from these mechanisms. An understanding of the site-specific biodegradation by anaerobic processes may also be factored into the natural attenuation estimates.

The mobility and recoverability of LNAPL can be estimated through the use of models. Some of the more widely used models are the American Petroleum Institute (API) LNAPL Distribution and Recovery spreadsheet models (API, 1999), API LNAPL Dissolution and Transport Screening Tool (LNAST) model (API, 2002), and multiphase, numerical, reservoir-simulation models. The user is cautioned that implementation of a numerical simulation model requires extensive site data in order to run and calibrate the model. The user is encouraged to begin with simple analytical tools and readily available information and only to move to higher complexity modeling if the simpler solutions are insufficiently discriminating for decision-making. For more information, see ASTM, 2000; API, 2002; DOE,1998; U.S. EPA, 1997a, and U.S. EPA, 2002.

In addition, if an LNAPL pumping system is currently operating at the site, as an interim-recovery measure, then the volume recovered plotted as a function of time and a graph of LNAPL recovery rate as a function of cumulative recovery can provide estimates of LNAPL volume, recoverability, and remaining LNAPL. If the LNAPL recovery rate is low or approaching a practical endpoint, then the LNAPL is approaching an immobile state and further recovery through pumping methods is unlikely. Simulated graphs of recovery rate and cumulative recovery are presented in Figures 2 and 3.

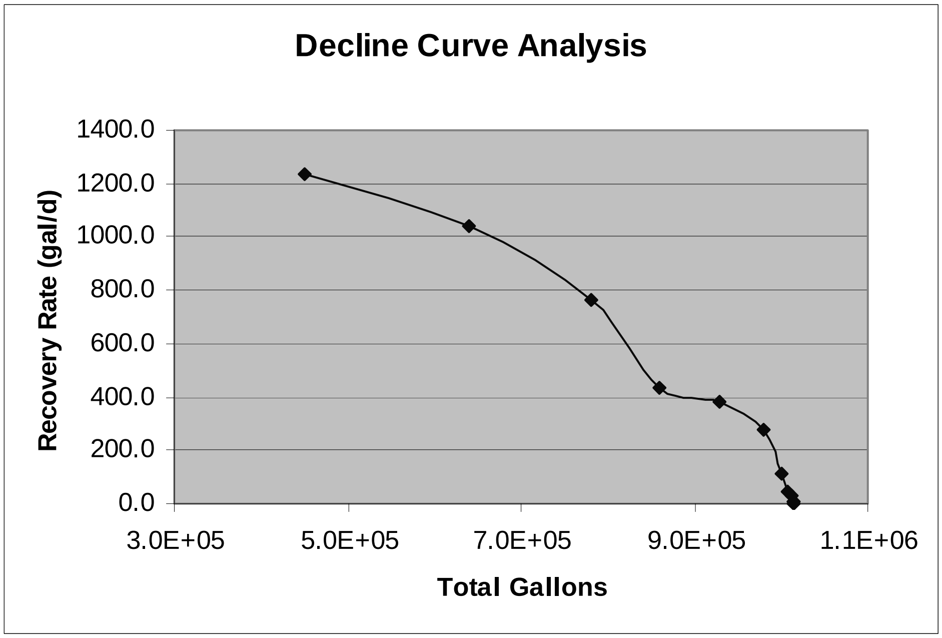

Figure 2. Hypothetical Decline Curve for an LNAPL Recovery System

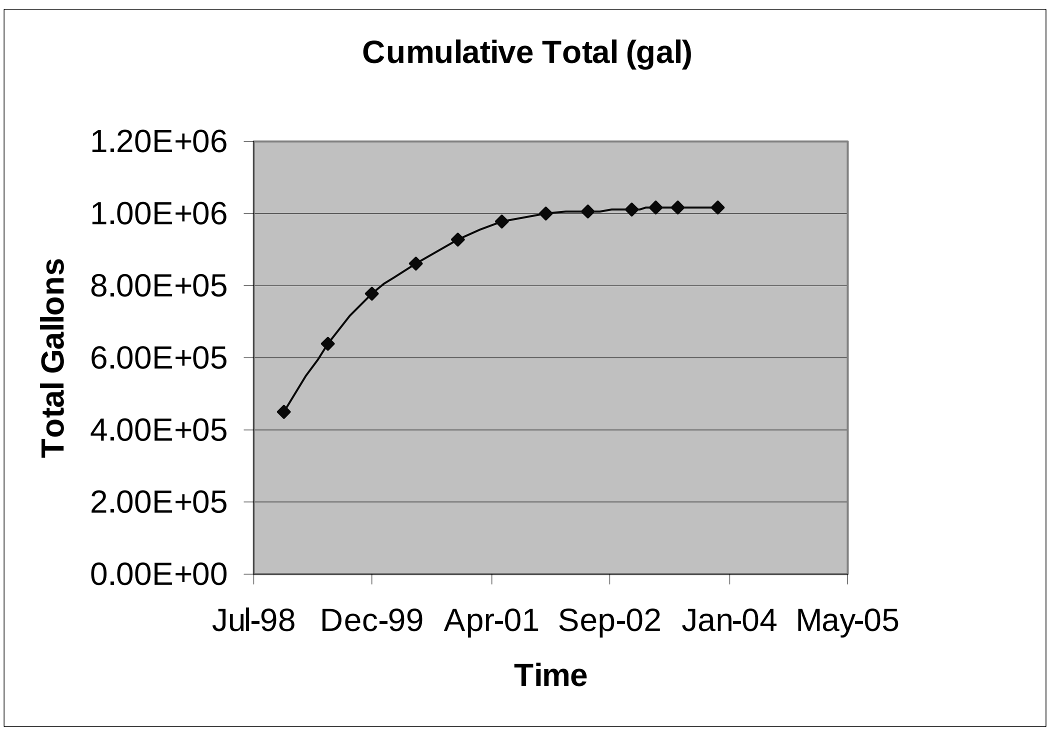

Figure 3. Hypothetical Cumulative Recovery for an LNAPL Recovery System

Targeted data collection can support the evaluation of viable LNAPL management options and the selection of the most appropriate alternative for a particular site.

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5.0 *Review and Refine Conceptual Model, Long-Term Vision, and Goals*

The LNAPL Management Plan, including the conceptual model, long-term vision, and goal, should be reviewed and refined based upon supplemental data collected in the previous step. The stakeholder group should consider the flexibility in the process to always base their decisions on the most up-to-date information.

The conceptual model should be reviewed after the supplemental data have been collected and analyzed in the previous step. If significant changes to the model or the new risks have been identified, the stakeholder group should revisit the long-term vision and goal presently being pursued. The iterative, flexible process should always utilize the best information to support the decisions underway. This step provides a chance for the stakeholder group to validate that the project is on course and that the goal and long-term vision remain reasonable and practicable.

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6.0 Identify, Evaluate, and Select Management Options

The LNAPL management option, a critical component of the LNAPL Management Plan, defines the alternatives for addressing LNAPL at a particular site. Selection of the LNAPL management option requires an understanding of LNAPL distribution, mobility, composition, and recoverability. LNAPL management options include treatment, removal, and containment technologies and institutional controls.

When an LNAPL management goal has been established by the stakeholder group and supplemental data have been collected, LNAPL management options should be identified and evaluated. It is important to the supplemental data collection process that potential options available for LNAPL management be identified before the data-collection process is finalized. The LNAPL management option may include one or a combination of active recovery or treatment and passive treatment technologies, containment technologies, and/or institutional controls. The LNAPL management option should also consider current and potential future exposure scenarios and associated risks in the selection of appropriate elements.

6.1 Identify and Evaluate LNAPL Management Options

The first step in developing the LNAPL management strategy is the identification and selection of specific options that support the long-term vision. The range of possible options includes active technologies, passive technologies, institutional controls, engineering controls (i.e., containment) and combinations of these options. Evaluation of active and passive technologies and engineering controls can be accomplished in several phases, beginning with screening, followed by a more detailed evaluation based upon specific criteria, and then, if necessary, laboratory or bench-scale tests, or field pilot tests. The screening process is diverging, where as many options as possible are reviewed, whereas the evaluation process is converging where the entire population of options is examined in detail so that the most promising options can be identified using a set of criteria developed for this specific site. Appendix C includes information on decision criteria that can be utilized to select management options and a checklist of questions that should be asked during the management-option step. The process may also include iterative phases of supplemental data collection and technology evaluation.

The selection of a management option should consider the application of multiple technologies and controls, either as a system or as a sequentially applied treatment train, as well as the application of a single technology or control. Multiple technologies and controls are often necessary to address different exposure pathways (e.g., hydraulic pumping of LNAPL to reduce LNAPL mobility along with soil vapor extraction to control volatile emissions near buildings). This strategic thinking should be considered during the screening and selection of technologies and controls.

6.2 Treatment, Removal, and Containment Technologies

A brief overview of various classes of technology and control options for addressing LNAPL impacts is provided in this section. Various references provide a more comprehensive review of active and passive technologies, including some examples listed in Appendix D and specifically TCEQ, 2003; API, 1996a; API, 1999; and Bedient *et al*., 1999; U.S. EPA, 1995.

Active treatment and removal technologies are typically used to reduce the mass of LNAPL in the source area or the volume of mobile LNAPL. Examples of active technologies follow.

- Recovery of LNAPL by hydraulic pumping is the skimming or pumping of LNAPL from wells or trenches under ambient pressure conditions. Groundwater may also be recovered at the same well or trench in order to induce flow of LNAPL to the recovery point by increasing the hydraulic gradient towards the well. This type of LNAPL recovery has been widely practiced in the environmental field; there are many references from which to gather more details (API, 1996a; API, 1999; API, 2002; Bedient *et al.,* 1999; Charbeneau, 2000). Hydraulic recovery of LNAPL is suited to lighter petroleum products and permeable hydrogeologic settings.
- Bioremediation is a broad category of technologies that endeavor to enhance the natural biological activity in the subsurface to reduce concentrations of COCs in soil and groundwater. For petroleum-related COCs, most technologies include introduction of oxygen and other nutrients, such as nitrogen and phosphorus, into the subsurface. References for bioremediation applications include Hughes, 2002; Bedient *et al.,* 1999; NRC, 1994; NRC, 2000. Traditionally, bioremediation is not attempted within the LNAPL; however this is an area of emerging technology application; the user is encouraged to consult references for the most current information.
- Aggressive source-removal technologies are those that endeavor to significantly reduce the mass of COCs in the subsurface by treating or removing LNAPL and highest concentrations of COCs in soil and groundwater. Examples of aggressive source-removal technologies include: soil vapor extraction, excavation, surfactant flushing, steam stripping, electrical heating, chemical oxidation, and high-vacuum, dual-phase extraction. Because a number of these technologies are relatively new, the user is cautioned to research the latest information on the technologies applicable for their specific problem. (API, 1996a; API, 2002; Bedient *et al*, 1999; TCEQ, 2003; http://www.clu-in.org; http://www.epareachit.org; http://www.gwrtac.org; http://www.groundwatercentral.info).

Engineering controls provide containment or isolation of the LNAPL to eliminate exposure pathways. These systems generally are designed to be in-place for long periods of time. Often they are used when available treatment or removal technologies are infeasible or impractical. They can also be used when the site land use prohibits or greatly restricts the opportunities for installation of active or passive technologies. Examples of engineering controls that are applicable to LNAPL management include:

- Containment strategies, such as sheet piles, slurry walls, and hydraulic control using various arrangements of pumping wells, involve physical barriers to flow. These strategies are used when continued migration of a groundwater plume or LNAPL as separate phase will result in unacceptable impacts to receptors. They can also be used when source removal is not viable or when passive technologies will not achieve the concentration reductions that are necessary to protect receptors. The groundwater flow system and the hydrogeologic setting should be well understood to implement effective containment systems. In fractured bedrock or highly heterogeneous settings, containment systems are difficult to design and operate. Containment strategies can be used for any type of LNAPL. However, it is important to implement a monitoring program with the containment system to ensure its reliable operation. Some containment systems have failed as a result of poorly understood site conditions or temporal variations in site conditions that were beyond the design basis for the containment system.

Passive treatment technologies are typically used to reduce concentrations of COCs within the dissolved-phase groundwater plume. Passive technologies alone generally are not appropriate for mobile LNAPL, but may have application for dissolved concentrations resulting from residual LNAPL. For some LNAPL sites, a combination of an active source-zone technology and a passive dissolved-phase groundwater plume technology may be appropriate. Examples of passive technologies include the following:

- Monitored natural attenuation (MNA) is a biodegradation process where the natural biological activity, as well as the other attenuation mechanisms such as dispersion, is monitored carefully to predict and evaluate the reduction in concentrations of COCs in groundwater. The applications for MNA include the lighter petroleum hydrocarbons, particularly in the distal portion of the dissolved plume. Natural conditions that are conducive to degradation are important for MNA to be successful (API, 1997; API 1997a; http://www.clu-in.org; U.S. EPA, 1999).
- Permeable reactive barriers are groundwater interceptor trenches that are filled with one or more materials that degrade, adsorb, or chemically alter the COCs in the groundwater. The reactive barriers may be applied in higher permeability groundwater zones that are relatively homogeneous down-gradient of the LNAPL plume. This is because the treatment of the dissolved COCs in groundwater depends upon the impacted groundwater flowing through and contacting the interceptor trench materials and it is not desirable for LNAPL to flow through the reactive media in the trench (http://www.clu-in.org).

Institutional controls are management options that reduce or remove the likelihood of exposure for a receptor through control of the land use or activities conducted on the property impacted by LNAPL and COCs in soil and groundwater. Institutional controls include restricting activities on a property (e.g., industrial uses). The restrictions can be implemented for example by using deed restrictions, deed notices, and zoning. Institutional controls should be integrated into the overall LNAPL Management Plan and may likely be required along with the passive or active technologies (U.S. EPA, 2003).

6.3 Select and Test Technology

Initially management options are screened using a set of criteria that reflect back to the goal previously agreed upon and the improved technical understanding of LNAPL distribution and behavior provided by the supplemental data collection. The screening process allows for comparison of various LNAPL reduction, recovery, and management alternatives. The process begins with development of screening criteria to compare alternative technologies for their suitability to the specific LNAPL conditions at the site (based on the LNAPL investigation results), their predicted ability to achieve the established goal, and their cost. The screening process supports the identification of the highest-benefit alternatives to meet the long-term vision, or highlights the need for additional data collection and evaluation. Additional information about decision criteria for the management-option selection process, including the potential trade-offs between short and long-term costs and performance of different technologies, is included in Appendix C.

Based on the screening and additional LNAPL investigation results, a more detailed analysis of the most promising technologies can be conducted. Laboratory, bench-scale, or pilot testing and computer modeling may also be recommended before full-scale implementation of one or more technologies selected as a result of the screening and detailed analysis.

As part of the evaluation process, these important questions should be addressed:

- Are there off-site releases of NAPL COCs?
- Should a phased or treatment-train approach be used (e.g., active technology followed by passive technology)?
- Is treatment preferred over engineering (e.g., hydraulic containment) or institutional controls (e.g., environmental covenant or deed restriction)?
- Can engineering or institutional controls be used as part of a combined strategy with active measures?
- Are there time constraints related to redevelopment, compliance or other issues that may affect the technology selection?[5]
- How long will it take to meet the endpoints and eventually, the goal? Include some assessment of the uncertainties associated with each evaluation.
- Are there surface disturbance restrictions and access issues that should be addressed?
- How can the LNAPL-recovery effort be integrated with existing or envisioned property-use plans?
- Are there other impediments that might influence technology selection?

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[5] It must be noted that there are potentially large uncertainties in the estimation of the time required to reach the endpoints with any particular technology (U.S. EPA, 2001). It may also be desirable to consider the various technologies in terms of their relative times to reach endpoints, rather than to focus on the absolute estimate of time for any one technology.

- Will removal of LNAPL have a measurable impact on COC concentrations in other media?
- Will removal of LNAPL make the site more appealing for reuse?
- What impact will removal of LNAPL have on the overall site remediation timeframe?
- If physical controls are chosen as an alternative to recovery, what will happen if the control strategy fails?

During the technology-selection process, feasible technologies are evaluated based on the capability and likelihood of meeting the established goal. Consideration of the limitations of the technology should be evaluated prior to selection. The goal may need to be revised based on the capabilities of the technology. Specific LNAPL investigation results and management options will provide a basis for identification of data that should be collected to measure progress. Appendix C includes additional information about the management-options selection process and criteria for selection.

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7.0 Define Endpoints and Develop Contingency Plan

Specific endpoint(s) must be defined for each goal. The endpoints provide a tool or metric to measure performance and relate that criterion to a specific goal. A contingency plan should also be developed, so that it can be implemented if endpoints cannot be achieved. Management options may be revisited and revised, if necessary.

The establishment of LNAPL management goals for a site involves development of an overall strategy or roadmap that includes multiple phases and activities that support each of the phases, as described in Section 3.0. After the goal is established for a particular phase of the project, the stakeholder group should agree upon endpoints, which are specific, measurable criteria that demonstrate progress toward achieving the goal.

Information regarding the establishment of endpoints should then be communicated to the broad stakeholder community so all are clear as to what will be accomplished when endpoints are achieved.

Endpoints are defined after an accurate understanding of the LNAPL distribution and behavior has been reviewed and technologies to address the LNAPL have been selected. Individual endpoints should be established for each phase of the LNAPL Management Plan. For example, an intermediate-performance goal might be LNAPL source-area recovery, through installation of a steam-injection system. The associated endpoint might be a targeted cumulative recovery within a specified length of time.

Endpoints may be performance-based specific to the remedial technology (such as removal of "x" amount of LNAPL) or may reflect a measurable long-term condition, such as a specific hydrocarbon concentration in soil or groundwater. An endpoint may also be identified to track progress on the management of dissolved plumes that remain after active management of the LNAPL phase has concluded.

Endpoints should be established for active, passive, and engineering-control systems at various points along the "path to closure." Final endpoints should be established as criteria for achieving closure for sites (i.e., "closure criteria). Stages for endpoint setting include:

- installation or operation of active or passive technologies and institutional or engineering control,
- discontinuation or modification of a system,
- initiation or conclusion of monitoring for stability, and
- final closure.

Specific examples of endpoints include:

- recovery rate for an LNAPL recovery system is reduced to an established value (e.g., three gallons per day);

- specific COC in LNAPL is reduced to a target value at “x” monitoring locations over “y” period of time;
- stability of the dissolved-phase plume is demonstrated based on a dissolved COC-concentration threshold at “x” monitoring locations over “y” period of time;
- LNAPL transmissivity is reduced to a certain value at “x” monitoring locations;
- LNAPL saturations at all points within the area of distribution have been reduced to levels below residual saturation, as measured by “a” method and cross-checked with “b” method;
- groundwater samples from “xx” monitoring wells did not contain LNAPL-related organic constituents at concentrations above drinking-water maximum contaminant levels (MCLs) for four consecutive quarterly monitoring events;
- LNAPL chemistry has been changed so it no longer contains VOCs at measurable concentrations using analytical method “d” and vapor concentrations in the vadose zone measured by method “e” are below measurable levels;
- a containment system meeting “g, h, i” specifications has been installed and tested for integrity;
- final relative permeability value is attained.

A critical endpoint that should be established involves the suspension of active technologies. Examples of such an endpoint might measure some component of LNAPL mobility or “x” volume recovered over a certain area, an alternative concentration limit within specific monitoring wells on the property, or a soil-concentration standard over a certain area of the site.

Endpoints should be defined with specific considerations including:

- type of measurement
- method for sample collection
- analytical method
- location of measurement, (including point of compliance)
- the timeframe for measurements
- number of measurements
- data analysis, statistical evaluation, and data presentation.

The more specifically the endpoints are defined the less likelihood there will be cause for confusion or dissension among the various stakeholders.

Significant uncertainties are associated with natural systems. Design and implementation of engineered systems to contain or remediate these natural systems are also associated with significant uncertainties. These uncertainties must be acknowledged through the evaluation of knowledge gaps and the development of contingency plans to enable meeting of the endpoints. The contingency plan should describe the possible causes for “failure” and appropriate response actions for each. It should be flexible enough that it allows revisiting of management options, including modifications, upgrades and new systems, if needed, long-term vision and goals, and collection of supplemental data, if necessary.

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8.0 Implement and Monitor Performance

Implementation of the LNAPL management strategy will occur in phases, near-term, intermediate, and long-term, as specific goals are addressed. During implementation, monitoring of the performance of the management options selected should be initiated so that progress towards meeting the endpoints and goals can be measured at some reasonable time thereafter.

The first step in implementation should be preparation of a detailed design for the selected management/technology option. The detailed design may be based upon the results of bench and/or pilot-scale testing, recommended to ensure optimization of the remediation process and reduction of uncertainties associated with the process. In some cases, the selected management/technology option may involve a phased or treatment-train approach (e.g., active technology followed by passive technology). Monitoring will thus need to be tailored to each phase of the project. Performance monitoring is conducted at regular intervals during operation of active remediation systems to track progress towards achieving the endpoints and to determine when active system operations can be suspended. Compliance monitoring is conducted following system shutdown to track progress of the passive technologies towards achieving an LNAPL management goal. If only active remediation is involved, confirmation monitoring will generally be required to monitor for rebound effects that may occur after system shutdown.

Both the Performance Monitoring Plan and the Compliance Monitoring Plan should be completed and agreed to by the stakeholders before implementation is initiated. If written reports are prepared, they should be provided to the stakeholder group with sufficient time for their review. When performance-monitoring data demonstrate that specific endpoints have been attained, approval may be given to suspend the active phase of LNAPL management and confirmation monitoring may begin. Once confirmation monitoring demonstrates that the LNAPL management goal has been achieved, approval may be given to close the site (if these were the final corrective measures), or the project may move into the next phase.

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9.0 Evaluate Progress

Progress towards meeting endpoints, goals, and long-term vision is measured using the data collected during implementation and monitoring. As data are collected on the effectiveness of the LNAPL management option, progress should be evaluated. If satisfactory progress is not being made, a contingency plan, which may include enhancements to the current system or selection of an alternative system, should be implemented.

The LNAPL Management Plan is revisited as new information is collected. A series of questions regarding progress with regards to endpoints, goals, and long-term vision are asked (Figure 1).

- Has the endpoint been achieved?
  - If yes, then perform confirmation monitoring to assess whether the goal has been achieved.
    - If yes, then assess whether this was a final goal, implying that the long-term vision has been achieved. If yes, then the process ends.
    - If no, is the management option on track to meet the goal. If yes, continue to implement and monitor. If no, implement contingency plan.
  - If no, is the management option on track to meet the endpoint?
    - If yes, continue implementation and monitoring.
    - If no, implement the contingency plan.

During definition of endpoints, a contingency plan should have been developed (Section 7.0). The contingency plan should be implemented if the management option is not on track to meet the endpoints or goals. Depending upon the specific situation, the contingency plan may require:

1) review and selection of alternative management options (Section 6.0)
2) modifications or upgrades to the current management system (Section 6.0)
3) collection and analysis of supplemental data (Section 4.0) or
4) revisiting long-term vision and goals (Section 3.0).

The LNAPL Management Plan comprises the collected understanding and desires of the stakeholder group that relate to the ultimate condition of the property. The LNAPL Management Plan begins with the current understanding of site conditions and progresses to a long-term vision, where appropriate science and engineering have been utilized to bring the site to a condition that protects human health and the environment to a reasonable and practicable level.

It is crucial to the success of the overall project that all of the stakeholders keep that long-term vision in-mind when working through the intermediate activities. This means that the long-term focus for the plan and the elements that define success for the stakeholders should be clearly articulated and the vision shared among all of the stakeholders. This may be accomplished with a document that is referenced and updated throughout the intermediate steps, or with another tool such as a series of documents, a section in a regulatory submittal, presentations, or web pages that communicates the common understanding developed by the stakeholder group.

The flexible, iterative process for LNAPL management ensures that the decisions at each step in the process are made using the latest information collected. The understanding of site conditions, the vision, goals, and endpoints in the document should be re-visited by the stakeholders at each major step and revised as necessary to reflect the current state of knowledge and the current preferences of the stakeholders. All changes should be documented and the broad stakeholder community should be notified if a revision has been completed.

Appendix A: Current Conditions Checklist

This checklist provides a detailed list of information and data that are most often needed to develop an LNAPL Management Plan. Not all of the information will be available for every site and not all of the information will be needed for every site. The first section covers general topics that include regulatory requirements, schedule, etc. The second section focuses on the current LNAPL management program, including site conditions.

Topic	**Status**			**Description/Comments**
Regulatory Setting	C	I	NA	
Specific legal and regulatory authorities (e.g., Resource Conservation and Recovery Act (RCRA), state groundwater program, state voluntary action program, etc.)				
RCRA Environmental Indicators, if applicable				
Endpoints previously defined (on site; off-site)				
Measurement/monitoring requirements				
Schedule				
Current county and local LNAPL-related requirements, if any (zoning, land use plan, etc.)				
Related issues (e.g., participation in voluntary program, permit requirements, consent decree, judicially imposed requirements, stakeholder information, etc.)				
COCs in soil, groundwater or other environmental media that may need to be addressed				

* C = Complete
I = Incomplete
NA = Not Applicable

Current LNAPL Management Program	**Data Available**		**Data Sufficient**		**Description, Comments**
	Yes	**No**	**Yes**	**No**	
Existing LNAPL management philosophy/approach					
Current monitoring/characterization approach					
Stabilization to prevent migration (e.g., by pumping, barriers, etc.)					
Control at the site's perimeter					
Recovery underway for source control to reduce plume's mass and volume					
Other engineering controls					
Site Conditions					
Hydrogeologic Setting					
Depth to and elevation of LNAPL and affected groundwater					
Hydraulic gradient and direction of flow of groundwater and LNAPL					

Current LNAPL Management Program	Data Available		Data Sufficient		Description, Comments
	Yes	No	Yes	No	
Potential for direct contact with LNAPL during excavation and proximity to underground structures and utilities					
Fluctuating groundwater elevation					
Seasonal or temporal fluctuations in groundwater elevation can result in residual LNAPL in pores in a smear zone and "pockets" of LNAPL trapped below the water table					
Groundwater classification system					
If there is a groundwater classification system, it may have requirements for LNAPL removal and may impact LNAPL management goals					
Proximity to surface water					
Potential influence of surface water on groundwater movement (e.g., aquifer receiving recharge from or discharging to surface water)					
Potential impact of LNAPL on receiving surface waters					
Surface cover					
The type and permeability of surface cover influences the rate and amount of surface-water infiltration (and distribution and dissolution of LNAPL) in the source area)					
Geologic Setting					
Unconsolidated deposits					
Texture of sediments, e.g., sands, silts, and clays					
Complexity of stratigraphy, vertically and laterally (i.e. heterogeneity)					
Consolidated materials					
Fractured or karst bedrock may be complicating factors in prediction of LNAPL behavior					
Complexity of stratigraphy, vertically and laterally (i.e. heterogeneity)					
Lithologic properties affect the distribution, mobility, and recovery of LNAPL					
Lithologic properties in the interval that contains LNAPL (e.g., grain-size distribution, porosity, effective porosity, hydraulic conductivity, etc.)					
Scale issue is important for designing/collecting and understanding field measurements, i.e. site-scale, and for determining sampling location for point measurements to be made in the field, or for samples to be taken for laboratory analyses					
Subsurface LNAPL Distribution					
Major LNAPL sources, release sites					
Identification of facility areas and operations contributing to LNAPL source areas, including underground utilities					
General boundaries of the area where LNAPL was released to the subsurface					
At a large facility, source areas will likely encompass multiple, separate-release incidents					
Estimated volumes (Note: accurate volume estimates are very difficult to obtain for a number of reasons)					

Current LNAPL Management Program	Data Available		Data Sufficient		Description, Comments
	Yes	No	Yes	No	
Based on records of release incidents					
Field measurements (i.e., LNAPL thickness)					
Innovative field screening techniques (e.g., LIF-based cone penetrometer)					
Results will generally be a weight-of-evidence estimate with uncertainty bounds					
Type of LNAPL					
Complex facilities likely have LNAPL with different characteristics at different locations					
Fate and transport properties and potential to contribute COCs to a dissolved-phase plume or volatilized in vadose zone					
Potential for LNAPL to be an ongoing source of COCs					
Focus is on LNAPL, which can float on the water table; for releases of dense NAPL (DNAPL), additional resources should be consulted[6]. Potential for some petroleum hydrocarbons to be DNAPL (e.g., lube oils) but their mobility, viscosity, solubility and COC content will make them easier to detect than for other types of DNAPL (e.g., chlorinated solvents					
LNAPL constituents and COCs					
Smear Zone					
Depends on the hydrogeologic regime, climatologic factors					
May be a source of vapor and dissolved-phase exposure pathways					
Above and below the water table, variable LNAPL saturations					
Estimates of saturations at various points throughout the LNAPL based on field measurements					
Potential for Future Releases					
Important for operating facilities					
Not an issue for closed facilities, or facilities to be closed unless tanks, vessels, and piping still contain LNAPL					
Could significantly impact LNAPL management strategy					
Measurement Tools to Characterize LNAPL Distribution					
Conventional measures (e.g., soil cores, borings, monitoring wells)					
Define methods, brief description of application, strengths, weaknesses, etc.					
Innovative measures (e.g., Rapid Optical Screening Tool (ROST™, cone penetrometer (CPT), Laser Induced Fluorescence (LIF), LNAPL Ribbon Sampler, GeoVis (a CPT-mounted imaging system), Membrane Interface Probe (MIP), etc.					
Define methods, brief description of application, strengths, weaknesses, etc.					

[6] See the Reference Section for selected sources of information of DNAPLs.

Current LNAPL Management Program	Data Available		Data Sufficient		Description, Comments
	Yes	No	Yes	No	
Appropriate methods and utility of methods for estimating the location, saturation, etc, of LNAPL in the subsurface will depend on site conditions and LNAPL properties					
Core and fluid analysis (fluid density, viscosity, interfacial tension, soil-fluid interaction properties including intrinsic permeability, capillary pressure and relative permeability)					
Known Fluid Properties – Groundwater and LNAPL					
Current NAPL characteristics (e.g., vapor pressure, boiling point, distillation curve)					
May be estimated based on literature values, or on a number of field samples throughout the LNAPL					
Characteristics change with time as the LNAPL ages in the environment					
Fluid properties that influence mobility and recoverability (e.g., viscosity, density, interfacial tension)					
Literature and calculated values based on specific LNAPL characterization					
Important parameters in design and analysis of LNAPL remediation systems					
Potential COCs released by LNAPL					
The COCs (including breakdown products) that can be released by a LNAPL plume will provide information as to the potential for the LNAPL plume to act as an ongoing source of COCs to groundwater					
History of Plume Extent (liquid and dissolved phases)					
What are plume dimensions over time?					
Provides anecdotal information concerning the mobility of the LNAPL and dissolved plumes (e.g., stable, shrinking, growing)					
Potential for future releases					
How has the assessment program impacted plume definition?					
Are there areas for which no information is available?					
Can the downgradient extent of the LNAPL be monitored with an existing sampling network?					
Are the measurement methods used effective for LNAPL characterization?					
How have historical water-table elevations impacted plume definition?					
Provides an indication of the impact of the smear zone and possible submerged "pockets" of LNAPL on the dissolved plume					
Have models been run?					
What types of models – analytical or numerical?					
What were the modeling results?					
Do field data support the predictions? What are the shortcomings of the models?					
Recovery History					
LNAPL recovery history and significant aspects of the program (graphs)					

Current LNAPL Management Program	Data Available		Data Sufficient		Description, Comments
	Yes	**No**	**Yes**	**No**	
Methods for recovery, time line, number of wells					
May include a narrative, volume vs. time graphs					
Qualitative and quantitative information					
Operational history and effectiveness					
Problems with recovery system can indicate potential long-term ineffectiveness of system, e.g., technology limitations or system location relative to mobile LNAPL					
Historical and current recovery rate provide an indication of the potential for ultimate LNAPL recovery, recovery efficiency, and practical endpoints					
Inference of LNAPL transmissivity characteristics, site-scale or aggregate recoverability of the LNAPL					
Existing and Potential Off-Site Impacts					
Factors that affect LNAPL management					
Potential for vadose-zone vapors, groundwater dissolved phase, and LNAPL migration					
Potential impact locations					
Adjacent natural environments and resources (e.g., ecological habitats)					
Discharge to surface water (e.g., rivers, streams, wetlands)					
Discharge to subsurface (e.g., water-supply aquifers)					
Adjacent man-made structures (e.g., buildings)					
Other (e.g., utility corridors)					
Land Use and Ownership					
Petroleum facility					
Adjacent properties potentially affected					
Surrounding area land uses					

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Appendix B: Potentially Affected Interests Matrix

IPMP: the Institute for Participatory Management and Planning, Box 1937, Monterey, CA 93942 Tel: (831) 373-4292, FAX: (831) 373-0760, E-Mail: ipmp@aol.com
Visit us on our Web-Site at **www.ipmp-bleiker.com** Contact us and let us train your key managers in Consent-Building methods and strategies. The management seminars we're best known for are: - **SDIC:** Systematic Development of Informed Consent, - **CPO-2:** Dealing with Domestic Terrorists

Project Name:

Issues: An "Issue" is an unambiguous statement.
It can be: - *a fact*, - *a fancy*, - *an accusation*, - *a concern*, - *a myth*, . . . *etc.*
A good way to express an"Issue" unambiguously is to dare to write all the Newspaper Headlines that, someday, will be written about those issues.

PAIs: Potentially Affected Interests include: individuals, groups, corporations, institutions, other agencies, and other officials, …outside and inside your organization

They are your PAIs

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
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Appendix C: Selection of LNAPL Management Options

Decision Criteria

EPA and many state agencies have identified decision criteria for selection of LNAPL management options (U.S. EPA, 2002; U.S. EPA, 1997a; ASTM, 1995; ASTM, 2000). These criteria are intended to reflect the values of the decision makers. The criteria that are used to decide which alternative has the highest net benefit include the following:

- protection of human health and the environment
- probability that goal will be met
- technology effectiveness and associated time frame
- appropriate technology for short-, intermediate-, or long-term remedial action
- stakeholder acceptability (tie to the goal agreed to by the stakeholder group)
- regulatory compliance (e.g., applicable or relevant and appropriate requirements [ARARs], state cleanup standards)
- implementability
- technical practicability
- reliability and maintainability
- long and short-term risks in implementing the technology
- cost-effectiveness of the technology
- technology maturity (proven performance or emerging technology)
- institutional issues and long-term controls as they affect technology implementation
- time constraints
- current and future land use.

Typically in a decision process a sub-set of these criteria will be used to evaluate the various available alternatives. It is likely that all of the decision criteria are not equally valued and therefore weighting factors would be applied to each of the criteria in order to reflect the priorities of the decision makers. The decision criteria must reflect the values of all of the stakeholders and therefore the decision criteria should be developed as part of the consensus process.

LNAPL Management Options Checklist

A checklist of questions to support the selection of LNAPL management options follows. In addition to the issues raised in Section 4, the following more detailed questions should be addressed during the technology-selection process.

Questions	**Answers**
How mobile is the LNAPL with respect to recovery or containment?	
What field evidence exists to support the stability of the LNAPL distribution or potential for migration of LNAPL?	
Have data been collected on LNAPL and site properties (e.g., viscosity, LNAPL saturation, relative permeability)?	
How likely is it that excavation and other construction activities will impact or be impacted by residual or mobile LNAPL?	
How accessible is the LNAPL (e.g., depth, surface activity)?	
How maintainable are institutional and engineering controls into the future? Is there a time limitation to the effectiveness of institutional or engineering controls (e.g., closure and transfer of the site in the future)?	
Should there be a contingency for addressing change in status of the site?	
Consider variability across the site. Are samples representative of the site as a whole?	
Is it helpful to understand the process of COC dissolution from the LNAPL, if meeting drinking water maximum contaminant levels (MCLs) is an issue or goal? If control of the down-gradient dissolved plume is a goal for the overall site remedial action, then a site-specific understanding of the release of specific COCs from the LNAPL is important.	
Are vapors an issue (with respect to LNAPL present or remaining) after endpoints are achieved?	
Does the management option reduce risks, under both current and potential future exposure scenarios?	
Can the LNAPL be treated in place to reduce/remove COCs and so reduce toxicity to an acceptable level?	
Can the LNAPL Management Plan meet regulatory/stakeholder requirements and concerns?	

Appendix D: Selected LNAPL Characterization and Remediation Technology Publications

General Information Sources

1. American Petroleum Institute (API) – http://www.api.org, LNAPL Resource Center link, catalog link, http://api-ep.api.org/filelibrary/ACFDA.pdf, and API Soil and Groundwater Research Bulletins link http://api.org/bulletins.

2. The Association for Environmental Health and Sciences (AEHS) TPH Working Group Series
http://www.aehs.com/publications/catalog/contents/tph.htm

3. ASTM International website – http://www.astm.org.

4. ASTM, 2000. Standard Guide for Risk-Based Corrective Action. Publication E2081-00. American Society for Testing and Materials, West Conshohocken, PA.

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10. Environment Canada Oil Properties Database
http://www.etcentre.org:8080/cgi-win/OilPropspill_e.exe?Path=\Website\river\

11. Environmental Security and Technology Certification Program Web Site – http://www.estcp.org and technical documents list,
http://www.estcp.org/documents/techdocs/index.cfm

12. Federal Remediation Technologies Roundtable (FRTR) Web Site – http://www.frtr.gov, FRTR Cost and Performance Report link at http://www.frtr.gov/costperf.htm, and LNAPL/DNAPL recovery optimization documents at http://www.frtr.gov/optimization/treatment/insitu.html#lnapl

13. *Groundwater Central*© Portal - Groundwater technology information portal for web-based information. Search engine is populated with a substantial number of documents related to LNAPL at http://www.groundwatercentral.info

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18. National Academy of Sciences. National Research Council: http://www.nas.edu

19. Remediation Technologies Development Forum (RTDF) NAPL Cleanup Alliance Web Site – http://www.rtdf.org/public/napl/

20. Texas Natural Resources Conservation Commission Publications Search Page http://www.tnrcc.state.tx.us/admin/topdoc/

21. United States Environmental Protection Agency (U.S. EPA) Technology Innovative Program Websites: http://www.epa.gov/swertio1/about.htm, http://www.clu-in.org, http://www.epareachit.org, and Technology Focus area, http://www.clu-in.org/techfocus/ for Air Sparging, Bioventing/Biosparging, Ground-Water Circulating Wells, Multi-Phase Extraction, Natural Attenuation, and Soil Vapor Extraction, especially Engineering/Regulatory Guidance categories for each topic.

22. U.S. EPA, Office of Underground Storage Tanks, Publications Page at http://www.epa.gov/swerust1/pubs/index.htm

Characterization, Monitoring, Fate and Transport Publications

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http://www.epa.gov/ada/csmos/models/hssmwin.html

14. Huntley, D., G.D. Beckett, 1997. The Life and Times of LNAPL Pools. An investigation into the lifespan and time-dependent magnitude of dissolved-phase impacts from free-phase hydrocarbon pools. AEHS West Coast Annual Convention, Oxnard, CA, March 1997.

15. Potter, T. and K.E. Simmons, 1998. Volume 2: Composition of Petroleum Mixtures. The Association for Environmental Health and Sciences (AEHS), ISBN 1-884-940-19-6, Amherst, MA.
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