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GROUNDWATER RISK MANAGEMENT HANDBOOK

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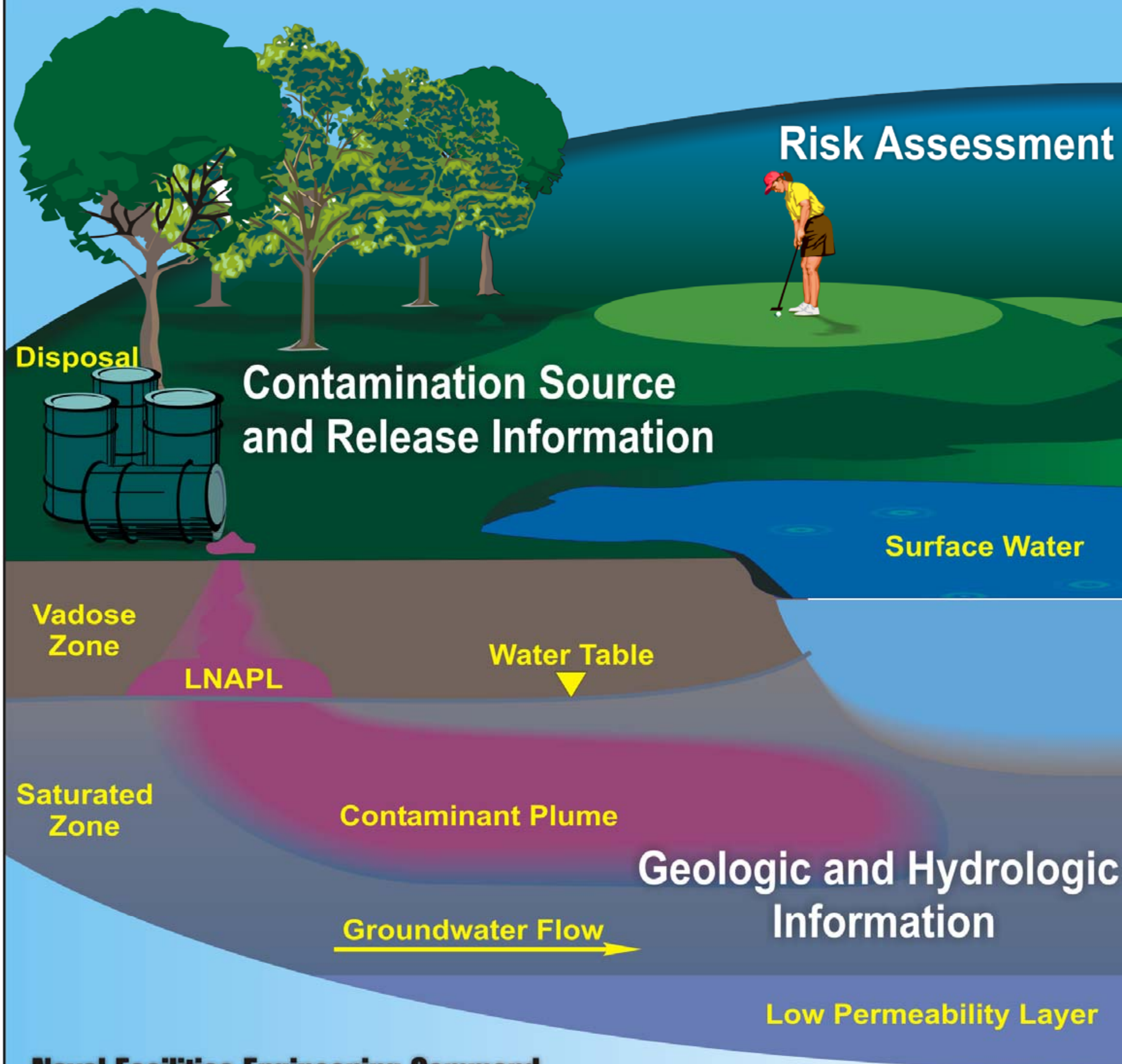
January 2008

Groundwater Risk Management Handbook



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GROUNDWATER RISK MANAGEMENT HANDBOOK

1.0 Introduction

Navy experience has shown that groundwater remediation poses a number of challenges, especially at sites with difficult conditions such as large, low concentration plumes, deep alluvial aquifers, fractured bedrock, and low permeability formations. In the past, pump-and-treat was often used to address groundwater impacts, but this approach has been largely ineffective in reaching final cleanup levels in a reasonable timeframe and often results in high operation and maintenance costs (Naval Facilities Engineering Command [NAVFAC], 2003). The US Environmental Protection Agency (U.S. EPA) has also recognized that restoration of groundwater to drinking water quality may not always be achievable due to technology limitations and, therefore, has developed a defined process for determining whether groundwater remediation is technically impracticable from an engineering perspective.

For this reason, Navy Remedial Project Managers (RPMs) should consider the use of risk management strategies to guide the decision-making process at their groundwater sites. Risk management strategies are based on an evaluation of the contaminated groundwater plume, exposure pathways, and impacts to current and potential future human and ecological receptors. Risk management can be used to assist in determining whether or not a site requires remedial action, or if it is technically feasible to achieve cleanup goals at a site. It is important to consider risk management options first because of the difficulty in addressing challenging groundwater sites with existing and innovative technologies.

1.1 Purpose

This document serves as a companion to the *Guidance for Optimizing Remedy Evaluation, Selection, and Design* (NAVFAC, 2010) and provides an overview of groundwater risk management strategies that can be used to support the six optimization concepts addressed in the guidance document (see Table 1-1). Key optimization concepts, including conceptual site models (CSM), remedial action objectives, target treatment zones, treatment trains, performance objectives, and optimization and exit strategies are briefly defined in Table 1-1 along with various plume management strategies that can be used to support effective and sustainable groundwater restoration at Navy sites. While the focus of this handbook is risk management options for challenging groundwater plumes, the underlying concepts can be applied to any response action. Plume management strategies described in this guidance are targeted on optimization concepts prior to remedy implementation as applied to the feasibility study (FS), record of decision (ROD), and remedial design (RD); however, the implementation of plume management strategies could be applied during later stages of the cleanup process. This document also complements information contained in the Navy's Dense Nonaqueous Phase Liquid (DNAPL) Management Overview document (NAVFAC, 2007), which discusses risk management options for source zones. Because DNAPL sites can be challenging, this document focuses heavily on the limitations of characterizing and removing DNAPL, and how to make realistic management decisions in the midst of these uncertainties.

1.2 Report Organization

The remaining portions of this document are divided into the following sections:

- Section 2.0 Site Evaluation: addresses challenging site conditions and the importance of developing a CSM for optimal strategies for groundwater plume management;
- Section 3.0 Risk Management: discusses the processes and tools available for evaluating and selecting among alternative actions to reduce risks;
- Section 4.0 Remediation Strategies: If a remedial action is required and feasible, it is often advantageous to use a combination of active and passive innovative technologies to reduce the timeframe and to improve the cost-effectiveness of groundwater remediation;
- Section 5.0 Challenges Associated with Groundwater Risk Management Approach: Describes primary challenges that may arise during implementation of the risk management approach.
- Section 6.0 Case Studies: Provides examples of two sites where risk management approaches were employed to develop optimal plume management strategies.

Table 1-1. Optimization and Risk Management Strategies for Groundwater Plumes

<table>
<tr><th>NAVFAC Optimization Concepts for Selection and Evaluation[a]</th><th>Groundwater Risk Management Concepts Included in this Handbook</th></tr>
<tr><td>Conceptual Site Model
Depicts the working hypothesis of the site by defining the relationship between the source area(s), transport mechanisms, and all of the potential receptors and routes of exposure.</td><td>1. Certain challenging site and contaminant characteristics may limit the effectiveness of subsurface remediation

2. Potential risk to the receptors is a driving factor in determining treatment and site management strategies for groundwater plumes</td></tr>
<tr><td>Remedial Action Objectives
Site-specific cleanup goals that are formed based on the COPCs, the impacted media, fate and transport of COPCs, the exposure routes, and the potential receptors identified in the CSM.</td><td rowspan="6">1. The remedial strategy should include a review of current State regulations for evolving risk management provisions.

2. Evaluate and select alternative actions to reduce risk to current and future receptors:
➢ Land Use Controls
➢ Source Controls
➢ Points of Compliance
➢ Alternate Concentrations Limits
➢ Mixing Zone Analysis
➢ TI Waivers
➢ ARAR Waivers

3. Apply several strategies to remediate and manage plumes:
➢ Partial Source Zone Treatment
➢ Passive Plume Treatment/Control Technologies
➢ Monitored Natural Attenuation</td></tr>
<tr><td>Target Treatment Zones
The volume or area at which the remedial action is determined to best apply.</td></tr>
<tr><td>“Treatment Train” Remedial Alternatives
The treatment train concept emphasizes that multiple remedial technologies often are needed to achieve cost-effective remediation at a given site.</td></tr>
<tr><td>Performance Objectives
Criteria that measure the operational efficiency and suitability of a particular remedial technology.</td></tr>
<tr><td>Optimization and Exit Strategy
Means of determining when it is time to stop, modify, or change a particular technology based on the achievement of previously established performance objectives.</td></tr>
</table>

[a] NAVFAC, 2004.

2.0 Site Evaluation

2.1 Challenging Site Conditions

The challenges and complexities associated with groundwater plumes are not limited to large, low concentration plumes; they also include plumes in deep alluvial aquifers, fractured bedrock, and low permeability formations. Certain site and contaminant characteristics may limit the effectiveness of subsurface remediation as shown in Figure 2-1. Factors that inhibit groundwater restoration are grouped under the following categories (U.S. EPA, 1993):

Hydrogeological Factors. Complex sedimentary deposits, aquifers of very low permeability, certain types of fractured bedrock, and other conditions that make extraction or in situ treatment difficult.

Contaminant Factors. Contaminant's potential to become sorbed or lodged within the soil or rock of the aquifer, dense nonaqueous phase liquids (DNAPLs) ability to sink and penetrate deeper portions of aquifers.

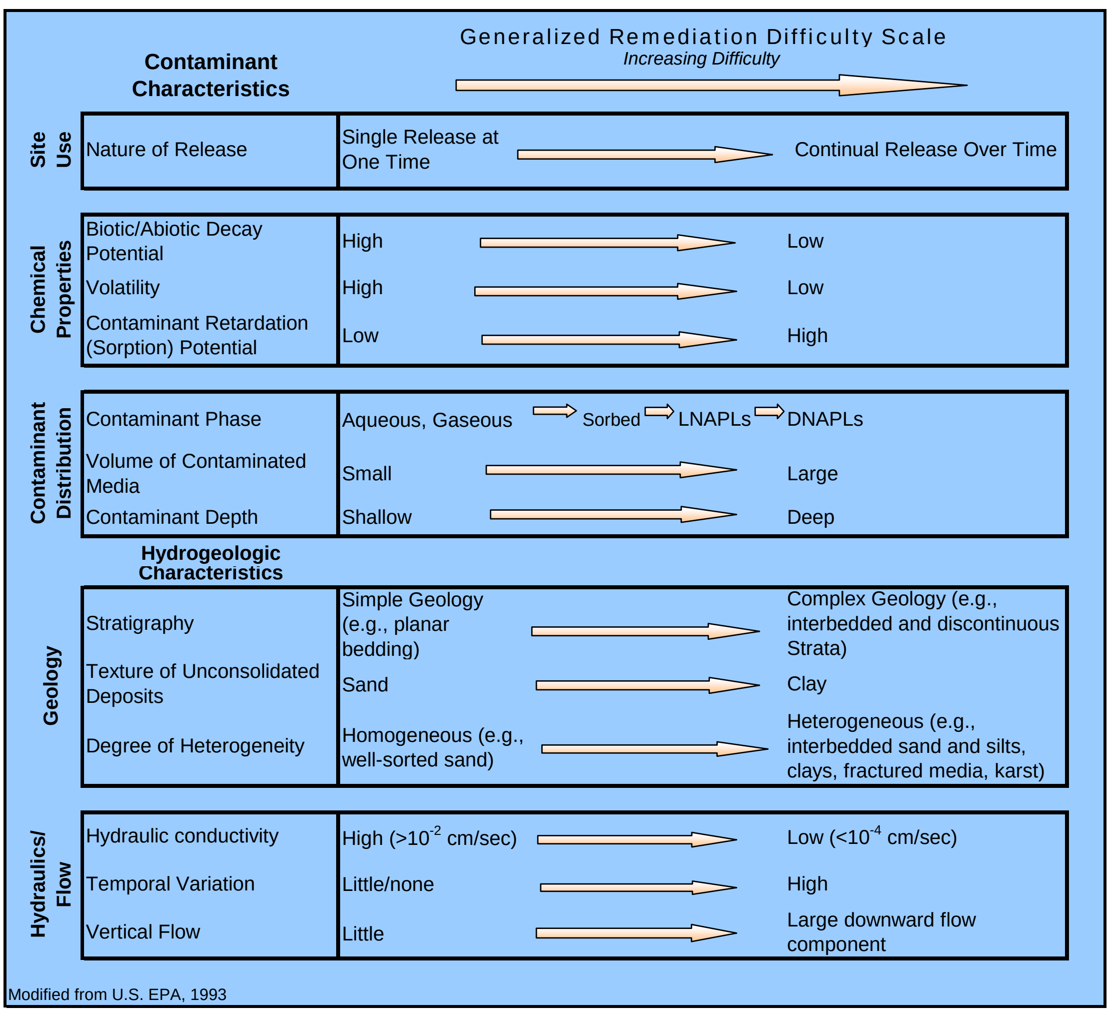


Figure 2-1. Examples of Factors Affecting Groundwater Restoration

2.2 Conceptual Site Model

A critical component in identifying the optimal strategy for management of a groundwater plume is defining the CSM. All CSMs should include the following components:

- Contaminant source and release information
- Geologic and hydrogeologic information
- Contaminant distribution, transport, and fate parameters
- Land use information
- Potential receptors and exposure pathways

The CSM depicts the working hypothesis of the site by defining the relationship between the source area(s), transport mechanisms, and all of the potential receptors and routes of exposure. It facilitates a consistent and comprehensive evaluation of risks by creating a framework for identifying the paths by which humans and the environment may be impacted by potential exposures to compounds in the environment. The CSM should be updated and further developed as additional data are collected.

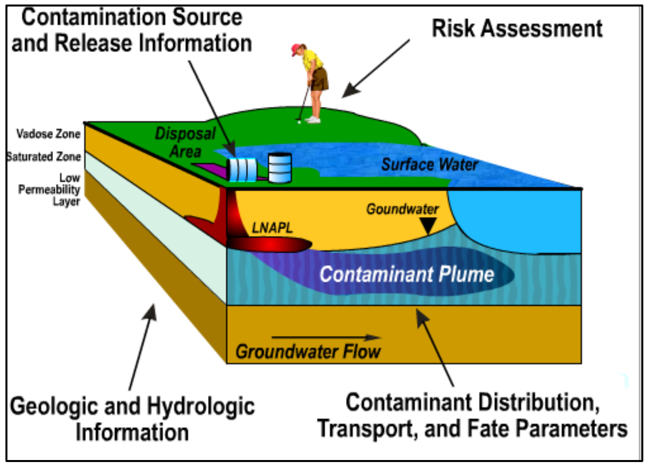


Figure 2-2. Conceptual Site Model Components

The CSM should be described in text and portrayed graphically or in tabular format to provide a clear understanding of site conditions (see Figure 2-2). Identification of current and reasonable potential future land and groundwater use is important for selecting appropriate exposure pathways and scenarios to depict on the CSM.

There must be a complete exposure pathway from the source of chemicals in the environment (i.e., from soil or groundwater) to receptors for chemical intake to occur. Common exposure routes to consider for groundwater sites include ingestion and dermal contact with groundwater, vapor intrusion, and impact to surface water for exposures to ecological and human receptors. A complete exposure pathway can be the result of either direct contact with the environmental medium containing the chemical (e.g., ingestion of drinking water) or indirect contact as a result of cross-media migration (e.g., vapor intrusion).

In order to determine if a complete exposure pathway exists for contaminants in groundwater, it first must be determined if the receptor can come into contact with contaminants in groundwater. Therefore, use of groundwater within and around the site needs to be examined. Some factors to consider when assessing groundwater use (pathway completeness) at the site include:

- Presence of domestic, public, or industrial wells
- Productivity and yield of the aquifer
- Presence and nature of impermeable zones

- Natural or background groundwater quality (e.g., salinity, total dissolved solids [TDS])
- Contaminant source characteristics
- Nature and extent (horizontal and vertical) of groundwater contamination
- Future plans for groundwater use in the area, including local water resource planning, zoning ordinances, land-use planning, and institutional controls that would regulate groundwater uses
- State/federal groundwater classifications.

An exposure pathway is considered incomplete when:

- Concentrations are below detection limits
- Concentrations are below regulatory criteria (e.g., maximum contaminant level [MCL]) or risk-based levels for the specific exposure pathway
- There is not an identified point of exposure in the environmental medium
- Site-specific data demonstrate that there is no transport mechanism in the identified media to move the chemical from the source area to a point of exposure
- Use restrictions enforceable by local government or regulatory agencies exist that will eliminate a point of exposure (e.g., drinking water supplied by public water system and groundwater beneath the site is restricted for potable purposes)
- Land use restrictions enforceable by local government or regulatory agencies exist that will eliminate a point of exposure (e.g., local zoning ordinances).

Understanding contaminant properties and geologic/hydrogeologic conditions is important for determining whether human or environmental receptors could potentially be exposed to the chemical of concern, and ultimately aid in identifying appropriate treatment technologies or other risk management alternatives to render the exposure incomplete. Potential risk to the receptors is a driving factor in determining treatment and site management strategies for groundwater plumes.

3.0 Risk Management

Risk management is the process of evaluating and selecting among alternative actions to reduce risk to current and future receptors. It is driven by an evaluation of the contaminated media, exposure pathways, and impact to current and future receptors. Important factors are evaluated such as land use, groundwater use, and groundwater point of compliance (POC) assumptions. It also involves an evaluation of cleanup goals for a site, which may be based on regulatory criteria (e.g., MCLs, background values, or site-specific, risk-based criteria). Risk management will also help determine the remedial strategy for a given site such as deciding between source containment versus treatment/removal. The availability of options (such as allowing contamination to remain in place at concentrations exceeding risk-based criteria and using institutional controls to prevent exposure) will depend on applicable State and local laws and regulations.

3.1 Federal and State Risk-Based Approaches

Response actions for contaminant releases to groundwater are typically guided by the processes defined under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or the Resource Conservation and Recovery Act (RCRA). Depending on the environmental law (e.g., CERCLA or RCRA), the U.S. EPA expects groundwater to be returned to its beneficial uses wherever practicable and requires that remedial actions attain cleanup levels that comply with Federal and more stringent state standards, which are legally applicable or relevant and appropriate requirements (ARARs) or reflect available or site-specific, risk-based cleanup standards.

Therefore, the development of the remedial strategy should include a review of current State regulations for evolving risk management provisions. Several states, including Florida, Texas, and Pennsylvania, have adopted tiered "Risk Management Options" (e.g., Florida's "Global Risk-Based Corrective Action [RBCA]"), which recognize the technical impracticability and high cost of continuing remediation of groundwater plumes that may pose little risk. These approaches can require a significant amount of characterization and analysis (e.g., groundwater fate and transport modeling, mixing zone analysis) to meet the criteria and demonstrate no unacceptable risk, but in some cases the remedy can be limited to land use controls (LUCs) with limited long-term monitoring, as discussed in the case study in Section 6.0. However, several states have an anti-degradation policy, which classifies all groundwater as high priority and/or as a potential drinking water source, regardless of actual or likely future use. This may limit the use of a risk-based approach for groundwater remediation in some states. Even in these cases, it may be possible and appropriate to develop a containment remedy that relies on monitored natural attenuation (MNA) or passive remediation technologies that focus active remediation on the source area to achieve the cleanup goals even if this requires a prolonged period of monitoring.

Note that state-sponsored, risk-based approaches may differ slightly among its programs (e.g., CERCLA, RCRA, leaking underground storage tank [UST], and voluntary action programs). The availability of options such as allowing contamination to remain in place at concentrations exceeding risk-based criteria and using institutional controls to prevent exposure will depend on applicable State and local laws and regulations for that particular environmental program. The Interstate Technology and Regulatory Council (ITRC) also completed a survey of states for RBCA programs; this survey is available at http://www.itrcweb.org/Documents/RISK-1.pdf. RPMs should refer to the State-specific program under which their site is regulated for more information.

3.2 Risk Management Strategies

It is not always technically feasible to achieve the final cleanup level at a site (e.g., presence of DNAPL in fractured bedrock, large waste disposal unit present on site), and large plumes may persist in groundwater. In this instance, there are several risk management strategies that should be considered and potentially implemented to manage risk associated with a release site, including exposure control, source control (e.g., treatment and/or migration control), and other plume management strategies. These strategies are discussed in more detail in the following subsections.

3.2.1 Exposure Control. When managing risk associated with exposure to residual groundwater contamination, consideration should be given to groundwater usage scenarios and land use provisions that may be implemented to minimize the potential for exposure.

Evaluating Groundwater Use. Current and future planned use of the groundwater beneath the site and adjacent properties must be considered and understood when evaluating exposure scenarios. Over time, land use may change, thus potentially changing exposure risks. If the groundwater usage scenarios are thoroughly understood, risk can be evaluated and measures associated with the remedy, such as LUCs, can be set in place to eliminate or reduce risk. Several states, such as Rhode Island, Texas, and Tennessee, have implemented a system that classifies/designates all groundwater-bearing units based on current and potential use, water quality, and/or vulnerability. Under this system, groundwater quality standards are established for each class that commonly indicate whether the groundwater is potable, non-potable without treatment, or non-potable regardless of treatment. It is important to consider the groundwater resource classification when designing a plume management strategy because it could significantly affect the components of the remedial action (e.g., groundwater may not be potable). The groundwater resource classification can be used to evaluate the quality of groundwater at a given location and assist in determining whether current or potential future exposure risks are present (refer to Section 2.2).

Guidelines for Ground-Water Classification Under the EPA Groundwater Protection Strategy (U.S. EPA, 1988) identifies three classes of groundwater:

- Class I **–** Groundwater body is an irreplaceable source of drinking water or is ecologically vital.
- Class II **–** Groundwater body is a current or potential source of drinking water or a water body that has other beneficial uses.
- Class III **–** Groundwater body is not a potential source of drinking water and is of limited beneficial use.

Classification of groundwater at Installation Restoration (IR) sites is based on a combination of criteria established by the Department of Defense (DoD) (refer to *Unified Facilities Criteria [UFC] 3-230-19N: Design: Water Supply Systems*. [June 2005]), U.S. EPA (1988), states, and an evaluation of site-specific characteristics as described in Section 2.2. Groundwater classification should be completed as a partnership between the Navy, U.S. EPA, and state agencies to ensure that the potentially different regulatory systems for groundwater classification are integrated and appropriately applied to federal lands, considering water use and development factors unique to federal facilities.

LUCs. LUCs are restrictions and administrative tools used to protect human health and the environment from potential exposure to residual contamination. LUCs are appropriate when a site cannot support unrestricted use and unlimited exposure, and are designed to limit land use and on-site activity that might interfere with the containment of residual contamination during or after completion of a response action. When considering LUCs as part of the remedial strategy, consideration is given for the existence and purpose of the LUC, where they will be necessary, and the entities responsible for implementing, monitoring, reporting on, anticipated future land use, and enforcing the LUCs. There are two categories of LUCs: engineering controls (ECs), which consist of engineered or physical controls, and institutional controls (ICs), which consist of administrative and/or legal mechanisms.

ECs consist of engineering measures designed to minimize the potential for human exposure to contamination by limiting direct contact with contaminated areas, reducing contamination levels, or controlling migration of contaminants through environmental media. ECs can be remedies designed to contain and/or reduce contamination, and/or physical barriers intended to limit access to property. ECs may include fences, signs, guards, landfill caps, provision of potable water, slurry walls, permeable reactive barriers, monitoring or extraction wells, sheet pile, trenches, covers, caps, and dikes.

ICs are non-engineered instruments such as administrative and/or legal controls that are designed to minimize the potential for human exposure to contamination by limiting land or resource use and/or by providing information to help modify or guide human behavior at the site. They are designed to maintain the viability and effectiveness of the selected remedy and any ECs. ICs are imposed to ensure that the ECs stay in place, or where there are no ECs, to ensure a restriction on land use. There are four main categories of ICs: governmental controls, proprietary controls, enforcement and permit tools with IC components, and informational devices. Each category of IC serves in different ways to define and limit the legal use of land in order to enforce restrictions developed by the land owner or responsible party. ICs are often most effective when more than one is in place and if they are layered or implemented in series, thus enhancing the protectiveness of the remedy. A summary of each type of IC is presented in Table 3-1. ICs can be implemented through a number of mechanisms to restrict future groundwater use and exposure, as follows:

- A Memorandum of Understanding (MOU) between the facility and other property owners, allowing the Navy to conduct remedial planning and implement and monitor remedial actions.
- A Memorandum of Agreement (MOA) containing an Environmental Restriction Covenant and Agreement (ERCA) between the facility and regulatory agency, containing pertinent restrictions and deed requirements making such restrictions transportable to and enforceable against all future land owners during the remedy.

Further detail on implementation of LUCs for the NAVFAC Environmental Restoration Program is provided in *DON/U.S. EPA Principles and Procedures for Specifying, Monitoring and Enforcement of Land Use Controls and Other Post-ROD Actions* (Department of the Navy [DON], 2003). Relevant policies related to LUCs include: 1) Policy Memorandum 99-02, Land Use Controls, Interim Final (DON, 1999) and 2) Policy and Land Use Controls Associated with Environmental Restoration Activities, Office of Under Secretary of Defense, (DoD, 2001). For non-Base Realignment and Closure (BRAC) real estate actions, the DON Environmental Policy Memorandum 06-06: *Streamlined Environmental Procedures Applicable to Non-BRAC Real Estate Actions* (September, 2006) should be consulted.

Table 3-1. Summary of Institutional Controls (U.S. EPA, 2000

Type of IC	*Purpose*	*Example*	*Enforcement*
Governmental Control	***Use government to impose land use restrictions on citizens.***	***Zoning/ordinances Building codes/permits Drilling permit requirements State or local groundwater use regulations Property condemnation***	***Commanding Officer (active Base) or State/Local Governments (closed Base)***
Proprietary Control	***Controls based on private property law to limit land use.***	***Easement Restrictive covenant Equitable servitude Reversionary interest State use restrictions Conservation easements***	***State Court of Law***
Enforcement and Permits Tools with IC Components	***Federal enforcement tools in order to prohibit certain parties to certain activities.***	***Administrative Orders Consent Decrees Permits***	***U.S. EPA under CERCLA and RCRA or the State***
Informational Devices	***Tools used to provide public knowledge of information with regards to contamination and remediation.***	***Deed notices State registries LUC tracking systems Advisories***	***Not legally enforceable***

3.2.2 Source Control When managing risk associated with exposure to residual groundwater contamination, it is imperative to review the CSM and understand the role historical or existing sources may have in contributing to existing groundwater contamination. Source control is a key element to consider because the source acts as a reservoir for continued contaminant migration. If sources are identified, risk can be reduced by ensuring the source is either contained/treated or viewed to be stable and not contributing to the existing plume. Partial source zone treatment should be evaluated for the potential to reduce both the timeframe and cost of downgradient plume treatment. It is sometimes a cost-effective approach to first accomplish partial source zone treatment with an active mass removal/destruction technology and to subsequently use MNA as a polishing step. The benefits of partial source zone treatment include reduced contaminant mass flux, reduced time of remediation, and more favorable conditions for MNA. Remediation strategies for partial source zone treatment and dissolved plume treatment/migration control are discussed in more detail in Section 4.0.

3.2.3 Plume Management Strategies. There are several strategies that may be applied for managing risk associated with groundwater plumes, including establishing points of compliance (POCs), alternate concentration limits (ACLs), performing mixing zone analyses, technical impracticability (TI) waivers, and ARAR waivers. These strategies are discussed in detail in the following subsections.

POCs. If the groundwater plume is shown to be stable or decreasing, it may not be feasible or desirable to contain or eliminate the source. Methods to evaluate plume stability include trend analysis/statistics to determine whether contaminant concentrations are found to be stable over a long period of time and analytical flow and contaminant transport models that simulate natural attenuation mechanisms. The trend analysis/statistics can be used to statistically show that there is not a significant difference between concentrations of target analytes over time or that there is a statistically significant decreasing trend.

The analytical flow and contaminant transport models can be a useful tool for evaluating plume stability and the extent to which a plume will expand before naturally attenuating to levels below risk based criteria. BIOSCREEN and BIOCHLOR are two examples of analytical groundwater flow and contaminant transport models that can be used as screening tools to simulate remediation through natural attenuation. BIOSCREEN simulates biodegradation of dissolved hydrocarbons by both aerobic and anaerobic reactions, whereas BIOCHLOR simulates biodegradation of dissolved chlorinated solvents via reductive dechlorination following a sequential first-order decay process. Simulations can be used as screening tools to estimate downgradient chemical concentrations and migration rates. Natural Attenuation Software (NAS) is an additional MNA screening tool that can be used to estimate the time required to achieve plume stabilization.

Plume Stability

Methods to evaluate plume stability:

- *Performance Monitoring of MNA Remedies for VOCs in Ground Water* (U.S. EPA, 2004).
- *Enhanced Attenuation: Chlorinated Organics* (ITRC, 2008).

Statistical applications at monitoring sites:

- *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Interim Final Guidance* (USEPA, 1989a; USEPA, 1992b).
- *American Society for Testing and Materials (ASTM) standard D6312-98* (2005).
- *Methods for Evaluating the Attainment of Clean-up Standards, Volume 2: Ground Water* (USEPA, 1992c).

Contaminant Transport Models:

- BIOCHLOR
  http://www.epa.gov/ada/csmos/models/biochlor.html
- BIOSCREEN
  http://www.epa.gov/ada/csmos/models/bioscrn.html
- NAS
  http://www.nas.cee.vt.edu/index.php

Plume stability is commonly verified by establishing POCs. POCs are the points at which the remedial action objectives are applied, and at which groundwater monitoring is conducted to demonstrate compliance. CERCLA regulations discuss two scenarios: 1) cleanup goals are attained throughout the contaminated plume, or 2) at the edge of the waste management area (i.e., the POC) when waste is left in place. Different POC options typically depend on the remedial action objectives, and may vary depending on the timeframe associated with the objective (e.g., short-term, intermediate, or long-term goals). Accordingly, POCs can be designated at mutually agreed upon locations that are consistent with the CSM and linked with in-place plume management strategies (i.e., monitored natural attenuation). RPMs should evaluate whether or not a POC strategy is applicable to their site.

Evaluation of Plume Stability at Former Department of Defense Housing Facility, California

Site characterization and remediation activities at the Former Underground Storage Tank (UST) Site 957/970, located at the Department of Defense Housing Facility (DoDHF) Novato in Novato, California, began in the early 1990s to address gasoline constituents in soil and groundwater originating from leaking USTs. Initial cleanup activities included tank removal and backfill, installation and sampling of soil borings, groundwater monitoring wells, soil-gas monitoring probes, and sampling at surface water locations within Pacheco Creek. In July of 2000, the San Francisco Regional Water Quality Control Board (Water Board) passed Board Order No. 00-064 requiring the Navy to perform additional activities at the site. Task 6 of the Order required the development and execution of a Corrective Action Plan (CAP) for groundwater, which led to the selection and implementation of biosparging with monitored natural attenuation (MNA) and institutional controls (ICs) to achieve the remedial action objectives (RAOs) at the site. The biosparging system was started in September 2002 and operated until March 2005, at which time a one-year shutdown test was performed before restarting the system in March 2006 on a pulsed operation schedule. One of the biosparging performance goal objectives is to establish a stable to shrinking plume on Navy property. Results of this performance goal evaluation to date indicate:

- Regression analyses consistent with those recommended in the U.S. EPA's *Monitored Natural Attenuation of MTBE as a Risk Management Option at Leaking Underground Storage Tank Sites* (U.S. EPA, 2005a) show that MTBE concentration trends are stable to decreasing in all monitoring wells on and immediately downgradient of Navy property (Figure A).

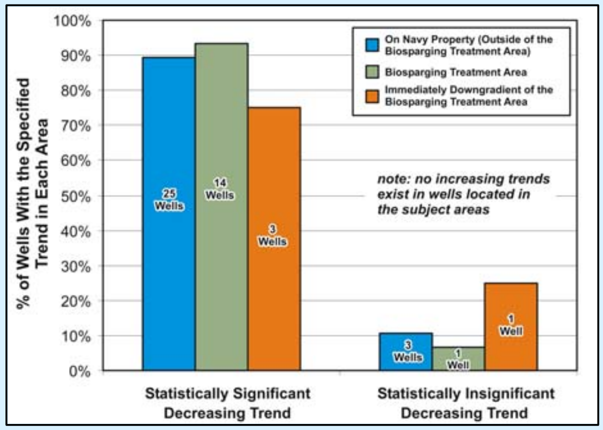


Figure A. Regression Analyses.

- The time series mass analyses depicted in Figure B show a significant decrease in MTBE mass on Navy property along with a stable to decreasing mass off Navy property during biosparging operations. This is important because it shows that the overall MTBE mass in groundwater is being reduced and that the reduction in MTBE mass on Navy property is not attributable to advective transport downgradient.

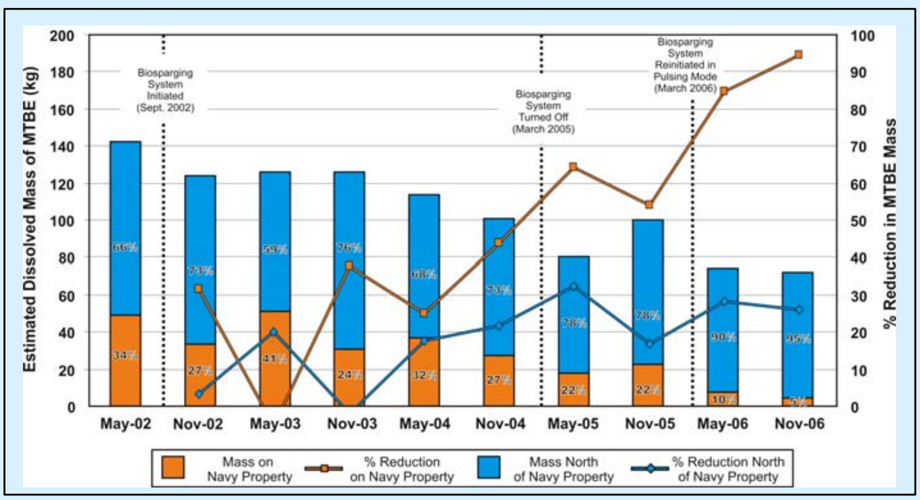


Figure B. Time Series Mass Analyses.

The Navy plans to discontinue operation of the biosparging system in the near future, at which time the one-year rebound monitoring program will begin to determine whether significant rebound occurs. In addition, the overall plume response on and off Navy property, including the leading edge, will be closely monitored to evaluate the extent to which MNA with ICs will allow the RAOs for the site to be achieved.

ACLs. ACLs can be proposed under CERCLA for contaminants in groundwater. ACLs must not presently pose a substantial or potential hazard to human health or the environment under site-specific circumstances required by the statute. ACLs may be established when the risk assessment process assumes a point of human exposure beyond the boundary of the facility. ACLs can be applied if: 1) there is a point of entry where groundwater discharges to surface water (e.g., near the mixing zone), 2) there is no statistically significant increase of constituents in the surface water, and 3) enforceable measures exist that will preclude human exposure (U.S. EPA, 2005b). ACLs are often developed using groundwater fate and transport models and mixing zone analyses for sites where the primary exposure pathway is discharge to surface water. Where ACLs are established as part of a remedy, the Record of Decision (ROD) should identify the applicable standards for which the ACLs have been substituted, and should document specifically how the site meets the specific conditions required by the statute. The ROD also should explain the process used to establish the ACLs and how the ACLs are protective of human health and the environment.

Groundwater Discharge to Surface Water. If the groundwater plume is expected to discharge to a surface water body, consideration must be given to the impact of the discharge on surface water quality (e.g., applicable surface water quality standards, ecological impacts). The boundary between adjacent groundwater and surface water bodies is referred to as the groundwater/surface water transition zone or interface. The transition zone plays a critical role in governing contaminant exchange and transformation between the two water bodies. It is important to understand the groundwater/surface water interactions in the transition zone to model contaminant fate and transport. The factors controlling contaminant transport to and within the transition zone should be outlined in the CSM. Factors to determine if groundwater contamination is reasonably expected to discharge to surface waters include: the proximity of the surface waters, the direction of groundwater movement, preferential pathways, source mass, and documented site-specific evidence of chemical-specific natural attenuation (i.e., dispersion, sorption, biodegradation).

Figure 3-1. Groundwater to Surface Water Discharge

Surface water concentrations in the transition zone are likely to be significantly lower than those observed in adjacent groundwater. An analysis of groundwater/surface water interaction is performed by collecting cross-media data (e.g., groundwater, surface water, sediment, and ecological data) in the form of tidal data, hydraulic gradients, chemical concentrations (including daughter products), indicator parameters, and physical parameters. The data are used to estimate the area of discharge and the contaminant mass flux (using Darcy's Law), and potentially establish ACLs for the site. Groundwater fate and transport modeling also may be used to simulate discharge to surface water, but should be used in conjunction with field measurements to ensure accurate predictions. NAVFAC and DoD have developed specialized equipment for measuring groundwater seepage and contaminant flux from groundwater into surface water bodies. The text box below describes the use of the Trident Probe and UltraSeep System at one Navy site to assess groundwater/surface water interactions.

One management option available for groundwater plumes discharging into surface waters is the use of mixing zone analysis. A mixing zone is described as a limited area or volume where the initial dilution of a discharge occurs (U.S. EPA, 1984). According to U.S. EPA (1992d), the mixing zone is defined as an “allocated impact zone” where numeric water quality criteria can be exceeded as long as acutely toxic conditions are prevented. Surface water quality standards typically apply at the boundary of the mixing zone and not within the mixing zone itself. In setting requirements for mixing zones, U.S. EPA (1984) requires that “the area or volume of an individual zone or group of zones be limited to an area or volume as small as practicable that will not interfere with the designated uses or with the established community of aquatic life in the segment for which the uses are designated,” and the shape be “a simple configuration that is easy to locate in the body of water and avoids impingement on biologically important areas.”

Many State surface water regulatory programs allow for mixing zones for National Pollutant Discharge Elimination System (NPDES)-permitted discharges into surface waters. Although this is commonly applied to point source discharges, groundwater discharge to surface water is a similar process that can be considered for application. The U.S. EPA rules for mixing zones recognize that the State has discretion on whether or not to adopt a mixing zone and to specify its dimensions. U.S. EPA maintains two water quality criteria for the allowable concentration of toxic substances: a criterion maximum concentration (CMC) to protect against acute or lethal effects, and a criterion continuous concentration (CCC) to protect against chronic effects (U.S. EPA, 1985). The less restrictive criterion, the CCC, must be met at the edge of the same regulatory mixing zone specified for discharges. In order to prevent lethal concentrations of toxics in the regulatory mixing zone, the restrictive CMC criterion must be met within a short distance from the discharge itself.

Site Investigation for Groundwater to Surface Water Discharge

A field demonstration of the Trident Probe and UltraSeep System was performed at Naval Support Activity (NSA) Panama City, Florida. The objective was to investigate chlorinated solvent fate and transport at the groundwater/surface water interface. The Trident Probe is a multi-sensor sampling device that screens for groundwater discharge into surface water based on differences observed in temperature and conductivity. The UltraSeep System is an integrated seepage meter and water sampling system for quantifying discharge rates and chemical loading from groundwater to surface water. The sampling results demonstrated that dichloroethene (DCE) concentrations in the discharge zones offshore from Area of Concern (AOC) 1 were below detection. This finding facilitated the determination that monitored natural attenuation was a feasible remedy for AOC 1, providing a potential cost avoidance of $1,250,000 over active remediation.

TI Waiver. A TI waiver is one of six types of ARAR waivers; others are discussed in the following sections. Experience in remedial action implementation has shown that restoration of contaminated groundwater to drinking water quality may not always be achievable due to limitations of available remediation technologies (U.S. EPA, 1989b; 1992a; NAVFAC, 2003). Many factors can inhibit groundwater restoration, including hydrogeologic factors, contaminant-related factors, and remediation system design inadequacies. Therefore, when evaluating remediation options for a complex groundwater plume, consideration should be given as to whether complete restoration is realistically attainable from an engineering perspective. If the effectiveness of the chosen remedial option will be limited, and complete restoration is not attainable, language may be added to the decision document (e.g., ROD) to make decision makers aware that an alternative remedial exit strategy may be necessary based on the information gathered during implementation of the remedy. An example where this type of language was added to the uncertainty and exit strategy can be found in the *Record of Decision for Former Naval Warfare Center – White Oak Site 49*.

A TI waiver may be invoked during a remedial action if restoration of groundwater to cleanup levels (e.g., ARARs) is technically impracticable from an engineering standpoint, based on the feasibility, reliability, and cost of the engineering methods required. TI waivers generally will be applicable only for ARARs used to establish cleanup performance standards or levels, such as chemical-specific MCLs or state groundwater quality criteria. TI decisions may be made either during development of the decision document or after the remedy has been implemented and monitored for a period of time. In some cases, front-end TI waivers are possible given an adequate CSM exists (i.e., sufficient site characterization and data analysis have been conducted). In other cases, it is found during remedial action operation and long-term monitoring that the implemented remedy is not effective in meeting the cleanup levels and in that case, a TI decision can be made after remedy implementation.

If the site shows reasonable potential that restoration of groundwater is technically impracticable, a TI waiver evaluation should be performed to assess the need for a TI waiver. Determinations of technical impracticability will be made by U.S. EPA based on site-specific characterization and remedial system performance (where applicable). The TI evaluation may be prepared by the owner/operator of the site or by U.S. EPA or the State as appropriate. TI evaluation criteria should include the following information (U.S. EPA, 1993):

1. *Specific ARARs or cleanup standards for which the TI waiver is sought*. This component should be limited to the specific contaminants for which attainment of the required cleanup levels is technically impracticable. In evaluating this information, U.S. EPA will consider the technical feasibility and potential advantages of attaining cleanup levels of only some of the contaminants present in groundwater.
2. *Spatial area over which the TI waiver will apply*. The proposed TI zone should be delineated spatially in area and in depth, and the zone should be fixed in space (i.e., not tied to an isoconcentration contour that is highly interpretive).
3. *CSM information*. Decisions regarding the technical practicability of groundwater restoration must be based on a thorough evaluation of site conditions, which are documented in the CSM (see Section 2.2). The CSM serves as the foundation for

evaluating restoration potential of the site and thus the technical impracticability as well.

4. *Restoration potential of the site*. This component should include data and analysis that support the assertion that attainment of cleanup levels is technically impracticable from an engineering perspective. This evaluation should include:
   - A demonstration that contamination sources have been identified and have been/will be removed and contained to the extent practicable.
   - An analysis of the performance of any ongoing or completed remedial actions.
   - Predictive analyses of the timeframe to attain required cleanup levels using available technologies.
   - A demonstration that no other remedial technologies (conventional or innovative) could reliably, logically, or feasibly attain the cleanup levels at the site within a reasonable timeframe.
5. *Cost estimates*. Estimates of the cost of a remedial alternative should be provided, including the present worth of construction, operation, and maintenance costs. Estimates also should be provided for the continued operation of the existing remedy or for any proposed alternative remedial strategies.
6. *Additional information*. Any additional information or analyses that U.S. EPA deems necessary for the TI evaluation, such as groundwater fate and transport modeling results or contaminant mass removal estimates.

The TI waiver must be incorporated into the site decision document (e.g., ROD) or incorporated into a modification or amendment of the original document. The TI evaluation will be reviewed and decisions regarding its acceptance will be made by the U.S. EPA or appropriate State agency. Under CERCLA, the TI waiver remains in effect as long as that strategy remains protective of human health and the environment, and a full assessment of the protectiveness of the remedy will be performed at least every five years. Under RCRA, conditions of the permit or order involving the TI decision may be revisited on a periodic basis to ensure protectiveness. The protectiveness of the TI waiver under CERCLA or RCRA must be ensured through a comprehensive monitoring program, with the data supplied to U.S. EPA to ensure adequate performance.

There are only a limited number of TI waivers approved for DoD sites. Most of the Navy TI waivers date back to the early 1990s and few recent Navy examples of TI waiver applications are available. This may be due to the difficulty and time involved in obtaining a TI waiver. In addition, a TI waiver still requires the development of an alternate remediation strategy (ARS) that defines what activities will be undertaken to protect human health and the environment at a given site such as monitoring, LUC implementation, and/or continued operation of a containment remedy. Examples are provided below for two TI waivers received at the Army’s Aberdeen Proving Ground (APG). Note that a TI waiver often requires intensive investigations of the nature and extent of the contamination, along with risks posed by the contaminants present. Extensive investigation of remedial technologies is also required to ensure that there are no practical solutions for cleanup of the contaminated groundwater. Numerous negotiations are usually required to obtain regulatory approval. Also, the public's perception of a TI waiver as a "do nothing" approach requires a long term commitment of public outreach education. More information on the Army's experience and guidance related to TI waivers can be found at: http://aec.army.mil/usaec/cleanup/techimprac.pdf

ARAR Waiver. CERCLA requires compliance with federal and state ARARs for on-site response actions. Under certain circumstances, an ARAR may be waived in favor of another protective remedy (U.S. EPA, 1989c; 1998). The following six types of ARAR waivers may be invoked during a remedial action.

1. *Interim measures*. An ARAR may be temporarily waived to implement a short-term alternative, or interim measure, provided that the final remedy will, within a reasonable time, attain all ARARs without causing additional releases, complicating the response process, presenting an immediate threat to public health or the environment, or interfering with the final remedy.

Examples of TI Waivers Obtained at Aberdeen Proving Ground (APG)

APG Operable Unit 8. As part of the TI waiver process, it was determined to be technically impracticable to fully recover DNAPL and attain the cleanup levels for dissolved phase constituents at this site. As part of the TI evaluation, an ARS was developed to reduce risk to human health and the environment. This ARS included establishing ICs, continuation of phytoremediation, and monitoring of biodegradation processes, to eliminate exposure to the groundwater and to control off-site contaminant migration from the confined aquifer. The TI waiver was granted because it was not anticipated that DNAPL recovery would be complete and/or result in achieving cleanup levels within the groundwater plume. Click on the link for more information: http://www.epa.gov/superfund/sites/rods/fulltext/r0301025.pdf.

APG Operable Unit 2. A TI waiver was granted because of the technical impracticability associated with remediating and/or containing the DNAPL contamination at this site. The ARS involved the use of institutional controls and a long term monitoring program. Click on the link for more information: http://www.epa.gov/superfund/sites/rods/fulltext/r0397090.pdf

The Army indicated that the TI waiver process for these sites involved extensive investigation of the nature and extent, as well as investigation of numerous technologies, to ensure that there were no practical remedial alternatives. At APG, they believe that they were able to successfully execute TI waivers with US EPA approval primarily due to their commitment to conduct the detailed pilot studies and the research necessary to identify and implement an optimal solution for a each site.

2. *Greater risk to human health and environment*. An ARAR may be waived if compliance with the requirement will result in greater risk to human health and the environment than non-compliance. Specific factors that may be considered in invoking the waiver for preventing greater risks include the magnitude, duration, and reversibility of adverse impacts associated with meeting the ARAR.
3. *Technical impracticability*. An ARAR may be waived if it is technically impracticable from an engineering standpoint, based on the feasibility, reliability, and cost of the engineering methods required (see TI Waiver).

4. *Equivalent standard of performance*. An ARAR may be waived if an alternative design or method of operation can produce equivalent or superior results, in terms of the degree of protection afforded, the level of performance achieved, long-term protectiveness, and the time required to achieve beneficial results. The waiver may be invoked when a substitute form of treatment for that which is specified or required in the ARAR achieves comparable reductions in either mobility or toxicity. The specific factors that can be considered in deciding whether to invoke this waiver include the time required to achieve beneficial results, the degree of protection, the level of performance, and the reliability of the alternative remedy.
5. *Inconsistent application of state standard*. A State ARAR may be waived if evidence exists that the requirement has not been applied to other sites or has been applied variably or inconsistently. This waiver is intended to prevent unjustified or unreasonable State restrictions from being imposed at CERCLA sites. A standard is presumed to have been consistently applied unless there is evidence to the contrary. Consistency of application may be determined by similarity of sites or response circumstances; proportion of non-compliance cases; reason for non-compliance; or intention to consistently apply future requirements as demonstrated by policy statements, legislative history, site remedial planning documents, or State responses to Federal-lead sites.
6. *Fund-balancing*. An ARAR may be waived if compliance would be costly relative to the degree of protection or risk reduction likely to be attained and the expenditure would jeopardize remedial actions at other sites. The lead agency should consider the fund-balancing waiver when the cost of attaining an ARAR is 20 percent or more of the annual remedial action budget or $100 million, whichever is greater.

When an ARAR waiver is chosen, the basis for waiving the requirement must be fully documented and explained in the ROD, in accordance with the criteria described above. If insufficient information exists to make a determination on whether an ARAR waiver is necessary, the lead agency may include a contingent ARAR waiver in the ROD, by specifying specific contaminant levels or circumstances that will trigger the waiver.

4.0 Remediation Strategies

If it is determined that treatment technologies are required and feasible, several strategies can be applied to remediate and manage groundwater plume sites. Often remediation efforts can be optimized by utilizing a treatment train approach that combines active and passive technologies and relies upon well-defined performance objectives and exit strategies. Source zone treatment alternatives can also be evaluated to determine if reductions in the overall timeframe and cost of plume cleanup can be achieved by targeting hot spots to remove a large amount of mass in a relatively short time period. These strategies can be used to develop appropriate remedial action objectives for a site and to optimize the overall remedial approach. Note that each remedy that is to undergo detailed evaluation should be developed in accordance with the *DON Policy for Optimizing Remedial and Removal Actions at all DON Environmental Restoration Program Navy Sites* (DON, 2012). This memorandum references several guidance documents including the Navy's *Guidance for Optimizing Remedy Evaluation, Selection and Design* (NAVFAC, 2010), which applies to the remedy development and evaluation phases of a project.

When comparing aggressive remedial technologies to passive technologies, the exposure risk and environmental impacts associated with technology implementation should be considered. For example, "active" or "aggressive" remediation technologies, such as pump-and-treat, can result in increased exposure risks, increased air pollution, and increased energy and materials consumption. In some cases, these more active remedies may increase exposure risk through ex situ extraction and handling of contaminants or combustion byproducts with little to no net benefit in terms of contamination reduction and/or accelerated remediation timeframes (Wilson et al., 2005). The authors' premise in Wilson et al. (2005) is that the net benefit must outweigh the negative effects. If intrusive methods are used to remediate a site, then the selected remedy needs to be effective and safe, and avoid the introduction of additional harmful contamination beyond existing conditions. The matrix provided in Table 4-1 can be used to compare natural attenuation in relation to impacts of active remediation. As explained in Wilson et al. (2005), the columns categorize the risk of the original contamination into "high and persisting" versus 'low and attenuating", and the rows characterize the environmental impacts as "low' or "high".

Table 4-1. Remediation Matrix (Wilson et al., 2005)

	Risks of original contamination are high and persisting	**Risks of original contamination are low and attenuating**
Environmental impacts of active remediation are low	Do active remediation	Consider relying on natural attenuation
Environmental impacts of active remediation are high	Consider means to reduce impacts of active remediation, including some reliance on natural attenuation	Rely on natural attenuation

Typically, No Further Action (NFA) or risk-based closure is the preferred approach for sites where the risks posed are low. If, however, remediation is required due to high site risks, remedial options should be evaluated from passive to active technologies (see Figure 4-1).

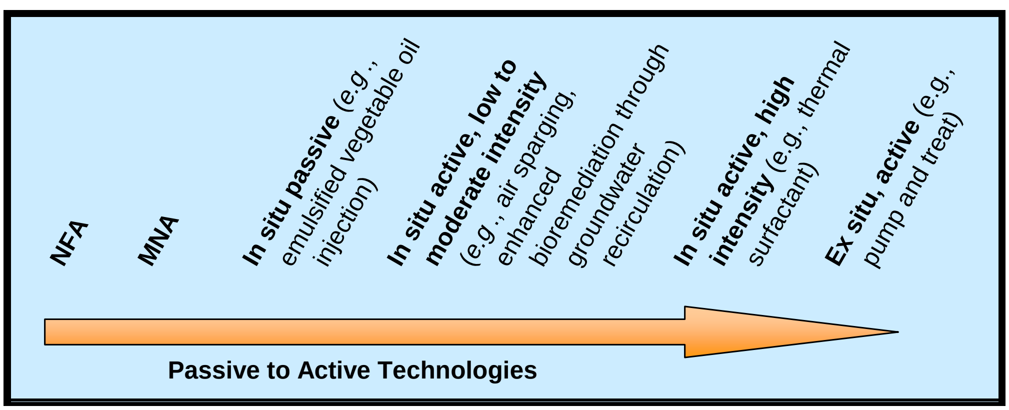


Figure 4-1. Remedial Technologies Ranging from Passive to Active

4.1 Target Treatment Zones

A target treatment zone is the volume, area or media for which the remedial action is determined to best apply. The target treatment zones are defined by the CSM and remedial action objectives, considering risk reduction, exposure routes, capabilities of existing remediation technologies, and the nature and extent of contamination.

Target treatment zones for a groundwater plume may include:

- Source zone
- Dissolved plume
- Localized areas with elevated concentrations within the plume (e.g., hot spot)
- Localized areas within plume where exposure is occurring (e.g., impacted drinking water supply well)
- Downgradient boundary of the dissolved plume
- Groundwater/surface water interface

Strategies that can be applied to remediate the various target treatment zones are summarized on Table 4-2.

Table 4-2. Example Remedial and Plume Management Strategies for Various Target Treatment Zones

Target Treatment Zone	*Treatment Technologies*	*Management Strategies*
Source Zone	Multi-Phase Extraction, In Situ Chemical Oxidation, In Situ Thermal Technologies, Nanoscale Zero Valent Iron, Physical Removal	Hydraulic Containment, Physical Containment, ICs, TI or ARAR Waiver, POC Strategy
Dissolved Plume	In Situ Air Sparging/Soil Vapor Extraction, Biosparging, Permeable Reactive Barriers, Enhanced Bioremediation, Phytoremediation, MNA	Hydraulic Containment, Physical Containment, ICs, ARAR Waiver
Localized areas where exposure is occurring within plume	Well head treatment for drinking water. Sub-slab vapor extraction for existing buildings with vapor intrusion concerns. Construction of new buildings with protective sub-slab vapor barriers.	ICs restricting groundwater and/or site use.
Downgradient boundary of the dissolved plume	Permeable Reactive Barriers, Biobarriers, Phytoremediation	Hydraulic containment, physical containment
Groundwater/surface water interface	If mixing zone analysis is not feasible, then treatment of groundwater would have to be addressed using the applicable technology listed above based on the appropriate treatment zone.	Mixing zone analysis and comparison to existing numeric water quality criteria or development of site-specific numeric water quality criteria

Partial Source Zone Treatment. Treatment of source zones can reduce contaminant mass contributing to the downgradient dissolved phase plume. Partial source zone treatment should be evaluated for the potential to reduce both the timeframe and cost of downgradient plume treatment. Software models can be used to perform an analysis of the level of source zone treatment required to reduce impacts to the dissolved phase plume. For example, see the text box below that highlights the use of the Navy's Natural Attenuation Software for this purpose. The most effective source zone treatment is dependent on factors determined in the CSM, including site geology/hydrogeology, types of contaminants, source zone age, contaminant distribution, and contaminant properties. Source zone treatment is often difficult to implement effectively and source treatment versus the cost of long-term plume management should be evaluated during the FS stage. Factors to consider related to source control include:

- Source areas are sometimes difficult to locate/delineate
- Success of remedial technologies is often highly dependent on geologic conditions
- Manage expectations/set realistic performance objectives for source zone treatment
- Risk of treatment can include potential mobilization of source (i.e., DNAPL)
- Limitations of existing remediation technologies
- Effects of source zone treatment on groundwater geochemistry and microbiology

For more information on source zone treatment strategies, please refer to the *DNAPL Management Overview* document (NAVFAC, 2007).

Dissolved Plume Control and Treatment. The degree of treatment necessary for the dissolved-phase portion of a plume is determined based on the level of risk associated with a particular site. Treatment and/or containment will be necessary at high risk sites with affected drinking water aquifers and/or the potential for significant contaminant migration to surface water or indoor air. Treatment technologies such as permeable reactive barriers (PRBs), biobarriers, or enhanced bioremediation can be used in targeted upgradient portions of the dissolved-phase plume to achieve plume migration control and/or contaminant removal. A PRB is just one example of a passive alternative to pump-and-treat that can be configured to treat a wide range of contaminants in groundwater. PRBs can be used for plume migration control to cut off plumes before migrating off-property. These less active or passive technologies can be applied in an upgradient target treatment zone with relatively high dissolved-phase concentrations and/or installed in a barrier configuration to reduce the required footprint for the remedial action. These less active or passive technologies can be used until dissolved-phase concentrations are reduced to a level at which MNA is appropriate for the remainder of the downgradient plume.

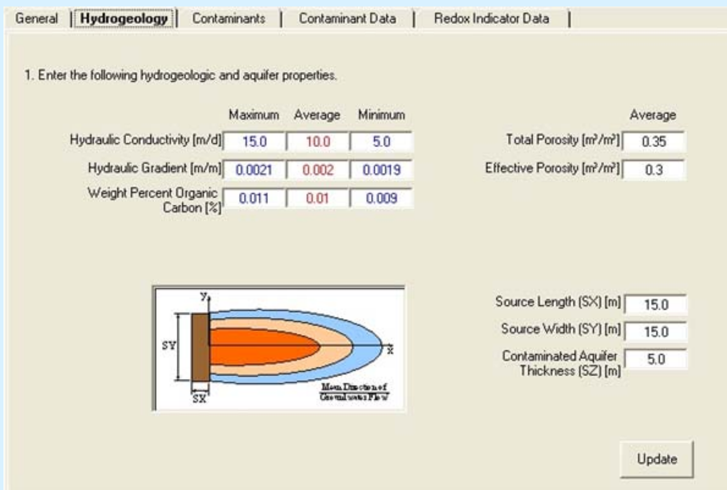
Is MNA a viable remedy for the site?

- Are stable to decreasing concentration trends observed in the plume?
- Do the analytical results indicate that decreasing trends are statistically significant at a 95% confidence level?
- Does the estimated dissolved mass of contaminants on-site, off-site, and within the entire plume continue to remain stable to decreasing?
- Does the groundwater chemistry data support geochemical conditions that are suitable for biodegradation and that active biodegradation has occurred?

MNA is often an effective treatment approach for the dissolved phase plume when the plume is stable or shrinking, the cleanup goals can be achieved in a reasonable timeframe, degradation is the dominant process, and it is used in combination with or as a follow-up to source zone treatment where applicable. MNA relies on naturally-occurring processes, such as biodegradation, dispersion, dilution, sorption, volatilization, and/or chemical and biochemical stabilization, to reduce concentrations in groundwater. However, it is important to understand that it is usually impossible to separate the individual contributions of each mechanism (U.S. EPA, 2005a).

Monitored Natural Attenuation Software and Resources

NAVFAC Natural Attenuation Software. The Navy's Natural Attenuation Software can be used to assess the natural attenuation capacity of an aquifer and estimate the time of remediation depending on the amount of source reduction performed. The tool is meant to assist RPMs in decision-making on the extent of source zone treatment required in conjunction with MNA using site-specific remediation objectives. This is a useful tool for the evaluation and design of treatment trains to optimize the overall remedy. This model has been validated with data from several Navy sites including NAWC Lakehurst, New Jersey, NAB Little Creek, Virginia, NAS Pensacola, Florida, and Naval Undersea Warfare Center Keyport, Washington. This software can be downloaded at http://www.nas.cee.vt.edu.



Other Software Models. Other public domain groundwater software models that can be used for MNA evaluations and fate and transport evaluations are located at http://www.epa.gov/ada/csmos/. Consultants also typically have access to a suite of commercially available contaminant fate and transport models that can be used for this purpose.

U.S. EPA Underground Storage Tank Program Web Site has a compilation of MNA documents at http://www.epa.gov/OUST/cat/mna.htm.

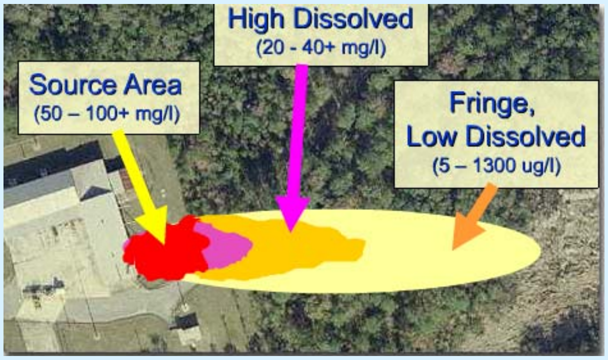
Treatment Trains, Performance Objectives, and Exit Strategies. Treatment trains can include the use of multiple remedial technologies over time in the same target treatment zone or the concurrent use of multiple remedial technologies over various locations of a large plume. For example, different target treatment zones may be designated within a plume, whereby in situ chemical oxidation (ISCO) is applied for the DNAPL source zone, use of a permeable reactive barrier (PRB) is used at the edge of the plume with high dissolved concentrations, and MNA is applied at the downgradient portion of the plume with lower concentrations.

Performance objectives should be developed and clearly defined for each stage if a treatment train approach is implemented. This will allow for transition from more active to more passive treatment technologies over the life of the project. Performance objectives are distinct from remedial action objectives and final cleanup goals because they take into account typical engineering performance and the limitations of the individual technology. Operation of each technology in the treatment train should be optimized by continually evaluating monitoring data and comparing to the performance objectives for that technology and continuously updating the CSM based on new data and the response of the system to treatment. Example performance objectives are provided in the text box below.

Example Treatment Train and Performance Objectives for a Groundwater Plume

An example for a plume-wide treatment train for a site might include ISCO for the DNAPL source zone, use of a PRB at the edge of the plume with high dissolved concentrations, and MNA for the downgradient portion of the plume with lower concentrations. Performance objectives could be proposed as follows for each technology in the treatment train:

- **Source Area with ISCO**: Achieve 60% reduction in source zone concentrations to limit mass flux and/or until oxidant injection is no longer cost-effective.
- **Edge of High-Concentration Dissolved Plume with PRB**: Minimize downgradient contaminant migration. Maintain PRB until influent contaminants of concern (COCs) achieve a level sustainable by MNA and/or is no longer cost-effective.
- **Low-Concentration Dissolved Plume with MNA**: Reduce dissolved phase groundwater concentrations to protect downgradient receptors.



The series of performance objectives defined for each stage of the project then form the basis of the overall exit strategy for the site. The exit strategy will determine when it is time to stop, modify, or change a particular technology, or terminate all remedial actions, based on the achievement of previously established performance objectives. Performance objectives for each technology in the treatment train and the overall exit strategy should be developed and documented in the Feasibility Study (FS), ROD, and RD phases. More information on these topics can be found in the *Guidance for Optimizing Remedy Evaluation, Selection and Design* (NAVFAC, 2010).

5.0 Challenges Associated with Groundwater Risk Management Approaches

Several challenges may arise during the development and implementation of a risk management approach. These challenges are provided below along with some direction for the RPM to obtain additional information/guidance.

- **Regulatory acceptance**. Each state has its own risk-based methodology and specific criteria for risk management approaches. Some states have "anti-degradation" policies, which limit the use of risk-based cleanup strategies. For information regarding risk assessment issues, the *Navy Policy for Conducting Human Health Risk Assessments* should be consulted at the link below: https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_nfesc_pp/environmental/erb/resourceerb/hrapolicy.pdf.

- **Planned use of the property**. For BRAC facilities, previous land use could change, potentially resulting in changing exposure risks. Where contamination remains on-site, it is important to anticipate long-term legal and financial factors related to the presence of contamination and how changing land use or site alteration may affect exposure risks. However, when evaluating future land use scenarios, only reasonably anticipated future land use should be considered.

- **Use of institutional or engineering controls**. The willingness and ability of the appropriate entity to implement, maintain, and monitor the IC or EC is another factor of importance. In some cases, a third party is responsible for LUC maintenance, although the Navy retains the overall responsibility for the site. Even where the Navy remains in control of the site, LUCs may need to remain in place for many years spanning multiple personnel responsible for LUC maintenance. Thus, it is crucial that the RPM has access to the historical documents related to the LUCs and has the ability to effectively and efficiently monitor the LUCs to ensure that protectiveness is maintained. To assist the RPM in maintaining LUCs, the Navy has developed LUC Tracker, which is a web-based management tool that has been deployed as part of the Naval Installation Restoration Information System (NIRIS). This tool can be used to store LUC information (e.g., maps, reports, inspection forms etc.), query LUC data (e.g., inspection results, violation and corrective action) and automatically send email reminders for inspections and reporting requirements.

- **Community acceptance**. Community acceptance of the selected approach should be evaluated. For information regarding risk communication, consult the information developed by the Navy and Marine Corps Public Health Center at http://www-nehc.med.navy.mil/Environmental_Health/.

6.0 Case Studies

6.1 Naval Air Station Jacksonville, Operable Unit 3

Operable Unit (OU) 3 at Naval Air Station (NAS) Jacksonville is located on the western bank of the St. Johns River. Historical site activities conducted at OU 3 included rework, repair, and modification of aircraft engines and aeronautical components. As part of the industrial activities, there were reports of past releases of hazardous substances onto or into the ground at OU 3. Several investigations and removal actions have been undertaken throughout OU 3 since 1982, and two interim remedial actions were implemented at Buildings 106 and 780 in 1998. Building 106 was the site of a former dry cleaning facility and Building 780 was the site of a former paint shop and chemical stripping facility. In addition to contamination at Buildings 106 and 780, seven named groundwater plumes were identified (Areas A through G) at OU 3 (Figure 6-1).

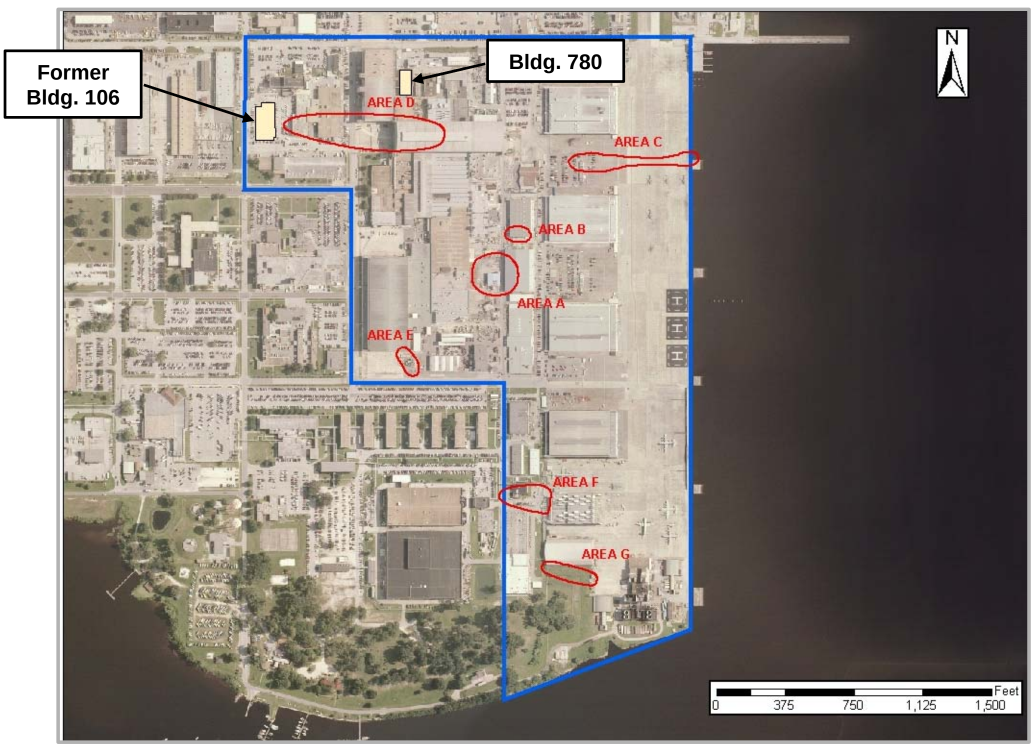


Figure 6-1. Operable Unit 3 at NAS Jacksonville

OU 3 is underlain by interbedded layers of sand, clayey sand, sandy clay, and clay. Groundwater, and the migration of contaminants, is controlled by a complex stratigraphy. The surficial aquifer is divided into an upper and lower zone by an extensive low permeability clay layer. The upper groundwater zone is slower moving and influenced by storm sewers, while the lower groundwater zone is faster moving and discharges to St. Johns River. The primary contaminants of concern (COCs) identified at OU 3 include tetrachloroethene (PCE), trichloroethene (TCE), 1,1-dichloroethene (1,1-DCE), and vinyl chloride (VC). Elevated contaminant concentrations in groundwater indicate the potential for residual DNAPL in the vicinity of Buildings 106 and 780. Current and anticipated future land use is industrial, and there is currently no groundwater use at the site. The primary exposure pathway is groundwater discharge to surface water in St. Johns River.

Remedies for Buildings 106 and 780 were implemented as interim remedial actions and later selected in a final ROD for OU 3. Air sparging with soil vapor extraction was implemented at Building 106 and groundwater extraction and treatment with soil vapor extraction was implemented at Building 780. Performance based interim remedial action objectives were established, rather than quantitative cleanup goals. The remedial action objectives included:

- Reduce present or future risks posed to human health and the environment
- Reduce contaminant concentrations in hot spots or source areas to adjacent levels of contamination.

After six years of operation, COC concentrations remained elevated compared to concentrations measured during preparation of the Engineering Evaluation and Cost Analysis (EE/CA); therefore, the five-year review and optimization study concluded that the treatment systems were not achieving the design goal of source removal and would be ineffective as a final remedy.

An optimized remedial strategy is now being developed for OU 3 which includes a risk management approach. Discharge of groundwater to St. Johns River as the primary receptor is the focus of the new risk management approach. In order to support the new approach, a direct push technology and membrane interface probe (DPT/MIP) investigation was completed to update the CSM by compiling additional information regarding site geology and extent of contamination in the soil and groundwater. Under Florida's risk-based cleanup rule, the updated CSM will be used in the groundwater fate and transport model and to perform a mixing zone analysis, which will be the basis for developing ACLs as new groundwater cleanup standards (Figure 6-2). ICs will also be developed for OU 3 to prevent exposure to contaminated soil and groundwater remaining at the site.

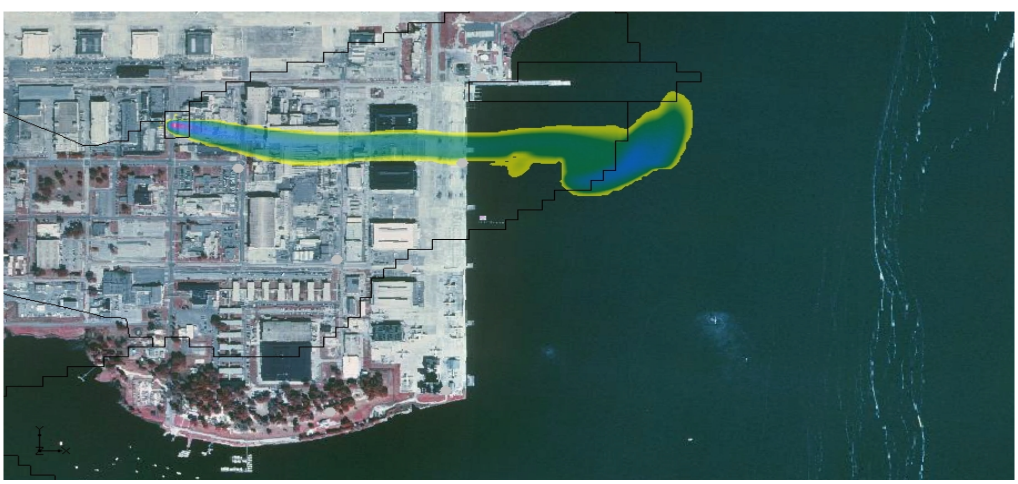


Figure 6-2. Contaminant Fate and Transport Model and Mixing Zone Analysis to be Applied at the Site

6.2 Naval Surface Warfare Center Crane, Solid Waste Management Unit 3

Naval Surface Warfare Center (NSWC) Crane is located in south-central Indiana and encompasses approximately 62,463 acres. It is located in a rural, sparsely populated area with most of the facility and surrounding area containing forest. Industrial activities that have taken place there include production and operations related to projectiles, bombs, mines, pyrotechnics, and rockets. Other operations have included demilitarization, ordnance disposal (through demolition and burning), solid waste disposal, small arms ranges, vehicle maintenance, and other activities. Solid Waste Management Unit (SWMU) 3 is designated as the Ammunition Burning Grounds (ABG). Since the 1940s, pyrotechnics, explosives, and propellants were disposed of using the "Open Burning" (OB) method. The material was burned directly on the ground in pad/pits and, prior to 1982, unlined impoundments existed for liquid waste disposal. RDX, TCE, and metals (barium) were identified as COCs in groundwater during the RCRA Facility Investigation.

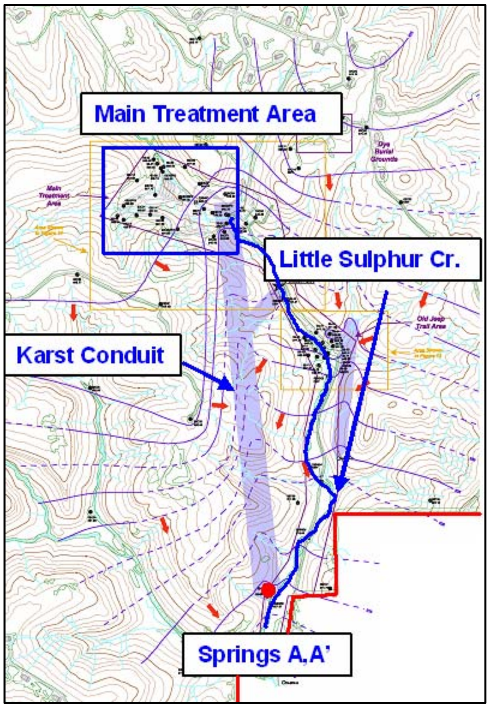


Figure 6-3. SWMU 3 and Surroundings

SWMU 3 is underlain by Big Clifty Sandstone and Beech Creek Limestone formations. It has been demonstrated with hydrologic and dye tracer studies that groundwater from SWMU 3 converges toward a karst conduit that subsequently discharges through surface springs to nearby Little Sulphur Creek (Figure 6-3). Surface water samples along portions of Little Sulphur Creek have indicated trace levels of RDX. RDX concentrations have been shown to decrease downstream of the springs due to dilution/mixing effects.

Several remedial option alternatives were considered for SWMU 3 as follows:

- Constructed Wetlands. This option was eliminated due to seasonal effectiveness issues (e.g., slow plant growth/biological activity in winter); potential for washout with 10,000 gpm peak flows; and limited land availability.
- Pump-and-Treat. This option was eliminated due to challenging lithology with a fractured bedrock and karst system; highly variable flows; and potential for high O&M costs over long-term.
- Risk Management with LUCs. This option was accepted by the regulatory stakeholders and included LUCs to protect current uses of ABG and Little Sulphur Creek, along with ACLs based on a site-specific risk assessment.

There were several considerations that contributed to stakeholder acceptance of the risk management strategy. Significant natural attenuation of the existing contamination was occurring over time in the karst conduit/surface water system. The current and future land use is a RCRA-permitted OB treatment unit on property owned by the Navy. This will facilitate implementation of LUCs to prevent exposure for on-site workers and exclude groundwater use. In addition, SWMU 3 is not a viable ecological habitat due to ongoing use of the OB treatment unit. ACLs for the spring were calculated in order to achieve Indiana Water Quality Standards (WQS) for point source discharge limits. The proposed water quality based limits for RDX are a maximum of 140 ppb for RDX discharging from the spring, 240 ppb for surface water (non-potable), and 3 ppb for public water supply located 11 miles downstream (at point of intake).

7.0 References

American Society for Testing and Materials (ASTM) standard D6312-98 (2005).

ITRC (Interstate Technology & Regulatory Council). 2008. EACO-1. Washington, D.C.: Interstate Technology & Regulatory Council, Enhanced Attenuation: Chlorinated Organics.

Naval Facilities Engineering Command (NAVFAC). 2003. *Groundwater Pump and Treat Systems*. Prepared by NAVFAC Optimization Workgroup. SP-2129-ENV. February. Available at: https://portal.navfac.navy.mil/pls/portal/url/ITEM/2C9C1D2B41C84A6CE0440003BA8967D9.

Naval Facilities Engineering Command (NAVFAC). 2010. *Guidance for Optimizing Remedy Evaluation, Selection and Design*. Prepared by NAVFAC Optimization Workgroup. March. Available at: https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_nfesc_pp/environmental/erb/resourceerb/ug2087env-remopt-w.pdf

Naval Facilities Engineering Command (NAVFAC). 2007. *DNAPL Management Overview*. Prepared by NAVFAC Alternative Restoration Technology Team.

US Department of Defense (DoD). 2001. *Policy and Land Use Controls Associated with Environmental Restoration Activities*. Office of Under Secretary of Defense. January.

US Department of the Navy (DON). 1999. *Policy Memorandum 99-02, Land Use Controls, Interim Final* May.

US Department of the Navy (DON). 2003. *DON/U.S. EPA Principles and Procedures for Specifying, Monitoring and Enforcement of Land Use Controls and Other Post-ROD Actions*, September.

US Department of the Navy (DON). 2006. *DON Environmental Policy Memorandum 06-06: Streamlined Environmental Procedures Applicable to Non-BRAC Real Estate Actions*. September.

US Department of the Navy (DON). 2012. *DON Policy for Optimizing Remedial and Removal Actions at all DON Environmental Restoration Program Navy Sites.* April.

U.S. Environmental Protection Agency (U.S. EPA). 1984. *Water Quality Standards Handbook*. Office of Water Regulations and Standards, Washington, DC.

U.S. Environmental Protection Agency (U.S. EPA). 1985. *Technical Support Document for Water Quality-based Toxics Control*. Office of Water, Washington, DC, September.

U.S. Environmental Protection Agency (U.S. EPA). 1988. Guidelines for Groundwater Classification Under the EPA Ground-Water Protection Strategy. PB95-169603, June 1988.

U.S. Environmental Protection Agency (U.S. EPA). 1989a. *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Interim Final Guidance.* Interim Final Guidance. Office of Solid Waste, Waste Management Division. April.

U.S. Environmental Protection Agency (U.S. EPA). 1989b. *Evaluation of Ground-Water Extraction Remedies*. EPA/540/2-89/054, Vols. 1-3.

U.S. Environmental Protection Agency (U.S. EPA). 1989c. *CERCLA Compliance with Other Laws Manual, Overview of ARARs: Focus on ARAR Waivers,* OSWER Dir. 9234.2-03/FS, Office of Emergency and Remedial Response, Washington, D.C.

U.S. Environmental Protection Agency (U.S. EPA). 1992a. *Evaluation of Ground-Water Extraction Remedies, Phase II*. OSWER Publication 9355.4-05, Vols. 1-2.

U.S. Environmental Protection Agency (U.S. EPA). 1992b. *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Interim Final Guidance. Addendum to Interim Final Guidance.* Office of Solid Waste. July.

U.S. Environmental Protection Agency (U.S. EPA). 1992c *Methods for Evaluating the Attainment of Clean-up Standards, Volume 2: Ground Water.* EPA 230-R-92-014.

U.S. Environmental Protection Agency (U.S. EPA). 1992d. *Technical Guidance Manual for Performing Waste Load Allocations Book III: Estuaries Part 3: Use of Mixing Zone Models in Estuarine Waste Load Allocations*. Office of Water. EPA-823-R-92-004.

U.S. Environmental Protection Agency (U.S. EPA). 1993. *Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration*. Interim Final. OSWER Directive 9234.2-25.

U.S. Environmental Protection Agency (U.S. EPA). 1998. *RCRA, Superfund & EPCRA Hotline Training Module. Introduction to: Applicable or Relevant and Appropriate Requirements*. US EPA Office of Solid Waste and Emergency Response. EPA540-R-98-020. June.

U.S. Environmental Protection Agency (U.S. EPA). 2005a. *Monitored Natural Attenuation of MTBE as a Risk Management Option at Leaking Underground Storage Tank Sites*. National Risk Management Research Laboratory, Office of Research and Development. Cincinnati, OH. January.

U.S. Environmental Protection Agency (U.S. EPA). 2005b. *Memorandum: Use of Alternate Concentration Limits (ACLs) in Superfund Cleanups*. Office of Solid Waste and Emergency Response. OSWER 9200.4-39. July. Available at: www.epa.gov/superfund/health/conmedia/gwdocs/pdfs/aclmemo.pdf.

Wilson, J., C. Newell, J. Seaberg, B. Rittmann, T. Wiedemeier, W. Z. Dickson, and P. Haas. 2005. *Monitored Natural Attenuation Panel: Social Issues of Active Remediation versus MNA. Remediation Summer*. Wiley Periodicals, Inc. pp. 126-138.