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A REVIEW OF EXIT STRATEGIES AND SITE CLOSEOUT CHALLENGES AT NAVY CLEANUP SITES

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Each Environmental Restoration (ER) site has its own unique set of conditions on the path to closure. However, useful insights can be drawn from similar site types or regulatory environments. This report identifies specific milestones along the path to site closeout (SC), as well as an array of approaches available to develop exit strategies. Three Navy case studies are provided as examples of sites that have implemented successful exit strategies that resulted in SC.

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ACRONYMS AND ABBREVIATIONS

ACL	alternate concentration limit
bgs	below ground surface
BRAC	Base Realignment and Closure
BTEX	benzene, toluene, ethylbenzene, total xylenes
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
COC	chemical of concern
COPC	chemical of potential concern
CPT	cone penetration test
CSM	conceptual site model
DCE	dichloroethene
DD	Decision Document
DoD	Department of Defense
DON	Department of the Navy
DTSC	Department of Toxic Substances Control
EISB	enhanced in situ bioremediation
EPA	U.S. Environmental Protection Agency
ER	Environmental Restoration
ER,N	Environmental Restoration, Navy
ESL	environmental screening level
F&T	fate and transport
FRTR	Federal Remediation Technologies Roundtable
FS	Feasibility Study
GSR	green and sustainable remediation
HRC™	Hydrogen Release Compound
IAS	in situ air sparging
I-RACR	Interim Remedial Action Completion Report
IRP	Installation Restoration Program
ITRC	Interstate Technology and Regulatory Council
LIF	laser induced fluorescence
LNAPL	light non-aqueous phase liquid
LTM	long-term monitoring
LTUSTCCP	Low-Threat Underground Storage Tank Case Closure Policy
LUC	land use control
MCB	Marine Corps Base

MCL	maximum contaminant level
MCRD	Marine Corps Recruit Depot
MCX	Marine Corps Exchange
MNA	monitored natural attenuation
MTBE	methyl *tert*-butyl ether
NAVWPNSTA	Naval Weapons Station
NFA	no further action
NSZD	natural source zone depletion
O&M	operation and maintenance
PCE	tetrachloroethene
PFAS	per- and polyfluoroalkyl substances
POC	point of compliance
RAO	remedial action objective
RA-O	remedial action operation
RACR	Remedial Action Completion Report
RC	response complete
RIP	remedy in place
ROD	Record of Decision
RPM	Remedial Project Manager
RWQCB	Regional Water Quality Control Board
SC	site closeout
SVE	soil vapor extraction
SWRCB	State Water Resources Control Board
TCE	trichloroethene
TCG	target cleanup goal
TI	technical impracticability
TPH-D	diesel-range total petroleum hydrocarbons
TPH-G	gasoline-range total petroleum hydrocarbons
UST	underground storage tank
UU/UE	unlimited use and unrestricted exposure
VC	vinyl chloride
VI	vapor intrusion
VOC	volatile organic compound

1.0 INTRODUCTION

Each Environmental Restoration (ER) site has its own unique set of conditions on the path to closure. However, useful insights can be drawn from the strategies employed to achieve site closeout (SC) at similar sites and/or sites managed under the same regulatory environment.

Department of the Navy (DON) Remedial Project Managers (RPMs) can take several steps to proactively develop exit strategies that can ultimately support response complete (RC) or SC. The RC milestone is met when a selected remedy achieves designated cleanup goals, but in some cases long-term management may still be required. SC is achieved when DON has completed active management and monitoring at a site; the remedy is protective of human health and the environment; contaminant levels at the site allow for unrestricted use; and there is no expectation of additional expenditures at the site (DON, 2018). The Navy's optimization policies and guidance encourage the use of ongoing optimization for cost-effectively achieving RC and/or SC at DON ER sites (NAVFAC, 2010 and NAVFAC, 2012).

This report identifies specific milestones along the path to SC, as well as an array of approaches available to develop exit strategies that support RC and/or SC. Three Navy case studies are provided as examples of sites that have implemented successful exit strategies that resulted in SC.

2.0 IDENTIFYING MILESTONES ON THE PATH TO SITE CLOSEOUT

Although the overall process of moving a site from site characterization to SC is well defined (Figure 1), in practice it is a highly complex process with the involvement of multiple stakeholders. The process itself involves technical, logistical, safety, and regulatory considerations. Furthermore, it can take time and significant resources to achieve SC due to uncertainties in the nature and extent of the contamination and/or remedial technology performance, as well as variability in regulatory expectations and requests.

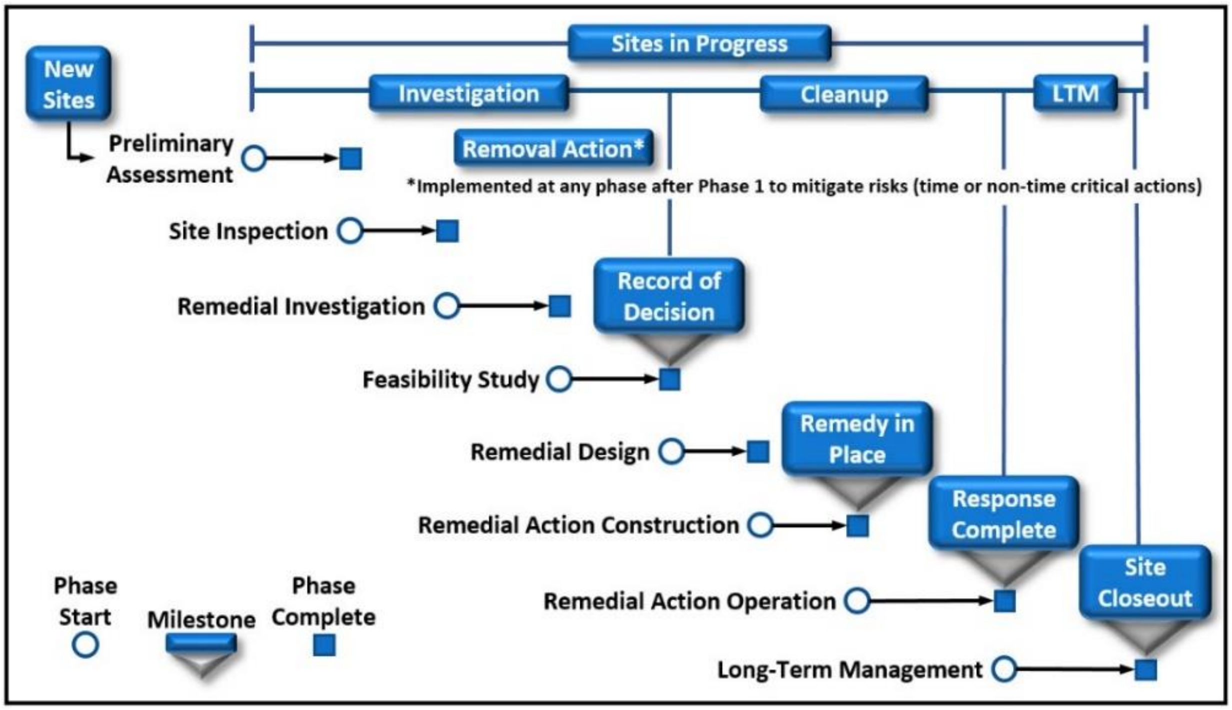

Figure 1. Phases and Milestones in the CERCLA Process (Courtesy of DON, 2018)

An exit strategy is defined as a "detailed, dynamic and succinct plan for accomplishing specific performance goals within a defined time period to assure protection of human health and the environment" (Interstate Technology and Regulatory Council [ITRC], 2006). Exit strategies help to establish metrics that can guide the path to SC. At sites regulated under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), the goal of the remedial process is to reach SC as defined by unlimited use and unrestricted exposure (UU/UE), a goal which may or may not be attainable for decades, or ever in some cases. For non-CERCLA sites and to some extent in certain instances under CERCLA, SC is often accompanied by a designation of "no further action" or NFA. For more information on the cleanup process for non-CERCLA sites, please refer to the DON Environmental Restoration Program Manual (DON, 2018).

The SC milestone can be achieved at any stage of the CERCLA process, depending upon the remediation requirements. As an example, for sites not requiring the long-term management phase, completion of the SC milestone occurs concurrently with the RC milestone. Similarly, sites requiring long-term management may never reach UU/UE conditions (e.g., such as landfills or sites cleaned to industrial standards). Table 1 summarizes common terminology related to key milestones in the CERCLA process.

Table 1. Key CERCLA Phases and Milestones Definitions

Key Milestones	Definitions
Remedy in Place (RIP)	This milestone is achieved when the construction of a long-term remedy is complete and the remedy is operating as planned to meet project remedial action objectives (RAOs) in the future. Determination on achieving the RIP milestone is a DON decision and regulatory concurrence for this milestone is not required. For a long-term remedy, the RIP milestone is achieved when remedy construction is complete and the remedy is operating properly. This can allow for the development of an Interim Remedial Action Completion Report (I-RACR). In some cases, short-term remedies such as excavation do not require a long-term operation phase. For a short-term remedy, the RIP milestone is achieved when the remedy has been successfully implemented and a Remedial Action Completion Report (RACR) is then prepared (DON, 2018).
Response Complete (RC)	This milestone is achieved when all cleanup goals specified in the Record of Decision/Decision Document (ROD/DD) are complete. For remedies requiring remedial action operation (RA-O), this milestone indicates completion of the RA-O phase (DON, 2018).
Long-Term Management	For sites reaching RC or with cleanup goals that do not allow for unrestricted use, monitoring may be required to determine the long-term protectiveness of the remedy. Actions may involve groundwater monitoring, implementation, and management of land use controls (LUCs), as well as preparation of five-year review reports (DON, 2018).
Site Closeout (SC)	This milestone signifies that DON has completed active management and monitoring at a site, the remedy is protective of human health and the environment, contaminant levels at the site allow for UU/UE, and there is no expectation of expending additional Environmental Restoration, Navy (ER,N) or Base Realignment and Closure (BRAC) funds at the site. The SC milestone can occur at any stage during the response action (DON, 2018).

More information on the specific documentation required to meet SC requirements can be found in the NAVFAC fact sheet on *Remedial Action Completion in the Navy's Site Closeout Process* (NAVFAC, 2014), the *DON Guidance to Documenting Milestones Throughout the Site Closeout Process* (DON, 2006), and the *DON Environmental Restoration Program Manual Section 5.2 on CERCLA Phases and Milestones* (DON, 2018). These resources provide a consistent approach for Navy RPMs to follow in recognizing and documenting specific milestones for achieving SC.

The primary focus of this report is to highlight options available for accelerating the path to RC or SC and to present tactics for overcoming barriers that may be faced along the way. As noted previously, the RC milestone is met when a selected remedy achieves designated cleanup goals, but in some cases long-term management is still required before reaching the SC milestone. Especially for high complexity ER sites, achieving the RC milestone can be challenging and the cleanup timeframe can extend into the decades (see Figure 2).

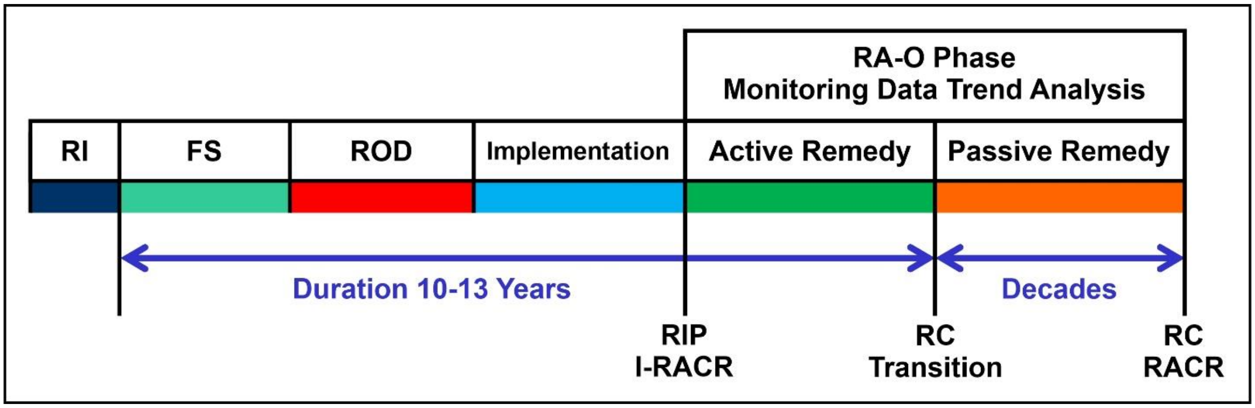

Figure 2. Typical Duration of the CERCLA Process for High Complexity Sites (Courtesy of NAVFAC)

When active remedies are no longer making adequate progress, Navy optimization approaches encourage progress tracking and performance-based remedy transitions from active to passive remedies. Although this proactive remedy transition does not achieve RC, it can result in significantly lower operation and maintenance (O&M) expenditures over the lifecycle of the cleanup project. Performance-based metrics for each selected remedy are an important part of the exit strategy for a given site and can inform when to make this transition. This RC transition approach should be incorporated into the optimization process for the cleanup of high complexity sites. Ongoing optimization efforts are encouraged over time until the RC milestone is achieved.

3.0 DEVELOPING EXIT STRATEGIES

Key project components that influence site cleanup progress over time include:

- Development of a conceptual site model (CSM);
- Remedial technology selection; and
- Optimization to achieve remedial goals in the most efficient, sustainable, protective, timely and cost-effective manner.

As summarized in Table 2, each of these project components in turn influences the exit strategies that are applicable at a given site.

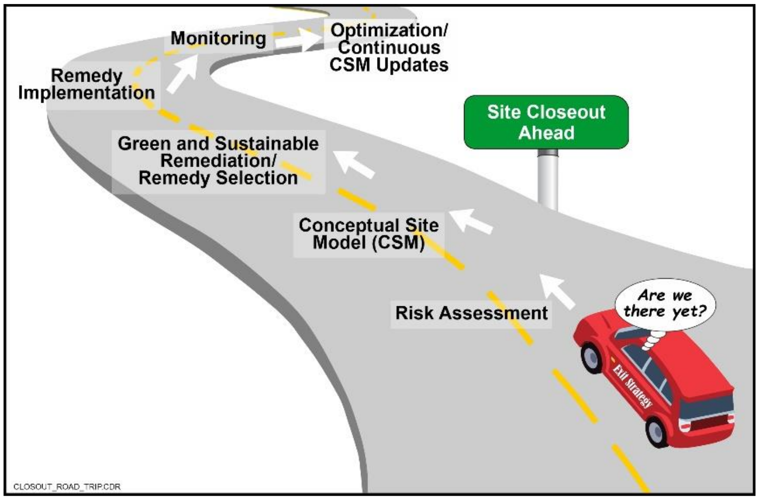

Figure 3. Key Project Considerations on the Path to Site Closeout (Courtesy of Battelle)

Figure 3 summarizes key project considerations on the path to SC. A critical component of site management is continuously updating the CSM to evaluate site conditions and to determine if completed exposure pathways exist. This includes performing a risk assessment based upon the contaminated media, completed exposure pathways, and impacts to current and future receptors. The potential risk to the site receptors drives the treatment approach, selection of remedy components, and the applicable site exit strategies. The risk assessment process defines the remedial goals, which may be based on regulatory criteria (e.g., maximum contaminant levels [MCLs]), background values, or site-specific, risk-based criteria. Under certain CSM scenarios, various exit strategies can be leveraged including: 1) updating the groundwater use classification to match site conditions, 2) utilizing alternate concentration limits with mixing zone analysis, and 3) establishing points of compliance (POCs).

The CSM and site risks will guide the remedy selection for a given site, along with green and sustainable remediation (GSR) considerations for reducing the environmental footprint of the remedy. Remedial strategies may include implementing source control/containment and/or treatment/removal. Exit strategies to be adopted will depend upon applicable Federal and state laws and regulations, as well as factors such as future land use and groundwater beneficial use. If source control/containment or a remedial option that does not permit UU/UE is selected, then institutional controls will be appropriate. Some states allow for a plume management zone to be established and/or for sites to be closed under low-threat policies under specified conditions. If sites have complex conditions that cannot be adequately addressed with current technology a technical impracticability (TI) waiver may be appropriate. See Table 2 for more information. These risk management strategies are also described in more detail in the *Groundwater Risk Management Handbook* (NAVFAC, 2008).

Table 2. Exit Strategies for Consideration Based on Site Conditions and Cleanup Requirements

Exit Strategy	Description
Groundwater Use Classification	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 (NAVFAC, 2008).
Alternate Concentration Limits (ACLs)/Mixing Zone Analysis	For sites with completed surface water exposure pathways, ACLs can be proposed under CERCLA for contaminants in groundwater as long as they do not pose a substantial or potential hazard to human health or the environment. They are developed using groundwater fate and transport (F&T) models and mixing zone analyses for discharge to surface water. They 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 (NAVFAC, 2008).
Points of Compliance (POCs)	POCs are the points at which the RAOs are applied, and at which groundwater monitoring is conducted to demonstrate compliance. CERCLA regulations provide 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. POCs can be designated at mutually agreed upon locations that are consistent with the CSM and linked with in-place plume management strategies (NAVFAC, 2008).
Institutional Controls/Land Use Controls (LUCs)	LUCs are administrative tools used to control exposure and protect human health and the environment from residual contamination. LUCs are used when a site cannot support UU/UE. LUCs can be placed to limit land use and on-site activities that might interfere with the containment of residual contamination. LUCs are also part of an exit strategy from active treatment or monitoring. In some cases, LUCs can be used to support termination of monitoring after demonstrating that a plume is stable and shrinking even though remedial goals are not met throughout the plume (NAVFAC, 2008).
Risk-Based Closure or Low Threat Closure	Most states have well established risk-based closure processes. In addition, low threat closure guidance is evolving in several states to allow for the closure of sites where the source zone is still present but determined not to pose an unacceptable risk. For example, the California State Water Resources Control Board (SWRCB) has allowed for the closure of "low-threat" underground storage tank (UST) sites where groundwater contaminant concentrations exceed MCLs (California SWRCB, 2012). The UST site may be eligible if certain criteria are met including the dissolved plume is shrinking and the groundwater has no future beneficial use as a drinking water source (National Research Council, 2013).

Table 2 (continued). Exit Strategies for Consideration Based on Site Conditions and Cleanup Requirements

Exit Strategy	Description
Technical Impracticability (TI) Waiver	A TI waiver may be invoked during a remedial action if restoration of groundwater to cleanup levels is technically impracticable from an engineering standpoint, based on the feasibility, reliability, and cost of the engineering methods required. The U.S. Environmental Protection Agency (U.S. EPA) has established guidance on the TI process (U.S. EPA, 1993). Although TI waivers have been granted at Department of Defense (DoD) sites, stakeholder approval of the TI waiver can be challenging.
Source Control or Partial Source Removal	The source acts as a reservoir for continued contaminant migration. It can be either remediated or contained based on site-specific conditions. Even partial source treatment can reduce the timeframe and cost of downgradient plume treatment. Partial source removal can be modeled with varying degrees of treatment and balanced versus the estimated timeframe and cost to achieve remedial goals. As the source is addressed, the exit strategy can incorporate a treatment train approach for the downgradient dilute plume.
Transition to Passive Technologies	It is important to establish metrics to determine the appropriate conditions to modify and transition from an active treatment technology to a passive treatment technology over time. This transition is an important optimization step that helps to maximize remedial effectiveness, minimize net environmental impacts, and improve the cost efficiency of a remedy. Although in many cases the use of passive technologies does not lead to RC, it does significantly reduce O&M costs in cases where the Navy is unable to achieve RC.
Establishing Plume Stability and/or Monitored Natural Attenuation (MNA) over Extended Timeframes	Establishing plume stability helps to manage site risks and provides a path to site closeout. Contaminant F&T models can evaluate plume stability and the extent to which a plume will expand before naturally attenuating to levels below risk-based criteria. These simulations can be used to estimate downgradient chemical flux and concentrations (NAVFAC, 2008). A comprehensive list of tools for screening MNA can be found on the Federal Remediation Technologies Roundtable (FRTR) web site: https://frtr.gov/matrix/Monitored-Natural-Attenuation/.
Transition to Natural Source Zone Depletion (NSZD)	NSZD is gaining acceptance for attenuating residual light non-aqueous phase liquid (LNAPL) at sites that pose little or no risks or at sites where active LNAPL recovery technologies have reached a point of diminishing return. NSZD requires an evaluation of naturally-occurring LNAPL degradation rates. Rates should continue to be monitored periodically (e.g., annually) to evaluate changes over time as the more easily degradable fractions of petroleum products are eliminated (NAVFAC, 2021).

RAOs and technology transition metrics should be clearly defined and developed jointly with input from all stakeholders, as discussed in the *DON Environmental Restoration Program Manual* (DON, 2018; Section 8.4.8.3). Adaptive site management can be employed, along with optimization principles to make appropriate adjustments in response to changing site conditions over time (U.S. EPA, 2018). The CSM, technology performance, and technological advances can all change over time (ITRC, 2006). It is important that the exit strategies and technology transition metrics are recorded in a document that receives regulatory review and concurrence, so that the agreement is memorialized for future reference. Examples of deliverables that could be used to define exit strategies include the ROD/DD, Remedial Action Work Plan, or long-term monitoring (LTM) reports. Optimization is ongoing and should be applied across all phases of the cleanup process. This includes continually updating the CSM, measuring remediation performance versus the established metrics, and adjusting exit strategies over time. Exit strategies to consider may include transitioning from active to passive treatment technologies, MNA over long timeframes, and NSZD (see Table 2). Depending on the site-specific circumstances, some of the exit strategies outlined in Table 2 may not achieve SC. However, RC may be achieved and/or optimization can result in an RC transition that reduces the lifecycle cleanup costs where RC/SC cannot be readily achieved. More information and phase-specific optimization considerations can be found in the *NAVFAC Guidance for Optimizing Remedy Evaluation, Selection, and Design* (2010) and the *NAVFAC Guidance for Optimizing Remedial Action Operation* (2012).

4.0 SITE CLOSURE SUCCESS STORIES

Three case studies are provided to illustrate exit strategies employed at various Navy sites. Each respective site closure was achieved through various technical approaches and regulatory processes. Two of the case studies presented are petroleum-contaminated sites and one represents a chlorinated solvent-contaminated site.

4.1 CASE STUDY 1: MARINE CORPS RECRUIT DEPOT SAN DIEGO

KEY SITE FEATURES AND CHALLENGES:

- ✓ Four UST areas (former and active)
- ✓ Shallow groundwater (1-3 ft below ground surface [bgs])
- ✓ COPCs in soil and groundwater (BTEX and MTBE) and soil gas (VOCs and TPH-G)
- ✓ Complete exposure pathway for vapor intrusion to indoor air
- ✓ Recreational boat channel downgradient of site

OUTCOME:

- ✓ Confirmed site investigation(s) and associated corrective actions followed requirements set forth in California's Health and Safety Code
- ✓ Approval by SWRCB of NFA and Site Closure

Introduction: The Low-Threat Underground Storage Tank Case Closure Policy (LTUSTCCP) established by the California SWRCB (2012) was followed to achieve site closure and NFA at Former UST Site 5, Marine Corps Recruit Depot (MCRD), San Diego, California. Overall, the low-threat closure policy defines "low-threat" as the absence of site-specific conditions that demonstrably increase the risk associated with residual petroleum constituents. It includes cases that do not pose a threat to human health, safety, or the environment, and are appropriate for UST case closures pursuant to California Health and Safety Code Section 25296.10. At former UST Site 5, the primary chemicals of potential concern (COPCs) were benzene, toluene, ethylbenzene, total xylenes (BTEX) and methyl *tert*-butyl ether (MTBE) in soil and groundwater and gasoline-range total petroleum hydrocarbons (TPH-G) and volatile organic compounds (VOCs) in soil gas. The path to site closure included multiple iterations of site characterization and groundwater monitoring, followed by F&T modeling, risk assessment, and CSM development. Through this process, multiple lines of evidence were developed to demonstrate that conditions at UST Site 5 met general and media-specific criteria established in the LTUSTCCP.

CSM Development: As shown in Figure 4, multiple site investigation efforts were conducted at MCRD former UST Site 5. Laser induced fluorescence (LIF) data were collected between 2002 and 2004. The results indicated a relatively consistent vertical contaminant distribution, between approximately 7 and 12 feet bgs.

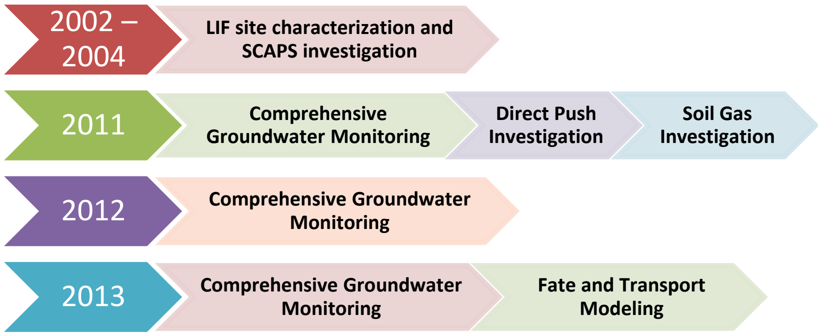

Figure 4. Summary of Site Investigation Efforts at MCRD San Diego Former UST Site 5 (Courtesy of Battelle)

From 2011 to 2013, several groundwater monitoring events were conducted to evaluate the stability of the dissolved-phase plume containing BTEX and MTBE. The results demonstrated that BTEX compounds were limited in distribution to the areas immediately surrounding and within 100 feet of the former source areas. However, the footprint of the MTBE plume was significantly larger. In 2013, a numerical model was developed using MODFLOW-SURFACT. The purpose of the modeling effort was to evaluate the fate and potential transport of MTBE in groundwater at the site to a recreational boat channel located approximately 4,300 feet downgradient of the leading edge of the plume. F&T modeling results indicated that MTBE is stable and naturally degrading in the environment and concentrations will not exceed regulatory limits (i.e., > 5 µg/L) upon discharge to the MCRD recreational boat channel. In addition to F&T modeling, a risk assessment was performed for subsurface contaminants at former UST Site 5.

As part of the risk assessment, three exposure pathways were evaluated:

- **Drinking Water** - Because the site is not designated as beneficial use by the California Regional Water Quality Control Board (RWQCB), impacted groundwater is not considered a water resource; thus, the drinking water pathway was considered incomplete. Furthermore, BTEX and MTBE concentrations in soil and groundwater across the site do not pose a threat to human health or the environment based on the current land use and exposure pathways.
- **Aquatic Habitat** - Marine aquatic receptors exist approximately 4,600 feet southwest of the site within the MCRD boat channel. Groundwater monitoring results indicate the leading edge of impacted groundwater is > 4,300 feet away from these receptors. F&T modeling demonstrated that dissolved-phase MTBE would not migrate to the boat channel. Because of these factors, the aquatic habitat pathway was considered incomplete.
- **Vapor Intrusion (VI)** - Several buildings exist near the impacted groundwater. A vapor barrier was installed beneath Building 642 during the gas station renovations in the late 1990s and is not considered to have a complete VI pathway to indoor air. However, Buildings 514 and 614 do not have any sub barriers, so the VI pathway was considered complete for these buildings. VOCs and TPH-G are present in soil gas near the footprints of Building 514 and 614. Of the detected compounds, only TPH-G exceeded the VI environmental screening level (ESL) for soil gas in two samples collected in September 2011. In June 2012 and April 2013, no TPH-G detections were reported in soil gas. The VI pathway is complete for site buildings; however, COPC concentrations are significantly below threshold levels. Therefore, soil gas concentrations do not pose a significant threat to human health based on the current land use.

Following the various phases of data acquisition, F&T modeling, and risk assessment, a comprehensive CSM was developed to further support the request for site closure and NFA (Figure 5).

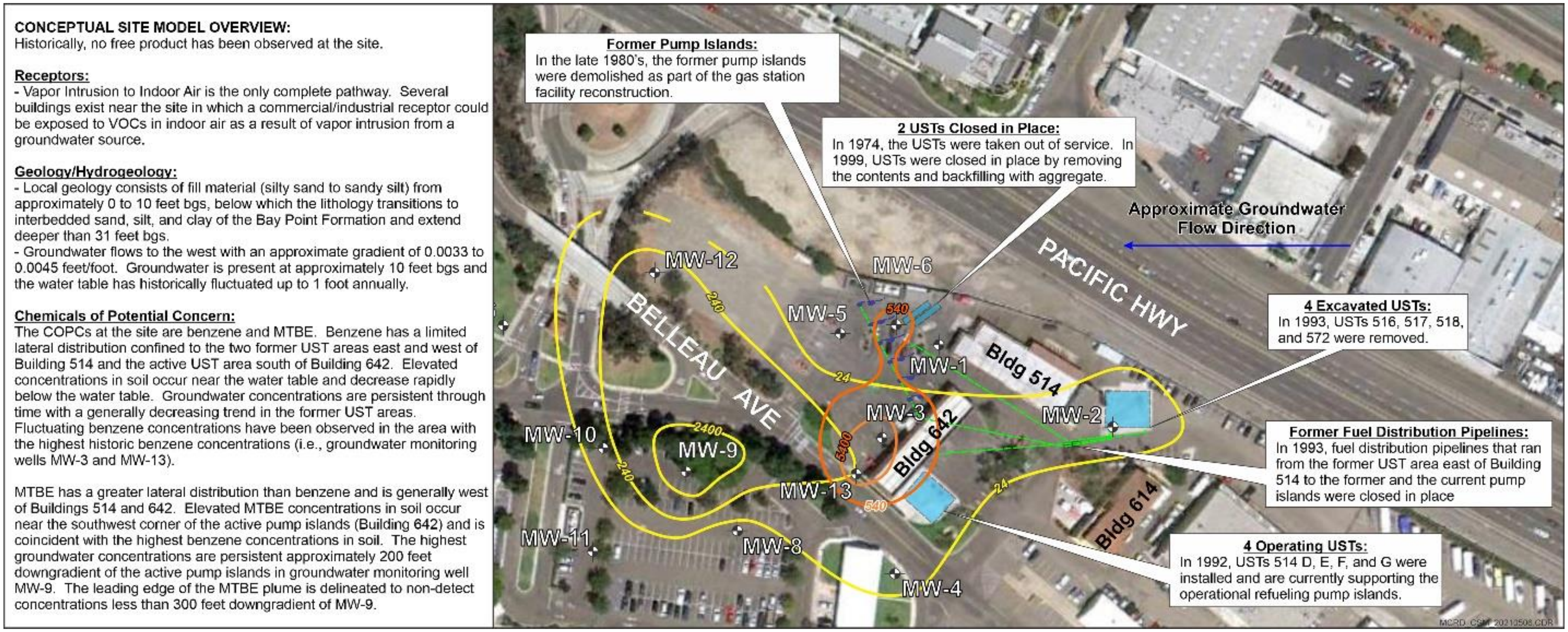

Figure 5. MCRD San Diego CSM (Courtesy of Battelle)

Exit Strategy Development: To formally request site closure and NFA for MCRD UST Site 5, general and media-specific criteria requirements defined in the SWRCB low-threat closure policy were evaluated against site conditions at MCRD. The results of this assessment are summarized in Table 3.

Table 3. Summary of Low-Threat Closure Criteria

Closure Criteria	Site-Specific Conditions
Is the unauthorized release located within the service area of a public water system?	Yes - The site is located within the service area of a public water system provided by the City of San Diego Public Utilities Department.
Does the unauthorized release consist only of petroleum hydrocarbons?	Yes - BTEX, TPH-G and TPH-D, polycyclic aromatic hydrocarbons, and common petroleum fuel oxygenates including MTBE.
Has the unauthorized release from the UST system been stopped?	Yes - Former USTs have been excavated or closed in place, and former distribution lines have been closed in place. Active USTs have a leak detection system in place and operational.
Has free product, if any, been removed to the maximum extent practicable?	Yes - Monitoring well MW-2 is the only location where free product has been historically identified at less than one-eighth of an inch in August 1996. Free product removal via absorbent socks was subsequently performed and free product has not been observed at the site since that time.
Has a CSM, meeting all the conditions of the LTUSTCCP, that assesses the nature, extent, and mobility of the release been developed?	Yes - A CSM meeting all conditions of the LTUSTCCP that assesses the nature, extent, and mobility of the release was developed. The dissolved-phase BTEX and MTBE plumes were shown to be limited to the site, stable and/or decreasing, and remediation by natural attenuation was demonstrated.
Has the secondary source, if any, been removed to the extent practicable?	Yes - Excavations of former USTs at the site have removed secondary source soil contamination to the extent practicable.
Has soil or groundwater been tested for MTBE and results reported in accordance with Health and Safety Code Section 25296.15?	Yes - Groundwater has been tested for MTBE and results were reported in accordance with California Health and Safety Code Section 25296.15. California's GeoTracker database contains datasets with all analytical results from the additional site assessment activities.
Does nuisance as defined by Water Code Section 13050 exist at the site?	No - Nuisance, as defined by California Water Code Section 13050, does not exist at the site.
Media-Specific Criteria	
Soil	Not a soils-only case.
Groundwater	• The dissolved-phase benzene plume exceeding its ESL is <250 ft in length. • Free product removed to the maximum extent practicable (none remaining). • The dissolved-phase BTEX/MTBE plume stable/shrinking for over 5 years. • The nearest surface water body is >1,000 ft from the site. • No drinking water supply wells are located within miles of the site.

Table 3 (continued). Summary of Low-Threat Closure Criteria

VI to Indoor Air	The site remains an active petroleum refueling station, the Marine Corps Exchange gas station at MCRD. As such, the petroleum VI to indoor air media specific criteria are not applicable per LTUSTCCP.
Direct Contact and Outdoor Air	This criterion was evaluated against soil concentration data, and no risk was identified. In addition, the area is capped by concrete and/or asphalt, which reduces the volatilization to outdoor air pathway. Furthermore, underground utilities do not exist where residual petroleum contamination exists in soil; thus, the direct contact pathway by utility trench workers is negligible.

Summary: High-resolution site characterization techniques, combined with comprehensive long-term groundwater monitoring, F&T modeling, risk assessment, and CSM development were undertaken to develop robust lines of evidence to substantiate closure and NFA at former UST Site 5, MCRD. The information generated was evaluated against requirements in the California's LTUSTCCP. Upon review, a letter was received from the California SWRCB on December 4, 2014, confirming the completion of the site investigation and corrective action for the UST site in compliance with the requirements of California's Health and Safety Code. The letter ultimately approved site closure and accepted NFA related to the petroleum release; thus, the SC milestone has been met.

4.2 CASE STUDY 2: MARINE CORPS BASE CAMP PENDLETON

KEY SITE FEATURES AND CHALLENGES:

- ✓ Two active gas station sites, with former releases
- ✓ Petroleum-related contaminants in soil and groundwater (TPH-G, BTEX and MTBE)
- ✓ Dissolved-phase MTBE plume extended >3,500 ft downgradient of source area, with dilute concentrations just above MCL of 5 µg/L
- ✓ Drinking water wells within 1 mile of the site

OUTCOME: The San Diego RWQCB letter:

- ✓ Confirmed site investigation and associated corrective actions were carried out in compliance with California's Health and Safety Code
- ✓ Approved NFA related to the petroleum release at the 22 Area Gas Station site
- ✓ Noted future land use changes may require re-evaluation

Introduction: In September 2016, the San Diego RWQCB issued a Uniform Closure Letter for the 22 Area, Marine Corps Exchange (MCX) Gas Station Site, Marine Corps Base (MCB), Camp Pendleton, California. Although trace amounts of petroleum-related contaminants, mainly MTBE, remained in groundwater above the California MCL, the RWQCB proceeded to grant site closure. The LTUSTCCP questionnaire was completed with supporting evidence to show remaining residual contaminants comply with the Health and Safety Code as adopted in the LTUSTCCP. Corrective actions were performed and various data analysis approaches were used to build the lines of evidence for site closure. Steps taken at the site included UST closure/replacement, site characterization, groundwater investigations, installation of two biobarrier oxygen injection systems, groundwater monitoring, F&T modeling with particle tracking, trend analyses, and a correlation study between MTBE concentrations and groundwater elevation. Collectively, this approach led to the development of multiple robust lines of evidence to substantiate a sound case for site closure.

Site Remediation Treatment Train: Corrective actions at the site began in 1997 to address source zone groundwater contamination (TPH-G, BTEX, and MTBE) from two gas station sites (22 Area Gas Stations). The gas stations are both active, approximately 400 feet apart, and the dissolved-phase hydrocarbon plume is within 1 mile of drinking water production wells at the Base. The remedial treatment train implemented at the site is presented in Table 4 below.

Table 4. Remediation Technologies Applied at the 22 Area Gas Station Site

Remediation Technology	Summary
Soil Vapor Extraction (SVE)/In Situ Air Sparging (IAS)	SVE and IAS were initially applied at the site to reduce high-volume source zone contamination. This approach was highly successful and removed approximately 22,802 lbs of petroleum hydrocarbon mass between 1997 and 2004.
Biobarrier System	Following active remediation, an approximate 3,500-ft long, dissolved-phase MTBE plume persisted. In conjunction with an extensive groundwater monitoring program, the dissolved-phase MTBE was addressed using two biobarrier oxygen injection systems – a mid-plume system and a leading-edge system. The biobarriers operated from 2004 to 2010 and successfully controlled plume migration and reduced TPH-G and BTEX to below action levels, while continuing to reduce dissolved-phase MTBE concentration. A third-party system optimization review was performed. Recommendations such as optimizing the groundwater monitoring program, shutting down the mid-plume system and enhancing the leading-edge system, and updating the CSM were made to ultimately result in cost savings.
Portable IAS	Treatment of a persistent MTBE "hot spot" in the source area was executed from 2010-2012 using a portable sparge system. This phase of remedial action decreased "hot spot" concentrations from 820 µg/L to 18 µg/L, however still above the MCL.
Monitored Natural Attenuation (MNA)	Collection and evaluation of MNA parameters was undertaken in conjunction with LTM at the site. MNA data were utilized to provide an additional line of evidence that the MTBE will naturally degrade over time and not pose a threat to human or ecological receptors located downgradient of the plume.

Development of Additional Lines of Evidence: Following various phases of active and passive remediation, the 22 Area Gas Station site dissolved-phase MTBE continued to persist at relatively low levels, but still exceeded the MCL for MTBE (5 µg/L) in isolated areas of the plume. A F&T model had been developed and demonstrated that the plume is relatively stable and will continue to degrade to concentrations below the secondary MCL. However, the San Diego RWQCB emphasized that, due to the proximity of the site (i.e., within 1 mile) to Base drinking water production wells, site closure could not be achieved unless MCLs were met, or additional lines of evidence were developed to further demonstrate that site contaminants do not pose a threat to human or ecological receptors. Table 5 provides a description of the actions taken to develop additional lines of evidence to support NFA at the 22 Area Gas Station site.

Table 5. Development of Additional Lines of Evidence to Substantiate Site Closure

Additional Action	Line of Evidence Summary
Sustainability Analysis	A sustainability analysis was performed to support shutdown of the biobarrier system. The analysis evaluated energy requirements and the environmental impacts of the system compared to the risk posed by site contamination.
Sen's Non-Parametric MTBE Trend Analysis	Performance of MTBE trend analysis in wells with MTBE > 5 mg/L was undertaken using Sen's non-parametric method. This analysis was able to demonstrate, with more confidence, the statistical significance of declining MTBE trends in groundwater.
Cone Penetration Test (CPT)	A CPT investigation at the leading edge of a dissolved-phase MTBE plume was performed to identify the most permeable pathways in the subsurface. This was followed by subsequent installation and sampling of groundwater monitoring wells in these locations.
Data Gap Analyses	New groundwater monitoring wells were installed and sampled to collect additional information on site COPCs, particularly in the vicinity of the leading edge of the plume.
Capture Zone Analysis	A capture zone analysis with 20-year backward particle tracking was performed for nearby Base production wells. Results demonstrated that current and/or increased pumping rates would not influence the migration of dissolved-phase MTBE into the capture zone of the production wells.
F&T Model	A F&T model was developed and later updated to include data from capture zone analyses and new groundwater monitoring wells. The revised F&T model demonstrated that Base production wells are not creating preferential pathways for vertical transport of MTBE below the groundwater table.
Correlation Between MTBE and Groundwater Elevation	The effect of seasonal fluctuating groundwater elevation on the MTBE concentrations was analyzed using statistical analysis methods (Mann-Kendall and Sen's Procedures). Twelve years of MTBE concentrations (2003 to 2015) were categorized into wet season, dry season, and all-season for the statistical analysis. With a high degree of confidence, it was determined that groundwater elevation at the site has minimal impact on the MTBE concentrations.

Summary: Since the inception of remediation efforts at the 22 Area Gas Station site, dissolved-phase petroleum hydrocarbon constituents declined by approximately 99%. Figure 6 illustrates the decrease in concentration and percent reduction of BTEX and MTBE from the site's maximum highs. These data clearly demonstrate the progress and effectiveness of the Navy's efforts to remediate the site. However, due to the proximity of nearby Base drinking water wells, the RWQCB required multiple lines of evidence that show the MTBE plume will not mobilize further downgradient (both vertically and cross-sectionally) and MTBE concentrations will continue to decrease in all seasonal conditions to substantiate site closure. In agreement with these lines of evidence, the RWQCB ultimately approved the site for closure and NFA.

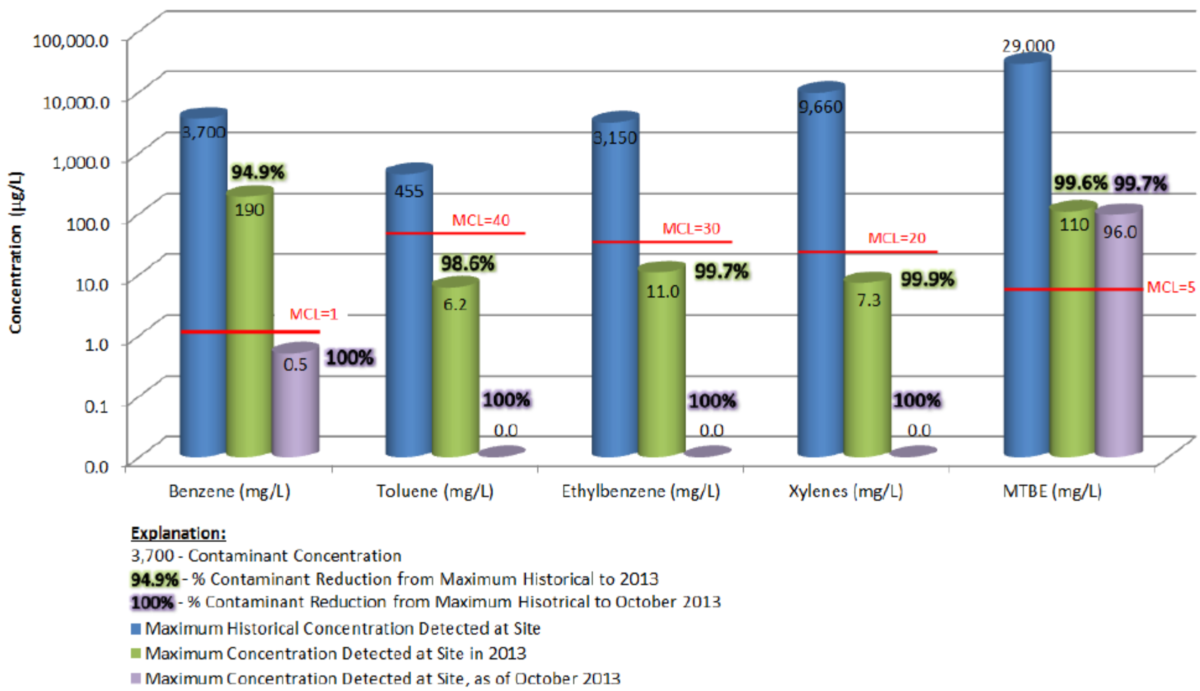

Figure 6. Historical Contaminant Concentration Trends Compared to MCLs (Courtesy of Battelle)

4.3 CASE STUDY 3: NAVAL WEAPONS STATION SEAL BEACH

***Introduction*:** Naval Weapons Station (NAVWPNSTA) Seal Beach is located in Orange County, California and provides ordnance to ships and weapons performance analysis. Installation Restoration Program (IRP) Site 40 is on the western portion of the installation. Site-related contamination is thought to have originated from previous activities at Building B. Historic activities near the shop are suspected to have resulted in the discharge of industrial solvents to soil and groundwater. In 2017, the California Department of Toxic Substances Control (DTSC) issued a concurrence letter in response to the Navy's request for SC NFA for NAVWPNSTA Seal Beach IRP Site 40.

KEY SITE FEATURES AND CHALLENGES:

- ✓ Chlorinated solvents, including tetrachloroethene (PCE) (up to 3,900 µg/L) are primary chemicals of concern (COCs) at the site
- ✓ Shallow contamination (20 to 45 feet bgs) with a dissolved-phase groundwater plume extending laterally 270 ft x 200 ft
- ✓ Enhanced in-situ bioremediation was the selected remedy
- ✓ Challenges encountered with electron donor distribution
- ✓ Optimization was performed and focused on introduction of additional donor amendments in site-specific areas

OUTCOME:

- ✓ Significant reductions of site-related COCs, achieving target cleanup goals in almost all cases
- ✓ VI monitoring revealed that detected VOCs and methane in nearby buildings/surrounding aboveground areas were not attributable to groundwater contamination or amendment injection
- ✓ SC and NFA approved by DTSC in May 2017.

Site Investigation Activities: Between 1995 and 1998**,** site investigations were carried out at IRP Site 40 to delineate the lateral and vertical extent of COPCs at the site. A dissolved-phase chlorinated hydrocarbon plume, including tetrachloroethene (PCE), trichloroethene (TCE), and cis-1,2-dichloroethene (DCE), was identified in groundwater, with a lateral extent of approximately 270 by 200 ft. Because PCE, TCE, and cis-1,2-DCE were detected at levels exceeding state and Federal MCLs, further action was recommended. It should be noted that low-level COPCs were also detected in soil, however a screening-level human health risk assessment determined that levels were below 5×10^{-7} for residential and industrial land use scenarios. As such, soil cleanup actions were not undertaken. Figure 7 represents the extent of dissolved-phase PCE contamination in groundwater at IRP Site 40 prior to full-scale remedial activities.

CSM Development and Pilot Testing: Following site investigation activities, an initial CSM was developed to inform a Feasibility Study (FS) and a pilot test program. RAOs focused on mitigating potential human exposure to groundwater, as well as assessing the potential for VI into Buildings A and B. It should be noted that ecological receptors were not included since complete exposure pathways were not found.

In 2000, the FS identified and evaluated five remedial alternatives, with enhanced in situ bioremediation (EISB) using sodium lactate and MNA as the preferred approach. An EISB pilot test was carried out in 2001 where approximately 55,000 gallons of sodium lactate (3%) were injected over a period of approximately 9 months. Groundwater conditions were monitored before, during, and after the pilot test study. Although anaerobic conditions were achieved and PCE was reduced to TCE and cis-1,2-DCE, further reduction stalled and little to no formation of vinyl chloride (VC) and ethene were observed. Subsequently, the pilot test summary report recommended the injection of an anaerobic microbial dechlorinating culture containing *Dehalococcoides* spp. to enhance complete reduction of the chlorinated hydrocarbons to ethene.

Site Remediation: The ROD was signed in 2004 with a selected remedy of EISB with MNA and LUCs. As part of the remedy, 18 injection wells, eight groundwater monitoring wells, and four vapor monitoring wells were installed to address COCs through the EISB effort. Once the infrastructure was in place, two rounds of injections were completed (March 2005 and October 2005), with a total injection volume of approximately 700,000 gallons of 3% lactate solution (472,000 gallons in Phase 1 and 217,000 gallons in Phase 2). In addition, a *Dehalococcoides* containing culture was applied at 10 selected well locations.

Following several rounds of monitoring, it was noted that the distribution of the electron donor (lactate) was not consistent and that some areas of the site did not receive an adequate amount. Therefore, an optimization effort was carried out resulting in the injection of Hydrogen Release Compound (HRC™) into targeted areas where lactate distribution and/or bioremediation performance was limited. In April 2007, 18,300 lbs of HRC™ was introduced to site groundwater. In October to November 2008, 25,000 lbs of HRC™ was introduced (at 186 locations) where residual contamination was still observed.

In addition to the actions taken above, LTM of groundwater occurred at the site between 2000 and 2014 and soil gas monitoring was conducted from 2005 to 2014. Furthermore, to assess the potential for indoor VI, the Navy performed annual surface emissions monitoring between 2010 and 2014 and collected indoor air samples from on-site buildings in 2015.

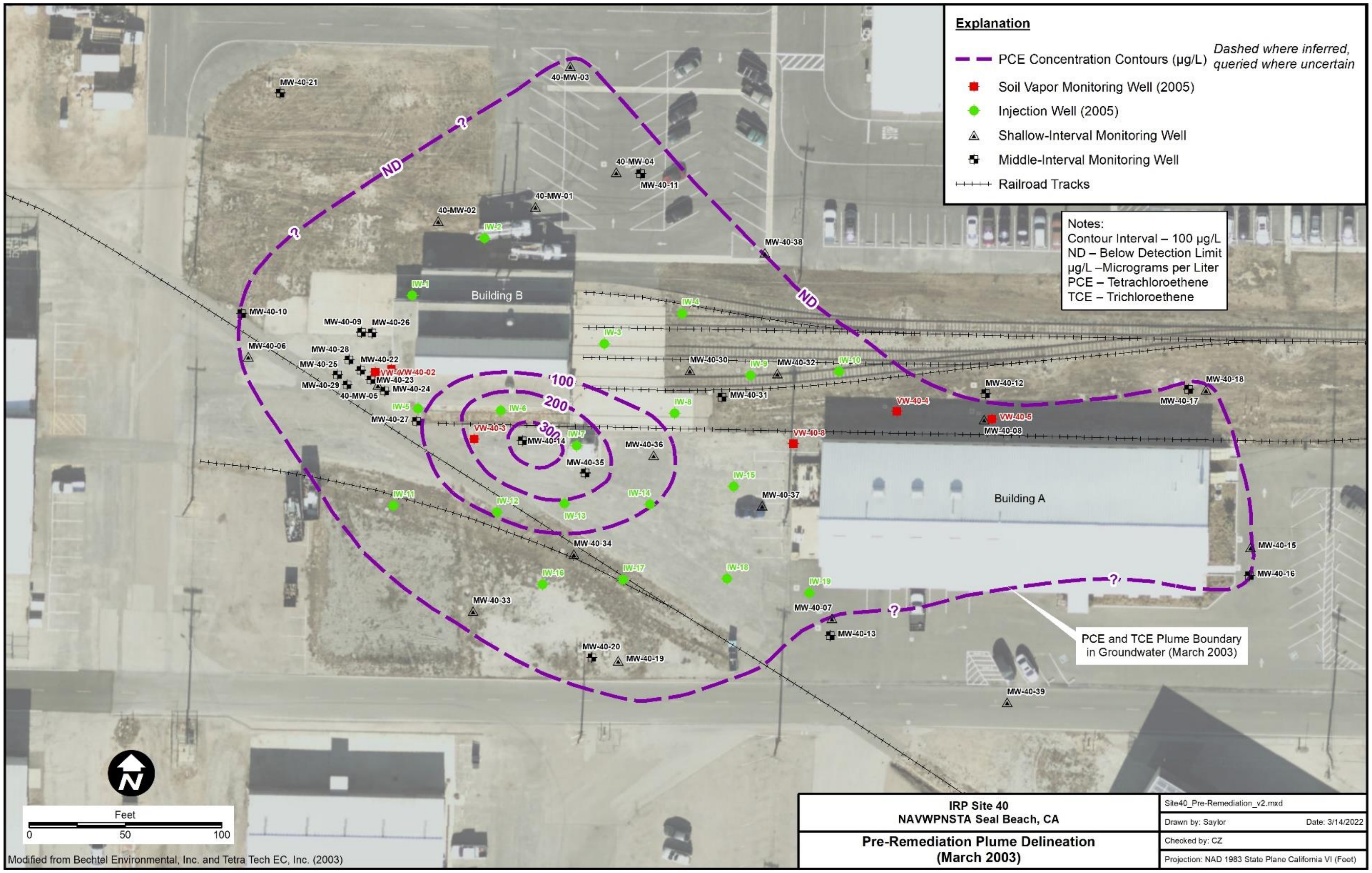

Figure 7. Pre-Remediation Plume Delineation at NAVWPNSTA Seal Beach Site 40 (Courtesy of NAVFAC)

Results: Significant reductions in site-related chlorinated hydrocarbons were observed during the LTM phase. In addition, generation of ethene and short chain volatile fatty acids such as acetate, propionate, and butyrate were also observed. In summary:

- No PCE exceedances of the target cleanup goals (TCG) of 5 µg/L were observed following the 2010 monitoring event;
- Only one TCE exceedance of the TCG (5 µg/L) was observed following the 2010 monitoring event;
- Regarding reductive dechlorination daughter products, cis-1,2-DCE was observed in four locations at concentrations two to five times the TCG (6 µg/L); and
- VC concentrations were generally between the 0.5 and 2 µg/L range (TCG of 0.5 µg/L) with several wells between 2 and 5 µg/L.
- Vapor monitoring performed between 2010 and 2014 demonstrated that neither VOCs nor methane detected inside Buildings A and/or B (or surrounding aboveground areas) was attributable to groundwater contamination or electron donors introduced to the site.

Figure 8 illustrates concentrations of cis-1,2-DCE and VC remaining in groundwater at the site in 2013 and demonstrates the success of the remediation program implemented at IRP Site 40.

The following lines of evidence were presented by the Navy in its request for SC and NFA, which was ultimately approved by DTSC:

- Although concentrations of cis-1,2-DCE and VC were above TCGs in some select wells, it is highly-unlikely that potential receptors will contact the groundwater;
- Given the site's proximity to the ocean, the brackish groundwater offers no beneficial use for consumption;
- The dissolved-phase groundwater plume is not migrating, and site conditions remain favorable for continued dechlorination;
- VI was not a pathway of concern, as determined through risk-assessment; and
- Site use is projected to remain under the Navy's control.

Summary and Lessons Learned: Although EISB initially was not performing as expected, the project team quickly executed a detailed optimization effort and addressed data and remedy gaps. The implemented solution (HRC™ target treatment) rapidly reduced dissolved-phase COC concentrations to levels near or below TCGs. This effort positioned the Navy to request SC and NFA, which was ultimately approved in October 2017. One important thing to note about IRP Site 40 is that the relatively small size of the dissolved-phase plume made a very intensive application of the remedy (e.g., multiple injections, closely-spaced locations) more viable from both technical and cost standpoints. For sites with larger chlorinated solvent plumes, the viability of taking a site to RC or SC with intensive injections in a relatively short timeframe should be carefully evaluated. For example, an EISB approach was also implemented at a much larger TCE plume at Seal Beach IRP Site 70 without a similar outcome to IRP Site 40. Optimization of the EISB remedy at Site 70 is ongoing, while the California DTSC concurrence letter resulted in successful SC at IRP Site 40.

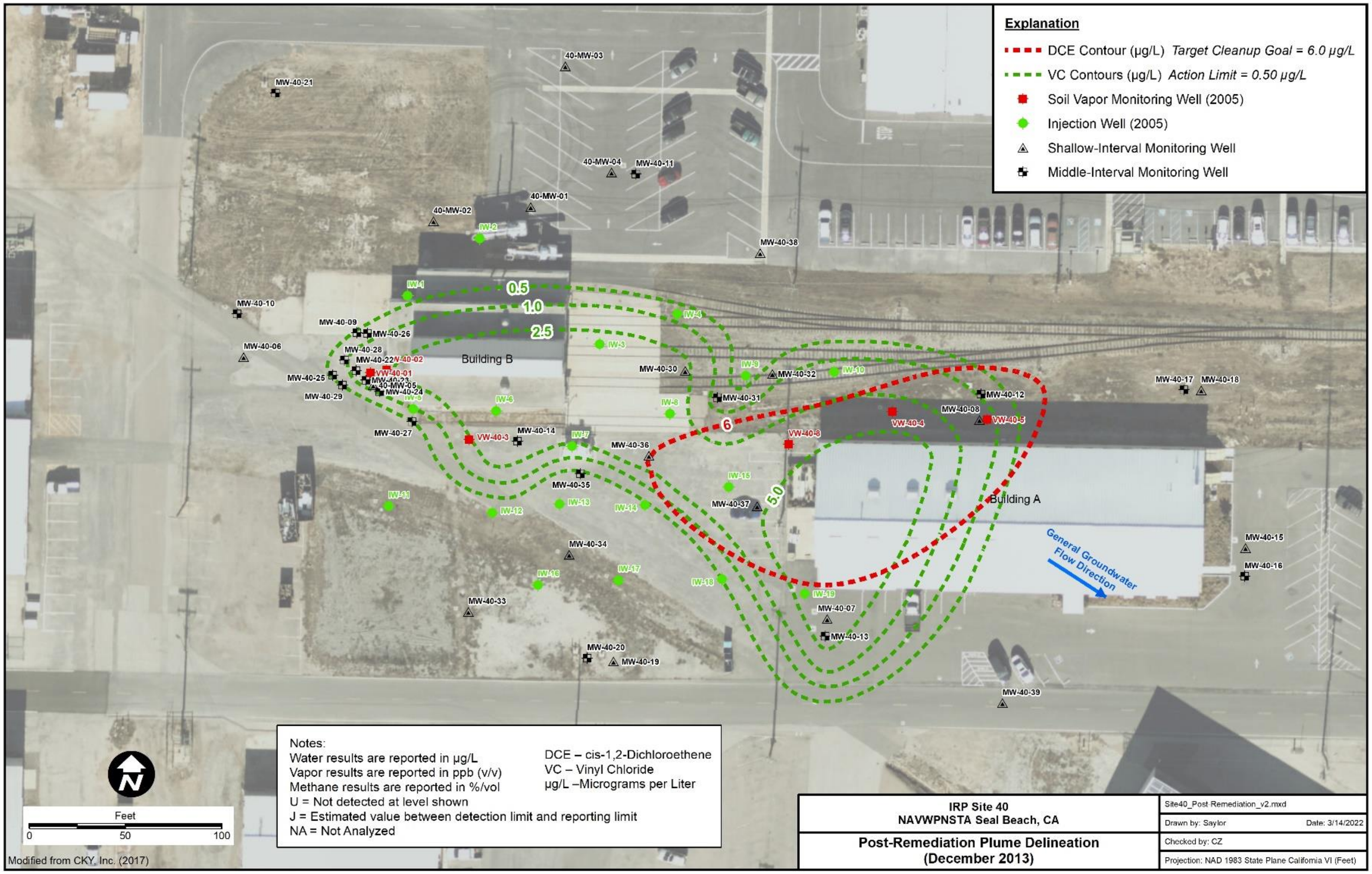

Figure 8. Post-Remediation Plume Delineation at NAVWPNSTA Seal Beach Site 40 (Courtesy of NAVFAC)

5.0 CONCLUSIONS

DON RPMs should keep be aware of technical and regulatory challenges that may be faced in the development of exit strategies and proactively look for solutions.

Challenges: As previously stated, site-related, technical, and/or regulatory challenges can be encountered when attempting to receive concurrence on exit strategies or site closure.

Site-related and technical challenges may include:

- Complex site conditions (e.g., fractured bedrock);
- Recalcitrant compounds;
- Emerging contaminants (e.g., per- and polyfluoroalkyl substances [PFAS]);
- Inadequate CSM; and
- Inefficient and/or ineffective technologies.

Regulatory challenges may include:

- Delays in document reviews and approvals;
- Lack of consensus or concurrence on strategies/metrics;
- Regulatory variability, such as inconsistent application of standards, guidance, or site-specific requirements being applied from regulator to regulator; and
- Multiple regulatory authorities/stakeholders with differing requirements or approaches.

Furthermore, there is state-to-state variability in exit strategy acceptance. States may have regulations or standards that are more stringent than Federal requirements (NAVFAC, 2019). States may vary significantly in their acceptance of new strategies or methodologies such as NSZD or LNAPL transmissivity. Regulatory variability can vary within a state as well. At some complex, longer-term sites, regulators assigned to the site may change over time. It is not uncommon for different regulators to vary in their interpretation of site conditions. In some instances, this may create additional delays when additional regulatory requests are made (e.g., additional site characterization, monitoring, modeling, etc.). These more conservative requests also lead to increased cost and required resources. In some situations, a site could be re-opened after it has been closed, especially when emerging contaminants are identified or new conditions are identified during property transfer activities.

Solutions to Challenges: The following is a list of best practices that will help facilitate the most efficient and cost-effective path to SC:

- Involve all stakeholders early on in discussions related to SC. Building trust and communication with all relevant stakeholders is critical for success.
- Formulate a plan of negotiation and areas of potential compromise with stakeholders.

- Document all decisions. In some cases where a site goes through several regulators, documentation is critical.
- Provide multiple lines of evidence to satisfy regulatory concerns, ensure sources are controlled, and ensure risks are mitigated.
- Apply lessons learned from similar types of sites or from other sites located in the same state and/or at the same installation.
- Continuously re-evaluate and update the CSM. The original site exit strategy may need to be amended as new data become available.

In summary, the development of exit strategies leading to site closure can be a complex process with many considerations. Development of a robust CSM, sound remedial technology selection, continuous process optimization, and most importantly, frequent communication among stakeholders are all key components of a successful site closure process.

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