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Recommendations To Improve the Cleanup Process for California's Leaking Underground Fuel Tanks (LUFTs)

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Executive Summary

This document summarizes the findings, conclusions, and recommendations resulting from an 18 month review of the regulatory framework and cleanup process currently applied to California's leaking underground fuel tanks (LUFT). This review was conducted by the Lawrence Livermore National Laboratory (LLNL) and the University of California at Berkeley, Davis, Los Angeles, and Santa Barbara at the request of the State Water Resources Control Board (SWRCB), Underground Storage Tank Program. The recommendations are made to improve and streamline the LUFT cleanup decision-making process.

Findings

LUFT Impacts to Groundwater Resources

Out of 12,151 public water-supply wells tested statewide, only 48 (0.4%) were reported to have measurable benzene concentrations. A review of the state's database of 28,051 LUFT cases shows that 136 LUFT sites (0.5%) have reportedly affected drinking water wells. Most of the affected wells are shallow private domestic wells in close proximity to the LUFT release site.

The total potential volume of groundwater impacted by LUFT plumes greater than 1 part per billion (ppb) benzene was estimated to be 0.0005% of California’s total groundwater basin storage capacity.

Groundwater cleanup policies are not applied to many sources of groundwater contamination because well construction standards have proven to be protective, it is not practical to regulate some types of sources, and the contaminants typically undergo rapid degradation in the subsurface.

Derivation of LUFT Cleanup Requirements

Under current regulations and policies, the minimum cleanup standards for LUFT cases affecting groundwater are the maximum contaminant levels (MCLs) for drinking water. Numeric cleanup standards are not established for residual fuel hydrocarbons (FHCs) in soil.

Application of LUFT Regulatory Framework and Cleanup Requirements

Even though there is a widely voiced complaint that the LUFT corrective action process is inconsistently applied, groundwater cleanup standards and soils cleanup guidance are consistent with the Water Code and SWRCB resolutions.

Groundwater cleanup requirements were found to be consistently applied statewide due to the presence of numerical standards. These groundwater cleanup requirements do not permit balancing of considerations of technical and economic feasibility, and protection of human health, the environment, and beneficial water uses as required by the Water Code.

While soils cleanup guidance is consistent with SWRCB resolutions, actual soils cleanup requirements vary in practice because there are no numeric standards.

Technical Feasibility

If a FHC source is removed, passive bioremediation processes act to naturally reduce FHC plume mass and to eventually complete the FHC cleanup. Benzene plume lengths tend to stabilize at relatively short distances from the FHC release site. Remediation alternatives that utilize pump and treat are recognized as being ineffectual at reaching MCL groundwater cleanup standards for FHCs in many geologic settings. Passive bioremediation can provide a remediation alternative that is as efficient as actively engineered remediation processes such as pump and treat.

Economic Impact of Current LUFT Problem

The current LUFT decision-making process does not result in cost-effective site closures, in part, because financial incentives to support this result do not exist for cases in the UST Cleanup Fund. The average cost of each LUFT case cleanup is $150,000. The overall fiscal effect of ongoing and future LUFT cleanups on the California economy can be estimated to be about $3 billion. About $1.5 billion will be raised by the time the UST Cleanup Fund storage fee ends in 2005. The current policies and regulations value FHC affected groundwater at about $637,000 per acre-foot.

Applicability of Risk-Based Corrective Action (RBCA) to LUFT Decision Making

A statewide, consistently applied RBCA decision-making framework will allow regulators and responsible parties (RPs) to know where they are in the decision-making process and what steps to take next. A RBCA approach to LUFT cleanups will provide guidance to reasonably manage risks to human health, ecosystems, and groundwater beneficial uses while considering technical and economic feasibility. The recently developed American Society for Testing and Materials (ASTM) RBCA framework offers a promising tiered decision-making approach to LUFT cleanups.

Conclusions

Fuel hydrocarbons (FHCs) have limited impacts on human health, the environment, or California’s groundwater resources. Where shallow groundwater has been impacted by LUFT FHCs, well construction standards provide protection of deeper drinking water wells. The costs of cleaning up LUFT FHCs are often inappropriate when compared to the magnitude of the impact on groundwater resources.

LUFT groundwater cleanup goals are derived from policies that are inconsistent with the current state of knowledge and experience. Since the LUFT Manual was prepared, the understanding of FHC fate and transport processes in subsurface environment has increased and new understanding of passive bioremediation processes is not reflected in the present LUFT cleanup process. There are few situations where pump and treat should be attempted.

The State Water Resources Control Board (SWRCB) policies that set groundwater cleanup requirements to MCLs or background are a barrier to setting risk-based groundwater cleanup goals and closing LUFT cases based on an evaluation of risk to human health and the environment.

A RBCA framework offers a common decision-making process to systematically address LUFT cleanup and reduce inconsistencies. In order for the ASTM RBCA framework to be used in California, modification would be necessary. This modified ASTM RBCA approach can incorporate the results of the SWRCB's historical LUFT case analysis to reflect California’s site-specific exposure parameters, as well as quantify the uncertainty in the assumptions that are used during risk evaluations. In addition, a modified ASTM RBCA tiered, decision-making approach will allow the formulation of streamlined closure criteria that can encompass a majority of California's LUFT cases.

Recommendations

Utilize passive bioremediation as a remediation alternative whenever possible

Minimize actively engineered LUFT remediation processes. Once passive bioremediation is demonstrated and unless there is a compelling reason otherwise, close cases after source removal and rely on passive bioremediation to cleanup FHCs. In general, do not use the UST Cleanup Fund to implement pump and treat remediation unless its effectiveness can be demonstrated.

Immediately modify the ASTM RBCA framework based on California historical LUFT case data

Perform LUFT historical case studies on soils-only cases to support development of a RBCA tier-one decision-making process. Use LUFT historical case data to modify ASTM RBCA to reflect California’s site-specific exposure pathways and quantify the uncertainty in the assumptions that are used during risk evaluations. The modified ASTM RBCA tier-one decision-making process should encompass a majority of California’s LUFT cases and facilitate and encourage the utilization of passive bioremediation.

Apply a modified ASTM RBCA framework as soon as possible to LUFT cases where FHCs have affected soil but do not threaten groundwater

There are no existing barriers to implementing ASTM RBCA at LUFT sites where FHCs have only affected soils.

Modify the LUFT regulatory framework to allow the consideration of risk-based cleanup goals higher than MCLs

Modify SWRCB policies to remove barriers to applying a modified ASTM RBCA framework to FHCs affecting groundwater. Once SWRCB policy barriers have been removed, apply ASTM RBCA process to LUFT cases where FHCs have affected groundwater.

Identify a series of LUFT demonstration sites and form a pilot LUFT closure committee

LUFT demonstration sites should be chosen to:

- Act as training grounds for implementation of a modified ASTM RBCA process.
- Facilitate the implementation of a revised LUFT decision-making process.
- Test recommended sampling and monitoring procedures and technologies to support passive bioremediation.
- Confirm cost effectiveness of the modified ASTM RBCA process.

A pilot LUFT closure committee, made up of scientific professionals from universities, private industry, and state agencies, should be set up to make professional interpretations and recommendations regarding LUFT evaluations and closures at the demonstration sites.

1. Introduction

In July 1994, the California State Water Resources Control Board (SWRCB) Underground Storage Tank (UST) Program embarked on a reevaluation of the Leaking Underground Fuel Tank (LUFT) cleanup procedures. To support this effort, the SWRCB UST Program contracted with the Lawrence Livermore National Laboratory (LLNL) and the University of California at Berkeley, Davis, Los Angeles, and Santa Barbara to form a team of scientific experts (the UC LUFT Team) to review the existing LUFT cleanup decision-making process and submit recommendations for improvement. This review was a collaborative effort among the SWRCB staff, LLNL, and UC LUFT Team members. Financial support for this effort was provided, in part, by the U.S. Environmental Protection Agency (EPA), Region IX, UST Program.

The objective of this collaborative research was to evaluate the present regulatory framework of the SWRCB and regional water quality control boards (RWQCBs) and to recommend any revisions necessary to streamline the petroleum UST site investigation and cleanup decision-making process to protect human health and the environment. This revised decision-making process would allow consideration of (1) the application of natural passive bioremediation processes to fuel hydrocarbons (FHCs), (2) eventual land use, and (3) existing and probable beneficial uses of water resources during the remediation process. Emerging characterization and monitoring technologies would also be recommended to support a revised LUFT cleanup decision-making approach.

In conjunction with the SWRCB review of the LUFT cleanup procedures, the California state legislature instituted Senate Bill 1764 (SB 1764, Thompson), which required the SWRCB to form a separate scientific committee to review the LUFT cleanup procedures and make recommendations to the legislature for any necessary changes. As part of SB 1764 committee's proceedings, the views of industry trade groups, consultants, contractors, impacted parties, environmental groups, and regulators were solicited through a request for white papers that address problems in the existing LUFT cleanup process and propose recommendations for improvement.

2. Methods

During the UC LUFT Team's research, available information was thoroughly evaluated to establish appropriate state-of-the-art approaches pertaining to:

- Current LUFT decision-making procedures and regulatory framework.
- Environmental fate and transport of petroleum constituents in soil, the vadose zone, and groundwater.
- Applicable LUFT cleanup characterization and monitoring technologies.

This evaluation included information available from:

- Extensive searches of scientific literature.
- U.S. EPA, Office of Underground Storage Tanks.
- American Petroleum Institute.
- American Society for Testing and Materials (ASTM).
- Council for the Health and Environmental Safety of Soil.
- U.S. Air Force Center for Environmental Excellence.
- Researchers working on Department of Energy efforts to deal with soil and groundwater contamination.

In addition, the UC LUFT Team reviewed the numerous white papers submitted to the SB 1764 LUFT committee.

As a precursor to developing decision-making approaches, the UC LUFT Team identified the decisions and characterization parameters that are necessary to implement a LUFT corrective action, including the selection of an appropriate remediation method. The parameters affecting the environmental fate of FHCs that were considered included the physical and chemical properties of soil, groundwater, and petroleum products, and subsurface microbiological activities.

A major component of the LUFT reevaluation effort was a case file analysis of more than 1,500 LUFT cases reported between 1985 and 1995. This LUFT historical case analysis was used to evaluate the FHC plume impacts on groundwater resources, behavior and factors that influence plume length and mass, and adequacy of historically collected decision-making data. This information was used during the evaluation of criteria for determining when remediation had been satisfactorily completed, the cleanup requirements for responsible parties (RPs), and the policies, guidelines, and methods that are used to establish those requirements. The UC LUFT

Team assisted the SWRCB in preparing the data-gathering procedures and database structure, identifying important questions to be asked of the resulting database, performing statistical analysis of the data, and integrating the data analysis results into a final report (Rice *et al*., 1995).

3. Background

3.1. Regulatory Framework

California USTs are regulated through a framework of laws, regulations, and state, regional, and local policies. The California Water Code is the law from which regulations and policies are derived. SWRCB resolutions are policies used to implement the Water Code. SWRCB resolutions are prepared though a public hearing process and consideration of the current state of knowledge and experience.

The Porter–Cologne Water Quality Control Act, Chapter 1 (commencing with Section 13000), Division 7, of the California Water Code, stipulates to state and regional water boards that "… those activities and factors (that) may affect the quality of the waters of the state shall be regulated to attain the highest water quality which is reasonable; considering all demands being made and to be made on those waters and the total values involved, beneficial and detrimental, economic and social, tangible and intangible …."

Because different regions have a range of hydrogeologic settings and water management practices and uses, the SWRCB and RWQCBs are required by law to manage the state's water resources through a policy that considers "... factors of precipitation, topography, population, recreation, agriculture, industry and economic development (that) vary from region to region within the state, and that the statewide program can be most effectively administered regionally, within a framework of statewide coordination and policy (California Water Code, Chapter 1, Section 13000, Division 7)."

The RWQCBs develop Regional Basin Plans to establish the present and probable beneficial uses of water within their regions, and these plans are subject to State Board policies during the formulation of water quality objectives and beneficial uses. According to Section 13241 of the California Water Code, the factors that RWQCBs should consider in setting water quality objectives "... shall include, but not necessarily be limited to, all of the following:

a) past, present, and probable future beneficial uses of water,

b) environmental characteristics of the hydrographic unit under consideration, including the quality of water available thereto,

c) water quality conditions that could reasonably be achieved through coordinated control of all factors which affect water quality in the area,

d) economic considerations,

e) the need for developing housing in the region, and

f) the need to develop and use recycled water."

In 1983, California began to regulate USTs containing FHCs, such as gasoline, diesel fuel, and fuel oils, in response to a perceived threat to the state's groundwater resources. A 1984 survey showed that there were approximately 200,000 USTs within the state.

California Underground Storage Tank Regulations were promulgated in 1985 by the SWRCB. According to these regulations, an RP is required to perform soil and groundwater investigations if any of the following circumstances apply:

1. There is evidence that surface water or groundwater has been or may be affected by the unauthorized release.
2. Free product is found at the site where the unauthorized release occurred or in the surrounding area.
3. There is evidence that contaminated soils are or may be in contact with surface water or groundwater.
4. The regulatory agency requests an investigation, based on the actual or potential effects of contaminated soil or groundwater on nearby surface water or groundwater resources or based on the increased risk of fire or explosion.

The California LUFT Field Manual was prepared in 1985 to address the regulatory problem of a growing number of contaminated fuel sites. The document was created by a 38-member LUFT Task Force, made up of a multiagency working group from the California Department of Health Services (DHS) and from the SWRCB staff from both the state and regional levels. The original LUFT Field Manual was last revised in 1989 (SWRCB, 1989).

The LUFT Field Manual procedures were intended to avoid unwarranted expense, analysis, or delays, while ensuring that site characterization analysis is adequate for identifying the extent of, and designing an appropriate response to, FHC soil contamination problems. The intended users included regulators and environmental engineering consulting firms that assist RPs in performing LUFT cleanups.

California is currently faced with about 21,000 active LUFT sites that must be evaluated to manage potential threats to human health, the environment, and groundwater resources. LUFT regulatory oversight is conducted by nine RWQCBs and 20 local oversight program (LOP) regulatory agencies (19 counties and one water district) under contract with the SWRCB. RWQCBs and LOP agencies are responsible for determining when cleanup requirements have been met and LUFT cases can be closed.

4. Findings

4.1. LUFT Impacts to Groundwater Resources

4.1.1. Impacts to Public Water-Supply Wells

- Out of 12,150 public water-supply wells tested statewide, 48 were reported to have measurable benzene concentrations.

The original LUFT Field Manual was prepared in an atmosphere of concern about "time bomb plumes." The capacity of the environment to naturally degrade FHCs was not recognized or considered (P. Hadley, written communication to J. Giannopoulos, 1995). There was a perception that with benzene in, or interconnected with, a usable aquifer, it was only a question of time as to when benzene would reach a municipal or domestic water-supply well. However, the weight of evidence is against this happening. A survey of well testing data from 7,167 California water-supply wells, during the period 1986–1989, found 10 water-supply wells (0.1%) affected by benzene (Hadley and Armstrong, 1991). A more recent evaluation of well testing data, during the period 1986–1995, indicates that out of more than 12,150 water-supply wells, 48 (0.4%) were reported to have detectable benzene concentrations (K. Ward, written communication to J. Giannopoulos, 1995). Of these, six (0.05%) could be attributed to LUFT releases.

4.1.2. LUFT FHC Impacts to Drinking Water Wells

- A review of the state's database of 28,051 LUFT cases shows that 136 LUFT sites have reportedly affected drinking water wells.
- Most of the affected wells are shallow private domestic wells in close proximity to the LUFT release site.

A review of the state's database of 28,051 LUFT cases, which extends over 10 years and includes both active and closed cases, shows that 136 LUFT sites have reportedly affected drinking water wells (SWRCB LUSTIS, 1995). This represents less than 0.7% of the total number of open LUFT cases. A recent review of 36 LUFT case files (R. Rempel, written communication to J. Giannopoulos, 1995), which have reportedly affected 55 water-supply wells in the Central Valley Region (RWQCB, Region 5), indicates that unreasonable impairment of actual beneficial uses by benzene from LUFT sites is rare. Of the 55 reportedly affected wells, 25 could be attributed to LUFT releases. The impact to Region 5 water-supply wells from LUFT FHCs constituted 0.3% of the total 5,871 LUFT sites in the region. Twenty-four of the 25 affected wells were private-domestic wells. Furthermore, the review found that 11 of the 24 affected private-domestic water-supply wells were the LUFT sites' own shallow onsite wells. The review concluded that the LUFT threats to groundwater resources should be evaluated based on proximity and construction of water-supply wells within a few hundred feet of the LUFT site.

4.1.3. Use of Well Construction Standards

- Separation between known or suspected sources of pollution and contamination is required during the siting and construction of water wells.

In addition to remediation, there are other ways that California prevents human and ecological exposure to LUFT FHCs. Shallow groundwater is often degraded from a variety of sources. California Well Standards outlined in California Department of Water Resources Bulletins 74-90 and 74-81 (CDWR, 1991) indicate that separation between known or suspected sources of pollution and contamination is required during the siting and construction of water wells. In addition to above- and below-ground tanks and pipelines for the storage and conveyance of petroleum products, sources of pollution and contamination identified by the California Well Standards include: sanitary sewers; storm drains; septic tank leach fields; sewage and industrial waste ponds; barn yard and stable areas; feedlots; solid waste disposal sites; and storage and preparation areas for pesticides, fertilizers, and other chemicals.

Well construction and separation standards have been found to prevent exposure to many of these contaminants and protective of human health and the environment. Groundwater cleanup policies are not applied to many of these sources of groundwater contamination because well construction standards have proven to be protective, it is not practical to regulate these sources, and the contaminants typically undergo rapid degradation in the subsurface. The impact to the 11 on-site private-domestic water-supply wells affected by LUFT FHCs that were identified during the review by R. Rempel (written communication to J. Giannopoulos, 1995) may have been prevented by following the California Well Standards construction requirements.

4.1.4. Volume of Groundwater Affected by LUFT FHCs

- The total potential volume of groundwater impacted by LUFT plumes greater then 1 parts per billion (ppb) benzene was 0.0005% of California's total groundwater basin storage capacity.

About 10,000 LUFT sites have reportedly affected groundwater. Using the historical LUFT case analysis (Rice *et al.*, 1995) plume lengths and widths, a conservative estimated total volume of groundwater that may be impacted above a concentration of 1 ppb benzene was 7,060 acre-feet. This volume of affected groundwater is 0.0005% of California's total groundwater basin storage capacity of 1.3 billion acre-feet.

4.2. Derivation of LUFT Cleanup Requirements

4.2.1. Groundwater

- Under current regulations and policies, the minimum cleanup standards for LUFT cases affecting groundwater are the maximum contaminant levels (MCLs) for drinking water.

For FHC releases, the primary constituent of concern is benzene with a California MCL of 1 ppb. This groundwater cleanup standard for LUFT cases is required by SWRCB and RWQCB adopted policies and plans as described below.

SWRCB Resolution 88-63, known as the Sources of Drinking Water Policy, requires a broad application of the municipal (MUN) designation to groundwaters. Resolution 88-63 was adopted in response to Proposition 65, which prohibited introduction of a carcinogen into any drinking water source. The SWRCB determined that any aquifer that could produce over 200 gallons per day and had less than 3,000 mg/L total dissolved solids would suffice as a "potential" source of drinking water. As a result, with few exceptions, bodies of groundwater in the state are regulated as MUN water quality. Availability of alternative sources of drinking water, cost of resource development, threat of subsidence or salt water intrusion, and/or potential for contamination from other sources are not considered (Fox, 1995). In many cases, cleanup is required even when public utilities and residents in the area both agree that the water will never be utilized (Graves, 1995a; Earnest, 1995).

RWQCB basin plans specify MCLs as protective of groundwater with a MUN designation. In California, these basin plans not only include the lowest MCLs in the nation, but also identify taste and odor as secondary MCLs. For benzene, the California MCL is 1 ppb, with an MCL goal of 0 ppb (nondetect). The U.S. EPA’s MCL for benzene is 5 ppb.

SWRCB Resolution 92-49 states that the setting of cleanup concentrations above background shall not result in water quality less than that prescribed in adopted plans and policies, e.g., basin plans. Therefore, the range of possible cleanup requirements for groundwaters is between MCL and non-detect.

SWRCB Resolution 68-16, known as the Non-Degradation Policy requires that waters that are of higher quality than the water quality objectives within a basin plan must be maintained at the higher quality. Through the interpretation of this resolution, cleanup standards are broadly applied to all points within a groundwater basin.

Resolution 68-16 also specifies that cleanup requirements assure that the highest water quality consistent with the maximum benefit to the people of the state will be maintained. Through Resolutions 88-63 and 92-49, the consideration of maximum benefit is limited to the range between MCLs and non-detect for most groundwater basins in the state.

4.2.2. Soils

- Numeric cleanup standards are not established for residual FHCs in soil.

The flexibility in LUFT soils cleanup requirements is greater than groundwater cleanup requirements. Numeric cleanup standards are not established for residual FHCs in soil. The LUFT Field Manual deals with soils-only FHC contamination; it does not offer guidance to deal with FHC plumes in groundwater because policies require groundwater cleanup to MCLs or nondetect.

Because most LUFT cases have occurred in locations with shallow depth to groundwater, there is a high probability of LUFT FHCs reaching groundwater. Gas stations and, therefore, LUFT sites are concentrated in urban and suburban areas, which are typically associated with layered, alluvial, hydrogeologic settings with a minimum depth to groundwater of 20 ft or less in more than one-half of the cases (Rice *et al*., 1995).

The LUFT Field Manual was intended to provide practical guidance to regulatory agencies and parties responsible for dealing with residual FHCs in soil associated with leaking fuel tanks. The fate and transport of FHCs in the subsurface is complex, and the influence of unique site-specific factors that influence FHC transport may be strong (Rice *et al*., 1995). Although the LUFT Field Manual was initially considered to be among the best working documents for dealing with subsurface FHC leaks, it has come under criticism in recent years as being unrepresentative of statewide LUFT site hydrogeologic conditions. As a result, the actual use of the LUFT Field Manual has been limited in California.

4.3. Application of LUFT Regulatory Framework and Cleanup Requirements

4.3.1. Groundwater

- Groundwater cleanup standards are consistent with SWRCB resolutions.

- Groundwater cleanup requirements were found to be consistently applied statewide due to the presence of numerical standards.
- These standards do not permit balancing of considerations of technical and economic feasibility, and protection of human health, the environment, and beneficial water uses as required by the Water Code.

There is a widely voiced complaint that the LUFT corrective action process is inconsistently applied. However, during the LUFT Team's research, groundwater and soils cleanup requirements were found to be consistent with SWRCB policies. Groundwater cleanup requirements were found to be consistently applied statewide due to the presence of numerical standards, e.g., MCLs.

In practice, because it is impracticable to remove the last bit of residual FHC, drinking water MCLs are often adopted as a more realistic cleanup target than the background concentrations (nondetect) that Resolutions 68-16 and 92-49 would require. G. Torres (written communication, 1993) found that groundwater cleanup standards often default to drinking water supply action levels or California MCLs for benzene (1 ppb), toluene (100 ppb), ethylbenzene (680 ppb), and xylenes (1,750 ppb), as opposed to taste and odor thresholds. Sixty-five percent of the closed groundwater-impacted cases were remediated to concentrations below the California MCL cleanup standard.

While groundwater cleanup standards are consistent with SWRCB resolutions, however, these standards are very restrictive and may be inappropriate. These requirements do not permit the balancing of considerations of technical and economic feasibility, and protection of human health, the environment, and beneficial water uses as required by the Water Code. Many cases are difficult to close because the existing groundwater standards and goals are often technically and economically infeasible and no systematic, statewide decision-making framework exists for closing LUFT cases above MCLs.

4.3.2. Soils

- Soils cleanup guidance is consistent with the Water Code and SWRCB resolutions.
- Actual soils cleanup requirements vary in practice because there are no numeric standards.

The current LUFT Field Manual guidance tables were developed using the one-dimensional vadose zone transport simulation model, SESOIL. The LUFT guidance tables allow a cumulative soil concentration of up to 1,000 ppm total petroleum hydrocarbons (TPH), sampled over 5-ft intervals, with no sample concentration to exceed 100 ppm. This guidance is based on earlier experiments performed in well sorted sands.

During the application of this model, the LUFT Field Manual creators made very conservative assumptions about the factors controlling the transport of FHCs to groundwater and regarded groundwater as the ultimate receptor. In practice, soil screening levels offered in the LUFT Field Manual are not sufficiently representative of the diverse geology in California and screening levels became "one-size-fits-all" action limits for determining if there is a threat to groundwater.

A review of 110 closed LUFT case histories from the North Coast, San Francisco Bay, Los Angeles, Central Valley, Santa Ana, and San Diego Regional Water Quality Control Boards by the SWRCB Division of Clean Water Programs staff (G. Torres, written communication, 1993) found that case closure criteria are often not clearly specified or consistently applied. Technical rationale, upon which site cleanup and closure criteria for soil and groundwater are based, is either lacking or inadequately documented. In lieu of cleanup standards grounded in a defensible technical rationale, Torres found that the criteria used for site closure typically default to a soil cleanup level of 100 ppm TPH, which is a screening level set in the LUFT Field Manual.

The Torres review indicated that 70% of the case closure requirements for soil-only impacted sites were below soil concentrations of 100 ppm TPH. Cases where soil concentration goals exceeding 100 ppm TPH were deemed acceptable included cases where underlying groundwater had no beneficial use, high levels of total dissolved solids, or acceptably low BTEX (benzene, toluene, ethyl benzene, xylene) concentrations over extended periods of monitoring. The closure criteria implemented in the remaining closed cases cannot be determined due to the inadequate documentation.

To address some of the perceived difficulties in the representativeness of the LUFT Field Manual, a number of supplementary LUFT guidance documents have been provided at state (SWRCB, 1992a; 1992b; 1993; 1994), regional (CRWQCB, 1993; 1994; 1995a; 1995b), and local levels (Crowley, 1995). This has resulted in a complex regulatory structure that has been inconsistently interpreted and applied across the state.

LOP and RWQCB staff make a variety of judgment calls regarding the determination of an unauthorized release and the establishment of soils cleanup requirements. Action limits are often inconsistently applied because different regulatory oversight programs do not think the limits are representative or are either overly protective or not protective enough of local geologic settings.

Even within the same regulatory oversight agencies case workers are not consistent in their decision-making process. One case worker may follow the letter of the LUFT Field Manual guidance and use the general soil cleanup requirements, while another may make a more site-specific determination of soil cleanup goals and relax the LUFT Field Manual action limits. The inconsistencies in these judgment calls are the result of the different levels of knowledge and experience of LUFT case handlers (Moran, 1995a). This causes different site owners with similar problems to have very different remediation costs (Gustafson, 1995a, b).

4.3.3. Data Collection

- The level of detail, amount, and uses of data collected are not consistent among different regulatory oversight agencies.
- Concerns have been raised concerning the validity of total petroleum hydrocarbon (TPH) measurements .

The data to support LUFT decision-making processes is difficult to access and use. The entire LUFT cleanup process revolves around reports submitted to regulatory agencies. Unauthorized release reports, work plans, remedial investigation and quarterly monitoring reports, and other special investigation results are all submitted during the normal course of a LUFT cleanup. There is essentially no electronic filing of the information that is submitted (Graves, 1995b).

Case records typically are maintained in paper copies. The Water Code endorses the need for an information system to support water resource management. According to the Water Code, Section 13166: "Information Program. The state board, with the assistance of the regional boards, shall prepare and implement a statewide water quality information storage and retrieval program. Such program shall be coordinated and integrated to the maximum extent practicable with data storage and retrieval programs of other agencies." Such a system exists only minimally as a reporting tool to the U. S. EPA and is not used as a LUFT case decision-making tool.

Many current LUFT Field Manual decisions are based on the TPH-gasoline and TPH-diesel concentrations in soil samples collected at the site. Concerns have been raised concerning the validity of TPH measurements because many natural organic compounds can lead to false positive results (Gustafson *et al.*, 1995c) and because inconsistencies in the use of TPH analytical methods make comparisons of results difficult (Clementsen, 1995; Simmons, 1995; Zemo, 1995). Often, TPH measurements are used to predict benzene concentrations. In practice, TPH measurements do not predict benzene concentrations well. Based on the results of the LUFT historical case analysis, where groundwater was measured for both TPH and BTEX compounds at the same time, Rice *et al.* (1995) found that only 60% of the variability in benzene groundwater concentrations were predicted by TPH measurements.

4.4. Technical Feasibility

The current regulatory framework does not allow for alternative approaches if technical or economic infeasibility is determined (Gustafson *et al.*, 1995d). There is no mechanism to define technical and economic feasibility because groundwater is valued at a very high level through the interpretations of Resolutions 88-63, 68-16, and 92-49. During the oversight of LUFT cleanup actions, the Water Code requirements for economic considerations are commonly disregarded (Stephenson, 1995).

4.4.1. Passive Bioremediation

- If a FHC source is removed, passive bioremediation processes act to naturally reduce FHC plume mass and to eventually complete the FHC cleanup.
- Benzene plume lengths tend to stabilize at relatively short distances from the FHC release site.

Subsurface microorganisms have been using petroleum hydrocarbons as a food source long before man began using them as an energy source. While the specific mechanisms by which FHCs are metabolized and degraded are not completely understood, knowledge of this phenomenon, gained from empirical studies, can nevertheless be incorporated into the management of site investigations and remediation.

The lack of widespread impact of LUFT plumes is because FHC plumes are often limited in extent. Based on groundwater flow velocity, and soil and FHC properties, we can now estimate the extent of FHC plumes. We now know that when plume lengths are measured in the field, plume length stability is often reached at a distance from the source shorter than would be expected without considering natural biodegradation. Groundwater scientists now recognize that a major factor responsible for the shorter stable plume lengths is the aerobic and anaerobic metabolism of indigenous soil microorganisms that digest FHCs and remove FHC mass from the plume (Scow, 1982; Barker *et al.*, 1987; Rifai *et al.*, 1988; Chiang *et al.*, 1989; Cozzarelli *et al.*, 1990; Baedecker *et al.*, 1992, 1993; Bennett *et al.*, 1993; Daniel, 1993; Eganhouse *et al.*, 1993; Salanitro, 1993; Cozzarelli *et al.*, 1994; NRC, 1994; Borden *et al.*, 1995; McNab and Narasimhan, 1995).

As groundwater flows through an area where FHCs are present in the soils, FHCs dissolve into the groundwater and are transported downgradient. Natural ubiquitous microbial populations in the soil are stimulated and begin degrading the FHC to organic acid intermediates, and, finally, to carbon dioxide and water. The microbes preferentially use oxygen as an electron acceptor, but switch to other electron acceptors, such as NO_3^{-1}, Fe^{+2}, Mn^{+2}, and SO_4^{-2} (Cozzarelli and Baedecker, 1992; Salanitro *et al.*, 1993). This process results in a large core area of the plume in which oxygen, pH, and oxidation-reduction potential measurements are low, whereas inorganic ion measurements of NO_3^{-1}, Fe^{+2}, Mn^{+2}, and SO_4^{-2} may be elevated relative to a measurement location upgradient to the FHC release. Around the margins of the plume is a transition zone in which oxygen becomes increasingly more available and aerobic microbial degradation of FHCs proceeds. The anaerobic core of the plume is much larger in area than the aerobic plume margins. Typically, biodegradation of FHCs proceeds most rapidly under aerobic conditions, whereas the bulk of the FHC mass is degraded more slowly within the larger anaerobic core.

The ability of microorganisms to degrade FHCs will be limited by the availability of electron acceptors (Bouwer and McCarty, 1984; Vogel *et al.*, 1987), but Air Force studies indicate that the availability of electron acceptors may not be limiting and there is usually an excess capacity for microbial FHC biodegradation (Wilson *et al.*, 1994). Because of this excess capacity, passive bioremediation may be expected to stabilize an FHC plume's length and mass, in spite of the presence of an active source that may be continually dissolving new FHC mass into the plume.

If the FHC source is removed to the point of residual saturation, these passive bioremediation processes act to naturally reduce FHC plume mass and eventually complete the FHC cleanup. A FHC will spread primarily due to the influence of gravity until the point is reached at which the fluid no longer holds together as a single continuous phase, but rather lies in isolated residual globules, i.e., in the so-called condition of residual saturation. At that point, the FHC has become largely immobile under the usual subsurface pressure conditions and can migrate further only: 1) in water according to its solubility; or 2) in the gas phase of the unsaturated zone (Schwille, 1988).

In a recent review of 200 LUFT cases in Napa County, 57 cases had groundwater impacts by FHCs. An analysis of FHC plume lengths in 51 of these cases, indicated that plume total petroleum hydrocarbon-gasoline (TPHg) concentrations greater than 50 ppb, the detection limit for TPHg, did not extend beyond 200 ft in 90% of the cases (R. Lee, written communication to S. Ritchie, 1995). Once contaminant sources were removed and the plume was stabilized, FHCs in groundwater appeared to degrade naturally, in some cases at a rate of 50%–60% per year.

The detailed analysis of 271 LUFT cases by the SWRCB (Rice *et al.*, 1995) as part of an evaluation of more than 1,500 LUFT cases reported between 1985 and 1995 from 13 counties, indicated that, in general, plume lengths change slowly and tend to stabilize at relatively short distances from the FHC release site. Using 10 ppb as a practical limit of quantitation for plume length estimates, this study found that plume concentrations greater than 10 ppb benzene extended no more than about 250 feet in 90% of the cases. This finding supports the results of the Napa County study.

4.4.2. Actively Engineered Remediation—Pump and Treat

- Pump and treat remediation alternatives are recognized as being ineffectual at reaching MCL groundwater cleanup standards for FHCs within many geologic settings.
- Passive bioremediation can provide a remediation alternative that is as efficient as actively engineered remediation process such as pump and treat.

During LUFT site remediation, FHC-contaminated groundwater is typically captured using groundwater extraction wells and then treated aboveground to remove the FHCs. Often, the treated groundwater is disposed of by releasing it to surface drainage or sanitary sewers, wasting the resource. This remediation alternative is referred to as pump and treat. Even though contaminated groundwater can be removed, the FHCs sorbed to the soil particulates tend to remain (Freeze and Cherry, 1979; Isherwood *et al.*, 1993; Cole, 1994). Hundreds of volumes of water may be required to flush the FHC off the contaminated solid particulates (Bear *et al.*, 1994). This flushing can be very slow and expensive and may take several tens of years to reach MCLs.

The LUFT historical case data analysis (Rice *et al.*, 1995) indicates that plume lengths decrease much more slowly than plume masses. This may occur because the FHCs sorbed onto the soil particulates tend to inhibit changes in plume length. Even if groundwater FHC concentrations become low, the soils desorb FHCs slowly back into groundwater (Karickhoff *et al*., 1979) and a measurable plume length may persist. The length of the lingering plume is defined by the extent of the soils with residual sorbed FHCs. This difficulty with removing the FHC mass sorbed onto the soil particulates is one of the primary reasons that pump and treat remediation alternatives are recognized as rarely effective at reaching MCL cleanup goals in many hydrogeologic settings (Ross, 1993; MacDonald and Kavanaugh, 1994; NRC, 1994; U.S. EPA, 1994).

In the exceptional cases where the FHC source was quickly controlled and removed, and a relatively small dissolved FHC plume has not diffused deeply into the solid materials in a shallow aquifer, pump and treat has achieved risk-based cleanup goals (MacDonald and Kavanaugh, 1994; NRC, 1994). However, the success of pump and treat at these sites is largely due to the action of passive bioremediation.

Although active remediation may help reduce dissolved plume mass, significant mass reduction can occur with time, even without active remediation (Rice *et al.*, 1995). In about 50% of the cases where no actively engineered remediation was reported, plume average groundwater benzene concentrations still decreased. In cases where pump and treat was reportedly used in conjunction with over excavation, the likelihood of decreasing plume average benzene concentrations with time improved by about 30% over instances where no active remediation was reportedly performed (Rice *et al.*, 1995).

The LUFT historical case analysis (Rice *et al.*, 1995), the Napa County LUFT plume study (R. Lee, written communication, to S. Ritchie, 1995), and other historical case studies (Hinchee *et al*., 1986; Buscheck *et al.*, 1993; McAllister and Chiang, 1994) found that once a FHC source is removed, the time for passive bioremediation to reduce dissolved FHC plume mass by a factor of 10 is about 1 to 3 years. Thus, passive bioremediation can provide a remediation alternative that is as efficient as actively engineered remediation.

4.5. Economic Impact of Current LUFT Problem

4.5.1. Lack of Financial Incentives

- The current LUFT decision-making process does not result in cost-effective site closures, in part, because financial incentives to support this result do not exist for cases in the UST Cleanup Fund.

Based on anecdotal interviews with regulatory case workers, it is easier to keep a case open and receive funds from the UST Cleanup Fund than to make a decision to close the case (Dembroff, 1995). Furthermore, a perception that the UST Fund is a “golden goose” does not encourage RPs or their consultants or contractors to actively pursue site closure.

To recover a perceived property value loss of a few tens of thousands of dollars, an RP can spend a million dollars from the UST Cleanup Fund for cleanup at a site with groundwater that poses a minimal risk or has limited beneficial use. Cleanup performance criteria are not linked to UST Cleanup funding.

4.5.2. UST Cleanup Costs

- The average LUFT case reimbursement from the UST Cleanup Fund is currently about $150,000.
- The ongoing and future fiscal effect of LUFT cleanups on the California economy is estimated to be over $3 billion.
- Only about $1.5 billion will be raised by the time the UST Cleanup Fund program ends in 2005.

Federal regulations and state law declare that by 1998, all operating USTs must be upgraded or replaced to meet new standards to reduce the likelihood of future contamination of groundwater resources. The initial rate of tank removal and replacement was slow, but as removals and upgrades continue, remediation cases will also increase, causing a climbing debt to RPs and to the state. Less than 60% of the operating USTs have been upgraded or replaced.

The Barry Keene Underground Storage Tank Cleanup Trust Fund Act of 1989 established the California Underground Storage Tank Cleanup Fund. An aggregate storage fee of six-tenths of a cent (i.e., six mills) for each gallon of petroleum placed in a UST is required to be deposited in the fund to pay for LUFT cleanups. Owners and operators of petroleum USTs are responsible for the first $5,000 to $10,000 of cleanup per site. Residential tank owners do not have a deductible. Cleanup costs above this are reimbursed from the fund up to $1 million. Any costs beyond this become the responsibility of the site owner.

To date, over 10,000 applications have been received by the UST Cleanup Fund for reimbursement. According to the UST Cleanup Fund, the average cost of each LUFT case cleanup is about $150,000. Applying this information to the approximately 20,000 currently open LUFT cases, the estimated cost to the California public is about $3 billion. If the approximately

7,000 previously closed sites are also included in this estimated cost, the overall fiscal effect of LUFT cleanups on the California economy can be estimated to be about $4 billion. There is some uncertainty in these numbers, because the average cost does not include costs over $1 million, the limit of fund reimbursement, and many applicants estimate the full amount of $1 million, even though they have not started cleanup efforts. Further, as the UST upgrade and replacement process continues, additional leak sites will be discovered, making these cost estimates conservative.

SB 1764, instituted in 1994, called for a fee increase to seven mills as of November 1, 1995, with further increases to nine mills on January 1, 1996, and 12 mills as of January 1, 1997. The fee increase is expected by legislative analysts to generate an additional $697 million between 1995 and 2005 when the storage fee ends. The projected income to the fund, generated from sales of petroleum, will be about $1.5 billion. Therefore, given the estimated cost to the California public of about $3 billion, there is a projected shortfall in funding of about $1.5 billion.

4.5.3. The Value of Groundwater

- The current policies and regulations value groundwater too highly.

The average cost of a LUFT groundwater cleanup has been estimated to be $450,000 (C. Stanley, personal communication). If this cost estimate is applied to the 0.7 acre-foot estimated average volume of 1 ppb benzene plumes (Rice, *et al.*, 1995), the value of the affected groundwater can be estimated to be $637,000 per acre-foot. In comparison, the current cost of developing a new water supply in California is estimated to be $700 to $900 per acre-foot. These are important economic factors, which, by state law, must be taken into account when developing cleanup requirements and policies.

4.6. Applicability of Risk-Based Corrective Action (RBCA) to LUFT Decision Making

Existing language within the Water Code has appropriate guidance to make needed changes to the LUFT cleanup decision-making process. The requirement to consider reasonable risk and economic and technical feasibilities already exists within the current regulatory structure. An RBCA decision-making approach meets the following requirements:

4.6.1. Systematized Site Evaluation and Selection of Cleanup Requirements

- A RBCA approach to LUFT cleanups will provide guidance to reasonably manage risks to ecosystems, and groundwater beneficial uses, as well as human health, while considering technical and economic feasibility.

A RBCA approach to LUFT cleanups will provide guidance to reasonably manage risks to ecosystems, and groundwater beneficial uses, as well as human health, while considering technical and economic feasibility (Feldman, 1995; Gustafson *et al.*, 1995e; Sickenger, 1995). The basic dividing point for an FHC remediation policy is whether its driver is to be MCLs or a risk-based consideration of FHC sources, exposure pathways, and receptors (Russell, 1995).

The existing LUFT decision-making framework is based on the problem of waste being where it is not supposed to be. In this approach, the assumption is that all sites must be returned to original cleanliness. The offsetting determinations of technical feasibility versus cost or consideration of health or ecological damage from the process of remediation itself are usually not considered.

An alternative decision-making process based on risk is a different framework than the one currently in use. Risk inherently lies along a continuum. A focus on risk places the emphasis on decisions that balance cost, value of the resource, and risk to human health and the environment. The goal of a risk-based cleanup is to implement a risk-management strategy that takes the focus of cleanup away from broadly defined numeric goals that have historically been technologically infeasible and focuses on a more site-specific elimination or reduction of risk.

4.6.2. Broad, Systematic Decision-Making Approach That Can Be Adopted at the State Level, but Permits Local Implementation

- A statewide, consistently applied RBCA decision-making framework will allow regulators and RPs to know where they are in the decision-making process and what steps to take next.

A statewide, consistently applied RBCA decision-making framework will allow regulators and RPs to know where they are in the decision-making process and what steps to take next. The RBCA framework also provides a means to systematize site evaluation, select remedial alternatives (Graves, 1995c; Job, 1995; Moran, 1995b).

A RBCA approach can be tiered (Yim, 1995). Lower tiers base decisions on conservative assumptions and typically require historical or screening level data to make decisions, thus limiting characterization expense. Tier-one evaluations rely on a generic approach and apply to a majority of LUFT cases and sites. Non- or minimally intrusive sampling is used to gather data, and can rely on site classes developed using historical LUFT data. Higher tier evaluations would be more costly, less conservative, and more representative of the site. Intrusive samplings are more frequently performed during tier-two evaluations and more site-specific information is considered during risk assessments .

4.6.3. Decision-Making Approach That is Technically Defensible and Strongly Supported

- The recently developed ASTM RBCA framework offers a promising tiered decision-making approach to LUFT cleanups.

The state can leverage the work of other national efforts to develop an RBCA LUFT decision-making approach. The recently developed ASTM RBCA framework offers a promising tiered decision-making approach to LUFT cleanups. The ASTM RBCA has received extensive review by many national experts and is technically defensible and strongly supported by the U.S. EPA. In addition, other ASTM standard sampling procedures can also be used, such as those developed in ASTM Committee D18.21.02, Groundwater and Vadose Zone Investigations. Further, there is a joint ASTM/U.S. EPA training program available for RBCA. The ASTM RBCA tiers can be adapted to California’s needs by applying historical LUFT case data to tier-one evaluation procedures.

4.6.4. Continuous Access and Utilization of Data for Decision Making

- The creation of a more credible LUFT site information system will expedite site closures.

A key to a LUFT RBCA decision-making approach is the continuous access and utilization of data for decision making. Improved data acquisition and information management infrastructure can make this data available and support the decision-making process. An RBCA approach will facilitate the creation of a more credible LUFT site information system to expedite site closures and improve the perception that FHCs are an adequately managed risk. The ASTM RBCA has a well-developed reporting structure and form that would facilitate an approach that relies on continuous data access for decision making.

5. Conclusions

5.1. Fuel Hydrocarbons (FHCs) Have Limited Impacts on Human Health or the Environment

In California, benzene rarely impacts water-supply wells. This is because FHC plumes typically are stable at relatively short distances from the source and LUFT releases usually occur in urban and suburban settings with shallow groundwater. These shallow groundwaters are often not recommended for use, as a matter of public policy, because they are susceptible to degradation from a variety of sources besides FHCs, e.g., sanitary sewers, storm drains, and septic tank leach fields as well as FHCs. In these settings, ecological risk and human drinking water exposure pathways are effectively protected using California Well Standards.

If LUFT FHC plumes do not impact drinking water wells and other potential FHC exposure pathways are evaluated and found to be safe, then a large proportion of existing LUFT cases potentially pose an insignificant risk to human health and the environment. Once sources have been removed, low-risk LUFT cases can often be safely closed while FHCs are allowed to cleanup through passive bioremediation.

5.2. The Cost of Cleaning Up Leaking Underground Fuel Tank (LUFT) Fuel Hydrocarbons (FHCs) is Often Inappropriate When Compared to the Magnitude of the Impact on California's Groundwater Resources

The costs and level of effort expended on LUFT cases is disproportionally high relative to the potential for adverse impacts on human health or the environment. Considerable amounts of money and groundwater resources have been spent cleaning up LUFT FHCs that have affected a very small proportion (0.0005%) of California total groundwater resource. The remediation of LUFT FHCs in groundwater can cost more than $1 million per acre-foot. This cost is high considering the small proportion of groundwater affected.

5.3. LUFT Groundwater Cleanup Requirements Are Derived from Policies That Are Inconsistent with the Current State of Knowledge and Experience

Knowledge and experience indicates that the assumptions that have guided LUFT groundwater cleanup must be reevaluated. Since 1985, when the original LUFT Field Manual was prepared, understanding of subsurface processes and the impacts of LUFT FHCs released into the subsurface environment has increased significantly. Existing LUFT cleanup procedures do not take into account the ability of soil or groundwater microorganisms to biotically and abiotically reduce hydrocarbon contamination.

This new understanding of dissolved FHCs degradation can change the way that FHCs are regulated. RWQCBs often choose not to regulate many shallow groundwater contaminants, e.g., nitrates or E. Coli from exfiltrating sanitary sewers or septic tank leach fields, because knowledge and experience has shown that these contaminants typically remain relatively close to release sites, rapidly degrade, and well construction and siting standards protect exposure pathways. Similar knowledge and experience can be applied to FHCs, and regulatory agencies can choose not to regulate FHCs at low risk LUFT sites.

The State Water Resources Control Board (SWRCB) policies that set groundwater cleanup requirements to MCLs or background are a barrier to setting risk-based groundwater cleanup goals and closing LUFT cases based on an evaluation of risk to human health and the environment. The California Water Code is the law from which all other guidelines, resolutions, policies, and procedures draw authority. The California Water Code provides adequate guidance to permit flexibility in groundwater resource management and risk-based determinations of groundwater cleanup levels for FHC releases.

Because a risk-based decision-making framework is not meaningful under the existing LUFT regulatory framework, time and cost are not being adequately factored into the evaluation of appropriate remedial strategies and the protection of beneficial uses of state waters. As a result, society’s time and money are being misallocated to technically infeasible groundwater remediation strategies, cleaning up groundwater that may not have a foreseeable economic beneficial use.

5.4. Current Understanding of Passive Bioremediation Processes in the Subsurface Environment Is Not Reflected in the Present LUFT Cleanup Process

Given current understanding of FHC fate and transport in the subsurface environment, passive bioremediation of soils and groundwater at LUFT sites can now be considered as an appropriate remedial option. At sites where passive bioremediation is used, cleanup requirements are not compromised or deferred, and the beneficial use of the groundwater is restored in approximately the same time period as can be expected using actively engineered cleanups.

5.5. There Are Few Situations Where Pump and Treat Should Be Attempted

The National Research Council (NRC) Committee on Groundwater Cleanup Alternatives concludes that conventional pump and treat systems will be able to restore contaminated groundwater to drinking water standards at only a limited number of sites (NRC, 1994). There are few situations where pump and treat remediation should be attempted. At the core of a revised LUFT decision-making approach is the need to recognize that in many cases, it is technologically and economically infeasible to reach MCLs of 1.0 ppb for benzene using pump and treat or other actively engineered groundwater remediation alternatives.

5.6. A Risk-Based Corrective Action (RBCA) Framework Offers a Common Decision-Making Process To Systematically Address LUFT Cleanup

No systematic, statewide decision-making framework exists for LUFT cases. In some cases, regulatory oversight agencies have developed their own criteria for LUFT case characterization and closure.

An RBCA decision-making framework can do a better job of implementing Water Code requirements than existing processes. The American Society of Testing and Materials (ASTM) RBCA framework meets the revised LUFT cleanup process requirements for a systematic, consistent decision-making approach that can be adopted at a state level, but permits local implementation.

The ASTM RBCA provides a basis to guide collection of data to support a systematic decision-making approach. ASTM RBCA identifies risk-based target compounds that need to be measured and continuously uses data to support the decision-making process. The ASTM RBCA framework also provides means to define technical or economic feasibility, and a basis to consider economic impacts during decision making by case managers. Further, the ASTM RBCA allows for alternative approaches if technical or economic infeasibility is reported.

5.7. Modifications Would Be Necessary for the ASTM RBCA Framework To Be Used in California

A modified ASTM RBCA tiered, decision-making approach will allow the formulation of streamlined closure criteria that can encompass a majority of California's LUFT cases. This modified ASTM RBCA approach can incorporate the results of the SWRCB's historical LUFT case analysis to reflect California’s site-specific exposure parameters, as well as evaluate the uncertainty associated with the assumptions used during risk evaluations.

Using a modified ASTM RBCA tier one decision-making process, cases would be evaluated on the basis of exposure pathways, e.g., proximity of drinking water well and depth to groundwater. This evaluation would include the consideration of existing risk management programs such as well construction and siting standards. By immediately implementing a modified ASTM RBCA framework, a large number of cases with minimal risk will be positioned for immediate closure if policies are revised to allow risk-based groundwater cleanup requirements.

Because a majority of LUFT cases occur in urban and suburban settings with depth to groundwater less than 20 ft, a conservative assumption that groundwater is impacted can be made in may cases. Source removal to residual saturation in conjunction with UST upgrade or removal would be required.

In these shallow settings, source removal can usually be accomplished by excavation. Sites with deeper groundwater would use the modified ASTM RBCA framework tier-one methodology to evaluate the threat to groundwater and establish soils cleanup requirements.

Once the FHC source is removed, a monitoring program and plume management program would be established while plumes are remediated using passive bioremediation. Plume management strategies would be based on a modified ASTM RBCA framework and the demonstration of plume stability.

At the heart of the ASTM RBCA framework is the idea of flexibility and continuous use of current information. Continuous access to the data can increase hydrogeologic representativeness. Use of local, regional, and state historical data minimizes “reinventing of the wheel at each site” and permits the transfer of knowledge from one site to the next, reducing the expense of site characterization. Site class specific target action screening levels can be established using historical information.

The continuous utilization of LUFT data in the decision-making process facilitates an “evergreen” approach. For example, LUFT action levels can periodically be reevaluated as knowledge of an area increases and water/ land use or toxicity factors change.

5.8. A Common, Systematic Decision-Making Process Using Standard Procedures Will Reduce Inconsistencies in Soils Cleanup Requirements

RBCA can provide a systematic process to develop site-specific soil numeric standards for LUFT cases. In addition, ASTM standard investigating techniques will ensure consistent data collection.

There are no policy barriers to applying a RBCA decision-making framework to soils contaminated by FHCs that do not pose a threat to groundwater. While the LUFT Historical Case Analysis conducted by the SWRCB provided important information regarding the behavior of FHC groundwater plumes, further study of LUFT soils-only cases is needed to assist in the development of soils cleanup criteria to be used by a modified ASTM RBCA approach.

5.9. Total Petroleum Hydrocarbons (TPH) Measurements Should Not Be Used to Predict Benzene Concentrations

Compounds such, as benzene, that are the primary components of a risk evaluation should be measured directly, whenever possible, and not estimated from other indicator compounds.

6. Recommendations

6.1. Utilize passive bioremediation as a remediation alternative whenever possible

- Minimize actively engineered LUFT remediation processes.
- Once passive bioremediation is demonstrated and unless there is a compelling reason otherwise, close cases after source removal to the point of residual FHC saturation.
- In general, do not use the UST Cleanup Fund to implement pump and treat remediation unless its effectiveness can be demonstrated.
- Support passive bioremediation with a monitoring program.

6.2. Immediately modify the ASTM RBCA framework based on California historical LUFT case data

- Perform LUFT historical case studies on soils-only cases to support development RBCA tier-one decision-making process.
- Use LUFT historical case data to modify ASTM RBCA to reflect California's site-specific exposure pathways
- Use LUFT historical case data to quantify the uncertainty in the assumptions that are used during risk evaluations.
- Modify the ASTM RBCA tier-one decision-making process to encompass a majority of California's LUFT cases and facilitate and encourage the utilization of passive bioremediation.

6.3. Apply a modified ASTM RBCA framework as soon as possible to LUFT cases where FHCs have affected soil but do not threaten groundwater

- There are no existing barriers to implementing ASTM RBCA at LUFT sites where FHCs have only affected soils.
- Perform LUFT historical case studies on soils-only cases to support RBCA tier-one development.

6.4. Modify the LUFT regulatory framework to allow the consideration of risk-based cleanup goals higher than MCLs

- Modify SWRCB policies to remove barriers to applying a modified ASTM RBCA framework to FHCs affecting groundwater.
- Once SWRCB policy barriers have been removed, apply modified ASTM RBCA process to LUFT cases where FHCs have affected groundwater.

6.5. Identify a series of LUFT demonstration sites and form a pilot LUFT closure committee

- LUFT demonstration sites should be chosen to:
    - Act as training grounds for the implementation of a modified ASTM RBCA process.
    - Facilitate the implementation of a revised LUFT decision-making process.
    - Test recommended sampling and monitoring procedures and technologies to support passive bioremediation.
    - Confirm cost effectiveness of the ASTM RBCA process.
- A pilot LUFT closure committee, made up of scientific professionals from universities, private industry, and state agencies, should be set up to make professional interpretations and recommendations regarding LUFT evaluations and closures at the demonstration sites.

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Acronyms

ASTM	American Society for Testing and Materials
BTEX	Benzene, toluene, ethylbenzene, xylene
DHS	Department of Health Services
FHC	Fuel hydrocarbon
LLNL	Lawrence Livermore National Laboratory
LOP	Local oversight program
LUFT	Leaking underground fuel tank
MCL	Maximum contaminant level
NRC	National Research Council
ppb	Part per billion
RBCA	Risk-Based Corrective Action
RPs	Responsible parties
SWRCB	State Water Resources Control Board
TPH	Total petroleum hydrocarbon
TPHg	Total petroleum hydrocarbon-gasoline
UST	Underground storage tank

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