FINAL REPORT ON MONITORED NATURAL ATTENUATION EVALUATION AND APPLICATION IN THE LAHONTAN REGION

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Report to the Lahontan Regional Water Quality Control Board
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LAHONTAN REGION

MONITORED NATURAL ATTENUATION, EVALUATION AND IMPLEMENTATION

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Executive Summary

The Lahontan Water Quality Control Board (Water Board) considered the application and implementation of Monitored Natural Attenuation (MNA) in the context of federal and state requirements and technical guidance. The Water Board provided direction on how MNA should be evaluated and implemented in the Lahontan Region. This report summarizes the Water Board's findings and recommendations, which include:

- Minimum requirements to demonstrate whether MNA, in a particular case, is appropriate, protective, and effective, including site-specific determination of a reasonable cleanup timeframe;
- Site conditions that would require additional deliberation by the Water Board and that could preclude the selection of MNA;
- Application of a remedial selection process in accordance with the Comprehensive, Environmental Response, Compensation, and Liability Act (CERCLA) or State Water Resources Control Board Resolution 92-49.

Introduction

MNA relies on natural processes to achieve site-specific remediation goals in a reasonable timeframe (U.S. Environmental Protection Agency [USEPA] 1999 Directive, *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites* [USEPA MNA Directive]). MNA includes a monitoring component to evaluate the effectiveness of natural attenuation processes over time and should also include triggers and contingencies to address unforeseen problems, such as plume migration.

Because of its reliance on naturally occurring processes, MNA is considered a "passive" remedial option as opposed to other remedial technologies, e.g., pump and treat or in-situ injections, which are considered active remediation. MNA has been recognized as a remedial technology for groundwater contamination since the 1990s when the USEPA, U.S. Air Force, and other organizations began issuing guidance documents for the evaluation and application of MNA.

Although MNA is considered a passive remedial option it is not a "do nothing approach." The USEPA MNA Directive (USEPA 1999a) states:

> EPA does not view MNA to be a "no action" or "walk-away" approach, but rather considers it to be an alternative means of achieving remediation objectives that may be appropriate for specific, well-documented site circumstances where its use meets the applicable statutory and regulatory requirements.

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As a remedial option, MNA must meet the requirements for site remediation specified in State Water Resource Control Board's (State Water Board) Resolution 92-49, subsections III. A-G, which include achieving cleanup goals in a reasonable timeframe. MNA is not equivalent to the containment zone designation contained in Resolution 92-49, subsection III.H, since a containment zone is based on a site-specific determination that remedial goals are not technically or economically feasible to achieve. MNA is also not equivalent to State Water Board's Petroleum Underground Storage Tank Low-Threat Closure Policy (LTCP). LTCP is a risk-based approach that is based on our extensive knowledge of the behavior of petroleum releases from underground storage tank (UST) sites.

MNA Framework

The USEPA MNA Directive is a primary MNA reference document that puts forth USEPA policy on MNA and describes the framework for evaluation and use of MNA. Additionally, specific guidances and technical documents have been developed for the various aspects of MNA, (e.g., remedy evaluation, implementation, performance monitoring, and application of MNA to different types of contaminants, i.e., chlorinated solvents, fuels, and inorganics). References and links to primary MNA resources are included in Appendix 1.

The USEPA Directive defines MNA as "reliance on natural attenuation processes (within the context of a carefully controlled and monitored site cleanup approach) to achieve site-specific remediation objectives within a time frame that is reasonable compared to that offered by other more active methods." USEPA MNA Directive states that factors associated with the potential advantages and disadvantages should be carefully considered before selecting MNA as the remedial method for a site. Major potential advantages and disadvantages include the following.

Major Potential Advantages:

- Lower remediation costs than active remediation (although lower initial costs may be offset by the longer timeframe for monitoring and requirements for more extensive site characterization).
- Smaller environmental footprint: less generated waste, surface disturbance, and energy use.

Major Potential Disadvantages:

- MNA usually takes longer to achieve cleanup goals.
- Uncertainties associated with a long-cleanup timeframe.
    - Changes in site conditions that could affect plume behavior.
    - Future needs for groundwater.

A complete list of potential advantages and disadvantages listed in the USEPA MNA Directive is included in Appendix 2.

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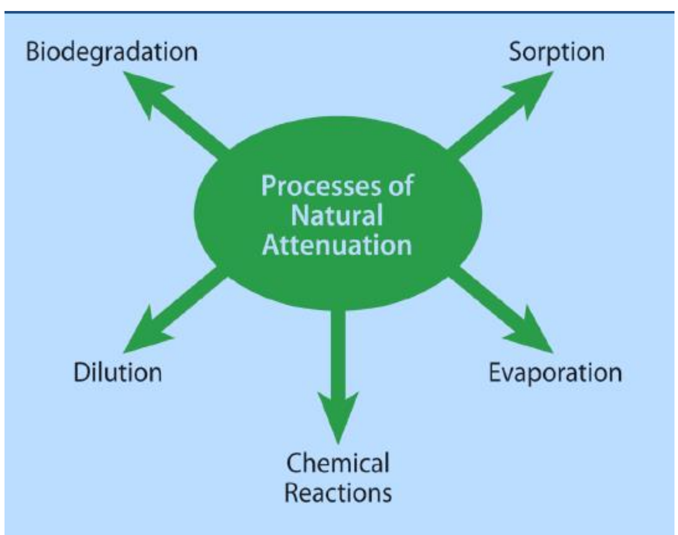
Demonstrating the Efficacy of MNA through Site Characterization

The USEPA MNA Directive states:

> Decisions to employ MNA as a remedy or remedy component should be thoroughly and adequately supported with site-specific characterization data and analysis. In general, the level of site characterization necessary to support a comprehensive evaluation of MNA is more detailed than that needed to support active remediation. Site characterizations for natural attenuation generally warrant a quantitative understanding of source mass; groundwater flow (including preferential pathways); contaminant phase distribution and partitioning between soil, groundwater, and soil gas; rates of biological and non-biological transformation; and an understanding of how all of these factors are likely to vary with time. This information is generally necessary since contaminant behavior is governed by dynamic processes which must be well understood before MNA can be appropriately applied at a site.

An understanding of the specific natural attenuation processes occurring at a groundwater site is a basic component of characterization to support an MNA evaluation. Natural attenuation can reduce the risk posed by contaminants in groundwater through processes that destroy or transform a contaminant to less toxic forms, and non-destructive processes that reduce the risk from the contamination. The primary natural attenuation processes are shown in Figure 1.

Figure 1, Natural Attenuation Processes



From Citizen's Guide to MNA, USEPA 2012a

All or some of these processes may be occurring at a particular site, depending on site conditions and the type of contaminant. All processes do not need to be present for MNA; however, the USEPA MNA Directive states that MNA's preferred application is at sites where destructive processes (e.g., biodegradation) are active. Appendix 3 contains a summary of the natural attenuation processes and their application to chlorinated solvents, fuels, and inorganic compounds.

All of the site characterization information is integrated into a conceptual site model, which forms the basis for the evaluation of the effectiveness of any remedial option. The evaluation of sources is especially critical for the MNA remedy since MNA is more likely to be effective at sites where there are no remaining sources or remaining sources are controlled to prevent further input of contaminants to groundwater. Additional discussion of conceptual site models and the characterization requirements for MNA are included in Appendix 4.

MNA Selection

The USEPA MNA Directive states that "MNA should be carefully evaluated along with other viable remedial approaches or technologies (including innovative technologies) within the applicable remedy selection framework. **MNA should not be considered a default or presumptive remedy at any contaminated site**." The Directive includes a detailed list of factors to consider when evaluating the appropriateness of MNA at a site (see Appendix 5). The Directive states the most important considerations that must be made to support the selection of MNA are:

1. Whether the contaminants present in soil or groundwater can be effectively remediated by natural attenuation processes.
2. Whether or not the contaminant plume is stable and the potential for the environmental conditions that influence plume stability to change over time.
3. Whether human health, drinking water supplies, other groundwaters, surface waters, ecosystems, sediments, air, or other environmental resources could be adversely impacted as a consequence of selecting MNA as the remediation option.

The expected outcome of the evaluation of MNA's efficacy is one of the following decisions (USEPA 2012a).

1. Select MNA as the sole remedy (usually following active remediation).
2. Select MNA as a component of the remedy in conjunction with one or more other remedial technologies.
3. Reject MNA and select another remedial technology.

MNA has most commonly been used in conjunction with an active remediation system (e.g., pump and treat or enhanced in-situ biodegradation in the plume hot spots and MNA in the low concentration areas) or as a polishing step after active remediation has reduced contamination to relatively low concentrations and active remediation is no longer cost effective. The USEPA MNA Directive states that it expects that the use of MNA as the only remedial method would be appropriate at a relatively few sites. The USEPA 2013

Superfund Remedy Report found that for the period from 2009 to 2011, MNA was selected as the sole remedy in 14% of all Superfund decision documents (e.g., record of decisions). Of the twelve groundwater sites with expected remedial decisions by 2017, Water Board staff is considering or expects proposed remedies of MNA at least half of the sites.

Water Board's Regulatory Requirements

The regulatory requirements that the Water Board must consider when evaluating the adequacy of a remedial method are specified in the State Water Resources Control Board's (State Water Board) Resolution No. 92-49, which establishes State requirements for investigation and cleanup and abatement of discharges. Resolution No. 92-49, section III specifies that:

> *The Regional Water Board shall*
>
> *A. Concur with any investigative and cleanup and abatement proposal which the discharger demonstrates and the Regional Water Board finds to have a substantial likelihood to achieve compliance, within a reasonable time frame, with cleanup goals and objectives that implement the applicable Water Quality Control Plans and Policies adopted by the State Water Board and Regional Water Boards, and which implement permanent cleanup and abatement solutions which do not require ongoing maintenance, wherever feasible;*
>
> *B. Consider whether the burden, including costs, of reports required of the discharger during the investigation and cleanup and abatement of a discharge bears a reasonable relationship to the need for the reports and the benefits to be obtained from the reports;*
>
> *C. Require the discharger to consider the effectiveness, feasibility, and relative costs of applicable alternative methods for investigation, and cleanup and abatement. Such comparison may rely on previous analysis of analogous sites, and shall include supporting rationale for the selected methods;*

Resolution 92-49 also requires that the cleanup actions conform to the provisions of State Water Board's Resolution No. 68-16, Statement of Policy with Respect to Maintaining High Quality of Waters in California and where background water quality cannot be met, that the cleanup meets the best water quality which is reasonable, considering all demands being made and to be made on those waters and the total values involved. Alternative cleanup levels must be consistent with the maximum benefit to the people of the state; not unreasonably affect present and anticipated beneficial use of such water; and not result in water quality less than that prescribed in the Water Quality Control Basin Plan for the Lahontan Basin. Therefore, MNA is an acceptable remedy, in compliance with Resolution 92-49 requirements in cases where the discharger adequately demonstrates that MNA will achieve compliance with cleanup goals and objectives in a reasonable timeframe, considering its relative effectiveness, feasibility, and cost.

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A factor that should be included in the consideration of an alternative cleanup level is the groundwater's assimilative capacity for those contaminants. Assimilative capacity is the ability of an aquifer to accept a constituent waste load while still maintaining the beneficial uses prescribed to that aquifer in the Water Quality Control Plan for the Lahontan Region (Basin Plan). The concept of assimilative capacity applies to all contaminants including non-naturally occurring organic compounds, such as solvents, but it is especially relevant to some naturally-occurring inorganic compounds, such as total dissolved solids (TDS) and nitrate. TDS and nitrate are commonly present in permitted discharges, such as wastewater treatment plant discharges, and other activities, such as agriculture. A proposed alternative cleanup level equal to a water quality objective (e.g., maximum contaminant level [MCL]) will exhaust the assimilative capacity for that constituent. In selecting an alternative cleanup level, the Water Board will consider the current and future demands on the assimilative capacity and whether the demand is in the best interest of the people of the state, i.e., permitted discharges. Therefore, the cleanup levels for unpermitted discharges should be as low as technically and economically feasible.

Additionally, the application of MNA must be consistent with all other state requirements, including those relating to environmental justice, the human right to water, and sustainable groundwater management. Environmental justice is providing fair treatment of people of all races, cultures and incomes with respect to the development, adoption, implementation, and enforcement of environmental laws, regulations, and policies. (Gov. Code § 65040.12(e).) Fair treatment means that "no group of people should bear a disproportionate share of the negative environmental consequences resulting from industrial, governmental and commercial operations or policies." (USEPA website: http://www.epa.gov/environmentaljustice/basics/index.html.) The goal of environmental justice is "for everyone to enjoy the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work." (*Id.*). The human right to water is based on California Water Code § 106.3 that establishes a state policy that every human being has the right to safe, clean, affordable, and accessible water adequate for human consumption, cooking, and requires state agencies to consider this policy when adopting or establishing policies, regulations and grant criteria that would be pertinent to those uses of water. The Sustainable Groundwater Management Act establishes a framework for sustainable, local groundwater management.

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Process of Remedy Selection

Remedial selection can follow one of several processes depending on the type of site as shown in Table 1.

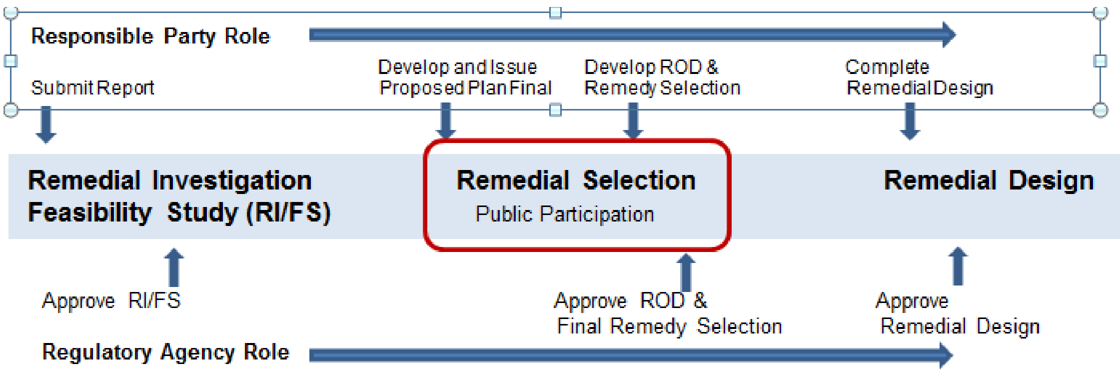
Table 1, Remedial Selection Processes

Site Type	Framework for Selection of Remedy
• USEPA National Priority List (Superfund) Sites • Federal sites[1] being addressed under CERCLA	• Remedial selection process per Comprehensive Environmental Restoration Compensation and Liability Act (CERLCA) (see Figure 2 below)
• Petroleum sites that do not qualify for consideration under from the Low Threat UST Closure Policy • Federal petroleum sites (based on the CERCLA petroleum exclusion)	• Corrective action process in California Code of Regulations, title 23, chapter 16 (UST Regulations) and California Health and Safety Code sections 25296.10 and 25296.15
• Discharges of waste to land	• Corrective action process in California Code of Regulations, title 27, section 20430 and title 23, chapter 15, section 2550.10
• Sites in the Water Board's Cleanup Program	• Procedures for investigations and cleanup and abatement activities State Water Resources Control Board Resolution 92-49
• Non-Petroleum Federal sites that are being addressed outside of CERCLA, e.g., some pesticides	• Corrective Action Process RCRA Subtitle C • Procedures for investigations and cleanup and abatement activities State Water Board Resolution 92-49

[1]. By agreement, non-CERCLA Federal sites, i.e., petroleum and some pesticide sites, can also follow the CERCLA process.

The remedial selection processes under the various regulatory frameworks range in complexity from the step-wise CERCLA process shown in Figure 2, to the simple process of the UST regulations involving a corrective action work plan that can include a preliminary assessment, investigation, and proposed corrective action. Regardless of the regulatory process followed, the considerations to determine the appropriateness of MNA for site cleanup are the same.

Figure 2, CERCLA Process



Modified from Office of Health, Safety and Security, Department of Energy website

MNA Implementation

Performance Monitoring

An MNA remedy always includes a performance monitoring program to determine the continued effectiveness of MNA and to determine the ongoing protection of human health and the environment. The monitoring program must be maintained until cleanup goals have been achieved. Performance monitoring is even more critical for MNA than for other remedies because of its longer cleanup timeframes, potential for contaminant migration, and other uncertainties associated with the MNA remedy. Information on the design and use an MNA performance monitoring network is included in Appendix 6 and references are listed in Appendix 1.

The performance monitoring data should be designed to determine the effectiveness of MNA, the adequacy of the monitoring program, and the adequacy of the conceptual site model. Based on these determinations, the following decisions can be made (USEPA 2004).

- Continue the performance monitoring program without change;
- Modify the performance monitoring program;
- Modify the institutional controls;
- Implement a contingency or alternative remedy; or
- Terminate monitoring because remedial goals have been obtained and the site is no longer a threat to human health or the environment.

Contingency Remedies

The USEPA MNA Directive describes a contingency remedy as a cleanup technology or approach specified in the site remedial decision document that functions as a backup remedy in the event that MNA fails to perform as anticipated. A contingency remedy should generally be flexible to allow for incorporation of new information about the site, risks, and remedial technologies. In some cases, it may be appropriate to include more than one possible remedy as contingencies. There should also be one or more criteria or triggers established in the decision document that will signal the unacceptable performance of MNA and indicate when to implement contingencies. The Directive states that such triggers should generally include, but not be limited to, the following.

- Contaminant concentrations in soil or groundwater at specified locations exhibit an increasing trend not predicted during remedy selection.
- Near-source wells exhibit large concentration increases indicative of a new or renewed release.
- Contaminants are identified in monitoring wells located outside of the original plume boundary.
- Contaminant concentrations are not decreasing at a sufficiently rapid rate to meet the remediation objectives.
- Changes in land and/or groundwater use that will adversely affect the protectiveness of the MNA remedy.

Examples of changes in a land or groundwater use that could trigger an evaluation of the protectiveness of the remedy include:

- Identification of increased need for the groundwater resource by an adjacent community.
- Increased pumping from existing or new wells, which could influence plume migration.
- Remediation of an adjacent plume (such as remediation involving extraction or injection of chemicals) that could impair the effectiveness of the MNA remedy.
- New or revised proposals for discharges of wastes that could require some portion of the assimilative capacity of the aquifer that is being used by the contaminant plume.
- New zoning allowing for increased development and water supply demand in the vicinity of the MNA remedy.

Institutional Controls

At some sites, especially those that have a long cleanup timeframe, it will be necessary to include reliable and effective institutional controls (ICs) as part of the MNA remedy in order to ensure long-term protectiveness. The USEPA defines institutional controls as "non-engineered instruments such as administrative and legal controls that help to minimize the potential for exposure to contamination and/or protect the integrity of the response action." ICs reduce exposure to contamination by limiting land or resource use and guide human behavior. ICs can include restrictions on land and water uses, deed restrictions, and prohibitions against excavations and well installations. ICs are critical components of the cleanup process to ensure short- and long-term protectiveness; however, there are complexities and challenges associated with selection, implementation, maintenance, and enforcement of ICs. The USEPA has provided several guidance documents on ICs and links to these documents are included in Appendix 1.

Overall, the Institutional Controls (ICs) should be reliable and effective. Some of the general considerations for ICs selection included in USEPA 2012b, are:

1. Duration of the ICs. ICs that "run with the land" are usually appropriate at sites where the ICs will be maintained for long durations.
2. Number of parcels that need to be restricted and whether the affected landowners are supportive of the ICs.
3. Effectiveness of the IC instrument to achieve and maintain the necessary use restriction.
4. Costs, including implementation, legal and monitoring, for the duration of the MNA remedy.
5. Identification of entities responsible for compliance assurance and ensuring entities are aware of roles and capable and committed to fulfilling them.

Although the ICs will be selected in the site decision document, a site-specific IC Implementation and Assurance Plan may be necessary to specify the details of how and by whom ICs will be implemented, maintained, enforced, modified, and terminated (USEPA 2012c).

Financial Assurance

Because of the generally longer timeframe for MNA remedies, financial assurance may be necessary to ensure that the responsible party bears the financial burden of implementing MNA, including contingencies to ensure final cleanup goals are met. The purpose of financial assurance is to demonstrate that adequate financial resources are available to complete the required cleanup effort. Permissible financial assurance mechanisms under CERCLA include: trust funds, letters of credit, surety bonds, insurance policies, corporate financial tests, and corporate guarantees. A link to the USEPA website on CERCLA financial assurances and financial assurance guidance is included in Appendix 1. Additionally, California Code of Regulations, title 27, division 2, chapter 6 contains financial assurance requirements for corrective actions at solid waste management units. Requirements for necessary financial assurance would be included in the MNA decision document.

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MNA Workshop, Water Board Meeting, September 11, 2014

The Water Board held an MNA workshop at the September 2014 Board Meeting in Barstow. In the workshop, staff presented a summary of MNA and its regulatory and technical requirements. Water Board members gave staff direction on factors that should be considering for the evaluation and implementation of MNA in the Lahontan Region. Water Board members recognized that consideration of MNA as a remedial option must be based on site-specific factors, including the determination of a reasonable timeframe for cleanup. Responsible parties proposing MNA must demonstrate, to the satisfaction of the Water Board, that the site meets regulatory and technical requirements using appropriate data and analysis methodologies.

Water Board members directed staff to prepare a report on MNA that summarizes regulatory and technical requirements and recommends site-specific criteria to consider for the evaluation and acceptance of an MNA remedy in the Lahontan Region.

Recommendations

Based on Water Board input, state and federal regulatory requirements, and USEPA technical guidance, the following criteria should be used for the evaluation and implementation of MNA in the Lahontan Region. State requirements include restoring water quality to background conditions or where background water quality cannot be met, the best water quality which is reasonable and will not result in water quality less than that prescribed in the Water Quality Control Basin Plan for the Lahontan Basin. The Water Board will be updated in Executive Officer reports on progress implementing these recommendations and MNA actions. The Executive Officer or the Water Board, as appropriate, may provide guidance on a MNA remedy requiring additional evaluation.

<u>Evaluation of Effectiveness and Protectiveness of MNA</u>

Consideration of MNA as a remedy option should be based on site-specific factors and a regulatory-approved demonstration of the following minimum requirements.

- The site has been adequately characterized for the purposes of an evaluation of MNA.
- Sources of contamination are controlled and are no longer contributing or threatening to contribute to groundwater contamination.
- The plume is stable or decreasing and it is reasonable to expect it to remain stable or continue decreasing.
- There is no threat to human health or the environment considering all pathways:
    - Existing and anticipated future beneficial use of groundwater (e.g., municipal or domestic supply, agricultural supply, industrial supply, and freshwater replenishment);
    - Vapor emissions (indoor and outdoor);

    - Direct contact and inhalations (e.g., via showers);
    - Discharge to surface water.
- Site contaminants can be effectively remediated by natural attenuation processes.
- Remedial goals will be achieved in a reasonable timeframe (see following discussion of determination of reasonable timeframe).

The demonstration must satisfy the Water Board that the site meets regulatory and technical requirements using appropriate data and analysis methodologies. The level of uncertainty that is acceptable for the technical demonstration must be considered on a site-specific basis, e.g., if MNA is proposed for a drinking water aquifer, the demonstration must reduce the uncertainties to a level that is acceptable to the Water Board and stakeholders.

An additional consideration is whether an active remedial method has been implemented at the site and whether there is benefit in its continued operation. Ideally, MNA is used following active remediation as a polishing step, i.e., after an active remedial system has reached a point where continued operation will provide limited benefits, including shrinking the plume or shortening cleanup time.

<u>Determination of Reasonable Timeframe</u>

Cleanup timeframe must be considered on a case by case basis. Evaluation of reasonable timeframe should, at a minimum, consider the following factors.

- Performance of MNA relative to other remedial technologies.
- Anticipated future need for the groundwater resource and for the assimilative capacity that the plume is impacting
- Considerations regarding site location.
    - The responsible party's ability to control the site and the area around the site, e.g., plume is contained within an active military base.
    - Site's proximity to a population center or in an area that may be developed in the future.
- Consideration of MNA remedy components.
    - Strength of triggers and contingencies, which should:
        - Include achieving milestones during the cleanup process;
        - Address changes in assumptions used for MNA selection.
    - Reliability of institutional controls to prevent incompatible uses.
    - Financial assurance in place to maintain the MNA remedy.
- Additional considerations for MNA remedies with projected long cleanup timeframes.
    - Responsible party's ability and commitment to continue to evaluate remedial progress, new technologies, changes in land use, and the other assumptions that supported MNA selection.

  - The resources required, including Water Board resources, to oversee long-term cleanup and evaluate assumptions that might affect MNA progress and success.

Site Conditions Requiring Additional Evaluation

Site conditions that require more evaluation and deliberation by the Water Board and which may preclude the selection of MNA include the following.

- Groundwater contamination impacts a primary water supply aquifer for an adjacent community or there is an anticipated need for the water resource or assimilative capacity.
- The plume is proximal to a population center or in an area that is likely to be developed in the future.
- The plume has an adverse impact on a disadvantaged community or Native American tribe.
- The plume impacts the sustainability of a groundwater basin or sub-basin, or otherwise adversely affects the implementation of the Sustainable Groundwater Management Act.
- The plume extends beyond the responsible party's property and/or land use restrictions will impact non-responsible parties.
- The plume unreasonably diminishes or exhausts the assimilative capacity for a particular constituent. One such example, would be a site where the plume impacts a permitted facility's (such as a wastewater treatment plant) ability/capacity to discharge its current and/or proposed future wastes to the groundwater.
- The estimated time to restore groundwater quality is greater than 40 years.
- Uncertainties associated with the responsible party's ability and/or commitment to maintain all MNA components for the duration of the cleanup timeframe.

MNA Selection Process

The Water Board and the responsible party should agree on the framework for the remedial selection (e.g., CERCLA or Resolution 92-49) early in the cleanup process. Because of the technical and regulatory challenges presented by the MNA remedy, the appropriate supporting documents for a MNA decision document (e.g., conceptual site model, evaluation of natural attenuation processes, comparative evaluation of appropriate remedial technologies (see Appendices 3 through 5 and resources listed in Appendix 1) should be approved by the Water Board prior to consideration of the decision document. The CERCLA process should be used at federal facilities because of CERLCA's clear, stepwise approach and its general application at federal facilities.

The decision document must meet all applicable state and federal requirements and be consistent with the USEPA MNA Directive. The decision document should include clear triggers and contingencies and description of reliable institutional controls and financial assurances that will be secured to protect public health and safety.

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The Water Board expects staff to follow the above recommendations and direction when evaluating the applicability of MNA for all groundwater contamination cases and to provide the Water Board updates on MNA remedies in the Lahontan Region in Executive Officer reports.

Appendix 1
References and Resources

General MNA

1. USEPA 2011a, An Approach for Evaluating the Progress of Natural Attenuation in Groundwater, http://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100DPOE.pdf

2. USEPA 2002, Groundwater Issue, Calculation and Use of First-Order Rate Constants for Monitored Natural Attenuation, http://www.epa.gov/ada/pubs/issue.html#2002

3. USEPA 1999a, OSWER Directive, Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites, http://www.epa.gov/oust/directiv/d9200417.pdf

4. Wiedemeier, T. H., et al, 1999, Natural Attenuation of Fuel Hydrocarbons and Chlorinated Solvents in the Subsurface, Wiley.

5. Additional resources on MNA:
http://www.epa.gov/superfund/health/conmedia/gwdocs/monit.htm
http://www.epa.gov/ada/gw/mna.html
http://www.clu-in.org/techfocus/default.focus/sec/natural_attenuation/cat/guidance/

MNA for Organic Constituents

6. Interstate Technology and Regulatory Council (ITRC), 2007, A Decision Flowchart for the Use of Monitored Natural Attenuation and Enhanced Attenuation at Sites with Chlorinated Organic Plumes, http://www.itrcweb.org/Documents/EACODecisionFlowchart_v1.pdf

7. USEPA 2013, Ground Water Issue Paper: Synthesis Report on State of Understanding of Chlorinated Solvent Transformation, https://clu-in.org/download/techfocus/na/NA-600-R-13-237.pdf

8. USEPA 2012a, Framework for Site Characterization for Monitored Natural Attenuation of Volatile Organic Compounds in Ground Water http://nepis.epa.gov/Adobe/PDF/P100HYBY.pdf

9. USEPA 2008, A Guide for Assessing Biodegradation and Source Identification of Organic Ground Water Contaminants using Compound Specific Isotope Analysis (CSIA), http://nepis.epa.gov/Adobe/PDF/P1002VAI.pdf

10. USEPA 2004, Performance Monitoring of MNA Remedies for VOCs in Groundwater, http://nepis.epa.gov/Adobe/PDF/10004FKY.pdf

11. USEPA 1999b, Ground Water Issue, Microbial Processes Affecting Monitored Natural Attenuation of Contaminants in the Subsurface, http://nepis.epa.gov/Adobe/PDF/10002E30.pdf

12. USEPA 1998a, Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water, http://www.epa.gov/superfund/health/conmedia/gwdocs/protocol.htm

13. USEPA, 1998b, Monitoring and Assessment of In-Situ Biocontainment of petroleum Contaminated Ground-Water Plumes, EPA/600/R-98/020, http://nepis.epa.gov/Simple.html

MNA for Inorganic Constituents

14. Interstate Technology and Regulatory Council (ITRC), 2010, A Decision Framework for Applying Monitored Natural Attenuation Processes to Metals and Radionuclides in Groundwater, http://www.itrcweb.org/GuidanceDocuments/APMR1.pdf

15. USEPA 2007, Monitored Natural Attenuation of Inorganic Contaminants in Ground Water:

Volume 1, Technical Basis for Assessment. http://nepis.epa.gov/Adobe/PDF/60000N4K.pdf

Volume 2, Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate, and Selenium. http://nepis.epa.gov/Adobe/PDF/60000N76.pdf

Volume 3, Assessment for Radionuclides Including Tritium, Radon, Strontium, Technetium, Uranium, Iodine, Radium, Thorium, Cesium, and Plutonium-Americium. http://nepis.epa.gov/Adobe/PDF/P100EBXW.pdf

16. USEPA 1994, Ground Water Issue, Natural Attenuation of Hexavalent Chromium in Ground Water and Soils, http://nepis.epa.gov/Adobe/PDF/P1009BHO.pdf

17. USEPA website: http://www.epa.gov/ada/gw/mna.html)

Resources for Evaluating Plume Stability

References 1, 4, 8, and 13, and:

18. USEPA 2009, Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidances, http://www.epa.gov/osw/hazard/correctiveaction/resources/guidance/sitechar/gwstats/unified-guid.pdf

19. USEPA 2006, Data Quality Assessment: Statistical Methods for Practitioners, http://www.epa.gov/quality/qs-docs/g9s-final.pdf

20. USEPA 1992, Methods of Evaluating the Attainment of Cleanup Standards, Volume 2, Groundwater, http://www.epa.gov/superfund/policy/remedy/pdfs/230r-92014-s.pdf

Resources on Institutional Controls

21. USEPA website: http://www.epa.gov/oerrpage/superfund/policy/ic/guide/index.htm

22. USEPA 2012b, Institutional Controls: A Guide to Planning, Implementing, Maintaining, and Enforcing Institutional Controls at Contaminated Sites, http://www.epa.gov/fedfac/institutional-controls-guide-planning-implementing-maintaining-and-enforcing-institutional

23. USEPA 2012c, Institutional Controls: A Guide to Preparing Institutional Control Implementation and Assurance Plans at Contaminated Sites

Resources on Financial Assurances

USEPA website: http://www.epa.gov/enforcement/financial-assurance-superfund-settlements-and-orders#fa

Resources on Models:

22. USEPA 2011b, Center for Subsurface Modeling Support of the U S Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Ada, OK. http://www.epa.gov/ nrmrl/gwerd/csmos/index.html

23. USEPA website: http://www2.epa.gov/water-research/methods-models-tools-and-databases-water-research

Appendix 2
Advantages and Disadvantages of Monitored Natural Attenuation

The USEPA MNA Directive states the following:

MNA has several potential advantages and disadvantages, and the factors listed below should be carefully considered during site characterization and evaluation of remediation alternatives before selecting MNA as the remedial alternative. **Potential advantages** of MNA include:

- As with any *in situ* process, generation of lesser volume of remediation wastes, reduced potential for cross-media transfer of contaminants commonly associated with *ex situ* treatment, and reduced risk of human exposure to contaminants, contaminated media, and other hazards, and reduced disturbances to ecological receptors;
- Some natural attenuation processes may result in *in-situ* destruction of contaminants;
- Less intrusion as few surface structures are required;
- Potential for application to all or part of a given site, depending on site conditions and remediation objectives;
- Use in conjunction with, or as a follow-up to, other (active) remedial measures; and
- Potentially lower overall remediation costs than those associated with active remediation.

The **potential disadvantages** of MNA include:

- Longer time frames may be required to achieve remediation objectives, compared to active remediation measures at a given site;
- Site characterization is expected to be more complex and costly;
- Toxicity and/or mobility of transformation products may exceed that of the parent compound;
- Long-term performance monitoring will generally be more extensive and for a longer time;
- Institutional controls may be necessary to ensure long term protectiveness;
- Potential exists for continued contamination migration, and/or cross-media transfer of contaminants;
- Hydrologic and geochemical conditions amenable to natural attenuation may change over time and could result in renewed mobility of previously stabilized contaminants (or naturally occurring metals), adversely impacting remedial effectiveness; and
- More extensive education and outreach efforts may be required in order to gain public acceptance of MNA.

Appendix 3
Natural Attenuation Processes

Natural attenuation refers to the naturally-occurring processes that can reduce the risk to human health and the environment from contaminants in soil or groundwater. Natural attenuation can reduce risk posed by contaminants in groundwater through destructive processes (e.g., biodegradation) that destroy or transform a contaminant to less toxic forms, and non-destructive processes (e.g., dilution) that reduce the risk from the contamination. Natural attenuation processes are divided into the following groups.

- **Biodegradation** is a destructive mechanism in which microbes in soil or groundwater break down the contaminant when they use the contaminants as food and energy sources.
- **Sorption** is non-destructive process of the contaminants becoming attached to soil particles. Sorption does not destroy the contaminants, but it inhibits their movement.
- **Evaporation** causes some contaminants, like fuels and solvents, to change from liquids to gases. If these gases escape to the atmosphere, the air will dilute them (non-destructive). In some case the sunlight may also break down the contaminants (destructive).
- **Chemical Reactions** with naturally-occurring substances may transform (destructive process) contaminants into less harmful forms. For example, in low-oxygen environments, reactions with naturally occurring iron and water can transform highly toxic hexavalent chromium to less toxic trivalent chromium.
- **Dilution** is a non-destructive process that decreases the concentrations of contaminants as they move into and mix with uncontaminated groundwater.

All or some of these processes may be occurring at a particular site, depending on site conditions and the type of contaminant. All processes do not need to be present for an acceptable MNA remedy; however, the USEPA MNA Directive states that MNA's preferred application is at sites where destructive processes (e.g., biodegradation or chemical transformation) are active.

Biodegradation is generally the fastest and most effective of the natural attenuation processes. Consequently, MNA is most often implemented to address contaminants that are subject to biodegradation, such as chlorinated solvents (e.g., trichloroethene [TCE] and tetrachloroethene [PCE])and fuels (petroleum hydrocarbons including benzene, ethylbenzene, toluene, and xylenes [BETX]).

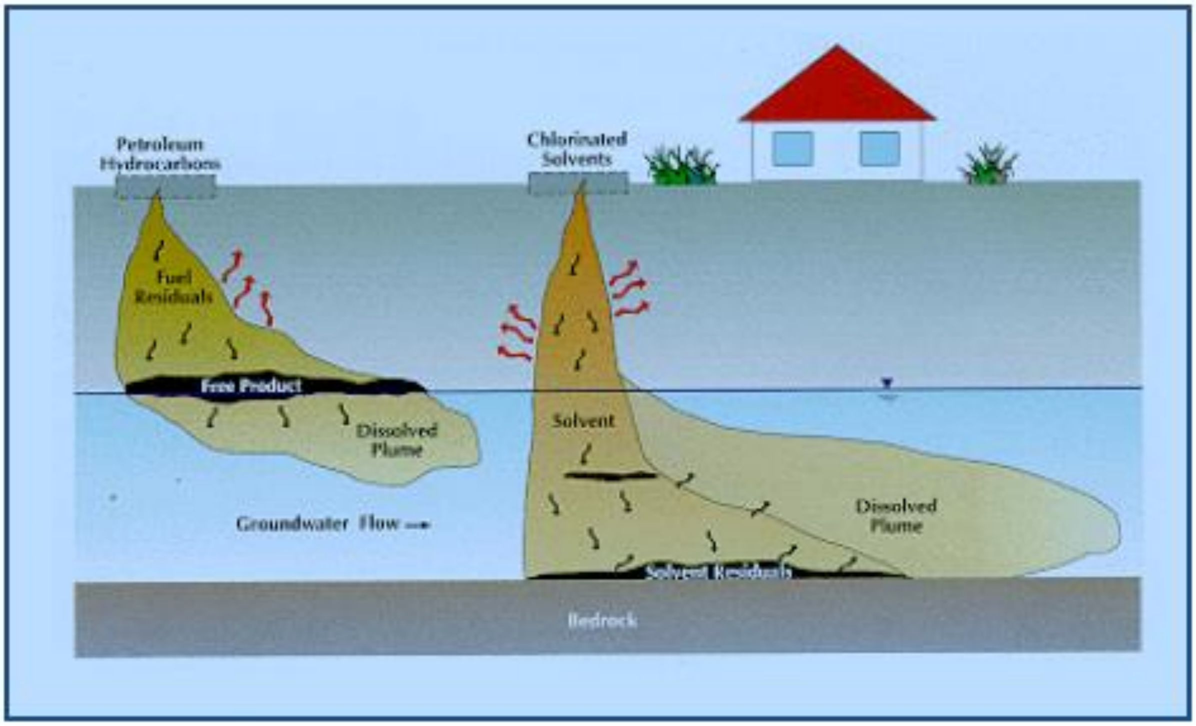
The BETX compounds are generally the more mobile fuel-related constituents. The fact that the BETX compounds are highly biodegradable under most conditions is a foundation for the State Water Resources Control Board's Low-Threat Underground Storage Tank Closure Policy.

EPA guidance states that, in general, MNA will be most appropriate at addressing groundwater contaminated by dissolved-phase volatile organic compounds (e.g., fuel and chlorinated solvents) and that it may be less applicable to sites with other types of contaminants (e.g., pesticides, wood-treating chemicals, and explosives) because the natural attenuation processes for these contaminants may be less understood or less effective than for chlorinated solvents and petroleum hydrocarbons.

However, biodegradation of solvents and fuels (i.e., petroleum hydrocarbons) may be limited under some conditions.

- Some contaminants are not readily biodegraded. For example, 1,4-dioxane (an additive to fuels and solvents) is more recalcitrant to biodegradation and it may take longer to achieve remedial goals for this compounds.
- If fuel or solvent in undiluted form reaches the groundwater, it will form a two-phase plume, consisting of undissolved, non-aqueous phase liquid (NAPL) and a dissolved phase plume. Fuel NAPL is less dense than water and will collect at the top of the groundwater surface. The collection of the NAPL fuel phase on the water table is sometimes referred to as "free product" or "floating free product.' Solvent NAPL is denser than water and tends to sink through the water table until it encounters a less permeable zone, such as a clay lens, where it collects and is referred to as "residual" contamination. Microbes cannot effectively biodegrade the contaminants in the product phase. Both the fuel free product and the solvent residual act as secondary sources that continue to release contaminants into the aquifer contributing to the dissolved plume phase as shown in Figure 1. USEPA guidance states that sites with NAPL sources are <u>unlikely</u> to be effectively remediated in a reasonable time frame using MNA alone because of continued contaminant mass flux from the NAPL body (USEPA 2012a).
- Plumes containing very high concentrations of dissolved contaminants may be toxic to the microbes responsible for biodegradation.
- Some site conditions do not support natural biodegradation of chlorinated solvents either due to the lack of appropriate microbes or nutrients to support their growth. Most chlorinated solvents (e.g., trichloroethene [TCE] MCL of 5 ppb, and tetrachloroethene [PCE], MCL of 5 ppb) are most readily broken down by microbes that can live in oxygen-poor environments (a.k.a. reducing conditions). Biodegradation under these conditions is referred to as *reductive dechlorination*. Reductive dechlorination may not be occurring at a significant level in an oxygen-rich aquifer, which does not promote the growth of the right microbes. In some cases biodegradation may stall at a toxic breakdown product such as cis-1,2-dichloroethene (MCL of 6 ppb) or vinyl chloride (MCL of 0.5 ppb).

Figure 1, NAPL Sources and Dissolved Plumes



from: Pachon, Carlos, USEPA, Groundwater Monitored Natural Attenuation at Cleanup Sites in the United States, 2011

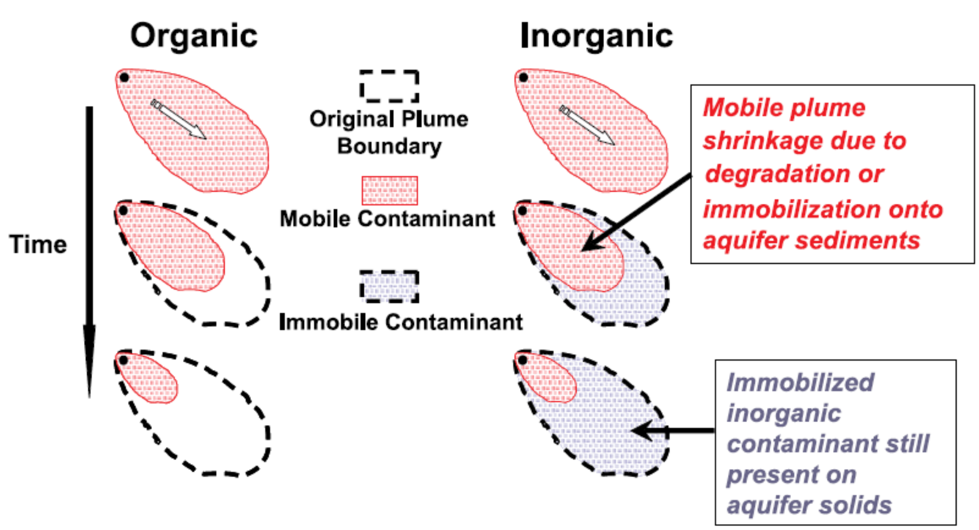
In the absence of biodegradation, MNA is slower and plume stability can be more problematic. Staff has found that in the Mojave Groundwater Basin, naturally-occurring conditions are not generally conducive for rapid biodegradation of many of the chlorinated solvent plumes. The low level of biodegradation may be the result of the lack of the nutrients needed to support the in-situ microbes responsible for biodegradation. At locations where reductive dechlorination is not occurring fast enough to remediate a site, the process can sometimes be enhanced by injection of a substrate to stimulate the microbes responsible for reductive dechlorination. Because this remedial technology, referred to as “enhanced bioremediation” or “enhanced attenuation,” is an active remedial technology it is not MNA. The Interstate Technology and Regulatory Council (ITRC) has developed a decision tree to help determine when MNA and when enhancement measures may be appropriate (ITRC 2007).

Inorganic contaminants that may be considered for MNA include metals, salts (e.g., nitrate and perchlorate), and radionuclides. With the exception of nitrate and perchlorate, inorganic contaminants are generally not destroyed by natural attenuation processes. Natural attenuation processes for inorganic compounds share some similarities with chlorinated solvents and petroleum hydrocarbons, but there are some important distinctions, including:

- Inorganic reactions are generally more complex, particularly with regards to geochemical conditions
- Many of the inorganic compounds, including most metals, are not degraded but are transformed to immobile or less mobile forms, typically through co-precipitation or sorption.

Therefore, the general goal for MNA of these types of compounds is to document that the existing site conditions promote reactions that generate a stable product with reduced mobility and potential for exposure, such that current and future risk is minimized. The Figure 2 shows the conceptual distinction between organic and inorganic contaminant plume behavior where natural process are active. A primary reference for MNA of inorganic compounds is USEPA *Monitored Natural Attenuation of Inorganic Contaminants in Groundwater*, October 2007, which states that "Natural attenuation of inorganic contaminants is viable only if the immobilized contaminant remains stable and resistant to remobilization during changes in groundwater chemistry."

Figure 2, Natural Attenuation of Organic and Inorganic Plumes

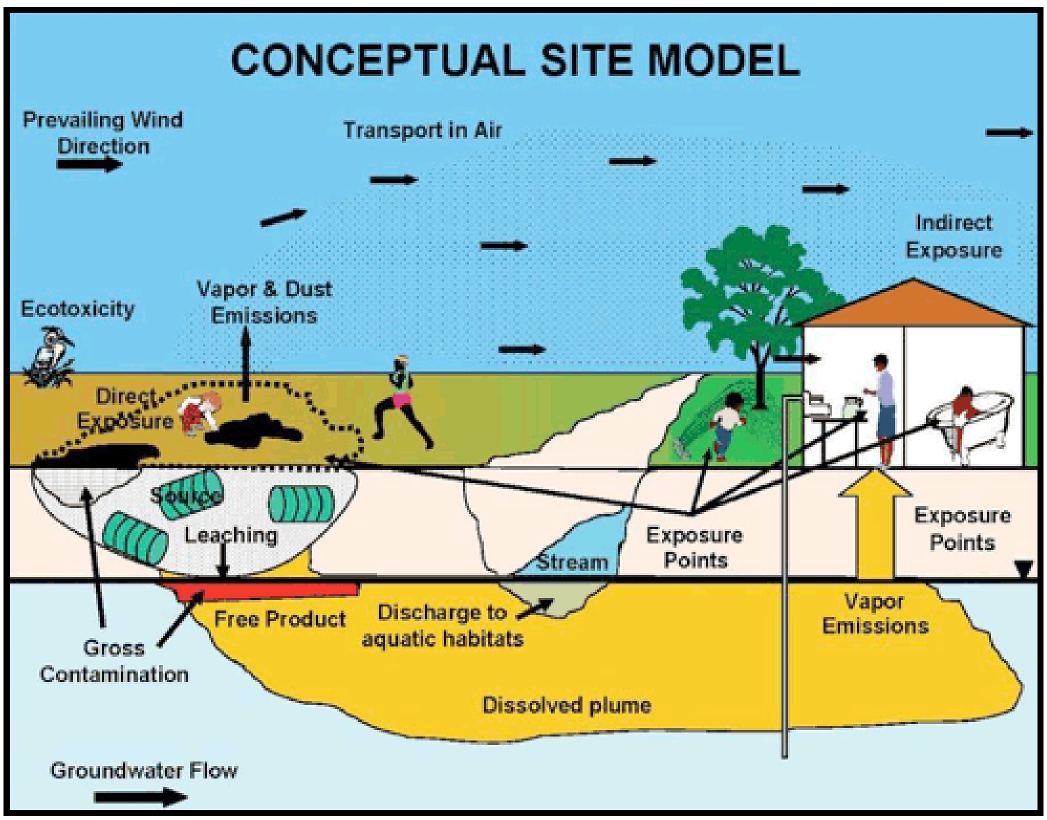


from EPA Monitored Natural Attenuation of Inorganic Contaminants in Groundwater, October 2007

Appendix 4
Site Characterization Requirements for MNA

Site characterization provides the specific data and analysis that form the basis for determining whether site remedial goals can be met with MNA. The site-specific data and analysis are integrated into a conceptual site model that conveys what is known or suspected about contamination sources, release mechanisms, contaminant transport and fate, migration pathways and potential receptors. Figure 1 is a conceptual site model that provides a graphical presentation of the site, including many of the potential contaminant migration pathways and exposure points that should be evaluated in a conceptual site model. The conceptual site model provides the basis for evaluating whether the contamination poses an immediate threat to receptors.

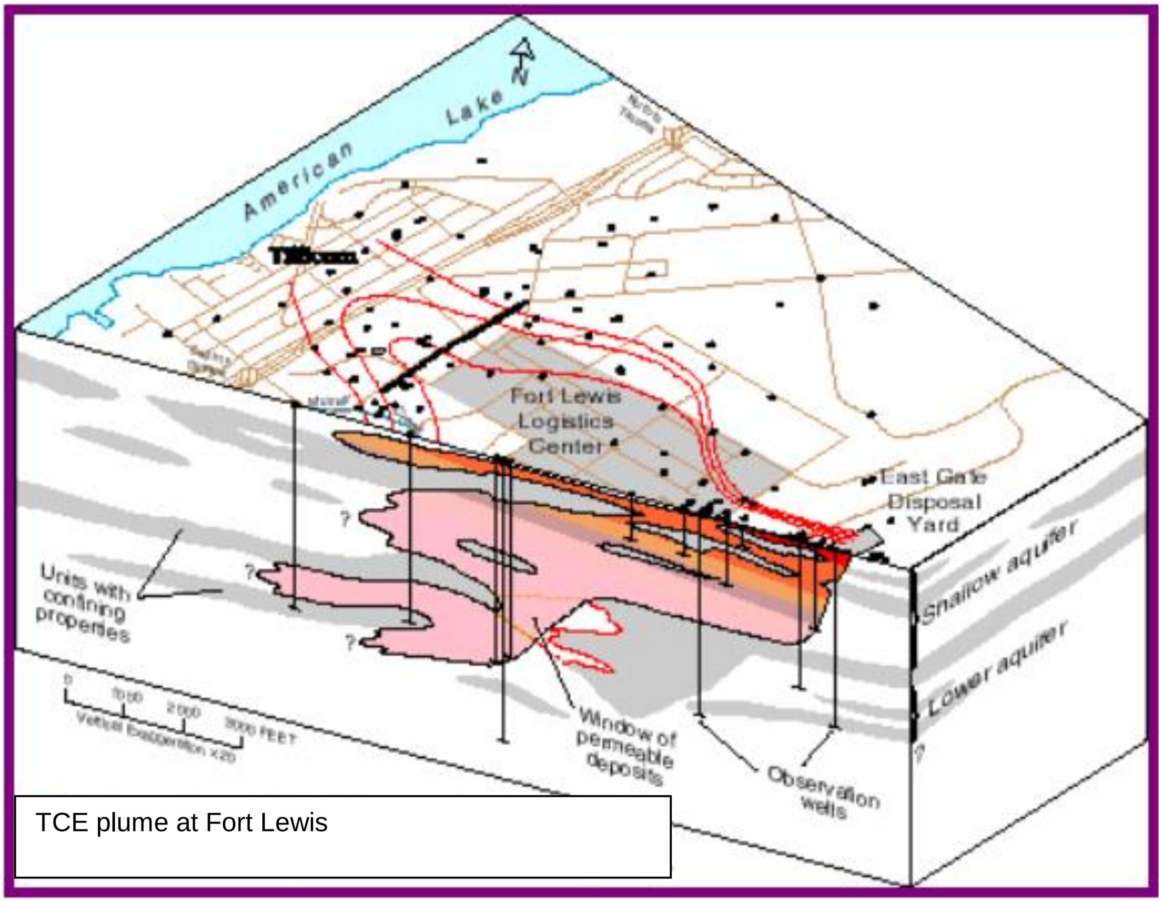
Figure 1, Conceptual Site Model



From ITRC website, Incremental Sampling Methodology

The Figure 2 shows a hydrogeologic conceptual site model that characterizes the groundwater plume and the subsurface conditions that control plume migration. Conceptual site models help identify data gaps, such as whether the data are adequate to determine the lateral and vertical extent of contamination or to determine whether a pathway is a likely exposure route. Development of a conceptual site model should continue to be continued until critical data gaps have been filled and uncertainties reduced to an acceptable level. Refine of the conceptual site mode should continue as additional data becomes available.

Figure 2, Hydrogeologic Conceptual Site Model



TCE plume at Fort Lewis

From US Geological Survey Fact Sheet 082-98

Evaluation of source areas is especially important part of characterization since MNA is more likely to be effective at sites where there are no remaining sources (such as non-aqueous phase liquids [NAPL]) or remaining sources are controlled to prevent further input of contaminants to groundwater.

Site characterization activities for MNA differ from the site characterization activities routinely conducted at contaminated sites, in that sites being evaluated for MNA require collection of more specific data on fate and transport of contaminants and the biological and geochemical agents and processes leading to attenuation.

MONITORED NATURAL ATTENUATION, EVALUATION AND IMPLEMENTATION

Groundwater specific characterization and evaluations that are required to support the selection of MNA include (USEPA 2012a):

- *Current and historic groundwater contamination data to demonstrate the plume is stable or decreasing*. A robust groundwater monitoring network is necessary to establish plume behavior. Methods for demonstrating plume stability range from visual inspection of temporal concentration trends, numerical and statistical methods, and evaluation of contaminant mass. It may be necessary to apply more than one method to reduce the uncertainties associated with plume stability/migration. See Section 4.3.4 of USEPA 2012a for a discussion of methods to determine plume stability.

- *Factors that may influence future plume stability should also be evaluated.* For example, conditions that could influence plume migration, e.g., groundwater recharge or extraction adjacent to the plume, may change with time and thus change the stability of the plume.

- *Hydrogeologic and geochemical data to determine the natural attenuation processes are protective and sustainable.* Hydrogeologic and geochemical data are necessary to understand the mechanism and rate of contaminant degradation/attenuation, quantify the risks from possible toxic breakdown products, and calculate the capacity of attenuation process to sustain degradation of contaminant mass within the plume. Establishing attenuation rates and their spatial and temporal variations is fundamental to the characterization and assessment of MNA. Site characterization efforts should be sufficient to minimize the impacts of uncertainties associated with attenuation rates. EPA guidance on the use or rate constants are included in USEPA 2002 Groundwater Issue, Calculation and Use of First-Order Rate Constants for MNA.

Appendix 5
Detailed List of Factors to Consider in the Selection of MNA

The USEPA MNA Directive includes the following detailed list of factors to consider when determining if MNA is an appropriate remedial alternative.

- Whether the contaminants present in soil or groundwater can be effectively remediated by natural attenuation processes;
- Whether or not the contaminant plume is stable and the potential for the environmental conditions that influence plume stability to change over time;
- Whether human health, drinking water supplies, other groundwaters, surface waters, ecosystems, sediments, air, or other environmental resources could be adversely impacted as a consequence of selecting MNA as the remediation option;
- Current and projected demand for the affected resource over the time period that the remedy will remain in effect;
- Whether the contamination, either by itself or as an accumulation with other nearby sources (on-site or off-site), will exert a long-term detrimental impact on available water supplies or other environmental resources;
- Whether the estimated timeframe of remediation is reasonable compared to timeframes required for other more active methods (including the anticipated effectiveness of various remedial approaches on different portions of the contaminated soil and/or groundwater);
- The nature and distribution of sources of contamination and whether these sources have been, or can be, adequately controlled;
- Whether the resulting transformation products present a greater risk, due to increased toxicity and/or mobility, than do the parent contaminants;
- The impact of existing and proposed active remediation measures upon the MNA component of the remedy, or the impact of remediation measures or other operations/activities (*e.g.*, pumping wells) in close proximity to the site; and
- Whether reliable site-specific mechanisms for implementing institutional controls (*e.g.*, zoning ordinances) are available, and if an institution responsible for their monitoring and enforcement can be identified.

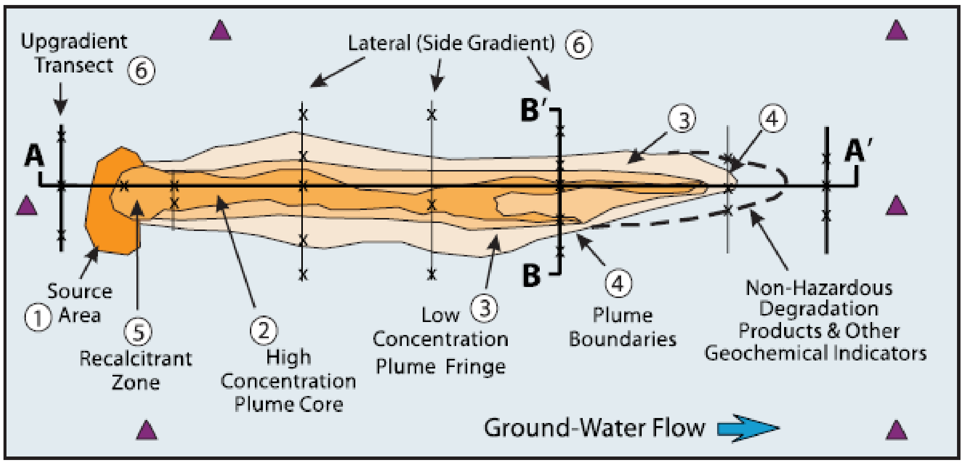
Appendix 6
Performance Monitoring

To evaluate the site-specific effectiveness of MNA, a performance monitoring program should establish a monitoring well network, monitoring parameters, monitoring frequency, and methods to analyze and interpret monitoring data. USEPA 2004 states that all performance monitoring programs should be designed to accomplish the following:

- Demonstrate that natural attenuation is occurring according to expectations;
- Detect changes in environmental conditions (*e.g.*, hydrogeologic, geochemical, microbiological, or other changes) that may reduce the efficacy of any of the natural attenuation processes;
- Identify any potentially toxic and/or mobile transformation products;
- Verify that the plume(s) is not expanding (either downgradient, laterally or vertically);
- Verify no unacceptable impact to downgradient receptors;
- Detect new releases of contaminants to the environment that could impact the effectiveness of the natural attenuation remedy;
- Demonstrate the efficacy of institutional controls that were put in place to protect potential receptors; and
- Verify attainment of remediation objectives.

The following figures show typical monitoring network and monitoring zones in map view and in cross-section.

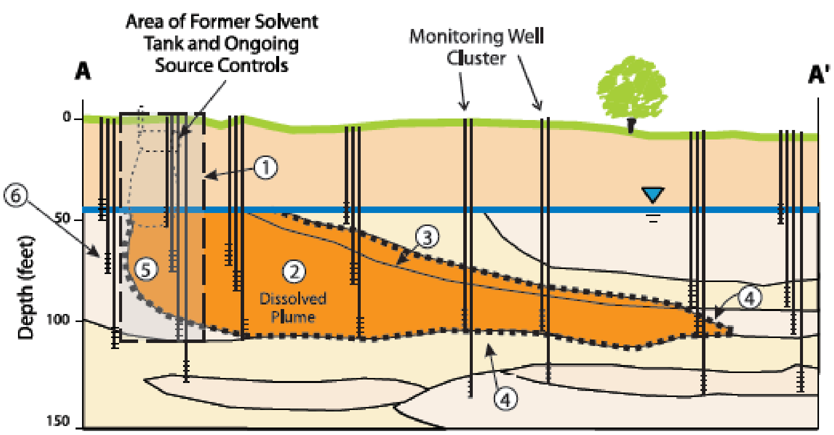
Site (Map View)



Target Monitoring Zones

1. Source area
2. Contaminated zones of highest concentrations and mobility
3. Plume fringes
4. Plume boundaries
5. Recalcitrant zone determined from historical trends
6. Upgradient and sidegradient locations

x Monitoring well cluster
▲ Piezometer
-x-x-x- Transect of well clusters



from USEPA 2004