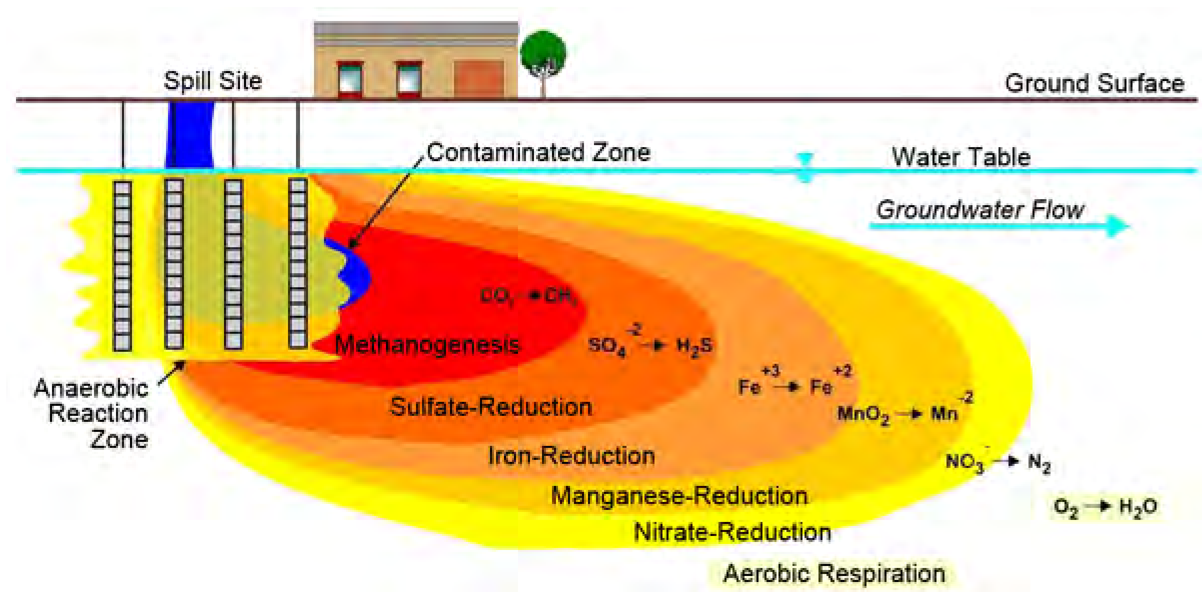
In Situ Remediation

Remediation and Redevelopment Division Resource Materials



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Protecting Michigan's Environment. Ensuring Michigan's Future.

In order to promote a consistent and informed approach for Michigan Department of Environmental Quality (MDEQ) staff, this document was developed to provide information to MDEQ staff and contractors on In situ Remediation.

This document is available as a technical reference to assist any party planning to use In situ Remediation.

This document is explanatory and does not contain any regulatory requirements. It does not establish or affect the legal rights or obligations for groundwater modeling. It does not have the force or effect of law and is not legally binding on the public or the regulated community. Any regulatory decisions made by the MDEQ regarding groundwater modeling will be made by applying the governing statutes and Administrative Rules to relevant facts.

Approved: ___________________________________

Robert Wagner, Chief
Remediation and Redevelopment Division
February 22, 2016

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1.0 Purpose and Scope

The purpose of this document is to provide general direction and requirements for the selection, design, implementation, and evaluation of in *situ* remedial technologies and discharges. This document provides information that is necessary to support the selection of an in *situ* remedy. It is intended to foster the development of viable strategies that are consistent with the applicable requirements of:

- Part 201, Environmental Remediation (Part 201), of the Natural Resources and Environmental Protection Act (NREPA), 1994 PA 451, as amended,
- the Part 201 Administrative Rules,
- Part 213, Leaking Underground Storage Tanks (Part 213), of the NREPA, and
- the Part 22 Groundwater Administrative Rules (Part 22 Rules) promulgated pursuant to Part 31, Water Resources Protection (Part 31) of the NREPA.

This document also describes the applicability of the Part 22 Rules to *in situ* remedial discharges and general requirements for obtaining a permit exemption.[1] The direct or indirect introduction of ANY SUBSTANCE into groundwater that meets the definition of a discharge is subject to the standards of the Part 22 Rules. As such, the standards of the Part 22 Rules apply to **All** *in situ* remedial discharges.

This document provides acceptable approaches and ranges of appropriate assumptions that are intended to support consistent exercise of professional judgment in a manner that produces satisfactory outcomes. Alternative approaches may be used if the person proposing the alternative demonstrates that the approach meets all the requirements of the statute and rules.

With the variety of established and developing *in situ* remedial technologies and a myriad of facility-specific applications, each with its own unique combination of circumstances and nuances, it is impossible to cover every scenario. However, commonly encountered scenarios are provided as examples to illustrate conceptual approaches where appropriate. Nevertheless, this document is not intended to be comprehensive, nor should it in any way be construed as a "how to" manual. Similarly, it is not intended as a substitute for valid scientific or technical references or direct experience and lessons learned from emerging or established technologies. Rather, it focuses primarily on the general process and considerations for selection, design, implementation, and evaluation of *in situ* remedial strategies. It is intended that this document will lead to a more comprehensive and systematic approach to *in situ* remediation, which in turn will promote the appropriate application of such technologies, or otherwise help to avoid the pitfalls of implementing remedies that have little or no chance for success.

This document is intended solely as guidance to foster consistent application of Part 201 and Part 213 of NREPA and the associated Administrative Rules. This document does not contain any mandatory requirements, except where requirements found in statute or administrative rule are referenced. This guidance does not establish or affect the legal rights or obligations for any of the issues addressed. This guidance does not create any

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[1] R 323.2210(u)(ii and iii)

rights enforceable by any party in litigation with the MDEQ. Any regulatory decisions made by the MDEQ in any matter addressed by this guidance will be made by applying the governing statutes and Administrative Rules to the relevant facts.

This document is based upon the requirements found in Part 201, Part 213, and Part 31 of NREPA and the rules promulgated thereunder. In addition to the requirements and rules of the NREPA, United States Environmental Protection Agency (U.S. EPA) Class V injection well requirements apply to *in situ* injections. For further information on the Class V injection well requirements, refer to EPA Class V Injection Well Requirements

2.0 Introduction

The Remediation and Redevelopment Division (RRD) supports and encourages the use and development of innovative remedial technologies, including *in situ* remediation. These technologies are commonly employed at contaminated facilities in Michigan, especially at petroleum contaminated leaking underground storage tank sites and facilities with chlorinated solvent releases.

In situ remedial technologies are often viewed as less costly, more effective, or otherwise more practical than *ex situ* cleanup methods such as groundwater pump-and-treat or soil excavation and disposal (or treatment). Although this contention is often true, *in situ* remedial technologies are not universally appropriate, nor do they render *ex situ* remedies obsolete. Rather, both *in situ* and *ex situ* methods are effective, depending on the facility-specific characteristics and the nature of the application. Often a synergistic remedial effect can be attained by using a combination of methods, such as *ex situ* methods to address grossly contaminated source soils or groundwater followed by *in situ* methods to provide for accelerated degradation of residual dissolved-phase contamination.

The efficacy or cost effectiveness of any remedial course of action at a particular site, whether *in situ* or otherwise, is determined by the amenability or limitations posed by a number of application-specific variables. These include the nature, mass, and distribution of the contamination, geological and hydrogeological complexity, geochemical and biochemical makeup of the contaminated media, site infrastructure, precision and detail of site characterization, or vulnerability of receptors. *In situ* technologies in particular tend to be sensitive to these variables, and therefore, may provide much less certainty in the outcome than other remedial approaches. Further, most *in situ* technologies have the potential to result in unintended effects resulting from the chemical reactions or biological processes involved.

Since this multi-faceted nature is inherent with most *in situ* technologies, thorough evaluation and planning are warranted to ensure that the selected technology is appropriate for the application; is implemented and monitored in an effective manner; has a reasonable chance for success; and can be implemented in a manner such that unintended effects from remedial processes can be reliably identified and controlled. Without such evaluation and planning, an otherwise effective technology is likely to have limited effectiveness in application, may prove to be ineffective altogether, may exacerbate an existing concern, or may pose risks to human health and safety.

3.0 Common *In Situ* Remedial Technologies

The following are some of the more commonly used *in situ* technologies that involve discharges and to which this document applies:

- Chemical Oxidation
  - hydrogen peroxide/Fenton's Reagent
  - ozone sparging
  - potassium or sodium permanganate
  - sodium persulfate
- Air Sparging
- Enhanced Bioremediation
  - Introduction of oxygen as an electron acceptor (e.g., oxygen sparging or oxygen releasing compounds)
  - Introduction of anaerobic electron acceptors (e.g., sulfates)
  - Bioaugmentation
  - Enhanced reductive dechlorination
- Surfactant Injection with Non-aqueous Phase Liquid Recovery
- Permeable Reactive Barriers

4.0 General Requirements and Considerations

A Final Assessment Report (FAR), Response Activity Plan (RAP), or pilot study (as part of a feasibility study) that proposes *in situ* remediation as a remedial option should contain the following general items, as appropriate to the facility-specific circumstances:

- Presentation of Site Characterization Data, Data Evaluation, and Conceptual Site Model
- Technical Basis for the Selection of the *In Situ* Remedial Strategy (Based on Site Characterization and Conceptual Site Model)
- Comprehensive Description of the Remedial Design, including:
  - Remedial objectives
  - Design and construction plans
  - Operational parameters
  - Implementation schedule
  - Contingency plans
- Comprehensive Monitoring and Evaluation Plan, including:
  - Environmental media that will be monitored
  - Monitoring parameters
  - Monitoring locations
  - Monitoring schedule
  - Specification of parameter thresholds and/or criteria that define remedial failure or success
  - Specification of parameter thresholds and/or criteria that will trigger the implementation of further response activity, corrective actions and/or contingency plans
  - Reporting schedule

Additional discussion of these general FAR, RAP, and pilot study requirements follows.

5.0 Site Characterization and Conceptual Site Model

The foundation for the selection of any remedial technology for further evaluation, pilot studies, or full scale implementation is site characterization. Ultimately, successful *in situ* remediation begins with site characterization sufficient to make informed and thoughtful decisions in the selection and design of a remedial strategy.

The development of a conceptual site model is an important part of the site characterization process, and a particularly critical component to implementing *in situ* remediation. A conceptual site model is the facility-specific qualitative and quantitative description of the migration and fate of contaminants with respect to possible receptors and the geological, hydrogeological, biological, geochemical, and anthropogenic factors that control contaminant distribution. For implementation of *in situ* remediation, the conceptual site model also requires a comprehensive understanding of what effects, influences, and interactions may arise as a result of the *in situ* remedial processes. The conceptual site model expresses an understanding of the facility structure, processes, interactions, and factors that will or may affect contaminant plume development and behavior before, during, and after implementation of *in situ* remediation. It is built upon assumptions and hypotheses that have been evaluated using facility-specific data and are continually reevaluated as new data are generated throughout the facility life cycle.

Generally, full scale implementation requires comprehensive site characterization, meaning that the extent of contamination is fully delineated, source contamination is well characterized, the geological and hydrogeological conditions are thoroughly understood, all transport mechanisms and exposure pathways have been evaluated, and all receptors have been identified. Interim responses, pilot studies, or smaller scale applications may warrant less comprehensive characterization prior to evaluation or implementation, depending on the remedial objectives, the nature of the technology, and the facility-specific circumstances.

At a minimum, the level of site characterization should be sufficient to demonstrate that the proposed *in situ* remedial strategy is appropriate for the site conditions, whether part of a pilot study, interim response, or full scale cleanup. This does not mean that the level of site characterization has to support a definitive conclusion as to the efficacy of a remedy, but rather it supports that the technology has a reasonable chance for success in the application.

Further, beyond a minimum effort needed to demonstrate that a technology is appropriate for a site, there is also a cost benefit balance to consider between the expense of increasing precision and detail in site characterization and the benefit those provide in terms of reducing the costs or hazards associated with the remedial technology. In many cases, extra effort in site characterization can facilitate a more focused and effective remedial approach, which is likely to reduce the magnitude of the remedial effort needed to meet the intended remedial objectives for a facility.

The following discusses the various aspects of site characterization as applicable to an *in situ* remediation:

5.1 Delineation

For implementation of full scale *in situ* remediation or *in situ* remedial discharges that are otherwise part of a final remedy associated with a FAR or RAP, the extent and distribution of contamination in the soil and groundwater should be defined both vertically and horizontally. For groundwater monitoring, this usually warrants permanent monitoring wells as a means to ensure that the vertical and horizontal extent of the contamination remains delineated during and after the implementation of any *in situ* remedial discharge.

In cases where the existing delineation is very broad, it will usually be necessary to more narrowly define the extent of contamination, both from a cost benefit as well as from a public health and safety and environmental protection standpoint. An example of where the latter would apply is a facility that has receptors located proximal to the defined extent of the contamination such that these receptors would be immediately threatened by plume expansion. In such circumstances, more precise delineation is needed prior to initiating the *in situ* remedial discharge to define a larger "buffer zone" around the contaminated area as a means to ensure the timely protection of vulnerable receptors. Note that where more precise delineation is needed prior to implementing an *in situ* remedial discharge, it may, in some circumstances, be appropriate to complete the additional delineation in the context of a FAR or RAP implementation, rather than prior to the development of a FAR or RAP.

For *in situ* remedial discharges that are part of a pilot study or interim response activity, the degree of comprehensiveness of site characterization that is warranted depends on the nature of the discharge in light of the facility-specific circumstances and conditions. Some of the factors to consider in evaluating whether the level of delineation is appropriate for a discharge include: (1) The volume and rates of the discharge; (2) Contaminant concentrations, including the presence of grossly contaminated media; (3) The distribution of contamination relative to receptors; and (4) Proximity of the discharge to receptors.

It is generally necessary to achieve comprehensive delineation prior to implementing a pilot study or interim response action. However, in some circumstances it may be appropriate to implement an *in situ* remedial discharge without completing comprehensive delineation. For example, this is often appropriate where an *in situ* remedial discharge is used as a barrier to protect a specific receptor or to prevent the longitudinal expansion of a contaminant plume. Similarly, *in situ* treatment of source contamination may also be appropriate as an interim response in certain circumstances if the area surrounding the discharge is otherwise well characterized.

5.2 Source Area Characterization

If an *in situ* remedy is intended to treat contaminant "source" areas or "hot spots" (e.g., any area containing or likely to contain anomalously high contaminant concentrations, or NAPL), or if the *in situ* remedial discharge will incidentally take place in an area where such levels of contaminants may be present, the source area should be well characterized prior to conducting the remedial discharge. This includes both the identification of maximum contaminant concentrations and the vertical and horizontal extent of such areas. Note that where applicable, source characterization includes the characterization of contamination that may be present in saturated zone soils (e.g., adsorbed non-aqueous phase liquids or "smear zone" contamination).

Thorough source area characterization is important for several reasons. First, the presence of high contaminant concentrations has implications with regard to whether or not an *in situ* remedial discharge can be conducted in a manner that does not result in unacceptable exposures, exacerbation of contamination, or fire and explosion hazards (as applicable to the contaminants of concern). This is especially true where the treatment of heavily contaminated media is implemented in close proximity to vulnerable receptors such as buildings, utilities, or surface water bodies that could be affected as a result of dimensional, chemical, or physical changes of the contamination or contaminated media brought about by an *in situ* remedial discharge.

Second, source area characterization is a critical component to estimating contaminant mass, which in turn is needed as part of predicting the scale of a remedy that will be needed to reach the intended objectives. Estimation the contaminant mass assists in determining the volume and/or concentration of amendments necessary to provide effective treatment. Without this type of estimation, it is impossible to know with any level of certainty what type of remedial approach is likely to be the most cost effective for any particular site or facility.

Third, source area characterization fosters a more targeted approach. With *in situ* remedies in particular, a targeted approach toward mitigating source contamination is likely to be more cost effective by reducing the overall amount of remedial materials needed to reach the intended objectives. What may be more significant, however, is that minimizing the amount of material discharged is a primary means to control potential threats to receptors resulting from the *in situ* remedial discharge. This is especially important when a discharge may involve reactions, such as exothermic oxidative reactions that are likely to lead to hazardous conditions or may exacerbate contamination. From a cost effective standpoint, a judgment has to be made, based on facility-specific circumstances, as to what level of detail is needed before the economic benefits of a targeted approach no longer offset the costs of obtaining additional detail in source area characterization.

In many cases, source area characterization is likely to reveal it to be much more practical and cost effective to implement a non-*in situ* remedy in conjunction with or in lieu of *in situ* remediation. For example, after consideration of contaminant mass estimates and remedy costs, along with the associated risks and uncertainty in efficacy, it is often much more efficient and practical to implement source treatment via another means, such as excavation, and to mitigate residual groundwater contamination via *in situ* technologies.

5.3 Geological and Hydrogeological Characterization

The geological and hydrogeological conditions should be thoroughly characterized and evaluated with respect to how those conditions affect contaminant transport and migration pathways, as well as the ability to effectively deliver the remedial reagents to the contaminated media. This includes:

- The delineation of geological units;
- Identification of the physical characteristics of geologic units (e.g., porosity, permeability, hydraulic conductivity, hydraulic gradients, groundwater flow rates, etc.);
- Identification of confining or semi-confining formations;
- The identification of preferential migration pathways; or
- Other related factors, as appropriate.

The assessment of these conditions should demonstrate that, in light of the selected technology and remedial system design, either the geological and hydrogeological conditions are amenable to the selected technology, or otherwise that impediments caused by these conditions can be feasibly overcome.

Facilities dominated by geological formations characterized as having low permeability are difficult to treat via *in situ* remedial methods due to the inherent resistance of such media to accepting a discharge. Further, fractures (existing or created as a result of the discharge) or even minor geological units of a comparatively high permeability are often present. These structures may serve as preferential pathways that can further inhibit the ability to distribute remedial material into and throughout contaminated media with low permeability.

Similarly, facilities with intricate or otherwise complex stratigraphy, such as those with alternating, thinly bedded, and/or discontinuous sand, silt, and clay units, are generally difficult to remediate with *in situ* remedial technologies because of the difficulty in distributing remedial reagents throughout the stratigraphic units intended for treatment. Many of the available *in situ* remedial technologies utilize reagents that rapidly degrade upon introduction to the subsurface (some only exist or remain active on the order of minutes, hours, or days after introduction). Therefore, where there are zones of varying permeability, treating contamination bound in the less permeable zones becomes very problematic due to the limited retention times of the remedial reagents and the limited ability of these reagents to effectively contact the contaminated media. Whereas the contaminants of concern may have had years or decades to work their way into the low permeable units, the comparatively short-lived nature of most remedial reagents are likely to render them only able to effectively treat the more highly permeable units or to surficially treat the low permeable units. These situations can potentially leave continued contaminated source media after *in situ* treatment, rendering the treatment virtually ineffective. That is not to say that obstacles associated with complex stratigraphy cannot be overcome when implementing *in situ* technologies, but such circumstances generally warrant a more detailed geological evaluation and a robust remedial design than may otherwise be necessary to ensure effective implementation.

Although permeable geological formations are generally amenable to *in situ* remediation, it should be recognized that even these conditions are not without concerns. First, even when the geological formation is characterized as having a homogeneous distribution, preferential flow pathways will still exist. Particularly when treating groundwater contamination, these can limit the ability to distribute the remedial reagents throughout the targeted media. Although this is generally much more easily overcome in permeable formations, it still warrants an understanding of how the geological or hydrogeological conditions will affect the *in situ* remedial discharge.

For example, an aquifer with an unusually high permeability could present certain problems with regard to lateral dispersion of remedial reagents, retention times, or even the ability to induce the necessary geochemical conditions in an aquifer if the *in situ* remedial discharge is "overwhelmed" by the rapid influx of untreated groundwater. This could be particularly problematic for a bioremediation technology such as *in situ* reductive dechlorination where the success of the remedy is contingent upon creating and maintaining an anaerobic environment in an aquifer. In addition, the presence of any geological variability within an otherwise permeable and homogenous formation, even if ostensibly minor, can significantly affect the implementability or success of an *in situ* remedial approach. For example, if an air sparge system discharges air below even a very thin clay unit in an otherwise sandy or gravelly formation, the clay could effectively preclude the upward migration of air through an aquifer rendering the air sparge system wholly or partially ineffective. In addition, implementation of this technology in such conditions could cause vapor or explosion hazards due to lateral migration of vapors.

5.4 Geochemical, Biogeochemical, and Biological Characterization

As appropriate to the selected remedial technology, the geochemical, biogeochemical, and/or biological conditions should be thoroughly characterized and evaluated with respect to:

- The presence or absence of geochemical, biogeochemical, or biological components or related parameters that are essential to the function of the remedial technology;
- The presence of these components that may, or are likely to interfere with the function of the remedial technology; and
- Geochemical or biochemical reactions and processes that are likely to occur and the potential outcome of those reactions or processes, especially those that may generate incidental or unwanted "side effects."

In almost all cases, this requires the establishment of baseline parameters to assess whether site conditions are amenable to and appropriate for the selected technology, to determine if certain supplementation is needed (or practical), and to serve a means by which to gauge or evaluate aspects of the remedial technology during implementation.

Most *in situ* remedial technologies involve considerable and often complicated chemical or biochemical interaction between the reagents and/or microbial communities used in the remedial process and various geochemical, biogeochemical, or biological components of the treated environmental media.

For some technologies, the presence of certain constituents in the environmental media and the resulting chemical or biochemical interaction is a critical and integral part of the remedial process. For example, the success of enhanced bioremediation depends on the presence of the heterotrophic microorganisms that are capable of either directly or co-metabolically degrading the contaminants of concern and subsequent daughter products. These microbes should also be able to thrive in sufficient quantities to achieve the desired rates of degradation, which in turn is heavily dependent on the presence of certain electron acceptors (oxygen, ferric iron, manganese, nitrates, sulfates, etc.), and food and nutrient sources as part of the energy cycle that supports microbe populations. Therefore, the design of a bioremedy should consider whether the right types or species of microbes are already present, or if microbial populations should be augmented, and whether the right biogeochemical conditions are present to support microbial populations.

Similarly, Fenton's Reagent is an oxidation remedy that requires the availability of sufficient quantities of ferrous iron, whether naturally occurring or supplemented, to catalyze the desired chemical oxidation reaction. Therefore, evaluation of this type of remedy should consider whether sufficient concentrations of dissolved iron are present or if they can otherwise be practically supplemented.

Most *in situ* remediation technologies also involve chemical or biochemical processes that are largely incidental and undesired because the reactions either impede the ability of the *in situ* remedial technology to degrade or remove contamination, or may otherwise generate certain "side effects" from the remedial processes. The primary reason for the former is the fact that certain remedial reagents, oxidants in particular, do not selectively react with the contaminants of concern. Rather, they will readily react with a number of naturally occurring materials including metals, organic materials, or inorganic carbon. In the case of oxidants, these materials scavenge the oxidant, thereby increasing the amount of oxidant needed to achieve the remedial objectives, perhaps to the point that naturally occurring materials become the primary driver behind the amount of oxidant needed. The potential "side effects" from *in situ* reactions can include the generation of explosive gases from the chemical or biochemical reactions, the leaching of metals from soils due to changes in redox conditions resulting from chemical or biochemical processes, or even the impact to certain receptors due to the incomplete consumption of remedial reagents or incomplete breakdown of certain contaminants. All of these factors should be assessed prior to implementation to determine whether the remedy is likely to be practical, whether potential side effects are likely to be generated, and most importantly, whether they can be effectively monitored and controlled.

5.5 Exposure Pathways, Transport Mechanisms, and Receptors

In no case is it appropriate to implement an *in situ* remedial discharge without first having conducted a thorough assessment of exposure pathways, transport mechanisms, and the impact to all potential receptors. This includes identification of any and all infrastructure or features on or near a facility that have the potential to become impacted due to the discharge. These may include: buildings, utilities (especially sewers, man-ways, or any other sub-grade enclosed spaces), water recovery wells, or surface water bodies. This assessment also includes comprehensive identification of any preferred migration pathways that could result in the impact to receptors.

6.0 Remedial Evaluation, Selection, and Design Considerations

The evaluation, selection, and design of *in situ* remedial strategies should utilize a systematic and logical approach, based on facility-specific conditions and attributes of available remedial alternatives to determine what remedial strategy (which may include more than one remedial technology or method) is most appropriate for a site. This may warrant successive levels of evaluation before a conclusion can be reached as to what remedial strategies are appropriate or how they are best implemented. Such levels may include initial conceptual and cost analysis, bench and field scale pilot studies, and finally a detailed feasibility study (based on site characterization and results of the pilot study).

The level of effort and detail that is warranted in evaluating remedial alternatives depends on facility-specific circumstances, how well established and effective the remedial alternatives are (in similar applications), and the general level of confidence as to the efficacy of the remedy. In some circumstances, there may be obvious choices as to what remedy is likely to provide the most cost effective and practical solution and which may not warrant comprehensive pilot studies prior to proceeding toward full scale implementation. In other circumstances, extensive evaluation may be warranted in order to determine the best remedial option.

Regardless of what level of evaluation is warranted, the selection of any *in situ* remedial technology for a pilot study or full scale implementation should be based on the facility-specific conditions and the attributes of potential remedial alternatives with respect to those conditions. This means that there has to be sufficient site characterization to show that site conditions are amenable to the selected remedial technology, and that the technology can be implemented in a predictable manner. This also means that there has to be enough known about the facility to allow the remedial design to be "tailored" to the site, either to optimize the remedy, reduce the risks to receptors, and/or to otherwise overcome remedial barriers presented by facility-specific conditions.

The RRD sometimes sees *in situ* remediation and remedial discharges implemented in an ad hoc and generic fashion, with little consideration given to facility-specific variables and little planning, and sometimes with little or no site characterization. Such approaches generally do not lend themselves to cost effective remediation over the long-term because they generally do not work, even after several different methods may have been "tried out" at a particular site. This is because the success of a remedy rests not only on whether a particular technology has potential for success; rather, selection and implementation of a remedial technology according to site conditions is much more critical to the success of any remedial strategy.

In many cases, existing site infrastructure (such as previous remediation system components) has been utilized in the design of *in situ* remediation systems. This sort of "recycling" often limits the effectiveness of a system because the components end up being used for something that they were not designed for, which in turn can result in incomplete remediation of a contaminated area or interval. There have also been circumstances where critical monitoring wells were used as treatment wells. This approach leads to ineffective remediation because the design of a proper monitoring well network is much different than what would be desired for a properly designed treatment well network. Further, the use of monitoring wells in this way leaves virtually no means to determine whether an *in situ* remedial discharge has been even marginally effective in reducing contaminant concentrations. This is because subsequent samples from treatment wells are not representative of the treatment area. Rather, they are representative of what may be a small and localized volume of treated groundwater at a discrete treatment location.

In addition, while there are a number of excellent and very reputable *in situ* remedial products and remedial service providers available, some manufacturers and service providers make exaggerated or erroneous claims about their products or processes. For example, claims are often made that a particular product or technology is effective in just about any set of conditions, including facilities with very low permeability (often claiming a very large radius of influence in formations with very low permeability) or complex stratigraphy alike. Often these claims are of an anecdotal, hypothetical, or presumptive basis, or otherwise based on case studies that are not really designed to show whether a technology is effective, but rather, massaged to show a specific outcome. This is not to say that such remedial technologies are ineffective, but contrary to such claims, there is no single remediation technology that works unequivocally well in all applications. Again, the success or failure of any particular remedial technology usually has less to do with the technology itself than how the technology or remedial strategy is implemented at a facility.

Further, the design of an *in situ* remedial strategy should ensure that the remedial discharge will not compromise the structural integrity of important infrastructure such as underground storage tanks, product lines, or natural gas lines. Note that discharging oxidants or other items of a corrosive nature in the vicinity of certain utilities or product storage and dispensing systems is generally not appropriate, and can pose a threat to worker health and safety.

The following include some general considerations for implementation of an *in situ* remediation:

6.1 Objectives

The RRD considers the definition of the overall remedial objectives for a facility and the objectives for each major component of a remedial strategy to be an important step in the remedial process because it facilitates a systematic and logical approach to remedial evaluation, selection, and design. Objectives for bench and field scale pilot studies should also be defined. Note that the RRD considers the definition of remedial objectives necessary as part of determining whether an *in situ* remedial strategy is appropriate, and in turn, determining whether a FAR or RAP meets the requirements of Part 213 or Part 201 of NREPA.

6.2 Pilot Studies

Pilot studies are particularly important in the evaluation of *in situ* remedial alternatives because of the large number of associated variables in field implementation. Virtually all *in situ* remedial technologies warrant some level of facility-specific pilot testing prior to full scale implementation of a remedial discharge.

Pilot studies serve a variety of purposes with the primary objectives being:

- Remedial decision making, including decisions as to whether or not to proceed to the next level of evaluation or to full scale implementation of an *in situ* remedial strategy;
- Establishment of remedial design or operational parameters; and
- Assessment of remedial “effects,” positive and negative.

Each of these general objectives can encompass a number of specific sub-objectives, as determined based on the facility-specific circumstances. These may include:

- Determining estimates of the radius of influence from treatment or recovery locations;
- Establishing long-term estimates or projections on the amount of remedial reagents needed, time frames to complete objectives, etc.; or
- Identification of specific problems that may be encountered during system operation, including problems with permeability, preferred migration pathways, the potential for secondary discharges, or the potential for exacerbation.

The need for a pilot study is facility or application-specific, but should consider:

- How well established is the remedy in similar applications;
- Variables, uncertainties, and complexities at the site that have the potential to affect the efficacy of the remedy;
- The general degree of confidence in the remedy based on facility-specific conditions and previous experience or reliable case studies dealing with a remedial alternative in similar conditions;
- The scale of the remedy; and
- The potential consequences (from a health, safety, environmental protection, or financial standpoint) of a failed remedy.

Pilot studies should be carefully designed to provide for **objective** evaluations of the remedial technologies in question. This is critical to ensuring the validity of the results and their utility as the basis for the design of further investigations or full scale remedial strategies.

When an outside party (including any remedial technology vendor) is retained to conduct any part of a pilot study (as opposed to completing this work “in house”), the end user should maintain direct involvement with the design and implementation, as well as the analysis and review of the results. Often, an outside contractor or vendor will have little if any knowledge of actual site conditions. For this and other reasons, the results of these investigations should not be blindly accepted by the end user. Rather, direct involvement is usually needed to ensure that the investigation meets the objectives for which it was intended, that the investigation appropriately represents site conditions, and that the results are reliable. The end user is ultimately responsible for any representations made as to the outcome of a pilot study, including the quality of the data.

Finally, pilot studies conducted by neutral or independent parties are preferred over those conducted by remedial technology vendors. Greater caution should be used when relying on the results from the latter because some vendors may be prone to be bias toward their own products. Vendor conducted investigations warrant greater scrutiny than independent investigations to ensure that the results are reliable; however, all pilot studies warrant careful scrutiny.

6.2.1 Bench Scale Pilot Studies

Bench scale pilot studies, such as packed column tests, are underutilized in evaluating *in situ* remedial alternatives; however, these can serve as a very cost effective screening tool in the remedial evaluation, selection, and design process. They can be simple and relatively inexpensive to do, yet can provide a large amount of initial information that can be used to better optimize field scale investigations or full scale remediation. Moreover, if a remedial alternative turns out to be impractical or ineffective, it is better to find that out in a bench scale study than after a relatively greater investment in a field scale study or full scale system.

An example of the benefits from a bench scale pilot study is well illustrated by the results of a packed column test performed as part of a remedial evaluation for a former plating operation. The test was used to evaluate the ability of hydrous ferric oxides (HFOs) to bind dissolved nickel contamination at the facility. Whereas the preliminary evaluation suggested that this method should be effective, and although the test showed that the HFOs did, in fact, bind lab grade nickel as predicted, the HFOs would not bind nickel in the groundwater collected from the site. Based on the results of this test, other remedial options were evaluated. It was later found that a chelating agent was also present in the contaminated media which had the effect of keeping nickel in a mobile state. In this case, the bench scale study was very beneficial in that it provided information that would not have been available without a facility-specific evaluation. Further, it prevented the premature initiation of a field scale study or remediation that would have proved to be of little or no benefit and at a relatively large expense.

Bench scale investigations should be designed to represent “real world” conditions to the extent possible. In regard to using bench scale tests to estimate required amounts of remedial reagents, caution should be used in that bench tests are likely to represent best case estimates due to the generally more “ideal” conditions associated with controlled tests (particularly, the ability to ensure more even and complete distribution of remedial reagents into the contaminated media, which is not the case with *in situ* remedial discharges in practice). However, such testing can be used to account for the “sum” of all of the reactions or processes likely to take place between the remedial reagent(s) and the treated media, including primary and secondary reactions, and reactions with all materials (naturally occurring or artificial) that may be present in the contaminated media. Often it is the facility-specific geochemical conditions, and not the contaminant mass itself, that is the primary driver behind the quantities of remedial reagents needed to reach remedial objectives. Therefore, such testing may often be a more practical means than stoichiometric analysis or complex modeling to estimate the minimum quantities of remedial reagents that will be required to reach remedial objectives. In regard to identifying potential problems or side effects that may result from the discharge, bench scale pilot studies may be the most appropriate means for initial evaluation of the following:

- The potential for the formation of hazardous “daughter” products or other by-products from *in situ* reactions;
- The potential for the generation or liberation of hazardous or explosive vapors;
- The potential for leaching of metals from soils;
- The formation of precipitates; or
- Problems associated with reaction rates or exothermic heat generation. Such data may indicate the need for monitoring in field scale investigations or implementation. Conversely, given a sufficiently designed test, such data may show that certain monitoring is not warranted or may support reduced monitoring of certain parameters in field applications.

An additional benefit from bench scale investigations is that they can be designed to provide the opportunity to directly observe certain remedial processes, which is advantageous in certain circumstances. For example, in evaluating an *in situ* technology to mitigate free product, a bench test could be designed that would allow direct observation of the product; therefore, providing a means to qualitatively assess degradation. A comparative field scale investigation may not be as conclusive in this regard because it is difficult to distinguish between genuine degradation from the *in situ* remedial discharge and natural fluctuations in product levels in recovery or monitoring wells.

6.2.2 Field Scale Pilot Studies

In practice, it is difficult to predict the exact outcome of a remedial discharge with respect to its effectiveness or whether or not it can be safely implemented. Moreover, once a substance is discharged, it may be difficult-to-impossible to reverse the process. Therefore, field scale pilot studies should be conducted whenever the following circumstances arise:

- There is an unacceptable degree of uncertainty as to the efficacy of a selected technology.
- The failure of a remedial alternative may result in unacceptable consequences for a facility, either from a health, safety, environmental protection, or economic standpoint.
- Facility-specific performance data is needed to establish design parameters for a full scale design (e.g., establishing the radius of influence, discharge rates, recovery rates, etc.).

Alternatively, in some circumstances, it may be more practical to over design certain aspects of a system in lieu of field scale pilot studies. However, this is not universally appropriate.

6.2.3 Pre-operational Pilot Studies Using Full Scale Remediation System Infrastructure

The RRD recognizes that in some circumstances it may be more practical and cost effective to proceed with the installation of a full scale system infrastructure without first conducting a separate pilot study, and using the full scale infrastructure to conduct the necessary tests. This may be appropriate for smaller scale efforts where the cost and effort to construct and install a full scale system infrastructure or even perhaps an "over designed" system may be less substantial than the cost and effort associated with a separate pilot study. This may also be appropriate where there is generally a high level of confidence in the design and integrity of a remediation system, absent a separate pilot study, based on comprehensive site characterization data and well established remedial design parameters. However, this does not in any way preclude the necessity of a proper evaluation prior to proceeding with full scale discharges.

6.3 Feasibility Study Requirements

Upon completion of any necessary pilot study, a detailed feasibility study should be completed to compare and evaluate remedial options. For remedial options that included a pilot study, site-specific data should be incorporated to the extent practical. This will derive more accurate projections and estimates as to remedial design parameters, pros and cons of the remedial option, and remedial costs.

6.4 Contaminant Plume and Migration Pathway Control

Any remedial discharge, whether part of a pilot study or full scale remedy, should be implemented in a predictable and controlled manner, such that the discharge does not result in unacceptable threats and exposures to receptors due to the chemical or physical changes resulting from remedial processes (e.g., vapor migration, explosion hazards, contaminant plume expansion, or exacerbation, etc.). Although this is achieved, in part, through proper monitoring as a means to determine whether such risks may become manifest, engineering and/or procedural mechanisms are also usually necessary to control these risks, especially where receptors are located in close enough proximity to a treatment area.

Where there are no receptors present that may be immediately threatened by the effects of an *in situ* remedial discharge, it may be adequate to rely on monitoring with contingency planning as a means to ensure that there is no risk of increased threat. However, most facilities such as operational gas stations, active manufacturing facilities, or facilities with residential homes in the area do not fit this type of scenario. Remedial discharges at these facilities may warrant robust engineering controls for certain *in situ* remediation technologies.

The following generally describes some of the methods that are often used as **part** of maintaining the contaminant plume and migration pathway control:

- It is often necessary to initiate remedial discharges in an incremental, step-wise fashion beginning with low volumes, concentrations, or discharge rates, and working up toward the desired operational parameters. This provides for greater predictability in determining the effects of a discharge, which is particularly important when highly reactive reagents are discharged.

- Discharge volumes and rates should be minimized, to the extent practical, to reduce plume expansion resulting from the displacement of fluids. This also prevents “mounding” of the groundwater table during the discharge, which can spread contamination (particularly free-phase contamination) vertically or horizontally.

- Whether discharging gases or liquids, the distribution of a discharge can be used to prevent the displacement of contamination. One way to do this is to ensure a relatively even discharge rate over an area that completely encompasses the contaminated media intended for treatment. An additional level of control that can sometimes be useful is to discharge at relatively higher rates around the perimeter of a contaminant plume than in its interior. Ideally, this will create a small degree of mounding around the outside of a plume to help hold contamination in place. A similar discharge protocol that may be practical in some circumstances is an “outside-in” approach where a remedial discharge is initiated around the perimeter of the treatment area and then incrementally shifted to discharge locations toward the interior of a plume. The goal of this method is to incrementally shrink a contaminant plume.

- If a remedial discharge requires the dilution of remedial reagents prior to discharge, it is often beneficial and practical to use contaminated groundwater from the site for dilution in order to minimize the net discharge volume. This may not be practical at facilities where a reliable means to recover sufficient quantities of groundwater is not available, or where dilution with contaminated groundwater might diminish the effectiveness of the discharge.

- If the discharge has the potential to generate hazardous or explosive levels of vapors or gases in the vicinity of vulnerable receptors, vapor recovery methods should be employed. In such cases, it may sometimes be sufficient to have a vapor recovery system on standby as a contingency with proper monitoring. The operation of a vapor recovery system does not in any way preclude the need for proper monitoring to ensure protection from vapor hazards.

- In circumstances where the discharge is likely to result in exacerbation, or where receptors are immediately threatened and other plume control mechanisms are not sufficient or otherwise unreliable, groundwater capture methods may be warranted. In some cases, it may be sufficient and appropriate to have a capture system on standby as a contingency.

7.0 Monitoring Requirements

Proper monitoring is critical to a successful *in situ* remediation, yet is one of the most common shortfalls when implementing an *in situ* remediation. This is usually because the monitoring program is overly simplistic and assumptive or attempts to utilize an existing monitoring network installed to delineate site contamination that is not adequate to evaluate the remediation. This leads to data gaps in some areas of evaluation, while attaining superfluous amounts of data in other areas. *In situ* remediation generally warrants monitoring of multiple environmental media and monitoring parameters to ensure implementation in a safe and effective manner. Periodic monitoring of contaminants of concern alone is not sufficient in this regard because it often provides virtually no information as to health, safety, or environmental concerns associated with the discharge, and provides only cursory evidence as to whether or not a remedy is effective. That is not to say that monitoring programs have to be extremely complex, but rather that strategic thinking in the development of a monitoring program is likely to lead to better data that is gathered more efficiently, ultimately leading to a more informed evaluation and a more cost effective *in situ* remediation project.

Monitoring requirements for *in situ* remediation are very application-specific. As such, a comprehensive description of the monitoring requirements and protocol for *in situ* remediation is beyond the scope of this document. However, general considerations for developing or evaluating the environmental media to monitor and common monitoring parameters for *in situ* remediation are described below. It is ultimately up to the party implementing the discharge to develop a thorough monitoring plan. In developing a monitoring plan, the party implementing the discharge should consult reliable scientific, engineering, and technical references specific to the remedial option to determine what media and parameters warrant monitoring.

7.1 Purpose and Objectives

Every monitoring plan for *in situ* remediation should be designed with application-specific purposes and objectives in mind and at a minimum should address the following areas:

7.1.1 Assuring Protection of Public Health, Safety, and Environment

The performance objectives of the monitoring plan include ensuring timely protection of public health, safety or welfare, and any environmental receptors that have the potential to become affected as the result of the discharge. For receptors that may already be affected, the monitoring plan should be sufficient to identify (in a timely manner) whether the discharge may result in an increased threat to that receptor. For example, if contamination is already discharging to a surface water body at unacceptable concentrations, the remedial discharge cannot result in any increased contaminant loading to that receptor. The monitoring plan should also ensure that the remedial discharge is not resulting in any contaminant exacerbation or otherwise any appreciable increase in the extent of contamination. Further, the monitoring plan should include specific action levels that would trigger specific response activity or corrective actions.

7.1.2 Evaluating Remedial Integrity and Effectiveness

The monitoring plan should provide for sufficient means to qualify and quantify the effectiveness of the remedial discharge in achieving remedial objectives, including consideration of facility- specific variables such as periodic fluctuations in contaminant concentrations, to distinguish whether genuine reductions in contaminant concentrations are occurring. Potential “side effects” from the remedial discharge should also be considered in the monitoring plan as part of the evaluation of integrity of the remedy. For example, if a remedial discharge has the potential to leach metals from soil, the monitoring plan should be sufficient to show whether this is occurring, and if so, whether metal concentrations will sufficiently attenuate before reaching a receptor. The monitoring plan should also include specified parameters and time frames that define the success or failure of the remedy. Again, it should be noted that samples collected directly from treatment wells are generally not representative of the treatment area as a whole, and should not be used for evaluating (or demonstrating) remedial integrity and effectiveness.

7.1.3 Assuring that Action Levels are Not Exceeded at Compliance Monitoring Points

The monitoring plan purpose also includes ensuring that the extent of contamination remains defined and that contaminants do not exceed applicable criteria at other specified compliance monitoring points (e.g., in sentinel monitoring wells).

7.2 Monitoring Phases

Monitoring phases can generally be broken down into the following: Baseline, co-implementation, post-implementation or remedial evaluation, and compliance.

7.2.1 Baseline Monitoring

Baseline sampling and analysis serves multiple purposes and should be completed prior to initiation of any *in situ* remedial discharge or series of *in situ* remedial discharges. Baseline sampling of geochemical, biochemical, and/or biological parameters should be completed, as applicable, as part of the *in situ* remedial evaluation, selection, and design process. This sampling also serves as a basis for gauging certain effects from remedial processes. Establishing baseline concentrations for contaminants of concern and potential daughter products is necessary for evaluating initial risks to environmental receptors, and also for gauging remedial success.

Four (4) consecutive quarters of sampling are preferred for establishing contaminant baseline concentrations, as this allows for a means to roughly gauge seasonal fluctuations in contaminant concentrations; however, less extensive baseline monitoring may be appropriate in some circumstances. In addition, it may sometimes be necessary to establish baseline concentrations for other parameters that may be present in both the treated media and in the remedial discharge to allow a determination of what component(s) may be due to the discharge versus naturally occurring or pre-remedial conditions.

7.2.2 Co-Implementation Monitoring

Co-implementation monitoring refers to any monitoring conducted as part of the *in situ* remedial discharge protocol, or otherwise just prior to, during, or immediately after implementation of an *in situ* remedial discharge. This monitoring generally centers around the assessment of the immediate environmental or health and safety concerns posed by an *in situ* remedial discharge or the general progress of the discharge. It generally comprises field screening techniques to assess immediate effects, such as groundwater mounding, temperature changes, vapor and explosion hazards, certain geochemical changes (e.g., dissolved oxygen, pH, oxidation- reduction potential (ORP).

Co-implementation monitoring should be sufficient to monitor the general progress and immediate effects of the discharge.

7.2.3 Post-implementation or Remedial Evaluation Monitoring

Post-implementation monitoring refers to any monitoring following the implementation of an *in situ* remedial discharge that is conducted specifically for the purposes of evaluating the effectiveness and integrity of the remedy. Post-implementation monitoring should include assessment of:

- Any potential "lingering" effects from the *in situ* remedial discharge;
- Changes to geochemical, biochemical, or biological conditions (both desirable and undesirable);
- Rates of contaminant degradation following *in situ* remedial discharges; and
- Other factors as necessary to evaluate the integrity of the remedy.

7.2.4 Compliance Monitoring

Although compliance monitoring may often be completed in the same event and may also use some of the same samples and analytical data as attained for post-implementation or remedial evaluation monitoring, it is distinguished here because it serves a different purpose, does not always require the same parameters, and does not necessarily warrant the same sampling frequency as the latter. For example, some technologies warrant a high frequency of remedial evaluation sampling in the treatment area (e.g., perhaps sampling at 1, 7, 14, 30, 60, and 180 days following each discharge event), and may also warrant a comprehensive list of analytical parameters (e.g., geochemical, biochemical, biological, contaminants of concern, and daughter product parameters). By comparison, compliance monitoring may take place well outside of the treatment area (although not always); generally warrants a much less substantial sampling frequency (e.g., quarterly or biannually); and may, depending on facility-specific circumstances, warrant a less comprehensive list of parameters (e.g., contaminants of concern, daughter products, and select geochemical or biochemical parameters based on remedial evaluation monitoring). The differences between remedial evaluation and compliance monitoring are mentioned here to point out the fact that overly simplified monitoring plans may not be sufficient or cost effective in implementation.

7.3 Environmental Media and Common Monitoring Parameters

The following lists the common environmental media and parameters that are generally monitored as part of an *in situ* remediation. The applicability of these items varies depending on the selected remedial option and facility-specific circumstances.

7.3.1 Soil Gas

Soil gas should be monitored before, during, and after implementation of an *in situ* remedial discharge when the contaminants of concern or remedial reagents have the potential to lead to vapor or explosion hazards. This includes circumstances where a remedial discharge has the potential to generate, mobilize, or displace vapors or generate higher than normal concentrations of oxygen gas, and these vapors or gases have the potential to migrate into enclosed spaces. In some circumstances, field screening techniques (e.g., photoionization or gas detectors) may be sufficient to assess risks, although some circumstances warrant the collection of soil gas samples for lab analysis. Soil gas monitoring is generally conducted for the purposes of sentinel monitoring to protect specific receptors; therefore, action levels should be specified for soil gas monitoring that will trigger specified response activity or corrective actions necessary to protect receptors. In some circumstances, it may be beneficial or even necessary to monitor various soil gas parameters for purposes other than vapor or explosion hazards, such as remedial evaluation. The RRD Guidance Document for the Vapor Intrusion Pathway should be consulted for guidance on soil gas monitoring.

7.3.2 Indoor Air and Enclosed Spaces

Indoor air monitoring (including monitoring of enclosed spaces such as storm sewers, utility man-ways, etc.) should be included in the monitoring program for any facility where vapor or explosion hazards are a concern. **However, when assessing any circumstance where acute risks (including explosion hazards) have the potential to develop rapidly upon implementation of a discharge; this type of monitoring cannot be exclusively relied upon to protect public health and safety.** For contaminants with potential chronic impacts, indoor air sampling should be implemented in conjunction with a more reliable monitoring method, or as a contingency that is implemented when a more reliable method indicates the exceedance of specified action levels. For example, it is often more appropriate to use soil gas monitoring as the primary basis for assessing potential risks to indoor air (i.e., sentinel monitoring), with indoor air monitoring implemented as a contingency only after specified action levels set for soil gas monitoring are exceeded. For contaminants that may pose an explosion hazard, indoor air sampling could provide an additional safeguard, but earlier detection at sentinel monitoring points still would be necessary. The RRD Guidance Document for the Vapor Intrusion Pathway should be consulted for guidance on indoor air and enclosed space monitoring.

7.3.3 Ambient Air

Ambient air monitoring is warranted whenever a discharge has a reasonable potential to generate concentrations of vapors in ambient air that either present unacceptable inhalation exposures to workers or non-workers, or that could present a risk of fire or explosion. In most applications, *in situ* discharges are applied at some depth beneath a cover material (i.e., soil and/or pavement), which usually inhibits the rapid diffusion of vapors to the surface, thereby minimizing the ability of gases or vapors to accumulate at hazardous concentrations in ambient air. However, this alone does not necessarily preclude the need for ambient air monitoring.

In determining whether ambient air monitoring is necessary as part of an *in situ* remedial strategy, the following should be considered:

- The concentrations of contaminants in soil or groundwater, especially where grossly contaminated media is present;

- The concentrations at which contaminants of concern or remedial constituents become toxic in air, especially if toxic at very low concentrations;
- The potential for explosive conditions to develop, in light of the chemical properties of the contaminants of concern **and** potential by-products from the discharge (e.g., generation of oxygen gas);
- The proximity of the treated media to the surface;
- The properties of the soil and/or cover above the treated media;
- Whether engineering controls are implemented as part of the remedial process, such as soil vapor extraction, that will otherwise stop the migration of gases or vapors to the surface; and
- The presence of conduits to the surface for gases and vapors, such as monitoring or treatment wells, that can result in the impact to the breathing zone air.

Examples of where ambient air monitoring may be necessary as part of an *in situ* remedial strategy include the application of oxidants to open excavations as a means to treat petroleum or solvent contamination; or discharges through, or in the vicinity of open wells where off-gassing through the well has the potential to result in unacceptable breathing zone exposures to site workers.

7.3.4 Groundwater

Groundwater monitoring is warranted at nearly every site in Michigan when implementing an *in situ* remediation to evaluate contaminants of concern, daughter products, geochemical parameters, biochemical parameters, and/or biological parameters, as appropriate to the application. In circumstances where vapor or explosion hazards are of concern, and the remedial discharge involves slow reaction rates (such as is generally expected with *in situ* bioremediation), it may sometimes be appropriate to rely on groundwater samples as tools for assessing potential vapor or explosion risks.

For this type of assessment, Part 201 Criteria Application Guidesheets 4 and 5 (developed under R 299.14) and Guidesheets 8 and 9 (developed under R 299.6(1)) should be consulted as appropriate.

If the groundwater surface water interface (GSI) pathway is relevant for a facility, sampling the groundwater prior to its discharge to a surface water or storm sewer is necessary as part of assessing the risks posed by the *in situ* remedial discharge. However, in some circumstances, it may be necessary to supplement GSI groundwater monitoring with direct sampling of the receiving water body or storm sewer.

Some remedial constituents, such as hydrogen peroxide, ozone, or permanganate, can be acutely toxic to aquatic life at very low concentrations; therefore, a similar assessment may also be warranted for remedial constituents. However, as in the assessment of indoor air hazards, if any potential impact to GSI receptors is anticipated, it is never appropriate to assess this exposure pathway via surface water or storm water sampling exclusively. Rather, GSI compliance monitoring points and sentinel wells where appropriate serve as the primary means to assess threats to GSI receptors.

7.3.5 Soil

In addition to assessing soil contaminant concentrations as part of the overall site characterization, periodic monitoring of vadose or saturated zone soil contamination may be necessary in some circumstances in order to evaluate the efficacy of an *in situ* remedial strategy. This should be included in the monitoring plan for any *in situ* remedial strategy that is specifically intended to remediate soil contamination. Such monitoring may also be warranted in circumstances where soil contamination presents an ongoing impact to groundwater contamination, or where the remedial reagents and processes themselves have the potential to contribute to soil contamination.

For *in situ* remedial technologies that are dependent on or inhibited by certain geochemical conditions (naturally occurring or anthropogenic), baseline soil sampling is usually necessary. Although this does not generally warrant ongoing monitoring, there may be circumstances where periodic monitoring for such parameters is appropriate.

7.4 Common Monitoring Parameters

The following briefly describes some of the common monitoring parameters associated with various *in situ* remediation technologies. Please be advised that this discussion is neither comprehensive nor intended to be so. Additional parameters may be warranted depending on facility-specific circumstances.

7.4.1 Contaminants of Concern and Daughter Products

Contaminants of concern or contaminant indicator parameters and their respective daughter product concentrations should be characterized as part of the baseline, co-implementation, remedial evaluation, and compliance monitoring, and is relevant for all types of environmental media as deemed necessary for the application. For the purposes of remedial evaluation, the level and frequency of monitoring should be sufficient to quantify degradation rates and/or to assess remedial progress in light of specified remedial objectives. Further, assessment of potential daughter products should show whether daughter products are being generated, and if so, whether daughter products are sufficiently abated. For the purposes of compliance monitoring, parameters should be sufficient to show that the extent of the contaminants of concern and daughter products remains delineated and that action levels are not exceeded in the compliance monitoring points.

7.4.2 Geochemical and Biochemical Parameters

The parameters used for geochemical and biochemical characterization are similar with consideration depending on whether the remedy is chemically or biologically oriented. Such parameters either inhibit/interfere with or enhance chemical reactions in chemically based technologies (such as *in situ* chemical oxidation), or may be necessary for or detrimental to the establishment or growth of the specific types of microbes necessary for intended bioremediation processes. Similarly, some of these parameters may be more indicative of chemical or biological processes than they are necessary for these processes to occur. Further, some geochemical and biochemical parameters have the potential to become contaminants of concern due to chemical changes brought about by remedial processes, such as the alteration of metals to a more mobile valent state, or conversions between ammonia and nitrate.

Characterization of geochemical and biochemical parameters is generally applicable to groundwater and soil, although other media may warrant characterization (e.g., oxygen, carbon dioxide, or methane in soil gas). Common geochemical and biochemical parameters for soil include: metals, fraction of organic carbon, natural oxidant demand (uncontaminated soil matrix), and soil oxidant demand (contaminated soil matrix). Common parameters for groundwater include: dissolved oxygen, dissolved carbon dioxide, dissolved methane, total metals, nitrate, sulfate, sulfide natural oxidant demand (or chemical or biological oxidant demand, as appropriate), specific conductance, alkalinity, total organic carbon, volatile fatty acids, pH, and ORP. Additional parameters may be needed depending on site conditions.

7.4.3 Biological Parameters

Characterization of biological constituents, including microbial species, is necessary if a remedial technology relies on the enhancement of biological processes or bioaugmentation to degrade contamination. This type of monitoring should be included as part of the baseline and remedial evaluation monitoring and is applicable to soil and groundwater media. In some circumstances, analysis of total heterotrophs as an indicator of relative microbial abundance (pre- and post-remedial discharge) may be sufficient to confirm that conditions are amenable to microbe survival, growth, and reproduction.

However, for remedies that rely on the presence of specific species, a more specific analysis may be warranted to confirm that the right organisms are present. *In situ* reductive dechlorination of dissolved-phase chlorinated hydrocarbons is the most commonly encountered example of enhanced bioremediation or bioaugmentation where a species-specific analysis is warranted. This remedial technology relies heavily on co-metabolic processes brought about by the presence of specific species of bacteria (i.e., dehalococcoides ethenogenes) to degrade chlorinated hydrocarbon contamination. Further, there are specific genotypes necessary to produce the necessary enzymes (vinyl chloride reductase) for the complete degradation of contamination. As such, implementation of this technology may require a species-specific analysis, and/or analysis for the vinyl chloride reductase gene (unless it can be demonstrated that vinyl chloride will breakdown into ethane via another mechanism).

7.4.4 Physical Parameters

Various physical parameters, such as temperature, water levels/hydraulic gradients, pressure, vacuum, hydraulic conductivity, or even color may be necessary as part of the co- implementation monitoring to assess the progress of or effects from remedial discharges. Often, such monitoring is necessary to ensure the protection of public health and safety and certain environmental receptors during implementation of a remedial discharge.

7.4.5 Discharge Constituents

Monitoring of *in situ* remedial discharge constituents (or additives) is necessary if the constituent in the *in situ* remedial discharge (or a by-product of a discharge constituent) has the potential to accumulate in the environment at concentrations exceeding residential cleanup criteria, or if the constituent otherwise has the potential to cause a threat to public health, safety, or the environment. Be advised that there are many remedial constituents in the latter category for which there are no criteria developed. These include oxidants (ozone, hydrogen peroxide, permanganate) which can be acutely toxic to aquatic life at relatively low concentrations. This can also include any unconsumed organic matter added as a food source to support microbial growth. In most cases, co-implementation and remedial evaluation monitoring of discharge constituents is beneficial or necessary in establishing distances or radii of influence from remedial discharges, or ensuring complete consumption or breakdown of certain remedial constituents.

8.0 Applicability of and Compliance with the Part 22 Rules

Authorization for all *in situ* remedial discharges falls under the Part 22 Rules. In summary, there are two (2) primary mechanisms by which the Part 22 Rules authorize *in situ* remedial discharges. The first option is to obtain a discharge permit through the MDEQ Water Resources Division. The second option is to obtain a permit exemption pursuant to R 323.2210(u)(ii) and (iii). The limited resources of the MDEQ do not allow the investment of staff resources to review a proposal for a permit that would otherwise qualify for an exemption. Permit exemptions authorized under R 323.2210(u)(ii) have essentially the same requirements as authorization under R 323.2210(u)(iii), only that the former does not require prior approval by the RRD. Further information on the applicability of the Part 22 Rules to an *in situ* remediation and the general requirements for obtaining a permit exemption are described in Appendix A.

Any direct or indirect discharge of a material (liquid, solid, or gas) into groundwater or onto the ground for the purposes of an *in situ* remediation is required to be authorized by a groundwater discharge permit or an appropriate permit exemption under the Part 22 Rules. For most types of *in situ* remedial discharges, prior approval from the RRD will be necessary before the discharge can be lawfully implemented. Requests should be submitted as a Response Activity Plan for sites regulated by Part 201 and for sites regulated by Part 213 with a FAR Coversheet and work plan.

9.0 Documentation Requirements for Obtaining a Permit Exemption

A permit exemption for remedial investigations, feasibility or pilot studies, or remedial action discharges (direct or indirect) that exceed or are anticipated to exceed generic residential cleanup criteria (and are subject to authorization under R 323.2210(u)(iii)), can be obtained by virtue of prior RRD approval of an associated remediation investigation, feasibility study, RAP or FAR/CAP.

For discharges implemented as part of a FAR or RAP, R 323.2210(u)(iii) provides for a permit exemption with approval from the RRD of the FAR or RAP. The Part 22 Rules do not provide for a permit exemption with the RRD approval of only portions of a FAR or RAP; therefore, **all of the information of a complete FAR or RAP needs to be**

provided, even if portions of the information are not directly related to the proposed *in situ* discharge.

For discharges implemented in the context of a remediation investigation or pilot study subject to approval pursuant to R 323.2210(u)(iii), the proposed discharge should be documented to the extent necessary to allow the RRD to evaluate the basis for and objectives of the discharge, the design and operational parameters, and how the discharge will be monitored and evaluated. This documentation is necessary in order for the RRD to make a determination as to whether or not to approve of the discharge in the context of an approved remediation investigation or feasibility study.

In order to obtain a permit exemption for a remedial investigation, pilot study, or remediation plan discharge pursuant to R 323.2210(u)(iii), documentation should be submitted to the RRD that describes all of the following:

- Objectives of the discharge;

- Site characterization information, including: (1) The nature and extent of contamination, (2) Geological and hydrogeological conditions, (3) Geochemical, biogeochemical, and/or biological characterization, and (4) Exposure pathways, transport mechanisms, and potential receptors;

- The remedial strategy and technical basis for selection of the *in situ* remedial technology and/or remedial strategy in light of facility-specific conditions;

- How the *in situ* remedial strategy will be implemented in a manner that is protective of the public health, safety, and welfare, and the environment. This should include an evaluation of specific concerns that may be encountered during the discharge (e.g., vapor migration, explosion hazards, formation of hazardous daughter products, exacerbation of contamination, etc.) and a description of how each environmental receptor will be protected;

- Design and construction plans, including: discharge or injection points, comprehensive list of constituents to be discharged, flow rates, discharge volumes, discharge protocol, and other pertinent information;

- A detailed monitoring plan, including parameters, general implementation schedule, data presentation and evaluation plan; and

- Contingency planning, including specified action levels that will trigger contingent response activity or corrective actions and time frames for implementing them.

In deciding what specific information to submit, response activity plan[2] or FAR/corrective action plan requirements[3] should be consulted in addition to published references specific to the *in situ* remedial application. Even where an *in situ* remedial discharge is proposed

[2] Section 20114b of NREPA
[3] Section 21309a of NREPA

as part of a remedial investigation or pilot study, and therefore does not necessarily have to meet all of the RAP or FAR requirements, these requirements still provide a good reference for evaluating what specific information and documentation should be submitted in order to obtain the RRD approval.

10.0 Miscellaneous Recommendations For Documentation

If a pilot study is necessary in order to determine what the essential or critical elements of a remedial strategy will be (e.g., such as to determine what remedial option to proceed with), it is recommended that the investigation be completed separate from and prior to the final development of the FAR or RAP, and the results from the investigation incorporated therein. If the purpose is to establish design parameters rather than to select a remedial option, it is generally acceptable to incorporate the pilot study into the FAR or RAP implementation. If the purpose of the pilot study is to decide whether or not to amend a FAR submitted under Part 213, it is acceptable to rely on the existing FAR in the interim if it is otherwise complete.

Plans for remedial discharges should incorporate some degree of flexibility to allow for adjustments during implementation. As such, where parameters are expected to vary throughout the process, such as discharge rates, concentrations or volumes, or geochemical or biochemical parameters, it is recommended that parameter ranges be specified, where appropriate, rather than specific values.

Often the most efficient manner to present a monitoring plan is in a table format that specifies monitoring parameters, monitoring location, media to be monitored, and time frames.

11.0 Submittals Requiring Prior RRD Approval

The FARs, RAPs, and plans for pilot studies or interim responses that require prior RRD approval in order to attain a permit exemption for a remedial discharge should be submitted directly to the respective MDEQ district office, and may be addressed directly to the MDEQ project manager assigned to the site (this does not represent any change in procedure). Except for proposals provided as part of a FAR, submittals should include a brief cover letter indicating that the RRD approval of the plan is requested in order to attain a permit exemption for a remedial discharge. The standard FAR cover sheet has been modified to include a check box to indicate that the RRD review is necessary.

In order to prevent excessive delays in the implementation of corrective actions, submittals that require prior approval in order to attain a permit exemption are given priority by the RRD. Although the RRD will try to respond to these submittals as quickly as possible, the turnaround time for the RRD review is dependent on workload as well as the complexity of the review. Persons seeking approval from the RRD of a plan are advised to notify the RRD project manager of the upcoming submittal ahead of time in order to facilitate a more expedient review.

The RRD will respond to the FAR, RAP, and feasibility or pilot study submittals that propose an *in situ* remedial discharge in writing to the person or institution that is responsible for undertaking the response activity or corrective actions to address the release (generally the “owner” and/or “operator” as defined in Parts 201 and 213), or who is voluntarily undertaking the response actions under Parts 201 or 213. Written notification from the RRD stating that the FAR, RAP, or feasibility study submittal is approved provides the requisite authorization pursuant to R 323.2210(u)(iii) of the Part 22 Rules to proceed with implementation of the remedial discharge. Note that if a submittal omits necessary information or is otherwise substantially deficient, the RRD project manager may request revisions prior to conducting a formal review and written response.

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Appendix A

Discharge to a Plume of Contamination Without a Permit
(Part 22 Rules, promulgated pursuant to Part 31 of NREPA)

Section 3112(1) of Part 31[1] of NREPA states that, "A person shall not discharge any waste or waste effluent into the waters of this state unless the person is in possession of a valid permit from the department…" Section 3109 of NREPA states that, "A person shall not directly or indirectly discharge into the waters of the state a substance that is or may become injurious to any of the following…" This section goes on to list public health, safety, or welfare, domestic, agricultural, recreational, etc., as the protected uses of the waters of the state. This is reiterated in R 323.2204 of the Part 22[2] Rules.

The Part 22 Rules establishes the criteria under which a discharge[3] (e.g., *in situ* remedial treatment) to groundwater meets the Section 3109 requirement of preventing the discharge of a substance that is or may become injurious to the protected uses. The Part 22 Rules also establishes the criteria for obtaining valid authorization from the MDEQ, in accordance with Section 3112(1), for the discharge of a waste or waste effluent into the waters of this state. The Part 22 Rules are applicable to the discharge and any effects resulting from the discharge; however, they do not control the level of remediation that needs to take place relative to the plume of contaminated groundwater.

Pursuant to the Part 22 Rules, the discharge of any pollutant[4], waste[5], wastewater[6], or waste effluent to groundwater constitutes a discharge of a waste or waste effluent as described in Section 3112; therefore, all discharges related to the groundwater cleanup activities requires a groundwater discharge authorization. The Part 22 Rules provides for the following types of authorizations: A permit exemption (R 323.2210), permit by rule (R 323.2211 and R 323.2213), general permit (R 323.2215), or specific discharge permit (R 323.2216 and R 323.2218).

[1] Part 31, Water Resources Protection, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended (NREPA).

[2] Part 22 Rules, Groundwater Quality Administrative Rules, promulgated pursuant to Part 31, Water Resources Protection, of NREPA.

[3] "Discharge" means any direct or indirect discharge of any of the following into the groundwater or onto the ground: (i) waste, (ii) waste effluent, (iii) wastewater, (iv) pollutant, (v) cooling water, (vi) a combination of items (i) to (v) {R 323.2201(i)}.

[4] "Pollutant" means any substance that may adversely affect a protected use of waters of the state,

{R
323.2202(m)}.

[5] "Waste" means any waste, wastewater, waste effluent, or pollutant that is discharged into water
{R
323.2203(n)}.

[6] "Wastewater" means liquid waste discharged directly or indirectly into the waters of the state or onto the ground that results from industrial or commercial processes or municipal operations, including liquid or water-carried process waste, cooling or condensing waters, and sanitary sewage. {R 323.2203(o)}. The wastewater associated with environmental response activity referenced in R 323.2210(u) was primarily intended to address discharges from groundwater purge and treatment. The discharges associated with *in situ* remedial discharges similarly meet the wastewater definition.Of these authorizations, R 323.2210(u) provides an exemption that allows wastewater associated with an environmental response activity, under certain constraints, to be discharged to the plume of groundwater contamination, including an area 100 feet hydraulically upgradient of the leading edge of the plume, without a permit. Note that it is very important that those responsible for managing and implementing a discharge (e.g., environmental consultants, liable parties, parties voluntarily undertaking response activities, state project managers, and others) carefully consider the conditions under which a R 323.2210(u) exemption applies.

R 323.2210(u) contains three (3) different provisions that apply to discharges associated with environmental response activities, depending on the nature of the discharge. Two (2) of these provisions apply to *in situ* remedial discharges (e.g., remedies that involve the use of hydrogen or oxygen releasing agents, oxidants, nutrients, microbes, permeable reactive barriers, etc.) which include the following:

(ii) A remedial investigation, feasibility study, or remedial action discharge that is at or below the residential criteria;

(iii) A discharge for a remedial investigation, feasibility study, or remedial action above the residential criteria, if a remediation investigation, feasibility study, RAP or FAR/CAP has been approved by the department division that has compliance oversight. The RAP or FAR/CAP shall indicate that the treatment system is designed and will be operated so that contaminated groundwater will eventually meet the appropriate land use based cleanup criteria authorized by Section 20120a(1)(a) of the act, if applicable, or Section 21304(a) of the act, if applicable.

Note that the definition of a "discharge" [see R 323.2201(i)] includes any direct or indirect discharges; therefore, the determination of which of the above applies needs to consider the content of the discharged material(s), including any additives contained therein, in addition to all potential secondary effects that may result from the discharge. Also, note that the definition of a discharge is not limited to discharges of liquid materials, but rather, also applies to discharges of solids and gases.

If the discharge is proposed for a remedial investigation, feasibility study (or pilot study), remedial action, or corrective action, a determination needs to be made whether the discharge **contains or creates** any substances that are above residential criteria authorized by Section 20120a(1)(a) or Section 21304(a) of NREPA, as applicable. Pursuant to R 323.2206(1), it is the responsibility of the person proposing a discharge to provide the information as required or necessary for the MDEQ to make a decision (or to concur) as to whether a discharge may contain or create substances above residential criteria. In some circumstances, this effort may warrant some level of site-specific testing or analysis.

If the discharge is below criteria, then the discharge is exempt from the requirement to obtain a permit. If a discharge has a reasonable potential to cause an indirect discharge that may exceed residential criteria, even if the content of the discharged material(s) in and of itself does not exceed residential criteria, then the discharge is subject to division approval pursuant to R 323.2210(u)(iii) before the discharge can be lawfully implemented, unless it is otherwise demonstrated (to the satisfaction of the RRD) that authorization under R 323.2210(u)(ii) applies instead.

If any substance in the discharge is above residential criteria or may cause a discharge above residential criteria, the person proposing the discharge needs to demonstrate that a feasibility study, RAP, or FAR **has been approved by the RRD** as the division that has compliance oversight. This demonstration consists of documentation to the file by the appropriate RRD representative that the conditions of R 323.2210(u)(iii) have been met.

Generally, the RRD considers R 323.2210(u)(iii) applicable whenever the discharge may result in the following conditions:

- Alteration of the geochemical equilibrium in the subsurface in a manner that promotes leaching of metals;
- Formation/creation of reactive, hazardous, or otherwise non-inert by-products, including hazardous “daughter” products formed from the breakdown of the originally released material(s); or
- Exacerbation of existing contamination.

For example, the discharge of hydrogen peroxide is a relatively common method proposed for treating petroleum contamination *in situ*. Although residential criteria have not been developed for hydrogen peroxide, injection of this acidic and oxidative material has been shown to cause metals to leach from soil into the groundwater. Similarly, supplementation of an aquifer with microbes, nutrients, and/or a food source to promote bioremediation can also alter groundwater geochemical conditions such that metals leach into the groundwater. Therefore, either of these types of remedies requires approval pursuant to R 323.2210(u)(iii).

Remedial discharges that involve oxidative or enhanced biological processes (including pilot studies) are subject to division approval pursuant to R 323.2210(u)(iii). This includes (but is not limited to): hydrogen peroxide (including Fenton’s Reagent or any “modified”

Fenton's Reagent), permanganates, persulfates, ozone, reductive dechlorination, or other enhanced bioremediation. Be advised that this is not all inclusive and that other types of *in situ* remedies not identified herein may also be subject to division approval. Please contact the RRD project manager if there are any questions pertaining to the applicability of R 323.2210(u)(iii) to a particular *in situ* remedy.

For *in situ* remedial discharges of oxygen or ambient air to groundwater (i.e., oxygen or air sparging), the MDEQ has determined that these discharges, when specifically used to treat hydrocarbon contamination, are authorized under R 323.2210(u)(ii) and do not typically require prior approval by the RRD. The basis for this determination is that in most applications it is not expected that the operation of an oxygen or air sparge system would create a direct or indirect discharge above residential criteria. This determination is based on the condition that there are no contaminants in the oxygen or air, including contaminants such as compressor oils, and that the system is operated in a manner that will not exacerbate contamination. However, although these discharges do not typically require prior division authorization, this should in no way be construed to waive any obligations to comply with other requirements under the Part 22 Rules, Part 201, and/or Part 213 (as applicable). Note that Section 21309a has very specific requirements regarding the implementation of corrective actions. This information needs to be submitted prior to implementing any *in situ* remedy, unless the remedial discharge is specifically intended to meet initial response obligations under Section 21307.

Other Permit Exemption Requirements

Discharges are exempt from permitting if they meet the criteria listed in R 323.2210(u), but they are never exempt from the requirements of Section 3109 of NREPA or R 323.2204. Further, regardless of whether an *in situ* discharge qualifies as an "item that is permitted to be discharged without a permit" under R 323.2210(u)(ii) or (iii), the discharge must comply with all other provisions of the Part 22 Rules, Part 201, and/or Part 213 (as applicable). For example, the person or persons completing the discharge remains responsible for taking the precautions to ensure that the discharge does not result in unacceptable exposures (such as could occur if the sparge system results in increased volatilization and/or vapor migration), does not exacerbate contamination (such as could occur if a sparge system was operated in an area of free product or heavily contaminated groundwater without hydraulic controls), or does not otherwise create fire, explosion, or vapor hazards. Further, "the discharge shall not be, or not be likely to become, injurious [R 323.2204(a)]," and "shall not cause nuisance conditions [R 323.2204(a)]."

R 323.2210(u) requires compliance with R 323.2204, which states that a person cannot discharge anything that is or may become injurious to the protected uses of the waters of the state. For discharges associated with groundwater remediation, **any additive contained in the discharge, or any secondary effect that occurs as a result of the discharge, must meet the groundwater standards described in R 323.2222.** For example, if potassium permanganate is used as a chemical oxidant to destroy chlorinated compounds, the residual manganese concentration in the groundwater must not exceed the groundwater standards for manganese contained in R 323.2222(3)(f). If nitrate is used to enhance the biological activity of petroleum degradation, the nitrogen concentration in the groundwater must meet the criteria contained in R 323.2222(2). If bioremediation is used to remediate organic constituents, the biological activity should not change the redox conditions such that the metals are stripped from the soil particles and suspended or dissolved in the groundwater at concentrations above the standards found in R 323.2222(5)(a).

Note that except where specifically noted, compliance with the R 323.2222 standards is measured in the groundwater. R 323.2224(1) states that the MDEQ shall approve a groundwater monitoring location for determining compliance with the standards of R 323.2222 if the location provides a practicable and effective point of measurement, is located on property owned or leased by the discharger and under the discharger's control, and is not more than 150 feet from the point of discharge. The MDEQ may approve, under criteria listed in R 323.2224(2)(a), an alternative groundwater monitoring location up to 1,000 feet hydraulically downgradient of the discharge to determine compliance with R 323.2222 when part of the RRD- approved remedial investigation, feasibility study, remedial action, corrective action plan, or FAR.

Appendix B

Acronyms and key definitions for terms used in this document:

NREPA:	The Natural Resources and Environmental Protection Act, 1994 PA 451, as amended
Part 22:	Part 22, Groundwater Quality Administrative Rules promulgated pursuant to Part 31 of NREPA
Part 31:	Part 31, Water Resources Protection, of NREPA
Part 201:	Part 201, Environmental Remediation, of NREPA
Part 213:	Part 213, Leaking Underground Storage Tanks, of NREPA
MDEQ:	Michigan Department of Environmental Quality
RRD:	Remediation and Redevelopment Division
U.S. EPA:	United States Environmental Protection Agency
Biologic Degradation:	Any process that acts to degrade a contaminant partially or completely as a result of biological activity. Also known as “bioremediation” or “biodegradation”
Chemical Degradation:	Any chemical alteration (e.g., oxidation, reduction, chelation, precipitation) which results in a reduction in the mass, mobility, and/or toxicity of a contaminant
Criteria or Criterion:	Includes the cleanup criteria for Part 201 of NREPA and the Risk-Based Screening Levels as defined in Part 213 of NREPA
Discharge:	As defined in R 323.2201(i) of the Part 22 Rules
Exacerbation:	As defined in Section 20101 of NREPA
Facility:	For the purpose of this technical resource document, the term “facility” is being used as a general reference to a property or portion of a parcel of property with environmental contamination and is not intended to be applied as it is statutorily defined in Section 20101(1)(s) of NREPA.
FAR:	Final Assessment Report as defined in Section 21311a of NREPA including a corrective action plan developed under Section 21309a of NREPA
Feasibility Study:	Includes “feasibility study” as defined in Section 20101 of NREPA and “feasibility analysis” as the term is conventionally used in Section 21311a(1)(c) of NREPA ;for the purpose of this document, the term also refers to the overall process for the evaluation and selection of response activities or corrective actions

In situ Remediation: designed	A course of action using an in situ discharge that is to meet remedial objectives
In situ Remedial Strategy:	A course of action that is designed to meet remedial objectives via the reduction of soil and/or groundwater contaminant concentration or mass in place by the use of any of the following chemical, physical, or biological processes: (1) The application of any material (liquid, solid, or gas) or combination of materials that ultimately results in the direct chemical degradation of contamination into less toxic or otherwise non- toxic products (e.g., chemical oxidation); (2) The physical removal or reduction of contaminant mass that utilizes the application of a material that physically or chemically interacts with soil or groundwater contamination in a manner that facilitates the removal or reduction in contaminant mass (e.g., product recovery utilizing surfactants); (3) The application of any material or biological organism that stimulates, enhances, or otherwise fosters "natural" processes that degrade contamination into less toxic or otherwise non-toxic products
In situ Remedial Discharge:	Any direct or indirect discharge of a material (liquid, solid, or gas) into the groundwater, the soil column, or onto the ground for the purposes of an *in situ* remediation
Pilot Study:	A component of a feasibility study (or feasibility analysis) that comprises the physical methods and data interpretation used to assess the performance of a remedial technology or strategy (or a specific component of such), typically for the purpose of: (1) Determining the potential efficacy of a remediation technology; (2) Technology comparison and/or selection; and/or (3) Establishing remedial design parameters. Includes "focused feasibility studies," bench and field scale pilot studies, and may also include pre-operational pilot studies using a full scale remediation system infrastructure
RAP:	Response Activity Plan, as defined in Section 20101 of NREPA
Source:	For purposes of this document source is not used as defined by Part 201, rather it means a hazardous substance or combination of hazardous substances in a quantity or concentration that acts as a reservoir that sustains and/or increases contamination within a single environmental media

or from one media to another media through dispersion, diffusion, migration or any other physical, chemical, or biological process. Source includes non-aqueous phase liquids (NAPL) and other highly concentrated areas of contamination such as residual NAPL.