Commingled Plume Technical Guidance

Contaminated Site Remediation & Redevelopment

New Jersey Department of Environmental Protection

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1.0 Introduction

1.1 Intended Use of Guidance Document

This technical guidance is designed to help the person responsible for conducting remediation (PRCR) to comply with the New Jersey Department of Environmental Protection (Department) requirements established by the Technical Requirements for Site Remediation (TRSR), N.J.A.C. 7:26E.

This guidance will be used by many different people involved in the remediation of a contaminated site, such as Licensed Site Remediation Professionals (LSRPs), non-LSRP environmental consultants, and other environmental professionals. Therefore, the generic term investigator will be used to refer to any person using this technical guidance to remediate a contaminated site on behalf of the PRCR, including the remediating party itself.

The procedures to vary from the TRSR at N.J.A.C. 7:26E-1.7. Variances from a technical requirement or departure from guidance must be documented and adequately supported with data or other information. In applying technical guidance, the Department recognizes that professional judgment may result in a range of interpretations on the application of the technical guidance to site conditions.

This guidance supersedes previous Department guidance issued on this topic. Technical guidance may be used immediately upon issuance. However, the Department recognizes the challenge of using newly issued technical guidance when a remediation affected by the guidance may have already been conducted or is currently in progress. To provide for the reasonable implementation of new technical guidance, the Department will allow a six-month "phase-in" period between the date the technical guidance is issued final (or the revision date) and the time it should be used.

This guidance document was prepared with stakeholder input. The following people participated on the committee that prepared this technical guidance:

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1.2 Purpose

The purpose of this technical guidance is to provide investigators with technical approaches to demonstrate the presence of a commingled plume condition and to evaluate the impacts on current and future remedial decisions, and to clarify the Department's administrative requirements for common commingled plume condition. Sites with a commingled plume condition, which is formally defined in Section 1.4, present challenges that may delay and complicate completion of required remedial activities. The technical tools and approaches presented here are meant to provide a better understanding of the potential variability in the data collected, the inherent heterogeneity of the natural system, factors that influence the behavior of commingled plumes (e.g., infiltration rate, presence of Dense Non-Aqueous Phase Liquid (DNAPL)) and other factors that may affect the confidence and accuracy in the Conceptual Site Model (CSM) and therefore, the remedial investigation and subsequent decision-making. Technical approaches provided in this technical guidance can be utilized to establish **"**lines of evidence**"** to support remedial decisions. The term lines of evidence generally refers to information that helps support a conclusion. A single line of evidence may not sufficiently support a conclusion. Therefore, this guidance document focuses on the development of multiple lines of evidence (MLE) that, when assessed cumulatively, can reduce uncertainty and provide sufficient support for remedial decisions.

In addition, this technical guidance provides a process to evaluate the impacts and impediments to completing remedial activities in accordance with the TRSR. It also provides a framework to determine when and how to employ the technical approaches by presenting possible "resolution alternatives" (e.g., how to manage an unresponsive party, allocate compliance options and potential regulatory resolution mechanisms). Resolution alternatives are strategies to resolve complex issues that may directly or indirectly involve other interested parties (e.g., adjacent property owners, other potentially responsible parties, etc.). The resolution alternatives can be used in conjunction with the technical approaches discussed within the guidance. The administrative process to achieve regulatory compliance is also outlined.

It is important to note that this technical guidance does not replace, supersede or alleviate the responsible party's obligations to complete an investigation and remediation pursuant to the Administrative Requirements for the Remediation of Contaminated Sites (ARRCS) N.J.A.C. 7:26C, Remediation Standards N.J.A.C. 7:26D and the TRSR, N.J.A.C. 7:26E. In all instances, the investigator and PRCR shall (N.J.S.A. 58:10C-16) ensure that the protection of public health and the environment is maintained. For example, a Receptor Evaluation (RE) is required pursuant to N.J.A.C. 7:26E-1.12 within one year after the earliest requirement to remediate (N.J.A.C. 7:26C-2.2), even when there may be uncertainty as to the specific source or responsibility for a component of a commingled plume.

1.3 Document Overview

This guidance:

- Defines a commingled plume condition
- Discusses the most common commingled plume scenarios that may be encountered (e.g., petroleum hydrocarbons and chlorinated volatile organic compounds)
- Describes the process of investigating commingled ground water contamination plumes and how to develop technical lines of evidence to help reach remedial decisions
- Identifies technical tools and techniques to help resolve problems that impede remedial progress
- Outlines the administrative process to achieve regulatory compliance

This guidance is not intended to resolve questions of remedial liability, contribution, allocation or the multifaceted complexities (e.g., technical, regulatory, administrative) of every commingled plume scenario. The guidance presents several case scenarios (see Appendix A) that illustrate typical commingled plume conditions found at sites and how the technical tools and techniques highlighted within this guidance could potentially be applied. Using these technical tools and techniques, in conjunction with the other strategies discussed may help to resolve some of these questions when considering site-specific conditions.

This guidance document focuses on commingled ground water contamination plumes; the tools and techniques presented may have similar application in other media regarding developing MLE (e.g., commingled soil or non-aqueous phase liquids in saturated or unsaturated media, or where there are vapor intrusion impacts). Other useful technical guidance documents can be accessed and downloaded from the Department's SRP Guidance Library (http://www.nj.gov/dep/srp/guidance/).

The information presented in Section 3.0 addresses the possible administrative resolution approaches for addressing commingled plumes. The Department recognizes that these administrative approaches are not "technical guidance" given the nature of the information in these sections. Accordingly, the Department does not expect the PRCR or the investigator to explain or document why any or all of these administrative approaches do not apply to their specific commingled plume situation (i.e., provide rationale for deviation), provided that the PRCR continues to satisfy its regulatory obligations.

With regard to technical guidance, in most instances, the investigation of a commingled plume will not involve the use of all of the techniques and approaches that are described in this guidance. The investigator should consider whether the techniques and approaches described in this guidance are applicable to the site being investigated and the extent to which such techniques and approaches will advance the investigation and/or remediation being performed. The extent of the investigator's consideration and use of this guidance should be described in the context of compliance with N.J.A.C. 7:26C-1.2(a)3, N.J.A.C. 7:26E-1.6(b)4ii and N.J.A.C. 7:26I-6.2 regarding the identification of guidance employed or deviation from any applicable guidance.

1.4 Definitions (as used within the context of this technical guidance)

Commingled Plume Condition: A commingled plume condition exists when ground water plumes, originating from two or more temporally or spatially discrete contaminant discharges, have mixed or encroached upon one another to the extent that the remediation performed on one plume will affect the remediation of the other contaminant plume(s).

Lines of Evidence: The term "lines of evidence" generally refers to information that helps support a conclusion. A single line of evidence may not sufficiently support a conclusion. Therefore, this guidance document focuses on the development of multiple lines of evidence (MLE) that, when assessed cumulatively, can reduce uncertainty and provide sufficient support for remedial decisions.

Overprinting: Is the condition that results when temporally discrete discharges are spatially co-located. This is further discussed in Section 2.1.4.

2.0 Identifying and Characterizing Commingled Plumes

2.1 Commingled Plume Scenarios

Depending on site conditions, the contaminants discharged, the timing of the discharge, and other factors, one or more of the following commingled plume scenarios could exist at a contaminated site, as discussed below. Once the investigator has sufficiently established the nature and extent of the subject Site's portion of the commingled plume, the PRCR is required to remediate/monitor only the contamination associated with the subject site's source [N.J.S.A. 58:10B-12g(5) and N.J.A.C. 7:26E-3.9(b)].

2.1.1 Off-site Source Contamination Scenario - Different Constituents

Contamination is migrating onto a site from an upgradient/sidegradient off-site property: This scenario involves the condition that results when contaminants are discovered on the subject site that may be the result of encroachment of an off-site contamination plume with contaminants that differ from those in the ground water contamination plume under investigation. If the contamination has not commingled with an on-site plume, the investigator should reference N.J.A.C. 7:26E-3.9 and the Department's Off-Site Source Ground Water Investigation Technical Guidance Document to demonstrate the contamination is from an off-site source.

If the contamination from the off-site plume that is migrating onto the site combines with an on-site plume, use the techniques and approaches described in this technical guidance, as well as those described in the Off-Site Source Investigation Technical Guidance Document to help differentiate between the two plumes and to evaluate how the commingled plume condition will affect the overall remedial investigation and remedy.

The administrative process to address the presence of an off-site source is contained in Section 5.2 of this technical guidance.

Contamination is detected during plume delineation downgradient of a site on another property:

This scenario involves the condition when contamination is detected downgradient of the subject site on another property during plume delineation. If the contamination is determined to be unrelated to any current or historic discharges from the subject site, the administrative process differs and the investigator should refer to Section 5.3.1 of this technical guidance.

2.1.2 Off-site Source Contamination Scenario - Similar Constituents

This scenario involves the condition that results when similar contaminants are discovered on the subject site, in which some contribution is the result of encroachment of an off-site contamination plume. This scenario is more complex than the scenarios mentioned above because the investigator must determine the contribution from the on-site source versus the off-site source. If the contamination has not commingled with an on-site plume, the investigator should reference the Department's Off-Site Source Ground Water Investigation Technical Guidance. The PRCR is required to remediate only the contamination associated with the on-site source [N.J.S.A. 58:10B-12g (5) and N.J.A.C. 7:26E-3.9(b)].

If the contamination from the off-site plume that is migrating onto the site combines with an on-site plume, use the techniques and approaches described in this technical guidance, as well as the Off-Site Source Investigation Technical Guidance, to help differentiate between the two plumes and to evaluate how the commingled plume condition will affect the overall remedial investigation and remedy.

The administrative process to address the presence of an off-site source is contained in Section 5.2 of this technical guidance.

Contamination is detected during plume delineation downgradient of a site and on another property:

This scenario involves the condition when contamination is detected downgradient of the subject site on another property during plume delineation. If the contamination is determined to be unrelated to any current or historic discharges from the subject site, the administrative process differs and the investigator should refer to Section 5.3.1 of this technical guidance.

2.1.3 On-site Source Contamination Scenario - Different Constituent

In this scenario, the commingled plumes result from the discharge of different contaminants from different on-site sources or areas of concern (AOCs). The investigator should proceed with the investigation in accordance with N.J.A.C. 7:26E and this technical guidance.

2.1.4 On-site Source Contamination Scenario - Similar Constituents (Overprinting)

This scenario involves the condition that results when similar contaminants are discovered on the same site/AOC from two or more discharges. When this condition is the result of temporally discrete discharges (at different times) that are spatially co-located (in the same location) it is defined within this technical guidance as overprinting. A common occurrence of overprinting would be two or more discharges at a gasoline service station that have occurred at different points in time impacting the same area. Similarly, a dry cleaning establishment may have had multiple discharges over time. Complexities in completing required remedial activities and regulatory compliance arises when an additional discharge(s) are associated with a subsequent owner/operator of the site. The investigator should proceed with the investigation in accordance with N.J.A.C. 7:26E and this technical guidance.

2.2 Characterizing Commingled Plumes

A commingled plume condition is often difficult to detect and can be identified at any phase of the remedial process. Some indicators that may help the investigator detect the presence of a commingled plume include, but are not limited to:

- The presence of contaminants that are different from the contaminants in the ground water plume under investigation (including, but not limited to, different chemical signatures consisting of multiple compounds)
- Changes in the ratios of contaminants detected in the ground water plume under investigation (e.g., Benzene consistently detected at 600 ppb and Toluene at 200 ppb; during subsequent sampling, the ratios suddenly change to 650 ppb of Benzene and 2,300 ppb of Toluene)
- Changes in the geochemical conditions in the ground water plume under investigation (e.g., significant changes in the field parameters such as temperature, pH, dissolved Oxygen (DO), and Oxidation-Reduction Potential (ORP)
- Unexplained sustained increase in contaminant concentrations in the ground water plume under investigation. Possible factors that may influence an unexplained increase include: 1) changes in ground water elevation; 2) changes in ground water flow direction; 3) NAPL migration; and 4) evidence of discharge of contaminant mass during active remediation or subsurface disturbance (drilling, construction, etc.).
- Plume length or configuration is different than analytical and/or numerical models predict

By following the Department's regulations and technical guidance (in particular the Ground Water – SI/RI/RA Technical Guidance Document) to complete a ground water investigation, the investigator may establish MLE to support decisions on the remedial investigation scope, remedial action and issuance of Response Action Outcomes (RAO), even in the presence of a commingled plume condition. One example is the identification of a plume from an upgradient, off-site source which overlaps the plume emanating from a site that is subsequently investigated in accordance with N.J.A.C. 7:26E-3.9. Another example is the identification of a plume downgradient from a subject site with different constituents than the site's contaminants. In these examples, the administrative process described in Section 5 of this technical guidance may allow the investigator to proceed without addressing the other plume(s).

In order to remediate a suspected or known commingled plume, it is beneficial to have site background information early in the remedial process. Site background information may be key to identifying or substantiating MLE to confirm the presence of commingled plumes. When investigating a site with a potential commingled plume condition, the investigator should attempt to gather background and basic site information that may include, but is not limited to:

- Site background and history by completing a Preliminary Assessment (PA) to identify possible sources of contamination

- The presence/location of any known contaminated sites proximal to the subject site
- Ground water quality data at known upgradient/side-gradient locations
- Hydrogeological and geochemical information
  - Flow direction and gradient, including vertical components
  - Site-specific hydraulic conductivity and effective porosity
  - Contaminant flow velocities
  - Presence of potential preferential contaminant pathways
  - Geochemical ground water data
  - Fate and transport evaluation for known site-related contaminants of concern
  - Current or historic ground water pumping influences proximal to the subject site

The investigator may also need to develop additional lines of evidence using techniques and analyses discussed in Section 3.0 and also presented in Table 1 Potential Lines of Evidence Checklist.

3.0 Techniques for Establishing MLE for Commingled Plumes

The tools and techniques described in Sections 3.1 through 3.8 below may assist the investigator in developing the MLE necessary to identify, understand, and address commingled plumes. Fundamentally, the question to be asked when considering the value of utilizing these tools and techniques is: How does the existence or possible existence of a commingled plume condition alter the timing or other components of the remediation or potential resolution mechanisms (see Section 4.0)?

In situations where the commingled plume characteristics, site complexities and/or other factors make it difficult to determine responsibility for discharges, there are more complex evaluation techniques and tools that can be used. Please note that the tools and techniques described below are examples. There are others that could also be used. Those described in this section may not need to be used in all cases. These tools and techniques are described in more detail in the Appendices B-F.

3.1 Site Background and Existing Data Sets

The importance of site background information in evaluating a commingled plume condition was introduced in Section 2.2. The data sets below may provide useful information for completing a background investigation at a commingled plume site.

3.1.1 Department Databases: HazSite Data:

The Site Remediation and Waste Management Program (SRWMP) has been collecting site-specific ground water data for many years, which can be obtained from the Department. The procedures to request HazSite data is available at the program's HazSite / EDD webpage at https://www.nj.gov/dep/srp/hazsite/.

A canvass of the area, particularly in the upgradient direction of the site (if known), can aid in determining potential off-site sources. Once these potential sites have been identified, looking at existing data resulting from investigations at these sites can provide useful information in developing lines of evidence.

3.1.2 United States Geologic Survey (USGS) Ground Water Watch

The USGS maintains several databases (http://groundwaterwatch.usgs.gov/) that include records for wells from studies performed over the past 100 years. These databases provide basic water-level data collected by USGS, Federal Programs, and cooperative agreements. The water level data are useful in determining the ground water flow direction and predominant ground water flow patterns surrounding the site under investigation.

3.1.3 NJ-Geo Web

This data source can be used to identify potential sources of contamination throughout the State and can be accessed through the SRP home page or here: http://www.nj.gov/dep/gis/geowebsplash.htm. In addition, ground water classification exception area (CEA) and ambient ground water quality data may be found on NJ-GeoWeb. To find ambient ground water quality data, selecting the "Environmental Monitoring" tab and then selecting "USGS NWIS Water Monitoring Stations". The CEA database can be found by selecting the "Sites and Facilities" tab and then "Groundwater Contamination Areas (CEA)."

3.1.4 NJDEP Data Miner

This internet tool contains a variety of reports, which provide public access to a wide range of the State's environmental information. Data Miner can be accessed here: https://www13.state.nj.us/DataMiner.

3.1.5 Other Commercial Sources of Information

Many commercial services provide site-specific reports that can include radius maps that present physical setting data, historic site records, Sanborn fire insurance maps, historic aerial photos, topographic maps, and building permit data that can provide useful information in identifying contaminant sources.

3.2 Additional Ground Water Sampling

If existing ground water data are not sufficient to determine if a commingled plume condition exists, accessing additional sampling points (on-site or off-site) or installing additional points may be necessary. Synoptic water level measurements in wells across multiple sites may also aid in interpreting ground water flow. The additional information gathered may indicate whether the plume under investigation has been impacted by other contaminant sources.

3.3 Evaluate the Potential for Preferential Pathways

In some cases, the available data may not indicate a clear source for the contamination coming on to the site under investigation. The presence of on-site and off-site preferential pathways (e.g., more permeable strata, buried stream channels, subsurface utility corridors, fracture and bedding planes) may influence ground water flow and result in preferential migration of contaminants that may contribute to a commingled plume condition. The effects of active and historic pumping wells near the site should be evaluated for potential impact on preferential pathways.

3.4 Fate and Transport Modeling

If adequate data are available, it may be possible to construct a fate-and-transport model in order to back-calculate the location of a source or to evaluate past conditions of the site (e.g. reverse particle tracking). Modeling results may help to demonstrate the plume dimensions from the site/AOC being investigated with and without influence from additional plume(s). Modeling results from various scenarios could be utilized as MLE and to refine the commingled plume CSM developed as part of Section 3.7. Finally, modeling results can be compared to actual site data/trends to illustrate the influence of additional plume(s). A list of public domain models to use can be found in Appendix E located at the end of this technical guidance.

3.5 Statistical Analysis

In order to evaluate contamination from unknown or multiple potential sources, a statistical or stochastic modeling approach may be used. Statistical techniques can unravel uncertainty intrinsic to site data, establish inherent trends, and differentiate contaminant sources. Statistical approaches can include techniques allowing for the comparison of data (e.g. contamination concentrations are higher), multivariate techniques that provide information about patterns in data sets that we would not otherwise see, and geostatistical methods that help elicit spatial distributions or patterns in the data set of interest.

Stochastic analysis has been used to study the physics of flow and transport in fractured and porous media. Stochastic modeling is defined as a tool for estimating probability distributions of potential outcomes by allowing for random variation in one or more inputs over time to overcome the uncertainties, or lack of knowledge about specific factors, parameters or models. Stochastic methods that can be utilized to identify contaminant sources include, but are not limited to, kriging, Monte Carlo, Minimum Relative Entropy (MRE) and Bayesian inference methods.

Other statistical procedures and models can provide a formal, quantitative method for assessing the relationship of sample measurements to characteristics of the sampled system, for using sample data to make decisions and for predicting future states of the sampled system. The need for application of statistical tests and the nature of the tests will vary as a function of site-specific conditions and data analysis. The Department's Monitored Natural Attenuation (MNA) Technical Guidance and the Ground Water Technical Guidance include additional information on the use of statistics that can be considered for use for commingled plume analysis as well.

More details on the use of these statistical methodologies can be found in Appendix B of this technical and the guidance.

3.6 Environmental Forensics

Environmental forensic methods involve the evaluation of historic, chemical and physical information in support of determining the source and/or age of a contaminant discharge. The discipline is constantly evolving and requires sufficient expertise to implement the techniques and evaluate the results. An environmental forensics technique overview for petroleum hydrocarbons and chlorinated solvents is provided in Appendix C to assist in understanding some of the more common techniques. A list of references in Section 7.0 is also provided to allow evaluation of a wider range of investigative options that may be appropriate for use at a site under investigation.

Many of the forensic tools and techniques go beyond typical compliance sampling and may require additional data collection. The use of these tools/techniques should be carefully evaluated in terms of how they will assist in meeting project objectives prior to their implementation.

3.7 Conceptual Site Model

A CSM is a written and/or illustrative representation of the physical, chemical and biological processes that control the transport, migration and potential impacts of contamination to human health and/or ecological receptors. The CSM is an effective tool for illustrating commingled plume conditions. Investigators should continually evaluate and if necessary, update and refine their site CSM as new data becomes available. The development and refinement of a commingled plume CSM will help incorporate and understand additional MLEs and ultimately help support remedial decisions. Technical Guidance on the Preparation and Submission of a Conceptual Site Model can be found on SRP's Guidance Library, available at: http://www.nj.gov/dep/srp/guidance/.

3.8 High-Resolution Site Characterization

High-resolution Site Characterization (HRSC) is an investigative approach utilizing focused data collection to more clearly define subsurface lithology and contaminant distribution in three dimensions. HRSC approaches may help establish lines of evidence regarding fate and transport and move a commingled plume investigation forward, particularly if standard investigative methods have been unsuccessful. Some sampling tools and investigative approaches for HRSC include Direct Push Technologies (DPT), Membrane Interface Probes (MIP), borehole flow meters, media-specific meters and test kits, soil gas sampling, real-time direct measurements and field screening technologies. See Appendix D for more information on using this technology.

3.9 Potential Lines of Evidence Checklist

This guidance document has provided some recommended investigation strategies for gathering the lines of evidence necessary to demonstrate the presence of commingled plumes. The Potential Lines of Evidence Checklist (Table 1) is a useful tool for tracking this information.

This is an optional checklist provided to the investigator as a tool that identifies the types of information or potential lines of evidence which could be collected to support the conclusion that there is a commingled plume present at a site under investigation. Use of this checklist is at the discretion of the investigator. Not every item on this checklist will necessarily apply to every site, and there may be other relevant information or lines of evidence that can be used that are not included on the checklist. The amount of information needed to develop any particular line of evidence will vary from site to site, depending on site complexity and other factors. Once the investigator has identified the presence of a commingled plume, evaluation and application of possible resolution mechanisms can begin.

4.0 Selecting a Resolution Mechanism

4.1 Evaluating the Need for a PRCR to Choose a Resolution Mechanism

It is important to have a good technical understanding of the site's plume and the commingled plume in order to make remedial decisions and move forward. Sections 2 and 3 of this Guidance discuss technical approaches to obtain relevant data. Once a commingled plume condition is identified, the investigator may seek a resolution mechanism. The objectives of a resolution mechanism should include:

- Allowing remedial activities to move forward without missing the regulatory and mandatory timeframes
- Protecting receptors
- Avoiding potential litigation
- Potentially reducing the overall time and/or costs associated with the remedial activities
- Potential input on planned remedial actions to address on-site releases

There are many scenarios involving commingled plumes that can impact a remedial investigation and remedial action. For example, commingled plumes with different chemical constituents and different source locations can negatively affect the design, cost or timing of a remediation. However, the presence of commingled plumes may not always have a substantive impact on the design, cost, scope or timing of remedial activities. The remediation of a commingled plume with similar contaminants or a commingled plume, where each contributing source substantially overlaps, may be identical to the remedial approach that would be used to address a single plume in the same area with only one source.

The investigator should consider the impact of a commingled plume on the remedial activities at their site. If the commingled plume will not negatively impact remedial activities, the investigator should consider proceeding with the work independently. However, if the commingled plume will impact remedial costs and the time needed to complete remedial activities, working cooperatively with other PRCRs, if they are known, is recommended. When known, contact with the other PRCRs should be initiated as early as possible in the remedial process to determine if they are legally and financially viable, willing to share information and interested in collaborating on an appropriate remedial strategy.

The following conditions must be evaluated and addressed as applicable, independent of moving forward with selecting a resolution mechanism:

- Identification and investigation of all potential receptors: N.J.A.C. 7:26E-1.11 through 1.16 requires that the person responsible for conducting the remediation shall conduct and submit a receptor evaluation. The receptor evaluation process must not be delayed beyond the required timeframes.
- Mitigation of any impacted or imminently threatened receptors: In accordance with N.J.A.C 7:26E 1.12 through 1.16, if any receptors are identified that are imminently threatened or actually impacted by the contaminant(s) of concern associated with the portion of the commingled plume resulting from their discharge, appropriate mitigation measures must be completed.
- Control of ongoing sources and implementation of Interim Remedial Measures (IRMs): N.J.A.C. 7:26E-1.10 requires ongoing sources to be controlled and IRMs to be implemented to remove, contain, or stabilize a source of contamination to prevent contaminant migration and protect public health, safety and the environment. This would include addressing LNAPL, if present.

For situations when the investigator has provided sufficient information and/or lines to evidence to document the presence of an off-site source of contamination (or contamination associated with another discharge for which the PRCR is not responsible) resulting in a commingled plume, but the PRCR for the off-site contamination has not been identified, the Department may move forward to investigate the source of the off-site discharge, if appropriate. The process for engaging the Department in these situations is presented in Section 5.0 of this technical guidance, which is identical to the process included in the Department's Off-Site Source of Ground Water Contamination Technical Guidance Document.

Similarly, for situations where a vapor intrusion (VI) investigation has been triggered with regard to a documented, unknown source of contamination, the Department may complete the necessary VI activities for that unknown source (as noted in the Department's Vapor Intrusion Technical Guidance Document). If it is determined through the course of investigation that a VI impact exists only for the compounds associated with the off-site source, then there would be no obligation on the PRCR responsible for the on-site contamination to address the VI requirements for the off-site VI impacts. However, if there is a VI obligation associated with any portion of the commingled plume that is the responsibility of the PRCR, the necessary VI activities must be completed by the PRCR regardless of the status of the off-site component of the plume. The Department may also move forward to investigate the source of the off-site discharge, if appropriate.

It is important to note that unless the investigator/PRCR has properly documented the presence of an off-site source, the required VI/receptor investigations must be completed within the required timeframes for all identified compounds. If the presence of an off-site component of the commingled plume is later confirmed, the PRCR could pursue the off-site responsible party for any associated costs (e.g., via a Spill Act Contribution Claim).

4.2 Potential Resolution Mechanisms

The purpose of this section is to discuss potential resolution mechanisms to advance the remediation at a site once the investigator has identified that a commingled plume condition is present (Section 2.0), established MLE that define the nature and extent of the commingled plume condition (Section 3.0), and determined how the presence of the commingled plume is affecting/will affect remedial decisions (Section 4.1). Once these items have been established, there are three potential resolution mechanisms that the PRCR can take with respect to advancing the remediation:

- <u>Work Cooperatively with other PRCRs</u>: Under this option, the PRCR would seek to work cooperatively with the one or more PRCRs contributing to the commingled plume condition. This option is considered to be the best path forward and the benefits and challenges of this option are discussed in Section 4.3 below.
- <u>Proceed with Completing the Remediation Independently:</u> Understanding that it is not always possible or practical to identify other PRCRs and work cooperatively together, the PRCR may need to complete the remediation of the portion of the commingled plume associated with their discharge independent of the other PRCRs. The benefits and challenges of this option are discussed in Section 4.4 below.
- <u>Seek Alternative Resolution with other PRCR(s)</u>: If the PRCR cannot work cooperatively with other PRCRs, and the effect of completing the remediation independently has a significant impact on the timing, cost, and/or selection of the remedy, the PRCR may elect to pursue an alternative resolution mechanism. A discussion of potential alternative resolution mechanisms is provided in Section 4.5 below.

Below is a more detailed discussion on the three potential paths forward and their associated benefits and challenges.

4.3 Work Cooperatively with Other PRCRs

As previously discussed, under this option, the PRCRs would seek to work cooperatively with the one or more parties contributing to the commingled plume condition. This option is generally considered to be the optimal path forward. If the entire project scope (cost and responsibility) cannot be allocated, the PRCR should consider breaking the work into smaller tasks that could be better defined and could be worked on cooperatively. For example, if the remedial investigation phase is defined, but the remedy is not defined, parties should consider working cooperatively on the remedial investigation and keep the remedial actions separate. Some of the benefits and challenges of this option are discussed below.

4.3.1 Benefits of Working Cooperatively

- <u>Results in a faster remediation</u>: Sharing of resources, costs and site access will help streamline the process resulting in a faster remediation. This may be particularly advantageous if a project is approaching a regulatory or mandatory timeframe.

- Allows for a more efficient use of available resources, including funding: Information can be shared which may result in a better understanding of subsurface conditions and plume characteristics. Additionally, sharing work responsibilities can help avoid redundancies resulting in reduced overall project costs.
- May expedite accessing off-site locations not within the control of a single PRCR: Gaining access to off-site locations can often be costly and time consuming. Working cooperatively, this challenge may be reduced or even eliminated.
- Addresses Immediate Environmental Concern (IEC) conditions in less time: If an IEC is identified, all PRCRs for the commingled plume are responsible for addressing the IEC condition. Working cooperatively may help to address the IEC more quickly.
- Protects potential receptors: Similarly, working cooperatively will help to facilitate a coordinated approach to identify and protect potential receptors more quickly.
- Can help avoid adverse impacts to the remediation of other plumes: Without communicating with other PRCRs, a remedy may be selected that could negatively impact the remediation of another plume.
- Inability to differentiate plumes: If two sources are known but the plumes cannot be differentiated, it may be advantageous for the PRCRs to work cooperatively to complete the remediation.

4.3.2 Challenges of Working Cooperatively

- Data Quality: Relying on data from others can present some data quality challenges. All parties should agree on data usability prior to moving forward with the remediation.
- Completeness of Investigation: Different investigations may be at different remedial stages. The investigator should use professional judgment in reviewing the completeness of remedial work from others within the context of the overall project to optimize the use of information.
- Cost Allocation: Cost allocation can be complex and may be subject to change over the life of the project. If parties cannot agree to the apportionment of costs, then the overall project scope and schedule may be impacted.
- Timeliness: While the overall project timeframe can be expedited when working cooperatively, it could also result in delays. If differences in opinions on technical approach, cost allocation, field decisions, etc. cannot be resolved in a timely manner, the overall project schedule could be affected.
- Possible Administrative issues: Possible administrative challenges include managing multiple case numbers, dealing with different remedial timeframes and execution and submission of appropriate Department forms and fees. More complicated administrative issues may need to be discussed with the Department prior to working cooperatively with other PRCRs.
- Conflicting Goals/End Use: It is possible that remedial goals and/or end use of the property changes over time. This could result in disagreements between the parties as to the overall project direction and impact the project scope, costs and schedule.

4.4 Completing Work Independently

In the event that work cannot be conducted cooperatively, the PRCR may decide to work independently to remediate the portion of the commingled plume resulting from their discharge and work toward regulatory closure as a priority. Some of the benefits and challenges of this option are discussed below.

4.4.1 Benefits of Remediating a Commingled Plume Independently

- Timing: The investigator can control the speed in which activities are initiated and completed without consultation with additional PRCRs. This may be particularly advantageous if the project is at risk for missing a Regulatory and/or Mandatory Timeframe.
- Remedy Scope and Selection: The investigator can develop the scope, select remedial actions and conduct work without consultation with other PRCRs. This may allow an investigator to streamline the scope of the investigation; gather data and select remedies that best meet the individual PRCR's remedial objectives; utilize alternative remediation standards and attainment tools (e.g., averaging); and/or complete remediation of their discharge.
- Costs: The investigator may better control costs by having sole decision-making capabilities in terms of negotiating and awarding contracts, making field decisions and proceeding with work without having to obtain approval from other PRCRs. The PRCR may also have the ability to select the most cost-effective and protective remedy available.
- Control of work product: The investigator would have greater control regarding decisions which can improve the quality of work products, manage risk and help maintain compliance with internal company policies and procedures.

4.4.2 Challenges of Remediating a Commingled Plume Independently

- Costs: It is common that an entity working independently would incur costs to remediate contaminants outside the PRCR's responsibility. In these cases, the PRCR may choose to seek cost recovery as discussed in Section 4.5.6. In addition, opportunities for cost sharing (data, remedy selection and implementation) with other PRCRs may not be available.
- Perceived Liability: While Department regulations only require a PRCR to remediate contaminants for which it is responsible, a PRCR deciding to work independently on a commingled plume may be perceived as being liable for the entire plume. Such a perception, even if inaccurate, may be enough to make a PRCR consider other resolution mechanisms.
- Impacts from off-site sources: If an off-site source is impacting the property under investigation, and the off-site source is not being remediated/controlled, it may not be possible to remediate the property under investigation until the off-site source is appropriately addressed.
- Cost recovery implications: Working independently may affect the ability to recover costs from other PRCRs. For example, another PRCR may be influenced by the absence of an opportunity to cooperate or to provide input for a given remedial approach. Such prejudice may adversely impact cost recovery from that PRCR.

- Potential conflicts with other Final Remediation Documents: As discussed throughout this technical guidance, commingled plume sites can be complex. A final remediation document prepared and submitted by a single PRCR may conflict with final remediation documents submitted by other PRCRs remediating the same commingled plume.

4.5 Uncooperative Responsible Entities

Should the PRCRs contributing to a commingled plume be unable to come to terms to act cooperatively or individually to address the commingled plume and protect human health and the environment, the following mechanisms are available.

4.5.1 NJDEP Technical Consultation

The Department has established a process to allow LSRPs and PRCRs to consult with experienced NJDEP staff to get feedback on technical issues and options. This process is not used to address regulatory or administrative issues such as timeframes, fee, forms or extensions. Similarly, a Technical Consultation process is not used for mediation.

Technical Consultation sessions will be held via conference call or face-to-face meetings to discuss technical issues related to the remediation of a site. These consultations will assist in obtaining compliance with the Department's applicable Site Remediation rule requirements and technical guidance. Contact information for setting up a Technical Consultation can be found at www.state.nj.us/dep/srp/srra/technical_consultation/.

Technical Consultation is more efficient if the Department representative can be provided with a focused, factual summary to assess the technical issues for which assistance is being sought. When the concerns relating to remediation involve the acceptability of a technical approach, the use of innovative or unique approaches, and/or concerns over regulatory compliance, Technical Consultation should be considered.

4.5.2 Neutral Party Technical Mediation

Mediation is a confidential, legal process that uses a neutral, third party LSRP (or other technical expert) to act as a facilitator to the agreement, but not as a decision-maker. This strategy may be used to avoid settling a dispute in court. The mediation process is informal and does not follow the rules of evidence or procedure used in litigation. The parties to the dispute are in control. Ultimately, success depends upon the mediating parties' ability to reach an agreement. The mediator stimulates discussion between the disputing parties to help the negotiation process move toward a resolution. Parties may agree in advance to be bound or not bound by the mediation outcome.

4.5.3 Other Mediation

Mediation can also be conducted without the involvement of an LSRP. Organizations, including the *New Jersey Judiciary* (http://www.judiciary.state.nj.us/), utilize mediators. Parties can select from existing programs or develop their own approach.

4.5.4 NJDEP Office of Dispute Resolution

The Department has established the Office of Dispute Resolution (ODR) to provide a forum other than the administrative and trial courts for resolution of disagreements between the regulated community and the Department. The program is voluntary, and the Department and the regulated entity or entities must agree to participate.

This forum aims to serve a dual purpose: not only to reduce lengthy legal proceedings that can be costly for all involved, but also to establish more meaningful and effective lines of communication between environmental regulators and the regulated community. The Department's mission is to ensure fair and efficient management and settlement of disagreements through alternative dispute resolution processes.

The goals of the Office of Dispute Resolution are to:

- Define and clarify issues disputed;
- Facilitate communication between regulated parties and Department staff;
- Encourage collaborative problem-solving;
- Explore options for resolution to the issues; and
- Promote and document a mutually satisfactory agreement.

A key element of dispute resolution is for the disputing parties to establish the practical implications of the issues in dispute, essentially answering the question: "What actions are needed for the parties to move forward?" Dispute resolution does not always involve resolution of every issue. Frequently, parties can agree on certain actions and "agree to disagree" on other issues.

In the context of remediating a commingled plume, the mediator may be helpful in focusing PRCRs on what actions will move the remediation forward in a cooperative process. If the mediator can establish areas of common interest or agreement, dispute resolution may be effective. Most importantly, that when pursuing mediation through the ODR, only certain limited circumstances may be appropriate when dealing with "dueling LSRPs." For example, since the ODR will not entertain disputes solely between private parties, the Department must have a significant interest. A matter in direct oversight may be appropriate for this forum. For more information, please see the ODR website: www.nj.gov/dep/odr.

4.5.5 Seek Treble Damages

"Treble damages" in law is a term indicating that a statute permits a court to triple the amount of the actual/compensatory damages to be awarded to a prevailing plaintiff. Pursuant to the Spill Compensation and Control Act, N.J.S.A. 58:10-23.11 *et seq.*, PRCRs have a right of contribution against all other dischargers and persons in any way responsible for a discharged hazardous substance or other persons who are liable for the cost of the cleanup and removal of that discharge of a hazardous substance. In order to be granted an award for treble damages by the court from one or more PRCRs (i.e. contribution defendants), the court must find that certain conditions have been met in accordance with N.J.S.A. 58:10-23.11f (a) 2-3. One of these conditions is that the contribution defendant is a person who was named on or subject to a directive issued by the Department and failed or refused to comply with such a directive.

A contribution plaintiff may request that the Department issue a treble damages directive to the dischargers and persons in any way responsible for a discharged hazardous substance requiring remediation at the Site. The request should include:

1. The name, address and registered agent of the potentially responsible party(ies) and that party's connection to the Site.
2. Evidence that a discharge of hazardous substances occurred during that party's ownership or operation of the Site and all documentation to support such claims.
3. Evidence that demonstrates the contribution plaintiff gave 30 days' notice to the contribution defendant(s) of the plaintiff's intention to seek treble damages pursuant to this subsection and gave the contribution defendant(s) an opportunity to participate in the cleanup.
4. Evidence that demonstrates the contribution defendant(s) failed or refused to enter into a settlement agreement with the contribution plaintiff.
5. Evidence that demonstrates the contribution plaintiff entered into an agreement with the Department to remediate the site. The Department will then evaluate such a request to determine if sufficient information and associated documentation has been submitted. If so, the Department may issue a directive to one or more of the PRCRs.

4.5.6 Litigation

Litigation is frequently available to seek redress from the actions of others. In the context of the remediation of commingled plume conditions, it is not uncommon for disagreements to arise in areas such as site access, allocation of costs and coordinating remediation efforts. The courts can provide relief in the form of monetary damages (legal relief) and orders compelling or prohibiting actions by others (injunctive or equitable relief). In exigent circumstances, equitable relief may be provided within a relatively short timeframe. However, in most instances, litigation, if pursued through trial and any appeals, may take many years. Further, in most instances, each party is required to pay their own legal costs. Nonetheless, in the absence of the success of an alternative dispute resolution process, litigation is often the only alternative for a party to seek redress for damages incurred.

The prosecution of litigation does not provide a basis for delaying required remediation. In general, the courts have provided that remediation obligations are not held in abeyance while litigation is pursued for cost recovery.

5.0 Administrative Requirements for Commingled Plumes

This section presents the administrative requirements related to contamination associated with a commingled plume. Typically, the presence of a commingled plume is identified during the investigation by the PRCR of a reported discharge that has resulted in the contamination of ground water.

During delineation of the ground water plume by the PRCR, other contamination is sometimes encountered that is not related to the discharge being investigated. If this newly-identified contamination is from a separate source, it represents a new discharge. Further, if this discharge has not been reported to the Department (to the knowledge of the investigator), it should be reported immediately in accordance with N.J.A.C. 7:1E-5.3(a) and 7:26C-1.7.

An unreported discharge can be reported to the Department by calling the NJDEP Hotline (1-877-WARNDEP). During this call, information regarding the discharge will be requested (e.g., the date when the discharge was detected, contaminant types and concentrations, the site name and address where the discharge was detected, any known receptors). It is important to record the incident number that the hotline operator will provide during this call. This number will be useful in documenting actions taken by the PRCR, and it may also be required to complete future remedial documents.

Based on all of the technical evidence available at the time of the newly-identified discharge, if it is unclear whether the newly-identified contamination is related to a new discharge, the PRCR should assume it is related to their discharge, as the PRCR could be subject to applicable fines and penalties if no action is taken and it is later determined that the contamination was a site-related discharge. The need for action is particularly important when an IEC condition exists. If an IEC condition exists, timeframes and requirements apply and must be addressed in accordance with N.J.A.C. 7:26E-1.11, as well as the Department's IEC Technical Guidance and IEC website (http://www.nj.gov/dep/srp/guidance/IEC/index.html).

In all instances, the investigator shall ensure prioritization of the protection of public health and safety and the environment (N.J.S.A. 58:10C-16), even when the investigator may be uncertain as to the specific source or responsibility of ground water contamination.

Usually, the issuance of the RAO will be at the conclusion of the investigation and remediation. However, issuance of an Area of Concern RAO (RAO-A) for the unrelated contamination may be indicated if the unrelated discharge triggers a receptor evaluation (e.g., a vapor intrusion investigation or potable well sampling). In such cases, the issuance of an RAO-A in advance of the regulatory timeframes can avoid questions relating to compliance with the regulatory timeframes.

Based on where the new discharge was detected, the administrative requirements may differ as discussed below. If the discharge discovered before issuance of a Remedial Action Permit, see Sections 5.0, 5.1, 5.2. and 5.3. If the discharge was discovered after the issuance if a Remedial Action Permit see Section 5.5.

5.1 Separate Discharge Detected On-site; Source of the New Discharge also Located On-Site

If the new discharge was detected **<u>on</u>** the subject site and the source of the separate discharge also exists on-site on the property that is owned and/or operated by the PRCR, then the discharge must be reported and remediated as required by N.J.S.A. 58:10B-1.3, in accordance with N.J.A.C. 7:26C and N.J.A.C. 7:26E. In this scenario, the PRCR must also submit a Confirmed Discharge Notification Form (CDN) to the Department [N.J.A.C. 7:26C- 1.7(d)] within 14 days of calling the NJDEP Hotline to report the new discharge. The PRCR is also required to retain an LSRP within 45 days, pursuant to N.J.A.C. 7:26C-2.3(a)2, and demonstrate that such contaminants are the result of a separate discharge on the property and the subject PRCR is not responsible for that contamination.

If the PRCR no longer owns or operates the property and it is determined that the discharge in question is **not** the responsibility of the PRCR doing the remediation, then the discharge should be reported to the hotline as stated below. The PRCR should also inform the current property owner that the contamination was found. Subsequently, it would be the current property owner's and operator's responsibility to investigate the newly-identified discharge.

Pursuant to N.J.A.C. 7:1E-5.3 and Site Remediation Reform Act (SRRA), the PRCR or the LSRP shall:

Call the NJDEP Hotline (1-877-WARNDEP) and report to the operator, using the specific terms ***italicized*** below. Provide the following information to the NJDEP Hotline operator even if you are not prompted to do so.

1. Identify that the contamination was observed **on** the subject site.
2. Identify the address of the on-site property and whether the on-site property (where the new source of contamination was detected) is residential or non-residential.
3. Identify the contaminants, the concentrations, and the media that are impacted (soils, ground water, surface water, sediments, etc.) associated with the commingled plume contamination.
4. Identify that the detected unknown ***"contamination has been detected at the subject site and available information supports the conclusion that the contamination is unrelated to the discharge(s) currently being remediated."***
5. Identify the Site Remediation Program - Program Interest (SRP PI) Number of the site that was conducting the investigation that resulted in the detection of the contamination.
6. Identify any available information regarding proximal receptors identified in the Receptor Evaluation (N.J.A.C. 7:26E-1.13) that may be impacted (schools, child care centers, residences, etc.).

The investigation should continue, pursuant to the Department's regulations and technical guidance documents. If other sources of contamination may be affecting the PRCR's samples, use appropriate technical approaches and tools to ascertain the effects of the other sources. See Section 3.0.

The site conditions may require the investigator to vary from the TRSR. In these cases, care must be taken to document any variances and the justifications for them (N.J.A.C. 7:26E-1.7). When the RIR/RAR is submitted, variances are to be listed on the RIR/RAR Form.

As part of the RAR and RAP application, the LSRP should include a ground water monitoring plan that accounts for the site's other contaminant contributions and reasonable conditions for termination of the permit.

When issuing the RAO, the appropriate commingled plume condition notice must be included. See Section 5.6 below.

5.2 Separate Discharge Detected On-site; Contaminants Migrating onto Site from Off-site Location

If contaminants are identified **on** the subject site (i.e., on the property owned or operated by the PRCR), migrating onto the site and are suspected to be unrelated to a known discharge at the subject site, then the PRCR of the subject site must call the hotline (N.J.A.C. 7:1E-5.3), submit a CDN and complete an investigation to demonstrate that such contaminants are the result of migration onto the property from an off-site source and the subject PRCR is not responsible for that contamination.

As appropriate, the PRCR shall perform an investigation pursuant to either: (1) N.J.A.C. 7:26E-3.9, "Site investigation - determination of off-site source of contamination in soil and ground water," or (2) N.J.A.C. 7:26E-3.10, "Site investigation - determination of off-site source of contamination in surface water and sediment." Note that both of these sections of the rule require the performance of a PA, and, if necessary, a site investigation (SI) pursuant to N.J.A.C. 7:26E-3 to determine whether a source of the observed contamination exists on site. For additional details regarding conducting an off-site source investigation, refer to the Department's Off-Site Source Ground Water Investigation Technical Guidance.

If the investigation conducted pursuant to N.J.A.C. 7:26E-3.9 or 3.10 **does not** demonstrate that the observed contamination is from an unknown off-site source, and it is the result of a discharge or contributions from an on-site source, then the responsible party is required to remediate the contamination in accordance with N.J.A.C. 7:26C and N.J.A.C. 7:26E (see Section 5.1 above).

If the investigation conducted pursuant to N.J.A.C. 7:26E-3.9 or 3.10 **does** demonstrate that the observed contamination is from an off-site source and the subject site is not contributing to that contamination, then the PRCR or LSRP shall:

Call the NJDEP Hotline (1-877-WARNDEP), pursuant to N.J.A.C. 7:1E-5.3, and tell the operator, using the specific terms ***italicized*** below. Provide the following information to the NJDEP Hotline operator even if you are not prompted to do so.

1. Identify if the sampling conducted to confirm the ***verified unknown off-site source*** was completed on or off the subject site.
2. Identify the address and land use of the property where the sampling was conducted (residential or non-residential).
3. Identify all contaminants detected (related to the off-site source), contaminant concentrations, and the media that are impacted (i.e., ground water, surface water, soils, sediments etc.).
4. Indicate that you are ***"reporting a discharge in soil/ground water/surface water/sediment that is not related to my site under investigation and that the contamination is verified to be from an unknown off-site source."***
5. Identify that a ***PA/SI*** was conducted to confirm a ***verified unknown off-site source***.

6. Identify the program interest number of the subject site (the site where the off-site source investigation was performed), and the incident number from the first hotline call.
7. Identify any available information regarding proximal receptors identified in the Receptor Evaluation (N.J.A.C. 7:26E-1.13) that may be impacted (schools, child care centers, residences, etc.).
8. Obtain a new Incident Number from the NJDEP Hotline operator for the ***verified unknown off-site source.***

The LSRP should then issue RAO-A for the contamination determined to be from an unknown off-site source. The RAO insert "Contamination Remains On-Site due to Off-site Contamination" must also be completed and included within the RAO.

5.3 Contamination was Detected During Plume Delineation that is Downgradient of the Site and on Another Property

5.3.1 Different Contaminants Found Downgradient

If contaminants are identified **off** the subject site and are suspected to be unrelated to a known discharge at the subject site, then the PRCR of the subject site must call the hotline (N.J.A.C. 7:1E-5.3), complete an investigation to demonstrate that such contaminants are **not** the result of migration from the subject site.

Once it has been confirmed that the contamination is not related to the subject site, the PRCR is not responsible for that contamination, and an RAO is not required. However, the PRCR of the subject site must (N.J.A.C. 7:1E-5.3) call the NJDEP Hotline (1-877-WARNDEP) and report to the operator, using the specific terms highlighted and underlined below. Provide the following information to the NJDEP Hotline operator even if you are not prompted to do so.

1. Identify that the contamination was observed **off** of the subject site.
2. Identify the address of the off-site property and whether the off-site property (where the unknown off-site source of contamination was detected) is residential or non-residential.
3. Identify the contaminants, the concentrations, and the media that are impacted (soils, ground water, surface water, sediments, etc.) associated with the off-site contamination.
4. Indicate that ***"the off-site contamination was never detected on the subject site and all available information supports the conclusion that the contamination is unrelated to the subject site."***
5. Identify any available information regarding proximal receptors identified in the Receptor Evaluation (N.J.A.C. 7:26E-1.13) that may be impacted (schools, child care centers, residences, etc.).

5.3.2 Similar Contaminants Found Downgradient

If contaminants are identified **off** the subject site and are chemically similar but are suspected to be unrelated to contamination from the subject site, the PRCR of the subject site must complete an investigation to demonstrate that such contaminants are **not** the result of migration from the subject site.

Once it has been confirmed that the contamination is not related to the subject site, the PRCR is not responsible for that contamination, and an RAO is not required. However, the PRCR of the subject site must (N.J.A.C. 7:1E-5.3) call the NJDEP Hotline (1-877-WARNDEP) and report to the operator, using the specific terms highlighted and underlined below, that "***an unknown, off-site source of contamination has been identified and is suspected to be from an unrelated source.***" Provide the following information to the NJDEP Hotline operator even if you are not prompted to do so.

1. Identify that the contamination was observed off of the subject site.
2. Identify the address of the off-site property and whether the off-site property (where the unknown off-site source of contamination was detected) is residential or non-residential.
3. Identify the contaminants, the concentrations, and the media that are impacted (soils, ground water, surface water, sediments, etc.) associated with the off-site contamination.
4. Identify that "***off-site contamination has been detected which is similar to that on the subject site, but all available information supports the conclusion that the contamination is unrelated to the subject site***."
5. Identify any available information regarding proximal receptors identified in the Receptor Evaluation (N.J.A.C. 7:26E-1.13) that may be impacted (schools, child care centers, residences, etc.).

Continue to delineate pursuant to guidance documents. Where other sources of contamination may be affecting delineation samples, use appropriate forensics to ascertain the effects of the other sources. See Section 3.0.

If additional responsible parties are identified during the investigation, consideration should be given to joint remedial operations. If case records exist for the other parties, OPRA reviews for those cases should be conducted. If sufficient data can be found in the case records, modeling should be conducted to demonstrate that site's contribution to the plume.

If a remedial action permit application is submitted, the LSRP must include a ground water monitoring plan that addresses the permitted site's contaminant contribution and reasonable conditions for termination of the permit.

5.4 Requirements for Classification Exception Area (CEA)

The PRCR is responsible for submitting the necessary information in order for the Department to establish the CEA for the contamination emanating from their discharge, pursuant to N.J.A.C. 7:9C-1.6 & 7:26C-7.3. In many situations, ground water is contaminated as a result of more than one PRCR's discharge. The ability to demonstrate that the contamination from a specific discharge is below standards may be difficult or impracticable. The extent and duration of the CEA under these conditions may be determined using appropriate modeling techniques, such as those outlined in the MNA Technical Guidance Document. The modeling must be based on site-specific conditions. Ground water quality data will continue to be gathered during the duration of the CEA and should be used to calibrate the model and demonstrate that the modeling assumptions were correct. If individual contributions to a commingled plume cannot be differentiated, a CEA must be established for the entire plume. Once the calculated CEA duration has passed, the CEA may be lifted if it can be demonstrated that it is appropriate.

If, instead, individual contributions to a commingled plume can be differentiated (through modeling as mentioned above, or through other means), then each PRCR must establish a CEA for its differentiated plume, and such CEA can be terminated upon a satisfactory demonstration that such differentiated plume has been remediated to applicable ground water remediation standards (N.J.A.C. 7:26C, Sections 7.9 and or 7.13). If there were sufficient GW sampling data available to document that the remedy was effective up to the time of the new discharge and that observed decreases in contaminant concentrations of the initial discharge were consistent with modeled predictions, it may be possible to develop MLE to extrapolate when the remediation of the original discharge would have been completed.

Refer to the Department's forms web page (http://www.nj.gov/dep/srp/srra/forms/) for the Classification Exception Area /Well Restriction Area (CEA/WRA) Fact Sheet Form and instructions.

5.5 Discharge Discovered After Issuance of Remedial Action Permit (RAP-GW)

For some cases, a new discharge may be detected on the site where an existing discharge is already being remediated and a RAP-GW is in place to monitor the effectiveness of the remedy. In this scenario, the administrative process for detecting a new discharge is similar to those described in the previous sections of Section 5. The new discharge shall be reported immediately in accordance with N.J.A.C. 7:1E-5.3(a) and 7:26C-1.7 by calling the NJDEP Hotline (1-877- WARNDEP). An evaluation should then be conducted to assess the impact of the new discharge on the on-going remediation. This evaluation should include an assessment of whether the conditions of the existing RAP-GW can still be met, and the results of this evaluation should be submitted as part of the next Remedial Action Protectiveness/Biennial Certification. If the new discharge detected at the site is a result of an off-site source unrelated to the site's discharge(s), an investigation may be conducted to demonstrate that contamination is from an off-site source as outlined in 7:26E-3.9 and the Department's Off-Site Source Investigation Technical Guidance. The results from the off-site source investigation should also be submitted with the next Remedial Action Protectiveness/Biennial Certification.

Table 2 and the remaining Sections 5 below present four potential scenarios involving the on-going remediation of an existing discharge where a RAP-GW for ground water is in place to assess the effectiveness of the remedy. In these four scenarios, a new discharge is subsequently detected that commingles with the initial discharge being remediated. Depending on the severity of the impact from the new discharge, several options exist for complying with RAP-GW requirements and proceeding with the remediation. These scenarios include:

A. The newly-identified discharge has commingled with the existing ground water contamination plume but has no effect on the continued protectiveness of the RAP-GW. No modification of the
B. The newly-identified discharge has commingled with the existing ground water contamination plume and negatively impacted the ability meet the approved RAP-GW objectives. A modification

to the existing RAP-GW is needed to maintain protectiveness and meet RAP-GW objectives. See Section 5.5.2.

C. The newly-identified discharge has commingled with the existing ground water contamination plume. Protectiveness of the remedy for the initial discharge cannot be evaluated under the current RAP-GW and modifications are not possible that could still meet permit objectives. A large volume of RAP-GW sampling information is available and MLE exist to extrapolate when remediation of the discharge would be completed. See Section 5.5.3.

D. The newly-identified discharge has commingled with the existing ground water contamination plume and protectiveness of the remedy for the initial discharge cannot be evaluated under the current RAP-GW. There are no modifications that could be made to the existing RAP to still meet permit objectives. There is a minimal amount of RAP-GW ground water sampling data available and insufficient MLE to accurately extrapolate when the remediation of the initial discharge would meet applicable standards. See Section 5.5.4.

5.5.1 New Discharge; Minimal Impact on Existing Remediation; No Remedial Action Permit Modification Necessary

If the newly identified discharge commingles with the existing ground water contamination being addressed by the RAP-GW, an evaluation should be conducted by the investigator to determine if the new discharge negatively impacts the ability to meet the RAP-GW objectives for the plume being remediated. As previously noted, this evaluation should be submitted with the next Remedial Action Protectiveness/Biennial Certification.

If the ability to meet RAP-GW objectives is not negatively impacted by the new discharge, no permit modifications are necessary and the PRCR may continue to perform the required monitoring and reporting activities in accordance with the existing RAP-GW. When the remedy has effectively reduced contaminant concentrations in ground water to below applicable standards, the PRCR may request termination of the RAP-GW and remediation of the existing (initial) plume will be considered complete. Under this scenario, the PRCR for the newly-identified discharge will remediate it under a new Spill Notification Case Number, which would be subject to the applicable regulatory/mandatory timeframes.

5.5.2 New discharge; Significant Impact on Existing Remediation; RAP-GW Modifications Needed

If the newly identified discharge has affected the RAP-GW Monitoring Plan (e.g., monitoring locations now contain free product or order of magnitude increase in contaminant concentrations), the investigator shall evaluate if modifications to the RAP-GW can be made to meet RAP-GW requirements and assure the continued protectiveness of the chosen remedy, pursuant to N.J.A.C. 7:26C-7.12. For example, if the new discharge only impacts monitoring wells within the main part of the plume, the investigator may propose to cease sampling at those monitoring wells and continue sampling of source area wells and sentinel wells that were not affected by the new discharge. Providing the investigator can determine that RAP-GW protectiveness monitoring can continue under the revised plan, a permit modification should be requested. As necessary, MLE should be utilized when developing a modified RAP-GW protectiveness monitoring plan to document that the original permit objectives can still be met. The modified monitoring plan should be implemented and permit required sampling continue until appropriate Standards are met. At that time, the RAP-GW can be terminated, a RAO can be issued for the initial discharge, and the remediation of that discharge will be considered complete. As stated above, it is assumed that the PRCR for the newly-identified on-site discharge will address that discharge under a new Spill Notification Case Number, which would be subject to the applicable regulatory/mandatory timeframes. If the newly-identified discharge is the result of an off-site source, the Department would assume responsibility for identifying a PRCR or remediate the discharge using public funds.

5.5.3 New Discharge; Significantly Impacts Existing Remediation; RAP-GW Modifications are not Possible. MLE Available to Extrapolate When Remediation would be Complete

In this scenario, the newly-identified discharge (new contamination found on-site or determined to originate from off-site) significantly impacts the remediation of the first discharge. An example of this scenario might be a new discharge of similar contaminants resulting in ground water contamination that is greater in areal extent and at much higher concentrations than the first discharge. Due to the presence of the newly identified discharge, the investigator remediating the first discharge may no longer be able to meet requirements or propose modifications that could demonstrate the continued protectiveness of the remedy.

If the investigator has determined that continued monitoring under a modified plan is not feasible (e.g., most/all monitoring points have been affected by the newly-identified discharge), continued documentation of the protectiveness of a chosen remedy and ultimately RAP-GW termination may still be possible. If there were sufficient RAP-GW sampling data available to document that the remedy was effective up to the time of the newly identified discharge and that observed decreases in contaminant concentrations of the initial discharge were consistent with modeled predictions, it may be possible to develop MLE to extrapolate when the remediation of the original discharge would be completed. These MLE would also include information on the timing, volume and fate and transport of the original discharge. In this scenario, the investigator would submit a permit abeyance proposal at the next Biennial Certification report to the Department's Bureau of Remedial Action Permits (BRAP) that would provide details on all changes in site conditions and the inability to meet RAP-GW requirements. It would also provide all lines of evidence to support the calculation of an extrapolated date when the original discharge would have been remediated to applicable standards. Pending approval from the Department, the investigator would then cease RAP-GW required sampling but continue to pay RAP-GW fees and submit Remedial Action Protectiveness/Biennial Certification reports. At each Biennial Certification, the investigator will re-evaluate its previous predictions to achieve standards, assess the continued protectiveness of the remedy, and evaluate if its RAP-GW ground water sampling should be reinstituted.

When the predicted time of achieving standards is reached and the investigator determines that its predictive models are accurate and the remedy is protective, the RAP-GW can be terminated and an RAO can be issued. A determination of this nature should include a detailed and updated conceptual site model. At the time when the original discharge is extrapolated to meet applicable standards, the investigator may request termination of the RAP-GW and issue a Response Action Outcome for the completed remediation of the initial discharge.

5.5.4 New Discharge; Significantly Impacts Existing Remediation. RAP-GW Modifications are not Possible; Inadequate MLE Available to Extrapolate When Remediation would be Complete

This scenario is similar to the scenario outlined in Section 5.5.3. The newly-identified discharge significantly impacts the remediation of the first discharge and prevents the investigator for the initial discharge from meeting RAP-GW objectives. Due to the severity of the impact, modifications cannot be made to the existing RAP-GW to meet permit objectives. In this particular scenario, only a few years of RAP-GW related ground water sampling data are available and there are insufficient lines of evidence in regard to the timing, volume, and fate and transport of the original discharge to confidently extrapolate when the remediation of initial discharge would be completed. In this case, the PRCR for the initial discharge may request a permit abeyance of the RAP-GW at the next Biennial Certification report submittal until the remediation of the second discharge has progressed to the point that monitoring of the first discharge is feasible. The PRCR for the initial discharge would continue to pay annual RAP-GW fees and conduct the Biennial Certifications, but no sampling would be required. The permit abeyance status of the RAP-GW would remain in effect until the investigator, through the completion of the Biennial Certifications, determines that the second discharge has been remediated sufficiently to reinstate the RAP-GW for the initial discharge. At this point, the investigator can either continue implementing the monitoring specified in the RAP-GW, or demonstrate that the first discharge is remediated and terminate the RAP-GW. Once again, under this scenario, it is assumed that PRCR for the newly-identified discharge will address that discharge under a new Spill Notification Case Number, which would be subject to the applicable regulatory/mandatory timeframes.

5.6 Issuance of the Remedial Action Outcome and Commingled Plume Notices

An RAO can be issued for the subject site (which may involve a single discharge or multiple discharges), if a new discharge is detected and reported as a commingled plume and the investigator can substantiate that the new discharge is not part of the case being investigated. When issuing the RAO at sites with commingled plume conditions, that appropriate notice must be included in the RAO. As Section 2.0 of the guidance describes, there are four scenarios in which more than one contaminant plume exists at a site. The notices for each of those four scenarios are found below.

Different constituents - On-site and Off-site Sources (2.1.1).

This situation can be used when an off-site plume is present on-site and is commingled with an on-site plume with different constituents or is mapped on a separate portion of the site. Refer to Guidance for the

Issuance of Response Action Outcomes Version 2.0 dated April 2016 for additional explanation and use of this notice.

“Contamination Remains On-site Due to Off-site Contamination

Please be advised that contamination in the ground water at this site exists above the Ground Water Quality Standards (N.J.A.C. 7:9C-1.7) which may limit ground water use at this site. Based on completion of a preliminary assessment and site investigation (as applicable), pursuant to N.J.A.C. 7:26E-3, and completion of a background investigation pursuant to N.J.A.C. 7:26E-3.9, there is no onsite contribution to this contamination and I have confirmed the source of this contamination is from offsite. This aspect of the site was reported to the Department and assigned the Department’s Hotline incident number 00-00-00-0000-00. [$$Select if applicable: This ground water contamination is being addressed under Department Program Interest #_____.$$] Any redevelopment on this site should take into consideration the potential for vapor intrusion from the ground water contamination.”

Similar constituents - On-site and Off-site Sources (2.1.2)

“On-site Commingled Plume Condition Exists: Similar constituents - On-site and Off-site Sources

Please be advised that contamination in the ground water at this site exists above the Ground Water Quality Standards (N.J.A.C. 7:9C-1.7) which may limit ground water use at this site. Based on completion of a preliminary assessment, site investigation, and/or remedial investigation pursuant to N.J.A.C. 7:26E-3&4 I have confirmed that a commingled plume condition exists as a result of contamination associated with an off-site source is combining with similar contamination associated with an on-site source. Contribution from the discharges being addressed by this RAO have been remediated. The separate discharge(s) contributing to the commingled plume condition was/were reported to the Department and assigned the Department’s Hotline incident number(s) 00-00-00-0000-00. [$$Select if applicable: The additional ground water contaminant plume(s) not being addressed under this RAO is/are being addressed under Department Program Interest #_____.$$] Any redevelopment on this site should take into consideration the potential for receptor impacts (i.e., vapor intrusion, potable wells) from the ground water contamination.”

Different constituents - multiple on-site discharges (2.1.3)

“On-site Commingled Plume Condition Exists: Dissimilar constituents - multiple on-site discharge

Please be advised that contamination in the ground water at this site exists above the Ground Water Quality Standards (N.J.A.C. 7:9C-1.7) which may limit ground water use at this site. Based on completion of a preliminary assessment, site investigation, and/or remedial investigation pursuant to N.J.A.C. 7:26E-3&4 I have confirmed that a commingled plume condition exists as a result of multiple on-site discharges with dissimilar constituents. Contribution from the discharges being addressed by this RAO have been remediated. The separate discharge(s) contributing to the commingled plume condition was/were reported to the Department and assigned the Department’s Hotline incident number(s) 00-00-00-0000-00. [$$Select if applicable: The additional ground water contaminant plume(s) not being addressed under this RAO is/are being addressed under Department Program Interest #_____.$$] Any redevelopment on this site should take into consideration the potential for receptor impacts (i.e., vapor intrusion, potable wells) from the ground water contamination.”

Similar constituents – multiple on-site discharges (2.1.4)

“On-site Commingled Plume Condition Exists: Similar constituents – multiple on-site discharges

Please be advised that contamination in the ground water at this site exists above the Ground Water Quality Standards (N.J.A.C. 7:9C-1.7) which may limit ground water use at this site. Based on completion of a preliminary assessment, site investigation, and/or remedial investigation pursuant to N.J.A.C. 7:26E-3&4 I have confirmed that a commingled plume condition exists as a result of multiple on-site discharges with similar constituents (“overprinting”). Contribution from the discharges being addressed by this RAO have been remediated. The separate discharge(s) contributing to the commingled plume condition was/were reported to the Department and assigned the Department’s Hotline incident number(s) 00-00-00-0000-00. [$$Select if applicable: The additional ground water contaminant plume(s) not being addressed under this RAO is/are being addressed under Department Program Interest #_____.$$] Any redevelopment on this site should take into consideration the potential for receptor impacts (i.e., vapor intrusion, potable wells) from the ground water contamination.”

6.0 Site Specific Case Studies of Commingled Plume Investigations

Appendix A contains several case study examples of commingled plume scenarios using investigatory techniques normally conducted in a remedial investigation of a site. The examples are for illustrative purposes only. These examples demonstrate how the information obtained using these methods can be used to determine the extent of contamination. There is also discussion of the outcome and possible resolution of each issue.

Case Study Scenario 1 illustrates the on-site source contamination of similar constituents at a manufactured gas plant (MGP) site which has underground storage tanks (USTs) that discharged Benzene. Case Study Scenario 2 depicts a UST site which has off-site ground water contamination from another UST site commingling with the on-site constituents. Case Study Scenario 3 demonstrates the discharges of spatially similar contamination, but temporally dissimilar contamination (a.k.a., overprinting) at a UST site. Case Study Scenario 4 illustrates the use of Compound Specific Isotope Analysis (CSIA) to determine potential sources of commingled chlorinated solvent contamination in ground water. Case Study Scenario 5 discusses a Brownfields Redevelopment site where a TCE has contaminated ground water in two different aquifer zones. Using CSIA and other lines of evidence, it was determined that the TCE in each zone was from different sources. Case Study Scenario 6 illustrates a case with off-site contamination with two different contaminants of concern and the PRCR is proceeding with the investigation alone. The case study is an example of using the Department’s HazSite Database to gather other existing data.

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TABLE 1

Potential Lines of Evidence Checklist

This is an optional checklist for the investigator that identifies the information or potential lines of evidence that could be collected to support the conclusion of an off-site source. Several items on this checklist may not apply to each site and depending upon the complexity/simplicity, there may be more or less information necessary in the data gathering process and/or development of potential lines of evidence to demonstrate the off-site source of contamination. Use of this checklist is at the discretion of the investigator. This is for the investigator's purposes only and is not required to be submitted to the Department.

Check off the boxes that support a commingled plume condition.

Site Name:	**Prepared By:**	
Site Address:	**NJDEP PI#**	
Incident #:	**Block:**	**Lot:**

	Source 1		Source 2		Source 3	
	Current Operations	Historical Operations	Current Operations	Historical Operations	Current Operations	Historical Operations
Source Location						
On-Site						
Off-Site						
Unknown						
Discharge Information						
Known Discharge						
Unknown Discharge						
Contaminant Type						
Similar Contaminants						
Different Contaminants						
Receptor Information						
Have Receptors Been Identified? (Yes/No)						
Does an IEC Condition Exist? (Yes/No) *						
Are there engineering controls associated with vapor intrusion or ground water contamination? (Yes/No)						
Are Receptors Protected? (Yes/No)						

TABLE 1 cont.

Potential Lines of Evidence Checklist

	Source 1		Source 2		Source 3	
	Current Operations	Historical Operations	Current Operations	Historical Operations	Current Operations	Historical Operations
Preliminary Assessment **						
Ownership and Operations						
Aerial Photography						
Historical Sanborn Fire Insurance Maps						
NJ GeoWeb						
Data Miner						
Site Inspection						
OPRA / File Reviews						
Potential / Existing / Historic Areas of Concern and Source Areas						
Remediation History/Status - NFA/RAO						
Deed Notice / CEA						
Constituents of Concern Utilized						
Conceptual Site Model***						
Ground Water Flow Direction						
Lithology / Depth to Ground Water						
Pathways: Utilities/Subsurface Features, Surface Water Features						
Contaminant Gradient						
Upgradient Samples****						
Fate and Transport Modeling *** (see Appendix E)						
Advanced Tools						
Environmental Forensics						
GC Fingerprinting						
PIANO Analysis						
Degradation Components						
Trace Compounds						
Compound Specific Isotope Analysis (CSIA)						
Biomarkers						
Other: ____________________						

TABLE 1 cont.

Potential Lines of Evidence Checklist

	Source 1		Source 2		Source 3	
	Current Operations	Historical Operations	Current Operations	Historical Operations	Current Operations	Historical Operations
Advanced Tools (cont.)						
Statistical Analysis						
Linear and Exponential Regression Analysis						
Mann-Kendall						
Mann-Whitney U						
Sen Test						
Principal Component Analysis (PCA)						
Geostatistical						
Factor Analysis						
Other: ________________________________						
Stochastic Methods						
Kriging						
Monte Carlo						
Minimum Relative Entropy (MRE)						
Bayesian Inference						
Other: ________________________________						

Notes:

* Required as per the NJDEP's Technical Requirements for Site Remediation (http://www.state.nj.us/dep/srp/regs/) N.J.A.C 7:26E- 1.11, last amended May 7, 2012.

** Required as per the NJDEP's Technical Requirements for Site Remediation (http://www.state.nj.us/dep/srp/regs/) N.J.A.C. 7:26E-3.1(b), last amended May 7, 2012; refer to the Preliminary Assessment Guidance Document and the Off-Site Source Ground Water Investigation Technical Guidance Document. (http://www.nj.gov/dep/srp/guidance/)

*** Refer to the Conceptual Site Model Guidance Document (http://www.nj.gov/dep/srp/guidance/)

**** Required as per the NJDEP's Technical Requirements for Site Remediation N.J.A.C. 7:26E-3.9(a), last amended May 7, 2012

Table 2: Post Remedial Action Permits Decision Tree

	Discharge Scenario	Action	Terminate RAP when
A (Section 5.5.1)	Newly identified discharge detected – does not affect protectiveness of the remedy – does not affect ability to sample – does not affect ability to meet RAP-GW objectives	Continue on typical RAP-GW path	Applicable standards are met
B (Section 5.5.2)	Newly identified discharge detected - Discharge impacts ability to meet permit objectives. - Modifications can be made to meet RAP-GW objectives	Make modifications to RAP-GW	Applicable standards are met
C (Section 5.5.3)	Newly identified discharge detected - Impact from new discharge is severe - Can't meet permit objectives - There is a good amount of RAP-GW monitoring data from the initial discharge and good fate and transport modeling	- RAP Monitoring Plan sampling not feasible. Consider alternate sampling - Request RAP-GW permit abeyance at next Biennial Certification submittal - Continue to pay permit fees and submit Biennial Certification - Develop lines of evidence to extrapolate when initial plume would have met applicable standards	When the initial plume is extrapolated to meet applicable standards
D (Section 5.5.4)	Newly identified discharge detected - Impact from new discharge is severe and covers footprint of initial discharge - Can't sample or meet permit objectives - There is a lack of RAP-GW monitoring data for the initial discharge and inadequate lines of evidence to extrapolate time when applicable standards would be met	- Request RAP-GW permit abeyance at next Biennial Certification submittal - RAP Monitoring Plan sampling not feasible. Consider alternate sampling - Continue to pay permit fees and submit Biennial Certification - Wait until remediation of 2nd discharge is completed	Once 2nd discharge is remediated and it is possible to demonstrate that the initial (1st) discharge is remediated

Appendix A

Site Specific Scenarios of Commingled Plume Investigations

Case Study Scenario 1

Case Type:	Industrial Site Recovery Act Onsite Source Contamination Scenario Similar Constituents (Benzene) Different Sources (Former MGP Operation and Gasoline USTs)
Tools Used:	Preliminary Assessment (PA)/Site Background SI/RI - Conceptual Site Model Environmental Forensics (GC Fingerprinting)
Resolution Strategy:	Working independently (PRCR for UST unknown).

Case Type

The investigator is responsible for the remediation of a former 19th-century Manufactured Gas Plant (MGP). The MGP resulted in contamination of soil and ground water at the site with MGP products and by-products. Dissolved phase gasoline constituents were also identified in the soil and ground water during the investigation activities. This case study will outline the steps taken to confirm the presence of a commingled condition using MLE, evaluate impacts to remedial phases, reach a resolution with all responsible entities, and achieve regulatory closure.

Tools Used

Preliminary Assessment/Site Background:

The site is approximately 1.5 acres and is located in an urban area, which has been utilized for industrial/commercial operations since 1879. The surrounding land use includes an industrial auto station/repair to the west and residential homes to the west and north. The site is divided into two parcels.

Parcel 1: Operated as:

- MGP (1879 to 1887)
- Soap manufacturing (1887 to 1966)
- Plastics manufacturing (1966 to 1980)
- Coal Tar manufacturing (1900 to 1915)
- Lumber warehouse from 1915 to present

Parcel 2: Operated as:

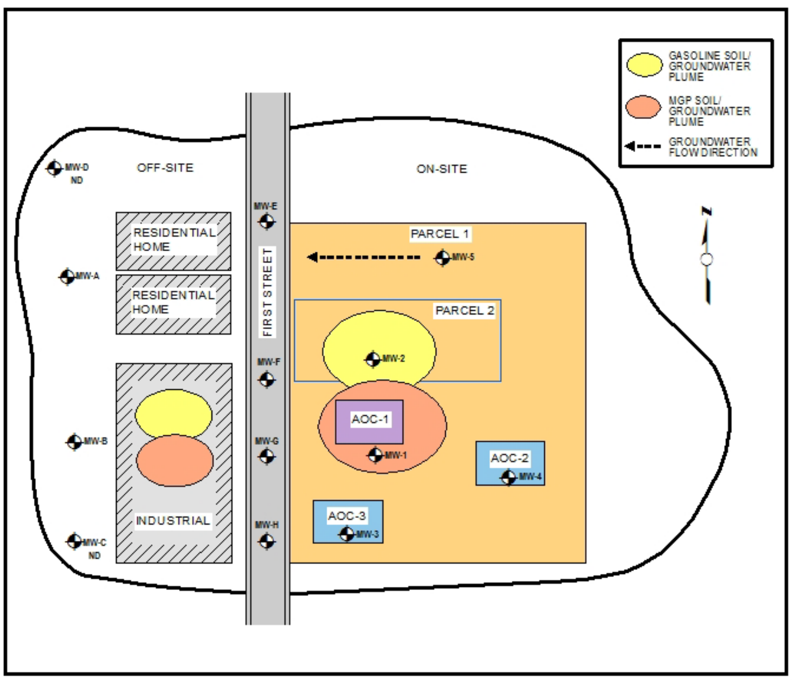
- Lumber mill (1900 to 1915)
- Lumber warehouse (1915 to present)

Based on a review of current operations and historic records, the lumber warehouse on Parcel 2 contained several underground storage tanks (USTs). The investigator is only responsible for remediating the MGP contamination. Based on the historic operations and product inventory records of the former MGP, gasoline and chlorinated solvents were not used or stored at the site.

In summary the PA, identified three (3) Areas of Concern (AOCs):

1. **AOC1: Former Gas Holder –** The gas holder was identified as a storage area of MGP product.
2. **AOC2: Former MGP Building –** The former building contained the MGP process and production processes/equipment.
3. **AOC3: Administrative Building –** Historic operations and inventory records indicated small quantities of hazardous substances, but no chlorinated solvents were used or stored in this building.

Figure 1: Site Map: Areas of Concern



<u>Site Investigation / Remedial Investigation (SI/RI):</u>

A total of ten (10) onsite soil samples were collected proximal to the three AOCs. Soils consisted of fill material (prevalent in the area and within NJDEP historic fill mapped area consisting of fine to coarse sands) and a clayey silt layer underlain by bedrock. The samples were analyzed for volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), polycyclic aromatic hydrocarbons (PAHs), Target Analyte List (TAL) metals, and cyanide.

The soil samples collected at AOCs 2 and 3 did not exceed the most stringent applicable Soil Remediation Standards (SRS). The soil samples collected in AOC-1 detected Benzene, Xylene, and Lead above the Department's Residential Direct Contact SRS (RDCSRS) and Default Impact to Ground Water Soil Screening Levels (DIGWSSL). A hydrocarbon odor indicative of gasoline (not MGP products) was noted in the soil samples from AOC-1.

Based on further investigation of the gasoline contamination by reviewing Sanborn maps and NJDEP Data Miner UST database, it was discovered that the current owner, a lumber warehouse, removed three underground storage tanks (USTs). These UST's reportedly contained heating oil and were located in the vicinity of soil samples at AOC-1 that identified the hydrocarbon odor indicative of gasoline. The lumber warehouse owner received a No Further Action (NFA) letter for these three USTs from the Department in 2006.

Based on the on-site results, 10 offsite soil samples were collected and analyzed for VOCs, SVOCs, PAHs, TAL metals and cyanide. The samples collected on downgradient industrial properties contained Benzene, Xylene and Lead above the RDCSRS and DIGWSSL. The soil samples collected on upgradient/sidegradient properties, including residential lots, did not exceed the most stringent applicable SRS.

A total of five (5) monitoring wells were installed on-site. Ground water was analyzed for VOCs, SVOCs, PAHs, TAL metals, and cyanide. Ground water was encountered at depths ranging from 10 to 13.4 feet below grade surface. The only on-site monitoring well, MW-1, in AOC-1 contains BTEX contaminants exceeding the Department's Ground Water Quality Standards (GWQS). Eight (8) monitoring wells were installed off-site to delineate the extent of ground water contamination identified in AOC-1. The locations of the onsite and offsite monitoring wells are illustrated on Figure 1. The extent of the dissolved phase plume is defined by side-gradient monitoring wells MW-C and MW-D. Monitoring wells MW-A and MW-B contained concentrations of benzene, lead, and trichloroethylene (TCE) above Department's GWQS. Based on the historic operations and product inventory records of the former MGP, gasoline and chlorinated solvents, TCE, were not used or stored at the site.

The SI/RI also included the completion of a Receptor Evaluation (RE). Based on the RE and onsite/ offsite conditions, vapor intrusion investigations were conducted at the offsite adjacent properties (residential and industrial). The results indicated that there were no vapor intrusion issues. There are no potable wells or surface waters adjacent to the site or within one mile of the property. No other potential receptor impacts were identified.

<u>Conceptual Site Model (CSM)</u>

The investigator developed and continually refined the CSM for the further investigation of AOC-1. Specifically, the investigator utilized the CSM to determine location and frequency of onsite and offsite soil and ground water samples. The investigator suspected the presence of a commingled plume condition when the petroleum hydrocarbon odors resembling gasoline were noted in the soils from AOC-1 and gasoline constituents (BTEX) and additives (lead) were detected in onsite and offsite soil and ground water samples.

At that time, the AOC-1 CSM was expanded to a Site-Wide CSM so multiple contaminant sources and migration pathways across the site could be evaluated. During this iterative step, additional historical documentation was uncovered that identified several UST's associated with the lumber warehouse on Parcel 2. During the PA investigation, the investigator thoroughly evaluated the historic operations and product inventory at the former MGP and, with a high degree of confidence, concluded gasoline was not stored or used during the MGP operation. The CSM was updated with this new information. An illustrated CSM was selected as the most appropriate form based on the site conditions and complexities. The illustrated CSM is provided as Figure 2.

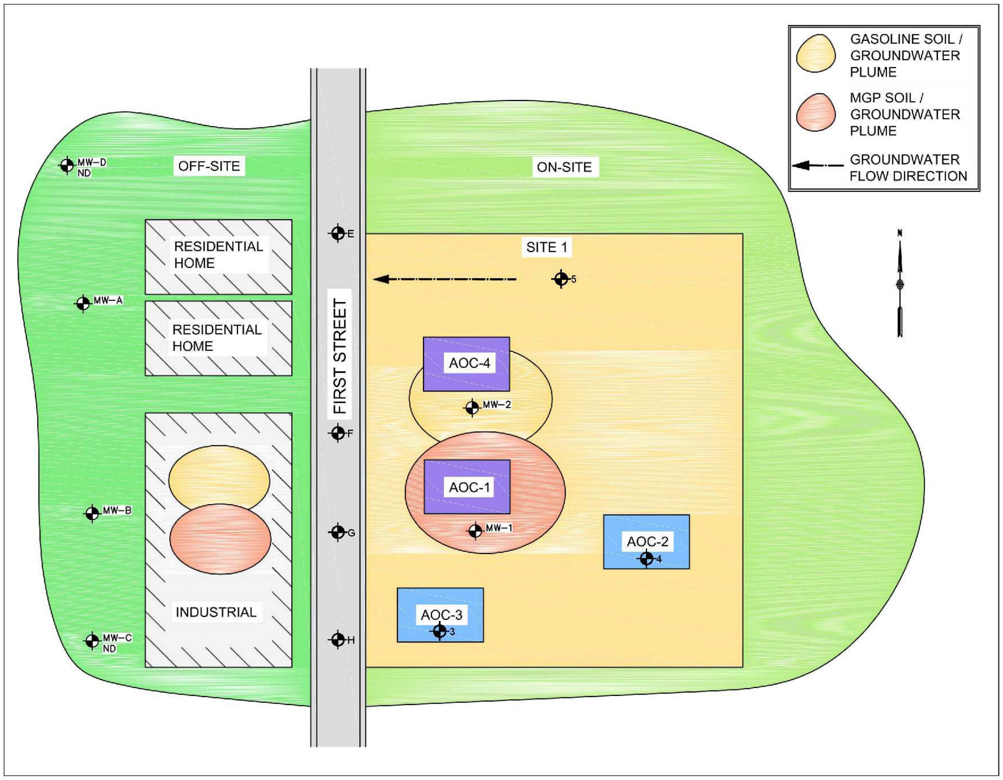
Environmental Forensics

The investigator utilized historic documentation of the soil and ground water (onsite and offsite) to develop a Site-Wide CSM illustrating a commingled plume condition. To confirm this to be the case, the investigator identified and utilized environmental forensics tools, specifically hydrocarbon pattern recognition or "GC Fingerprinting" and tracer compounds analyses.

A soil sample from AOC-1 was collected for fingerprinting analysis via Qualitative GC Fingerprint EPA Method 8015C. The sample was analyzed and the results indicated that the contaminant was gasoline, a non-MGP related contaminant. This result confirmed the presence of contamination associated with the recently added AOC-4. The fingerprint analysis of four offsite soil samples indicated substantially weathered coal tar to tar- derived compounds and gasoline compounds.

In the soil media, Lead was identified as a tracer compound in gasoline additives. Analytical results of the various Lead-based gasoline additives revealed that the gasoline present in the environment was from mid-1970s. Ground water samples from the downgradient monitoring wells were further analyzed by hydrocarbon fingerprinting and Lead additives.

Figure 2: Conceptual Site Model



Resolution Strategy

The investigator developed a commingled plume CSM with strong MLE identifying soil and ground water contamination associated with MGP operations and former USTs. The tools used to develop the CSM/MLE included site background information obtained during the PA, soil and ground water data collected during the SI/RI phases, and environmental forensics. This information was evaluated in an iterative process, where the CSM was continually updated as additional information was obtained. Based on the above, the investigator is confident in the CSM findings that a commingled plume condition exists, which leads to a new set of challenges.

Using Section 5.0 of this technical guidance, the investigator decided to continue to work independently and move the project through their remedial process. This decision was made based on:

- Locating and engaging the former UST owner/operators was determined to be a difficult task due to the current status of the former lumber mill.

- The downgradient monitoring wells installed to delineate the MGP related contaminants, also delineated the dissolved phase gasoline constituents, therefore no additional resources were used or costs were incurred in completing the RI phase.
- The selected remedies, institutional (CEA, deed notice) and engineering controls (surface capping) would be required for addressing the MGP contaminants in the absence of the gasoline related contaminants. It was determined that presence of the dissolved phase gasoline constituents did not significantly impact the selection of implementing the final remedy for this property.

Conclusions

Soil and ground water sampling identified two distinct contaminant discharges, one containing MGP-related constituents and one containing gasoline-related constituents. The MGP-related constituents are attributed to historic MGP operations. The source of the gasoline-related constituents is unknown. Benzene is a constituent found in both the MGP- and the gasoline-related discharges. The concentration of Benzene in off-site downgradient ground water samples is much lower than the on-site ground water samples, suggesting the source is located on or upgradient of the site. Off-site soil samples underwent fingerprint analysis that indicated substantially weathered coal tar to tar- derived compounds and gasoline compounds. In addition, soil samples that indicated an elevated level of Lead were further analyzed for Lead additives to identify the approximate age of the petroleum product. The results indicate that the gasoline discharge occurred in the mid-1970s. Also, Lead was detected in ground water.

TCE detected in off-site ground water indicates that there is an additional contaminant source and identifies the presence of a commingled plume. The presence of a commingled plume condition may or may not impact how remediation is conducted.

Administrative Considerations

In regard to the leaded gasoline discharge, the investigator is required to report to the NJDEP Hotline that a leaded gasoline discharge was detected in soil and ground water (on-site and off-site) that is not related to the subject site and that the contamination is verified to be from an unknown source. The PRCR has conducted a PA and reviewed the NJDEP Data Miner UST database to determine that the PRCR is not responsible for the Lead contamination.

The PRCR will prepare a Deed Notice and install a cap for the MGP–related constituents. A remedial action permit application for soil will be submitted to NJDEP. A restricted use RAO will be issued for the soil.

In regard to the Trichloroethylene (TCE) discharge, the investigator is required to report to the NJDEP Hotline that a discharge of TCE was detected in off-site ground water and is verified to be unrelated to the subject site (verified as discussed in Preliminary Assessment/Site Background Section above).

The PRCR is required to submit an initial CEA package with the RIR for the MGP-related ground water contamination constituents (this would not include TCE). Once natural attenuation is established, a monitored natural attenuation remedial action permit application for ground water will be submitted to NJDEP, which includes the CEA of the contaminants. A limited restricted use RAO that includes an off-site source and appropriate commingled plume notice (see Section 5.6 above) will be issued for the ground water until ground water meets the Department's GWQS.

Case Study Scenario 2

Case Type	Underground Storage Tank Offsite Source Contamination Similar Constituents *(BTEX, MTBE, TBA)* Different Sources *(Adjacent Gasoline Stations)*
Tools Used	SI/RI Preliminary Assessment/OPRA File Review Conceptual Site Model Environmental Forensics (PIANO Analyses) Fate and Transport Modeling
Resolution Strategy	Working cooperatively w/ other responsible entities.

Case Type

The investigator (Star Retail Station or Star) is responsible for the remediation of an active retail gasoline station, which began operations in the 1950's and was assigned a NJDEP Case Number in the early 1990's during UST upgrade activities. The adjacent property is also an active retail gasoline station with a similar operational and regulatory history. Both parcels were un-developed prior to the development dates. The sites are approximately 0.5 acres and are located in a mixed commercial/residential area. Star's investigator met its statutory/regulatory obligations to complete its RI, however would like to continue to progress this toward a final remedy. The data discussed within this case study reflects contaminants and conditions typically encountered at retail service (gasoline) stations. The investigator can apply this example to other operations and contaminants, such as dry cleaners and chlorinated solvents.

Tools Used

Site Investigation/Remedial Soil Investigation

At the time of Star Retail's UST upgrades, the investigator observed the presence of gasoline related contaminants in the soil and ground water around the tanks. Based on field observations, the investigator initiated remediation at the time of the UST closure activities by completing partial source area removal (soil excavation). The UST closure and post-remedial soil sampling indicated that contamination remained onsite and a ground water investigation was required. The Investigation continued with the collection of additional soil samples, the installation of monitoring wells, and the installation and operation of a ground water pump and treat and soil vapor extraction systems (GWPT/SVE) in the proximity of the former UST tank fields. The remedial system operated pointedly for the removal of non-aqueous phase liquid (LNAPL) for the first few years of operation.

The onsite soil investigation consisted mostly of the aforementioned post excavation soil samples and soil samples collected during the installation of monitoring, ground water recovery and soil vapor extraction wells. The soil profile consisted of fill material, native soils primarily of fine to coarse sands and clayey silts. Bedrock was not encountered during the investigation. Soil sampling revealed the presence of gasoline constituents, i.e., Benzene, Toluene, Ethylbenzene, Xylenes (BTEX) at concentrations above the most stringent applicable SRS. Lead was detected onsite above impact to ground water concentrations in the vicinity of the former USTs. Subsequently, remedial soil investigation borings delineated the BTEX concentrations to onsite. The Total Lead concentrations were detected in remedial soil investigation borings completed across the properties, which along with observations of fill debris and NJDEP mapping resources confirmed the presence of historic fill underlying the site.

Star Retail Station installed three (3) onsite monitoring wells to initiate the ground water investigation. The monitoring well network consisted of a source area well located in close proximity to the former USTs (Star A) and two (2) onsite plume wells (Star B & C). Once containing free product and dissolved phase BTEX concentrations exceeding the Ground Water Quality Standards (GWQS), monitoring well Star A (and the surrounding area) has been subject to the remedial efforts (excavation, GWPT/SVE system) that has reduced the contamination to only Benzene at concentrations approximately 20 ppb. The remaining BTEX compounds have all degraded to concentrations below the GWQS. As the use of MTBE and TBA was phased out the concentrations, which historically were detected above the GWQS, are now all below the GWQS. Historically, dissolved phase conditions similar to Star A have been observed in monitoring wells Star B and C (BTEX, MTBE, and TBA exceeding GWQS), but currently intermittent LNAPL is measurable in Star B and only Benzene persists above the GWQS at concentrations ranging from 10 to 20 ppb in Star B and C. Upon implementing a low-flow sampling technique, Lead (Pb) was not detected above the laboratory method detection limits and was eliminated as a contaminant of concern for this remediation. Ground water is encountered at depths ranging from 11 to 13 feet below ground surface (bgs).

Star Retail Station installed three (3) offsite monitoring wells in an attempt to delineate the ground water contamination. The monitoring well network consisted of two (2) plume wells (Star D & E) and one (1) attempt at a sentinel well (Star F). Star D has had dissolved concentrations at or below the GWQS standards for BTEX, MTBE, and TBA, indicating the horizontal extent of the dissolved phase plume is defined in this direction (north). Star E has consistently had BTEX, MTBE, and TBA concentrations above the GWQS, most notably Benzene at concentration of > 10,000 ppb in the first few years of monitoring. Most recently, Benzene concentration range have ranged 500 to 1,000 ppb, but measurable LNAPL is present intermittently. The remaining BTEX compounds are below the GWQS ranging in concentrations of 100 to 300 ppb. Star F was installed as an attempted sentinel well of the plume defined by Star B, C, D, and E, however the dissolved phase concentrations observed have consistently been detected above the GWQS and in some instances are higher than concentrations detected in Star E and Star onsite monitoring wells. LNAPL has never been detected Star F.

The vapor intrusion investigations conducted based on site conditions of onsite and nearby buildings indicated the migration pathway to indoor air was not completed. There are no potable wells or surface waters adjacent to the site or within 1 mile of the property. No other potential receptor impacts were identified.

Preliminary Assessment/OPRA File Review

Because this is an UST case, there was no regulatory requirement to complete a PA. However, Star's investigator conducted a PA when data from well F was received, to investigate a potential secondary source of contamination or a commingled plume condition with contaminants migrating from the adjacent property (Octagon Retail). The PA did not identify any additional AOC's on the Star property. In the PA data gathering process to assess the potential of a commingled plume condition, information on Octagon Retail was determined to be:

- The gasoline stations stored and distributed gasoline for retail sale since the 1950's.
- Prior to development as gasoline station, property was un-developed or used for non-commercial/industrial operations.
- Similar to Star Retail, the original USTs systems at Octagon were typical for the time of construction (single wall steel tanks and appurtenant piping, no leak detection, secondary containment, or overfill protection).
- Per federal and state regulations the USTs systems were upgraded in the early 1990s; holes in the tanks/piping were noted upon removal; evidence of discharges was observed, and a NJDEP Case Number was assigned.
- Since that time, the UST systems have been upgraded to state-of-the-art systems and Octagon has a relatively clean compliance record with only small quantity spills (< 10 gallons) reported as the result of operator error (delivery overfills, customer drive offs, etc.).
- Similar to Star, Octagon operated during the time period when gasoline containing both Lead and oxygenated additives were sold.

In addition to the operational history, information about the remedial activities completed at the Octagon Service Station was also obtained. Based on the review of past reports it was determined that Octagon initially installed three (3) onsite monitoring wells including a source area well located in proximity to its former USTs (Octagon A) and two (2) onsite plume wells (Octagon B & C). The historic data for the site indicates LNAPL was present in all onsite monitoring wells, at a greater thickness, and for a longer period of time compared to the Star onsite monitoring wells. Historically, BTEX, MTBE, and TBA were detected at concentrations above the GWQS.

Currently, no LNAPL is detected in the onsite monitoring wells and Benzene is the only compound that persists above the GWQS at concentrations ranging from 500 to 1,000 ppb.

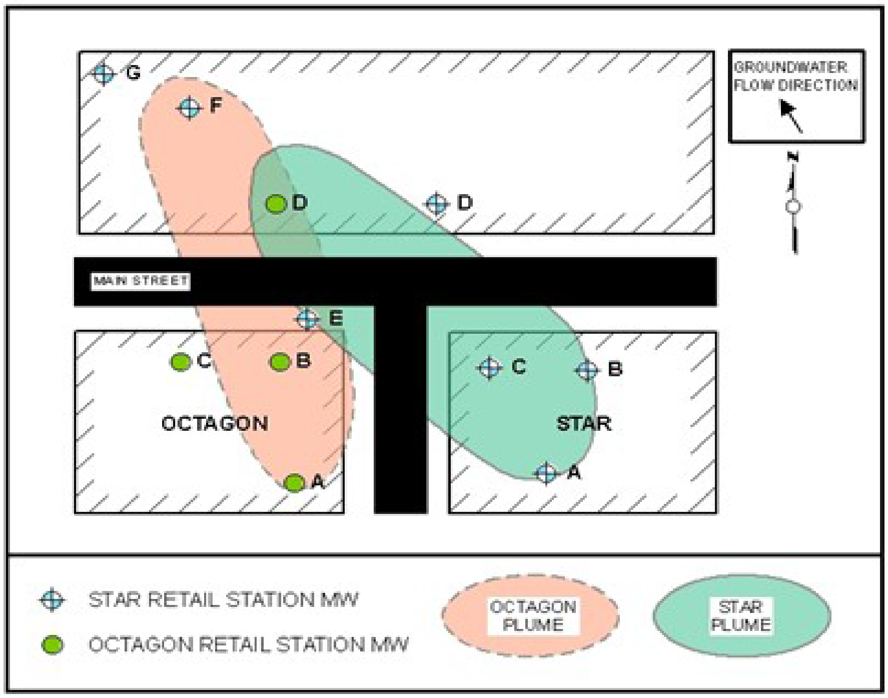
Octagon subsequently installed one (1) off-site monitoring well (Octagon D) to evaluate the ground water contamination. Historically, BTEX, MTBE, and TBA concentrations have exceeded the GWQS, however currently only Benzene persists above the GWQS at concentrations ranging from 500 to 1,000 ppb. Upon implementing a low-flow sampling technique, Lead (Pb) was not detected above the laboratory method detection limits. Ground water at off-site locations is encountered at similar depths as the on-site locations (ranging from 11 to 13 feet bgs).

Conceptual Site Model (CSM)

Star's investigator developed an AOC CSM, based on the former UST field and the resulting contaminant migration to soil and ground water. The CSM was used in selecting the locations of the initial onsite wells and the offsite monitoring wells, including Star F (the attempted sentinel well). Incorporating the information from the completed PA, the CSM was expanded to a Site-Wide CSM when the ground water analytical results from Star-F were received, so a more thorough assessment of potential contaminant sources and migration pathways could be completed. Integrating the Octagon site information, the CSM was further refined. An illustrated CSM was selected as the most appropriate form based on the site conditions and complexities. The illustrated CSM is provided as Figure 1.

The CSM illustrates a commingled plume of similar contaminants from two adjacent/nearby properties (in this case Benzene plumes from retail gasoline stations). The Star monitoring well network has defined the nature and extent of its plume where it has not been affected by the Octagon plume, specifically from data from Star MWs A, B, C, and D. The data collected from Star E and F is inconsistent with what would be expected based on Star's CSM and the evaluation of Star MW A, B, C, and D data trends, indicating a possible commingled plume condition with Octagon's plume. Based on the current well network, it is difficult to determine the nature and extent of the plume emanating from the Octagon Service station.

Figure 1 – Conceptual Site Model



<u>Environmental Forensics</u>

The investigator has utilized site background information and soil and ground water sampling results to develop a CSM indicating a commingled plume condition. While not required in every scenario, Star's investigator decided to utilize environmental forensics tools, specifically hydrocarbon pattern recognition or "PIANO Analysis" to differentiate the contaminants detected in Star MW-E.

LNAPL samples were collected from Star A (onsite) and Star E (offsite). The PIANO analysis, which compares the presence of paraffins, isoparaffins, aromatics, naphthalenes and olefins compounds collectively, differentiated the fuels based on a lack of isoparafins in the onsite samples compared to the offsite sample. The absence of these indicator compounds confirms a difference in fuel type in the onsite versus offsite sample locations. Star's investigator utilizes this line of evidence in his CSM development.

<u>Resolution Strategy</u>

The investigator has developed a commingled plume CSM with MLE identifying ground water contamination associated with two adjacent retail gasoline stations. The tools used to develop the CSM/MLE included SI and remedial investigation data, site background information obtained during the PA/OPRA File Review and environmental forensics (PIANO analysis). The information was evaluated in an iterative process, where the CSM was continually updated as additional information was obtained. Based on above, the investigator is confident in the CSM and that a commingled plume condition exists, which leads to a new set of challenges.

Using Section 4.0 of this technical guidance, the investigator contacted Octagon and decided to work cooperatively to move the project through the remedial process. This decision was made based on:

- Octagon's Site was in compliance and had plans for further ground water investigation activities (including a sidegradient and downgradient/sentinel monitoring well)
- Star was actively pursuing a final remedy. Octagon's investigators agreed and adopted Star's CSM as part of Octagon's investigation. With pending timeframes and the ability for Star and Octagon to achieve a final remedy, it was mutually beneficial for the parties to work cooperatively.
- The investigators determined that long-term remedial actions for offsite conditions would be limited to natural remediation.

Administrative Considerations

This scenario represents a situation where a separate discharge of similar constituents has been detected commingling in an offsite location. The source of the separate discharge is a known contaminated site; therefore, notification to the Department is not warranted.

Star's investigator utilized data gathered from Octagon's new sidegradient and downgradient/sentinel monitoring well to refine its CSM. Once an adequate number of samples were collected from the newly installed Octagon wells, Star prepared and submitted its Remedial Action Report, Remedial Action Permit for Ground Water Application, eliminating Star E and Star F from its Long-Term Monitoring Plan due to the commingled plume with Octagon. Upon approval of the RAP-GW, the limited restricted use RAO was issued utilizing the appropriate RAO insert in Section 5.6.

The RAP-GW Monitoring Plan excludes Star Plume Wells E and F as these wells have been affected by the discharge from Octagon's property and cannot be utilized to monitoring the plume emanating from Star's property. Going forward, Star will be required to complete its monitoring program; pay its permit fee; and submit its Remedial Action Protectiveness / Biennial Certification Form confirming the selected remedy remains protective. As part of this submittal, Star's investigator will also have to continue to assess the status of Star Wells E and F and consider if they should be returned to the monitoring program.

Case Study Scenario 3

Case Type:	Underground Storage Tank Onsite Source Contamination Scenario Similar Constituents (Overprinting)
Tools Used:	SI/RI Conceptual Site Model Statistics and Trend Analysis Fate and Transport Modeling
Resolution Strategy:	Working with an uncooperative responsible entity.

Case Type

The investigator (ABC Retail Station) has completed the remediation at a former retail gasoline station and is maintaining a Natural Attenuation Remediation Action Permit for Ground Water (RAP-GW) at its retail gasoline station, that is now owned/operated by a new entity (XYZ Retail Station). During the course of RAP-GW monitoring program the data indicates a discharge of similar contaminants has occurred in the same area of concern (AOC) – the UST Field. This case study will outline the steps necessary to continue to monitor the protectiveness of the RAP-GW and continue to pursue regulatory closure for a site when a discharge of similar contaminant are spatially similar, but temporally dissimilar. This scenario is defined as "overprinting" within this technical guidance. The example can be applied to any operation and contaminant, such as dry cleaners and chlorinated compounds.

Tools Used

Site Investigation/Remedial Investigation

In response to the discovery of petroleum discharge during 1996 UST piping system replacement, ABC Gasoline completed partial source area removal (soil excavation) and vacuum truck based LNAPL and dual-phase extraction events. While these remedial measures were initiated, the investigation of soil and ground water underlying the site commenced. The onsite soil investigation consisted mostly of UST piping closure samples and post excavation soil samples. The soil boring profile consisted of fill material and native soils primarily of fine to coarse sands and clayey silts. Bedrock was not encountered during the investigation. Soil samples were analyzed for volatile organic compounds (VOCs) and total Lead.

Typical gasoline constituents Benzene, Toluene, Ethylbenzene, Xylenes (BTEX) were detected above impact to ground water, residential, and non-residential cleanup criteria in the soils in close proximity to the USTs Field. Total Lead was detected across the site, which is indicative of the underlying historic fill. Subsequently, remedial soil investigation borings delineated the BTEX and Lead concentrations to below impacts to ground water and residential levels onsite. Based on the onsite site/remedial investigation results, no offsite soil investigation was required.

The monitoring well network consists of two (2) source area wells (A & B); two (2) onsite plume monitoring wells (C & D); and one offsite sentinel well. These wells were routinely sampled while ABC was operating the station and then while the station was operated by XYZ Retail. LNAPL was never been measureable in the onsite monitoring wells. Ground water is encountered at depths ranging from 11 to 13 feet bgs.

<u>1996 – 2010</u>

The total BTEX concentrations in source area monitoring wells (A&B) were at or below the GWQS concentrations. However, oxygenated additives MTBE and TBA were detected above the GWQS at concentrations ranging from non-detect to 1,500 ppb. The onsite plume monitoring wells exhibited total BTEX concentrations ranging from ND to 20,000 ppb during this time period. The MTBE and TBA concentrations ranged ND to 3,000 ppb. The concentration fluctuations appeared to correlate fairly well to seasonal water table fluctuations. The concentrations exhibited a decreasing trend, which was attributed to the source removal (soil excavation) and vacuum truck based dual-phase extraction events. The dual phase extraction events ceased in 2008. Quarterly ground water monitoring continued and ground water concentration trend analysis was continually assessed. The total BTEX concentrations in sentinel monitoring well E have always remained at or below the GWQS. MTBE and TBA were detected, however at concentration below the GWQS (typically ~ 50 ppb).

ABC Retail ceased its operations on the property in late-2010.

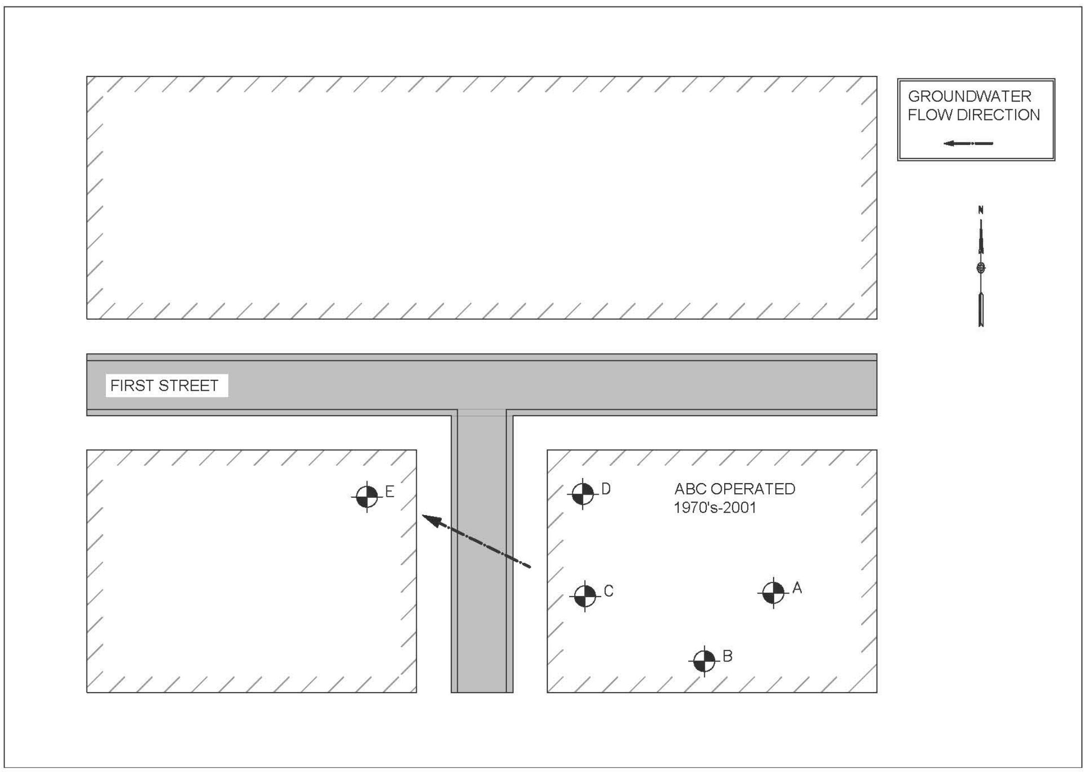
<u>2011 - Present</u>

Based on the ground water data from 1996 to 2010, ABC's investigator applied for and secured a Natural Attenuation RAP-GW and subsequently submitted a Limited Restricted Use RAO for its 1996 NJDEP Case #. Retailer XYX began operating onsite in late-2010.

The dissolved phase concentrations remained consistent and continued to demonstrate an overall decreasing trend for the first four (4) years of RAP-GW monitoring. In 2015, the dissolved phase concentration of BTEX compounds increased by an order of magnitude. Most notably, the concentration of Benzene increase from ND to 10,000 ppb in source area well MWB. Confirmation samples were collected, analyzed, and returned similar results. The dissolved phase concentrations in source area MWA remained consistent with historic trends.
The BTEX concentrations in onsite plume monitoring MWC and MWD also increased by an order of magnitude. Most notably, Benzene increased from ~100 ppb to ~6,500 ppb.

The total BTEX concentrations in the sentinel well remained below the GWQS during this time period. The vapor intrusion investigations conducted based on site conditions of onsite and nearby buildings indicated the migration pathway to indoor air was not completed. There are no potable wells or surface waters adjacent to the site or within 1 mile of the property. No other potential receptor impacts were identified.

Figure 1: Conceptual Site Model



Conceptual Site Model

ABC's investigator had developed a CSM for this Site in developing the RAP-GW Monitoring Plan and continually refined the CSM along with its biennial certifications. The investigator suspected the presence of an overprinting condition when an order of magnitude increase of dissolved phase concentrations was detected (and confirmed). At that time, the CSM was refined to account for a potential second source of contaminants (the current UST system). A narrative CSM was selected as the most appropriate form based on the site conditions and complexities. The CSM is provided below.

ABC Retail Station stored and distributed gasoline for retail sale since the 1970's. The original USTs systems was upgraded in the early 1990's and was equipped with the required leak detection, secondary containment, corrosion protection and overfill protection. NJDEP Case # was assigned during the upgrade activities; however it was subsequently closed based on the results of UST closure sampling and a ground water investigation. In 1996, the flexible piping installed in 1990 was replaced. Upon uncovering the flexible piping, failed connections and evidence of discharge was observed at multiple tanks/piping joints/unions. NJDEP Case # was assigned; remedial activities (soil removal, vacuum truck based dual phase extraction events) were implemented, and the required soil and ground water investigation was initiated. Ground water monitoring was consistently conducted quarterly since 1996. LNAPL was never measured in monitoring wells. The dissolved constituents were delineated and exhibiting post-remedial decreasing trends. A Monitored Natural Attenuation RAP-GW secured and a Limited Restricted Use RAO were issued for the AOC in 2011. The CEA/RAP-GW had predicted that the dissolved phase constituents would attenuate to the GWQS in all monitoring wells in 7 years (2018).

ABC Retail Station ceased operations in late-2010. XYZ Retail Station began operations in early 2011. ABC continued to monitor the ground water on an annual basis as part of the approved RAP-GW Monitoring Plan.

XYZ had no reportable incidents. The ground water monitoring data revealed similar conditions and trends for the first 4-years of RAP-GW monitoring, while XYZ was operating. In 2015, the dissolved phase concentrations increased by orders of magnitude in the existing source area and onsite plume monitoring wells. ABC's investigator concluded that the concentration increase represented a new discharge to the environment.

Statistics and Trend Analysis

In preparation of the RAP-GW, ABC's investigator employed the use of several statistical analyses to confirm decreasing concentrations have been established. The statistical analyses included regression analysis, Mann-Whitney U Test, and Mann-Kendall Test. These three analyses confirmed a decreasing trend in onsite source and plume monitoring wells.

Fate and Transport Modeling

In preparation of the RAP-GW and CEA, ABC's investigator employed the use of the BioScreen computer model to estimate the horizontal extent and time to attenuate to GWQS. The result of this analysis of ABC's discharge was 7 years from the time the RAP-GW was secured/CEA was updated (2018).

Resolution Strategy

The investigator has developed a commingled plume CSM with MLE identifying ground water contamination associated with an overprinting scenario. The tools used to develop the CSM/MLE included SI and remedial investigation data. The information was evaluated in an iterative process, where the CSM was continually updated as additional information was obtained. Based on above, the investigator is confident in the CSM and the fact that a commingled plume condition in fact exists, which leads to a new set of challenges.

Using Section 4.0 of this technical guidance, ABC's investigator contacted XYZ Retail to discuss the recent ground water analytical results and its refined CSM. XYZ Retail and its investigator do not agree with ABC's CSM and refuse to initiate the required investigation activities. ABC continues to comply with its obligations to report and remediate, despite now having an overprinting/commingled condition and an uncooperative party.

Administrative Considerations

This scenario represents an overprinting scenario at a retail gasoline station. The new discharge was detected on the subject site and the source of the new discharge also exists on-site, therefore the NJDEP Hotline was called. ABC Retail also notified XYZ Retail of the new discharge; NJDEP Hotline; and newly assigned NJDEP Case number. Having developed its CSM utilizing MLE, ABC Retail is deemed to not be obligated to further investigate or remediate the new discharge. A Limited Restriction Use RAO is to be issued using the appropriate comingled plume notices found in section 5.6 of this technical guidance.

If it was determined that XYZ Retail was responsible for the new discharge, they would be required to remediate it pursuant to N.J.S.A. 58:10B-1.3 and in accordance with N.J.A.C. 7:26C and N.J.A.C. 7:26E.

Utilizing its Commingled Plume CSM and in accordance with Section 5.4.2. of this technical guidance, ABC's investigator submitted modified RAP-GW. The modified RAP-GW Monitoring Schedule committed ABC to continue to monitor the unaffected source area well (Well A) and the sentinel well (Well E). Using MLE, ABC's investigator determined that the remaining monitoring well network (Well B, Well C, Well D), was impacted by XZY's discharge and could no longer be utilized to monitor the protectiveness of the ABC's selected remedy (Natural Attenuation). Going forward, ABC will be required to complete its monitoring program; pay its permit fee; and submit its Remedial Action Protectiveness / Biennial Certification Form confirming the selected remedy remains protective. As part of this submittal, ABC will also have to continue to assess the status of Wells B, Well, C, and Well D, and consider if they should be returned to the monitoring program. If the concentrations in source area Well A attenuate as predicted in 7 years, and sentinel Well E remains below GWQS, ABC's investigator will be able to terminate its RAP-GW at the end of 7 years. As part of this submittal, ABC will have to reconfirm its inability to utilize the wells impacted by XYZ's discharge.

Case Study Scenario 4

Case Type:	Similar constituents – Chlorinated Compounds Off-site contribution
Tools Used:	PA/SI/RI, Compound-Specific Isotope Analysis
Resolution Strategy:	Continued Remediation (MNA/CEA) or report as unknown source to Department

Case Type

TCE and PCE were detected in ground water in a commercial area; potential sources were unknown. Compound-Specific Isotope Analysis (CSIA) was used to determine potential sources of contamination and demonstrate the cost-effectiveness of this type of analysis. This case study will outline the steps taken to investigate the contamination and evaluate potential resolution mechanisms that will allow completion of remedial activities.

Tools Used

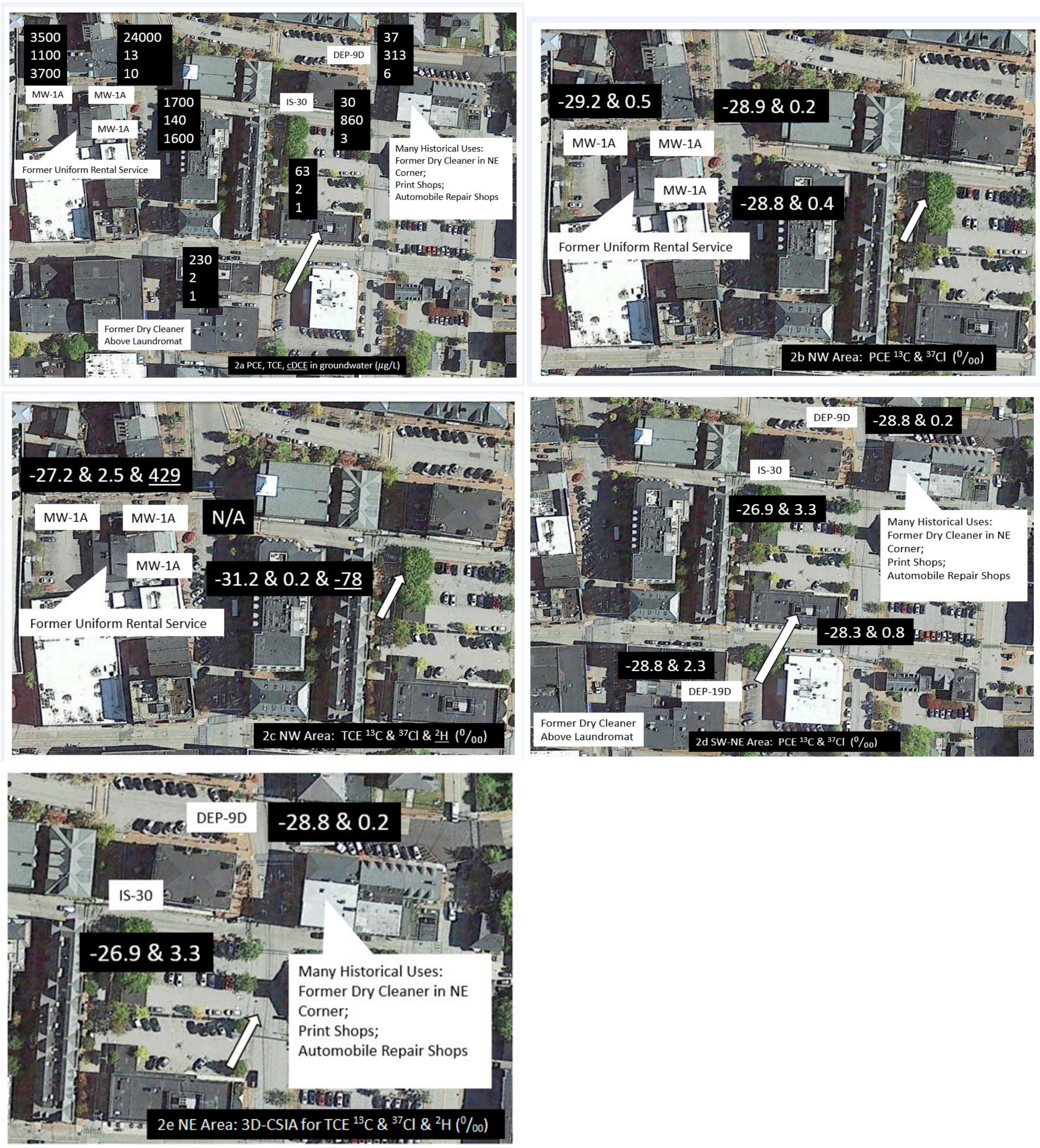
Preliminary Assessment/ Site Background:

No Areas of Concern (AOCs) were identified; however, several potential sources of both PCE and TCE were or had been present within the investigation area. These included dry cleaners, print shops and auto repair shops. The operational history for these facilities was not known.

The investigation area encompassed eight city blocks with mixed commercial and residential use in a downtown area. There were 74 monitoring wells and greater than a hundred screen points tested prior to the 3-D CSIA being performed. The vadose zone and the shallow ground water showed no contamination. All deep ground water samples had detectable levels of chlorinated hydrocarbons, primarily PCE and TCE. The highest concentrations were detected near a former uniform rental service; however, numerous other potential contaminant sources were located in the area.

The source(s) of the ground water contamination in this downtown commercial area were unknown. Given the variety of contaminants, it is likely that there is more than one source. To expedite cleanup and determine PRCRs for remediation, source identification for the constituents detected in the ground water was required.

Figure 1: Site Map: Study Area Showing VOC Concentrations and CSIA Results at Various Locations



Site Investigation/Remedial Investigation:

On-and Off-Site Soils

As this was an area-wide source identification investigation, on-site soil samples were not taken. The focus of the investigation and CSIA sampling was to determine the source of the area's deeper ground water contamination.

On-and Off-Site Ground Water

The original study was designed to help determine area-wide VOC sources over eight city blocks; two distinct VOC sources were confirmed and other potential sources are noted, based on the CSIA results. So, while it is analogous to having on and off-site ground water and is useful as a case study, at the time this study was conducted, there was no identified source "site".

Past and current uses of VOCs are noted, and the location of confirmed and potential sources identified. The study, while it determined that there are unique isotopic signatures from distinct sources, does not provide information on releases that may have occurred at different times (e.g., "overprinting" of PCE from more than one dry cleaning operation) potentially at the same location. Site-specific investigation would be needed to make that determination.

The highest concentrations of PCE, ranging from 1,700 to 24,000 ug/L were detected in the three wells near the former uniform rental service in the northwest portion of the study area (Table 1).

Receptor Evaluation

The area is located in a mixed commercial/residential neighborhood. The lack of contamination noted in the vadose zone and use of a monitored and treated public water supply limited the potential threat to local residents from vapor intrusion and contaminated ground water ingestion.

CSIA Approach and Results

As described in the Compound Specific Isotope Analysis EMD Team Fact Sheet (ITRC, 2011) CSIA measures the extent of isotopic fractionation that has occurred in specific elements. This is possible because isotopes of a given element (e.g., carbon, hydrogen, chlorine as noted in Case Study Figure 1) have the same number of protons and electrons but a different number of neutrons and therefore, a different atomic mass. Each element has a most-abundant isotope (e.g., 12C for carbon) and one or more less-abundant isotopes (13C). The less-abundant isotopes can be heavier and contain one or more extra neutrons. The increased mass leads to isotopic fractionation, and it is the fractionation that is measured by CSIA.

Table 1. The isotopic ratios of PCE, TCE, and cis-1,2-Dichloroethene (cis-DCE) detected suggest multiple releases of PCE and TCE that result from direct release and degradation of PCE.

3D Isotope Ratios Signatures* and Chlorinated Hydrocarbon Concentrations												
		Carbon			Chlorine		Hydrogen		Concentration		
Potential Source	**Sample ID**	cis-DCE ($\delta^{13}C$)	TCE ($\delta^{13}C$)	PCE ($\delta^{13}C$)	TCE ($\delta^{37}Cl$)	PCE ($\delta^{37}Cl$)	cis-DCE ($\delta^{2}H$)	TCE ($\delta^{2}H$)	cis-DCE (ppb)	TCE (ppb)	PCE (ppb)
Former Dry Cleaner	DEP-19D	-	-	-28.8	-	2.3	-	-	<1	2	230
	DEP-14D	-	-	-28.3	-	0.8	-	-	<1	2	63
Other	IS-50'	-	-35.8	-26.9	0.5	3.3	-	128	3	860	30
	DEP-9D	-	-34.8	-28.8	0.5	3.7	-	161	6	313	37
Former Uniform Rental Service	MW-1A	-29.9	-27.2	-29.2	2.5	0.5	292	429	3,700	1,100	3,500
	MW-1C	-	-	-28.9	-	0.2	-	-	10	13	24,000
	MW-1D	-29.7	-31.2	-28.8	0.2	0.4	192	-78	1,600	140	1,700

* Quality analysis and quality control measurements indicated a ± 0.5‰ precision for both carbon and chlorine and ± 5‰ precision for hydrogen.

Derived Signature Value		
Heavy	Light	Neither

Likely Origin of Compound		
Manufactured	Degradation	Both

CSIA data are reported as isotopic ratios, showing the difference in the ratio of the sample relative to the compound-specific international standard. The ratios are provided as "per mil" (parts per thousand, or ‰) values, using the delta (δ) notation, as shown in Table1.
If the carbon isotope δ(13C) for a TCE sample is given as "–31 per mil" (which is typical for undegraded TCE), the 13C to 12C ratio in the sample is 31 per mil, or 3.1 percent, lower than in the internationally agreed-upon standard.

As shown in both Table 1 and Figure 1, the PCE δ(13C) results for the 2b NW area (MW 1A, 1B and 1C), the Former Uniform Rental Service site, are noted as being -28.8, -28.9 and -29.2 per mil; PCE δ(37Cl) results are 0.5, 0.2 and 0.4, respectively. Only 2D CSIA can be done for PCE, as it lacks hydrogen. The TCE 3D CSIA results in this multi-depth MW1 well are shown in Table 1, including hydrogen. The PCE in the wells have similar δ13C and δ37Cl ratios. These concentrations and isotopic ratios are indicative of a major release of PCE from a single source, as are the results for the Former Dry Cleaner Site in 2d SW NE Area. Other potential sources were also identified as shown in Figure 1.

The δ13C measured in TCE at MW-1A is indicative of a manufactured TCE, rather than TCE generated via PCE degradation. The significant difference in the δ37Cl results and the very high δ2H provide additional evidence that there is a manufactured TCE source in this well. The ratios measured for TCE in MW-1D indicate some biodegradation of PCE is occurring. The lighter δ13C, similar δ37Cl, and low δ2H suggest biodegradation of PCE to TCE in MW-1D.

For these samples, the -28.8 sample is isotopically heavier than the other two samples, though not by much. This can be confusing as it is expressed as a negative number; the numbers reflect the heavier isotope content of the sample characterized. Most environmental CVOCs samples will have negative isotope ratios, i.e., they are generally isotopically lighter (or negative), as compared to the selected standards. For example, the carbon standard consists of carbonate (inorganic carbon), which tends to be isotopically heavy compared to the organic carbon compounds of interest at environmental sites.

Resolution Strategy

Multiple chlorinated hydrocarbon discharges were identified that suggested the former uniform rental service and former dry cleaner were primary contributors to the PCE contamination detected, along with other, unidentified TCE sources in the northeast portion of the investigation area. Further study was to be completed in an attempt to identify those sources. The TCE results indicating biodegradation of PCE also provided evidence that in situ bioremediation was a feasible remedial option to consider for the site.

Potential resolution strategies include the establishment of a CEA for any identified discharge sources. CEA plume is commingled with other ground water contamination from unknown sources. The site was reported to NJDEP Hotline as an unknown source and a RAO-A was issued for the off-site source.

Conclusions

Distinguishing between TCE sources and those resulting from TCE discharges versus PCE biodegradation requires 3D-CSIA to be performed. Use of CSIA provided another line of evidence indicating the potential source of contamination. The highest concentrations of PCE were detected in multi-level Well MW-1, which had similar $\delta^{13}C/\delta^{37}C$ ratios, indicating a discharge from a single source, one that could be emanating from the suspected source location. The sample locations and CSIA results are included in Figure 1. The lack of contamination in the vadose zone did not allow for the contamination to be tracked back to a specific source at the surface using this type of analysis alone; further evidence is necessary.

Administrative Considerations

This scenario represents a situation where a separate discharge has been detected on-site; with contaminants migrating on to the site under investigation from off-site location:

An investigation to demonstrate that the contaminants are the result of migration onto the property from an off-site source and the subject site is not a contributor to that contamination is appropriate in accordance with N.J.A.C. 7:26E-3.9, "Site investigation - determination of off-site source of contamination in soil and ground water". This requires a PA, and, if necessary, a SI pursuant to N.J.A.C. 7:26E-3 to determine whether a source of the observed contamination exists on site. See the Department's Off-site Source Ground Water Investigation Technical Guidance.

If the investigation conducted pursuant to N.J.A.C. 7:26E-3.9 or 3.10 **does not** demonstrate that the observed contamination is from an unknown off-site source, and it is the result of a discharge or contributions from an on-site source, then the responsible party is required to remediate the contamination in accordance with N.J.A.C. 7:26C and N.J.A.C. 7:26E.

If the investigation conducted pursuant to N.J.A.C. 7:26E-3.9 or 3.10 **does** demonstrate that the observed contamination is from an off-site source and the subject site is not contributing to that contamination, then the person responsible for conducting remediation or designee should call the NJDEP Hotline (1-877-WARNDEP) and tell the operator, that they are ***"reporting a discharge in soil/ground water/surface water/sediment that is not related to my site under investigation and that the contamination is verified to be from an unknown off-site source."*** and provide the information noted in Section 5.4 of this technical guidance to the NJDEP Hotline operator even if you are not prompted to do so.

The LSRP should then issue an Area of Concern RAO (RAO-A) for the contamination determined to be from an unknown off-site source. The RAO insert "Contamination Remains On-Site due to Off-site Contamination" must also be completed and included within the RAO.

Summarized with permission from the author from *Chlorinated Hydrocarbon-Contaminated Site Investigation with Optimized 3D-CSIA Approach*; Yi Wang, PhD, Zymax Labs in REMEDIATION Spring 2013 and from *3D-CSIA Forensics at the FAMU Law School Site Reveals Multiple Contaminant Sources*, USEPA Technology News and Trends, Issue 52, March 2011.

Case Study Scenario 5

Case Type:	Similar Constituents – Chlorinated Compounds On-site contributions – Possible Off-site Contribution (multiple PRCRs)
Tools Used:	PA/SI/RI, Compound-Specific Isotope Analysis
Resolution Strategy:	Continued Remediation (MNA/CEA) or report as unknown source to Department

Case Type:

A large discharge(s) of TCE had occurred and impacted ground water, resulting in contamination including two "hot spots" (TCE maximum concentration of 390 ppm, likely indicating the presence of DNAPL) and multiple layers of the underlying aquifer being affected.

Tools Used:

Site Background:

The site in question is a large New Jersey Brownfields redevelopment property. The site has been redeveloped as a 443,101-square-foot shopping center. It includes 46.3 acres, with several large anchor stores.

Preliminary Assessment:

Initial sampling and analysis of chlorinated hydrocarbons in ground water were inconclusive regarding the contamination in various zones of the aquifer underlying the site and whether there was one or more sources contributing to the detected impacts. There was evidence that contamination in two zones was from distinct sources, with a third commingled plume being detected in other monitoring wells. Biodegradation potential was also in question based on preliminary results.

Historic aerial photos indicate the site was part of the active operations/runways of a municipal airport prior to being converted to commercial use. A truck and bus manufacturing plant and what remains of the municipal airport are currently located adjacent to the site.

The varied phases and locations of detected contamination indicate there are different sources, types or dates of discharges that have impacted the site. Distinguishing the number and location of contaminant sources had significant impacts on timing and cost of the remediation.

Site Investigation/Remedial Investigation:

On- and Off-Site Soils

This was a source identification investigation focusing on ground water contamination. Soil samples were not discussed in the case study.

On-and Off-Site Ground water

Previous sampling indicated a large discharge of TCE had occurred, with impacts to several zones of the aquifer underlying the site. DNAPL was also suspected to be present, which complicates interpretation of biodegradation processes. No off-site results were specifically noted in the case study; however, the Brownfields site was formerly part of the local airport and is located next to a major manufacturing facility on Route 9.

It was unclear what areas were source zones based solely on TCE concentration data. The CSIA investigation indicated that the isotopic signature for TCE in the upper and lower zone of the aquifer were from different sources. Careful interpretation and additional lines of evidence (e.g., results of MIP sampling) were needed to improve confidence in the results due to presence of DNAPL and varying and sporadic rates of biodegradation at the site.

There is evidence of some biodegradation, as cis-DCE and VC were detected, but at concentrations much lower than that of the parent TCE. TCE was also present in the source zone at concentrations greater than 1% of solubility, so DNAPL was likely present and actively contributing to the plume; therefore, the isotopic ratio of the TCE is not being changed by biodegradation. TCE concentration data were unclear in identifying the TCE sources in the aquifer's upper and lower zones. Figure 1 illustrates the TCE concentration data did not clearly show which locations were on-site sources and which were areas impacted by the upgradient sources. The CSIA results are shown on Figure 1.

The figure shows that the $\delta^{13}C$ of the TCE in UZ-1 and LZ-1 is very similar in both the upper and lower zones, as is the $\delta^{13}C$ of the TCE in UZ-2 and LZ-2. It differs from that in UZ-1 and LZ-1. This indicates that the TCE in UZ-1 and LZ-1 is from a different source than that in UZ-2/LZ-2. That the $\delta^{13}C$ of the TCE in LZ-3 and LZ-4 is between that in UZ-1/LZ-1 and UZ-2/LZ-2, it is suspected those wells don't represent a unique source, but are impacted by both sources.

In other areas of the former airport site where the concentrations were not suggestive of DNAPL and significant degradation was observed, this interpretation was complicated by the variations resulting from the biodegradation. The more extensive the degradation is, the less certain any conclusions involving multiple sources are.

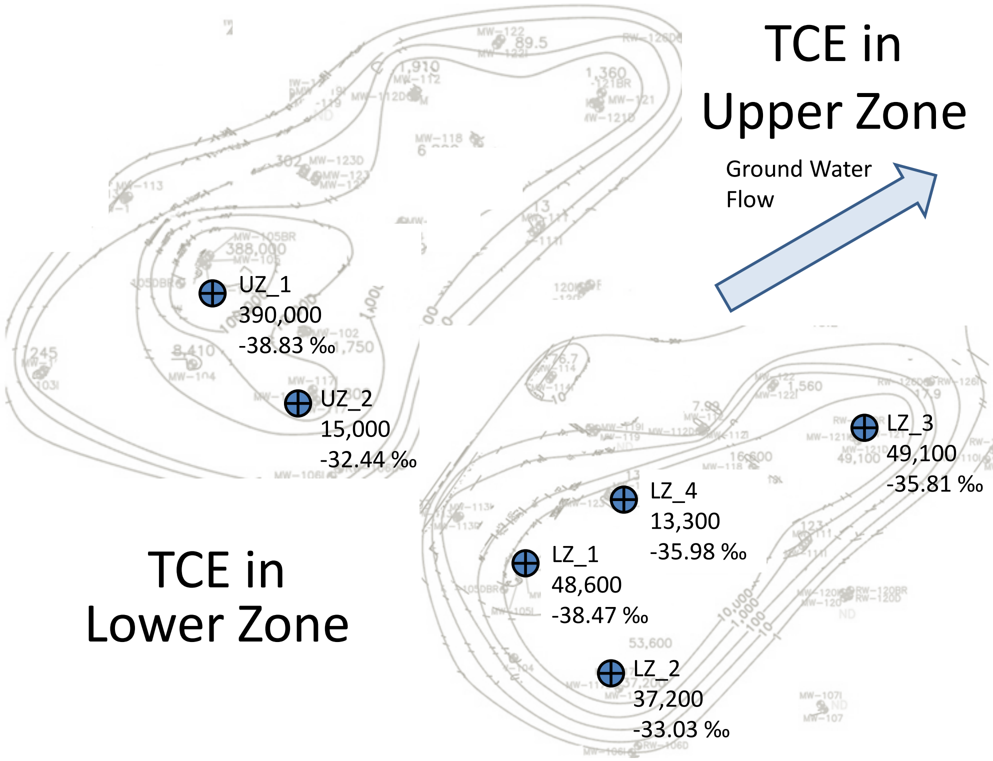


Figure 1 TCE *concentrations and* $\delta^{13}C$ *values for the former airport site, with the upper zone portrayed at the top, the lower zone at the bottom. (Wang, 2013).*

The CSIA investigation was followed up with Membrane Interface Probe (MIP) sampling, which corroborated the CSIA results and provided additional information helpful in distinguishing the suspected multiple sources. The MLE were useful in determining the effectiveness of the biodegradation during remediation of the site.

Receptor Evaluation

A receptor evaluation was not included as part of this case study.

Conclusions:

CSIA showed a significant difference in the $\delta^{13}C$ of the TCE at the two different hot spots. A MIP study confirmed the CSIA data and provided other useful information for the CSM. Combined, these MLE indicated there were two discharges, resulting in impacts to time and costs. Possible resolution mechanisms are identified in Table 1.

Table 1: Conditions and Possible Resolution Mechanisms

Issue	Condition	Resolution Mechanisms
Identify the source(s) of TCE vs. TCE and other VOCs	• Differentiate between sources of TCE using 3-D CSIA and additional lines of evidence	• Proceed with remediation as was funded by insurer • Issue a CEA for any identified discharge sources. CEA plume is commingled with other ground water contamination with unknown sources • Report to NJDEP Hotline as off-site contamination unknown source, NJDEP will investigate further

Adopted from ITRC (Interstate Technology & Regulatory Council). 2013. *Environmental Molecular Diagnostics, New Site Characterization and Remediation Enhancement Tools*. EMD-2. Washington, D.C.: Interstate Technology & Regulatory Council, Environmental Molecular Diagnostics Team. www.itrcweb.org.

Administrative Considerations

Several administrative paths would be necessary at this site. The on-site discharge must be reported to the Department and remediated in accordance with N.J.S.A. 58:10B-1.3, 7:26C and 7:26E. The PRCR must also submit a CDN Form to the Department [N.J.A.C. 7:26C- 1.7(d)] within 14 days of calling the NJDEP Hotline to report the new discharge. The PRCR must also retain an LSRP to complete an investigation associated with the on-site discharge.

Where the MLE indicate a potential off-site source for a separate discharge that was detected on-site; with contaminants migrating on to the site under investigation from off-site location, the administrative resolution will be similar to that for Case Study # 4 above. An investigation to demonstrate that the contaminants are the result of migration onto the property from an off-site source and the subject site is not a contributor to that contamination as described in "Site investigation - determination of off-site source of contamination in soil and ground water" (N.J.A.C. 7:26E-3.9). This would include a PA, and, if necessary, a SI to determine whether a source exists on the site.

If the investigation demonstrates the observed contamination is from an off-site source and the subject site is not contributing to the contamination, then the person responsible for conducting remediation or designee should call the NJDEP Hotline (1-877-WARNDEP) and tell the operator, that they are "reporting a discharge in soil/ground water/surface water/sediment that is not related to my site under investigation and that the contamination is verified to be from an unknown off-site source." and provide the information noted in Section 5.2 of this technical guidance to the NJDEP Hotline operator even if you are not prompted to do so.

The LSRP should then issue an Area of Concern RAO (RAO-A) for the contamination determined to be from an unknown off-site source. The RAO insert "Contamination Remains On-Site due to Off-site Contamination" must also be completed and included within the RAO.

If the investigation does not demonstrate that the observed contamination is from an off-site source, and emanates from an on-site source, then the PRCR is required to remediate the contamination.

Case Study Scenario 6

Case Type:	Offsite Source Contamination Scenario – Different Sources / Different Compounds of Concern
Tools Used:	SI/RI, with subsequent PA Conceptual Site Model NJDEP HazSite Database
Resolution Strategy:	Working with a responsible entity and completing work independently.

Case Type

The investigator is responsible for remediation of a former heating oil UST at a mixed-use retail/office building (Retail/Office Complex ABC). During the course of ABC's investigation, the ground water data indicated the presence of a compound that is not typically associated with heating oil. This case study will outline the steps necessary to pursue regulatory closure for a site using data obtained from the onsite investigation and data obtained from the NJDEP HazSite Database to develop the necessary MLE to facilitate regulatory case closure. This example can be applied to any site and contaminant, provided that the appropriate lines of evidence are documented.

Tools Used

Site Investigation/Remedial Investigation

During the removal of No. 2 heating oil UST, a discharge of heating oil was identified and the NJDEP Spill Hotline was notified. A soil excavation program was implemented to remove the heating oil source material in the overburden soil, which was confirmed to be sufficient based upon the collection of post-excavation soil samples. However, the excavation extended to the top of the water table, and therefore, a requirement to initiate a ground water investigation was triggered pursuant to the Technical Requirements for Site Remediation.

A single monitoring well was installed within the UST excavation area and sampled for VOCs/SVOCs + TICs. Laboratory results confirmed the absence of any VOCs/SVOCs above NJDEP standards with the exception of naphthalene and PCE (at 150 ppb and 10 ppb, respectively). Four additional monitoring wells were subsequently installed to confirm ground water flow direction and which also confirmed that the extent naphthalene was delineated to below standard in accordance with NJDEP requirements. The well network for the Site included one source area well; three plume delineation wells and one vertical delineation well. Ground water flow was documented to be towards the north.

However, the concentration of PCE was variable (ranging from 10 ppb to 25 ppb) and above the NJDEP standard for PCE of 1 ppb in three of the four wells installed as part of the RI activities. Additionally, based upon the placement of the monitoring wells at the Site, there were no monitoring wells located at or immediately proximate to the upgradient property boundary of the subject boundary for the Site. Accordingly, a commingled plume was documented to exist on the ABC property.

Preliminary Assessment

Although it is well understood that PCE is not a compound that is associated with No.2 heating oil, additional assessment of the Site was needed to satisfy NJDEP requirements (see Technical Requirements for Site Remediation N.J.A.C. 7:26E-3.9 and NJDEP's Off-Site Source of Ground Water Investigation Document). In particular, a PA was completed which documented that the property had only been utilized for retail/commercial and office purposes; in particular, there was no former dry cleaning establishments or any other manufacturing operations known to ever exist at the subject Site.

Additionally, as part of the PA activities, the investigator reviewed the NJDEP's Dataminer database and identified the presence of an active SRP Site (XYZ Corporation) in the area of the ABC property. While there was no existing Ground Water CEA established for the XYZ Corporation Site, the site was listed as a Site with a Remedial Level of C3: Multi-Phased RA - Unknown or Uncontrolled Discharge to Soil or Ground Water. The investigator contacted the LSRP for XYZ Corporation who advised that the site had not yet completed the Remedial Investigation but that several reports had historically been submitted to the Department that included ground water sampling results; the LSRP also indicated that ground water flow for the XYZ Corporation site was to the north, which is similar to the ground water flow documented at the ABC property.

NJDEP HazSite Data

Based upon the additional information obtained as part of the PA, the investigator contacted the NJDEP to inquire about the availability of HazSite EDD data associated with the XYZ Corporation Site (see Appendix E). The NJDEP was able to provide ground water sampling data for PCE and several other VOCs associated with the XYZ Corporation Site, including X-Y coordinate in the North American Datum 1983 (NAD83) for each sampling location. The investigator utilized the information/data and was able to plot the XYZ sampling results on a figure that clearly depicted the presence of PCE present at the upgradient XYZ Corporation Site at concentration similar to those identified in the ground water at the ABC Site. This information eliminated the costs and additional time that would have been needed to install additional wells either at the upgradient property boundary or at an off-site location to adequately document the presence of an off-site source of PCE that is commingled with the on-site naphthalene plume.

Conceptual Site Model (CSM)

The investigator developed and continually refined an AOC CSM for the ABC Site. Following the removal of the primary and secondary source of contamination (i.e.., the former heating oil UST and associated impacted soil); the investigator identified and delineated the presence of a fuel oil constituent (naphthalene) plume associated with the former heating oil UST. The investigator also identified the presence of PCE in ground water at the Site. PCE is not a compound associated with heating oil. Information from a PA indicated that the current and historical use of the ABC property did not involve operations or activities that would have utilized chlorinated solvents, specifically PCE.

A well search was completed that confirmed the absence of any potable well or ground water use receptors in the vicinity of the Site. No on-site or nearby surface water bodies or ecological receptors were identified. Additionally, the concentration of site-related compounds of concern were all below the NJDEP vapor intrusion screening levels, confirming that the vapor intrusion pathway is not a concern at the site. A case closure strategy of monitored natural attenuation was selected as an acceptable approach for the Site.

Resolution Strategy/Conclusion

The investigator has developed a commingled plume CSM with strong MLE identifying ground water contamination associated with an adjacent upgradient source. The tools used to develop the CSM/MLE included SI and remedial investigation data, a PA and the use of NJDEP HazSite data from an adjacent SRP Site. The information was evaluated in an iterative process, where the CSM was continually updated as additional information was obtained. Based on above, the investigator is confident in the CSM and the fact that a commingled plume condition in exists. However, only one of the two compounds (e.g., naphthalene) present in the plume is associated with the heating oil discharge at the Site.

The presence of PCE, commingled with the naphthalene plume, was documented to be from an off-site source, but this was accomplished in timely and cost-effective manner without the need for additional wells either off-site or at the upgradient property boundary using data obtained from the NJDEP HazSite EDD database. Accordingly, the investigator then followed the NJDEP administrative guidance and contacted the NJDEP Hotline to document the presence of an off-site impact of PCE; this then allowed for regulatory closure of the PCE issue at the site and the use of an MNA case closure strategy for the former heating oil UST AOC.

Administrative Considerations

This scenario represents a situation where a separate discharge of different constituents has been detected commingling on the subject property (ABC). The source of the separate discharge is a known contaminated site (XYZ) and ABC has concluded through MLE that PCE is not a compound of concern for its site. However, because the offsite up gradient impacts have been detected on the ABC property as part of the ABC investigation, the investigator is required to report to the NJDEP Hotline that PCE was detected in ground water (on-site and downgradient off-site) that is not related to the site under investigation. During the Hotline notification call, the investigator should include reference to the XYZ site because the data from that site was utilized as part of the investigation of the ABC site.

ABC continued to complete a MNA sampling program to collect the necessary data to demonstrate that the concentration of naphthalene will continue to ultimately degrade to NJDEP standards. When the RIR is submitted, the CEA for the ABC site only includes naphthalene, but reference is included in the RIR regarding the presence of PCE from an offsite source. Once the necessary MNA data has been collected, ABC would submit a Remedial Action Report, Remedial Action Permit for Ground Water Application, and once the NJDEP issues the Permit, the LSRP would issue the limited restricted use RAO that includes an off-site source and commingled plume notice (see Section 5.6 above) will be issued for the ground water until ground water meets the Department's GWQS.

Appendix B

Statistical Analysis

Appendix B
Statistical Analysis

In many situations, statistical approaches can assist in evaluating data Statistical approaches can include techniques allowing for the comparison of data (e.g., to determine where contamination concentrations are higher); multivariate techniques that provide information about patterns in data sets that we would not otherwise see; and geostatistical methods that help elicit spatial distributions or patterns in the data set of interest.

Stochastic methods that can be utilized to identify contaminant sources include, but are not limited to kriging, Monte Carlo, Minimum Relative Entropy (MRE) and Bayesian inference methods. Using an expert in stochastic modeling is recommended to conduct the work and characterize the environmental impacts of the contaminant plume(s) and source(s).

Stochastic methods utilized in real life case studies are identified below:

- Kriging and Monte Carlo methods were utilized to address ground water and/or soil contamination over a region from observations of the contaminant for an Air Force Base in Eglin, Florida and a site near Phoenix, Arizona (EPA, 2000).
- MRE and Bayesian inference were applied to estimate the contaminant discharge history from the Gloucester Landfill site in Ontario, Canada (Michalak & Kitanidis, 2002)
- A Bayesian inference approach was used to estimate the history of contamination in an aquifer located at the Dover Air Force Base, Delaware (Michalak & Kitanidis, 2004)

The benefits, costs and applicability of various statistical methods should be considered to determine if they would be useful to characterize a commingled plume.

The NJDEP Monitored Natural Attenuation (MNA) Technical Guidance, dated March 1, 2012 includes additional information on use of statistics (i.e., 6.1.3 Statistical Tests, http://www.nj.gov/dep/srp/guidance/#mon_nat_atten) that can be considered for use for commingled plume analysis as well. The NJDEP Ground Water SI/RI/RAW -Technical Guidance also includes information on statistical analyses (http://www.nj.gov/dep/srp/guidance/#pa_si_ri_gw).

These statistical procedures and models can provide a formal, quantitative method for assessing the relationship of sample measurements to characteristics of the sampled system, for using sample data to make decisions and for predicting future states of the sampled system. The need for application of statistical tests and the nature of the tests will vary as a function of site-specific conditions and data analysis requirements (e.g., identifying trends or determining background).

Statistical procedures are often used to evaluate the variability associated with data, and to use estimates of variability to guide decision making processes. For example, if multiple analyses are performed, statistical procedures can be used to express a measure of the analytical variability associated with contaminant concentrations, analyze and compare trends by considering data variability through time. These analyses can be used to calculate attenuation rates, as well as the variability associated with those rates.

Monitoring data subject to regression or trend analysis and other statistical tests can demonstrate an increasing, decreasing or constant plume. These can provide a high level of confidence that the plume and therefore, the associated risk of migration and contamination are decreasing. An increasing plume may require additional investigation or monitoring.

Consistent characteristics throughout a plume provide a higher level of confidence that the behavior of the plume is understood. This involves evaluating the trend of multiple sampling locations with multiple observations. Confidence is lower when plume monitoring wells exhibit different trends, or when characteristics are not consistent across relevant monitoring wells.

There are limitations using statistical analysis with a small number of data sets. Where trend analyses tests are appropriate, regression analyses, Mann Kendall Test, Mann-Whitney U Test, and the Sen's non-parametric test for the slope of a trend can be applied. Below is a short synopsis of these methods. Additional information on the selection of statistical methods and more details on the statistical tests are provided in the MNA guidance.

- **Linear and exponential regression analysis:** Provides estimate of the functional relationships (i.e., determine variables influencing concentration values), identifies the rate of concentration change, and forecasts future concentrations. A minimum of 8 to 10 measurements are generally necessary to compute a linear regression. Nonlinear regression models (e.g., exponential, logarithmic, polynomial, moving average) can be applied to predict the data trends. These utilize a form of data transformation to provide a more accurate fit for the regression line. Exponential regression is commonly utilized to analyze attenuation of petroleum compounds in the environment.
- **Mann-Kendall: Plume Trend Analysis:** A non-parametric test to determine linear trend analysis based on the idea that if an increasing trend exists in a data set, the sample taken first from any random pair of measurements should have a lower concentration than the measurements collected later on. A positive statistical value represents an upward trend. Values around 0 indicate the lack of a trend. A Seasonal Kendall Test can be used to address seasonal fluctuations.
- **Mann-Whitney U:** A statistical test based on the theory that for two samples drawn from the same population, the probability of the first sample being larger than the second sample is 0.5, and if these comparisons do not "average out" to approximately 0.5, then it is likely

that factors affecting the two samples are not the same. A specific adaptation of the Mann-Whitney U test (Mann and Whitney, 1947) to determine ground water data trends has historically been used by the Department, using eight consecutive quarterly events.

- **Sen Test**: A nonparametric estimator of trend robust to outliers, missing data, and non-detects, which can be used with small sample sizes (minimum of eight) and calculating the slope as a change in measurement per change in time. This allows determination of whether the median slope is statistically different from zero and development of a confidence interval for the data set.
- **Principal Component Analysis (PCA):** Multivariate statistical analysis is used more and more in the environmental field, with PCA, which helps to analyze numerous variables to explain the reasons for the variance in a data set, thereby identifying patterns and relationships in the data that would otherwise remain unseen. PCA is being used most often to determine the relationships in concentration and distribution, for example, between VOCs in a plume. Partial Least Squares analysis, a type of co-variance-based Structural Equation Modeling (SEM) can also be used to measure the amount of variance and apportion contributions from different sources in a commingled plume and other environmental settings. Multi-Dimensional Scaling (MDS), Factor Analysis (FA), Cluster Analysis (CA) and Discriminant Analysis (DA) methods are also available, among others.
- **Geostatistics:** Geostatistical methods are used to correlate and interpret data spatially, e.g., in developing a contour plot. Examples include variogram analysis and kriging, which is used to express temporal or spatial differences in data. Anisotropy methods can be used along with kriging to assign a specific weighting factor to data with a spatial variation to visualize actual conditions.
- **Factor Analysis:** Factor Analysis has been applied to the assessment of ground water quality and ground water contamination investigations. This technique can also be used to determine whether there are significant statistical differences between various data sets and identify commingling of contamination from different sources.

  Principles of Factor Analysis can be learned from any standard statistics text book. Factor Analysis is a multivariate statistical technique and provides a general relationship between measured concentrations and other measured variables by showing multivariate patterns that may be of help in grouping the original data. The first step in the Factor Analysis is to standardize the data. (see Table 2). The standardization procedure tends to increase the influence of variables whose variance is small, and reduce the influence of variables whose variance is large. Furthermore, the standardization process also eliminates the influence of different units of measurements and makes the data dimensionless.

  Factor Analysis rearranges the data into a correlation coefficient matrix (see Table 3 in the example) which measures how well the variance of each constituent can be explained by relationships with each of the others. Then Eigenvalues and Eigen vectors are calculated for the covariance matrix (see Table 4 in the example). Then the data are transformed into Factors (see Table 5 in the example). Each Factor is associated with a certain percentage of the variance. These values are summed to express as a cumulative Eigen value and percentage of variance, respectively. The number of factors extracted is to be determined based on the site complexity and the processes that influence the contaminant concentrations. Generally, Factors with Eigen values that exceed one are retained for interpretation. The rotation (Varimax rotation scheme) of the factor axis is performed to yield a simple structure with factors that are marked by high loadings for some variables and low loadings for some others. The factor loadings (Table 5 in the example) correlate factors and the variables. They represent the most important information on which the interpretation of factors is based. Then, the contribution of each factor at every sampling point is calculated (see Table 6 in the example). These are called factor scores. Factor scores are projections of data onto corresponding Eigen vectors. The grouping of the sampling locations based on factor score can provide insight into the sources of contamination. The factor scores are generally plotted to visualize the spatial distribution patterns for interpretations. The interpretations based on the factor analysis are subjective and should be corroborated by other lines of evidence.

The following tables are included as examples of the output of the Factor Analysis and these are excerpted from Chen-Wuing Liu, et al., 2003.

Table 2
Data matrix for 28 groundwater sample concentrations [in mg/l, except for E.C. (μS/cm) and As (μg/l)]

No.	E.C.	Alk	TDS	Cl^-	$SO4^{2-}$	$NO3^-$–N	TOC	Na^+	K^+	As	Mg^{2+}	Ca^{2+}	TH
#1	2390	482	1676	399	218	0.21	1.53	259	41	3.4	72	119	593
#2	39 500	387	35 140	13 789	1813	0.52	2.05	9104	494	17.6	1413	61	5971
#3	22 900	395	18 620	7713	345	0.25	1.16	4255	207	61.0	873	541	4946
#4	14 660	384	11 890	4594	255	0.18	1.07	2275	117	24.9	342	242	2011
#5	808	378	566	37	18	0.40	1.07	43	9	5.4	52	68	384
#6	15 310	539	12 500	4914	680	0.80	3.00	2655	138	245.0	197	58	565
#7	2760	650	1932	540	100	0.00	3.89	333	41	226	102	59	2699
#8	27 200	359	23 360	9109	1502	0.25	0.71	4470	169	7.0	620	243	636
#9	3010	756	2210	414	270	0.90	18.03	646	33	558.0	7	2	3373
#10	36 700	318	32 020	12 642	2029	0.45	0.53	5690	266	7.9	818	368	919
#11	1112	421	778	103	0	0.00	1.97	131	42	90.4	25	17	147
#12	18 130	400	14 700	5722	990	0.28	0.87	2550	91	36.4	284	282	1874
#13	8740	368	6810	2522	527	0.0	0.84	1642	91	20.0	286	291	1904
#14	1522	488	1065	115	192	0.98	1.82	234	16	31.8	15	12	93
#15	9220	456	7200	2621	611	0.24	1.50	1296	49	2.3	210	271	1541
#16	1523	444	1066	63	434	1.07	0.64	48	5	1.7	64	237	855
#17	2630	336	1841	552	171	6.37	0.78	324	20	4.2	30	146	488
#18	1564	346	1095	105	677	0.0	1.01	81	16	8.5	75	173	738
#19	11 970	566	5855	3747	265	0.23	3.48	2760	93	28.2	265	97	1331
#20	1427	366	998	72	325	0.0	0.92	64	4	4.9	43	207	693
#21	969	279	678	59	181	0.12	1.80	73	12	7.2	43	62	332
#22	568	266	398	5	37	0.28	1.45	43	4	255.0	18	56	213
#23	525	266	368	6	24	0.72	0.48	34	16	11.4	30	21	176
#24	528	258	370	13	25	0.24	0.91	56	2	19.9	11	57	188
#25	853	451	597	9	3	1.67	3.13	136	33	113.0	21	11	111
#26	447	248	313	5	0	0.0	1.28	51	2	66.6	6	33	107
#27	663	364	464	13	31	1.89	3.50	28	38	21.9	15	63	219
#28	758	334	531	37	6	6.36	3.33	64	12	46.0	17	66	237

on coefficients for hydrochemical data in Yun-Lin coastal area, Taiwan

Alk	TDS	Cl^-	SO_4^{2-}	NO_3^-–N	TOC	Na^+	K^+	As	Mg^{2+}	Ca^{2+}	TH
−0.002	0.996	0.999	0.897	−0.188	−0.135	0.977	0.933	−0.136	0.943	0.535	0.606
1.000	−0.034	−0.025	−0.037	−0.101	0.703	0.025	0.026	0.627	−0.050	−0.142	0.358
	1.000	0.997	0.909	−0.178	−0.141	0.972	0.939	−0.135	0.946	0.517	0.600
		1.000	0.894	−0.182	−0.146	0.979	0.939	−0.145	0.948	0.521	0.600
			1.000	−0.194	−0.139	0.851	0.803	−0.167	0.801	0.457	0.414
				1.000	0.067	−0.176	−0.156	−0.049	−0.190	−0.150	−0.191
					1.000	−0.090	−0.078	0.848	−0.157	−0.339	0.284
						1.000	0.979	−0.113	0.973	0.427	0.687
							1.000	−0.098	0.970	0.345	0.716
								1.000	−0.183	−0.336	0.226
									1.000	0.507	0.745
										1.000	0.379
											1.000

Table 4
Eigenvalues, percent of variance, cumulative eigenvalue, cumulative percent of variance for the factor analysis of hydrochemical data in Yun-Lin coastal area, Taiwan

Factor	Eigenvalue	Percent of variance	Cumulative eigenvalue	Cumulative percent of variance
1	7.4245	57.1113	7.4245	57.1113
2	2.6908	20.6987	10.1153	77.8100
3	0.9958	7.6598	11.1111	85.4698
4	0.7346	5.6505	11.8456	91.1202
5	0.5048	3.8831	12.3504	95.0033
6	0.3675	2.8270	12.7179	97.8303
7	0.1506	1.1583	12.8685	98.9886
8	0.0905	0.6962	12.9590	99.6848
9	0.0220	0.1695	12.9810	99.8542
10	0.0100	0.0770	12.9911	99.9312
11	0.0082	0.0627	12.9992	99.9939
12	0.0007	0.0056	12.9999	99.9995
13	0.0001	0.0005	13.0000	100.0000

Table 5
Loading for varimax rotated factor matrix of two-factor model explaining 77.8% of the total variance

Variable	Factor 1	Factor 2
E.C.	0.9844[a]	0.0619
Alk	0.0454	−0.8449[a]
TDS	0.9830[a]	0.0736
Cl^-	0.9835[a]	0.0757
SO_4^{2-}	0.8786[a]	0.1120
NO_3^-–N	−0.2287	0.0626
TOC	−0.0883	−0.9349[a]
Na^+	0.9849[a]	0.0021
K^+	0.9603[a]	−0.0233
As	−0.1040	−0.9025[a]
Mg^{2+}	0.9755[a]	0.0703
Ca^{2+}	0.5379	0.3321
TH	0.7183	−0.4109
Eigenvalue	7.3967	2.7186
Variance	0.5690	0.2091

[a] Absolute loading values >0.85.

Table 6
Scores for the two-factor model

Well no.	Factor 1 (seawater salinization)	Factor 2 (arsenic pollutant)
#1	−0.4405	0.0774
#2	3.1970	−0.3992
#3	1.5765	0.0676
#4	0.4596	0.2755
#5	−0.6538	0.3759
#6	0.3949	−0.9238
#7	−0.2764	−1.5267
#8	1.3855	0.6484
#9	−0.2174	−4.3250
#10	2.1895	0.8733
#11	−0.6389	−0.1019
#12	0.7079	0.3195
#13	0.2362	0.4184
#14	−0.6328	−0.0680
#15	0.1415	0.2050
#16	−0.4302	0.3830
#17	−0.6225	0.6847
#18	−0.3940	0.5353
#19	0.2026	−0.5285
#20	−0.4843	0.5209
#21	−0.6308	0.5594
#22	−0.7071	−0.0459
#23	−0.7269	0.7053
#24	−0.7219	0.6823
#25	−0.6906	−0.3371
#26	−0.7452	0.5239
#27	−0.6772	0.1428
#28	−0.8007	0.2574

APPENDIX C

Environmental Forensic Techniques

Appendix C

Environmental Forensic Techniques

Table of Contents

1.0 Introduction

As discussed in this technical guidance, investigators (in some scenarios) may be required to employ environmental forensic techniques to evaluate commingled plume conditions and establish the MLE necessary to achieve a RAO. Environmental forensics techniques are most commonly used to determine or assist in determining the age of contamination and potential source(s). The age and source of contamination should be considered critical lines of evidence in any commingled plume CSM.

The following provides a brief summary of environmental forensic techniques as they apply to petroleum hydrocarbon and chlorinated volatile organic compounds (CVOCs). The environmental forensic field is constantly evolving and requires an elevated level of experience and expertise to properly implement the techniques and evaluate the results. For this reason, it is recommended that investigators seek out appropriate personnel/consultants and employ a tiered approach tailored to the site conditions and complexities.

2.0 Petroleum Hydrocarbon Pattern Recognition via Fingerprinting

Hydrocarbon pattern recognition, commonly referred to as "GC Fingerprinting" or petroleum hydrocarbon fingerprinting, is a qualitative technique used to identify fuel types (gasoline, diesel/No. 2 heating oil, No. 6 heating oil, etc.) of an unknown product. Fingerprinting analysis is conducted on light non-aqueous phase liquid (LNAPL) or sheen samples collected in the environment. The LNAPL/sheen sample is typically analyzed using gas chromatography-flame ionization detector (GC/FID), which reveal the relative mass of various carbon chained constituents within the sample (typically ranging from C3 to C40). The analysis results are displayed as mass chromatographs, which are qualitatively evaluated to identify components of the LNAPL. investigators should be aware that some laboratories are equipped to conduct fingerprint analyses using varying equipment and to a much higher degree of certainty. The investigator should select, or consult with someone knowledgeable to ensure the appropriate laboratory and laboratory method is selected.

Mass chromatographs from LNAPL/sheen collected in the environment can be compared to mass chromatographs of known standards for various fuels (diesel, gasoline, jet fuels, marine fuel, and kerosene), which have their own distinct chromatographs. Examples of standard mass chromatographs are provided as Figure 1.

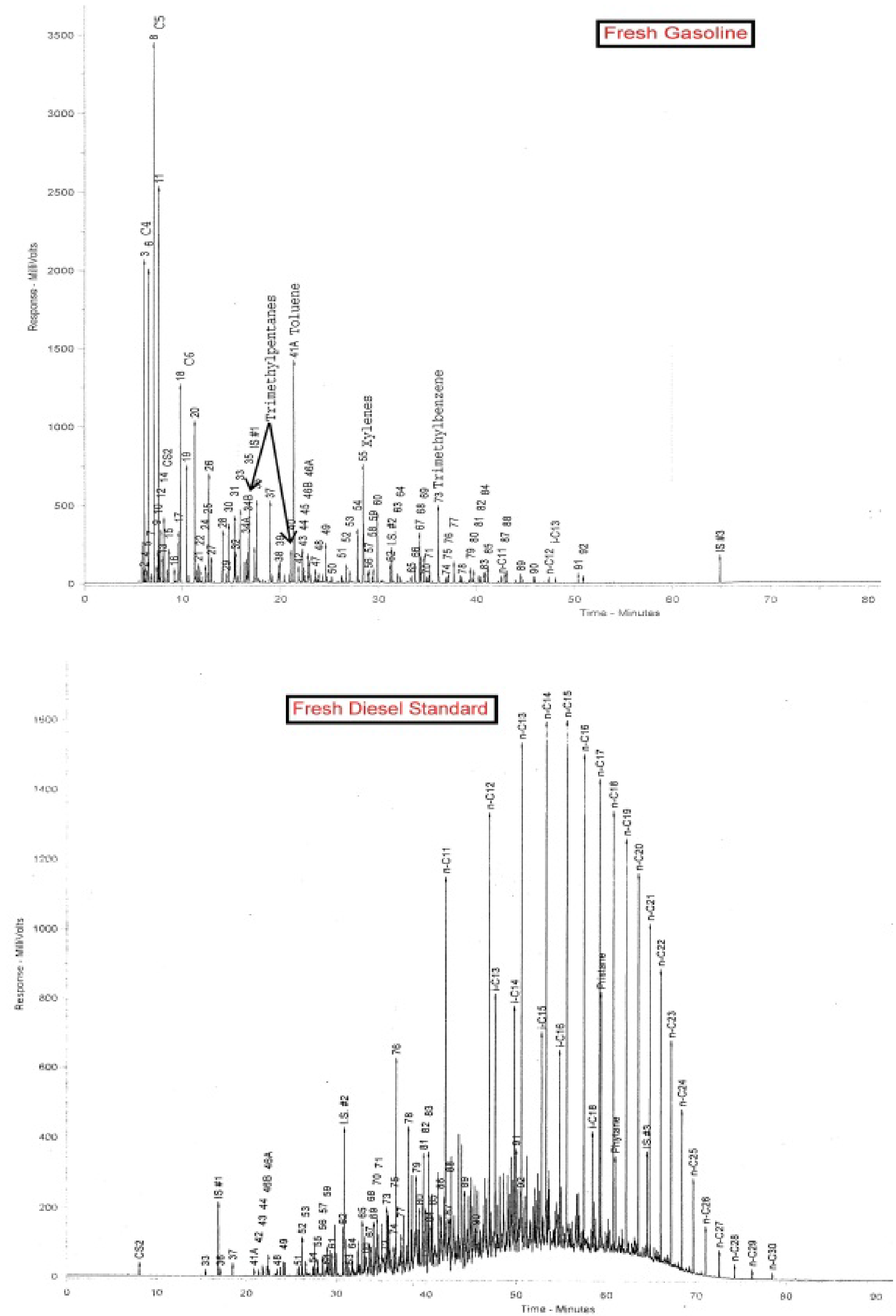


Figure 1: Standard Mass Chromatographs for Fresh Gasoline and Diesel [Courtesy of Pace Analytical (Forensics 101, 2014)].

Based on this comparison, the type of fuel present in the environment can be identified. Samples collected from the environment after recent/fresh single source discharges will generally match the standard chromatographs and can be evaluated with a high degree of certainty. Due to the effects of weathering and degradation, evaluations of chromatographs from historic discharges or in the case of product mixtures become much more difficult and conclusions are typically less certain. An experienced reviewer will be required to properly decipher and evaluate the results in these situations.

A second common approach is to compare mass chromatographs of two samples collected from the environment (or from a spill area and a suspected source, for example a UST) to determine the presence of different products and/or the presence of fresh versus weathered product. This technique is limited in its ability to differentiate the origin of similar products found in the environment due to the variability products, particularly for petroleum products.

Laboratory fingerprinting may also provide a qualitative estimate of age range (i.e., fresh, ~ 10 years old, > 10 years old, etc.) that can be used as a line of evidence. An investigator should be cautious with this technique, however due to the variability of crude feedstock and product weathering is dependent on a multitude of environmental factors including but not limited to; anaerobic/aerobic conditions; soil texture; and the amount of product present; (Morrison, 2000b). A qualitative age range, along with additional lines of evidence regarding the site environmental conditions, the condition of the contaminant source (i.e., UST condition), site history, and the extent of contamination can be used to strengthen/validate an age-date opinion. Oudijk, 2009a and 2009b discuss an approach where MLE are utilized to "age-date" No. 2 Fuel Oil in New Jersey.

3.0 Petroleum Hydrocarbon Pattern Recognition via PIANO Analysis

Many forensic investigators (Forensics 101, 2014 A. Davis, et. al, 2005, Galperin and Kaplan, 2007, Petrisor, 2005, Stout, et. al, 2010, Oudjik, 2005, 2009a, 2009b) discuss the use of a more quantitative hydrocarbon pattern technique called PIANO. PIANO analysis evaluates the relative percentage of 5 general categories of petroleum constituents – **P**araffins, **I**soparaffins, **A**romatics, **N**aphthalenes, and, **O**lefins. The PIANO approach evaluates the percentage of the constituent groups to known percent distributions to standards for various fuels and, in the case of gasoline, fuel grades. PIANO analyses can also be used to evaluate two samples collected from the environment (from spill areas and/or suspected source areas). The result of PIANO analyses from multiple samples is typically graphically illustrated in histograms or star diagrams where the relative percentage of each group can be quickly compared.

A star diagram illustrating the results of differing fuels (e.g., gasoline to aviation fuel), can quickly be identified. While gasoline from various feed stock and refineries will have inherent compositional differences, gasoline will stand out when compared to other fuels. The differences inherent in gasoline, as mentioned in previous sentence, can also be identified via PIANO analyses (e.g., the identification of differing gasoline grades).

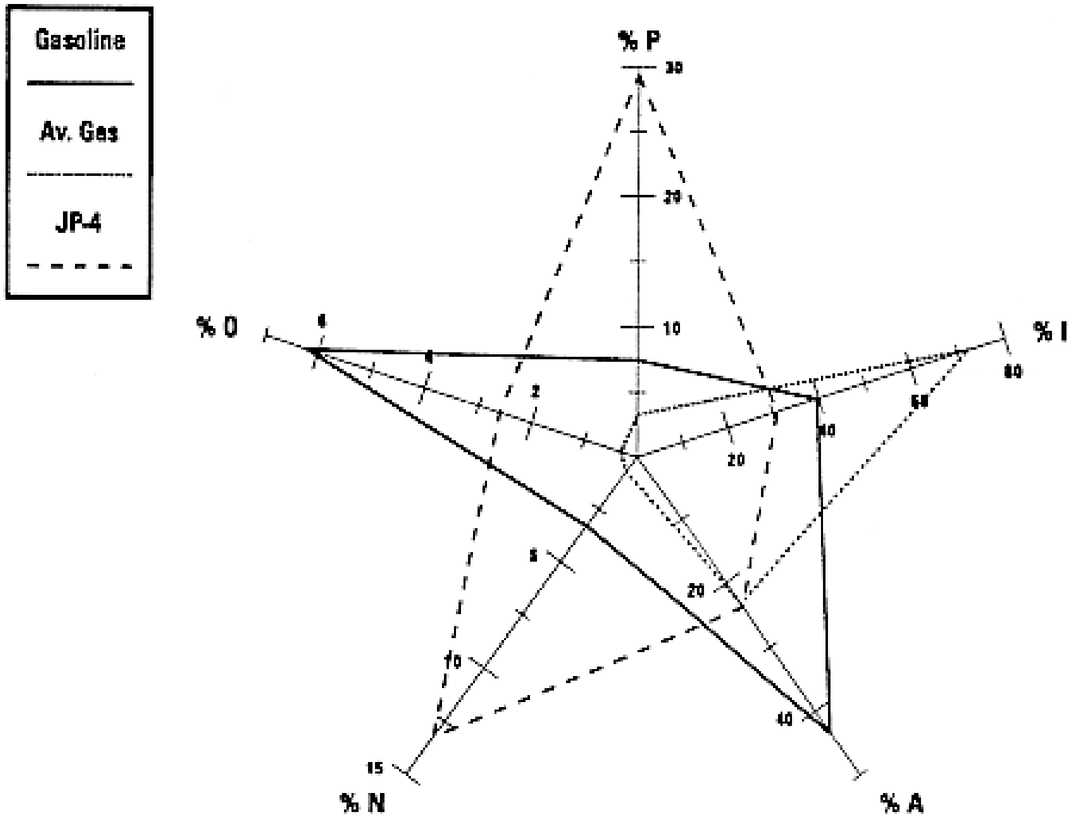


Figure 2: PIANO results illustrated in a Star Diagram to differentiate fuel types (gasoline, aviation gas, jet fuel).

In comparison to GC Fingerprinting, PIANO analysis provides a way to correct for weathering effects such as evaporation, water washing, biodegradation, as category groups are more or less susceptible to various forms of weathering. The evaluation of PIANO groups when compared to multiple samples or standard fuel distributions provides a more quantitative analysis and account for the effects of weathering. In general terms, the investigator can account for weathering evaluating target analyte ratios from the PIANO analysis. For example,

Weathering Process	Example Constituent Ratio
Evaporation	n-Pentane/n-Heptane
Waterwashing	Benzene/Cyclohexane
Biodegradation	3-Methylhexane/n-Heptane

Hydrocarbon pattern recognition analysis (GC Fingerprinting or PIANO) techniques will assist in identifying or confirming the age and presence of differing fuel types (gasoline, diesel/No. 2

heating oil, No. 6 heating oil, etc.) of an unknown product. Utilized properly, these techniques can provide strong MLE.

4.0 Tracer Compounds (Additives)

Unlike the pattern recognition techniques discussed above, which can only be applied to petroleum hydrocarbons, trace compound or additives identification have application to both hydrocarbons and CVOCs.

With regard to hydrocarbons, petroleum fuels have distinctive compositions of numerous compounds based on its crude feedstock, refining methods, and additives, therefore can be used to distinguish and differentiate products in the environment and/or source areas. The differences in feedstock and refining techniques are typically identified in the GC Fingerprinting methods previous discussed. However, the additives to petroleum fuels, which have well documented changes over time due to engine design and regulatory mandates can be used to establish MLE. This is the case particularly for gasoline. Example of gasoline additives are provided below (DPRA, 2006).

Additive Purpose	Tracer Compound(s)	Timeline
Antiknock	Tetraethyl Lead (TEL)	exclusively until 1960 varying usage 1960-1980 most common again post 1980,
	Tetramethyl Lead (TML)	1960 – 1980
Lead Scavengers	Ethylene dibromide (EDB)	Introduced in 1920's
	Ethylene dichloride (1,2 DCA)	
Oxygenates	Methyl Tertiary Butyl Ether (MTBE)	late 1970's – early-2000's
	Tertiary Butyl Alcohol (TBA)	
	Ethanol	Early 2000's to present

Based on the above, the investigator can utilize the history of petroleum fuel additives to target trace compounds during an investigation to distinguish the age and source of an unknown product found in the environment. However, in many instances the presence of the additive only provides part of the information. Regulatory mandates required the Lead content of gasoline to be reduced over time, therefore Lead, which ranged from 3 to 4 g Pb/gal from the 1920's to the 1950's; was reduced to 0.5 g Pb/gal by 1985; and 0.1 g Pb/gal in 1988. Knowledge of the presence of these additives, but also the regulatory mandated concentrations could be used to further establish MLE.

Furthermore, knowledge of the characteristics of the additives compounds can also provide a line of evidence. The classic example is MTBE, which has a low octanol/water coefficient, high solubility, low retardation, and limited biodegradation. For these reasons, MTBE was typically identified at the leading edge of dissolved phase plumes from gasoline discharges. Tying the concepts of this section together, an investigator that identifies MTBE at the leading edge of a dissolved phase plume may be able to establish a line of evidence supporting a discharge of gasoline to the environment from the late 1970's to the early 2000's.

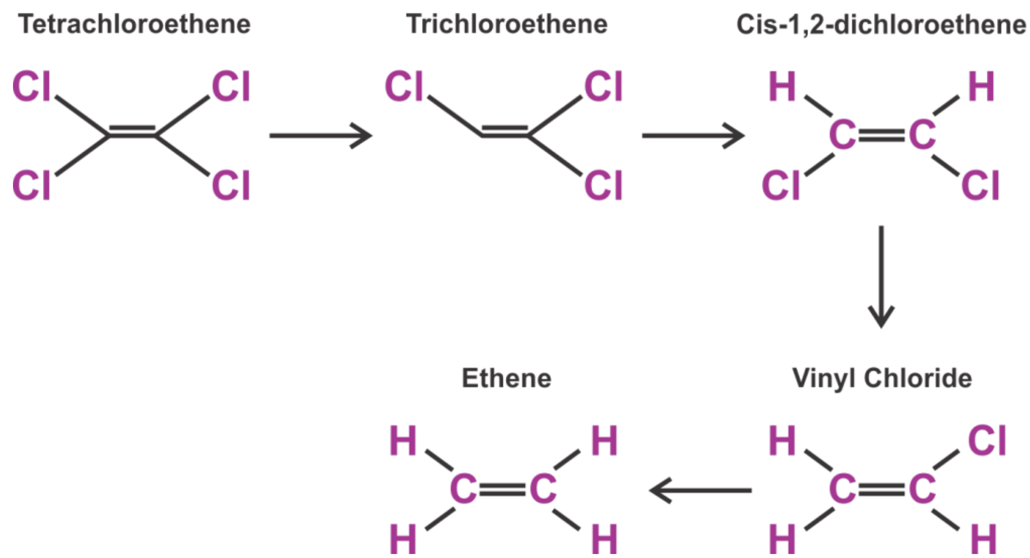
With regard to CVOCs, there is a similar history of manufacturer and time specific additives that were common in the production of the various products. Specifically, specific additives were used in various chlorinated solvents to inhibit acids, metals, and light effects. Also, antioxidants were added to minimize degradation of various products once manufactured. Similar to petroleum fuels, the investigator can use the knowledge of the product, product additives, various manufacturers, and the industry as a whole could target compound as part of an investigation to develop MLE in support of a commingled CSM.

Compounds	Solvent Additive Summary
CT	Inhibitor use was rare, but when present for corrosion inhibitor (antioxidant) and at low concentrations when compared to other solvents.
PCE	Inhibitor use varied based on use. For example, PCE for dry cleaning fluid contained higher concentrations of acid, light, and corrosion inhibitors than PCE used in metal cleaning and degreasing, which typically contained acid and corrosion inhibitors at low concentrations
TCE	Typically contained inhibitors for acid, metal, light, and corrosion at concentrations greater than other solvents.
TCA	Acid and metal inhibitors were typically used at higher concentrations than other solvents. Antioxidants were not required in TCA; however, their use has been reported for the benefit of other additives.

5.0 Compound Degradation

The evaluation of petroleum hydrocarbon degradation after a discharge has been well researched and documented (Forensics 101, 2014, Morrison, 2006, Morrison, 2000b). For instance, calculating ratios of Benzene, Toluene, Ethylbenzene, and Xylene (BTEX Ratios) can assist in evaluating degradation processes such as volatilization and dissolution in ground water that ultimately can be an indicator of how long since a spill has occurred. Similar techniques can be used for BTEX in free product and soils, however due to difference in resistance to degradation based on the environmental conditions (LNAPL thickness, soil type, etc.) differing ratio relationships may exist. investigators must be aware of limitations to degradation evaluation techniques especially with regard to the assumptions that many of the techniques are based. For example, first order biodegradation models assume uniform degradation in the environment and degradation rates independent of environmental conditions (microbial populations, aerobic/anaerobic conditions) (Morrison, 2000b). Morrison (2000b) also identifies challenges associated with uncertainties of the initial BTEX concentrations, which varies based on refiner, octane rating, and, in colder climates the time of year. investigators should be aware of the limitations of using compound degradation evaluations for petroleum hydrocarbons. In most settings, compound degradation conclusions should be substantiated with other techniques and lines of evidence.

The degradation of chlorinated parent compounds (also known as dechlorination), such as PCE, TCE, 1,1,1-TCA, under varying environmental conditions are well researched and documented. The following illustrates the one example of a well breakdown pattern of a chlorinated compound parent product (PCE) to its daughter products (TCE, cis-DCE, vinyl chloride, and eventually ethene).



The rate of the degradation processes varies based on a multitude of factors including but not limited to the parent compound (chemical half-life); environmental conditions (aerobic, anaerobic), microbial community, and soil types/geology. An investigator with knowledge of the degradation processes of the various chlorinated compounds and the ability to properly characterize the environmental conditions (aerobic/anaerobic, microbial community), in some circumstance, may be able to differentiate and distinguish the age and source of chlorinated discharges. At a minimum, a thorough assessment of the presence and concentrations of parent and breakdown products should be a line of evidence in any commingled plume CSM involved chlorinated compounds.

Geochemical Indicators

An evaluation of subsurface geochemistry can provide many clues on tracking a contaminant plume. Chlorinated solvents can leave a trail even after the actual concentrations of the chemicals themselves have dropped below levels of concern. Indirect evidence of a plume's presence, or conversely, the ability of subsurface conditions to support contaminant biodegradation can be garnered from analysis of dissolved oxygen levels, nitrate and sulfate depletion, elevated iron, methane, ethane, ethene and chlorine concentrations. The amount of hydrogen present can indicate whether reductive dechlorination or methanogenesis is occurring; as does subsurface pH. Determination of what is termed "cis-stall", where natural attenuation stops at the point of cis-Dichloroethylene (cis-DCE) production and does not proceed further can also be made using analysis of carbon dioxide and chlorine presence, along with an understanding of the mass balance of the plume being considered.

6.0 Compound Specific Stable Isotopes Analyses

The great utility of stable isotope analysis as a tracer in petroleum fuels is that that the isotopic ratios (carbon, sulfur) do not change (or are effected by) degradation processes. Stable isotope analysis can be used to clearly identify the presence of multiple petroleum sources, especially when the tools discussed above (hydrocarbon pattern recognition, tracer compounds) are ineffective due to degradation/weathering. An example is provided below:

Compound Specific Isotope Analysis (CSIA)

CSIA is a method that analyzes the relative abundance of various stable isotopes (such as 13C:12C, 2H:1H) in a contaminant of interest. Degradation, manufacturing and other processes can change the relative abundance of these isotopes that are then measured and can provide a unique identification of the contaminant. Recent developments in this technology allow for determination of one chlorinated solvent source versus another – temporally and spatially. The Interstate Technology and Regulatory Council (ITRC) document "Compound *Specific Isotope Analysis, November 2011*" provides a short summary on the technique at: http://www.itrcweb.org/documents/team_emd/CSIA_Fact_Sheet.pdf

Elemental and Isotopic Ratio Analyses

Stable isotopic ratio analyses can be used in evaluating the sources of heavy metal contamination, for example, in determining the reduction and therefore, toxicity of hexavalent chromium to trivalent chromium both naturally and as a result of remedial action; in identifying methane sources; differentiating PCB congeners; and petroleum hydrocarbon source differentiation and age-dating studies in free product and ground water. Radionuclide concentrations and ratios can also be used as part of contaminant tracer and dating studies, e.g., examining ground water contaminant transport using radon and radium tracers to determine distribution in the subsurface and discharges to surface water.

CSIA of petroleum compounds is more advanced than that for chlorinated solvents and has been in use for more than a decade. CSIA measures changes in intrinsic isotope ratios – not concentrations of chemical constituents. This fractionation occurs with degradation in chlorinated ethenes and ethanes, MTBE and other compounds; less so in long chain n-alkanes, PCBs and multi-ring PAHs. Original source "signatures" are more stable in free product, DNAPL and things such as tar balls, less so (or requiring more complex analysis) for LNAPL, due to evaporation effects. Such isotope "fingerprinting" –both bulk and compound-specific can be used to identify geologic sources, manufacturers and other specifics of petroleum products. Quantitative interpretation of CSIA data can provide confirmation that natural or enhanced degradation is occurring and by which pathway. Given the need to consider several potentially confounding factors, expert analysis is suggested in support of data interpretation.

7.0 Source-Specific Target Biomarker Analysis

Useful in petroleum crude and product identification, particularly in spill response, biomarker "fingerprinting" uses data analysis, univariate and multivariate statistical techniques to identify hydrocarbon sources. Diagnostic ratios of alkanes and other constituents in product and weathered samples can be compared, cross-plots of one biomarker against another evaluated and unique biomarker compounds identified to help determine the source(s) of a petroleum spill.

Weathering Analyses/Diagnostic Ratios

Biomarker analysis can also be used to determine the effect of weathering on petroleum compounds. The evaporation, emulsification, dissolution, biodegradation and other processes ensuing after a discharge has occurred, along with the changes in chemical composition of the product discharged can thereby be evaluated to identify the spill source, even in samples having very similar composition.

APPENDIX D

High-Resolution Site Characterization

APPENDIX D

HIGH- RESOLUTION SITE CHARACTERIZATION

High-Resolution Site Characterization (HRSC) is an investigative approach utilizing focused data collection to more clearly define subsurface lithology and contaminant distribution in three dimensions. The application of HRSC will differ at every site; there is no standard sample size or frequency. The scale of HRSC measurements are based on the objectives of the investigator, the size and complexity of a site, contaminant type, the nature and timing of a discharge, and the heterogeneity in subsurface conditions.
HRSC Technologies can be used in both unconsolidated and bedrock environments. A primary HRSC strategy for ground water contamination in unconsolidated aquifers is to create vertical subsurface profiles in transects oriented perpendicular to the direction of ground water flow. HRSC approaches may help establish lines of evidence regarding fate and transport and move a commingled plume investigation forward, particularly if standard investigative methods have been unsuccessful.

Some sampling tools and investigative approaches for HRSC include direct push technologies (DPT), membrane interface probes (MIP); borehole flow meters; media-specific meters and test kits, soil gas sampling, real-time direct measurements and field screening technologies.

The higher density data sets generated during HRSC allows for 3-D visualization and the development of a more accurate and realistic CSM. An accurate and realistic CSM may allow targeted in situ and ex situ remedies to be evaluated and implemented. This may result in a faster and more effective site cleanup. A realistic CSM will also help identify data gaps, reduce uncertainty and provide for an advanced site analysis.

For more information on HRSC, see the Discrete Fracture Network (DFN) Approach for Contaminated Bedrock Site Characterization provided at https://g360group.files.wordpress.com/2017/11/the-discrete-fracture-network-dfn-approach-for-contaminated-bedrock-site-characterization-articles1-9-2011-04-28_final-1.pdf and http://www.acquesotterranee.it/en/rivista/aquamundi/articoli/discrete-fracture-network-approach-studying-contamination-fractured-rock. The Contaminated Site Clean-Up Information (CLU-IN) program provides information about HRSC and other technologies related to hazardous waste remediation. See the HRSC Characterization and Monitoring web page at https://clu-in.org/characterization/technologies/hrsc/index.cfm for further information. Other useful information on integrated DNAPL site characterization and available tools can be found on the Interstate Technology and Regulatory Council (ITRC) website at: http://www.itrcweb.org/DNAPL-ISC_tools-selection/#Welcome.htm%3FTocPath%3D

APPENDIX E

LIST OF MODELING RESOURCES

APPENDIX E
LIST OF MODELING RESOURCES

The following is a partial list from the USEPA (https://www.epa.gov/water-research/forms/contact-us-about-water-research). USEPA Office of Research and Development (ORD), the National Risk Management Research Laboratory provides public domain ground water and vadose zone modeling software and services to public agencies and private companies throughout the United States.

BIOCHLOR	2.2	June 2002	Windows 95/98/NT, Excel	1-D Domenico screening model
BIOPLUME III	1.0	September 1997	Windows 95/98	2-D USGS MOC transport with Windows GUI
BIOSCREEN	1.4	July 1997	Windows 95/98/NT, Excel	3-D Domenico transport
CHEMFLO-2000		April 2003	Windows 95/98/NT/2000/XP, Linux, Solaris, Mac OS X	Updated CHEMFLO
FOOTPRINT	1.0	June 2008	Windows 98/XP	2-D transport of BTEX and ethanol
HSSM-Windows	1.2.e	September 1997	Windows 95/98	Multiphase LNAPL flow/transport
Infiltration Models			Mathcad	Unsaturated/saturated zone transport
PESTAN	4.0		Windows	Simulate leaching of pesticides
Regression MNA		December 2011	Windows 95/98/NT/2000/XP	Supplemental information to EPA 600/R-11/204
REMFuel	1.0	February 2012	Windows 98 or greater	Simulating the effects for fuel hydrocarbons
REMChlor	1.0	December 2007	.Net	Simulate transient plum remediation
UTCHEM	9.0	July 2000	Windows	3-D multiphase flow/transport
VLEACH	2.2.a	May 2007	Windows	1-D vadose zone leaching model
WhAEM2000	3.2	June 2005	Windows 95/98/NT/2000/XP	Analytical element capture zone model

The above list is comprised of screening models. More sophisticated models can be found by a web search for MODFLOW and MT3DMS or accessing the Integrated Groundwater Model Center at the Colorado School of Mines (http://igwmc.mines.edu/). Many of these models are public domain. There are also many expanded forms of the models that are available from private vendors.

MODELING STANDARDS

There is always concern whether the conclusions drawn by using a model will be accepted by those in the position of evaluating the conclusions (courts, the Department, etc.). In order to construct a robust, defensible model, the Department recommends following ASTM modeling standards. (Seehttp://www.astm.org/Standard/index.shtml and search on key word "model").

Appendix F

List of Acronyms

ACRONYMS

AOC – Area of Concern
ARRCS - Administrative Requirements for the Remediation of Contaminated Sites
BRAP – Bureau of Remedial Action Permits
BTEX – Benzene, Toluene, Ethylbenzene, and Xylene
CA – Cluster Analysis
CDN – Confirmed Discharge Notification
CEA – Classification Exception Area
cis-DCE – cis-1,2-dichloroethene
COCs – Contaminants of Concern
CLU-IN – Contaminated Site Clean-Up Information
CSIA – Compound-Specific Isotopic Analysis
CSM – Conceptual Site Model
CT – Carbon tetrachloride
CVOCs – Chlorinated Volatile Organic Compounds
DA – Discriminant Analysis
1,2 DCA – Ethylene dichloride
DFN – Discrete Fracture Network
DIGWSSL – Default Impact to Ground Water Soil Screening Levels
DNAPL – Dense Non-Aqueous Phase Liquid
DO – Dissolved Oxygen
DPT – Direct Push Technologies
EDB – Ethylene Dibromide
EDD – Electronic Data Deliverable
EMD – Environmental Molecular Diagnostics
FA – Factor Analysis
GC/FID – Gas Chromatography-flame ionization detector
GWQS – Ground Water Quality Standards
GWPT/SVE – Ground Water Pump and Treat and Soil Vapor Extraction System
HRSC – High-Resolution Site Characterization
IEC – Immediate Environmental Concern
IRM – Interim Remedial Measure
ISRA – Industrial Site Recovery Act
ITRC – Interstate Technology and Regulatory Council
LNAPL – Light Non-Aqueous Phase Liquid
LSRP – Licensed Site Remediation Professional
MDS – Multi-Dimensional Scaling
MGP – Manufactured Gas Plant
MIP – Membrane Interface Probes
MLE – Multiple Line of Evidence
MNA – Monitored Natural Attenuation
MRE – Minimum Relative Entropy
MTBE – Methyl Tert Butyl Alcohol
NJDEP – New Jersey Department of Environmental Protection
ODR – Office of Dispute Resolution of NJDEP
OPRA – Open Public Records Act

ORP – Oxidation Reduction Potential
PA – Preliminary Assessment
PAHs – Polycyclic Aromatic Hydrocarbons
PCE – Tetrachloroethylene
PIANO – **P**araffins, **I**soparaffins, **A**romatics, **N**aphthalenes, and **O**lefins
PRCR – Person Responsible for Conducting Remediation
RA – Remedial Action
RAO – Response Action Outcome
RAO-A – Response Action Outcome – Area of Concern
RAO -E – Response Action Outcome – Entire Site
RAP – Remedial Action Permit
RAP-GW Remedial Action Permit for Ground Water
RDCSRS – Residential Direct Contact Site Remediation Standards
RE – Receptor Evaluation
RI – Remedial Investigation
SEM – Structural Equation Modeling
SI – Site Investigation
SI/RI – Site Investigation/Remedial Investigation
SRP-PI – Site Remediation Program – Program Interest Number
SRWMP – Site Remediation and Waste Management Program
SRRA – Site Remediation Reform Act
SRS – Soil Remediation Standards
SVOCs – Semi Volatile Organic Compounds
TAL – Target Analyte List
TBA – tert-Butyl Alcohol
TCA – 2,4,6-Trichloroanisole
TCE – Trichloroethylene
TEL – Tetraethyl Lead
TICs – Tentatively Identified Compounds
TML – Tetramethyl Lead
TRSR – Technical Requirements Site Remediation
USEPA –United States Environmental Protection Agency
USGS – United States Geological Society
VI – Vapor Intrusion
VOCs – Volatile Organic Compounds
UST – Underground Storage Tank