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OU-3 Site-Related Groundwater Focused Feasibility Study

Ringwood Mines/Landfill Superfund Site

September 2018

Prepared for:
Ford Motor Company

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REPORT CERTIFICATION

SITE-RELATED GROUNDWATER FOCUSED FEASIBILITY STUDY

RINGWOOD MINES/LANDFILL SUPERFUND SITE
OPERABLE UNIT No. 3

RINGWOOD, NEW JERSEY

The material and data in this report were prepared under the supervision and direction of the undersigned.[1]

Cornerstone Environmental Group, LLC

10/10/2018

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[1] Arcadis US, Inc. prepared a draft of this report dated July 2015, and the content of the Arcadis report has been incorporated herein, and has been edited and updated with information developed since July 2015. Cornerstone acknowledges Arcadis US, Inc.'s contribution to the preparation of this report.

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Glossary of Acronyms

95% UCL	95th percentile upper confidence interval of the mean
AC	Area of Concern
AOC	Administrative Order on Consent
ARAR	Applicable or Relevant and Appropriate Requirements
AS	air sparging
ATSDR	Agency for Toxic Substances and Disease Registry
bgs	below ground surface
BHHRA	Baseline Human Health Risk Assessment
CEA	Classification Exception Area
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CMP	Cannon Mine Pit
COC	constituent of concern
COPC	constituent of potential concern
COPEC	constituent of potential ecological concern
CSM	conceptual site model
CT	central tendency
EBSL	ecologically-based screening level
EMP	environmental monitoring program
DO	dissolved oxygen
FFS	focused feasibility study
GRA	general response action
GWQS	groundwater quality standard
IC	institutional control
IGGWQC	interim generic groundwater quality criteria
ISCO	in-situ chemical oxidation
ISGWQS	interim specific groundwater quality standard
ITRC	Interstate Technology & Regulatory Council
LTM	long term monitoring
MCL	maximum contaminant level
MNA	monitored natural attenuation
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NJDEP	New Jersey Department of Environmental Protection
NPL	National Priorities List
OCDA	O'Connor Disposal Area
O&M	operation and maintenance
ORC	oxygen release compound
ORP	oxidation-reduction potential

PM	Peters Mine
PMP	Peters Mine Pit
PRB	passive reactive barrier
RAOs	remedial action objectives
RI	remedial investigation
RIR	remedial investigation report
RME	reasonable maximum exposure
ROD	Record of Decision
SDWA	Safe Drinking Water Act
SIP	stable isotope probing
s.u.	standard units
SVE	soil vapor extraction
SWQS	surface water quality standards
TBC	to-be-considered
TCE	trichloroethene
TOC	total organic carbon
SRGEA	Site-Related Groundwater Ecological Assessment
SVOCs	semi-volatile organic compounds
USEPA	United States Environmental Protection Agency
VOCs	volatile organic compounds
WCC	Woodward-Clyde Consultants
WRA	Well Restriction Area
µg/L	micrograms per liter

EXECUTIVE SUMMARY

Cornerstone Environmental Group, LLC (Cornerstone), on behalf of Ford Motor Company (Ford), has prepared this *Site-Related Groundwater Focused Feasibility Study* (FFS) Report for the Ringwood Mines/Landfill Superfund Site located in the Borough of Ringwood in Passaic County, New Jersey (Site).

This FFS Report has been prepared in accordance with the United States Environmental Protection Agency's (USEPA's) *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* [Comprehensive Environmental Response, Compensation and Liability Act], and the Administrative Order on Consent (AOC) for the Site, dated May 2010. The AOC separates the Site into four Areas of Concern (ACs): Peters Mine Pit (PMP) Area, Cannon Mine Pit (CMP) Area, O'Connor Disposal Area (OCDA), and Site-Related Groundwater. The first three ACs are being addressed as Operable Unit No. 2 (OU2), and are referred to as the Land ACs. Site-Related Groundwater is being addressed as Operable Unit No. 3 (OU3).

This FFS Report provides a holistic evaluation of remedial alternatives to address the distribution of Site-related constituents of concern (COCs) in groundwater and surface water as identified by the Site-related Groundwater RIR and Site-related Groundwater RIR Addendum: benzene, chloroethane, 1,4-dioxane, arsenic, and lead.

Groundwater was designated by the USEPA as a separate AC and operable unit from the Land ACs; however, the evaluation of remedial action alternatives for groundwater includes consideration of the decision-making process that has already been completed for the Land ACs because information from the Land AC remedial actions informs issues such as the absence of a discrete, defined source of COCs to groundwater. This FFS, therefore, considers each of these three Land ACs and the evaluation of potential remedial action alternatives for regulatory compliance to address numerical exceedances of the New Jersey Groundwater Quality Standards (GWQS) and/or Safe Drinking Water Act (SDWA) Maximum Contaminant Levels (MCL) in groundwater.

The data generated during the Groundwater Remedial Investigation (RI) have confirmed that groundwater is not used for potable or domestic purposes at the Site, sampling of potable wells down-gradient of the Site indicated no adverse impact to groundwater quality, COCs in groundwater are generally not discharging to surface waters on Site above Surface Water Quality

Standards (SWQS), COCs are generally not found in surface water beyond the Site boundaries, and a discrete, defined source of COCs has not been identified.

The Site COCs of benzene, 1,4-dioxane, chloroethane, arsenic, and lead may be as much associated with the overall system of mine workings at the site as with historical disposal practices, and in the case of arsenic and lead also with natural sources. For example, benzene is a common constituent in lubricants and petroleum products that would have been in widespread use in the mine workings. A focused investigation in the OCDA did not indicate a discrete source of 1,4-dioxane within the fill/waste, and while 1,4-dioxane is most commonly associated with chlorinated solvents as a stabilizer, it was also available commercially as a solvent as early as the 1920s and is widely used in various commercial products (Mohr, 2010). Chloroethane's predominant past use was in the manufacture of tetraethyl lead used as an anti-knock compound in fuel, and is also a degradation product of chlorinated solvents, any of which could be associated with multiple anthropogenic sources. Lead was a common fuel additive, has been detected in paint waste, and is also naturally occurring in soils. Arsenic, naturally occurring in the soils, bedrock, and mine tailings at the Site, has also been found in paint waste. Overall, the collective data generated by the extensive RI activities at the Site indicate that Site COCs are not associated with a single, identifiable or discrete source. The extent to which they may be associated with the larger waste/fill mass, the larger mine workings, or are naturally occurring is a significant consideration in the evaluation of remedial alternatives. Apart from the absence of a discrete, defined source, groundwater analytical results show that concentrations of COCs, although exceeding SDWA MCLs and New Jersey GWQS at some well locations principally in the area of PMP and immediately down gradient, are consistently in the ug/L range and are limited in areal extent.

A Baseline Human Health Risk Assessment (BHRRA) was completed, and assumed that a hypothetical future resident could be exposed to COCs in Site-related groundwater or mine water via ingestion as drinking water as well as via inhalation and dermal contact while showering or bathing because, although groundwater is not used for potable or domestic purposes, the potential future use of groundwater is not currently prohibited based on the Class IIA classification of the aquifer. The BHHRA risk characterization was then completed using a series of conservative assumptions including a doubling of the default exposure duration, use of overburden groundwater data even though it would not be available as a water supply because of regulations prohibiting the use of the upper 50 feet of an aquifer, a shower model that likely overestimates risk contributions from inhalation, and treating mine water as groundwater. Based on these multiple lines of conservatism, the findings of the BHHRA indicate that the potential risk associated with these exposure scenarios is not significant.

The Site-Related Groundwater Ecological Assessment (SRGEA) evaluated the site-related constituents of potential ecological concern (COPECs) of benzene, chloroethane, 1,4-dioxane, arsenic and lead using the highest reported concentrations in groundwater and surface water. These concentrations were compared to the EBSLs, and there were no exceedences of the EBSL for any COPEC. Consequently, the overall conclusion of the SRGEA is that the "…the potential for ecological risk associated with the five COPEC reported in both groundwater and surface water or additional COPEC selected in sediment is low and no further evaluation is warranted."

Remedial action objectives (RAOs) are established to select and evaluate remedial action alternatives that will protect human health and the environment; consider the requirements of USEPA and NJDEP Standards, Criteria, and Guidelines; provide practical, cost-effective remediation; and utilize permanent remedies to the extent possible. The Site-specific RAOs for groundwater include:

- Prevent consumption of groundwater containing COC concentrations above their respective NJDEP GWQS.
- Prevent exposure to groundwater by residents, which would exceed the USEPA's risk benchmarks of an additional lifetime cancer risk range between 1×10^{-6} and 1×10^{-4}, and a lifetime non-carcinogenic hazard index of less than 1.0.
- Restore the aquifer to Class IIA GWQS within a reasonable time frame, and to the extent practicable for Site-related COCs.

Screening of remedial alternatives was performed to refine the list of alternatives for detailed evaluation. The screening of remedial alternatives was initially presented in the *Memorandum of Candidate Technologies for Site-Related Groundwater* (Cornerstone, 2018b), which was approved by the USEPA in a letter dated April 4, 2018, and has been incorporated in this FFS. The alternatives that were screened include the following for Site-wide groundwater and the PMP Air Shaft:

Site Wide Groundwater:

- No Action
- Monitored Natural Attenuation with a CEA/WRA
- Enhanced Monitored Natural Attenuation Treatment Barrier with a CEA/WRA
- In Situ Chemical Oxidation (ISCO)
- Air Sparging/Soil Vapor Extraction
- Groundwater Extraction, Treatment and Discharge
- Groundwater Extraction, Treatment and Recirculation

PMP Air Shaft:

- No Action
- Oxygen Diffusion via Chemical Addition
- In-Situ Chemical Oxidation
- Biosparging
- Treatment/Closure

The screening process resulted in the elimination from detailed evaluation the following Site-wide groundwater alternatives

- In Situ Chemical Oxidation (ISCO);
- Air Sparging/Soil Vapor Extraction;
- Groundwater Extraction, Treatment, and Discharge; and
- Groundwater Extraction, Treatment, and Recirculation.

The elimination of these alternatives was primarily based on the impracticability of addressing the mass of material that would have to be oxidized (for the ISCO alternative), and the low transmissivity of the aquifer on Site which limits the ability to distribute air or effectively employ groundwater extraction and treatment.

The screening process also eliminated from detailed evaluation the In-Situ Chemical Oxidation and Biosparging alternatives for the PMP Air Shaft. These alternatives were not retained for detailed evaluation primarily based on the impracticability of addressing the mass of material in the Air Shaft that would have to be oxidized (for the ISCO alternative), and that oxygen diffusion by chemical addition is a more cost-effective approach than biosparging for the same basic remedial alternative.

Based on the screening processes performed in accordance with USEPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*, the following remedial action alternatives were developed for more detailed evaluation:

- Site-Wide Groundwater
    - Alternative 1 – No Action
    - Alternative 2 – Monitored Natural Attenuation with a CEA/WRA
- Site-Wide Groundwater Focused on Combined PMP Area and OCDA
    - Alternative 3 – Enhanced, Monitored Natural Attenuation Treatment Barrier with a CEA/WRA
- PMP Air Shaft
    - Alternative 4 – No Action
    - Alternative 5 – Oxygen Diffusion via Chemical Addition
    - Alternative 6 – Treatment/Closure

A detailed analysis of each of the alternatives was used to evaluate alternatives based on the threshold and balancing criteria described in the *National Contingency Plan (NCP)*, and consistent with *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*, as follows:

Threshold criteria:

- Overall protection of human health and the environment; and
- Compliance with Applicable or Relevant and Appropriate Requirements (ARARs).

Balancing criteria:

- Long-term effectiveness and permanence;
- Reduction of toxicity, mobility, or volume through treatment or removal;
- Short-term effectiveness;
- Implementability; and
- Cost.

Evaluation against these criteria provides the basis for selection of an alternative or combination of alternatives for implementation. Additionally, a comparative analysis was performed to identify the relative advantages and disadvantages of each alternative, considering the above evaluation criteria, and to facilitate the selection of a remedial action alternative for the Site.

Overall, the comparative analysis indicates the following:

- Under existing conditions, the potential human health or ecological risks are not significant, and therefore, the alternatives are protective.
- Through the permit equivalent process, each of the alternatives would be able to satisfy ARARs. However, given the potential contributions of COCs from both natural and anthropogenic sources, meeting NJ Groundwater Quality Standards is not likely in the near term for any alternative.
- The protectiveness of each alternative can be maintained for the long term through established institutional controls and processes.
- The only alternatives that actively promote reduction of toxicity, mobility, or volume through treatment or removal are Enhanced MNA Treatment Barrier for Site-Wide Groundwater, and Oxygen Diffusion and Treatment/Closure for the PMP Air Shaft. Other alternatives rely on natural attenuation processes to reduce toxicity and mobility.
- None of the alternatives has significant short-term impacts, and each of the alternatives can be implemented in a relatively short time frame.
- Each of the alternatives can be implemented with conventional equipment, materials, means and methods.
- The costs of the various alternatives may be summarized as follows:

Alternative	Estimated Cost
Site-Wide Groundwater	
No Action	$622,000
Monitored Natural Attenuation	$1,439,000
Enhanced, Monitored Natural Attenuation	$2,815,000
PMP Air Shaft	
No Action	$0
Oxygen Diffusion	$334,000
Treatment/Closure	$598,000

1 INTRODUCTION

1.1 General

Cornerstone Environmental Group, LLC (Cornerstone), on behalf of Ford Motor Company (Ford), has prepared this *Site-Related Groundwater Focused Feasibility Study* (FFS) Report for the Ringwood Mines/Landfill Superfund Site located in the Borough of Ringwood in Passaic County, New Jersey (Site).

This FFS Report has been prepared in accordance with the United States Environmental Protection Agency's (USEPA's) *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* [Comprehensive Environmental Response, Compensation and Liability Act], EPA/540/G-89/004 (USEPA 1988a) and the Administrative Order on Consent (AOC) for the Site, dated May 2010. The AOC separates the Site into four Areas of Concern (ACs): Peters Mine Pit (PMP) Area, Cannon Mine Pit (CMP) Area, O'Connor Disposal Area (OCDA), and Site-Related Groundwater. The first three ACs are being addressed as Operable Unit No. 2 (OU2), and are referred to as the Land ACs. Site-Related Groundwater is being addressed as Operable Unit No. 3 (OU3).

Under the AOC a *Site-Related Groundwater Remedial Investigation Report* (RIR) was prepared by Arcadis US, Inc., on behalf of Ford, dated January 2015. The January 2015 RIR was conditionally approved by the USEPA on June 24, 2015, with final approval pending the installation of additional groundwater monitoring wells, and completion of further groundwater, mine water, and surface water sampling and analysis. During the period from March 2015 through August 2017, eight additional groundwater monitoring wells were installed, and eleven additional monitoring events were performed. The results of the additional monitoring are presented in the *Site-Related Groundwater Remedial Investigation Report Addendum* (Groundwater RIR Addendum) prepared by Cornerstone, dated September 2018.

This FFS Report provides an evaluation of remedial alternatives to address the distribution of Site-related constituents of concern (COCs) in groundwater and surface water as identified by the Site-related Groundwater RIR and Site-related Groundwater RIR Addendum: benzene, 1,4-dioxane, chloroethane, arsenic, and lead. This FFS Report has been prepared to complete the screening evaluation of remedial alternatives as presented in the final *Memorandum of Candidate Technologies for Site-Related Groundwater* (CTM, Cornerstone, 2018a) as approved by the USEPA in a letter dated April 4, 2018. The approved CTM presented a screening process for potential alternatives for Site-wide groundwater and the PMP Air Shaft. The alternatives that were screened in the CTM are as follows:

Site Wide Groundwater:

- No Action
- Monitored Natural Attenuation with a CEA/WRA
- Enhanced Monitored Natural Attenuation Treatment Barrier with a CEA/WRA
- In Situ Chemical Oxidation (ISCO)
- Air Sparging/Soil Vapor Extraction
- Groundwater Extraction, Treatment and Discharge
- Groundwater Extraction, Treatment and Recirculation

PMP Air Shaft:

- No Action
- Oxygen Diffusion via Chemical Addition
- In-Situ Chemical Oxidation
- Biosparging
- Treatment/Closure

The screening process in the approved CTM resulted in the following alternatives being retained for detailed evaluation in this FFS:

Site Wide Groundwater:

- No Action
- Monitored Natural Attenuation with a CEA/WRA
- Enhanced Monitored Natural Attenuation Treatment Barrier with a CEA/WRA

PMP Air Shaft:

- No Action
- Oxygen Diffusion via Chemical Addition
- Treatment/Closure

In the OU2 Record of Decision (ROD), and the Explanation of Significant Differences Document dated April 15, 2015, USEPA selected Land AC remedies for the PMP Area, CMP Area, and OCDA that include construction of an engineered soil cap as an Engineering Control along with a Deed Notice. For the PMP Area, the land AC remedy also includes excavation of approximately 22,000 tons of waste/fill to the groundwater table prior to engineered cap construction and either reuse or off-site disposal. For the OCDA the land AC remedy includes fill/waste consolidation prior to cap construction followed by redevelopment as the Borough of Ringwood's Recycling Center. Finally, in the CMP, the land AC remedy includes consolidation of materials in fringe areas and removal and offsite disposal of drums should any be encountered.

Groundwater was designated by the USEPA as a separate AC and operable unit from the Land ACs; however, to be complete the evaluation of remedial action alternatives for groundwater needs to be conducted with consideration of the decision-making process that has already been completed for the Land ACs because information from the Land AC remedial actions informs issues such as the absence of a discrete, defined source of COCs to groundwater. The balance of this document, therefore, considers each of the three Land ACs and the evaluation of potential remedial action alternatives for regulatory compliance to address numerical exceedances of the New Jersey Groundwater Quality Standards (GWQS) and/or Safe Drinking Water Act (SDWA) Maximum Contaminant Levels (MCL) in groundwater.

The environmental and human health risk assessments, based on an extensive environmental database and multiple conservative assumptions, indicate that the potential risks associated with the Site COCs in groundwater and surface water are not significant. However, in accordance with CERCLA guidance and New Jersey Department of Environmental Protection (NJDEP) regulations, numerical exceedances of the GWQS and/or MCLs for benzene, 1,4-dioxane, and chloroethane in groundwater warrant an evaluation of remedial action alternatives. Also, any non-naturally occurring metal COC concentrations that exceed their respective GWQS and/or MCLs in groundwater warrant an evaluation of whether or not a Classification Exception Area (CEA)/Well Restriction Area (WRA) as an institutional control is warranted to restrict potential future potable use of groundwater in these areas. In addition, as part of the Land AC remedies, groundwater and surface water quality monitoring will be conducted in the three Land ACs in accordance with the USEPA's OU2 ROD until a groundwater remedy is selected.

1.2 Report Organization

Following this introductory section, the remainder of this FFS Report is organized as follows:

- *Section 2 – Site Background and History:* Provides an overview of the Site setting and history.

- *Section* 3 – *Summary of the Remedial Investigation*: This section provides a summary of the findings of the Site-Related Groundwater RIR and Site-Related Groundwater RIR Addendum, with a focus on information related to preparation of this FFS.

- *Section 4 – Remedial Action Objectives*: This section identifies the Remedial Action Objectives (RAOs) for remediation at the Site.

- *Section 5 – Applicable or Relevant and Appropriate Requirements:* This section provides the various State, Federal, and Local regulations and guidance that may be Applicable or Relevant and Appropriate Requirements (ARARs) for implementation of a remedial action.

- *Section 6 – Identification and Screening of Remedial Technologies*: This section summarizes screening of remedial technologies used to generate remedial alternatives.

- *Section 7 – Development of Remedial Alternatives*: This section describes in detail sufficient for the evaluation in Section 8, the remedial alternatives resulting from the technology screening and retained for the detailed evaluation.

- *Section 8 – Detailed Evaluation of Alternatives:* This section provides a detailed evaluation of each retained, remedial alternative against the criteria established in the National Contingency Plan (NCP).

- *Section 9 – Comparative Analysis:* This final section of this FFS compares the remedial alternatives against each other using the results of the detailed evaluation in Section 8.

2 SITE BACKGROUND AND HISTORY

2.1 Site Description

As shown on the Title Sheet of the accompanying figures, the Site is located in the New Jersey Highlands, a mountainous part of northern New Jersey, located near the New York State border. The Site is approximately 500 acres in size, 0.5 miles wide, and approximately 1.5 miles long. The Site consists of moderately rugged forested areas, open areas of overgrown vegetation, abandoned mine shafts and surface pits, an air shaft, a closed municipal landfill, small surficial depositional areas, automobile carcasses, a municipal recycling center, the Borough of Ringwood Department of Public Works Garage, and residential properties. Ringwood State Park borders the Site to the north and east and also encompasses the majority of the PMP Area of the Site. Because it is a part of Ringwood State Park, the State of New Jersey owns the property on which the PMP Area is located.

The Site is bordered by mountainous ridges to the west (Whaleback Mountain, Mine Hill) and north (Hope Mountain, Unnamed Mountain) and lower hills and ridges to the east and south, and is situated on the western side of a valley defined by the Wanaque River watershed. There are four primary streams in different parts of the Site that are tributaries to Ringwood Creek: Mine Brook (western and southern areas), Peters Mine Brook (a drainage feature in the central part of the Site), Park Brook (north-central area), and an unnamed tributary of Ringwood Creek identified as North Brook (northern area). The Ringwood Creek watershed drains to the Wanaque Reservoir, which, as shown on the Title Sheet of the accompanying figures, is nearly 2 miles from the PMP Area and approximately 0.75 mile from the Site boundary in the CMP Area.

There are paved roads in the residential areas and leading to former mining areas. These roads are Peters Mine Road, Cannon Mine Road, Van Dunk Lane, Sheehan Drive, Milligan Drive, Horseshoe Bend Road, and Petzold Avenue. There are also former mine roads and trails; some are dirt roads and others are covered with asphalt, gravel, or mine tailings. A few of the trails and former mine roads are in various states of natural reclamation.

The Borough of Ringwood Department of Public Works Garage is located near the intersection of Peters Mine Road and Margaret King Avenue, and the Borough Recycling Center is located approximately 0.5 miles north on Peters Mine Road. There is a Public Service Electric and Gas Company power substation on the east side of Peters Mine Road, approximately 400 yards north of the Margaret King Avenue intersection.

2.2 Geology and Hydrogeology

2.2.1 Geology

The Site is located in the southeastern extension of the New England Highlands Physiographic Province. The portion located in New Jersey is known as the New Jersey Highlands. The topography of the site within the New Jersey Highlands consists of northeast-southwest trending parallel ridges, created by well foliated gneiss. The more common, less foliated gneiss forms rounded or broad-topped topographic highs. Granite gneiss and pegmatite form sharp ridges separated by narrow troughs underlain by less resistant gneiss. Major cross faults are visible as trench-like features that interrupt drainage. These faults generally strike approximately east-west across the predominant northeast strike of the major ridges and valleys (Hotz 1953).

Structural features of the New Jersey Highlands, which are regionally related either spatially or tectonically, include folds, faults, lineation trends, and jointing. The New Jersey Highlands has experienced a complex history of folding and faulting, the result of both Precambrian and post-Precambrian tectonism. The formation of the New Jersey Highlands and the associated faulting and folding, which produced structural complexities in the region, occurred during the closing periods of the Paleozoic Era concurrent with the formation of the Appalachian Mountains (WCC 1988).

The New Jersey Highlands in Passaic County are drained by the Pequannock, Wanaque, and Ramapo Rivers, which ultimately join to form the Pompton River, a tributary of the Passaic River. The drainage pattern north of the terminal moraine in the New Jersey Highlands is classified as deranged, and is marked by many poorly drained areas of lakes and swamps. Greenwood Lake and Lake Hopatcong are large lakes formed by the blocking of pre-glacial drainage courses. South of the terminal moraine, stream drainage generally follows structural valleys toward the southwest (WCC 1988).

Unconsolidated soil and sediment deposits are primarily confined to the stream valleys and corridors. The unconsolidated deposits are thickest in the eastern and southern parts of the Site. The overburden ranges from approximately 25 to 50 feet thick. Glacial deposits blanket the lower slopes of ridges and hills and consist of heterogeneous mixtures of silt, sand, and gravel with boulders, typical of a ground moraine. The stream deposits are observed within the floodplains of the creeks and swamps and consist of clay and silt with some sand and gravel. These stream deposits are thought to be primarily derived from reworking of the glacial sediments.

The overburden consists of the Rahway Till dating from the Pleistocene age, which is reddish-brown, light reddish-brown, reddish-yellow silty sand to sandy silt containing some to many sub-round and sub-angular pebbles and few sub-rounded boulders. The matrix is compact, non-plastic to slightly plastic with coarse sub-horizontal fissile structures, and the clasts are composed of red and gray sandstone and siltstone, gray gneiss, and white to gray quartz and quartzite gravel. Boulders are mainly gneiss, and a few are quartzite or gray and red sandstone (Stanford 2002).

Bedrock in the valleys and other topographic low areas is generally covered by overburden, which consists of unconsolidated and reworked glacial deposits and weathered bedrock. In some areas, the overburden is overlain by excavated rock, mine tailings, fill soil, and refuse from historical mining activities and historical fill/waste placement.

Bedrock is encountered at approximately 25 to 50 feet below ground surface (bgs). Bedrock consists of Mesoproterozoic age metasedimentary rocks of the Vernon Supersuite and gneisses of the Losee Metamorphic Suite, approximately 1.3 billion years old. The rock primarily consists of calc-alkaline and plagioclase gneisses. There are occurrences of pegmatite, pyroxene-amphibolites, biotite-quartz feldspar gneiss, and magnetite iron ore. The structural nature of bedrock at the Site is complex. The gneisses are moderately to well foliated, have mineral lineation, and display evidence of three distinct folding events. Joints are prevalent in the bedrock and are characteristically moderate to well developed, planar, typically unmineralized, and moderately to steeply dipping with spacing from one foot to several tens of feet (Volkert 2008).

The iron ore found in Ringwood is thought to be associated with hydrothermal deposits consisting primarily of magnetite that replaced pyroxene amphibolites and skarn rocks. The iron ore formed around the same time as emplacement of granite and pegmatite, approximately 950 million years ago.

2.2.2 Hydrogeology

Groundwater at the Site occurs in both overburden and bedrock, but only in overburden where it is sufficiently thick to be continually saturated, usually a thickness observed to be greater than 8 feet. Where saturated, the overburden defines an upper aquifer and fractured bedrock a lower, or deeper, aquifer. The transition from the overburden aquifer, where it is present, to the bedrock aquifer is marked by a weathered bedrock zone of variable thickness (ranging from 0 feet to approximately 20 feet). There is limited hydraulic communication between the overburden and bedrock aquifers beyond the immediate vicinity of the underground mine workings because of the poor vertical permeability and transmissivity of the basal boulder till as well as the crystalline bedrock.

Groundwater occurs in the overburden under unconfined water table conditions in the PMP Area and the OCDA. Although saturated overburden has not been encountered in the CMP Area because of insufficient overburden thickness, groundwater occurs in the bedrock aquifer beneath the entire Site, including within the CMP Area. The overburden aquifer is monitored in two zones, the upper water table and the lower, or deeper, overburden. The bedrock aquifer is monitored in multiple zones ranging from tens of feet in depth to approximately 500 feet below ground surface (bgs). Based on observed monitoring well yields during the more than 25 years of groundwater sampling at the Site, the hydraulic conductivity of the overburden aquifer is low to moderate and is low to very low in the bedrock aquifer.

In the PMP and CMP Areas, the abandoned underground mine workings have filled with groundwater and, therefore, represent significant storage of groundwater, with the volumes of stored water estimated at 213,000,000 gallons and 49,000,000 gallons, respectively (Getz 1965). Based on the very low historical mine dewatering rates (less than 54 and 33 gallons per minute, for the PMP and CMP Areas, respectively) and low to very low monitoring well yields during purging and sampling, the significant storage of groundwater within the abandoned mine workings does not appear to contribute to or increase the overall local hydraulic transmissivity, or groundwater movement, within the massive crystalline bedrock. Moreover, this large volume of groundwater storage and lack of yield from the area-specific monitoring wells indicates that fractures within the crystalline bedrock have very limited transmissivity and/or connectivity. The depth to groundwater in the overburden fluctuates seasonally and is typically deeper during dryer summer months with some wells being dry, or nearly dry, when conditions are sufficiently dry.

The direction of groundwater flow in both the overburden and bedrock aquifers is generally to the southeast. Groundwater contour maps are provided on Figures 1 through 3 and illustrate the direction of groundwater flow. Groundwater ultimately discharges to streams, creating base flow in the perennial streams. Surface water within the streams ultimately discharges into the Wanaque Reservoir, located approximately one mile from the confluence of Park Brook, North Brook, Mine Brook, and Ringwood Creek (WCC 1988).

Although groundwater at the Site is classified as Class IIA, a potential potable water source, as classified by NJDEP, groundwater at the Site is not used as a potable water source, and the vast majority of drinking water for residents near the site is provided by four water production wells maintained by the Borough of Ringwood located more than a mile from the Site in a different sub-watershed, with a limited amount of water supply from the Wanaque Reservoir.

2.3 Site History

The Ringwood Mines/Landfill Site is a historical iron mining site that operated from the 1700s until the 1950s. In 1942, the U.S. Government purchased the Upper Ringwood Area (approximately 870 acres) and invested heavily in the mines to prepare them for potential use in World War II.

Activities conducted by the U.S. Government's lessee, the Alan Wood Steel Company, from 1942 until 1945 included the reconstruction of a number of mine-related structures; refurbishment of the mines' water supply system; dewatering of the mines; excavation and onsite disposal of more than 100,000 cubic yards of waste rock and mine tailings (pulverized ore and small pieces of mined rock and mineral materials discarded after separation from iron ore during the mining process); reopening, enlarging, reconditioning, and extending of the original mine levels; production and processing of some ore; and related activities. The U.S. Government sold the mines in 1947 to a private party, but the property reverted to the U.S. Government one year later after the private party filed for bankruptcy. As a result of this long history of mining operations, large volumes of mine tailings were disposed of on Site and then re-worked or scattered across the Site.

In 1958, the U.S. Government sold the property to Pittsburgh Pacific Company, and in 1965 Pittsburgh Pacific Company sold the property to the Ringwood Realty Corporation, a former subsidiary of Ford. In 1967, Ringwood Realty contracted O'Connor Trucking and Haulage Company (O'Connor) to dispose of paper, cardboard, wood, metal, plastic scrap, general trash, paint waste, scrap drums, car parts, and other non-liquid plant wastes from Ford's former Mahwah Assembly Plant. The O'Connor agreement ran from 1967 until 1971, and required O'Connor to properly dispose of Ford wastes at three locations on the Ringwood Site: the PMP Area, the CMP Area, and the OCDA. O'Connor's disposal activities during this time were approved by state and local officials.

In November 1970, Ringwood Realty donated 290 acres of the Site to the Ringwood Solid Waste Management Authority. By November 1971, Ringwood Realty had sold all but 145 acres of the Site, and by December 1973 Ringwood Realty no longer owned any portion of the Site. Dumping by others occurred before, during, and after the four-year period during which Ford-related wastes were disposed of at the Site.

After disposal ceased, these Land ACs were graded and an approximately 2-foot clean fill cap was placed on the surface. Surficial paint waste, soil, and other waste materials have been removed from various excavation areas at the Site and disposed of between 2004 and 2014. Today, this former mining Site has numerous former mine pits, prospect pits, underground mine workings, and mine waste disposal areas. The material present in the Land ACs (PMP Area, CMP Area, and OCDA) consists of fill cover soil, mine tailings, construction and demolition debris, general manufacturing wastes, general municipal-type wastes, dried paint waste pieces (PMP Area and OCDA only), drum remnants, and miscellaneous fill.

2.4 Operable Unit 2 Remediation

As described in Section 1, Operable Unit 2 (OU2) includes the remediation of the three Land ACs: the CMP Area, PMP Area, and OCDA. A brief description of each area and the remediation to be performed under OU2 is presented in the sections that follow.

2.4.1 CMP Area

The CMP Area is located in the southwestern portion of the Site, and encompasses an area of approximately 2-3 acres. This land AC is situated adjacent to the Van Dunk Lane cul-de-sac. The CMP Area is mostly an open field surrounded by a chain-link fence, but includes areas such as access roads and rock piles and outcroppings.

The remedy for the CMP Area is briefly summarized as follows:

- Pull-back of fringe area of waste and removal drums of waste, if any, and proper offsite disposal;
- Placement of compacted fill to promote proper drainage of the area;
- Installation of an Engineered Geotextile/Soil Cap as an Engineering Control and restoration with vegetation;
- Additional Engineering Controls (e.g., fence, boulders, signs, etc.) to control access; and
- Institutional Controls and long-term monitoring, maintenance, and reporting.

2.4.2 PMP Area

The PMP Area is located in the north central portion of the Site. This area encompasses approximately three acres, and is located such that the majority of the area is within Ringwood State Park and the balance is located on Borough of Ringwood property. An approximately one-half acre pond, an expression of the groundwater table, is located within the approximate center of the PMP Area where a former soil cap has subsided due to fill/waste settlement, thus enabling the pond to form. The PMP Area is otherwise forested and overgrown with vegetation.

The remedy for the PMP Area is briefly summarized as follows:

- Excavation of soil and fill to the water table, unless drums and paint waste are found to extend below the water table and can be removed, in which case, excavation will also include such materials to the extent practicable;
- Segregation of excavated materials for re-use or off-site disposal based on the nature of the materials and the results of laboratory analyses, as applicable;
- Placement of compacted fill to achieve grades above the water table and provide overall grading of the area as necessary for Engineering Cap construction;
- Installation of an Engineered Geotextile/Soil Cap as an Engineering Control and restoration with indigenous vegetation consistent with Ringwood State Park and for restoration of riparian zone; and
- Additional engineering (e.g., boulders) and institutional controls (e.g., deed notice) and long-term monitoring, maintenance, and reporting.

2.4.3 OCDA

The OCDA is located in the north-central portion of the Site, just south of the PMP Area, and encompasses approximately 12 acres. The OCDA is situated along Peters Mine Road, and slopes to the east toward Park Brook. Wetlands have been delineated within the OCDA and generally adjacent to Park Brook. This area's historic use was as a settling pond for mine tailings from the wet ore processing operations. This area is also currently mostly overgrown with vegetation.

The remedy for the OCDA is briefly summarized as follows:

- Excavation of fringe area fill down to the mine tailings, and consolidation within the OCDA;
- Installation of an Engineered Geotextile and Soil Cap followed by redevelopment of the area above the Engineered Cap as a Recycling Center for the Borough of Ringwood. Construction of the Recycling Center above the Engineered Cap will function as a protective feature above the cap (e.g., asphalt pavement, etc.);
- Additional Engineering Controls (e.g. fencing, signs, etc.) to control access;
- Restoration of vegetation, riparian zone, and wetlands in areas outside of the Recycling Center;
- Institutional Controls and long-term monitoring, maintenance, and reporting.

3 GROUNDWATER REMEDIAL INVESTIGATIONS SUMMARY

3.1 General

As previously noted, a Groundwater RIR was prepared by Arcadis US, Inc. (Arcadis), on behalf of Ford, dated January 2015. The January 2015 RIR was conditionally approved by the USEPA on June 24, 2015, with final approval pending the installation of additional groundwater monitoring wells, and completion of further groundwater, mine water, and surface water sampling and analysis. The conditional approval required submittal of a Groundwater RIR Addendum to present the results of the further groundwater, mine water, and surface water sampling and analysis. Cornerstone, on behalf of Ford, prepared the Groundwater RIR Addendum dated September 2018, which presented the additional data collected through the installation of eight additional monitoring wells and eleven additional sampling events. In addition, a potable well search was completed as a part of the RIR Addendum, and potable wells identified at the Eleanor G. Hewitt School and Ringwood Manor State Park were sampled, the nearest of which is one of the Ringwood Manor State Park wells, located approximately 0.75 mile from the Site. The Groundwater RIR Addendum was submitted to the USEPA in September 2018.

The sections that follow summarize the results of the Groundwater RIR and RIR Addendum in the context of forming a basis for alternative evaluation, particularly as relates to the completion of this FFS. The reader is referred to the Groundwater RIR (Arcadis, 2015) and RIR Addendum (Cornerstone, 2018a) for details beyond that provided in this summary.

3.2 Summary of Investigations

3.2.1 Overview

The studies conducted at the Site for the remedial investigations, considered in concert with nearly 30 years of historical data, confirm that:

- There is an understanding of the flow of groundwater/mine water and surface water at the Site;
- The occurrence and distribution of COCs in groundwater are generally sporadic and limited to localized former landfill areas;

- Natural processes are at work lowering concentrations of benzene, lead, and arsenic – three of the key Site COCs in groundwater, the fourth being 1,4-dioxane for which data were more recently generated;

- Groundwater and mine water are somewhat distinct as the mine water is largely stagnant, and subject to conditions not representative of groundwater (e.g., thermocline in the PMP Air Shaft); and

- Wanaque Reservoir and Ringwood Borough wells have not been impacted by groundwater at this Site, nor have any of the potable wells located at the Eleanor G. Hewitt School and Ringwood Manor State Park which are located even closer to the Site (the nearest well being at the Park approximately 0.75 mile from the Site).

The data generated during the RI have confirmed that groundwater is not used for potable or domestic purposes at the Site[2], COCs in groundwater are generally not discharging to surface waters on site above Surface Water Quality Standards (SWQS)[3], COCs are generally not found in surface water beyond the Site boundaries, although 1,4-dioxane is detected in surface water within and beyond the site boundaries, it does not occur downstream of

[2] In its November 2016 Fact Sheet issued to the public, the USEPA stated "Although benzene and 1,4-dioxane continue to be detected, the levels do not present an imminent health threat as the water is not used for drinking."

[3] In the nine surface water sampling events performed since January 2015, benzene is the only Site-related constituent detected nominally above its surface water quality standard, but as estimated values. Detections were reported in December 2015 (0.33J ug/L), May 2016 (0.35J ug/L), February 2017 (0.2J ug/L), and August 2017 (0.21J ug/L) at one sample location in Park Brook (PAB-01), adjacent to the PMP area, above its SWQS of 0.15 ug/L. In the annual sampling event in August 2016, benzene was reported below (0.12J ug/L) the SWQS at this same location in Park Brook. 1,4-dioxane has been detected in surface water samples. NJDEP has not developed a SWQS for 1,4-dioxane but, as a point of comparison, the Ecologically-Based Screening Level for 1,4-dioxane presented and approved by USEPA in the Site-Related Groundwater Ecological Assessment (SRGEA) is 22,000 ug/L. Bis(2-ethylhexyl)phthalate has also been detected above its SWQS; however, this compound is not considered a Site-related COC. It was not detected above its SWQS in the most recent August 2017 annual sampling event.

Sally's Pond at concentrations above its GWQS[4]. The results of the RI and subsequent testing performed and presented in the RI Addendum, including the nature and extent of COCs, support the conclusions that (1) the Site characterization data indicate that there is no identifiable, discrete source for the residual concentrations of COCs in groundwater within the PMP Area and/or within the PMP Air Shaft mine structure and associated mine workings, including benzene, chloroethane, 1,4-dioxane, and metals COCs, including arsenic and lead, which are also naturally occurring and/or not associated with a discrete source, (2) there is no complete pathway to human or environmental receptors associated with Site COCs in groundwater, and (3) potential risk to a hypothetical future resident is not significant, if groundwater was ever used as a potable resource or for domestic use.

As used in this FFS, an identifiable, discrete source refers to an individually distinct source separate from potential contributions of COCs from the larger waste/fill mass in the land ACs, or from naturally occurring sources and the larger mine workings, any of which may be contributing COCs to groundwater. This distinction is important in assessing remedial action alternatives that are practicable for an identifiable, discrete source, but impracticable for addressing a large waste mass that may contribute COCs, but in a diffuse manner. This distinction is discussed in more detail in the sections that follow for the evaluation of the various remedial action alternatives.

As is discussed in greater detail in the sections that follow, even though there is an absence of complete exposure pathways; potential human health and ecological risk are not significant; and a discrete, defined source of COCs has not been identified, concentrations of COCs are present in groundwater above the SDWA MCLS and New Jersey GWQS, from contributions of COCs potentially from both natural and anthropogenic sources.

3.2.2 Conceptual Site Model

The Groundwater RI presents a detailed description of the Conceptual Site Model (CSM) for groundwater that includes the inter-relationship between overburden and bedrock

[4] Comparison to the GWQS is provided as a point of reference, but GWQS are not applicable to surface water quality, and are not applicable to a surface water ecological assessment.

groundwater, the mine workings, and surface water. The CSM is summarized here and the reader is referred to the Groundwater RIR for additional detail.

3.2.2.1 CMP Area

The CMP Area is a former mine pit located on a bedrock ridge in the southern portion of the Site, adjacent to the cul-de-sac at the end of Van Dunk Lane. The CMP Area has underground mine workings and a mine pit that was closed by blasting in the sides. The pit was filled to ground surface after it was initially closed, when it was used as a permitted landfill.

The CMP is located on a bedrock ridge, and as a result the overburden is thin to non-existent. Therefore, groundwater occurs in the shallow and deeper bedrock and within the mine pit, but the overburden, where it occurs, is too thin to sustain a water-bearing zone and is unsaturated. The bedrock aquifer is monitored in multiple zones ranging from tens of feet in depth to approximately 500 feet below ground surface (bgs). As described in Section 2, based on observed monitoring well yields the hydraulic conductivity of the bedrock aquifer is low to very low. The bedrock is interconnected with the mine workings, albeit this interconnection is controlled by the low hydraulic conductivity of the aquifer.

Groundwater flows radially away from the bedrock ridge toward Mine Brook to both the east and west. The center of the ridge represents an approximate location of a groundwater divide (see Figure 3) and the CMP is located at this divide. The overall CSM for the CMP Area is illustrated on Figure 4A.

3.2.2.2 PMP Area

The PMP Area is located at the head of a valley with the terrain consisting of a relatively flat area where the mine pit is located in the northern portion of the Site, at the end of Peters Mine Road. Groundwater in the PMP Area occurs in the overburden, shallow bedrock, and deeper bedrock. The overburden is up to 60 feet thick in the PMP Area and the depth to groundwater in the overburden ranges from 12 to 17 feet bgs. Similar to the CMP Area, the bedrock aquifer is monitored in multiple zones ranging from tens of feet in depth to approximately 500 feet bgs, and based on observed monitoring well yields the hydraulic conductivity of the bedrock aquifer is low to very low. The bedrock is interconnected with the mine workings, albeit this interconnection is controlled by the low hydraulic conductivity of the aquifer. Groundwater flow in the overburden and bedrock is generally to the south-southeast (see Figures 1 and 2).

The results of the Groundwater RI, including the geochemical and environmental tracer study show that in the PMP Area, groundwater in bedrock has an upward vertical gradient. Because of this upward gradient, shallow bedrock groundwater is mixing with the overburden groundwater, and discharge is eventually to the adjacent Park Brook and into the low-lying area of the seeps identified as SR-3 Seeps 1 and 2. Surface water within Park Brook discharges into Sally's Pond that ultimately discharges to Ringwood Creek approximately 1 mile upstream of its confluence with the Wanaque Reservoir. The reservoir is located approximately 1.5 miles downstream of the PMP Area.

The Air Shaft groundwater flow study conducted during the Groundwater RI documents an upward gradient in the PMP Air Shaft, with reducing conditions at depth and increasing oxygen levels in the groundwater moving upwards in the PM Air Shaft. A fluid log plot for the PMP Air Shaft is illustrated on Figure 4B. Figure 4B illustrates the presence of a thermal and geochemical stratification of the water in the air shaft at approximately 170 to 180 feet bgs. Referred to as a thermocline and a chemocline, these are common phenomena in flooded mine workings where stratified conditions exist as a result of isolated mine areas that have no drainage or flow pathway at depth. The presence of a thermocline creates conditions that limit the physical mixing between the water above and below the depth of stratification.

The overall CSM for the PMP Area is illustrated on Figure 4C.

3.2.2.3 OCDA

The OCDA is a former aboveground mine process waste disposal area, and there are no mines or underground workings associated with the OCDA. Fill materials were historically deposited on top of the mine waste materials. Consequently, investigation of the OCDA focused on characterization of the fill material, underlying mine waste materials, and native soil.

Overburden soils at the OCDA are typically on the order of 40 feet thick, and are underlain by the regional bedrock. Shallow groundwater flows through the native overburden soil up gradient of the OCDA then through OCDA fill materials and mine process waste prior to discharging to Park Brook and wetlands on the eastern, downgradient OCDA boundary. Groundwater flow also occurs in the bedrock below the fill/waste and native soils. Groundwater flow in the shallow bedrock also exhibits upward gradients with eventual discharge to Park Brook (see Figures 1 and 2).

The overall CSM for the OCDA is illustrated on Figure 4D.

3.2.3 Groundwater Remedial Investigation Findings

Implementation of the groundwater remedial investigations has included a comprehensive suite of field activities and data evaluation, including:

- Geologic investigation (e.g., fracture orientation) and evaluation;
- Monitoring well installation and groundwater sampling and analysis;
- Sampling and analysis of mine water contained within existing mine structures such as the PMP Air Shaft and the CMP Shaft;
- Surface water sampling and analysis;
- Groundwater flow and connectivity evaluations comprised of:
    - Environmental tracer study,
    - Flow characterization,
    - Surface water measuring stations and rain gauge installation,
    - Pressure transducer study,
    - Stable isotope probing and Bio-Trap® investigation, and
    - Compound-specific isotope analysis for 1,4-dioxane;
- Sediment investigation;
- Forensic analysis of Peters Mine Shaft;
- Human population survey; and
- Ecological investigation.

The results of these field activities and data evaluation are detailed in the Groundwater RIR (ARCADIS, 2015) and RIR Addendum (Cornerstone, 2018a). These comprehensive surface water, mine water, and groundwater investigations were completed between 2005 and 2017, and were used to characterize the residual conditions and supplement historical data to develop a Site-wide conceptual site model (CSM) that provides the framework for describing the nature, extent, fate, and transport of Site-related constituents or COCs. The Site-specific COCs include benzene, chloroethane, 1,4-dioxane, arsenic, and lead.

Key findings of the Groundwater RIR and RIR Addendum are provided below.

- The comprehensive monitoring well network and surface water sampling locations, coupled with the geologic, hydrogeologic, geochemical, and environmental data accumulated over the last 30 years of investigation activities at the Site, have enabled the characterization of the nature and extent of Site-related COCs in groundwater and an understanding of Site-wide groundwater flow pathways.

- The occurrence, movement, and connectivity of groundwater in and between the bedrock and overburden layers at the Site is understood. Geophysical, environmental tracer, isotope, and geochemical studies indicate that groundwater from shallow fractured bedrock moves upward into overburden where groundwater then discharges to surface water. Deep bedrock groundwater studies indicate a potential upward gradient; however, well purging data show that yield is very low to negligible, indicating that actual flow through fractures at depth is negligible. Groundwater and stormwater that infiltrated into the underground mine workings after cessation of mine operations is essentially trapped and held in storage, with little flow back out and into the fractures of the surrounding fractured bedrock aquifer.

- The CSM describes the occurrence, distribution, and fate and transport of constituents in groundwater and surface water. The key elements of the CSM, as previously described, are that there is very little groundwater flow in the deep bedrock, minimal flow in shallow bedrock, and upward movement of groundwater from the shallow bedrock and overburden, and groundwater discharges to surface water streams that ultimately flow to and through the surface water system downstream to the Ringwood Creek. Routine sampling of the surface waters confirms that natural recovery mechanisms at work under current conditions are limiting the migration of Site-related constituents in surface water and groundwater which dissipate before the farthest downstream segments of the surface water system are reached.

- The collective Site characterization data have not identified a discrete source for the residual concentrations of COCs in groundwater. The Site COCs of benzene, 1,4-dioxane, chloroethane, arsenic, and lead do not correlate to a single or discrete source. In the case of arsenic and lead, the concentrations are also associated with natural sources. As such, the Site-related COCs may be as much associated with the overall system of mine workings at the Site or natural sources as with historical disposal practices, as illustrated by the following:

  - Benzene is a common constituent in lubricants and petroleum products that would have been in widespread use in the mine workings.

  - A focused investigation in the OCDA (see further discussion below) indicated no discrete source of 1,4-dioxane within the fill/waste. 1,4-dioxane was also detected above its 0.4 ug/L GWQS at a concentration of 13.6 ug/L in bedrock monitoring well RW-2 (279'-289' depth interval) located adjacent to the CMP Shaft, and evidence of paint waste in the CMP Area was not identified during the RI, although ten drums that contained plant-type waste (not paint waste) were found in the area and were characterized and disposed of off Site. Of note, while 1,4-dioxane is most commonly associated with chlorinated solvents as a stabilizer, it was also available commercially as a solvent as early as the 1920s and has been used widely in commercial products (Mohr, 2010).

  - Chloroethane's predominant past use was in the manufacture of tetraethyl lead used as an anti-knock compound in fuel, and is also a degradation product of chlorinated solvents, any of which could be associated with multiple anthropogenic sources.

  - Lead was a common fuel additive, has been detected in paint waste, and is also naturally occurring in soils.

  - Arsenic, naturally occurring in the soils, bedrock, and mine tailings at the Site, has also been found in paint waste

- Overall, collectively, the findings of the RI and supplemental RI activities indicate that the Site-related COCs are not associated with a single or discrete source and may be associated with either the waste/fill, the larger mine workings, or naturally occurring sources. To the extent the data indicate they are associated with the larger mine workings or are naturally occurring, this is a significant consideration in the evaluation of groundwater remedial action alternatives.

- Groundwater analytical results show that concentrations of COCs, although exceeding SDWA MCLs and New Jersey GWQS at some well locations, are consistently in the ug/L range and are limited in areal extent to the immediate vicinity of one or more Land ACs. Recent groundwater, surface water, and mine water sampling results for the Site-specific COCs are presented in Tables 1 to 8. Benzene, chloroethane, and 1,4-dioxane are generally localized to the PMP Area with sporadic detections of benzene and 1,4-dioxane in the CMP and OCDA; arsenic is primarily reported in the OCDA and to a lesser extent the PMP Area; and lead is sporadically reported in the PMP Area, OCDA, and CMP Area. Figures 5 through 14 illustrate the distribution of these Site-specific COCs in the overburden and bedrock aquifers. Figures 5 through 14 provide an overview of these constituents differentiating locations where the COCs were not detected, were detected but are below the GWQS, or were detected above the GWQS. These figures depict monitoring data for the two most recent Site-wide sampling events in 2016 and 2017, with the highest concentration from the two events used to prepare the figures. While there is some spatial and temporal variability of COC concentrations in groundwater and mine water over time, the 2016 and 2017 data are considered representative for illustrating groundwater quality conditions. The reader is referred to the Groundwater RIR and RIR Addendum for additional data details, and Tables 1 through 8 for a summary of recent groundwater, mine water, and surface water sampling results.

- In addition, Figures 15 and 16 illustrate the 1,4-dioxane concentrations in overburden and bedrock groundwater/mine water as isoconcentration lines in the PMP Area and OCDA. This mapping could not be performed for the CMP Area as the distribution of all COCs is intermittent and sporadic. Only 1,4-dioxane is mapped as the other COCs are found within the limit of detections of 1,4-dioxane, and the detections of other COCs, such as intermittent detections of lead and arsenic, are even more sporadic and not amenable to isoconcentration mapping. For the bedrock 1,4-dioxane isoconcentration lines, the highest concentration measured at any depth interval is used for the mapping. As would be expected in a bedrock aquifer of low hydraulic conductivity and variable interconnectivity of fractures as exist at this Site, the measured concentrations of 1,4-dioxane vary at individual locations. Nonetheless, by mapping the highest concentration at any depth interval, which is a conservative approach, a general representation of the overall lateral extent of benzene and 1,4-dioxane emerges that is consistent with the Conceptual Site Model, and which indicates that Site COCs are contained onsite and do not extend off-Site in groundwater at concentrations above GWQS.

- As previously described, other than 1,4-dioxane that is discussed further below, COCs are generally not detected in surface water at the Site and none are reported above SWQS in surface water beyond the Site boundaries. Benzene is localized and reported at trace concentrations in the SR-3 seeps and the Cannon/Diamond Seep, but was not detected in the 2014 pore water sampling conducted within the Park Brook. In the nine surface water sampling events performed since January 2015, benzene is the only Site-related constituent detected nominally above the surface water quality standard at one location, but at estimated values. Detections were reported in December 2015 (0.33J ug/L), May 2016 (0.35J ug/L), February 2017 (0.2J ug/L), and August 2017 (0.21J ug/L) at one location in Park Brook (PAB-01), adjacent to the PMP area, above its SWQS of 0.15 ug/L. In the annual sampling event in August 2016, benzene was reported below (0.12J ug/L) the SWQS at this same location in Park Brook. Chloroethane is not detected in surface water. Arsenic and lead are periodically reported in the four streams at the Site, including upstream of the Land ACs, but not at the downstream confluence with the Ringwood Creek, and these COCs also have natural sources in the soil and/or bedrock at the Site.

- With respect to 1,4-dioxane, it has been detected in groundwater primarily in the PMP Area, with concentrations decreasing in the down-gradient direction from the PMP Air Shaft, however, there is no established temporal concentration trend based on the database developed since this COC was identified in 2015. 1,4-dioxane has been reported in groundwater at well OB-17 in the OCDA at concentrations above its GWQS and at levels below the GWQS in other OCDA wells; however, the results of a focused investigation of unsaturated and saturated soil and paint fragment samples conducted in 2016 indicated no 1,4-dioxane in soil/fill and, therefore, no specific OCDA source. 1,4-dioxane was also detected in CMP Area bedrock monitoring well RW-2 at depth (279'-289' interval) and in the deep CMP Shaft groundwater but not in the shallow bedrock suggesting that the 1,4-dioxane concentrations are not likely attributable to an identifiable discrete source, and their detection at depth only may not be associated with past disposal practices but rather the historic mining operations.

- 1,4-dioxane has also been detected in surface water samples in low, part per billion concentrations, well below the ecologically-based screening level (EBSL) of 22,000 ug/L, but above its GWQS[5], although not detected downstream of Sally's Pond. Since the NJDEP does not have an ecological screening value or surface water quality standard for 1,4-dioxane, an alternative, an EBSL from the Michigan

[5] Comparison to the GWQS is provided as a point of reference, but GWQS are not applicable to surface water quality, and are not applicable to a surface water ecological assessment.

Department of Environmental Quality (MDEQ), was used for the Site-specific EBSL with agency concurrence/acceptance. The MDEQ EBSL is considered protective of freshwater species and is also the lowest EBSL for 1,4-dioxane identified from US state agencies (Arcadis, 2017). In addition, 1,4-dioxane has never been reported in public water supplies in Ringwood, other than trace, sporadic detections that were subsequently verified as non-detect, the nearest of the public water supply wells being approximately two miles from the Site.[6] 1,4-dioxane was also not detected in private potable wells within approximately one mile of the Site at the Eleanor G. Hewitt School and the Ringwood Manor State Park as previously discussed in Section 3.1, and discussed further below. Figures 17 through 21 illustrate the distribution of Site COCs in surface water based on results from the 2016 and 2017 annual sampling events.

- Concentration trend analysis shows indications of declining benzene concentrations in groundwater in the PMP Area, and at a minimum, the benzene concentrations are consistently at low levels, which is believed to be due to ongoing natural attenuation (including microbial degradation among other natural mechanisms) which the results of the RI have shown is occurring under the existing moderately reducing pre-remediation groundwater conditions at the Site. Biodegradation of benzene was conclusively demonstrated through a Stable Isotope Probing (SIP) and BioTrap® study (although at lower rates in the PMP Air Shaft), in which each location tested showed that ^{13}C was incorporated into biomass showing that microbial populations capable of degrading benzene exist in the PMP Area groundwater. The groundwater analytical data from 2005 to the present show the low levels of benzene and trace levels of other VOCs (many below their respective GWQS but still present) to be representative of PMP Area groundwater. The benzene data from September 2014 (wells SC-01 and RW 6A) and March 2015 (wells SC-01 and RW-6) are inconsistent with historical data. Supplementary groundwater sampling and evaluation of the data has been performed that verifies these benzene concentrations have not been replicated and, therefore, are not considered representative of groundwater quality. Data analysis that further supports the conclusion that the

[6] See November 2016 USEPA Fact Sheet for additional conclusions regarding 1,4-dioxane.

data from September 2014 and March 2015 are not representative of overall groundwater conditions in the PMP are reported in the Groundwater RIR Addendum (Cornerstone, 2018a).

- In the PMP Area, where the groundwater flow pathway was documented as part of the RI using natural environmental tracers, the data indicate that groundwater discharges to Park Brook. However, benzene in groundwater is attenuated by one or more natural mechanisms prior to discharging to Park Brook surface water with low levels sporadically reported but most sample locations indicating no benzene detected. Surface water sampling results with comparison to EBSLs and SWQS indicate that discharge of groundwater to surface water is not of ecological or human health concern.

- In general, benzene is mostly detected in the moderately reducing groundwater environment within and downgradient of the PMP Area (see Figures 5 and 10 for a graphical representation). The PMP groundwater geochemistry shows the preferential scavenging of oxygen, nitrate, and sulfate from the groundwater. With distance farther downgradient of the PMP reducing zone and in the vicinity of the OCDA, the effects of recharge and higher dissolved oxygen concentrations in groundwater and surface water demonstrate that benzene is attenuated to below detection levels.

- To assess potential degradation of 1,4-dioxane, during the August 2016 annual sampling event at the Site, samples were collected for compound-specific isotope analysis (CSIA) of 1,4-dioxane. The CSIA results can provide an indication of biotic or abiotic degradation through changes in isotope ratios. The lighter isotopes are degraded first with a concomitant accumulation of heavier isotopes as a result. The results of the CSIA indicated no measurable biotic or abiotic degradation of 1,4-dioxane. However, there is a more limited groundwater quality data set for 1,4-dioxane, as sampling for this compound on an individual basis and using the preferred USEPA Method 8270 with isotope dilution, only began in May 2016 after use and evaluation of several different analytical methods. Given that concentrations of 1,4-dioxane decrease in the downgradient direction with distance from the PMP Area, this decrease is evidence of natural attenuation even if the data cannot specifically distinguish between physical, chemical, and/or biological contributions, all of which could be concurrently at work.

- In addition to the CSIA analyses, the RIR Addendum included a screening model (BIOCHLOR) of 1,4-dioxane concentration declines with distance, along a transect coincident with bedrock fracture orientation, to further assess the fate and transport of this compound. This modeling indicates that 1,4-dioxane concentrations will decline below the GWQS for 1,4-dioxane of 0.4 ug/L downgradient of the PMP Area on-site, irrespective of whether biodegradation may or may not be occurring, and also indicates that with the understanding of 1,4-dioxane fate and transport, delineation is complete for this compound for the purpose of this FFS.

- Analytical data for organic compounds in overburden groundwater in the CMP Area and OCDA show that water quality meets the surface water quality standards with sporadic exceptions that are not associated with the Site. For example, pentachlorophenol was detected in several wells at low level, estimated concentrations, and this compound is also detected in two wells, upgradient from the CMP some 1,600 feet, indicating this is not Site related. The only other compounds detected above surface water quality standards are singular, low-level, estimated concentrations of hexachlorobenzene and MTBE, neither of which is associated with the Site, and neither of which is detected in adjacent surface water.

- Arsenic and lead are detected sporadically in groundwater with many of the historical concentrations reported in groundwater reflective in whole or in part to particulates in the samples (i.e., total concentrations are elevated while dissolved concentrations are not), particularly in overburden groundwater.

- Furthermore, as discussed in the Groundwater RIR (Arcadis, 2015a), recent data generated during the 2014 groundwater sampling event using an alternative analytical method for quantification of arsenic concentrations also indicate that previous historic rounds of sampling may be biased high for dissolved arsenic due in part to interference from rare earth elements, which further supports the conclusion that arsenic is not a prevalent COC in groundwater.

- Analytical data for metals and cyanide from overburden groundwater in the CMP Area and OCDA shows that the water quality meets the surface water quality standards for FW-2 streams at NJAC 7:9B, except for sporadic detections of naturally occurring minerals (e.g., iron, manganese, arsenic).

- Similarly, there are no adverse impacts to Ringwood's municipal drinking water supply wells located two miles farther downgradient of the Site and in a separate sub-watershed from the Site, and the wellhead protection areas for the Borough's wells are located in the immediate area of the wells and not in the vicinity of the Site (see Title Sheet of the figures for locations).

- As a part of the RIR Addendum, one private potable well at the Eleanor G. Hewitt School well and five private potable wells at Ringwood State Park were sampled by the Borough of Ringwood [Alpha Analytical performed the sampling and analysis for the Borough under the supervision of the Borough's environmental consultant, Excel Environmental Resources, Inc. (Excel)] on August 15 and 16, 2018. The School well sample was analyzed for the required primary and secondary SDWA parameters plus 1,4-dioxane, which includes all of the Site COCs, to be consistent with the School's routine potable well sampling program. Samples from the five Ringwood State Park wells were analyzed for the same parameters as the Site's annual sampling program (volatile and semi-volatile organic compounds, metals, PCBs, and general chemistry). The results of this potable well sampling confirm the Conceptual Site Model and the absence of any adverse impact on groundwater quality at the potable well locations. All of the parameters, including the primary Site COCs (1,4-dioxane, benzene, chloroethane, arsenic, lead) were either not detected (i.e., 1,4-dioxane, benzene, chloroethane), or if sporadically detected (i.e., arsenic, lead) were detected well below NJ GWQS or federal MCLs.

- As a part of the RI, analytical data were collected and a forensic evaluation was conducted on a sample of the sediments at the base of the PMP Air Shaft to evaluate the source of COCs detected in the sediment. The forensic evaluation included a direct comparison of polycyclic aromatic hydrocarbons, a cluster analysis of metals, a direct comparison of metals concentration and distribution, and an evaluation of VOC and SVOC distributions. Ford concluded that the sediment contains products related to manufactured gas plant sources (i.e., creosote, which is commonly found in mine timbers) and combustion sources (like urban dust/combustion from cars, gasoline-fired engines, or even fires), not paint waste. Apart from the possible explanation of sources, Table 9 provides a comparison of the concentrations of detected compounds in the Air Shaft sediment sample to the New Jersey Residential Direct Contact Soil Remediation Standards (RDCSRS) and the Default Impact to Groundwater Soil Screening Levels (IGWSSL). As shown in Table 9, none of the compounds were detected at concentrations above the RDCSRS, and only benzene, beryllium, and mercury were detected at concentrations above the Default IGWSSL, with only benzene a Site-related COC. These data suggest little potential for the sediments to be a discrete, Site-related source to groundwater.

3.3 Risk Assessment Summary

As a part of the remedial investigations performed at the Site, a BHHRA and SRGEA were completed (Arcadis, 2015, 2017, 2018). This section summarizes the results of these risk assessments.

As previously noted, drinking water is supplied to residents in the Borough of Ringwood from well fields located within a different sub-watershed downgradient and approximately two miles southeast of the Site (see the Title Sheet of the attached figures). Groundwater and surface water are not used for potable or domestic purposes at the Site. Consequently, there is currently no complete exposure pathway for groundwater. However, a portion of the Site is zoned for residential use and the State of New Jersey has classified the aquifers at the Site as Class IIA, meaning that groundwater can potentially be used for potable purposes. Consequently, the BHHRA assumes that a hypothetical future resident could be exposed to COCs in Site-related groundwater via ingestion as drinking water as well as via inhalation and dermal contact while showering or bathing because, although groundwater is not used for potable or domestic purposes, the potential future use of groundwater is not currently prohibited based on the Class IIA designation of the aquifer. In addition, the USEPA requested a separate, distinct hypothetical exposure scenario assuming that water in the PMP Air Shaft is used as a potable supply.

The BHHRA risk characterization was then completed using a series of conservative assumptions and exposure scenarios, based on both overburden and bedrock groundwater data for the period from 2008 to 2017, including that the hypothetical future resident could use groundwater and mine water at the Site for both drinking and showering. The findings of the BHHRA indicate that the potential risk associated with these exposure scenarios may be summarized as follows:

- A calculated potential cancer risk of $2x10^{-4}$ (USEPA acceptable risk range is $1x10^{-6}$ to $1x10^{-4}$) for the hypothetical future resident, reasonable maximum exposure (RME) scenario for groundwater as a potable supply, primarily as a result of potential exposure to arsenic in groundwater;

- A calculated potential cancer risk of $4x10^{-4}$ for the hypothetical future resident RME scenario assuming mine water in the PMP Air Shaft is used as a potable water supply;

- An estimated percentage of the population with a blood lead level for a young child resident less than the USEPA's target threshold of five percent, for groundwater as a potable supply;

- Hazard indices assessed by target organ for the future hypothetical resident RME scenario for the adult, older child, and young child, all at or below the USEPA's target hazard index limit of 1, for groundwater as a potable supply;

- Hazard indices assessed by target organ for the future hypothetical resident RME scenario for the adult, older child, and young child, at or below the USEPA's target hazard index limit of 1 except for the GI tract organ due to iron concentrations, for mine water as a potable supply.

The target organ hazard index for the GI tract is above the hazard index of 1 for mine water due to iron, which is naturally occurring and is not a Site-related COC.

Both the groundwater and mine water potential cancer risks are only slightly above the USEPA acceptable cancer risk range, and these risk estimates are considered very conservative for the following reasons:

- **Overburden groundwater with particulates that increase arsenic concentrations** (i.e., dissolved arsenic concentrations are low) and which is not representative of groundwater quality because the upper 50′ of an aquifer cannot be used for water supply (NJAC 7:9D-2.3(a)3.i), and because particulates would not be sustained in an active water supply well;

- **The assumption of a 52-year exposure duration** used in the risk estimates, as opposed to the 26-year USEPA default exposure duration assumption;

- **Use of a conservative shower model** that likely over estimates risk particularly for less volatile compounds;

- **Arsenic is a Site-related COC as well as found in mine tailings and naturally occurring**, and it is not possible to distinguish the relative risk contributions from the various sources, but each would contribute; and

- **The mine water is not representative of groundwater**, and the water in the PMP Air Shaft would not be used as a potable water supply, and is not groundwater as relates to the NJDEP Class IIA aquifer designation.

For the above reasons, and as further detailed in the BHHRA, the human health risk assessment calculations are not representative of a significant potential risk to human health for the purpose of this FFS, even though very conservative potential exposure scenarios can be hypothesized and calculations performed that result in risk estimates slightly higher than the USEPA acceptable risk range.

The Site-Related Groundwater Ecological Assessment (SRGEA) (Arcadis, 2017) evaluated the site-related constituents of potential ecological concern (COPECs) of benzene, 1,4-dioxane, chloroethane, arsenic and lead, using the highest reported concentrations in groundwater and surface water. These concentrations were compared to the EBSLs, and there were no exceedences of the EBSL for any COPEC. Consequently, the overall conclusion of the SRGEA is that the "…the potential for ecological risk associated with the five COPEC reported in both groundwater and surface water or additional COPEC selected in sediment is low and no further evaluation is warranted."

In addition to the Human Health and Ecological Risk Assessments, a report separate from the Remedial Investigation entitled *Final Report of the Potential Fate and Transport of Benzene, 1,4-Dioxane, Lead and Arsenic at the Ringwood Mines Superfund Site Relative to the Wanaque Reservoir* (Jacobs, 2017) was prepared on behalf of the North Jersey District Water Supply Commission (NJDWSC) to assess the potential risk of Site-related COCs reaching the Reservoir at concentrations above drinking water standards or health-based levels. While the Jacobs Report concluded the risk is low, it recommended groundwater to surface water modeling, as well as additional monitoring well locations, largely because it deemed that if 1,4-dioxane were to ever reach the NJDWSC treatment plant intake, then the finished water supply quality could be impacted. In addition, Jacobs recommended implementing an active treatment approach, particularly for the PMP Air Shaft, because of concerns over potential migration of 1,4-dioxane down gradient toward the Wanaque Reservoir.

Following release of the above report, the NJDWSC provided information regarding the Reservoir and inputs to the Reservoir for the years 2014 (partial), 2015 (partial), 2016 (full year), and 2017 (partial) that were used in analytical modeling of potential Site-related COCs, in particular 1,4-dioxane, and the potential for it reaching the Reservoir. These modeling calculations are presented in the RIR Addendum and in a report entitled *Assessment Modeling of Potential 1,4-Dioxane Transport* (Cornerstone, 2017a). The modeling presented in the RIR Addendum and Assessment Modeling Report are summarized as follows:

- Using multiple conservative assumptions including the highest measured surface water concentration of 1,4-dioxane at the Site reaching surface water at Ringwood

Creek just prior to the inlet to the Wanaque Reservoir, the modeling showed that 1,4-dioxane would be non-detect at the Wanaque Reservoir.

- Using multiple conservative assumptions and the highest measured groundwater concentrations of 1,4-dioxane at the PMP Air Shaft discharging to surface water at Ringwood Creek just prior to the inlet to the Wanaque Reservoir, the modeling showed that 1,4-dioxane would not be non-detect at the Wanaque Reservoir.

Despite the absence of any information indicating that groundwater at the Site could have an impact on the water quality of the Wanaque Reservoir, in the sections that follow, active remedial action alternatives for the PMP Air Shaft are evaluated.

4 REMEDIAL ACTION OBJECTIVES

Remedial action objectives (RAOs) have been established to select and evaluate remedial action alternatives for groundwater that will protect human health and the environment; consider the requirements of USEPA and NJDEP Standards, Criteria, and Guidelines; provide practical, cost-effective remedial action; and utilize permanent remedies to the extent possible. Site-specific RAOs were developed based on the media of concern; the nature and extent of Site-related COCs in groundwater; and the Site geologic, hydrogeologic, and geochemical conditions.

Groundwater beneath the Site is classified by the NJDEP as Class IIA, which means that, although it is not used as a potable or domestic resource, it has the future potential for such uses. Based on the Class IIA aquifer designation, and the results of the risk assessments as described in the previous section, the medium-specific RAOs for Site-related groundwater include:

- Prevent consumption of groundwater containing COC concentrations above their respective NJDEP GWQS.
- Prevent exposure to groundwater by residents, which would exceed the USEPA's risk benchmarks of an additional lifetime cancer risk range between 1×10^{-6} and 1×10^{-4}, and a lifetime non-carcinogenic hazard index of less than 1.0.
- Restore the aquifer to Class IIA GWQS within a reasonable time frame, and to the extent practicable for Site-related COCs.

5 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

This section outlines Federal and/or State environmental regulations and laws which can be used for evaluation of the remedial alternatives for the Site. Such requirements are typically referred to as applicable or relevant and appropriate requirements (ARARs). The ARARs may be applicable to the constituent(s) of interest, location of the remedial action, or the type of remedial action. Both Federal and State environmental regulations and laws are considered. The Federal and State ARARs presented in this section are then used subsequently for screening and evaluating remedial alternatives and the permit equivalency (i.e., permits are not required under CERCLA) requirements that may apply.

"Applicable" requirements are standards and requirements promulgated under Federal and/or State environmental laws that specifically address a constituent of concern, remedial action or location of a site.

"Relevant and Appropriate" requirements are standards and requirements promulgated under Federal and/or State environmental laws that, while not directly applicable, may be suitable to address a constituent of concern, remedial action or location of a site.

"To be Considered" (TBC) requirements are local ordinances, unpromulgated criteria, advisories, or guidance that do not meet the definition of ARARs but that may assist in the development of remedial objectives or cleanup criteria, or evaluation of alternatives, particularly where ARARs may not address each aspect of a remedial alternative.

ARARs fall into three general categories, which are determined on the basis of how they are applied at a site. These categories are as follows:

- Chemical-specific: These ARARs typically define concentration-based limits for specific constituents in an environmental medium. An example of a chemical-specific ARAR is a groundwater quality standard.

- Location-specific: These ARARs set restrictions on remedial activities at a site due to its proximity to specific natural or man-made features. An example of a location-specific ARAR would be wetlands regulations, assuming a portion of a remedial action were performed in a regulated wetland.

- Action-specific: These ARARs set controls and restrictions on the remedial action to be used at the site. Each remedial action will be governed by appropriate action-specific ARARs that will specify performance standards for the remedial action. A NJPDES permit for discharge to surface water is an example of an action-specific ARAR, which would apply to an action such as discharge of groundwater that is managed as part of a remedial alternative.

The chemical, location, and action-specific ARARs potentially applicable to the Site are presented in Table 10. TBCs that may be potentially applicable are also noted in Table 10. While the remedial alternatives for the Site are to be developed to meet the remedial action objectives presented in Section 4, implementation of a remedial alternative may have other environmental or permit equivalent considerations. Therefore, the ARARs represent a range of regulatory jurisdiction pertaining to the following broad categories: air, groundwater, sediment, surface water, soil, wetlands, hazardous and solid waste, and fish and wildlife. Compliance with ARARs is part of the evaluation criteria used in the screening process for the detailed analysis of the remedial alternatives presented in Section 8.

6 IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES

This section of the FFS describes the screening evaluation of technologies[7] from which the alternatives are identified for further development and detailed evaluation. This is the first step in the development of alternatives. The technology screening starts with the identification of general response actions, and then is followed by the technology screening organized by the three Land ACs. The screening process was performed in accordance with USEPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*, EPA/540/G-89/004 (USEPA 1988a).

6.1 Identification of General Response Actions

General response actions are broad categories of remedial response that may meet the remedial action objectives and provide technologies applicable to site-specific characteristics. From these general response actions, remedial action alternatives and/or techniques are developed that can be used individually or in combination to achieve the RAOs established for the Site. The overall general response actions available for groundwater are summarized as follows:

- No action;
- Monitored Natural Attenuation (MNA) coupled with a CEA (i.e., institutional control) with a WRA to restrict the future use of groundwater;
- Active in-situ remediation of COCs reported in groundwater in the PMP Area, including in the PMP Air Shaft and/or groundwater downgradient of the PMP;
- Active groundwater extraction from the PMP Area and downgradient followed by ex-situ treatment and discharge of treated groundwater onsite; and

[7] Identification and screening of remedial technologies and process options was also completed as part of the *Memorandum of Candidate Technologies for Site-Related Groundwater* (Cornerstone, 2017), which was approved by the USEPA in a letter dated April 4, 2018.

- Active groundwater extraction from the PMP Area and downgradient followed by ex-situ treatment and recirculation of treated groundwater to Site groundwater.

6.2 Preliminary Screening of Technology Types and Process Options

Specific technologies and process options applicable to the general response actions for groundwater are evaluated in this section. The purpose of the preliminary evaluation is to evaluate remedial action technologies or combinations of technologies that can be technically implemented for the specific COCs applicable to each Land AC at the Site. The preliminary screening of each alternative is performed based on Site-specific factors including COCs, geology and hydrogeology, the technical feasibility of the alternative given the COCs and Site setting, the advantages and disadvantages of the alternative, and relative cost. Subsequent evaluation of alternatives that are retained through the screening process, based on the nine evaluation criteria specified in the National Contingency Plan, is then presented in Section 8 that follows. Table 11 presents a summary of the remedial action alternative screening step, the details of which for each remedial action alternative are presented in the sections that follow.

6.2.1 Peters Mine Pit Area: PMP/Downgradient Groundwater and PMP Air Shaft

The prior remediation activities at the Site, the OU2 remedial actions for the Land ACs (PMP Area, CMP Area, and OCDA), the removal actions, and the current site characterization data have not identified a discrete source for the residual VOC and SVOC concentrations in groundwater within the PMP Area and/or within the PMP Air Shaft or associated mine workings, including the Site-specific COCs of benzene, chloroethane, 1,4-dioxane, lead, and arsenic. In the absence of a specific source of these COC concentrations within the PMP or PMP Air Shaft a remedial action to target an actual source cannot be designed or implemented and, therefore, such an approach is infeasible.

In addition, the abundance of decaying organic material within the PMP as well as within the PMP Air Shaft, including wood and debris, tree limbs, leaves, etc., represent competitive “sinks” that would diminish the effectiveness of any active in-situ remedial action technique designed to come in contact with the COC mass that may be causing the concentrations reported in the PMP Area groundwater.

For example, in-situ chemical oxidation (ISCO) involves the introduction, commonly by injection, of a commercially available oxidant to the saturated zone whereby the oxidant can react with the organics to create free radicals and/or transfer electrons to remediate the COCs. To affect remediation, the oxidant must contact the constituent mass, but since the actual location of the constituent mass is not specifically known (or even reasonably identifiable) and the PMP is filled with materials that include competing organic material and iron, ISCO and any other similar in-situ remedial action technologies are not feasible within the PMP Pit itself. Within the PMP, the abundance of decaying organics within the materials used to fill the Pit--coupled with the abundance of iron associated with the iron ore residuals--would be oxidant "sinks" that would compete for and consume the oxidant. This direct competition between the abundance of decaying organic material and iron in comparison to some low-level source located somewhere within the PMP, or the underlying mine system, creates an insurmountable challenge for the oxidant to come in direct contact with the constituent mass causing the low levels reported in groundwater within and downgradient of the PMP.

In fact, the low levels of benzene and other COCs in groundwater within the PMP Area are not consistent with a definitive source, but are more likely associated with a non-specific source or sources, and possibly some contribution, albeit likely small, from diffuse sources adsorbed within lower permeability lithologies [i.e., fine-grained soils or crystalline rock which has defined but low matrix porosity and diffusivity (Mutch et al, 1991)]. The results of the Site-Related Groundwater RI (ARCADIS 2015a), BHHRA (ARCADIS, 2015b, 2017), Site-Related Groundwater Ecological Assessment (SRGEA) (ARCADIS, 2017), and Groundwater RI Addendum (Cornerstone, 2018a) support the conclusion that there is no complete discharge pathway and no ecological risk, and limited potential for human health risk above USEPA benchmarks associated with historic disposal activities. However, evaluation of remedial action alternatives is warranted based on the very conservative exposure assumptions and risk calculations for potential use of groundwater as a potable source and the numerical exceedances of the GWQS and/or MCLs.

However, for the aforementioned reasons, any active remedial action alternative to be considered for groundwater in the PMP Area would be implemented downgradient of the PMP Air Shaft and PMP Pit as a "barrier" approach for addressing the residual COC concentrations within the plume. Alternatives associated with the PMP Air Shaft itself are discussed separately in Section 6.2.2 that follows.

With the above as background, specific technology options are screened in the sections that follow.

6.2.1.1 No Action

No Action involves no remedial action for the reduction, control, or monitoring of future human health or ecological risks associated with COCs in groundwater in the PMP Area.

This alternative would not actively reduce the mobility, toxicity, or volume of COCs in groundwater; although, natural attenuation processes are expected to continue to reduce the concentrations of benzene, chloroethane, 1,4-dioxane, and arsenic in groundwater over time. However, such reductions would not be documented because there would be no monitoring program in place, and no institutional control would be implemented to verify that groundwater use is restricted and human health and the environment continues to be protected. In Addition, a No Action scenario would not provide monitoring data to document whether conditions are unchanged.

Since there are numerical exceedances of the GWQS and/or MCLs for certain COCs in groundwater, No Action would not be an effective technology for achieving the RAO for preventing potential future groundwater consumption or achieving aquifer restoration to the extent practicable within a reasonable timeframe.

This alternative could be implemented without technical or administrative limitations; however, the NJDEP regulatory requirement for a CEA as an institutional control to document any non-naturally occurring, non-secondary metal COC exceedances would be necessary for regulatory compliance even under the No Action scenario.

There is no capital cost associated with this alternative.

No Action is retained as a potential alternative as a baseline for comparison to other alternatives.

6.2.1.2 Monitored Natural Attenuation with a CEA/WRA

Natural attenuation mechanisms include the natural, physical, chemical, and/or biological processes that reduce COC concentrations in groundwater or surface water based on existing Site conditions without active remediation. MNA is used to collectively describe these processes and monitor their effect on COC concentrations over time. This remedial action alternative is designed to monitor through quantitative data gathering whether or not site-specific RAOs are being achieved. Stable or decreasing trends in the concentration of COCs in groundwater over time provide a primary line of evidence that one or more of the natural attenuation mechanisms are taking place and the net result is overall plume contraction or, at a minimum, plume stability as COC mass reduction occurs over time.

Geochemical, microbiological, and other indicator parameters also provide supplemental, or secondary and tertiary lines of evidence to document that groundwater conditions are conducive to natural attenuation. These data are also used to demonstrate that one or more of the natural attenuation processes is occurring, including microbial degradation of COCs which was documented to be occurring in the PMP Area based on the results of the Stable Isotope Probing (SIP) and Bio-trap® study conducted as part of the Site-Related Groundwater RI (ARCADIS, 2015a).

The locations evaluated in the SIP/Biotrap® study included the PMP, the PMP Air Shaft, and key overburden and bedrock monitoring wells downgradient of both the PMP and the PMP Air Shaft. As detailed in the Groundwater RIR (ARCADIS, 2015a), the results showed that Carbon 13 was incorporated into microbial biomass at all PMP locations included in the SIP/Bio-Trap® study, providing conclusive evidence that microbial populations capable of degrading benzene exist in PMP Area groundwater. These data further confirm that benzene is actively being degraded by indigenous microbes in PMP Area groundwater under the existing moderately reducing, pre-remediation conditions at the Site.

During the August 2016 annual sampling event at the Site, samples were also collected for compound-specific isotope analysis (CSIA) for 1,4-dioxane at select PMP Area bedrock well locations. The CSIA results can provide an indication of biotic or abiotic degradation through changes in isotope ratios. The lighter isotopes are degraded first with a concomitant accumulation of heavier isotopes as a result. The results of the CSIA indicated no measurable biotic or abiotic degradation of 1,4-dioxane along the bedrock well flow transect that was included in the evaluation. However, there is a more limited groundwater quality data set for 1,4-dioxane, as sampling for this compound began in 2015 and analysis using the preferred USEPA Method 8270 with isotope dilution, only began in May 2016 after use and evaluation of several different analytical methods. Given that concentrations of 1,4-dioxane decrease in the downgradient direction with distance from the PMP Area, this decrease is evidence of natural attenuation even if the data cannot specifically distinguish between physical, chemical, and/or biological contributions, all of which could be concurrently at work. In addition, as the groundwater analytical data base increases through future monitoring that will be performed per both the OU-2 ROD and the eventual OU-3 ROD, temporal and spatial concentration trends will be further assessed, all of which is important to the ongoing assessment of MNA.

MNA (along with a CEA/WRA) would effectively restrict potential future exposure to COCs by restricting the future withdrawal and use of groundwater in the PMP Area for most purposes, including potable and domestic uses. This alternative includes routine, active monitoring of groundwater quality and the natural attenuation processes that are expected to continue to reduce the mobility, toxicity, and volume of benzene, 1,4-dioxane, and chloroethane concentrations in groundwater over time. In addition, the monitoring of groundwater geochemical conditions will help to determine whether the conditions exist for continued, sustainable natural attenuation of some or all of these COCs. Since Site-related COCs in groundwater under current conditions pose no significant potential risk to human health (i.e., the groundwater is currently not in use as a potable water supply and residents are provided water from the Borough's water supply located in another sub-watershed), and there is no unacceptable ecological risk to surface water based on COC concentrations in comparison to EBSLs, the MNA approach would be an effective remedial action alternative for the PMP Area COCs in groundwater. In addition, this alternative would go hand in hand with the monitoring associated with the OU2 Land AC remedy approved for the PMP Area.

As necessary to develop and implement an MNA remedy, additional wells would be installed down gradient of the PMP Area. The additional monitoring wells would expand the MNA network and provide additional supporting data to confirm that down gradient concentrations of Site-related COCs are below their respective GWQS on Site due to the currently demonstrated natural attenuation processes. Such additional wells would also function as sentinel wells. Key wells within the additional monitoring well network would also be utilized to assess and further evaluate the potential application and location of MNA enhancements, if deemed necessary, as detailed in Section 6.2.1.3 below.

This alternative could be implemented without technical, administrative, or regulatory limitations or waivers. MNA with a CEA/WRA would consist of routine monitoring of COCs in groundwater over time, along with continued monitoring of groundwater geochemical conditions to document that conditions are conducive to continued natural attenuation. A long-term monitoring program would be established for specific existing or additional site monitoring wells and surface water sampling locations in accordance with this alternative and the OU2 ROD. As data are generated, a detailed analysis of geochemical data and flow pathways would be performed to assess the effectiveness of MNA and, after the first full year of monitoring, to identify any necessary improvements to the monitoring plan in accordance with the USEPA Office of Solid Waste and Emergency Response (OSWER) Directive for MNA (USEPA, 1999). Follow-up evaluations would be performed periodically to confirm the continued effectiveness of MNA.

There are limited (e.g., additional monitoring and sentinel wells) capital costs associated with MNA and the operation and maintenance (O&M) costs associated with this remedy are relatively low in comparison to other groundwater remedial action alternatives. An indefinite timeframe is associated with MNA because there is no definitive source of the residual benzene, 1,4-dioxane, chloroethane, lead, and arsenic in the PMP Area and monitoring over time is necessary to document that (1) COC concentrations are decreasing or stable and natural attenuation is continuing and (2) RAOs are achieved. This results in ongoing costs for groundwater and surface water sampling and laboratory analyses, data reduction, evaluation, reporting, and assessment of the overall MNA progress over the duration of the monitoring.

MNA with a CEA/WRA is retained as a potential remedial action alternative for detailed evaluation for the groundwater down gradient of the PMP Area. Note that remedial action is not proposed for the pit in the PMP Area for the reasons previously discussed in Section 6.2.1. The PMP Air Shaft is evaluated separately in subsequent subsections of this document.

6.2.1.3 Enhanced MNA Treatment Barrier with a CEA/WRA

Enhanced MNA downgradient of the PMP would include the injection of electron acceptors, such as oxygen, sulfate, or nitrate, and/or nutrients in a treatment barrier approach, to enhance the natural COC biodegradation process (principally benzene) that is occurring under existing, pre-remediation groundwater conditions. In addition, the preferred biodegradation pathway for 1,4-dioxane is aerobic through both direct metabolism of 1,4-dioxane as a growth supporting substrate or co-metabolism by certain monooxygenase-expressing aerobic microorganisms that utilize other organic compounds as growth substrates and co-oxidize 1,4-dioxane. If the dominant mechanism of 1,4-dioxane microbial degradation is co-metabolism, the monooxygenase-expressing organisms require oxygen, and to date, based on the published literature, application of other terminal electron acceptors as a substitute for oxygen has not been demonstrated to be effective.

To address the organic COCs in groundwater in the PMP Area, Enhanced MNA utilizing oxygen as the preferred electron acceptor should, therefore, be the focus of this evaluation. Increasing dissolved oxygen concentrations will also enhance precipitation and co-precipitation of arsenic along with other reactive metals, such as iron given its abundance in groundwater at this former iron mine site.

The injections would occur downgradient of the PMP and PMP Air Shaft at a location that will be identified following installation and sampling of additional monitoring wells. As previously discussed, because there is no definitive source of COCs identified within the PMP and/or PMP Air Shaft and there is an abundance of degrading organic material (e.g., wood debris, leaves, etc.) and an abundance of iron that will compete for and consume available electron acceptors, the active bio-enhancement component of this alternative can only be feasibly conducted downgradient of the PMP by creating a reactive zone or barrier through which groundwater containing COCs would flow.

Injection would be accomplished through the use of permanent injection wells or geoprobe points using a reactive zone/barrier approach in the overburden between the PMP and PMP Air Shaft and down-gradient groundwater. In addition, injection would also occur in select locations (e.g., adjacent to the PMP Air Shaft) within the bedrock groundwater. Use of wells or geoprobe points (overburden only) would depend on the selection of commercially available electron acceptor remediation products and their solubility/injectability, etc. A reactive zone/barrier approach would be used and designed to increase the biodegradation rate of organic COCs as groundwater flows through the treated area. Other natural COC attenuation mechanisms such as dilution, dispersion, and adsorption would continue to occur after implementing enhanced biodegradation and MNA. Following the bio-enhancement/treatment barrier activities, MNA would be implemented with a CEA/WRA as described in Section 6.2.1.2. As monitoring is conducted, geochemical and hydrogeologic data would be generated and evaluated to assess the effectiveness of MNA and, after the first year of MNA, an evaluation would be conducted and the need for potential adjustments evaluated based on the empirical data. The evaluation would help define where and what adjustments may provide the most benefit in reducing the need for any additional injections, the duration of monitoring, and the duration of the MNA and CEA/WRA.

Ultimately, groundwater geochemistry would be evaluated and commercially available electron acceptors/reagents would be selected based on their compatibility and anticipated longevity in the subsurface downgradient of the PMP Area. As discussed in detail in Section 6.2.1.2, geochemical and other indicator parameters provide supplemental lines of evidence to document that groundwater conditions are conducive to natural attenuation and that one or more of these natural attenuation processes are occurring. Increasing dissolved oxygen levels can enhance aerobic biodegradation of the organic COCs in the PMP Area, including the biodegradation pathways for 1,4-dioxane in the presence of monooxygenase-expressing microorganisms.

Additionally, the SIP and Bio-Trap® study conducted in the PMP Area confirmed the presence of microbial populations that are degrading organic COCs in the PMP Area groundwater under the existing moderately reducing conditions. Biodegradation of organic COCs at the Site would be facilitated if conditions were less reducing and more aerobic. Enhanced MNA would, therefore, be accomplished by providing additional oxygen as the preferred electron acceptor and creating an oxidizing environment.

Enhanced MNA along with a CEA/WRA would effectively restrict potential future exposure to COCs by restricting the future withdrawal and use of groundwater in the PMP Area for most purposes, including potable and domestic uses. This alternative would include active monitoring of groundwater quality and the attenuation processes that are expected to continue to reduce the mobility, toxicity, and volume of organic COCs in groundwater over time. Since COCs in groundwater under current conditions do not pose significant potential risk to human health (i.e., groundwater is not used as a potable supply) and there is no adverse impact to surface waters based on COC concentrations by comparison to EBSLs, although implemented downgradient of the PMP and Air Shaft because the specific source of the low level VOCs is not specifically known and to avoid competing oxidant sinks, this would be an effective remedial action alternative for the PMP Area groundwater in the event that COC concentrations are shown to be increasing over time.

This alternative could be implemented without technical, administrative, or regulatory limitations or waivers. Note that several rounds of injection would likely be required to maintain the reagent levels required for Enhanced MNA to be effective and since a definable source has not been identified within the pit or PMP Air Shaft and the remedy would be implemented downgradient in a barrier approach, the duration of any active enhancement cannot be determined, but would likely be long-term. Injection radius of influence may be limited for specific reagents due to local soil type, resulting in a high density of injection points. Similarly, the distribution of reagents within the underlying shallow bedrock would be difficult given the low hydraulic conductivity and, based on the upward vertical flow gradient documented within the PMP Area, active enhancement would be primarily focused to the overburden aquifer. There are moderate capital costs associated with this remedy, and the O&M costs associated with this remedy are moderate in comparison to other groundwater remedial action alternatives.

The Enhanced MNA Treatment Barrier with a CEA/WRA is retained as a potential remedial action alternative for detailed evaluation for the groundwater down gradient of the PMP Area. Note that remedial action is not proposed for the PMP pit for the reasons previously discussed in Section 6.2.1.

6.2.1.4 In-Situ Chemical Oxidation

ISCO involves the introduction, commonly by injection, of a commercially available oxidant to the saturated zone whereby the oxidant can react with the organic COCs to create free radicals and/or transfer electrons to remediate the COCs. Examples of oxidants include hydrogen peroxide, ozone, calcium peroxide, sodium percarbonate, permanganate, and persulfate. These oxidants range in longevity from hours to days (hydrogen peroxide and ozone) to weeks to months (permanganate, persulfate). ISCO requires direct contact between the oxidants and the COCs for remediation to occur and, as such, are typically injected into defined source areas to allow direct contact with the contaminant mass. Other natural attenuation mechanisms such as dilution, dispersion, and adsorption would continue to occur after implementing ISCO. Natural attenuation processes, including microbial degradation of organic COCs, would be temporarily interrupted by the ISCO process, but would resume within the remediated area after completion of ISCO and after re-establishment by the natural microbial population.

ISCO is applicable to the organic COCs in the PMP groundwater including benzene, 1,4-dioxane, and chloroethane. Addition of an oxidant (and potentially an activator in the case of persulfate ISCO), would increase the redox potential of the groundwater and create a more oxidizing and aerobic environment in the groundwater. Note that consideration must be made that creating a more oxidized environment could result in the localized immobilization of certain inorganics in groundwater, including arsenic, but possibly enhance the solubility of some inorganic COCs such as lead and/or secondary metals that tend to be more soluble under oxidized conditions thus creating unpredictable consequences in terms of overall impacts to groundwater quality.

Implementation of ISCO in the PMP Area would likely be completed using injection wells in a reactive zone/barrier-style approach for treating groundwater as it flows from the PMP Area in the downgradient direction given that there is far too much decaying organic material and iron within the PMP Pit itself that would compete for and consume any oxidant that was injected into the PMP resulting in the need to repeatedly inject oxidant with no focused location to target. Even in the downgradient direction, multiple rounds of injection would be required to maintain the oxidant levels in the overburden and shallow bedrock aquifers. Multiple rounds of injection would be necessary given the naturally reducing groundwater geochemical conditions that occur within the PMP and areas immediately downgradient due to the abundance of degrading organic material within the PMP (e.g., wood debris, leaves, etc.), and the abundance of iron (associated with the iron ore residuals), that would act as oxidant sinks (i.e., would compete for and consume the oxidant). Chemical oxidants, for the most part are also short lived in the environment, and as such are better to be deployed to address a well-defined source, as opposed to downgradient treatment of a plume with no definitive source or source area.

Capital costs would be moderate for this alternative. The O&M costs would be high in the long-term due to the need for multiple injections given the competitive oxidant consumption issues noted above coupled with the difficulty in delivering the oxidant and ensuring radial distribution of the oxidant in the fractured bedrock.

ISCO is not retained as a potential technology in the detailed alternatives evaluation for groundwater downgradient of the PMP based on the following:

- ISCO is targeted to source mass removal, and there is no definitive source for the oxidant to target within the 89,270 cubic yards of material located within the PM Pit so ISCO would have to be implemented to address groundwater downgradient of the PMP itself in a barrier-style approach.

- The moderately reducing groundwater geochemical conditions that occur in the areas immediately downgradient of the PMP due to the abundance of degrading organic material within the PMP (e.g., wood debris, leaves, etc.), along with the abundance of iron associated with the iron ore residuals, would be oxidant sinks, thus negating the effectiveness of ISCO at remediating any residual organic COC mass.

- Dissolved-phase metals (specifically iron) in the moderately to strongly reducing groundwater conditions within and immediately downgradient of the PMP Area would also act as an oxidant sink that would require repeatedly overdosing of an oxidant in an effort to try to overcome this sink.

- Chemical oxidants, for the most part are also short lived in the environment, and as such are better to be deployed in defined sources, as opposed to downgradient treatment barriers for a plume.

- Oxidation of the groundwater may mobilize other metals such as lead among others causing unpredictable and potentially adverse changes in groundwater quality. Whereas, under existing conditions, the results of the RI and risk assessments for Site-Related Groundwater do not indicate significant adverse impact to human health or the environment (ARCADIS, 2015a, 2015b, 2017), which could be altered by such adverse changes in groundwater quality.

- There would be a high cost of implementing ISCO in the long-term due to the need for repeated injections over time given the highly competitive oxidant consumption issues noted above.

- The moderate to high costs of operation of ISCO over what would likely be an indefinite timeframe of implementation due to the fact that there is no definitive source area mass to target within the PMP Area.

6.2.1.5 Air Sparge/Soil Vapor Extraction

Air sparge/soil vapor extraction (AS/SVE) involves injection of air into the saturated zone where it can strip VOCs from the water and/or create more aerobic conditions that facilitate the COC biodegradation which the Groundwater RIR (ARCADIS 2015a) has documented is occurring for benzene in the PMP Area under existing, pre-remediation conditions. The volatilized compounds are then extracted from the soil gas in the unsaturated, or vadose, zone using an SVE system. If there are low COC concentrations in the vapor, active SVE, specifically the collection and treatment of the vapor prior to discharge to the atmosphere may not be necessary. However, for purposes of this evaluation, it is assumed that active vapor collection and treatment would be required.

AS/SVE is applicable to volatile organic COCs in groundwater downgradient of the PMP, including benzene and chloroethane. In addition, AS would promote aerobic conditions in the groundwater, thereby enhancing natural attenuation in the groundwater via microbial degradation of the organic COCs, including benzene, chloroethane, and 1,4-dioxane if the aerobic microorganisms capable of directly metabolizing or co-metabolizing this compound exist in the PMP saturated zone.

Implementation of AS/SVE would need to be completed using injection wells in a barrier style approach in the overburden downgradient of the PMP to create a sparge curtain within the PMP Area. Continuous operation or periodic pulsing of the system would be required to maintain sufficient contact between volatile COCs in the groundwater and the sparge curtain. Application in the bedrock would not be appropriate due to the limited fracture porosity and resulting minimal radius of influence within the bedrock in the PMP Area.

In addition, the overburden downgradient of the PMP Area is characterized by up to 50 feet of unconsolidated sediments that are dominated by poorly sorted glacial tills--with intermittent lenses of silty and clayey sand--all of which show seasonal fluctuation of saturation evidenced by stream beds, surface water, and shallower sediments being dry during summer and early fall months. Such heterogeneity adds significant complexity to placing vertical sparge points that can affect mass via the vertical migration of sparged air bubbles. Sparge points could effectively target more permeable zones; however, some of the residual COC mass is likely entrained/adsorbed in the lower permeability matrices of the overburden itself, which are not transmitting water. The Site-specific geology and changing water table also pose challenges for placement of SVE points that would be required to recover VOC mass stripped during AS operations.

The capital cost for AS/SVE would be moderate to high due to the need for multiple injection wells, sparge pumps, vacuum pumps, a power drop and connection to the Site, and lateral trenching to run the subgrade piping associated with the AS and SVE components of the system. The ongoing O&M costs would be moderate.

AS/SVE is not retained as a potential technology for detailed evaluation for groundwater downgradient of the PMP. Note that remedial action is not proposed for the PM pit itself for the reasons previously discussed in Section 6.2.1 and the PMP Air Shaft is evaluated separately in subsequent subsections of this document. The reasons for ruling out this remedial action alternative are as follows:

- The technical difficulty and questionable ability to create and sustain a continuous vertical curtain of sparged water within the PMP Area due to the significant heterogeneity of the overburden geology within and immediately downgradient of the PMP Area.

- Given its low Log K_{oc} and Henry's Law Constant, this technology would not effectively strip 1,4-dioxane from groundwater or saturated soil, therefore, it does not address all of the Site-specific organic COCs through the primary physical removal mechanism, even though it may potentially enhance microbial biodegradation

- Even without the SVE component, the capital costs would be high given the area that would require sparging (equipment, trenching and power drop requirements). The AS/SVE technology would cost substantially more than Enhanced MNA, but would only be as effective if the challenges of delivering air discretely into small vertical intervals could be overcome.

- The moderate to high O&M costs due to the elevated naturally occurring iron and manganese levels in groundwater in the PMP Area and the resultant fouling of the sparge well screens that would occur.

- The moderate to high costs of operation of what would likely be an indefinite timeframe of implementation due to the fact that there is no definitive source area mass to target within the PMP.

6.2.1.6 Groundwater Extraction, Treatment, and Discharge

Groundwater extraction, treatment, and discharge involves the physical removal of groundwater by pumping extraction wells to recover groundwater in an effort to reverse the groundwater flow gradient thus creating some degree of hydraulic control of the groundwater to minimize the potential for migration of COCs. Constituent mass in the recovered groundwater would also be removed. Under this scenario, extracted water would be treated above ground before being discharged to a publicly owned treatment works or, more likely at this Site, to surface water under a New Jersey Pollutant Discharge Elimination System permit.

Although not an efficient constituent mass removal technique, when subsurface conditions are appropriate, groundwater extraction could be effective at providing containment of the dissolved-phase COCs in groundwater within the PMP Area. However, at this Site, capture effectiveness in the crystalline bedrock may be limited by the low-yield and resulting minimal radius of influence as well as the lateral discontinuity of the bedrock fractures.

Groundwater extraction would likely be implemented using extraction wells in an effort to create hydraulic capture zones downgradient of the PMP Area focusing on the well locations with the comparatively higher benzene and 1,4-dioxane concentrations in the overburden and shallow bedrock. Extracted water would be treated using either activated carbon, shallow tray aeration or a similar VOC stripping technique before being discharged. In addition, based on its chemical characteristics, treatment of 1,4-dioxane would likely require an additional treatment process such as enhanced oxidation or resin adsorption. Continuous and long-term operation and monitoring of the groundwater extraction and treatment systems would be required.

The capital cost for groundwater extraction and treatment would be high due to the need for extraction wells, pumps and/or a vacuum pumping system, lateral trenching for subgrade piping, holding tanks, an effective above ground treatment system (which would need to include iron and other metals removal), and a power drop and connection to the system. The ongoing costs associated with O&M of the extraction and treatment system components would also be high due to multiple factors including: energy consumption; the elevated naturally occurring iron and manganese levels in groundwater in the PMP Area that will readily foul extraction well screens and various treatment system components; and a high degree of system maintenance as a result of the fouling of the treatment system components.

Groundwater extraction is not retained as a potential technology for detailed evaluation based on the following:

- Groundwater extraction and treatment is a technology to control migration of COCs to downgradient receptors or off Site. Under existing conditions, there is no significant human health or ecological risk associated with groundwater or surface water at the Site and no risk to any downgradient receptor, including the Wanaque Reservoir or the Borough's public water supply wells.

- The low yield of overburden and bedrock and limited lateral continuity of bedrock fractures as documented by the RI would limit the overall effectiveness of this alternative by limiting the ability to induce and sustain effective hydraulic control.

- The generally poor mass removal efficiency associated with groundwater extraction in comparison to in-situ remedial action alternatives. In addition, given the absence of a definitive source or elevated concentrations of benzene or 1,4-dioxane within the PMP itself as documented at well SC-01, the dissolution of residual mass is likely a contributor to the low-level concentrations of organic COCs reported in groundwater that are more efficiently addressed through natural biodegradation and other attenuation processes that the data indicate are ongoing.

- Pumping of groundwater stresses the flow regime and may have an unwelcome or adverse effect on the hydraulic communication among overburden, bedrock and mine features in and downgradient of the PMP Area and may adversely affect the COC concentration distribution. Under existing conditions, COC concentrations are comparatively low in the pit and areas downgradient of the PMP Air Shaft and COC concentrations already decrease in the down-gradient direction. Given the existing groundwater quality and absence of a significant human health or ecological risk under existing conditions, the downside risks outweigh any potential benefit associated with active groundwater pumping.

- The high capital cost (equipment and electrical power drop installation) and high O&M costs associated with pump and treat equipment operation and maintenance. The elevated naturally occurring iron and manganese levels in groundwater in the PMP Area will result in fouling of extraction well screens and treatment system components necessitating a high frequency of maintenance.

- The high costs of operation of what would likely be a long-term period of operation and monitoring and an indefinite timeframe of implementation due to the inefficient mass removal associated with this alternative and the fact that there is no definitive source area mass to target in the PMP itself.

6.2.1.7 Groundwater Extraction, Treatment, and Recirculation

Extraction, treatment, and recirculation involves the physical removal of groundwater by pumping extraction wells and, in doing so, reversal of the groundwater flow gradient, thus creating some degree of hydraulic control of the groundwater to minimize the potential for migration of COCs down gradient of the source area. Under this scenario, extracted groundwater would be treated above ground before being reinjected to the subsurface. Reinjection of the treated groundwater would likely increase the natural hydraulic gradient in the immediate vicinity of the PMP Area and could accelerate the dissolution of COCs via pore water flushing in the overburden, assuming that the overburden is a source of the COCs in the PMP Area groundwater. However, a recirculation approach more aggressively stresses the flow regime and this could have unwelcome or adverse effects on the hydraulic communication among overburden, bedrock and mine features and in and down gradient of the PMP Area, as previously discussed in Section 6.2.1.6.

In addition to the low yield of the overburden and bedrock aquifers in the PMP Area, one of the biggest challenges to effective implementation of this alternative is the presence of elevated iron in the PMP Area groundwater given the natural abundance of iron and manganese in the vicinity of this former iron mine. Since reinjected treated water is highly oxidized, this will significantly exacerbate fouling of the screens of the recirculation wells themselves and in the immediate vicinity of the extraction and recirculation wells.

Although not an efficient remedial action technique in comparison to others, groundwater extraction, treatment, and recirculation could be effective at directly addressing dissolved-phase COCs in groundwater within the PMP Area if the subsurface conditions are conducive.

Implementation of groundwater extraction, treatment, and recirculation would likely be completed using extraction wells to create hydraulic capture zones to focus on the well locations with the comparatively higher benzene and 1,4-dioxane concentrations in the overburden and shallow bedrock. Extracted groundwater would be treated using either activated carbon/resin, shallow tray aeration, or a similar VOC stripping technique above ground before being reinjected to the subsurface, likely under a New Jersey Underground Injection Control permit. As noted previously, treatment of 1,4-dioxane may require an additional treatment process such as advanced oxidation or resin. Continuous operation of the groundwater extraction, treatment, and recirculation system would be required.

The capital cost for groundwater recirculation would be high due to the need for extraction wells, pumps or a vacuum pumping system, a power drop and connection for the Site, lateral trenching for subgrade piping, an above ground treatment system, holding tanks for treated water prior to reinjection, and a reinjection system with well points and associated pumps, piping, etc. The O&M costs associated with any groundwater treatment system and well network would be high due to elevated naturally occurring iron and manganese concentrations in the groundwater and the resultant fouling of extraction well and injection well screens and treatment system components, etc., necessitating a high frequency of maintenance.

Groundwater extraction, treatment, and reinjection is not retained as a potential technology for detailed evaluation based on the following:

- Groundwater extraction, treatment, and recirculation is a technology to control migration of COCs to downgradient receptors or off Site. Under existing conditions, there is no significant human health or ecological risk associated with groundwater or surface water at the Site and no risk of migration to any downgradient receptor, including the Wanaque Reservoir or the Borough's public water supply wells.

- The low yield of overburden and bedrock and the limited lateral continuity of bedrock fractures that would limit the overall effectiveness of the approach, by limiting the ability to move substantial volumes of groundwater and, therefore, to induce and sustain effective hydraulic control and achieve pore flushes, which is the inherent advantage of the technology vs conventional groundwater extraction.

- The generally poor mass removal efficiency associated with groundwater extraction and recirculation in comparison to in-situ remedial action alternatives, especially in the absence of a definitive source mass.

- Pumping of groundwater stresses the flow regime and may have an unwelcome or adverse effect on the hydraulic communication among overburden, bedrock and mine features in and downgradient of the PMP Area and may adversely affect the COC concentration distribution. Under existing conditions, benzene COC concentrations are comparatively low in the pit and areas downgradient of the PMP Air Shaft and COC concentrations already decrease in the down-gradient direction. Given the existing groundwater quality and absence of a significant human health or ecological risk under existing conditions, the downside risks outweigh any potential benefit associated with active groundwater pumping.

- The very high capital cost and high O&M costs associated with pump and treat equipment operation and maintenance due to the elevated naturally occurring iron and manganese levels in groundwater in the PMP Area. This would result in fouling of extraction and injection well screens and treatment system components necessitating a high frequency of maintenance.

- The high costs of operation of what would likely be a long-term period of operation and monitoring and an indefinite timeframe of implementation due to the inefficient mass removal associated with this alternative and the fact that there is no definitive source area mass to target within the PMP itself.

6.2.2 PMP Air Shaft

Concentrations of COCs, and in particular benzene and 1,4-dioxane, are among the highest detected at the Site in the mine water within the PMP Air Shaft which is largely stagnant water at the base of the shaft that is in hydraulic communication with the deeper historic iron mine system. However, the benzene concentrations, in the low part per billion range, are not indicative of a discrete, defined source area. For example, the highest measured concentration of benzene near the base of the Air Shaft is 33.2 ug/L and concentrations decrease vertically upward within the Shaft and in wells located in the downgradient direction. By comparison to the benzene solubility limit of 1,791 mg/L, the concentration at the base of the Air Shaft is only approximately 0.002% of the solubility limit which is not indicative of a discrete source.

Similarly, with respect to 1,4-dioxane, the concentrations at the base of the PMP Air Shaft have remained consistent based on the data collected to date, and also decrease vertically upward within the Air Shaft and in wells located in the downgradient direction. Concentrations of 1,4-dioxane detected in the Air Shaft are also in the part per billion range, despite the fact the 1,4-dioxane is miscible in water. If there was a discrete source within the Air Shaft, higher dissolved phase concentrations would be expected.

In addition, it is important to take into consideration that the concentrations of COCs in the water sampled from the Air Shaft are likely not representative of groundwater quality in the surrounding bedrock aquifer given that at the base of the Shaft, the mine water is largely stagnant and there is no practicable means by which to purge the Shaft as is routinely done prior to collection of a sample of groundwater from a monitoring well. The PMP Air Shaft is not isolated from the underlying mine system and, in fact, is connected directly to the inclined shaft of the Peters Mine, therefore, contribution of reported COC concentrations, as well as other naturally occurring constituents that make up the overall groundwater quality, should be anticipated.

In the absence of a specific and definitive source area mass to target as a presumed source within the PMP Air Shaft, any active remedial action alternative would only be treating water stored in the PMP Air Shaft, which as the RI indicates, is largely stagnant water stored within this remnant mine feature. Active remedial action alternatives would not be implemented in a typical saturated zone but into a standing body of water within the rock walls of the PMP Air Shaft which contains debris and natural detrital organic materials (including tree limbs, wood timbers, leaves, sediment, etc.) thus making it even more unlikely that reagents would come into contact with COC mass.

In the absence of a definitive source of COCs in the PMP Air Shaft mine water, and given the possibility that some amount if not all of the COCs in the mine water may be reflective of the water quality in the deeper mine and will, therefore, likely remain at levels similar to those documented over the course of monitoring, active remediation of the water stored within the PMP Air Shaft will likely have little to no remediation value. In addition, depending on the technique utilized, active remediation within the Air Shaft may disrupt the natural geochemistry and/or hydrology resulting in unwelcome, unpredictable and potentially detrimental effects.

However, because concentrations of COCs in the PMP Air Shaft are above their respective GWQS and, in the case of benzene and 1,4-dioxane, are the highest measured in groundwater or mine water at the Site, remedial action alternatives for the Air Shaft have been screened and are discussed in the subsections that follow. The alternatives screened for the PMP Air Shaft could be considered as stand-alone remedial action alternatives or used in combination with previously discussed options for the PMP Area groundwater.

6.2.2.1 No Action

Similar to the PMP Area, the No Action alternative for the PMP Air Shaft involves no remedial action for the reduction, control, or monitoring of the COCs above their respective GWQS in the mine water stored within the Air Shaft. This alternative would not actively reduce the mobility, toxicity, or volume of COCs in mine water in the Air Shaft; although, natural attenuation processes, such as biodegradation of benzene [as demonstrated by a SIP and Bio-Trap® study for benzene in the PMP Area in 2012 as part of the Supplemental Site-Related Groundwater RI (ARCADIS 2015a)], are expected to continue.

Note, however, that reductions of COC concentrations over time from natural attenuation processes would not be documented because the No Action alternative would have no monitoring program. As previously noted, there is no evidence of a definitive or discrete source within the Air Shaft and concentrations of COCs measured in the mine water in the Air Shaft may not be representative because of the stagnant water given that there is no way to properly purge the Shaft as is done prior to sampling a monitoring well. As such, while No Action would not actively seek to reduce COC levels in the mine water in the Air Shaft, it is not clear that the Air Shaft is a source of COCs distinct from the larger mine workings at the Site. Therefore, this alternative could be considered appropriate for the PMP Air Shaft as the historic iron mine workings are not the subject of the OU-3 Site-Related Groundwater remedial action or the RAOs discussed in this FFS.

This alternative is not disruptive to the current steady state water quality and geochemical conditions in the mine water within the PMP Air Shaft.

This alternative could be implemented without technical or administrative limitations because there is no defined activity.

There is no capital cost associated with this alternative.

No Action is retained as an alternative in the detailed evaluation as a baseline for comparison to other PMP Air Shaft alternatives, and as a stand-alone alternative.

6.2.2.2 Oxygen Diffusion via Chemical Addition in the PMP Air Shaft

As noted above, a SIP and Bio-Trap® study for benzene was conducted in the PMP Area in 2012 as part of the Supplemental Site-Related Groundwater RI (ARCADIS 2015a). The results of this study showed that ^{13}C was incorporated into biomass at all PMP locations included in the SIP/Bio-Trap® study, providing conclusive data that indigenous microbial populations capable of degrading benzene occur in groundwater in the PMP Area, including within the PMP Air Shaft and active degradation of benzene is occurring under existing, pre-remediation conditions. Benzene degradation is enhanced where redox conditions are more favorable (e.g., less reducing to aerobic conditions in overburden groundwater) and occurs at a slower rate where conditions are less favorable (more reducing and less aerobic conditions), as documented in the mine water at the 220- to 230-foot depth interval in the PMP Air Shaft.

Note also that the preferred biodegradation pathway for 1,4-dioxane is aerobic whether through direct metabolism or co-metabolism by aerobic microorganisms that produce monooxygenase enzymes. However, if the prevailing mechanism of degradation is co-metabolism, the microorganisms expressing the monooxygenase enzymes require oxygen and their use of other terminal electron acceptors has not been demonstrated to date.

Therefore, increasing the concentration of dissolved oxygen in the mine water could potentially facilitate degradation of both 1,4-dioxane and benzene, two of the primary organic COCs in mine water stored within the PMP Air Shaft.

Although the results of the RI demonstrate that mine water within the PMP Air Shaft is increasingly oxidized as it moves along the preferred flow pathway vertically within the Air Shaft itself from deeper to shallower depths and then downgradient of the PMP Air Shaft and biodegradation of benzene is already occurring along this flow pathway, an oxygen releasing substrate, such as calcium or magnesium peroxide, could theoretically be utilized to enhance aerobic conditions and biodegradation of organic COCs at the base of the PMP Air Shaft. This remedial action alternative could be implemented by installing several canisters containing calcium or magnesium peroxide in a solid form at various depths within the reducing zones of the PMP Air Shaft. Both calcium and magnesium peroxide have relatively low solubility as compared to other reagents, and as a result, these chemicals are less reactive and provide a slow release of oxygen over the course of several months to a year, depending on the strength of the dosage delivered, and the groundwater flux.

This remedial action alternative would be applicable in addressing organic COCs such as the residual benzene and 1,4-dioxane concentrations in the mine water in the PMP Air Shaft; however, there is no discrete source that has been identified within the PMP Air Shaft. In the absence of a discrete source to target and in the presence of reducing conditions in the mine water caused by an abundance of decaying organic material within the PMP Air Shaft (including decaying organic materials such as wood, tree limbs, leaves, etc.) as well as an abundance of iron that will compete for dissolved oxygen, this alternative would likely be ineffective at source mass removal.

This remedial action alternative would not substantially affect the mobility, toxicity, or volume of organic COCs beyond the PMP Air Shaft, as any diffused oxygen would follow the preferred pathway, which would be upward within the vertical PMP Air Shaft water column. Under existing conditions, dissolved oxygen levels in mine water already increase along this upward vertical flow pathway with oxidized conditions increasing from the 230-foot to the 180-foot to the 50-foot depth interval.

The capital cost for this alternative would be moderate to low. The ongoing O&M costs would be comparatively low.

This remedial action alternative has a number of concerns which have been considered in evaluating it for possible detailed evaluation, as follows:

- COC concentrations in mine water stored within the PMP Air Shaft do not pose any significant risk to human health or the environment, and treatment of mine water within the PMP Air Shaft would have a negligible effect on meeting long-term groundwater quality objectives since the data indicate decreasing concentrations in the downgradient direction beyond the PMP Air Shaft under existing pre-remediation conditions.

- In the absence of a specific and discrete source area mass to target within the PMP Air Shaft, this technology is only treating mine water stored in the PMP Air Shaft that is largely stagnant and concentrations of COCs may be associated with the mine workings and, therefore, may be sustained over the long term at similar levels. Where flow is documented, it is primarily upward within the shaft and dissolved oxygen levels already increase vertically along the upward flow pathway as documented by data from the 230-foot, 180-foot, and 50-foot depth intervals.

- Mine water in the lower sections of the PMP Air Shaft exhibits reducing geochemical conditions caused by an abundance of decaying organic material within the PMP Air Shaft (e.g., wood, tree limbs, leaves, etc. that are inadvisable to remove as discussed in Section 6.2.2.3) coupled with an abundance of iron at the base of the PMP Air Shaft associated with ore deposits and historic iron ore mining. The organic materials and iron would continually compete for and consume added dissolved oxygen thus diminishing the effectiveness of this remedial action alternative.

- Application of any active technology would likely be for an indefinite timeframe of implementation (and, therefore, costs would likely continue to mount over time) due to the fact that there is no discrete source area mass to target within the PMP Air Shaft, thus limiting the effectiveness of this technology in achieving significant mass removal or source reduction.

Despite these contra-indicating concerns, this alternative would have limited disruptive effects on the PMP Air Shaft, because it would involve only introducing a slow release oxygen compound using canisters. Disruption of the Air Shaft has the potential to change the existing steady-state geochemical and hydraulic conditions, which in turn would have the potential to cause unwelcome and unanticipated impacts on down-gradient groundwater, assuming that there may be COCs in the deeper portion of the Air Shaft and/or mine workings that could be affected by altering the steady-state conditions. Because of the low impact potential of this alternative, it is retained for detailed evaluation.

6.2.2.3 In-Situ Chemical Oxidation in the PMP Air Shaft

ISCO involves the introduction, commonly by injection, of a commercially available oxidant to the saturated zone whereby the oxidant can react with the organic COCs to create free radicals and/or transfer electrons to remediate the COCs, as discussed in detail in Section 6.2.1.4. Calcium and magnesium peroxide, as described in Section 6.2.1.4, are weak oxidants. This section addresses the delivery of a stronger chemical oxidant, such as sodium persulfate. Sodium persulfate is preferred, given its longevity in the subsurface (months), and its solubility. Other oxidants are either not applicable to benzene (such as permanganate) or too short lived (hydrogen peroxide, ozone, percarbonate, etc.).

However, even with use of sodium persulfate, multiple rounds of injection would be required to maintain the oxidant levels in the mine water at the base of the PMP Air Shaft given the naturally reducing groundwater geochemical conditions that occur in the deeper sections of the PMP Air Shaft due to the abundance of degrading organic material within the PMP Air Shaft itself, including wood debris, tree limbs, leaves, etc. and the abundance of iron associated with the iron ore residuals which would be oxidant sinks.

If utilized, implementation of ISCO in the PMP Air Shaft would involve injection of a sodium persulfate solution into various depths in the mine water reducing zone of the PMP Air Shaft to oxidize organic COCs. Sodium persulfate is corrosive to some forms of metal, such as carbon steel and brass. Existing drop tubes in the PMP Air Shaft are constructed of carbon steel, and therefore, new drop tubes would need to be installed that are made of a corrosion-resistant material, such as polyvinyl chloride or high-density polyethylene.

To be effective at reducing COC mass and, therefore, reducing residual concentrations in mine water stored within the PMP Air Shaft, the injected oxidant must come into contact with the mass of organics causing the residual benzene, 1,4-dioxane, and other COC concentrations in mine water at the base of the PMP Air Shaft. Since there is no discrete source area mass identified within the PMP Air Shaft and the oxidant would be injected directly into the standing mine water stored in the Air Shaft as well as competing with the decaying organics and abundant iron, ISCO would have to be repeated over and over again to maintain oxidant levels with no anticipated effectiveness at coming into contact with any discrete COC source, if it exists.

In addition, since the preferred flow pathway is vertically upward within the PMP Air Shaft itself and COC concentrations already decrease vertically in the mine water within the Air Shaft and in groundwater in the downgradient direction, there would be limited additional value with ISCO implementation in the PMP Air Shaft with respect to reducing mobility, toxicity, or volume of organic COCs in mine water or in groundwater downgradient of the PMP Air Shaft.

Note also that microbial degradation of organic COCs, which the results of the RI data has indicated is occurring under existing conditions, would be interrupted by the ISCO process during implementation. Since repeated rounds of ISCO injection would be required, this would effectively be an indefinite timeframe given that there is no discrete source mass to target, and an abundance of competing oxidant sinks in the mine water within the Air Shaft. Natural biodegradation processes would, however, be expected to resume within the PMP Air Shaft after cessation of ISCO treatment.

Capital costs would initially be low to moderate for this process option; however, the costs would be moderate to high in the long-term due to the need for repetitive injections over time and an indefinite period of implementation given that there is no discrete source area mass to target and an abundance of oxidant sinks in the mine water in the PMP Air Shaft that would compete for and consume the oxidant thus negating its effectiveness.

This alternative is not retained for the detailed evaluation based on the following:

- COC concentrations in mine water stored within the PMP Air Shaft do not pose any significant risk to human health or the environment, and treatment of mine water within the PMP Air Shaft would have a negligible effect on meeting long-term groundwater quality objectives since the data indicate decreasing concentrations in the downgradient direction under existing pre-remediation conditions.

- In the absence of a specific and discrete source area mass to target within the PMP Air Shaft, this technology is only treating mine water stored in the PMP Air Shaft that is largely stagnant and COC concentrations may be associated with the mine workings and, therefore, would likely be sustained over the long term at similar but generally low levels.

- Where flow is documented, it is primarily upward within the Air Shaft, and dissolved oxygen levels already increase vertically along the upward flow pathway as documented by data from the 230-foot, 180-foot, and 50-foot depth intervals.

- Mine water in the lower sections of the PMP Air Shaft exhibit reducing geochemical conditions caused by an abundance of decaying organic material within the PMP Air Shaft (including decaying organic materials, including wood, tree limbs, leaves, etc. that is inadvisable to remove as discussed in Section 6.2.2.5) and an abundance of iron at the base of the PMP Air Shaft associated with ore deposits and historic iron ore mining. These conditions would continually compete for and consume added ISCO reagent thus negating the effectiveness of this remedial action alternative. ISCO would, therefore, have to be repeated over and over again to maintain oxidant levels with no anticipated probability of coming into contact with the actual COC mass or source.

- Application of any active alternative would likely be for an indefinite timeframe of implementation (and progressively increasing remedial action costs over time) due to the fact that there is no discrete source area mass to target within the PMP Air Shaft and an abundance of decaying organics and iron competing for and consuming oxygen thus limiting the effectiveness of this alternative in achieving significant mass removal or source reduction if a source exists in the Air Shaft itself.

6.2.2.4 Biosparging of the PMP Air Shaft

Biosparging would involve injection of air into the subsurface where it can create more oxidized conditions to enhance aerobic biodegradation which the results of the Site-Related Groundwater RI confirm are already occurring with respect to benzene in mine water within the PMP Air Shaft under existing conditions. Implementation of biosparging in the PMP Air Shaft would involve installation of one or more drop tubes into the lower section of the Air Shaft, and using these points for the delivery of air via at grade compressors. Existing drop tubes in the PMP Air Shaft that are currently used for gauging depth to water would likely be converted into the injection points. The two existing drop tubes extend to depths of 180 feet and 230 feet, respectively. Based on the low levels of air expected to be delivered to enhance ongoing aerobic biodegradation processes (as opposed to air sparging), it is not anticipated that capture of extracted vapors or treatment of vapor would be required.

An air compressor would be used to inject air into the injection points. Air would be injected at pressures and flow rates sufficient to expand the radius of influence to cover the entire surface area of the PMP Air Shaft, and achieve target dissolved oxygen concentrations for enhanced aerobic biodegradation. A power drop would be required to operate the air compressor (alternative power sources, such as solar could also be evaluated). The nearest power connection point is currently approximately 2,000 feet away at Peters Mine Road.

Biosparging would be applicable to enhancing biodegradation of residual COCs including benzene and potentially 1,4-dioxane concentrations in mine water stored in the PMP Air Shaft, assuming that the microbes to metabolize or co-metabolize it occur in the mine water, and in creating more oxidized conditions that would enhance natural attenuation via microbial degradation of the organic COCs. Since there is no discrete source area mass identified within the PMP Air Shaft, the air would be injected directly into the standing mine water stored in the Air Shaft, and decaying organics and abundant iron at the base of the PMP Air Shaft would readily consume additional dissolved oxygen, biosparging would have to be implemented over an extended, if not indefinite, period of time.

In addition, since the preferred flow pathway is vertically upward within the PMP Air Shaft itself, dissolved oxygen levels already increase vertically within the mine water in the Air Shaft and in groundwater downgradient of the PMP Area, therefore, there would be limited additional remediation value with respect to reducing mobility, toxicity, or volume of organic COCs in mine water within or in groundwater downgradient of the PMP Air Shaft.

The capital cost for biosparging in the PMP Air Shaft would be low-moderate, driven by the cost for completing a power drop. The ongoing O&M costs would be initially low to moderate but would increase over time due to the elevated naturally occurring iron and manganese levels in the PMP Air Shaft and the resultant fouling of biosparging points.

This remedial action alternative is not retained for detailed evaluation based on the following:

- COC concentrations in mine water stored within the PMP Air Shaft do not pose any significant risk to human health or the environment, and treatment of water within the PMP Air Shaft will have a negligible effect on meeting long-term groundwater quality objectives since the data indicate decreasing concentrations in groundwater in the downgradient direction from the PMP Air Shaft.

- This alternative largely duplicates the option of oxygen diffusion, but with greater potential to be disruptive to materials adhering to the Air Shaft sidewalls or at the base of the Air Shaft, and at higher cost.

- In the absence of a specific and discrete source area mass to target within the PMP Air Shaft, this technology is only treating mine water stored in the PMP Air Shaft that is largely stagnant and COC concentrations may be associated with the mine workings and, therefore, may be sustained over the long term at similar levels.

- Where flow is documented, it is upward within the shaft and dissolved oxygen levels already increase vertically under existing pre-remediation conditions along the upward flow pathway as documented by data from the 230-foot, 180-foot, and 50-foot depth intervals.

- Mine water in the lower sections of the PMP Air Shaft exhibit reducing geochemical conditions caused by an abundance of decaying organic material within the PMP Air Shaft (e.g., wood, tree limbs, leaves, etc. that are inadvisable to remove as discussed in Section 6.2.2.5) and an abundance of iron at the base of the PMP Air Shaft associated with ore deposits and historic iron ore mining. These conditions would continually compete for and consume added dissolved oxygen thus negating the effectiveness of this alternative. Biosparging would, therefore, have to be repeated over and over again to maintain oxygen levels with no anticipated effectiveness with respect to reducing mobility, toxicity, or volume of organic COCs in mine water within or groundwater downgradient of the PMP Air Shaft.

- High naturally occurring iron and manganese levels in the PMP Air Shaft would result in increased O&M to address fouling of sparge points.

- High potential capital costs associated with a power drop.

- Application of any active technology would likely be for an indefinite timeframe of implementation due to the fact that there is no discrete source area mass to target within the PMP Air Shaft and an abundance of decaying organics and iron competing for and consuming oxygen thus limiting the effectiveness of this technology in achieving significant mass removal or source reduction.

6.2.2.5 Closure/Treatment in the PMP Air Shaft

This alternative would use conventional mine shaft closure technology with a remedial component to address the concentrations of COCs measured in mine water in the PMP Air Shaft. Permanent closure of the PMP Air Shaft by sealing the entire shaft has the added benefit of addressing the long-term physical safety issues surrounding the ground surface access to the Shaft. The shaft measures about 16 feet by 16 feet and is about 230 feet deep. Since there is no associated mine slope for men and material access or for ore removal, it is believed that this shaft was only used for ventilation of the mine. At the time of the Air Shaft construction (approximately 200 years ago) the technology used would have been blasting and hand loading the shot rock for removal by hoisting buckets out of the shaft. Since the shaft was not used for men and material access or for ore removal, the shaft was likely not lined with treated wood as would have been needed to guide a permanent hoisting system. This appears to be confirmed in the shaft video that was completed by Arcadis (April 2007). The shaft walls appear as bare rock once past the concrete collar, and are not smooth like the drilled shafts being constructed using today's technology. The camera used for the video was lowered twice and did not encounter severe obstructions such as collapsed timber lining as is fairly common in other abandoned shafts constructed during the same era.

Materials encountered in the shaft, as evidenced in the above-noted video, included a tree limb at the bottom of the shaft, three rectangular wood timbers measuring approximately 10" x 12" (termed cribs in the video report), and miscellaneous debris (e.g., boulders) and what appears to be organic biomatter, likely fungi. The timbers were estimated to be 6 to 8 feet long, with one laying on top of the other and located at a depth of about 182 feet below the top of the Shaft where there may be a connection to an upper level of the mine.

Based on experience and discussion with mine closure experts, design and construction of mine shaft closures does not include removal of materials such as the above-noted timbers as this has the potential to destabilize the shaft and possibly result in an unsafe environment for the closure workers. In addition, experience with design and construction of mine shaft closures, to our knowledge, never includes removal of materials such as the above-noted timbers at the depths encountered in the PMP Air Shaft. This practice would be considered by mine closure industry experts as an unsafe practice.

For example, the Pennsylvania Department of Environmental Protection, Bureau of Abandoned Mine Reclamation, which has sealed over 200 shafts and, therefore has substantial mine closure experience, and has never removed any materials below the water surface (communications with Mr. Dean Baker- Environmental Program Manager February 13, 2017). Equipment to remove the woody material at the depths that it occurs in the PMP Air Shaft is not readily available and would have to be designed and tested prior to use. There would also be a high potential to induce an unsafe condition for the closure workers if the shaft's sidewalls were destabilized by efforts to remove materials from the shaft, which is a possibility given the unknowns associated with this activity. If the shaft walls were to collapse, the area surrounding the shaft collar could also be destabilized and, therefore, unsafe for worker access. The amount of debris seen in the 2007 video and the success of lowering the video camera through the full depth of the shaft indicate that the shaft can be closed successfully using a grout without removal of debris thus avoiding unnecessary destabilization and safety risks.

As described above, conventional closure of the PMP Air Shaft would constitute isolation of the shaft and its contents from the surrounding environment. Given the preference under the Superfund Amendments and Reauthorization Act (SARA) for treatment to reduce toxicity, mobility, or volume, a treatment component could be applied to the base of the Air Shaft prior to closure as part of this alternative. A treatment component would also be incorporated into the closure using a similar method of analysis as the in-situ remedial action alternatives described in the preceding sections for oxygen diffusion, ISCO, and biosparging. In summary, these in-situ remedial action technologies are generally not feasible alternatives on their own (although oxygen diffusion has been retained for the FFS). This is in part because of the significant oxygen sink created by decaying organic matter and iron that would require ongoing dosing and/or operation but that would not be the case with permanent closure of the shaft since, once it is closed, the potential for continued dissolution of any source at the base of the shaft, if it exists, would be reduced. Post-closure disruption and long-term O&M associated with the Shaft would also be minimized. This alternative also has merit in light of the data that indicates that COC concentrations in the Air Shaft mine water are potentially reflective of the larger mine workings and, if the Air Shaft is a potential conduit for COC-impacted mine water, that potential would also be reduced.

Adsorbents [e.g., granular activated carbon (GAC) and/or resin] could be introduced into the base of the PMP Air Shaft prior to its closure. The GAC and/or resin would adsorb organic COC concentrations to varying degrees, including benzene, chloroethane (amenable to GAC treatment), and 1,4 dioxane (amenable to resin treatment). The effectiveness of the adsorbents would not be reduced by the subsequent physical closure of the Air Shaft following placement of the adsorbents because the adsorbed COC constituents would remain adsorbed. Also of note, the GAC would provide a substrate for biological activity (which was conclusively demonstrated for benzene using SIP as documented in the Groundwater RI Report). Based on the part per billion concentrations of COCs in the Air Shaft, the absence of a discrete source of COCs, and the low flux of mine water out of the air shaft (i.e., during the RI the flow rate was not quantified because it was below the minimum detectable levels of the flow measurement equipment), practicable quantities of GAC and resin could be placed in the base of the Air Shaft as a first step in the closure process.

An approach to permanently close the mine in combination with GAC/resin would be to place angular stone (non-calcareous) interspersed with smaller sized GAC at the bottom of the Air Shaft. The angular stone is a larger size (6”-12”) so it will stabilize the base for grout placement and is typically placed mechanically (i.e., allowed to settle through the water column). The resin typically used for treatment of 1,4-dioxane (Dow Ambersorb 560®) has a density of less than that of water, therefore, the resin would be introduced in canisters or “socks” lowered to the base of the Air Shaft. The rock would provide bearing strength to temporarily support grout that would be placed above the rock. The angular shape of the rock would limit its movement within the mine workings toward the adjacent mine slope entry. Mine water and bottom sediments, including disturbed sediments, would also contact the carbon and resin for adsorption of COCs. The rock and carbon/resin would be placed at the floor of the Air Shaft.

After placement of the carbon/resin and rock, the Air Shaft would be sealed by using a tremie pipe to place a designed flowable flyash/concrete grout. A fast sealing grout would initially be placed so that the grout would not flow deeply into the rock and carbon/resin and the grout would seal it from contacting the mine water. After the initial grout placement (about 10 feet high from the base of the Shaft), the remaining section of the Air Shaft would be filled by placing a slower setting mix. The grout would encapsulate any remaining wood material and fill voids within the Shaft. The grout mix would be designed to have a strength of between 500 to 1000 psi (at 28 days). The Air Shaft closure plan is typical of other shaft closures historically conducted and currently practiced in the US.

The grouting operation would displace the mine water in the Air Shaft. This displaced water would in effect be a dewatering operation that would be managed through the permit-by-rule provisions within NJAC 7:14A-7.5. In addition, if coordinated with the Land AC remediation, discharge to groundwater options could include the PMP excavation area and the area of the future detention basin within the PMP Area (see OU2 Final Remedial Design, Cornerstone, 2017b).

Following closure of the Air Shaft, routine groundwater monitoring as a part of the OU2 ROD or for the future OU3 groundwater remediation could be used to assess the effects of the PMP Air Shaft closure, if any (i.e., if it does not contain a defined source, closure would not be expected to have a meaningful impact on groundwater quality).

The capital cost for closure of the PMP Air Shaft would be moderate, driven primarily by the cost for sealing the Air Shaft and handling the displaced mine water. The addition of GAC/resin to the Air Shaft closure would add a moderate amount to the cost of this alternative.

Closure/treatment of the PMP Air Shaft is retained as a potential remedial action alternative for detailed evaluation based on the following:

- The principal activity for this alternative is conventional shaft closure which will isolate the shaft from the surrounding environment, and will have the added benefit of eliminating a potential future physical safety hazard.

- GAC/resin can be added to the conventional shaft closure technology because its use is consistent with closure of the PMP Air Shaft (i.e., ongoing maintenance or operation are not needed) and it would serve the purpose of minimizing the potential for organic COCs from migrating from the PMP Air Shaft, including benzene and 1,4-dioxane.

- Placement of the initial Air Shaft closure materials (i.e., angular stone) will cause disruption of the sediments at the base of the Shaft. However, the adsorbents will be placed at the same time as the stone (i.e., the materials will be intermixed), and shaft closure will follow immediately thereafter. The disturbance will be short term and adsorbents will be placed with the stone, and therefore, while there is the potential for altering the geochemistry and water quality within and down gradient of the Air Shaft, the potential impacts, if any, would be expected to likewise be short term. Note that there is some risk associated with the disturbance, even though there is no discrete source of the COCs, by disturbing whatever is affecting water quality causing unwanted changes in groundwater in the downgradient direction. Given the anticipated short-term nature of disturbance, the benefits of closure of the Air Shaft could outweigh the potential adverse water quality changes and/or impacts from disturbance of the Shaft.

- As noted previously, closure of the Air Shaft will displace the water in the Shaft, and so pumping will accompany the shaft closure. Pumping of the water from the Shaft will simulate the current upward flow path. However, this alteration of the mine water may also have an impact on the geochemistry and water quality of the mine water and be manifested in a potential change, and possibly an adverse impact, in down-gradient groundwater quality. However, similar to the sediments disturbance, the impact, if any, would be expected to be short term, and, over the long term, the closure of the Air Shaft will isolate it from the surrounding environment.

- The cost of this alternative is moderate and PMP Air Shaft closure is permanent.

6.3 Cannon Mine Pit (CMP) Area

6.3.1 No Action

No Action involves no remedial action for the reduction, control, or monitoring of future human health or ecological risks associated with COCs in groundwater in the CMP Area.

This alternative would not actively reduce the mobility, toxicity, or volume of COCs in groundwater. No monitoring program would be in place for groundwater, and no institutional control would be implemented to verify that groundwater use is restricted and human health and the environment continues to be protected. Although the BHHRA conducted based on a hypothetical future use of groundwater for potable and domestic purposes indicates that, even if groundwater is ever used for these purposes in the future, the risk is not significant under existing conditions at the Site, a No Action scenario would not provide data to show that COC concentrations continue to represent a potential risk that is not significant.

Since there are numerical exceedances of the GWQS and/or MCLs for certain COCs in groundwater, No Action would not be an effective technology for achieving RAOs within a reasonable timeframe because there is no monitoring component to verify groundwater concentrations and document that human health and the environment continues to be protected.

This alternative could be implemented without technical or administrative limitations; however, the NJDEP regulatory requirement for a CEA as an institutional control to document any non-naturally occurring COC exceedances of the GWQS would be necessary even under the No Action scenario.

There is no capital cost associated with this alternative.

No Action is retained as an alternative in the detailed evaluation as a baseline for comparison to other alternatives.

6.3.2 Monitored Natural Attenuation with a CEA/WRA

Natural attenuation mechanisms include the natural, physical, chemical, and/or biological processes that reduce COC concentrations in groundwater or surface water without active remediation of any kind. MNA is used to collectively describe these processes and monitor their effect on COC concentrations over time as a way to achieve site-specific RAOs. Stable or decreasing trends in the concentration of COCs in groundwater over time provide a primary line of evidence that one or more of the natural attenuation mechanisms are taking place and the net result is overall plume stability and COC mass reduction over time. Geochemical and other indicator parameters also provide supplemental lines of evidence to document that groundwater conditions are conducive to natural attenuation and that one or more of the natural attenuation processes is occurring, including microbial degradation.

MNA (along with a CEA/WRA) would effectively remove potential future exposure to COCs by prohibiting the future withdrawal and potable use of groundwater in the CMP Area, including for potable and domestic purposes. This alternative would include active monitoring of groundwater quality and the natural attenuation processes that are expected to continue to reduce the mobility, toxicity, and volume of 1,4-dioxane concentrations in groundwater over time. In addition, the monitoring of groundwater geochemical conditions would document the presence of conditions conducive for continued natural degradation as well as the natural attenuation of non-naturally occurring metals. This alternative would be an effective remedial alternative for the CMP Area COCs in groundwater.

This alternative could be implemented without technical, administrative, or regulatory limitations. MNA with a CEA/WRA would consist of routine monitoring of COCs in groundwater over time, along with continued monitoring of groundwater geochemical conditions to document that groundwater conditions are conducive to continued natural attenuation. A long-term monitoring program would be established for specific Site monitoring wells and surface water sampling locations in accordance with this alternative and the OU2 ROD.

There are no capital costs associated with MNA and the O&M costs associated with this remedy are relatively high in comparison to other groundwater remedial action alternatives for CMP. This is due to the moderate to long timeframe associated with MNA, which is necessary to document that natural attenuation is occurring and RAOs are achieved. MNA with CEA/WRA is retained as a potential alternative for the detailed evaluation.

6.4 O'Connor Disposal Area (OCDA)

6.4.1 No Action

No Action involves no remedial action for the reduction, control, or monitoring of potential future human health or ecological risks associated with COCs in groundwater in OCDA.

This alternative would not actively reduce the mobility, toxicity, or volume of COCs in groundwater. No monitoring program for groundwater would be in place, and no institutional control would be implemented to verify that groundwater use is restricted and human health and the environment continues to be protected. Although the BHHRA conducted based on a hypothetical future use of groundwater for potable and domestic purposes indicates that, even if groundwater is ever used for these purposes in the future, the potential risk is not significant under existing conditions at the Site, a No-Action scenario would not ensure that COC concentrations continue to represent a potential risk that is not significant.

Since there are numerical exceedances of the GWQS and/or MCLs for certain COCs in groundwater, No Action would not be an effective technology for achieving RAOs within a reasonable timeframe because there is no monitoring component to verify groundwater concentrations and document that human health and the environment continues to be protected.

This alternative could be implemented without technical or administrative limitations; however, the NJDEP regulatory requirement for a CEA as an institutional control to document any non-naturally occurring COC exceedances of the GWQS would be necessary even under the No Action scenario.

There is no capital cost associated with this alternative.

No Action is retained as a potential alternative in the detailed evaluation as a baseline for comparison to other alternatives.

6.4.2 Monitored Natural Attenuation with a CEA/WRA

Natural attenuation mechanisms include the natural, physical, chemical, and/or biological processes that reduce COC concentrations in groundwater or surface water without active remediation of any kind. MNA is used to collectively describe these processes and monitor their effect on COC concentrations over time as a way to achieve site-specific RAOs. Stable or decreasing trends in the concentration of COCs in groundwater over time provide a primary line of evidence that one or more of the natural attenuation mechanisms are taking place and the net result is overall plume stability and COC mass reduction over time. Geochemical and other indicator parameters also provide supplemental lines of evidence to document that groundwater conditions are conducive to natural attenuation and that one or more of the natural attenuation processes is occurring, including microbial degradation.

MNA (along with a CEA/WRA) would effectively remove potential future exposure to COCs by prohibiting the future withdrawal and potable use of groundwater in OCDA for any purpose, including any future potable and domestic uses. This alternative would include active monitoring of groundwater quality and the natural attenuation processes with potential to reduce the mobility, toxicity, and volume of non-naturally occurring COCs in groundwater over time. In addition, the monitoring of groundwater geochemical conditions would help to determine whether the conditions exist for continued natural attenuation of 1,4-dioxane as well as arsenic, the latter via changes in the redox conditions downgradient of the OCDA. As groundwater quality under current pre-remediation conditions poses no significant potential risk to human health or the environment, this alternative would be an effective remedial alternative for OCDA COCs in groundwater.

This alternative could be implemented without technical, administrative, or regulatory limitations. MNA with a CEA would consist of routinely monitoring COCs in groundwater over time, along with continued monitoring of groundwater geochemical conditions to document that groundwater conditions are conducive to continued natural attenuation. A long-term monitoring program would be established for specific Site monitoring wells and surface water sampling locations in accordance with this alternative, the OU2 ROD, and the April 2015 Explanation of Significant Differences (ESD).

There are no capital costs associated with MNA and the O&M costs associated with this remedy are relatively high in comparison to other groundwater remedial action alternatives for OCDA due to the moderate to long timeframe associated with MNA as necessary to document that natural attenuation is occurring and RAOs are achieved. MNA with a CEA/WRA is retained as a potential alternative in the detailed evaluation.

6.4.3 Inter-Relationship of the Land ACs

As shown on Figure 1, the OCDA and PMP Area are directly adjacent to each other. As also shown in Figures 1 and 2, there is an inter-relationship of groundwater flow in the area of these two land ACs, which may be summarized as follows:

- Overburden groundwater flow from the PMP Area is in a generally south-southeasterly direction toward the OCDA.
- Overburden groundwater flow from the PMP Area and OCDA converge in the northern portions of the OCDA, and flow is then generally toward Park Brook.
- Bedrock groundwater flow is also generally in a south-southeasterly direction along the axis of more open bedrock fracture orientation. As a result, bedrock groundwater flow from the PMP Area passes through the area of the OCDA in the down-gradient direction.

Because of the proximity of these two Land ACs and the inter-relationship of groundwater flow, these two areas are more appropriately evaluated together in the detailed evaluation of alternatives that follows, and as such are combined in the discussions that follow.

In addition, certain alternatives (i.e., No Action, MNA) apply Site-wide, and are not specific to a Land AC. For example, the CMP area is some 4,000 feet southwest of the southernmost extension of the OCDA, and there is no relationship of groundwater flow; however, the description of MNA as an alternative is not dependent on locations. Consequently, while the MNA remedy would apply equally to any of the Land ACs, some components, such as monitoring well locations, are discussed and evaluated separately because of geography.

By approaching the detailed evaluation of alternatives as described above, the number of alternatives is manageable, without diminishing the ability to select any combination of alternatives.

7 DESCRIPTION OF THE ALTERNATIVES

7.1 General

The alternatives retained for detailed evaluation following the screening described in Section 6, and understanding the inter-relationships of the Land ACs relating to groundwater flow, are as follows:

- Site-Wide Groundwater
  - Alternative 1 – No Action
  - Alternative 2 – Monitored Natural Attenuation with a CEA/WRA
- Site-Wide Groundwater Focused on Combined PMP Area and OCDA
  - Alternative 3 – Enhanced Monitored Natural Attenuation Treatment Barrier with a CEA/WRA
- PMP Air Shaft
  - Alternative 4 – No Action
  - Alternative 5 – Oxygen Diffusion via Chemical Addition
  - Alternative 6 – Treatment/Closure

In the sections that follow, each of the above alternatives are developed in sufficient detail to permit detailed evaluation using the criteria described in Section 8 of this report.

7.2 Site-Wide Groundwater

7.2.1 Alternative 1 - No Action

The No Action alternative would not include implementation of any remedial actions. Typically, the No Action alternative is retained as a baseline against which to evaluate other remedial alternatives. However, as discussed in Section 6 and described in more detail in Section 8, the No Action alternative is also retained for groundwater to be evaluated on its merits given that the BHHRA and SRGEA concluded that potential risks are not significant.

Although the No Action alternative would not include any specific remedial action, as part of this alternative, a CEA/WRA would be established nonetheless based on the regulatory requirements at NJAC 7:9C-1.6, which state that the NJDEP will establish a CEA when groundwater quality standards for a constituent are not met due to

> "…natural quality; localized effect of a discharge approved through a NJPDES permit action; pollution caused by human activity within a contaminated site as defined by the Department in the context of an applicable regulatory program (for example, Site Remediation Program); or an ACL as approved by the Department pursuant to NJPDES."

In addition, NJAC 7:9C-1.6(d) states that the "…Department shall restrict or require the restriction of potable ground water uses within any Classification Exception Area where there is or will be an exceedance of the Primary Drinking Water Quality Standards (in N.J.A.C. 7:10)."

A CEA/WRA is an institutional control that while not a remedial action, is required by regulation based on the presence of constituents in the Site groundwater that exceed the Class IIA GWQS at NJAC 7:9C, which as previously explained, are from either natural or anthropogenic sources, or both. The CEA/WRA would apply to both the overburden and bedrock groundwater aquifers. Based on the groundwater quality monitoring performed at the Site, as summarized in Section 3 of this report, the estimated extent of the CEA/WRA boundaries associated with the remediation are illustrated on Figures 22 and 23. In addition, the CEA/WRA boundaries are inclusive of the Areas of Attainment for each of the Land ACs. The Areas of Attainment are included in the CEA/WRA boundaries even though in some instances wells within these areas meet the GWQS, because fill/waste will remain within the Areas of Attainment, and therefore, it would be prudent to restrict use of the aquifers in these areas for water supply.

The duration of the CEA/WRA is considered to be indeterminate due to:

- The presence of both naturally occurring as well as anthropogenic sources of constituents that are present in concentrations above the GWQS;
- The absence of a discrete, defined source of COCs, including the potential for contributions from the overall mine workings, which are not the subject of remediation, as described in Section 3.2.2.

7.2.2 Alternative 2 - Monitored Natural Attenuation with a CEA/WRA

Alternative 2, Monitored Natural Attenuation (MNA), would be carried out within and downgradient of the CMP Area, PMP Area, and OCDA. This alternative would include active monitoring of groundwater quality and the natural attenuation processes that are expected to continue to reduce the mobility, toxicity, and volume of Site COC concentrations in groundwater over time. The active monitoring program would provide a means to track COC trends and provide data that confirms the distribution and fate of COCs has not changed and as a result, is protective of potential receptors. An MNA monitoring program typically consists of two components (1) monitoring within the area where COCs are found in concentrations above GWQS to assess trends, and (2) sentinel monitoring at locations where COCs are found in concentrations below GWQS or are not detected to confirm the long-term understanding of fate and transport.

As described in Section 2, remediation of the three Land ACs is covered under OU2, and as a part of OU2 remedial efforts, additional work will be performed to assess and remove certain source materials (e.g., paint waste, drummed waste), if any are found. Further, paint waste removal has been performed as a part of prior removal, remedial actions, as described in Section 2. As described in Section 3, a discrete, defined source has not been identified for the COCs found in groundwater, and the COCs may be from either natural or anthropogenic sources, or both, including the Site-wide mine workings. As a consequence of former source removal operations, the OU2 remediation, and the absence of a discrete defined source for COCs in groundwater, a source control component, as would be typical of an MNA remedy, is not included, as it is considered to have already been completed, to the extent practicable.

The individual components of this alternative include:

- Installation of three, additional bedrock monitoring wells downgradient of the PMP/OCDA areas, to function in concert with existing wells RW-12 and RW-16 as a sentinel monitoring well array in a south-southeasterly down-gradient direction. The proposed locations of these wells are shown on Figures 22 through 24, and are based on the understanding of groundwater flow and COC fate and transport from the RI and RI Addendum, as well as consideration of monitoring well locations recommended in the Jacobs Report. The proposed sentinel monitoring well array is as follows:
    - Existing well RW-16 is within the footprint of the OCDA, and is along the western boundary of the groundwater flow paths from the PMP Area and

down gradient. Concentrations of COCs in this well have been historically non-detect or below groundwater quality standards.

- Proposed well OB-7D is farther down gradient to the south, and would form a couplet with existing shallow bedrock well OB-7, and would be a deep bedrock well. This sentinel well location is recommended in the Jacobs report.

- Proposed bedrock well RW-17 is even farther down gradient to the south of the PMP Area and OCDA groundwater flow paths, but is also down gradient to the east of the CMP and would serve as a sentinel well for the CMP as well. This sentinel well location is also recommended in the Jacobs Report.

- Proposed bedrock well RW-18, which is down-gradient of the PMP Area and OCDA, is south and east of existing bedrock wells RW-16 and the RW-15 couplet, and is in an intermediate location forming the east-west array. This proposed well is also positioned based on the 1,4-dioxane fate and transport modeling presented in the Groundwater RIR Addendum at a location where GWQS are expected to be met.

- Finally, existing bedrock well RW-12 and overburden monitoring wells OB-10 and OB-29 would be the monitoring locations farthest to the east in the sentinel well array. Concentrations of COCs in these wells have been predominantly non-detect or below groundwater quality standards, with the exception of arsenic that, as explained previously, has both anthropogenic and natural sources, and trace levels of 1,4-dioxane in OB-29 below its GWQS.

- The locations of these additional sentinel wells are based on groundwater quality monitoring data and the 1,4-dioxane fate and transport modeling presented in the Groundwater RIR Addendum. Each of the existing bedrock well locations has not had a detection of 1,4-dioxane, and each of the proposed bedrock well locations is farther down gradient than the point at which the fate and transport modeling predicted that 1,4-dioxane would be non-detect or below GWQS. However, the locations may not represent the point at which all Site-related COCs are non-detect or below GWQS because of the possibility of naturally occurring sources of certain COCs, particularly arsenic and lead.

- The depth of the proposed bedrock sentinel wells will be selected during installation based on observed locations of transmissive zones in the rock using packer testing procedures. Each well will be two inches in diameter, with a ten-foot screened interval. Investigation-derived waste (IDW) generated from well installation will be containerized, sampled, and properly disposed of.

- The number and location of overburden groundwater monitoring wells are sufficient to function as both interior and sentinel monitoring wells, and additional overburden monitoring wells are not proposed as a part of this alternative. Based on the locations where key indicator parameters have been detected and including sentinel, downgradient locations, the recommended groundwater monitoring locations for this alternative are illustrated on Figures 22, 23, and 24 for the PMP Area/OCDA and the CMP Area. More specifically, the proposed monitoring locations and rationale for each are summarized below.

  PMP Area/OCDA:

  - Overburden monitoring wells OB-11R, OB-19, OB-20B, OB-27, OB-31, and OB-32, which form a transect from the PMP down-gradient to the seep area. These locations provide interior monitoring to assess long-term trends.

  - SR3-Seep 1 and SR3-Pond, providing surface water locations where groundwater manifests down-gradient of the above-noted overburden monitoring well transect.

  - Overburden monitoring wells OB-14A, OB-16, OB-17, OB-24, and OB-25 which create a fence line of monitoring along the length of the OCDA, and will function as overburden sentinel wells.

  - Bedrock monitoring wells RW-3, RW-3DS, RW-3DD, RW-5, RW-6, RW-6A, RW-11S, RW-11D, RW-14S, RW-14D, RW-15S, and RW-15D, which similar to the overburden wells, form a transect from the PMP to the farthest down-gradient bedrock monitoring wells with 1,4-dioxane above the GWQS, and along open fracture orientation. Similar to the interior overburden monitoring well array, these wells will provide data for long-term trend analyses.

  CMP Area:

  The bedrock surface in the CMP Area is shallow and so there are no overburden monitoring wells. Further, the CMP Area is located on a groundwater divide so groundwater flow is both to the east toward Ringwood Creek and to the west toward Mine Brook. As a result, down-gradient monitoring locations are required in both directions of groundwater flow. Last, the groundwater in the CMP area has very few detections of Site COCs and concentrations infrequently above GWQS. Consequently, in addition to proposed bedrock monitoring well RW-17, the existing array of monitoring wells provides overall coverage for trends and sentinel monitoring, as follows

- OB-3 provides downgradient monitoring to the west.
- OB-4 and OB-5 provide downgradient monitoring to the east. These wells are the farthest existing monitoring points from the Site in this direction and have historical detections of 1,4-dioxane, albeit below GWQS.
- OB-13 provides downgradient monitoring to the southeast.
- RW-2, down-gradient to the east, and also a location with historical detections of 1,4-dioxane and arsenic above GWQS.
- RW-8, immediately down gradient to the west, and also a location with historical detections of arsenic and lead.
- RW-9, immediately down gradient to the east, and also a location with historical detections of arsenic and lead.
- RW-10, an intermediate down gradient location to the southeast.

- A long term monitoring plan (LTMP) would be implemented that includes groundwater elevations, COCs, and biogeochemical parameters. Groundwater elevations would be collected prior to sampling at each of the proposed well locations, and the data used to confirm groundwater contours associated with each sampling event. The COC monitoring would include the Target Compound List volatile organic compounds (VOCs) which will include the COCs of benzene and chloroethane, 1,4-dioxane using USEPA Method 8270 SIM with isotope dilution, arsenic, and lead. Geochemical parameters would include typical field parameters (pH, conductivity, ORP, turbidity, temperature, and oxygen) and nitrate, sulfate, iron, and alkalinity.
- As described in the Groundwater RIR and RIR Addendum, there is a long history of groundwater monitoring at the Site, and generally the data have presented a consistent picture of the distribution of COCs in groundwater. Based on the consistency of the data, initially sampling is recommended on a semi-annual basis for

the first year (i.e., two events) to provide a baseline of data including new well installations. Following this initial year of monitoring, the recommended monitoring frequency is every five quarters. The approach of five quarters monitoring provides a rotation through the seasons to assess the potential effects of seasonal conditions on groundwater quality. Following a period of approximately five years, and assuming the data are consistent, conversion to a biennial frequency is recommended, consistent with the NJDEP guidance for monitored natural attenuation monitoring and with the biennial certification process for a CEA/WRA.

- Establish the CEA/WRA as an institutional control to restrict future withdrawal and use of the overburden and bedrock groundwater for any purpose as described for Alternative 1, in Section 7.2.1.

- To complete the monitoring program, a surface water monitoring component is also included as a means to confirm that Site COCs are not influencing downstream surface water quality at concentrations that would be of concern to downstream receptors, including the Wanaque Reservoir. The recommended surface water monitoring program includes the same Site-related COCs as for groundwater (benzene, chloroethane, 1,4-dioxane, arsenic, and lead). The recommended locations are as follows to provide coverage adjacent to the Site as well as in downstream locations:

PAB-00	PAB-04	MRB-03	SW-03
PAB-01	SP-01	NOB-01	SW-04
PAB-01A	MRB-00	NOB -02	SW-11
PAB-02	MRB-01	PMB-01	
PAB-03	MRB-02	PMB - 02	

  This array provides coverage adjacent to the Site, as well as downstream, on each of the streams adjacent to and downstream of the Site.

- Various miscellaneous activities including maintenance of the monitoring well network and routine inspections, and routine reporting associated with maintenance of the CEA/WRA. In addition, because this alternative is not considered a permanent remedy under CERCLA, it would be subject to five-year reviews by the USEPA.

7.2.3 Alternative 3 - Enhanced MNA Treatment Barrier in the PMP Area/OCDA

Under this alternative, MNA would be implemented with an enhancement in a treatment barrier approach to promote and support the degradation of COCs through natural attenuation processes. As described in Section 6.2.4, the preferred degradation pathway for benzene is aerobic, even though under current reducing conditions benzene degradation has been conclusively demonstrated. In addition, the preferred biodegradation pathway for 1,4-dioxane is aerobic whether through direct metabolism or co-metabolism by monooxygenase expressing microorganisms. If the dominant mechanism of 1,4-dioxane microbial degradation is co-metabolism, the monooxygenase-expressing bacteria require oxygen, and, to date, based on the published literature, application of other terminal electron acceptors as a substitute for oxygen has not been demonstrated to be effective. To address the organic COCs in groundwater in the PMP Area, the Enhanced MNA Treatment Barrier using oxygen as the electron acceptor is, therefore, the focus of this alternative.

Two primary alternatives exist for introducing oxygen to the groundwater: (1) as a slurry injection (e.g., slurried granular calcium peroxide) using equipment such as a Geoprobe® or (2) as a solid or granular material typically contained within a permeable sock, and suspended in a permanent well installation. The formations at the Site are documented to be low yield. Consequently, the probability is low of achieving a uniform distribution of an oxygen release compound (ORC) slurry. In addition, using an ORC slurry would require remobilization of equipment, and drilling new injection points each time the ORC would have to be refreshed. If using a solid/granular ORC sock type arrangement, the release of oxygen to the aquifer would be principally by diffusion. While this does not guarantee uniform distribution throughout the aquifer, especially a low-yield aquifer as is present at the Site, diffusion is a mechanism that will function even in a low-yield formation. Another advantage of this alternative is that vendors can provide solid materials that also include nutrients (e.g., nitrogen) and are buffered to support indigenous microbial growth. For the above reasons, for the purpose of evaluating this alternative, the selected process option is suspending or placing solid ORC in wells.

Introduction of the ORC would be accomplished through wells that would be installed in a barrier-style configuration perpendicular to the direction of groundwater flow. The principal location for these wells would be in the overburden. The focus on the overburden is a consequence of the difficulty of introducing any material into a low-yield fractured bedrock environment, and the fact that groundwater flow within the area down gradient of the PMP is upward from the bedrock, into the overburden, and ultimately to surface water. Therefore, a portion of the bedrock groundwater would pass through an oxygen enriched overburden aquifer. The radius of influence for diffusion of ORC varies with formation characteristics, but is typically quite small, in the range of five to 20 feet. For the purpose of evaluating this alternative, a radius of influence of 10 feet is assumed (i.e., a well spacing of 20 feet). The barrier arrangement of wells is situated adjacent to an existing gravel access road for ease of access, and down gradient of the PMP and PMP Air Shaft where Site COCs have typically been detected at their highest concentrations. The overburden well arrangement is illustrated on Figure 25.

Wells for introduction of oxygen into the bedrock aquifer are also recommended on a limited scale. The focus of the bedrock aquifer wells is adjacent to two key areas where COCs have been detected at their highest concentrations, namely at the RW-11D and RW-3 well clusters. As such, one ORC well is located generally upgradient of well RW-11D and the PMP Air Shaft, and three wells are located upgradient of the RW-3 well cluster. Given the difficulty of promoting movement of any additives in the low-yield bedrock formation, these wells would be assessed during the initial period of enhancement, and if diffusion of oxygen is not demonstrated, use of the bedrock wells would be terminated. The locations of the bedrock ORC wells are shown on Figure 26.

Last, 1,4-dioxane has been found in concentrations exceeding the GWQS in OCDA monitoring well OB-17. However, as previously described, a focused investigation in the area up gradient of monitoring well OB-17 did not identify a source of 1,4-dioxane, and in fact 1,4-dioxane was not detected in any soil or paint waste fragments collected during this focused investigation. This indicates the possibility of some diffuse source of 1,4-dioxane in the area of monitoring well OB-17. Under this alternative, an ORC sock could also be installed in this monitoring well to promote biodegradation of 1,4-dioxane in this localized area.

Commercial products are available that can be applied in socks/canisters within wells in a solid or granular form, as described above, so the application approaches are flexible. These commercially available products also can be supplied with buffering compounds and essential inorganic nutrients to further support the microbial populations. Examples of such products include ORC Advanced®, PermeOx®, and EHC-O®. In addition, current commercially available formulations can support the slow release of dissolved oxygen at levels in groundwater in the range of 8 ppm for up to a year. For the purposes of this FFS, this alternative assumes the use of a chemical, slow release, source of oxygen, applied in the above-described array of wells, at a typical application rate in the range of 2-5 pounds of oxygen release compound per foot of saturated thickness within the treatment zone.

ORC canisters or socks are typically provided in a range of sizes from two inches to six inches suitable for placement in conventional well installations. For the purpose of evaluating this alternative, four-inch wells are assumed with ORC socks contained in reusable canisters suspended in each well. Once the compound is exhausted, the canisters can be retrieved and the oxygen source can be replenished, on a regular basis. Given the low yield and transmissivity of the aquifers at the Site, for the purpose of this alternative, the ORC is assumed to be replaced annually.

In addition to the MNA Treatment Barrier enhancement components described above, the components of this alternative include:

- Installation of the three, proposed bedrock sentinel monitoring wells as described for Alternative 2, in Section 7.2.2 (see Figures 25 and 26).

- An LTMP with the same well and surface water sampling locations in the CMP Area and PMP Area/OCDA, and the same analytical program and monitoring frequency as described for Alternative 2, in Section 7.2.2.

- A CEA/WRA as an institutional control to restrict future withdrawal and use of the overburden and bedrock groundwater for any purpose as described for Alternative 1, in Section 7.2.1.

- Various miscellaneous activities including maintenance of the monitoring well network and routine inspections, and routine reporting associated with maintenance of the CEA/WRA. In addition, because this alternative is not considered a permanent remedy under CERCLA, it would be subject to five-year reviews by the USEPA.

7.3 PMP Air Shaft

7.3.1 Alternative 4 – PMP Air Shaft, No Action

Under Alternative 4, the No Action alternative, remedial measures specific to the PMP Air Shaft would not be implemented. Typically, the No Action alternative is retained as a baseline against which to evaluate other remedial alternatives. However, as discussed in Section 6 and described in more detail in Section 8, the No Action alternative is also retained for evaluation on its merits given that the BHHRA and SRGEA did not indicate significant potential human health or ecological risks. Further, while No Action would not actively seek to reduce COC levels in the Air Shaft, it is not clear that the Air Shaft is a source of Site-related COCs distinct from the larger mine workings as a whole at the Site, as discussed previously. Therefore, this alternative could be considered appropriate for the Air Shaft as the mine workings are not the subject of the remediation or the RAOs.

Since the CEA/WRA established for the PMP Area/OCDA (see Section 7.2.1) encompasses the PMP Air Shaft, no additional regulatory requirements specific to the PMP Air Shaft, such as an additional CEA/WRA, are expected to be necessary for the No Action Alternative.

7.3.2 Alternative 5 - Oxygen Diffusion in the PMP Air Shaft

As discussed in Section 6.3, concentrations of benzene and 1,4-dioxane, are among the highest at the Site in the mine water (i.e., largely stagnant water at the base of the shaft) within the PMP Air Shaft. Therefore, even in the absence of a discrete source of these COCs in the PMP Air Shaft, this alternative, along with Alternative 6 that follows, were retained for detailed evaluation.

As also discussed for Alternative 3, Enhanced MNA Treatment Barrier, benzene is preferentially degraded aerobically, and the preferred biodegradation of 1,4-dioxane is in the presence of oxygen. Therefore, under Alternative 5, several canisters containing an oxygen release compound would be installed at various depths within the zone of the PMP Air Shaft that is largely anoxic and with predominating reducing conditions, to create positive redox conditions and enhance aerobic biodegradation of organic COCs. Similar to Alternative 3, the ORC in permeable socks was selected as the method of introducing oxygen, as it is amenable to installation in the Air Shaft, which essentially functions for the purposes of this alternative, as a large diameter well, and has the added advantage of incorporating nutrients (e.g., nitrogen) and buffering to support biological growth.

The focus of the ORC canisters would be in the lower portion of the PMP Air Shaft. As documented in the Groundwater RIR, approximately the lower 60 feet of the air shaft is where the concentrations of COCs are highest, reducing conditions prevail, and the mine water is a largely stagnant pool, with minimal upward gradients to the more oxygenated water at shallower depths. To promote aerobic conditions in the lower portions of the air shaft, the ORC canisters would be spaced vertically and horizontally, as follows:

- Three canisters distributed equidistant horizontally in the shaft; and
- Canisters positioned vertically within ten feet of the base of the shaft, and then 20 feet apart vertically.

If necessary based on oxygen levels measured in the PMP Air Shaft, canisters can be suspended in series to provide greater oxygen distribution. However, for the purpose of this alternative evaluation, single, three feet long, four-inch diameter canisters are assumed.

To implement this alternative will require a cap closure of the PMP Air Shaft with locking sleeves through the cap, from which the canisters can be suspended on cable. The cap closure of the PMP Air Shaft is assumed to be as follows:

- Removal of the current wooden cap on the air shaft;
- Placement of beams supported on the collar of the air shaft, assuming the structural integrity of the collar is confirmed during design;
- Placement of a reinforced concrete slab supported by the beams, much the same as a bridge deck would be constructed;
- A minimum of three, locking sleeves through the concrete slab, of sufficient diameter to allow suspension of the ORC canisters, plus two spares to provide for flexibility in placement of the ORC material; and
- Extension of the existing 50-foot, 180-foot, and 230-foot sampling drop tubes that currently exist in the PMP Air Shaft through the new concrete shaft cap for monitoring purposes.

As noted previously, solid ORC material has a life expectancy from a few months and up to one year depending on groundwater conditions and flux. In the more stagnant environment of the PMP Air Shaft, greater longevity may be possible. However, the abundance of oxygen sinks in the Air Shaft would cause competing conditions that could deplete the ORC material more quickly. Overall, replacement of the ORC canisters is assumed for this alternative to occur on a semi-annual basis, with actual replacement time to be determined through empirical data collected assuming this alternative is selected.

Monitoring would be performed in the Air Shaft to check for positive redox conditions at depth and to assess the effect of aerobic conditions on benzene and 1,4-dioxane concentrations. Given the assumed life span of the ORC, sampling is recommended on a semi-annual basis for the first one to two years of operation. Depending on the monitoring results, the sampling frequency may be reduced to annual or biennial, consistent with other site groundwater monitoring programs. The initially more frequent testing will allow an assessment of the life of the ORC and whether measurable reductions in COC concentrations are confirmed. The testing protocol would include oxygen, pH, ORP, benzene, and 1,4-dioxane (via USEPA Method 8270 SIM, with isotope dilution).

In addition to the above, routine inspections of the cap over the PMP Air Shaft would be performed, and as noted above, operations would include replacement of the ORC canisters. Routine reporting of monitoring data would also be performed, and integrated with other Site-wide monitoring.

7.3.3 Alternative 6 – Treatment/Closure in the PMP Air Shaft

Under Alternative 6, the PMP Air Shaft would be permanently closed using conventional mine shaft closure technology. Closure of the PMP Air Shaft would constitute isolation of the shaft and its contents from the surrounding environment. In addition, this alternative includes a treatment step using granular activated carbon (GAC) and resin prior to permanent closure of the Air Shaft.

Developing the components of this alternative starts with an evaluation of the quantity of GAC and resin that would be placed at the base of the Air Shaft. As an aid in assessing the use of GAC, benzene isotherm data (Speth & Miltner, 1990) were used to estimate the quantity of GAC that would be applied in the PMP Air Shaft. Since there is no quantifiable benzene source data, two methods were initially employed to estimate the quantity of GAC: (1) based on a mass of COC in the Air Shaft mine water, and (2) based on an estimate of flow through the Air Shaft into the bedrock aquifer.

First, benzene has been detected typically in the range of 25-33 ug/L at the 230′ depth interval of the PMP Air Shaft. At the 180′ depth interval benzene concentrations are typically in the single digit ug/L range and benzene is generally not detected in the 50′ depth interval samples. To estimate the mass of benzene, the assumption was conservatively made that the 33 ug/L maximum concentration of benzene detected at the base of the Air Shaft represents the mass of benzene throughout the water column in the air shaft up to the 50′ depth interval (i.e., 180 feet total). Based on Air Shaft dimensions of 16′ x 16′ x 180′, this concentration represents a total of approximately 43 grams of benzene in the mine water in the Air Shaft. Using the Freundlich equation for adsorption and an adsorption capacity at unit concentration of 47.9 (mg/g)(L/mg)$^{1/n}$ and a strength of adsorption of 0.533 (dimensionless), the quantity of carbon necessary to adsorb the 43 grams of benzene equates to approximately 12 pounds (calculated adsorption rate of 7.8 mg/g carbon). This would be a very small quantity of GAC for addition to the base of the PMP Air Shaft.

Second, groundwater flow through the PMP Air Shaft can also be used to estimate carbon usage. Testing performed during the RI demonstrated that flow out of the Air Shaft is very low; however, the flow rate was not quantified because it was below the minimum detectable levels of the flow measurement equipment. However, the flow rate can be estimated using Darcy's Law, and assuming that flow through the Air Shaft reflects hydraulic conditions in the bedrock aquifer. The groundwater flow estimate through the PMP Air Shaft is calculated using Darcy's Law, as follows:

Q = kiwd, where:

K = hydraulic conductivity of the bedrock around the Air Shaft. This value is taken as 1 x 10^{-6} cm/sec based on the BIOCHLOR modeling in the RIR Addendum.

i = hydraulic gradient, which is taken as 0.011 which reflects groundwater elevations in the area of the Air Shaft within the bedrock aquifer (see RIR and RIR Addendum for groundwater contour maps)

w = width of the flow path, which is taken as the dimension of the Air Shaft, or 16 feet.

d = depth of the flow path, taken as the same 180 feet noted above in the calculation for the total mass of benzene in the Air Shaft.

Using the above method of calculation, the estimated total flow out of the PMP Air Shaft is 2.54 liters/day. At the GAC benzene adsorption rate of 7.8 mg/g of carbon, this is a depletion rate of 0.0174 grams of carbon per day, or 3.9 grams of carbon per year. The 12 pounds of carbon noted above, would have a life of approximately 1,400 years for adsorption of benzene.

1,4-dioxane is not efficiently adsorbed on GAC, although research has shown that removal varies with the type of carbon. For example, one study (Fukuhara et al, 2011) showed that an activated carbon prepared from sawdust adsorbed 1,4-dioxane at a rate of 410 ug/g. Assuming a 1,4-dioxane concentration similar to that detected in August 2016 (146 ug/L), and the same basis as above for a mass calculation, this concentration represents a total of approximately 191 grams of 1,4-dioxane. At this adsorption rate, the quantity of carbon is 1,050 pounds or similar to a typical small delivery to a groundwater treatment plant. This calculation is conservative, in that the 146 ug/L does not exist throughout the 180' interval of PMP Air Shaft water column. However, these calculations illustrate that conventional quantities of carbon could be used to provide treatment within the PMP Air Shaft, as a part of closure, and provide a substantial adsorption capacity by comparison to the typical residual concentrations in the Air Shaft.

As noted above, 1,4-dioxane is not efficiently adsorbed on GAC. However, resins have been shown to have higher 1,4-dioxane removal efficiencies, and in particular recent data for the Dow Ambersorb 560® resin has indicated removal efficiency in the range of 1 mg/g of resin, higher than the highest GAC removal efficiency reported in the literature to date. Consequently, for the purpose of this alternative, the assumption is that the GAC would be supplemented with a resin such as Ambersorb 560®. Since the focus of the resin is 1,4-dioxane and as a supplement to GAC, the quantity of resin is estimated based on the lower 180 feet of the air shaft where 1,4-dioxane has been detected (20.3 ug/l maximum in the 180′ interval, and 146 ug/L maximum in the 230′ interval, typically non-detect or very low levels in the upper 50′). Similar to the above calculation, using the maximum detected concentration of 1,4-dioxane throughout the lower 180 feet of the air shaft results in a 1,4-dioxane mass of approximately 190 grams. At the adsorption rate of 1 mg/g noted above and 190 grams of 1,4-dioxane, the quantity of resin calculated for adsorption is 420 pounds. Dow provides the resin in 100 kg drums (220 pounds), therefore, based on these calculations, two drums could be used in lieu of the GAC for 1,4-dioxane adsorption. However, since GAC is more readily available and lower cost than resins, an appropriate approach would be to use resin as a supplement to GAC. For example, one drum of the Ambersorb 560® resin could be used in conjunction with the 1,050 pounds of GAC calculated above.

Using the groundwater flow rate through the air shaft as calculated above, and the 1,4-dioxane concentration of 146 ug/L, at the adsorption rate of 1 mg/g of resin, this is a depletion rate of 0.371 grams of resin per day, or 135 grams of resin per year. Therefore, one 100 kg drum of resin would have a life of approximately 740 years.

Absent an identifiable source of either benzene or 1,4-dioxane, these calculations conservatively estimate the mass for treatment so that excess adsorption capacity would exist as demonstrated by the estimated life span of the adsorbents. These calculations would be refined during the design of such a remedy, if it were selected for implementation. Also of note, the GAC would provide a substrate for biological activity (which was conclusively demonstrated for benzene using stable isotope probing, as documented in the Groundwater RIR, albeit at a lower rate in the Air Shaft).

Using the estimates of GAC and resin described above, the specific components of this alternative are as follows:

- Initial site preparation to provide work space for heavy equipment. This would include an aggregate pad adjacent to the shaft, scaffolding structure around the shaft perimeter for safe access to the shaft opening, and erosion and sediment controls as applicable based on the total area of disturbance.

- Introduction of granular activated carbon (GAC) and resin to the base of the PMP Air Shaft, which would adsorb organic COC concentrations to varying degrees, as noted above. The effectiveness of the GAC and resin would not be reduced by subsequent closure of the Air Shaft, as adsorbed constituents would remain adsorbed. To permanently close the Air Shaft in combination with GAC/resin angular stone (non-calcareous) would be interspersed with smaller sized GAC at the bottom of the shaft. The Dow resin density is less than that of water (approximately 20 lbs/ft^3), therefore, the resin would be introduced in canisters or socks lowered to the base of the air shaft. The rock would provide bearing strength to temporarily support grout that would be placed above the rock. In addition, the angular shape of the rock would limit its movement within the mine workings toward the adjacent mine slope entry. Mine water and bottom sediments would contact the carbon and resin for adsorption of COCs. The angular rock would typically be in the range of up to 12 inches in size, and would be placed with a hopper and conveyor belt, or other suitable means.

- The next step in the closure process would be the placement of a fast-setting, low-slump grout mix atop the stone and GAC/resin to a total thickness of approximately 10 feet. The fast setting grout would initially be placed so that the grout would not flow deeply into the rock and carbon and seal it from contacting the mine water. The fast-setting grout would also limit the potential for loss of grout into the adjacent mine slope entry.

- To complete the closure of the PMP Air Shaft, flowable flyash/concrete grout would be placed using a tremie pipe above the fast setting grout, to the top of the air shaft, fully sealing the shaft. The flyash grout is a slower-setting, low-strength mix commonly used in mine shaft closures. The grout mix would be designed to have a strength of between 500 to 1000 psi (at 28 days). The grout would encapsulate any remaining wood material and fill voids within the shaft. Flyash grout mixtures are used in transportation projects, and have become commonly available as a ready-mixed material. For example, the New Jersey Department of Transportation has a standard specification for controlled low-strength material (e.g., a flowable fill or low strength grout with fly ash). Consequently, material for the PMP Air Shaft closure could be supplied by ready-mix vendors or a Contractor could opt to provide a mixing plant on site, if cost effective. The grout could be placed with conventional concrete pumping equipment through a tremie pipe.

- The grouting operation would displace the water in the Air Shaft. This displaced water would in effect be a dewatering operation that could be managed through the permit-by-rule provisions within NJAC 7:14A-7.5. In addition, if coordinated with the OU2 Land AC remediation, discharge to groundwater options could include the PMP excavation area and the area of the future detention basin within the PMP Area (see OU2 Final Remedial Design, Cornerstone, 2017b). For the purpose of this FFS, the displaced water is assumed to be treated through filtration and GAC and then discharged to groundwater within the same general locations, pursuant to a permit-by-rule under NJAC 7:14A-7.5. Based on the dimensions of the Air Shaft, the total volume of water that will be displaced is approximately 450,000 gallons. The OU2 Final Remedial Design includes provisions for treating dewatering waters with filtration and GAC at a flow rate of 50 gallons per minute. At this flow rate, the total quantity of displaced water would require approximately only six days to complete, and overall is consistent with the schedule that would be expected for the Air Shaft closure.

- Following placement of the low-strength grout fill, a concrete cap would be placed with a marker as a final closure and identification measure. The concrete cap would be a conventional poured slab that would provide a durable, final closure surface. Upon closure completion, the temporary support and access facilities would be removed and the area restored with vegetation.

Closure of the PMP Air Shaft would be permanent, and would isolate the shaft from the environment. As such, monitoring within the PMP Air Shaft would cease upon completion of the closure operation. To the extent that monitoring is performed for Site-wide groundwater, such monitoring could be used to assess the effects of the PMP Air Shaft closure, if any (i.e., if it does not contain a defined source, closure would not be expected to have a meaningful impact on down-gradient groundwater quality).

There would be no other operation or maintenance requirements for this alternative, again, because the closure is permanent. This PMP Air Shaft alternative would also not be subject to five-year reviews under CERCLA because the closure is permanent and the PMP Air Shaft would be isolated from the surrounding environment.

8 DETAILED ANALYSIS OF ALTERNATIVES

This section presents a detailed analysis of each alternative described in Section 7. This evaluation uses the criteria described in the NCP, and consistent with *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*. In the sections that follow the evaluation criteria are described followed by the evaluation of each retained alternative.

8.1 Evaluation Criteria

Section 300.430(e) of the NCP lists nine criteria against which each alternative must be assessed. Evaluation against these criteria provides the basis for selection of an alternative or combination of alternatives for implementation. The first two criteria are threshold criteria that must be met by an alternative to be eligible for selection. The two threshold criteria are:

- Overall protection of human health and the environment; and
- Compliance with ARARs.

The next five criteria are the primary balancing criteria. These criteria are used to compare trade-offs between alternatives. The five primary balancing criteria upon which the detailed evaluated is based are:

- Long-term effectiveness and permanence;
- Reduction of toxicity, mobility, or volume through treatment;
- Short-term effectiveness;
- Implementability; and
- Cost.

The final two criteria are referred to as modifying criteria. The modifying criteria include:

- Community acceptance, and
- State acceptance.

The modifying criteria are typically evaluated after the feasibility study as a part of the process of developing a proposed remedial action plan and issuing a ROD. Typically, the USEPA will collect the input regarding these criteria through its role as the lead agency and coordination with the NJDEP, and through the public participation portion of the ROD process. Consequently, these criteria are not evaluated further in this FFS.

The preferred alternative will be the alternative that satisfies the first two criteria and achieves the best combination of the remaining five.

The following sections provide additional detail to describe each of the evaluation criteria. A summary of this detailed evaluation of Site remedies in comparison to the FFS evaluation criteria is presented in Table 12 (threshold criteria) and Table 13 (balancing criteria).

8.1.1 Overall Protection of Human Health and the Environment

This criterion assesses the overall performance of a remedy in protecting human health and the environment by evaluation of the remedy's ability to meet the remedial action objectives, the efficacy of the remedy, and its ability to control or eliminate the potential risk pathways.

8.1.2 Compliance with Applicable or Relevant and Appropriate Requirements

This criterion is used to establish whether a remedy complies with applicable or relevant and appropriate environmental laws, regulations, standards, and guidance. This criterion also reviews the relative permitting requirements applicable to the remedy, although permits are not required under CERCLA, but the substantive requirements of the regulations must be met. In the State of New Jersey, demonstrating compliance with the substantive requirements of regulations is done through a permit equivalent process.

8.1.3 Long-Term Effectiveness and Permanence

This criterion is used to assess how the remedy is expected to perform over the long-term and whether the remedy is permanent. The long-term effectiveness criterion also assesses the degree, extent, and manner in which the alternative continues to protect human health and the environment over the long term. This criterion considers the residuals following completion of the remediation, and the degree of controls required for the continued protectiveness of the remedial action.

8.1.4 Reduction of Toxicity, Mobility, or Volume

This criterion is used to assess how the remedy reduces the toxicity, mobility, or volume of site-related constituents, through removal or treatment, and the quantity of residuals, if any, remaining after treatment.

8.1.5 Short-Term Effectiveness

This criterion is used to evaluate the implementation-related impacts of a remedy, safety, and the remedy's protectiveness related to the community, the workers, and the environment during the short-term implementation period. In addition, this criterion is used to evaluate the length of the time required for the remedy to meet remedial action objectives.

8.1.6 Implementability

The technical and administrative feasibility of implementing an alternative and the availability of services and materials are addressed by this criterion. This criterion also considers the degree of coordination required to implement an alternative, successful implementation of the remedial action at similar sites, and commercial availability of technologies used for the alternative.

8.1.7 Cost

This criterion provides an overall estimate of the capital, operation, maintenance, and monitoring costs associated with a remedy, for comparison to the remedy's expected performance and to other remedies. Present worth costs are calculated for each remedy using a discount rate of seven percent (the USEPA default guidance value) and a planning horizon of 30 years. Cost estimates are typically evaluated on an accuracy of +50%/-30%. This criterion addresses the capital costs, the O&M costs, and the present worth analysis of costs anticipated for the implementation of the response action. Direct capital costs include items such as construction, equipment, land and site development, relocation, and disposal. Indirect capital costs include items such as engineering expenses, legal and administrative fees, and contingency allowances. O&M costs include post-construction activities necessary to properly operate, maintain, and monitor a given alternative.

The cost estimates presented in this FFS were prepared in accordance with USEPA guidance (USEPA, 2000) in combination with engineering judgment; vendor input; cost information from similar, previous projects; and costing tools such as the RS Means guide.

8.2 Site-Wide Groundwater

8.2.1 Alternative 1 – No Action

This site-wide groundwater alternative was retained as a baseline for comparison with other alternatives. In addition, as previously noted, the results of the BHHRA do not indicate significant potential future risks associated with groundwater. Further, the SRGEA concluded that the potential ecological risks were low and no further evaluation is warranted. As such, No Action was also retained for evaluation as an alternative for implementation and direct comparison to other alternatives, not just as a baseline.

Evaluation of the No Action alternative against the seven criteria is as follows:

- Overall Protection of Human Health and the Environment
  - Because there are no significant, potential human health or ecological risks, the No Action alternative is protective of human health and the environment, under current conditions.
  - Even though not a remedial action per se, a CEA/WRA would nonetheless have to be implemented for the No Action alternative, as it is a regulatory requirement regardless of remedial action. A CEA/WRA requires, at a minimum, biennial certification that it remains protective relative to restrictions on the use of groundwater that does not meet the standards at NJAC 7:9C or the Primary Drinking Water Standards (i.e., MCLs). Consequently, this alternative would have a mechanism for evaluation of protectiveness in the future.
  - The No Action alternative would meet the RAOs of preventing consumption of groundwater with concentrations of COCs above GWQS through the CEA/WRA, and preventing exposure to residents above the USEPA's risk benchmarks (i.e., under current conditions groundwater is not used). However, because remedial action would not be undertaken, this alternative would not meet the RAO of attempting to restore the aquifer to Class IIA GWQS within a reasonable time frame. Of note, given the natural presence of certain COCs (e.g., arsenic), and the potential presence of anthropogenic sources related to the larger mine workings, it is unlikely this RAO could be met for this alternative within a reasonable time frame, in any event.
- Compliance with ARARs

  - This alternative, with implementation of a CEA/WRA, would comply with the primary ARAR for controlling use of groundwater in a CEA per NJAC 7:9C. However, as previously described, this alternative would not be expected to meet the GWQS, although as noted above, given the natural presence of certain COCs, and the presence of anthropogenic sources related to the larger mine workings, it is unlikely this GWQS could be met for this alternative in the near future.

  - There would not be any location or action-specific ARARs applicable to this alternative.

- Long-Term Effectiveness and Permanence

  - As described in Section 6, the CEA/WRA would be of indeterminate duration because GWQS are not met due to both natural and anthropogenic contributions. As such, for as long as the CEA/WRA is in effect, this alternative would be protective. However, this alternative is not a permanent remedy as ongoing certification of the CEA/WRA is necessary along with the monitoring required by the biennial certifications required for the CEA/WRA.

- Reduction of Toxicity, Mobility, or Volume

  - This alternative would not implement any removal or treatment-based remedial actions to reduce toxicity, mobility or volume.

- Short-Term Effectiveness

  - No remedial or construction activities occur, therefore no short-term impacts are associated with implementation. Implementing the CEA/WRA is an administrative action of short duration, weeks to one-two months for preparation of the documentation and for the NJDEP to put the CEA/WRA into its system.

- Implementability

  - The No Action alternative is readily implementable, as the only activity would be the administrative task of setting up the CEA/WRA, which is accomplished through coordination with the NJDEP.

- Cost
    - The No Action alternative results in costs for implementation because of the regulatory requirement for a CEA/WRA, not for any specific remedial action.
    - The total 30-year net present worth cost to establish the CEA/WRA and implement the minimum required biennial monitoring and reporting is $622,000, as shown in Table 14.

8.2.2 Alternative 2 – Monitored Natural Attenuation

Evaluation of the Monitored Natural Attenuation (MNA) alternative against the seven evaluation criteria is as follows:

- Overall Protection of Human Health and the Environment
    - Because there are no significant, potential human health or ecological risks, the MNA alternative is protective of human health and the environment, under current conditions.
    - Under the MNA alternative a routine monitoring program would be implemented that would provide a mechanism for assessment of continued protectiveness in the future (i.e., confirming that groundwater and surface water conditions do not change).
    - A CEA/WRA would be required for the MNA alternative, as it is a regulatory requirement. A CEA/WRA requires, at a minimum, biennial certification that it remains protective relative to restrictions on the use of groundwater that does not meet the standards at NJAC 7:9C or the Primary Drinking Water Standards (i.e., MCLs). The biennial certification would be based on the results of the groundwater monitoring program to assess the effectiveness of MNA.
    - The MNA alternative would meet the RAOs of preventing consumption of groundwater with concentrations of COCs above GWQS through the CEA/WRA, and preventing exposure to residents above the USEPA's risk benchmarks (i.e., under current conditions this RAO is met because groundwater is not used, and monitoring and use restrictions would provide mechanisms for assessing that the remedy continues to meet this RAO). This alternative would use the naturally occurring attenuation mechanisms (biodegradation, dispersion, advection) to over time meet the RAO of

attempting to restore the aquifer to Class IIA GWQS within a reasonable time frame, and provide monitoring to assess the effectiveness of these natural attenuation mechanisms. However, as previously described for Alternative 1, given the natural presence of certain COCs (e.g., arsenic), and the presence of anthropogenic sources related to the larger mine workings, it is possible that this RAO would not be met for an extended period of time, which is consistent with the indeterminate time frame for the CEA/WRA.

- Compliance with ARARs
    - This alternative, with implementation of a CEA/WRA, would comply with the ARAR for controlling use of groundwater in a CEA per NJAC 7:9C.
    - This alternative requires the installation of additional monitoring wells, and would comply with the ARAR for well installation at NJAC 7:9D, as the well installations would be conventional and meet the requirements of this regulation.
    - Some of the additional sentinel well locations may be in wetland areas (although exact locations to be confirmed during design) and may require permit equivalents for the disturbance of wetlands for access and well installation. Installation of the additional sentinel wells would be anticipated to occur under NJAC 7:7A, General Permit 4, hazardous site investigation and cleanup. The wetlands disturbance would be small, and General Permit 4 requires mitigation. Because of the small area of disturbance, it is anticipated that mitigation would be performed on site, in a peripheral area of the currently designated wetlands. Depending on final locations, some additional wetlands delineation may also be necessary.
    - The additional sentinel well locations may also be in the floodplain of Park Brook (again, exact locations to be confirmed during design), and would require a permit equivalent for installation. This work would most likely be covered under Permit-by-Rule 46, Installation of One or More Monitoring Wells.
    - The MNA alternative is designed to meet the GWQS over time through the use of the natural attenuation mechanisms of biodegradation, dispersion, and advection. However, as previously noted, given the natural presence of certain COCs, and the presence of anthropogenic sources related to the larger mine

workings, it is unlikely that GWQS would be met for this alternative in the near term.

- Overall, the mechanisms are in place for this alternative to comply with ARARs through a conventional permit equivalent process.

- Long-Term Effectiveness and Permanence
  - The ability of MNA to reduce concentrations of COCs in groundwater has been demonstrated through
    - Testing performed during the RI (e.g., stable isotope probing) that conclusively demonstrated biodegradation of benzene.
    - The influence of redox conditions, as described in the Groundwater RIR, within and down gradient of the PMP Area that help to inhibit the mobility of soluble metals in the downgradient direction (e.g., the distribution of arsenic).
    - Modeling of 1,4-dioxane fate and transport that shows even absent documentation of measurable biodegradation (i.e., the results of the CSIA analyses), advection and dispersion are sufficient to bring concentrations below the GWQS for 1,4-dioxane on Site.
  - As described in Section 7, the CEA/WRA would be of indeterminate duration because GWQS are not met due to both natural and anthropogenic contributions. As such, for as long as the CEA/WRA is in effect, this alternative would be protective. While this alternative is not a permanent remedy as ongoing certification of the CEA/WRA is necessary along with the routine monitoring, the routine monitoring and biennial certifications of the CEA/WRA would be performed as long as necessary to maintain long-term effectiveness, and the administrative processes are in place to allow this to occur.

- Reduction of Toxicity, Mobility, or Volume
  - This alternative relies on the natural attenuation processes of biodegradation (conclusively demonstrated for benzene), advection, and dispersion (each COC) to reduce the concentrations and mobility of COCs. In addition, as noted above, redox conditions within and down gradient of the PMP Area help to

inhibit the mobility of soluble metals in the down-gradient direction. Monitoring would be conducted to confirm these processes are maintained.

- Short-Term Effectiveness
    - Remedial construction activities will be limited to installation of monitoring wells, and this limited work effort would not have any significant short-term impacts.
    - Health and safety of workers and the public would be maintained during the installation of the additional monitoring wells, as this work would be completed under a Site-specific health and safety plan.
    - Implementing the CEA/WRA is an administrative action of short duration. The installation of the three additional sentinel monitoring wells is also short duration. Consequently, the anticipated schedule to have this alternative in place is on the order of six months, including obtaining permit equivalents, assuming some of the additional monitoring wells are confirmed to be within a wetland area and/or flood hazard area.
    - Short term exposure risks to the health and safety of workers, although unlikely, may occur during installation of sentinel monitoring wells. Safeguards, per a Site-specific health and safety plan, will be implemented to protect human health and the environment during installation of the wells. No other remedial or construction activities (e.g., access) will present short-term risks.
- Implementability
    - This alternative is readily implemented with conventional equipment and materials available in the marketplace (e.g., for well installations).
    - As noted above, a wetlands general permit equivalent and a flood hazard area permit by rule may be necessary, based on the confirmed, design locations of additional sentinel monitoring wells. Impediments to obtaining such permit equivalents are not anticipated, assuming they are needed.
    - A CEA/WRA is readily implementable through regulatory coordination.

- Cost
  - The total 30-year net present worth estimated cost for this MNA alternative is $1,439,000, as shown on Table 15. The costs include installation of three sentinel monitoring wells and appurtenant activities (e.g., wetland permit equivalent and mitigation), 30 years of groundwater and surface water monitoring and reporting, biennial certifications, and routine operation and maintenance activities (e.g., well maintenance).

8.2.3 Alternative 3 – Enhanced MNA Treatment Barrier in the PMP Area/OCDA

Alternative 3 – Enhanced MNA Treatment Barrier in the PMP Area/OCDA is similar to Alternative 2 with the addition of supplying oxygen and essential nutrients in a barrier approach to enhance naturally occurring biodegradation mechanisms.

Evaluation of the Enhanced MNA Treatment Barrier alternative against the seven evaluation criteria is as follows:

- Overall Protection of Human Health and the Environment
  - Because there are no significant, potential human health or ecological risks, the Enhanced MNA Treatment Barrier alternative is protective of human health and the environment, under current conditions. In addition, oxygen and nutrients would be introduced into the groundwater to support and enhance natural attenuation mechanisms that help to control potential risks through reductions in concentrations of COCs.
  - Under the Enhanced MNA Treatment Barrier alternative a routine monitoring program would be implemented that would provide a mechanism for assessment of continued protectiveness in the future (i.e., confirming that groundwater and surface water conditions do not change).
  - A CEA/WRA would be required for the Enhanced MNA Treatment Barrier alternative, as it is a regulatory requirement. A CEA/WRA requires, at a minimum, biennial certification that it remains protective relative to restrictions on the use of groundwater that does not meet the standards at NJAC 7:9C or the Primary Drinking Water Standards (i.e., MCLs). The biennial certification would be based on the results of the groundwater monitoring program to assess the effectiveness of this alternative.

- The Enhanced MNA Treatment Barrier alternative would meet the RAOs of preventing consumption of groundwater with concentrations of COCs above GWQS through the CEA/WRA, and preventing exposure to residents above the USEPA's risk benchmarks (i.e., under current conditions this RAO is met because groundwater is not used and monitoring and use restrictions would provide mechanisms for assessing that the remedy continues to meet this RAO). In addition, this alternative would support and enhance the naturally occurring attenuation mechanisms (biodegradation, dispersion, advection) to over time meet the RAO of attempting to restore the aquifer to Class IIA GWQS within a reasonable time frame, and provide monitoring to assess the effectiveness of these enhanced natural attenuation mechanisms. As previously described for Alternatives 1 and 2, given the natural presence of certain COCs (e.g., arsenic), and the presence of anthropogenic sources related to the larger mine workings, it is possible that this RAO would not be met for an extended period of time, which is consistent with the indeterminate time frame for the CEA/WRA. However, the enhancement methods used in this alternative may help to shorten the term of a CEA/WRA.

- Compliance with ARARs
  - This alternative, with implementation of a CEA/WRA, would comply with the ARAR for controlling use of groundwater in a CEA per NJAC 7:9C.
  - This alternative requires the installation of additional monitoring and enhancement wells, and would comply with the ARAR for well installation at NJAC 7:9D, as the well installations would be conventional and meet the requirements of this regulation.
  - Some of the additional well locations are in wetland and/or transition areas (although exact locations will be confirmed during design) and would require permit equivalents for the disturbance of wetlands and transitions areas for access and well installation. Installation of the additional wells would be anticipated to occur under NJAC 7:7A, General Permit 4, hazardous site investigation and cleanup. The wetlands and transition area disturbances would be small, and General Permit 4 requires mitigation. Because of the small area of disturbance, it is anticipated that mitigation would be performed on site, in a peripheral area of the currently designated wetlands.

Depending on final well locations, some additional wetlands delineation may also be necessary.

- Some of the additional well locations may also be in the floodplain of Park Brook (again, exact locations to be confirmed during design), and would require a permit equivalent for installation. This work would most likely be covered under Permit-by-Rule 46, Installation of One or More Monitoring Wells.

- Introducing oxygen and essential nutrients into the aquifer would constitute injection under NJAC 7:14A. For this alternative, it is anticipated that a permit-by-rule, subject to the provisions at NJAC 7:14A-7.5 and NJAC 7:14A-8.5, would be necessary to introduce oxygen and essential nutrients. These permit-by-rule provisions are designed to facilitate permitting for remediation, and the regulatory framework to obtain approval is in place.

- The Enhanced MNA Treatment Barrier alternative is designed to meet the GWQS over time through the natural attenuation mechanisms of biodegradation, dispersion, and advection, which are further supported by the introduction of oxygen and essential nutrients. However, as previously noted, given the natural presence of certain COCs, and the presence of anthropogenic sources related to the larger mine workings, it is unlikely that GWQS would be met for this alternative in the near term.

- Overall, the mechanisms are in place for this alternative to comply with ARARs through a conventional permit equivalent process.

- Long-Term Effectiveness and Permanence

  - The ability of the Enhanced MNA Treatment Barrier alternative to reduce concentrations of COCs in groundwater has been demonstrated through:

    - Testing performed during the RI (e.g., stable isotope probing) that conclusively demonstrated biodegradation of benzene. The addition of oxygen and essential nutrients would serve to further support this existing natural attenuation mechanism.

    - The influence of redox conditions, as described in the Groundwater RIR, within and down gradient of the PMP Area that help to inhibit the mobility of soluble metals in the downgradient direction (e.g., the distribution of arsenic). Again, introduction of oxygen would oxidize ferrous iron and arsenic is co-precipitated with iron, which would further support this natural attenuation mechanism.

- Modeling of 1,4-dioxane fate and transport that shows even absent documentation of measurable biodegradation under existing conditions (i.e., the results of the CSIA analyses), advection and dispersion are sufficient to bring concentrations below the GWQS for 1,4-dioxane on Site. However, under this alternative, the addition of oxygen and essential nutrients may support biodegradation of 1,4-dioxane, in addition to advection and dispersion.

  - As described in Section 7, the CEA/WRA would be of indeterminate duration because GWQS are not met due to both natural and anthropogenic contributions. As such, for as long as the CEA/WRA is in effect, this alternative would be protective. While this alternative is not a permanent remedy as ongoing certification of the CEA/WRA is necessary along with the routine monitoring, the routine monitoring and biennial certifications of the CEA/WRA would be performed as long as necessary to maintain long-term effectiveness, and the administrative processes are in place to allow this to occur.

- Reduction of Toxicity, Mobility, or Volume

  - This alternative relies on the natural attenuation processes of biodegradation (conclusively demonstrated for benzene), advection and dispersion (each COC) to reduce the concentrations and mobility of COCs, and provides the additional step of supporting and enhancing these processes. In addition, as noted above, redox conditions within and down gradient of the PMP Area help to inhibit the mobility of soluble metals in the downgradient direction, and the enhancement of the MNA processes could also aid the positive effects of redox conditions. Monitoring would be conducted to confirm these processes are maintained, supported, and enhanced.

- Short-Term Effectiveness

  - Remedial construction activities would be limited to installation of monitoring and MNA enhancement wells, and this limited work effort would not have any significant short-term impacts.

- Health and safety of workers and the public would be maintained during the installation of the additional wells, as this work would be completed under a Site-specific health and safety plan.

- Implementing the CEA/WRA is an administrative action of short duration. The installation of the additional wells is also of relatively short duration. Permit equivalents would be covered by a general permit and a permit-by-rule. Consequently, the anticipated schedule to have this alternative in place is on the order of one year to 18 months, including obtaining permit equivalents, assuming that some of the additional wells are confirmed to be within a wetland area and/or a flood hazard area, and the addition of oxygen and essential nutrients requires a permit-by-rule.

- Short-term exposure risks to the health and safety of workers, although unlikely, may occur during installation of additional wells. The ORC material is considered hazardous because of its oxidative properties; however, it would be handled in accordance with manufacturer's instructions to maintain safety. Safeguards, per a Site-specific health and safety plan, will be implemented to protect human health and the environment. No other remedial or construction activities (e.g., access) will present short-term risks.

- Implementability

  - This alternative is readily implemented with conventional equipment and materials available in the marketplace (e.g., for well installations, ORC is commercially available).

  - As noted above, permit equivalents may be necessary, based on the confirmed, design locations of additional wells and the need for a NJPDES permit-by-rule. Impediments to obtaining permit equivalents are not anticipated.

  - A CEA/WRA is readily implementable through regulatory coordination.

- Cost

  - The total 30-year net present worth estimated cost for the Enhanced MNA Treatment Barrier alternative is $2,815,000, as shown on Table 16. The costs include installation of additional monitoring and enhancement wells and appurtenant activities (e.g., wetland permit equivalent and mitigation), 30 years of groundwater and surface water monitoring and reporting, biennial certifications, and routine operation and maintenance activities (e.g., replacement of ORC, well maintenance).

8.3 PMP Air Shaft

8.3.1 Alternative 4 – PMP Air Shaft, No Action

As noted in Section 6, because the concentrations of COCs in the PMP Air Shaft are among the highest measured in groundwater at the Site and are above the GWQS, alternatives for the Air Shaft have been retained for evaluation. These Air Shaft alternatives could be stand-alone remedial options, or used in combination with the previously discussed options for the Site-wide groundwater or PMP Area/OCDA.

The No Action PMP Air Shaft alternative was retained as a baseline for comparison with other alternatives. In addition, as previously noted, the results of the BHHRA indicate that there are no significant potential future risks associated with groundwater. Further, the SRGEA concluded that the potential ecological risks were low and no further evaluation is warranted. Last, a discrete, defined source of COCs has not been identified for groundwater, including within the PMP Air Shaft. As such, No Action was also retained for evaluation as an alternative for implementation and direct comparison to other alternatives, not just as a baseline.

Evaluation of the Air Shaft No Action alternative against the seven criteria is as follows:

- Overall Protection of Human Health and the Environment
  - Because there are no significant, potential human health or ecological risks, the No Action alternative is protective of human health and the environment, under current conditions (e.g., the Air Shaft is not used as a water supply). The concentrations of COCs among the highest on Site in the PMP Air Shaft does not alter the fact that there is an absence of significant risks associated with groundwater.
  - As described for the Site-wide groundwater and PMP Area/OCDA alternatives, a CEA/WRA would be put into place for groundwater and would also cover the area adjacent to and down-gradient from the PMP Air Shaft. The CEA/WRA is not specific to the Air Shaft.

- The No Action alternative for the PMP Air Shaft would not alter the ability of the Site-wide groundwater or PMP Area/OCDA alternatives to meet the RAOs of preventing consumption of groundwater with concentrations of COCs above GWQS through the CEA/WRA, and preventing exposure to residents above the USEPA's risk benchmarks (i.e., under baseline conditions this RAO is met because groundwater is not used for potable supply).

- Because remedial action would not be undertaken at the PMP Air Shaft, it is possible that not meeting the RAO of attempting to restore the aquifer to Class IIA GWQS within a reasonable time frame would take longer, although currently the time frame for meeting this RAO is considered indeterminate because of the absence of a defined source, the natural presence of certain COCs (e.g., arsenic), and the presence of anthropogenic sources related to the larger mine workings.

- Compliance with ARARs
  - There would not be any chemical, location, or action-specific ARARs applicable to this PMP Air Shaft alternative. The chemical-specific ARAR of a CEA/WRA would be covered by any of the Site-wide or PMP Area/OCDA groundwater alternatives.

- Long-Term Effectiveness and Permanence
  - This alternative is not a permanent remedy, and under this alternative there would not be any mechanisms to demonstrate that the concentrations of COCs at the PMP Air Shaft do not change over time and alter the absence of significant risks under current conditions.

- Reduction of Toxicity, Mobility, or Volume
  - This alternative would not implement any removal or treatment-based remedial actions to reduce toxicity, mobility or volume.

- Short-Term Effectiveness
  - No remedial or construction activities occur, therefore no short-term impacts are associated with implementation.

- Implementability
    - The No Action alternative does not require any activity and, therefore, implementability is not a consideration.
- Cost
    - The No Action alternative for the PMP Air Shaft does not involve any costs.

8.3.2 Alternative 5 – Oxygen Diffusion in the PMP Air Shaft

The Oxygen Diffusion alternative focuses on changing redox conditions at the base of the PMP Air Shaft to promote aerobic biodegradation. Evaluation of the Oxygen Diffusion alternative against the seven criteria is as follows:

- Overall Protection of Human Health and the Environment
    - Because there are no significant, potential human health or ecological risks, the Oxygen Diffusion alternative is protective of human health and the environment, under current conditions. However, implementation of this alternative may further reduce concentrations of COCs within the air shaft, and as a result, may reduce concentrations of COCs in down-gradient groundwater, although the hydraulic connection between the PMP Air Shaft and surrounding groundwater is limited by the low-permeability of the bedrock aquifer.
    - As described for the Site-wide groundwater and PMP Area/OCDA alternatives, a CEA/WRA would be put into place for groundwater and would also cover the area of and down-gradient from the PMP Air Shaft.
    - The Oxygen Diffusion alternative for the PMP Air Shaft would not alter the ability of the Site-wide groundwater or PMP Area/OCDA alternatives to meet the RAOs of preventing consumption of groundwater with concentrations of COCs above GWQS through the CEA/WRA, and preventing exposure to residents above the USEPA's risk benchmarks (i.e., under baseline conditions this RAO is met because groundwater is not in use as a potable supply).
    - Using oxygen diffusion in the PMP Air Shaft would be designed to reduce concentrations of COCs in the Air Shaft. Under the assumption that there is

hydraulic communication between the PMP Air Shaft and the surrounding aquifer, reductions in COC concentrations within the PMP Air Shaft may be reflected in the surrounding aquifer. This potentially beneficial reduction in the COC concentrations may result in meeting the RAO of attempting to restore the aquifer to Class IIA GWQS within a reasonable time frame in a shorter time period. However, as previously noted, the time frame for meeting this RAO is considered indeterminate because of the absence of a defined source, the natural presence of certain COCs (e.g., arsenic), and the presence of anthropogenic sources related to the larger mine workings.

- Oxygen diffusion was also retained as an alternative because it would be a low-impact process introduced to the PMP Air Shaft. Placing ORC in the lower portions of the Air Shaft has a low potential to alter conditions in a manner that would increase concentrations of COCs, as there would be limited disturbance of the PMP Air Shaft, and making the conditions at the base of the air shaft aerobic, based on the results of the RI, should decrease concentrations of COCs by promoting aerobic biodegradation. However, it is possible that the solubility of some inorganics could be enhanced under aerobic conditions (e.g., secondary metals) that tend to be more soluble under oxidized conditions.

- Compliance with ARARs
    - The mine water in the PMP Air Shaft would, from a regulatory perspective, likely be considered groundwater even though it is not contained in a natural environment, but is interconnected, albeit at low permeability, with the surrounding aquifer. Consequently, introducing oxygen and essential nutrients into the aquifer would likely constitute injection under NJAC 7:14A. For this alternative, it is anticipated that a permit-by-rule, subject to the provisions at NJAC 7:14A-7.5 and NJAC 7:14A-8.5, would be necessary to introduce oxygen and essential nutrients. These permit-by-rule provisions are designed to facilitate permitting for remediation, and the regulatory framework to obtain approval is in place
    - There would not be any other chemical, location, or action-specific ARARs applicable to this PMP Air Shaft alternative.
    - Overall, the mechanisms are in place for this alternative to comply with ARARs through a conventional permit equivalent process.

- Long-Term Effectiveness and Permanence
    - This alternative is not a permanent remedy; however, ORC could be placed in the PMP Air Shaft indefinitely, and therefore, to the extent there are beneficial effects from oxygen diffusion, the effectiveness could be maintained for the long term.
    - Under this alternative there would be monitoring of the mine water quality to assess the performance of the oxygen diffusion. Consequently, this alternative includes a mechanism to demonstrate that the concentrations of COCs at the PMP Air Shaft decline, assuming the alternative has the anticipated effect.
- Reduction of Toxicity, Mobility, or Volume
    - This alternative would introduce oxygen and essential nutrients into the base of the PMP Air Shaft to promote aerobic biodegradation of COCs, which would reduce toxicity (e.g., degrade benzene) and volume. As a discrete, defined source of COCs has not been identified, and concentrations of COCs in the PMP Air Shaft are in the part per billion range, a substantial reduction in toxicity or volume of COCs is not anticipated.
- Short-Term Effectiveness
    - The most significant construction element associated with this alternative is the concrete cap on the PMP Air Shaft. This cap is necessary to support the suspension of ORC canisters and provide a stable, permanent work surface for the remedial activities. However, construction of a concrete slab to cap the PMP Air Shaft is a limited work effort that would not have any significant short-term impacts.
    - Health and safety of workers and the public would be maintained during the installation of the concrete cap and ORC placement, as this work would be completed under a Site-specific health and safety plan.
    - Obtaining the permit-by-rule per NJAC 7:14A is an administrative action of short duration. The installation of the concrete cap is also short duration. Consequently, the anticipated schedule to have this alternative in place is on the order of six months to one year, including obtaining the permit-by-rule equivalent.

  - Short-term risks to the health and safety of workers, would be associated with capping the PMP Air Shaft, as workers would be above a deep, open shaft. In addition, the ORC material is considered hazardous because of its oxidative properties, however, it would be handled in accordance with manufacturer's instructions for safety. Safeguards, per a Site-specific health and safety plan, would be implemented to protect human health and the environment. No other remedial or construction activities are anticipated to present short-term risks.

- Implementability

  - The Oxygen Diffusion alternative can be implemented with conventional equipment, materials, means and methods available in the marketplace.

- Cost

  - The total 30-year net present worth estimated cost for PMP Air Shaft Oxygen Diffusion alternative is $334,000, as shown on Table 17. The costs include installation of the Air Shaft cap and appurtenant activities (e.g., NJPDES permit-by-rule, ORC canister suspension), 30 years of mine water monitoring and reporting, and routine operation and maintenance activities (e.g., replacement of ORC material and canisters).

8.3.3 Alternative 6 – Treatment/Closure in the PMP Air Shaft

The Treatment/Closure alternative focuses on a short-term treatment step followed by closure of the PMP Air Shaft which would isolate it from the environment. Evaluation of the Treatment/Closure alternative against the seven criteria is as follows:

- Overall Protection of Human Health and the Environment

  - Because there are no significant, potential human health or ecological risks, the Treatment/Closure alternative is protective of human health and the environment, under current conditions. However, implementation of this alternative may further reduce concentrations in the bedrock aquifer adjacent to the Air Shaft as a result of the closure, essentially isolating the Air Shaft from the environment. However, under current conditions the hydraulic connection between the PMP Air Shaft and surrounding groundwater is limited by the low-permeability of the bedrock aquifer.

- As described for the Site-wide groundwater and PMP Area/OCDA alternatives, a CEA/WRA would be put into place for groundwater and would also cover the area of and down-gradient from the PMP Air Shaft.

- The Treatment/Closure alternative for the PMP Air Shaft would not alter the ability of the Site-wide groundwater or PMP Area/OCDA alternatives to meet the RAOs of preventing consumption of groundwater with concentrations of COCs above GWQS through the CEA/WRA, and preventing exposure to residents above the USEPA's risk benchmarks (i.e., under current conditions this RAO is met because groundwater is not in use as a potable supply).

- Treatment/Closure of the PMP Air Shaft would be designed to reduce concentrations of COCs in the bedrock aquifer outside of the Air Shaft by providing GAC and resin to adsorb COCs and then permanently closing the shaft which would essentially isolate it from the surrounding environment. Under the assumption that there is hydraulic communication between the PMP Air Shaft and the surrounding aquifer, isolation of the Air Shaft may be reflected in improvement of the groundwater quality in the surrounding aquifer down gradient of the Air Shaft. This potentially beneficial reduction in the COC concentrations may result in meeting the RAO of attempting to restore the aquifer to Class IIA GWQS within a reasonable time frame in a shorter time period. However, as previously noted, the time frame for meeting this RAO is considered indeterminate because of the absence of a defined source, the natural presence of certain COCs (e.g., arsenic), and the presence of anthropogenic sources related to the larger mine workings.

- Compliance with ARARs
    - Closure of the PMP Air Shaft would result in displacement of the groundwater in the shaft. This displaced water would in effect be a dewatering operation that could be managed through the permit-by-rule provisions within NJAC 7:14A-7.5. This would require regulatory coordination, and the mechanism for obtaining coverage under the permit-by-rule is in place.

    - To close the PMP Air Shaft, and place the stone, GAC, resin, and grout materials, will require access with heavy equipment. Consequently, stone access pads and roads may be necessary in the area of the PMP Air Shaft.

Because the area around the PMP Air Shaft includes wetlands and transition area, a permit equivalent would likely be necessary. This work would be anticipated to occur under NJAC 7:7A, General Permit 4, hazardous site investigation and cleanup. The wetlands and transition area disturbances would be small, and General Permit 4 requires mitigation. Because of the small area of disturbance, it is anticipated that mitigation would be performed on site, in a peripheral area of the currently designated wetlands. Depending on final limits of disturbance, some additional wetlands delineation may also be necessary.

  - The activities necessary to close the Air Shaft may also require a flood hazard area permit equivalent, as some of the areas of disturbance for access of heavy equipment are in the floodplain of Park Brook. If this were the case, the work could be covered under Permit-by Rule 8 – Construction at or Below Grade in a Fluvial Flood Hazard Area, or via an individual permit, both of which would involve limited disturbance of a riparian zone, and restoration upon completion. The mechanism is in place to obtain the approval for this work.
  - There would not be any other chemical, location, or action-specific ARARs applicable to this PMP Air Shaft alternative.
  - Overall, the mechanisms are in place for this alternative to comply with ARARs through a conventional permit equivalent process.

- Long-Term Effectiveness and Permanence
  - This alternative would be a permanent remedy as the closure component would permanently seal the Air Shaft, and to the extent that the GAC and resin adsorb COCs, the COCs would remain adsorbed as there would not be a mechanism to regenerate the carbon or resin and release the COCs. Being a permanent closure of the PMP Air Shaft, this alternative would be effective for the long-term without any operation and maintenance.
- Reduction of Toxicity, Mobility, or Volume
  - This alternative would provide GAC and resin at the base of the PMP Air Shaft to absorb COCs and in doing so reduce the mobility of the COCs as they would be bound in the GAC and resin matrices. As noted above, this reduction in mobility would be permanent. As a discrete, defined source of

COCs has not been identified, and concentrations of COCs in the PMP Air Shaft are in the part per billion range, a substantial reduction in mobility through the use of GAC and resin is not anticipated.

- In addition to the GAC and resin adsorbing COCs, the permanent closure of the PMP Air Shaft and resulting isolation from the surrounding environment would also reduce the mobility of COCs from within the PMP Air Shaft to the bedrock aquifer. However, this would be through encapsulation and not treatment or removal.

- Short-Term Effectiveness
  - The most significant construction element associated with this alternative is the closure of the PMP Air Shaft. However, the work would be completed in a relatively short period of time, as the work is conventional and is primarily comprised of flyash-cement grout which is readily available for placement in the shaft.
  - Placement of the initial Air Shaft closure materials (i.e., angular stone) will cause disruption of the sediments at the base of the Shaft. However, the adsorbents will be placed at the same time as the stone (i.e., the materials will be intermixed), and shaft closure will follow immediately thereafter. The disturbance will be short term and adsorbents will be placed with the stone, and therefore, while there is the potential for altering the geochemistry and water quality within and down gradient of the Air Shaft, the potential impacts, if any, would be expected to likewise be short term. Note that there is some risk associated with the disturbance, even though there is no discrete source of the COCs in the Air Shaft sediments, by disturbing whatever is affecting water quality causing unwanted changes in groundwater quality in the downgradient direction. Given the anticipated short-term nature of disturbance, the benefits of closure of the Air Shaft could outweigh the potential adverse water quality changes and/or impacts from disturbance of the Shaft.
  - Health and safety of workers and the public would be maintained during the installation of the stone, GAC/resin, and shaft grouting, as this work would be completed under a Site-specific health and safety plan.
  - Obtaining the permit equivalents described previously is an administrative action of short duration. The installation of the stone, GAC/resin, and shaft

grouting is also relatively short duration. Consequently, the anticipated schedule to have this alternative in place is on the order of one-year to 18 months, including obtaining the permit equivalents.

  - Short-term risks to the health and safety of workers, would be associated with closure of the PMP Air Shaft, as workers would be above a deep, open shaft. Safeguards, per a Site-specific health and safety plan, would be implemented to protect human health and the environment.

  - Assuming the shaft is closed with pre-mixed grout delivered to the Site, on the order of 250 truck trips would be required to complete the work. Truck transportation increases the risk of accidents as the work would require traffic through residential areas. However, the number of truck trips is not large for a construction project. Truck traffic would be managed by the remedial action contractor to support safe movement of equipment and materials.

  - No other remedial or construction activities are anticipated to present short-term risks.

- Implementability

  - The Treatment/Closure alternative can be implemented with conventional equipment, materials, means and methods available in the marketplace.

- Cost

  - The total estimated capital cost for the PMP Air Shaft Treatment/Closure alternative is $598,000, as shown on Table 18. The costs include site preparation and access for heavy equipment, installation of stone and GAC/resin at the base of the shaft, grouting the full depth of the air shaft and a concrete cap above the grout, and appurtenant activities (e.g., permit equivalents). There would not be any operation and maintenance costs for this alternative.

9 COMPARATIVE ANALYSIS OF ALTERNATIVES

The following sections present a comparative analysis of the alternatives described and evaluated in Sections 7 and 8, respectively. The purpose of the comparative analysis is to identify the relative advantages and disadvantages of each alternative, considering the evaluation criteria described in Section 8, and to facilitate the selection of a remedial action for the Site. The results of the comparative analysis for Alternatives 1 through 6 are summarized in Table 19.

To briefly reiterate for ease of reference, the alternatives compared in this section are as follows:

- Site-Wide Groundwater
    - Alternative 1 – No Action
    - Alternative 2 – Monitored Natural Attenuation with CEA/WRA
- Site-Wide Groundwater Focused on Combined PMP Area and OCDA
    - Alternative 3 – Enhanced Monitored Natural Attenuation Treatment Barrier with CEA/WRA
- PMP Air Shaft
    - Alternative 4 – No Action
    - Alternative 5 – Oxygen Diffusion via Chemical Addition
    - Alternative 6 – Treatment/Closure

9.1 Site-Wide Groundwater

9.1.1 Overall Protection of Human Health and the Environment

Because there are no significant, potential human health or ecological risks, under current conditions, Alternatives 1, 2, and 3 are protective of human health and the environment under current conditions. Alternatives 2 and 3, with implementation of a routine monitoring program beyond the minimum required for a CEA/WRA, would provide the advantage of a more robust mechanism for assessment of continued protectiveness in the future (i.e., confirming that groundwater conditions do not change).

Each of the alternatives would meet the RAOs of preventing consumption of groundwater with concentrations of COCs above GWQS through the CEA/WRA, and preventing exposure to residents above the USEPA's risk benchmarks through the CEA/WRA.

Alternatives 2 and 3 would use the naturally occurring attenuation mechanisms (biodegradation, dispersion, advection) to over time meet the RAO of attempting to restore the aquifer to Class IIA GWQS within a reasonable time frame, and provide monitoring to assess the effectiveness of these natural attenuation mechanisms. Only Alternative 3, with the introduction of oxygen and nutrients into the groundwater, would have the advantage of supporting and enhancing these naturally occurring attenuation mechanisms. Of note, given the natural presence of certain COCs (e.g., arsenic), and the presence of anthropogenic sources related to the larger mine workings, it is unlikely that any of these alternatives would meet the RAO of aquifer restoration to Class IIA GWQS within a short time frame.

9.1.2 Compliance with Applicable or Relevant and Appropriate Requirements

Alternatives 1, 2, and 3, with implementation of a CEA/WRA, would comply with the ARAR for controlling use of groundwater in a CEA per NJAC 7:9C.

The MNA Alternatives 2 and 3 are designed to meet the GWQS over time through the use of the natural attenuation mechanisms of biodegradation, dispersion, and advection. However, as previously noted, given the natural presence of certain COCs, and the presence of anthropogenic sources related to the larger mine workings, it is unlikely that GWQS would be met for these alternatives in the near term.

Alternatives 2 and 3 each would require permit equivalents, and would comply with ARARs through the permit equivalent application process.

Overall, the mechanisms are in place for Alternatives 2 and 3 to comply with ARARs through a conventional permit equivalent process.

9.1.3 Long-Term Effectiveness and Permanence

Alternatives 1, 2 and 3 are all effective long-term through maintenance of the institutional control provided by the CEA/WRA. The CEA/WRA, established under each of these three alternatives would be of indeterminate duration because GWQS are not met due to both natural and anthropogenic contributions. As such, for as long as the CEA/WRA is in effect, these alternatives would be protective.

None of these alternatives are permanent as ongoing certification of the CEA/WRA is necessary along with the monitoring required by the biennial certifications required for the CEA/WRA. In addition, Alternative 3, Enhanced MNA Treatment Barrier, would require ongoing addition of ORC and nutrients to continue to support and enhance the MNA processes.

MNA, which is a component of Alternatives 2 and 3, has been demonstrated from the groundwater investigations, and is functioning to reduce concentrations of COCs in groundwater naturally, and these processes are expected to continue over the long-term as conditions in the aquifer are not expected to change materially over time in a manner that would affect these processes.

9.1.4 Reduction of Toxicity, Mobility, or Volume

Alternative 1 would not include any removal or treatment-based remedial actions to reduce toxicity, mobility, or volume of COCs.

Alternatives 2 and 3 would reduce the toxicity and mobility of COCs present on Site through the natural attenuation processes of biodegradation, advection, and dispersion. In addition, as noted above, redox conditions within and downgradient of the PMP Area help to inhibit the mobility of soluble metals in the downgradient direction. Monitoring would be conducted to confirm these processes are maintained.

Alternative 3, with the introduction of oxygen and nutrients, provides the additional step of supporting and enhancing the natural attenuation processes, which aids the positive effects of redox conditions, and thus would further reduce toxicity and mobility of COCs.

9.1.5 Short-Term Effectiveness

For Alternative 1, no remedial or construction activities occur, therefore no short-term impacts are associated with implementation. Implementing the CEA/WRA is an administrative action of short duration.

For Alternatives 2 and 3, remedial construction activities will be limited to installation of additional wells, and this limited work effort would not have any significant short-term impacts, and would occur over a relatively short duration. Health and safety of workers and the public would be maintained during the installation of these wells utilizing safeguards, per a Site-specific health and safety plan, to limit short-term exposure risks.

The estimated time frames for each of the alternatives is comparatively short, and is summarized in the Table below.

Alternative	Estimated Time Frame for Implementation
1 – No Action	Up to 2 months
2 – Monitored Natural Attenuation	Approximately 6 months
3 – Enhanced Monitored Natural Attenuation Treatment Barrier	Approximately 12 – 18 months

9.1.6 Implementability

Alternatives 1, 2 and 3 are all readily implementable. The administrative task of setting up the CEA/WRA, a component under each alternative, is readily accomplished through coordination with the NJDEP.

Alternatives 2 and 3 are readily implemented with conventional equipment and materials available in the marketplace (e.g., for well installations, commercially available ORC).

As noted above, permit equivalents may be necessary under Alternatives 2 and 3 for well installations and placement of ORC in the aquifer. Impediments to obtaining permit equivalents are not anticipated.

9.1.7 Cost

Alternative 1, is the least expensive with only implementation of the CEA/WRA. Alternative 2, which provides an additional level of monitoring over Alternative 1 has a cost approximately 231% higher than Alternative 1. Alternative 3 provides a comparable level of protectiveness to Alternative 2 but at higher costs of approximately 195% more, respectively. A cost comparison of the alternatives is provided in the tabulation below.

Alternative	Estimated Net Present Worth Cost
1 – No Action	$622,000
2 – Monitored Natural Attenuation with a CEA/WRA	$1,439,000
3 – Enhanced Monitored Natural Attenuation Treatment Barrier with a CEA/WRA	$2,815,000

9.2 PMP Air Shaft

9.2.1 Overall Protection of Human Health and the Environment

Because there are no significant, potential human health or ecological risks, Alternatives 4, 5, and 6 are all protective of human health and the environment, under current conditions. In addition, as described for the Site-wide groundwater alternatives, a CEA/WRA would be put into place for groundwater and would also cover the area of and down-gradient from the PMP Air Shaft.

Alternatives 4, 5, and 6 would not alter the ability of the Site-wide groundwater alternatives to meet the RAOs of preventing consumption of groundwater with concentrations of COCs above GWQS through the CEA/WRA, and preventing exposure to residents above the USEPA's risk benchmarks (i.e., under baseline conditions this RAO is met).

Under the assumption that the PMP Air shaft is hydraulically connected to the surrounding PMP Area aquifer, the treatment associated with Alternatives 5 and 6 (oxygen diffusion and GAC/resin) would be potentially beneficial to reducing the COC concentrations which may result in meeting the RAO of attempting to restore the aquifer to Class IIA GWQS within a reasonable time frame in a shorter time period. However, as previously noted, the time frame for meeting this RAO is considered indeterminate because of the absence of a defined source, the natural presence of certain COCs (e.g., arsenic), and the presence of anthropogenic sources related to the larger mine workings. Alternative 6 may also beneficially affect down-gradient groundwater quality by isolating the PMP Air Shaft from the surrounding aquifer.

9.2.2 Compliance with Applicable or Relevant and Appropriate Requirements

Alternative 4 would not have any chemical, location, or action-specific ARARs that would be applicable as there would not be any action. The chemical-specific ARAR of a CEA/WRA would be covered by any of the Site-wide groundwater alternatives.

Alternatives 5 and 6 would require obtaining permit equivalents by rule (i.e., underground injection, dewatering of the Air Shaft) to be implemented. As described above, mechanisms are in place to obtain approval for these permit equivalents.

Overall, the mechanisms are in place for Alternatives 5 and 6 to comply with ARARs through a conventional permit equivalent process.

9.2.3 Long-Term Effectiveness and Permanence

Alternative 4 is not a permanent remedy, and under this alternative there would not be any mechanisms to demonstrate that the concentrations of COCs at the PMP Air Shaft do not change over time and alter the absence of significant risks under current conditions.

Alternative 5 is not a permanent remedy; however, ORC could be placed in the PMP Air Shaft indefinitely, and therefore, to the extent there are beneficial effects from oxygen diffusion, the effectiveness could be maintained for the long term. Monitoring of the quality of the mine water to assess the performance of the oxygen diffusion would confirm that the concentrations of the COCs at the PMP Air Shaft decline.

Alternative 6 is a permanent remedy as the closure component would permanently seal the Air Shaft and essentially isolate it from the surrounding environment, and to the extent that the GAC and resin adsorb COCs, the COCs would remain adsorbed as there would not be a mechanism to regenerate the carbon or resin and release the COCs. Being a permanent closure of the PMP Air Shaft, this alternative would be effective for the long-term without any operation and maintenance.

9.2.4 Reduction of Toxicity, Mobility, or Volume

Alternative 4 would not implement any removal or treatment-based remedial actions to reduce toxicity, mobility or volume.

Alternative 5 would reduce COC toxicity and volume by introducing oxygen and essential nutrients into the base of the PMP Air Shaft to promote aerobic biodegradation of COCs.

Alternative 6 would reduce mobility of COCs within the PMP Air Shaft by providing GAC and resin at the base of the Air Shaft to adsorb COCs and bind them in the GAC and resin matrices. As noted above, this reduction in mobility would be permanent. Isolating the Air Shaft from the surrounding aquifer through the closure process would also reduce mobility.

As a discrete, defined source of COCs has not been identified, and concentrations of COCs in the PMP Air Shaft are in the part per billion range, a substantial reduction in toxicity, volume, or mobility of COCs is not anticipated for Alternatives 4, 5, or 6.

9.2.5 Short-Term Effectiveness

Under Alternative 4, no remedial or construction activities occur, therefore, no short-term impacts are associated with implementation.

There are minimal short-term risks associated with implementation of Alternatives 5 or 6. The most significant construction element associated with Alternative 5 is the concrete cap on the PMP Air Shaft, which would be complete in a relatively short period of time. The most significant construction element associated with Alternative 6 is the grouting and closure of the PMP Air Shaft. This too would be completed in a relatively short period of time. Neither Alternative 5 nor Alternative 6 are anticipated to have any significant short-term impacts. Health and safety of workers and the public would be maintained during construction of both of these alternatives. Safeguards, per a Site-specific health and safety plan, would be implemented to protect human health and the environment. No other remedial or construction activities are anticipated to present short-term risks.

Obtaining the required permits-by-rule will be of short duration for Alternatives 5 and 6. Construction of these alternatives is also expected to be of short duration. Consequently, the anticipated schedule to have Alternative 5 in place is on the order of six months to one-year and one-year to 18 months for Alternative 6.

As part of Alternative 6, the placement of stone, GAC, and resin in the base of the Air Shaft has the potential to disturb sediments and debris, which could in turn alter the geochemistry in the base of the shaft on a short-term basis. As the hydraulic communication between the shaft and the bedrock aquifer is limited, and adsorbents would be added at the same time as the disturbance, a significant impact is not expected. However, such disturbance could potentially cause a short-term increase in COC concentrations in the bedrock aquifer adjacent to the PMP Air Shaft.

9.2.6 Implementability

Alternative 4 does not require any activity and, therefore, implementability is not a consideration.

Alternatives 5 and 6 can both be implemented with conventional equipment, materials, means and methods available commercially.

9.2.7 Cost

Alternative 4, is the least expensive as No Action does not involve any costs for the PMP Air Shaft because the CEA/WRA cost element is already accounted for in the Site-wide groundwater alternatives. The second most expensive is Alternative 5, which includes installation of the Air Shaft cap and appurtenant activities, 30 years of mine water monitoring and reporting, and routine operation and maintenance activities for a total estimated net present worth cost of $334,000. Alternative 6 is approximately 179% more costly than Alternative 5, and the cost includes site preparation, installation of stone, GAC, resin, grouting the full depth of the Air Shaft, a concrete cap, and appurtenant activities for a total estimated cost of $598,000. While Alternative 6 is more costly, it is also permanent.

LIMITATIONS

The work product included in the attached was undertaken in full conformity with generally accepted professional consulting principles and practices and to the fullest extent as allowed by law we expressly disclaim all warranties, express or implied, including warranties of merchantability or fitness for a particular purpose. The work product was completed in full conformity with the contract with our client and this document is solely for the use and reliance of our client (unless previously agreed upon that a third party could rely on the work product) and any reliance on this work product by an unapproved outside party is at such party's risk.

The work product herein (including opinions, conclusions, suggestions, etc.) was prepared based on the situations and circumstances as found at the time, location, scope and goal of our performance and thus should be relied upon and used by our client recognizing these considerations and limitations. Cornerstone shall not be liable for the consequences of any change in environmental standards, practices, or regulations following the completion of our work and there is no warrant to the veracity of information provided by third parties, or the partial utilization of this work product.

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TABLES

TABLE 1
ORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE NEW JERSEY GROUNDWATER QUALITY STANDARDS (NJGWQS) IN GROUNDWATER
MARCH 2015 THROUGH AUGUST 2017
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD MINES/LANDFILL SUPERFUND SITE

Peters Mine Pit (PMP) Area

Parameter	Sampling Event	NJGWQS ug/l	OB-11R	OB-19	OB-20B	OB-27	OB-31	OB-32	RW-3 (77-87)	RW-3DS (155-160)	RW-3DD (175-180)	RW- 4A (113-123)	RW-5	RW- 6	RW- 6A	RW-11S (236-241)	RW-11D (262-267)	RW-14D (175-185)	RW-15D	SC-1
Benzene	Mar-15	1	3.2	NS		2.8								344	13.3		NS	NS	NS	150
Benzene	Apr-15	1	2.9	NS		3.1								2.2	8.7		NS	NS	NS	1.8
Benzene	Jun-15	1	2.9	NS		3								1.7	9.1		NS	NS	NS	1.6
Benzene	Aug-15	1	2.9			3								1.2	7.7		1.6	NS	NS	1.3
Benzene	Dec-15	1	3.1	1.4		1.9								1.5	5.9		2.4	NS	NS	2.9
Benzene[1]	May-16	1	2.4/2.5	1.3/1.5		2.1/2.4								2.1/2.0	5.7/6.9		3.0/3.5			1.6/1.7
Benzene	Aug-16	1	3.2			2.3								1.9	8		6.4			1.8
Benzene	Feb-17	1	2.2			2						NS		2.1	8.7		1.5			
Benzene	Aug-17	1	2.5			2.1								1.4	6.1		6.3			2
Chloroethane	Mar-15	5	24.3	NS		76.7											NS	NS	NS	
Chloroethane	Apr-15	5	21.2	NS		87.2											NS	NS	NS	
Chloroethane	Jun-15	5	22	NS		79											NS	NS	NS	
Chloroethane	Aug-15	5	23			83												NS	NS	
Chloroethane	Dec-15	5	30	8.7	6.7	48 J								5.3				NS	NS	
Chloroethane	May-16	5	20	6.8		55														
Chloroethane	Aug-16	5	24			61								10	5.7		8.6			
Chloroethane	Feb-17	5	17			50						NS		5.4						
Chloroethane	Aug-17	5	17			79	15							6.1						
Total PCBs	Aug-15	0.5										1.3						NS	NS	
1,4-Dioxane	Jun-15	0.4		NS			NS	NS	NS	NS	NS		NS			NS	NS	NS	NS	
1,4-Dioxane	Aug-15	0.4	4.3 J		0.95 J	6.2 J	NS	NS	22	38	20		6.7 J	1.5 J	2.7 J	1.1 J *	26	NS	NS	
1,4-Dioxane	Dec-15	0.4	1.3	1.89	1.37	1.28	NS	NS	8.27	5.25	8.95		3.28	1.09	1.28	1.88	17.9	NS	NS	1.3
1,4-Dioxane[2]	May-16	0.4	1.8/5.41	1.34/4.77	1.0/2.0*	1.2/7.32	0.41/1.74	<0.4/0.412	8.6/28.7	3.3/25.5	4.9/28.1		3.6/10.7	0.37/2.89	2.4/4.81	0.6/1.05	16/54.6	0.17/0.89	0.47/0.843	0.74/1.6
1,4-Dioxane	Aug-16	0.4	5.97	0.878	1.26	6.47	1.9	0.422	29.1	25.1	152/29.2/20.9**		10.8	3.7	3.1	1.08	73.4/54.4*	0.973	0.86	0.905
1,4-Dioxane	Feb-17	0.4	3.57	3.14	3.08	5.81	2.31	0.454	NS	24.8	27.7		10.6	4.44	3.59	1.39	86.6	0.834	0.846	NS
1,4-Dioxane	Aug-17	0.4	6.11		1.05	15.5	2.1	0.56	29.4	23.8	26.1		10.2	4.01	2.72	1.63	88.3	0.719	0.982	1.13

Cannon Mine Pit (CMP) Area

Parameter	Sampling Event	NJGWQS ug/l	OB- 3	OB-12	OB-13	RW-2 (279-289)	RW- 2 (452-462)	RW- 8 (204-214)
Benzene	Aug-16	1						3.8
Hexachlorobenzene	Aug-17	0.02	0.046					
bis(2-Ethylhexyl)phthalate	Aug-15	3	6.3	3.7	3.6			
Total PCBs	Aug-16	0.5					0.77	
1,4-Dioxane	Aug-15	0.4				10	4.7 J	
1,4-Dioxane	Aug-16	0.4				11.9	0.901	
1,4-Dioxane	Feb-17	0.4				10.6	1.18	
1,4-Dioxane	Aug-17	0.4				13.6	1.23	

O'Connor Disposal Area (OCDA) Area

Parameter	Sampling Event	NJGWQS ug/l	OB-14B	OB-17
Hexachlorobenzene	Aug-17	0.02	0.026	
1,4-Dioxane	Aug-15	0.4		17
1,4-Dioxane[2]	May-16	0.4		2.9/18.9
1,4-Dioxane	Aug-16	0.4		17.5
1,4-Dioxane	Feb-17	0.4		16
1,4-Dioxane	Aug-17	0.4		20.7

No Exceedances within the Sally's Pond Area

Notes:
If a duplicate sample was collected, the highest result from the Parent Sample or its Duplicate is reported.
NS - Well was not sampled during noted sampling event.
blank cells - Constituent was not reported above the applicable NJGWQS.
[1] 2.4/2.5 Values represent split samples between Test America and Alpha Analytical.
[2] 1.8/5.41 Values represent split samples between Test America (w/o isotope dilution) and Alpha Analytical (with isotope dilution).
* First result via 8270 SIM-ID by Alpha Analytical , second result via Method 522 from Pace Analytical as part of isotope study.
**First result via 8270 SIM-ID by Alpha Analytical, second result via Method 522 from Pace Analytical as part of isotope study, third result re-analysis by Alpha Analytical via 8270 Sim-ID out of hold time.

TABLE 2
INORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE NEW JERSEY
GROUNDWATER QUALITY STANDARDS (NJGWQS) IN GROUNDWATER
MARCH 2015 THROUGH AUGUST 2017
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD MINES/LANDFILL SUPERFUND SITE

Peters Mine Pit

Parameter	Total or Dissolved	Sampling Event	NJGWQS ug/l	OB-11R	OB-15B	OB-19	OB-20A	OB-20B	OB-21	OB-25	OB-27	OB-30B
Aluminum	D	Aug-15	200						640	1800		
Aluminum	T	Aug-15	200		890				2200	12800 B		
Aluminum	D	Aug-16	200									
Aluminum	T	Aug-16	200		244				635	804		
Aluminum	D	Aug-17	200									
Aluminum	T	Aug-17	200						4390 B	728		
Arsenic	D	Aug-15	3									
Arsenic	T	Aug-15	3	25 B			7.1 B			4.1 B	26 B	
Arsenic	D	Aug-16	3									
Arsenic	T	Aug-16	3	23.8							22.5	
Arsenic	D	Feb-17	3									
Arsenic	T	Feb-17	3	24.4							36.1	
Arsenic	D	Aug-17	3									
Arsenic	T	Aug-17	3	27.3			5				23.1	
Chloride	T	Aug-15	250000									
Chloride	T	Aug-16	250000									
Chloride	T	Aug-17	250000							543000 D		
Iron	D	Apr-15	300	68800			26400	44800			61200	
Iron	T	Apr-15	300	70000			26800	46700	1740		65200	
Iron	D	Aug-15	300	5400		4700	19800	28300	880	1600	5100	
Iron	T	Aug-15	300	70400	1600	16500	31700	42500	3500	8100	52000	
Iron	D	Aug-16	300	18900		946		22700			14300	
Iron	T	Aug-16	300	81100	640	21200	25900	44800	1250	1260	52100	
Iron	D	Aug-17	300	11300								
Iron	T	Aug-17	300	84500		16300	36600	43900	6820	1250	47300	
Lead	T	Aug-15	5							11		
Lead	T	Aug-16	5							6.8		
Lead	T	Feb-17	5									

TABLE 2
INORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE NEW JERSEY
GROUNDWATER QUALITY STANDARDS (NJGWQS) IN GROUNDWATER
MARCH 2015 THROUGH AUGUST 2017
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD MINES/LANDFILL SUPERFUND SITE

Peters Mine Pit

Parameter	Total or Dissolved	Sampling Event	NJGWQS ug/l	OB-11R	OB-15B	OB-19	OB-20A	OB-20B	OB-21	OB-25	OB-27	OB-30B
Lead	T	Aug-17	5									
Manganese	D	Aug-15	50	11900	420 B	310 B	790 B	10600 B		51	8200	1600
Manganese	T	Aug-15	50	11900	4000	290	760	10200	150	340 B	8000	1600
Manganese	T	Dec-15	50	11100	NS	357	566	9680	NS	NS	7120	NS
Manganese	T	Jan-16	50	NS	NS	NS	NS	NS	NS	NS	NS	NS
Manganese	D	Aug-16	50	12000	136	297	494	10300			7340	1030
Manganese	T	Aug-16	50	12700	1200	329	554	9820	219	178	7410	1180
Manganese	D	Aug-17	50	10800	269	257	756	8510			6760	1370
Manganese	T	Aug-17	50	11500	1490	295	779	8610	315		7200	1450
Nickel	D	Aug-15	100	900								
Sodium	D	Aug-15	50000							67700		
Sodium	T	Aug-15	50000							69900		
Sodium	D	Aug-16	50000							67600		
Sodium	T	Aug-16	50000							71300		
Sodium	D	Aug-17	50000							75500		
Sodium	T	Aug-17	50000							78300		
Sulfate	T	Aug-15	250000									
Sulfate	T	Dec-15	250000		NS				NS	NS		NS
Sulfate	T	Aug-16	250000									
Sulfate	T	Aug-17	250000									
Zinc	D	Aug-15	2000									
Zinc	T	Aug-15	2000									
Zinc	T	Aug-16	2000									

All values ug/L
NS - Location not sampled

TABLE 2
INORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE NEW JERSEY
GROUNDWATER QUALITY STANDARDS (NJGWQS) IN GROUNDWATER
MARCH 2015 THROUGH AUGUST 2017
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD MINES/LANDFILL SUPERFUND SITE

Peters Mine Pit

Parameter	Total or Dissolved	Sampling Event	NJGWQS ug/l	OB-30C	OB-31	OB-32	RW- 3 (77-87)	RW- 3 DS (155-160)	RW- 3DD (175-180)	RW- 4 (333-343)	RW- 4 (393-403)	RW- 5
Aluminum	D	Aug-15	200							1000		
Aluminum	T	Aug-15	200	1800						860	1600	400
Aluminum	D	Aug-16	200							850		
Aluminum	T	Aug-16	200	238						942	448	
Aluminum	D	Aug-17	200							779		208
Aluminum	T	Aug-17	200	723						746	566	910 B
Arsenic	D	Aug-15	3					14	19			7.2 B
Arsenic	T	Aug-15	3					12	20			8.9 B
Arsenic	D	Aug-16	3					13.5	16.6			7.9
Arsenic	T	Aug-16	3		12.8	15.2		14.7	16.8			8
Arsenic	D	Feb-17	3					12.9	17.5			7.5
Arsenic	T	Feb-17	3		18.1	3.3		13.9	16.6			7
Arsenic	D	Aug-17	3					15.8	18.1			12.8
Arsenic	T	Aug-17	3		14.2	17.7		16.1	20.9			14.1
Chloride	T	Aug-15	250000				2190000					
Chloride	T	Aug-16	250000									
Chloride	T	Aug-17	250000									
Iron	D	Apr-15	300									
Iron	T	Apr-15	300									
Iron	D	Aug-15	300									730
Iron	T	Aug-15	300	3000							900	2300
Iron	D	Aug-16	300		11500	20800						
Iron	T	Aug-16	300	397	43300	65800						506
Iron	D	Aug-17	300		1720	4200						
Iron	T	Aug-17	300	994	39600	67400					738	1710
Lead	T	Aug-15	5									6.6
Lead	T	Aug-16	5									
Lead	T	Feb-17	5									

TABLE 2
INORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE NEW JERSEY GROUNDWATER QUALITY STANDARDS (NJGWQS) IN GROUNDWATER
MARCH 2015 THROUGH AUGUST 2017
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD MINES/LANDFILL SUPERFUND SITE

Peters Mine Pit

Parameter	Total or Dissolved	Sampling Event	NJGWQS ug/l	OB-30C	OB-31	OB-32	RW- 3 (77-87)	RW- 3 DS (155-160)	RW- 3DD (175-180)	RW- 4 (333-343)	RW- 4 (393-403)	RW- 5
Lead	T	Aug-17	5									
Manganese	D	Aug-15	50	66			93					110 B
Manganese	T	Aug-15	50	160			96					290
Manganese	T	Dec-15	50	NS	NS	NS	91.3			NS	NS	351
Manganese	T	Jan-16	50	NS	5920	8750	NS	NS	NS	NS	NS	NS
Manganese	D	Aug-16	50	56.2	6120	9300	115					
Manganese	T	Aug-16	50	103	6150	9370	120					60.5
Manganese	D	Aug-17	50	81.3	5000	7640	229					
Manganese	T	Aug-17	50	109	5240	8150	249					133
Nickel	D	Aug-15	100									
Sodium	D	Aug-15	50000					220000	51200			
Sodium	T	Aug-15	50000					221000	53700 B			
Sodium	D	Aug-16	50000					166000				55900
Sodium	T	Aug-16	50000					189000				57700
Sodium	D	Aug-17	50000					182000				73300
Sodium	T	Aug-17	50000					192000				84000
Sulfate	T	Aug-15	250000					467000				
Sulfate	T	Dec-15	250000	NS	NS	NS		425000 D		NS	NS	
Sulfate	T	Aug-16	250000					393000 D				
Sulfate	T	Aug-17	250000					434000 D				
Zinc	D	Aug-15	2000									
Zinc	T	Aug-15	2000									
Zinc	T	Aug-16	2000									

All values ug/L
NS - Location not sampled

TABLE 2
INORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE NEW JERSEY
GROUNDWATER QUALITY STANDARDS (NJGWQS) IN GROUNDWATER
MARCH 2015 THROUGH AUGUST 2017
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD MINES/LANDFILL SUPERFUND SITE

Peters Mine Pit

Parameter	Total or Dissolved	Sampling Event	NJGWQS ug/l	RW- 5A	RW- 6	RW- 6A	RW- 7	RW-11 S (236-241)	RW-11D (262-267)	RW-13 (71-91)	RW-13 (100-120)	RW-13 (150-170)
Aluminum	D	Aug-15	200				420				4800	
Aluminum	T	Aug-15	200				380		730	1700	5600	530 B
Aluminum	D	Aug-16	200						8170			
Aluminum	T	Aug-16	200				295		9100		5080	
Aluminum	D	Aug-17	200						8720		5050	
Aluminum	T	Aug-17	200				406 B		6260		5450 B	
Arsenic	D	Aug-15	3									
Arsenic	T	Aug-15	3	3.3							3.2	4.6 B
Arsenic	D	Aug-16	3									
Arsenic	T	Aug-16	3								3.1	
Arsenic	D	Feb-17	3									
Arsenic	T	Feb-17	3									
Arsenic	D	Aug-17	3								4.2	
Arsenic	T	Aug-17	3								4.2	
Chloride	T	Aug-15	250000									
Chloride	T	Aug-16	250000							436000 D		
Chloride	T	Aug-17	250000									
Iron	D	Apr-15	300		33200	23800						
Iron	T	Apr-15	300		40400	24000	522					
Iron	D	Aug-15	300		26100	9800					310	2700
Iron	T	Aug-15	300	4300	36300	22200			490	4300	380	650
Iron	D	Aug-16	300		7640	7170						
Iron	T	Aug-16	300	306	43800	23600	1050				344	365
Iron	D	Aug-17	300		21400						306	
Iron	T	Aug-17	300	1460	49800	19100	1370	413		334	550	
Lead	T	Aug-15	5									
Lead	T	Aug-16	5									
Lead	T	Feb-17	5									

TABLE 2
INORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE NEW JERSEY
GROUNDWATER QUALITY STANDARDS (NJGWQS) IN GROUNDWATER
MARCH 2015 THROUGH AUGUST 2017
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD MINES/LANDFILL SUPERFUND SITE

Peters Mine Pit

Parameter	Total or Dissolved	Sampling Event	NJGWQS ug/l	RW- 5A	RW- 6	RW- 6A	RW- 7	RW-11 S (236-241)	RW-11D (262-267)	RW-13 (71-91)	RW-13 (100-120)	RW-13 (150-170)
Lead	T	Aug-17	5									
Manganese	D	Aug-15	50	1000 B	7400 B	14200 B		200				220
Manganese	T	Aug-15	50	1000	7400	15700		220 B		56		92 B
Manganese	T	Dec-15	50	778	6150	11700	NS	234		NS	NS	NS
Manganese	T	Jan-16	50	NS	NS	NS	NS	NS	NS	NS	NS	NS
Manganese	D	Aug-16	50	675	7420	14800		331				110
Manganese	T	Aug-16	50	678	7470	14800		327				104
Manganese	D	Aug-17	50	326	8250	12600		404				
Manganese	T	Aug-17	50	566	7240	13100		446				
Nickel	D	Aug-15	100									
Sodium	D	Aug-15	50000						209000		210000	153000
Sodium	T	Aug-15	50000						210000		246000	
Sodium	D	Aug-16	50000						187000			
Sodium	T	Aug-16	50000						184000		190000	
Sodium	D	Aug-17	50000						146000		154000	
Sodium	T	Aug-17	50000						145000		172000	
Sulfate	T	Aug-15	250000									
Sulfate	T	Dec-15	250000				NS			NS	NS	NS
Sulfate	T	Aug-16	250000									
Sulfate	T	Aug-17	250000									
Zinc	D	Aug-15	2000									
Zinc	T	Aug-15	2000									
Zinc	T	Aug-16	2000									

All values ug/L

NS - Location not sampled

TABLE 2
INORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE NEW JERSEY GROUNDWATER QUALITY STANDARDS (NJGWQS) IN GROUNDWATER
MARCH 2015 THROUGH AUGUST 2017
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD MINES/LANDFILL SUPERFUND SITE

Peters Mine Pit

Parameter	Total or Dissolved	Sampling Event	NJGWQS ug/l	RW-14 S	RW-14D	RW-15 S	RW-15D	SC-1
Aluminum	D	Aug-15	200					
Aluminum	T	Aug-15	200					
Aluminum	D	Aug-16	200					
Aluminum	T	Aug-16	200					
Aluminum	D	Aug-17	200					
Aluminum	T	Aug-17	200					
Arsenic	D	Aug-15	3					
Arsenic	T	Aug-15	3					
Arsenic	D	Aug-16	3	11.3		7.8		
Arsenic	T	Aug-16	3	14	8.8	12.7		
Arsenic	D	Feb-17	3	7		12.6	4.2	
Arsenic	T	Feb-17	3	6.6	13.8	25.6	4.4	
Arsenic	D	Aug-17	3	4.7		27.9	4.7	
Arsenic	T	Aug-17	3	4.8	8.9	36.8	5.3	
Chloride	T	Aug-15	250000					
Chloride	T	Aug-16	250000					
Chloride	T	Aug-17	250000					
Iron	D	Apr-15	300					87000
Iron	T	Apr-15	300					84400
Iron	D	Aug-15	300					51400
Iron	T	Aug-15	300					70100
Iron	D	Aug-16	300	1890	3990 J			44600
Iron	T	Aug-16	300	3400	26000			77200
Iron	D	Aug-17	300					21400
Iron	T	Aug-17	300		19900			73100
Lead	T	Aug-15	5					13
Lead	T	Aug-16	5					7.9
Lead	T	Feb-17	5					

TABLE 2
INORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE NEW JERSEY GROUNDWATER QUALITY STANDARDS (NJGWQS) IN GROUNDWATER
MARCH 2015 THROUGH AUGUST 2017
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD MINES/LANDFILL SUPERFUND SITE

Peters Mine Pit

Parameter	Total or Dissolved	Sampling Event	NJGWQS ug/l	RW-14 S	RW-14D	RW-15 S	RW-15D	SC-1
Lead	T	Aug-17	5					13.6
Manganese	D	Aug-15	50					640 B
Manganese	T	Aug-15	50					750
Manganese	T	Dec-15	50	NS	NS	NS	NS	856
Manganese	T	Jan-16	50	NS	NS	NS	NS	NS
Manganese	D	Aug-16	50	101	889			764
Manganese	T	Aug-16	50	110	608			839
Manganese	D	Aug-17	50	60.8	685			701
Manganese	T	Aug-17	50	70	739			661
Nickel	D	Aug-15	100					
Sodium	D	Aug-15	50000					
Sodium	T	Aug-15	50000					
Sodium	D	Aug-16	50000	53900	115000		83100	
Sodium	T	Aug-16	50000	58900	68200		81800	
Sodium	D	Aug-17	50000		167000	56900	104000	
Sodium	T	Aug-17	50000		206000	70700	112000	
Sulfate	T	Aug-15	250000					
Sulfate	T	Dec-15	250000	NS	NS	NS	NS	
Sulfate	T	Aug-16	250000					
Sulfate	T	Aug-17	250000		349000 D		260000 D	
Zinc	D	Aug-15	2000					
Zinc	T	Aug-15	2000					
Zinc	T	Aug-16	2000					

All values ug/L
NS - Location not sampled

TABLE 3
INORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE NEW JERSEY
GROUNDWATER QUALITY STANDARDS (NJGWQS) IN GROUNDWATER
MARCH 2015 THROUGH AUGUST 2017
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD MINES/LANDFILL SUPERFUND SITE

Cannon Mine Pit

Parameter	Total or Dissolved	Sampling Event	NJGWQS ug/l	OB- 3	OB- 4	OB- 5	OB- 6	OB- 7	RW- 2 (279-289)	RW- 2 (452-462)	RW- 8 (163-173)	RW- 8 (204-214)	RW- 9 (206-216)	RW- 9A (85-95)	RW-10 (120-130)	RW-10 (185-195)	RW-10A (51-61)	RW-10A (75-85)	SC-2
Aluminum	D	Aug-15	200						250										
Aluminum	T	Aug-15	200						250										
Aluminum	T	Aug-17	200										686						
Arsenic	D	Aug-15	3							5.6 J				3.4	6.7	5.2			4.6
Arsenic	T	Aug-15	3							5.4	3.6 B			3.2	7.5 B	6.7 B			
Arsenic	D	Aug-16	3							4.8					7.2	5.1			
Arsenic	T	Aug-16	3							4.3					6.6	4.6			
Arsenic	D	Feb-17	3							4.8									
Arsenic	T	Feb-17	3							4.7									
Arsenic	D	Aug-17	3							4.2					7.8	6.2			
Arsenic	T	Aug-17	3							4.9					7	5.7			
Cadmium	T	Aug-15	4																
Cadmium	T	Aug-16	4																
Chloride	T	Aug-15	250000							601000 F									
Chloride	T	Aug-16	250000							636000 J									
Chloride	T	Aug-17	250000		292000 D					631000 D									
Iron	D	Aug-15	300		6300	8400	320										330		13300
Iron	T	Aug-15	300	1800	13500	31300	3800	1700				1500		340			700		
Iron	D	Aug-16	300		528	5150	2980												
Iron	T	Aug-16	300	1060	5850	21100	12100	2360					663	405			648		331
Iron	D	Aug-17	300			3830													
Iron	T	Aug-17	300	1380	10100	29400	4130	4630				510							
Lead	T	Aug-15	5																
Lead	T	Aug-16	5																
Lead	T	Feb-17	5																
Manganese	D	Aug-15	50	120	2700	2300	730	2700				270					3000		1100
Manganese	T	Aug-15	50	130	2600 B	2200	760	2700				310					2100		210 B
Manganese	D	Aug-16	50		1470	2490	749	2670									2310		
Manganese	T	Aug-16	50		1400	2430	836	2710					316				2460		
Manganese	D	Aug-17	50		1640	2230	536	2530				181	190						
Manganese	T	Aug-17	50		1670	2430	569	2700				164	99.1						
Sodium	D	Aug-15	50000		97200				125000	382000		92500			64900				64100
Sodium	T	Aug-15	50000		109000				134000	371000	52400	87500	162000		65800				
Sodium	D	Aug-16	50000		87800				116000	332000		89100			63600				
Sodium	T	Aug-16	50000		92700				106000	297000		86300	166000		68800				
Sodium	D	Aug-17	50000		99700				107000	281000	56500	89000	137000		65000				
Sodium	T	Aug-17	50000		107000				120000	327000	59500	85600	144000		60700				
Sulfate	T	Aug-16	250000							375000 J						1200000 D		754000 D	
Sulfate	T	Aug-17	250000						308000 J				495000 D						
Thallium	D	Aug-15	2							2.9 J									
Zinc	T	Aug-15	2000																
Zinc	T	Aug-16	2000																

All values ug/L
NS - Location not sampled

TABLE 4

INORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE NEW JERSEY GROUNDWATER QUALITY STANDARDS (NJGWQS) IN GROUNDWATER

MARCH 2015 THROUGH AUGUST 2017

GROUNDWATER FOCUSED FEASIBILITY STUDY

RINGWOOD MINES/LANDFILL SUPERFUND SITE

				O'Connor Disposal Area								
Parameter	Total or Dissolved	Sampling Event	NJGWQS ug/l	OB-14A	OB-14B	OB-16	OB-17	OB-18	OB-24	OB-28	OB-33	RW-16
Aluminum	T	Aug-15	200					270		1400		
Aluminum	T	Aug-16	200							1190	317	
Aluminum	D	Aug-17	200								540	
Aluminum	T	Aug-17	200						355	207	1220	
Arsenic	T	Aug-15	3	9.2		12	5 B					
Arsenic	T	Aug-16	3			7.9						
Arsenic	T	Feb-17	3			6.9						
Arsenic	T	Aug-17	3	3.5		9.3						
Iron	D	Aug-15	300	27300		2900						
Iron	T	Aug-15	300	59300	930	20100	6100	360		2700		
Iron	D	Aug-16	300	2980								
Iron	T	Aug-16	300	41800	593	18000	1340			2160	446	956
Iron	D	Aug-17	300	9550							523	
Iron	T	Aug-17	300	36800	358	18200	1140		447	1490	1660	
Manganese	D	Aug-15	50	1800	3300	4000	550			540		
Manganese	T	Aug-15	50	1500 B	1600 B	4900 B	530		1300 B	4400 B		
Manganese	D	Aug-16	50	1290	1610	3110	309			3470		
Manganese	T	Aug-16	50	1590	1770	3690	327		486	4140		
Manganese	D	Aug-17	50	736	1250	3830	294					
Manganese	T	Aug-17	50	922	1350	3990	317		617	3740		

				Sally's Pond Area			
Parameter	Total or Dissolved	Sampling Event	NJGWQS ug/l	OB-10	OB-29	RW-12 (55-65)	RW-12 (130-140)
Aluminum	D	Aug-15	200		840	240	300
Aluminum	T	Aug-15	200		1700 B	280	900 B
Aluminum	D	Aug-16	200				506
Aluminum	T	Aug-16	200		1180		877
Aluminum	T	Aug-17	200		753		424
Arsenic	D	Aug-15	3		12	12	
Arsenic	T	Aug-15	3			13	13 B
Arsenic	D	Aug-16	3			13.9	15
Arsenic	T	Aug-16	3			12	13.5
Arsenic	D	Aug-17	3			17.4	7
Arsenic	T	Aug-17	3			16.4	8.2
Iron	D	Aug-15	300				320
Iron	T	Aug-15	300		1200		
Iron	T	Aug-16	300		1530		400
Iron	T	Aug-17	300	316	1040		
Sodium	D	Aug-15	50000		131000	155000	
Sodium	T	Aug-15	50000			170000	98800
Sodium	D	Aug-16	50000			140000	85100
Sodium	T	Aug-16	50000			128000	84200
Sodium	D	Aug-17	50000			135000	
Sodium	T	Aug-17	50000			149000	
Sulfate	T	Aug-15	250000			299000	
Sulfate	T	Aug-16	250000			291000 D	1390000 D
Sulfate	T	Aug-17	250000			376000 D	

All values ug/L

NS - Location not sampled

TABLE 5
ORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE NEW JERSEY GROUNDWATER QUALITY STANDARDS (NJGWQS) IN MINE WATER
MARCH 2015 THROUGH AUGUST 2017
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD MINES/LANDFILL SUPERFUND SITE

			Cannon Mine Shaft			Peters Mine Air Shaft		
Parameter	Sampling Event	NJGWQS ug/l	CM-100	CM-160	CM-275	PM Air Shaft-50	PM Air Shaft-180	PM Air Shaft-230
Benzene	Mar-15	1						
Benzene	Apr-15	1					2.3	7.8
Benzene	Jun-15	1					5.4	25
Benzene	Aug-15	1					4.1	25
Benzene	Dec-15	1					7.1	25
Benzene	May-16	1					6.4	25
Benzene	Aug-16	1					5.9	29
Benzene	Feb-17	1					5.5	33
Benzene	Aug-17	1					6	33
Chloroethane	Mar-15	5						
Chloroethane	Apr-15	5					7.9	29.1
Chloroethane	Jun-15	5					14	8
Chloroethane	Aug-15	5					14	7.7
Chloroethane	Dec-15	5					33	7.1
Chloroethane	May-16	5					48	23
Chloroethane	Aug-16	5					44	17
Chloroethane	Feb-17	5					47	24
Chloroethane	Aug-17	5					15	6.4
1,4-Dioxane	Jun-15	0.4						150 J
1,4-Dioxane	Aug-15	0.4	0.47 J	0.54 J			12	140 D
1,4-Dioxane	Dec-15	0.4					5.76	31.1
1,4-Dioxane	May-16	0.4					5.0/18.2*	15/144*
1,4-Dioxane	Aug-16	0.4					20.3/16.6**	146/107**
1,4-Dioxane	Feb-17	0.4			0.832	0.707	15.2	129
1,4-Dioxane	Aug-17	0.4					18.7	130E

*1.8/5.41 Values represent split samples between Test America (w/o isotope dilution) and Alpha Laboratories (with isotope dilution).

** First result by 8270 SIM-ID, second result via Method 522 from Pace Analytical as part of isotope study.

E = Exceeds calibration range

TABLE 6
INORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE NEW JERSEY GROUNDWATER QUALITY STANDARDS (NJGWQS) IN MINE WATER
MARCH 2015 THROUGH AUGUST 2017
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD MINES/LANDFILL SUPERFUND SITE

Peters Mine Air Shaft						
Parameter	Total or Dissolved	Sampling Event	NJGWQS ug/l	PM Air Shaft- 50	PM Air Shaft-180	PM Air Shaft-230
Aluminum	D	Aug-15	200			
Aluminum	T	Aug-15	200			
Aluminum	D	Aug-16	200			
Aluminum	T	Aug-16	200			
Aluminum	D	Aug-17	200			202
Arsenic	D	Aug-15	3			
Arsenic	T	Aug-15	3			
Arsenic	D	Aug-16	3			
Arsenic	T	Aug-16	3			
Arsenic	D	Feb-17	3			
Arsenic	T	Feb-17	3			11.6
Arsenic	T	Aug-17	3			3.5
Chloride	T	Aug-15	250000			
Chloride	T	Aug-16	250000			
Iron	D	Apr-15	300	496	93600	35800
Iron	T	Apr-15	300		91600	38000
Iron	D	Aug-15	300			
Iron	T	Aug-15	300	470	79300	126000
Iron	D	Aug-16	300		19400	22600
Iron	T	Aug-16	300		89600	139000
Iron	D	Aug-17	300		414	79100
Iron	T	Aug-17	300	339	81100	145000
Lead	T	Aug-15	5		24	980
Lead	T	Aug-16	5		131	8.2
Lead	T	Feb-17	5		6.4	3000
Lead	T	Aug-17	5		9.8	203
Manganese	D	Aug-15	50		750	2900
Manganese	T	Aug-15	50		810 B	2100
Manganese	T	Dec-15	50		868	2150
Manganese	T	Jan-16	50	NS	NS	NS
Manganese	D	Aug-16	50		826	1860
Manganese	T	Aug-16	50		955	2340
Manganese	D	Aug-17	50		819	1930
Manganese	T	Aug-17	50		877	2040
Nickel	D	Aug-15	100			
Sodium	D	Aug-15	50000			
Sodium	T	Aug-15	50000			
Sodium	D	Aug-16	50000			
Sodium	T	Aug-16	50000			
Sulfate	T	Aug-15	250000			
Sulfate	T	Dec-15	250000			
Sulfate	T	Aug-16	250000			
Zinc	D	Aug-15	2000		2800	4600
Zinc	T	Aug-15	2000		4000	5700
Zinc	T	Aug-16	2000		3090	
Zinc	D	Aug-17	2000		2340	
Zinc	T	Aug-17	2000		3850	

Cannon Mine Shaft							
Parameter	Total or Dissolved	Sampling Event	NJGWQS ug/l	CM- 50	CM-100	CM-160	CM-275
Aluminum	D	Aug-15	200				
Aluminum	T	Aug-15	200				
Arsenic	D	Aug-15	3				
Arsenic	T	Aug-15	3				3.2 B
Arsenic	D	Aug-16	3				
Arsenic	T	Aug-16	3				
Arsenic	D	Feb-17	3				
Arsenic	T	Feb-17	3				
Cadmium	T	Aug-15	4				6.4
Cadmium	T	Aug-16	4			10.8	13.2
Chloride	T	Aug-15	250000				
Chloride	T	Aug-16	250000				
Chloride	T	Aug-17	250000	276000 J	290000 D	283000 D	
Iron	D	Aug-15	300	5100 F			
Iron	T	Aug-15	300	20000	18500	19000	25500
Iron	D	Aug-16	300				2090
Iron	T	Aug-16	300	1180	8650	12900	21900
Iron	D	Aug-17	300	792	364	1300	
Iron	T	Aug-17	300	28400	28500	31600	18200
Lead	T	Aug-15	5			7.8	91
Lead	T	Aug-16	5			163	192
Lead	T	Feb-17	5			36.3	97
Lead	T	Aug-17	5			7.8	14.5
Manganese	D	Aug-15	50	1400	1200	1200	1400 B
Manganese	T	Aug-15	50	1200	1300 B	1400 B	1300
Manganese	D	Aug-16	50	109	253	396	1160
Manganese	T	Aug-16	50	121	275	453	1230
Manganese	D	Aug-17	50	878	944	894	1200
Manganese	T	Aug-17	50	1000	1030	947	1230
Sodium	D	Aug-15	50000	90400	83200	77300	87200
Sodium	T	Aug-15	50000	85700	79600	79800	82700
Sodium	D	Aug-16	50000	83600	83200	87100	58300
Sodium	T	Aug-16	50000	77400	80500	80400	53600
Sodium	D	Aug-17	50000	98900	106000	100000	58100
Sodium	T	Aug-17	50000	109000	110000	107000	60200
Sulfate	T	Aug-16	250000				
Thallium	D	Aug-15	2				2800
Zinc	T	Aug-15	2000			2500	8200
Zinc	T	Aug-16	2000			3010	4260
Zinc	T	Aug-17	2000		2720	2890	

TABLE 7
ORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE
NEW JERSEY SURFACE WATER QUALITY STANDARDS (NJSWQS) IN SURFACE WATER
MARCH 2015 THROUGH AUGUST 2017
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD MINES/LANDFILL SUPERFUND SITE

Parameter	Sampling Event	NJSWQS ug/l	PMP Pond	SR-3 Pond	SR-3 Seep 1	SR-3 Seep 2	SW-03	SW-MRB-02	SW-MRB-03	SW-NOB-01	SW-PAB-01	SW-PAB-02	SW-PAB-03	SW-PMB-01	SW-PMB-01A	SW-PMB-02	SW-PMB-02A	SW-SP-01	SW-SW-04	SW-RC-01
Benzene	Aug-15	0.15			0.33 J	0.67 J														
Benzene	Dec-15	0.15		0.51 J	0.75 J	2.4					0.33 J									
Benzene	May-16	0.15		0.32 J		1.7					0.35 J									
Benzene	Aug-16	0.15			0.38 J	0.61 J														
Benzene	Feb-17	0.15			0.31 J	0.91 J					0.2 J									
Benzene	Aug-17	0.15			0.31 J	0.76 J					0.21 J									
Methylene Chloride	Aug-17	2.50															3.6 B			
Bis(2-ethylhexyl) phthalate	Aug-16	1.20	1.9 J	1.5 J			2 J	3.1	2.1	2.3	1.4 J	3.2	1.9 J	4		2.2 J		4	1.7 J	
Bis(2-ethylhexyl) phthalate	Aug-17	1.20	1.8 J																	
Dibenz(a,h)anthracene	Aug-17	0.0038																		0.05 J
Vinyl Chloride	Dec-15	0.08				0.47 J														
Vinyl Chloride	May-16	0.08				0.22 J														
PCB-1260	Aug-17	0.000064													0.23 J					

TABLE 8

INORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE

NEW JERSEY SURFACE WATER QUALITY STANDARDS (NJSWQS) IN SURFACE WATER

MARCH 2015 THROUGH AUGUST 2017

GROUNDWATER FOCUSED FEASIBILITY STUDY

RINGWOOD MINES/LANDFILL SUPERFUND SITE

Parameter	Total or Dissolved	Sampling Event	NJSWQS ug/l	SR-3 Pond	SR-3 Seep 1	SR-3 Seep 2	SW-03	SW-11	SW-MRB-00	SW-MRB-01	SW-MRB-02	SW-NOB-02
Arsenic	D	Aug-15	0.017						0.6 J	0.59 J	0.54 J	
Arsenic	T	Aug-15	0.017	1.8 J B	4.7 B	2.7 B			0.65 J	0.76 J	0.8 J	1.5 J B
Arsenic	T	Aug-16	0.017		1.4 J	0.8 J						
Arsenic	T	Feb-17	0.017			3.3						
Arsenic	T	Aug-17	0.017		5.1	1.3 J						
Chloride	T	Aug-15	250000				520000					
Lead	T	Aug-16	5		17							
Lead	T	Feb-17	5			5.1						
Lead	T	Aug-17	5		6.8							
Thallium	D	Aug-15	0.24					0.68 J				
Thallium	T	Aug-15	0.24					0.79 J				

TABLE 8

INORGANIC COMPOUNDS AT CONCENTRATIONS ABOVE

NEW JERSEY SURFACE WATER QUALITY STANDARDS (NJSWQS) IN SURFACE WATER

MARCH 2015 THROUGH AUGUST 2017

GROUNDWATER FOCUSED FEASIBILITY STUDY

RINGWOOD MINES/LANDFILL SUPERFUND SITE

SW-PAB-01	SW-PAB-01A	SW-PAB-02	SW-PAB-03	SW-PAB-04	SW-PMB-01	SW-RM-01
	0.62 J				0.65 J	
0.52 J	1.3 J	0.56 J	0.54 J	2 B	1 J	
1.1 J			0.86 J		3.5	
0.71 J	0.78 J				0.96 J	0.75 J
		0.4 J	0.88 J			
		0.33 J	1.1 J			

TABLE 9

PETERS MINE AIR SHAFT SEDIMENT, DETECTED COMPOUNDS WITH COMPARISON TO NEW JERSEY RESIDENTIAL DIRECT CONTACT SOIL REMEDIATION STANDARDS AND DEFAULT IMPACT TO GROUNDWATER SOIL SCREENING LEVELS

GROUNDWATER FOCUSED FEASIBILITY STUDY

RINGWOOD MINES/LANDFILL SUPERFUND SITE

COMPOUND	CONCENTRATION, MG/KG	RDCSRS, MG/KG	DEFAULT IGWSSL, MG/KG
1,2,4-trichlorobenzene	0.0041J	73	0.7
1,2-dichlororbenzene	0.0096J	5300	17
1,3-dichlororbenzene	0.0267	5300	19
1,4-dichlororbenzene	0.0785	5	2
acetone	0.121	70000	19
benzene	0.0463	2	0.005
chlorobenzene	0.0692	510	0.6
cyclohexane	0.0336	NA	NA
isopropylbenzene	0.207	NA	NA
methylcyclohexane	0.0356	NA	NA
Xylenes	0.209	12000	19
2-methylnaphthalene	0.127	230	8
bis(2-ethylhexyl)phthalate	1.21	35	1200
dimethylphthalate	0.25J	NA	NA
n-nitrosodiphenylamine	0.165	99	0.4
acenaphthene	0.0592	3400	110
anthracene	0.0384	17000	2400
benzo(a)anthracene	0.105	5	0.8
benzo(a)pyrene	0.109	0.5	0.2
benzo(b)fluoranthene	0.144	5	2
benzo(g,h,i)perylene	0.0889	380000	NA
benzo(k)fluoranthene	0.122	45	25
chrysene	0.115	450	80
dibenzo(a,h)anthracene	0.0402	0.5	0.8
fluoranthene	0.182	2300	1300
fluorene	0.065	2300	170
indeno(1,2,3-cd)pyrene	0.0886	5	7
naphthalene	0.345	6	25
phenanthrene	0.168	NA	NA
pyrene	0.188	1700	840
aluminum	14800J	78000	6000
arsenic	10.6J	19	19
barium	165J	16000	2100
berylium	0.84	16	0.7
cadmium	1	78	2
chromium	23.1	1*	NA
cobalt	6.2J	1600	90
copper	42.2	3100	11000
lead	64.8	400	90
manganese	244	11000	65
mercury	0.57	23	0.1
nickel	24.2	1600	48
vanadium	55.8	78	NA
zinc	148J	23000	930

Blue highlight, > Default IGSSL

*For Cr^{+6}, for comparison USEPA Cr^{+3} RSL is 120,000 mg/kg

Table 10
Summary of Applicable or Relevant and Appropriate Requirements
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

Standard, Requirement, or Criterion	Citation or Reference	Type	Description	Status	Comments
FEDERAL					
Air: Clean Air Act	42 USC 7401, Section 112	Action specific	Establishes limits on emissions to atmosphere from industrial and commercial activities.	Applicable	Applicable to alternatives that may have air emissions such as a treatment system
National Ambient Air Quality Standards (NAAQS)	40 CFR Part 50	Action specific	Establishes emissions limits for primary and secondary NAAQS	Applicable	Applicable to alternatives that may have air emissions such as a treatment system
Standards of Performance for New Stationary Sources	40 CFR Part 60	Action specific	Establishes emissions requirements for new stationary sources	Applicable	Applicable to alternatives that may have air emissions such as a treatment system
National Emission Standards for Hazardous Air Pollutants (NESHAPs)	40 CFR Part 61	Action specific	Establishes limits on hazardous emissions to the atmosphere	Applicable	Applicable to alternative that may have air emissions. Sets requirements for potential exposure.
OSHA Permissible Exposure Limits	29 CFR 1910.1000	Chemical specific	Provides time weighted average exposure concentrations for workers for air pollutants	Applicable	Applicable to alternatives where workers are potentially exposed to air emissions.
Vapor Intrusion Guidance	OSWER Technical Guide for Assessing and Mitigating Vapor Intrusion	Chemical specific	Provides soil vapor, indoor air screening levels	TBC	Unlikely to be applicable because of absence of exceedance of VI screening levels in overburden. Development with a building would require checking VI screening levels at that time.

Table 10
Summary of Applicable or Relevant and Appropriate Requirements
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

Standard, Requirement, or Criterion	Citation or Reference	Type	Description	Status	Comments
Fish and Wildlife:					
Fish and Wildlife Coordination Act	16 USC 661, 40 CFR 6.302(g)	Location specific	Provides protection of fish and wildlife from actions resulting in the control or structural modification of natural streams and water bodies.	Relevant and Appropriate	Potentially applicable if there were placement of any fill in surface streams
Endangered Species Act	16 USC 1531(h) through 1543, 50 CFR 17,402, and 40 CFR 6.302(b)	Location specific	Provides protection of endangered/threatened species and habitats	Relevant and Appropriate	Threatened or endangered species habitat exists at the Site and is being addressed under OU2
Migratory Bird Treaty Act	16 USC 703 et seq	Location specific	Requirements for not killing, hunting, taking, or capturing any migratory birds or nests or eggs	Relevant and Appropriate	Threatened or endangered species habitat exists at the Site and is being addressed under OU2, and would be potentially applicable if migratory birds present during work
Groundwater:					
Maximum Contaminant Levels (MCLs)	40 CFR Part 141	Chemical specific	Maximum permissible concentrations in water that is delivered to any user of a public water system.	Relevant and Appropriate	Applicable to determining whether groundwater if used from the Site for drinking would require treatment to reduce concentrations to levels below the MCLs. Groundwater at the site is not anticipated to be used
National Secondary Drinking Water Standards	40 CFR 143	Chemical specific	Establishes concentrations for the protection of the aesthetic quality of drinking water (non-enforceable)	TBC	Would be considered for naturally occurring constituents such as iron

Table 10
Summary of Applicable or Relevant and Appropriate Requirements
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

Standard, Requirement, or Criterion	Citation or Reference	Type	Description	Status	Comments
Underground Injection Control Program	40 CFR Part 146	Action specific	Establishes technical criteria and standards for underground injection wells.	Relevant and Appropriate	Potentially applicable if the remedial activities introduce amendments (e.g., enhanced MNA) into the ground
USEPA Regional Screening Levels	Risk-Based Preliminary Remediation Goals	Chemical specific	Provides guidance for screening level chemical-specific concentrations for various media	TBC	Used as a screening tool in human health risk assessment
Hazardous Waste: General Hazardous Waste Management System Regulations	40 CFR Part 260	Action specific	Provides definitions of terms and general standards applicable to hazardous waste management system regulations.	Applicable	Applicable if remedial activities include the management of hazardous waste. Not likely applicable to groundwater
Identification and Listing of Hazardous Waste	40 CFR Part 261	Chemical specific	Defines those wastes, which are subject to regulation as hazardous wastes, and lists specific chemical and industry-source wastes.	Applicable	Applicable to determining whether wastes are hazardous. Not likely applicable to groundwater
Generators of Hazardous Waste	40 CFR 262	Chemical specific	Establishes requirements for generators of hazardous waste (EPA ID numbers and manifests).	Applicable	Applicable to remedial activities that involve the management of a hazardous waste. Not likely applicable to groundwater

Table 10
Summary of Applicable or Relevant and Appropriate Requirements
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

Standard, Requirement, or Criterion	**Citation or Reference**	**Type**	**Description**	**Status**	**Comments**
Transportation of Hazardous Wastes.	40 CFR 263 and 49 CFR 107, 171-180	Action specific	Established standards for the transportation of hazardous wastes and/or materials.	Applicable	Applicable to remedial activities that involve the off-site transportation of hazardous waste. Not likely applicable to groundwater
Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities	40 CFR 264	Action, location, and chemical specific	Establishes the minimum standards for the management of hazardous waste and includes regulations for land disposal units.	Applicable	Applicable to remedial activities that include disposal of hazardous wastes, or treatment of hazardous waste at the Site. Not likely applicable to groundwater.
Land Disposal Restrictions	40 CFR 268	Chemical specific	Identifies hazardous wastes which are restricted from land disposal and identifies treatment requirements prior to disposal	Applicable	Applicable to remedial activities that include disposal of hazardous wastes. Not likely applicable to groundwater.
Surface Water: Clean Water Act (CWA)	33 USC 1342	Action and chemical specific	Sets standards for the restoration and maintenance of chemical, physical and biological characteristics of surface water.	Applicable/ TBC	Applicable if there were to be a discharge to surface water. Unlikely for the groundwater alternatives
Ambient Water Quality Criteria	Various documents	Chemical specific	Recommended water quality criteria for the protection of aquatic life	TBC	Used as an additional aid for comparison of site-specific concentrations to EPA recommendations
National Pollutant Discharge Elimination System	40 CFR 122	Action and chemical specific	Requires permits for the discharge of pollutants from any point source into waters of the United States	Applicable	Applicable for remedial technologies that involve treatment and discharge

Table 10
Summary of Applicable or Relevant and Appropriate Requirements
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

Standard, Requirement, or Criterion	Citation or Reference	Type	Description	Status	Comments
Wetlands:					
Executive Order No. 11990 - Protection of Wetlands	40 CFR 6.302(a) and Appendix A	Location specific	Requires Federal agencies to take action to avoid adversely impacting wetlands wherever possible and to minimize wetlands destruction.	Applicable	Applicable to remedial actions that affect wetland areas
Executive Order No. 11988 - Floodplain Management	40 CFR 6.302(b) and Appendix A	Location specific	Requires Federal agencies to evaluate the potential effects of actions it may take in a floodplain to avoid adversely impacting floodplains wherever possible.	Applicable	Applicable to remedial actions that affect floodplains
Section 404 CWA	33 CFR 330	Location and Action Specific	Regulates discharge of dredged or fill material into waters of the United States	Applicable	Applicable to remedial actions that may involve placement of fill in a surface water
Wetland Permits	40 CFR 230 – 233	Location specific	Provides wetland permitting requirements for actions in and around wetlands and waters of the United States	Applicable	Applicable to remedial actions that may impact wetlands
Other:					
Comprehensive Environmental Response, Compensation, and Liability Act and Superfund Amendments and Reauthorization Act	CERCLA Act of 1980 and Superfund Amendments and Reauthorization Act (1986)	Action specific	Outlines requirements for sites managed under Superfund	Applicable	Applicable to Superfund remedial actions

Table 10
Summary of Applicable or Relevant and Appropriate Requirements
Groundwater Focused Feasibility Study
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Standard, Requirement, or Criterion	Citation or Reference	Type	Description	Status	Comments
National Oil and Hazardous Substances Pollution Contingency Plan (aka National Contingency Plan)	40 CFR 300	Action specific	Establishes comprehensive requirements for responsibility, planning, operational response, hazardous substance response, remedy selection (subpart E relates to remedy selection), natural resources, state involvement and various administrative provisions, among other requirements (e.g., Federal facilities)	Applicable	Applicable to Superfund remedial actions
STATE OF NEW JERSEY					
Air:					
Permits and Certificates for Minor Facilities	NJAC 7:27-8	Action specific	Governs permits and certificates for facilities classified as minor air emission sources.	Applicable	Applicable if the selected remediation system qualifies as a minor source (e.g., groundwater treatment of VOCs)
Ambient Air Quality Standards	NJAC 7:27-13	Action and chemical specific	Establishes air quality standards for the protection of public health and the preservation of ambient air quality.	Applicable	Applicable to remedial alternatives that result in air emissions (e.g., groundwater treatment of VOCs)
Control and Prohibition of Air Pollution from Diesel-Powered Motor Vehicles, Gasoline-Powered Motor Vehicles, VOCs, Toxic Compounds	NJAC 7:27-14, 15, 16, 17	Action and chemical specific	Establishes allowable emissions from general industrial process source categories.	Applicable	Applicable to remedial alternatives that result in air emissions, such as VOCs

Table 10
Summary of Applicable or Relevant and Appropriate Requirements
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

Standard, Requirement, or Criterion	Citation or Reference	Type	Description	Status	Comments
Control and Prohibition of Air Pollution from New or Altered Sources Affecting Ambient Air Quality (Emission Offset Rules)	NJAC 7:27-18	Action and chemical specific	Establishes air quality guidelines and standards for specific sources.	Applicable	Applicable emissions during remedial activities that may impact ambient air quality
Operating Permits and Certificates	NJAC 7:27-22	Action specific	Describes requirements and procedures for obtaining operating permits and certificates for major sources	Applicable	Applicable to remedial alternatives that result in air emissions such as groundwater treatment for VOCs
Vapor Intrusion Guidance	NJDEP Guidance Document, 2012	Chemical specific	Provides soil vapor, indoor air, rapid action, and health department notification screening levels	TBC	Unlikely to be applicable because of absence of exceedance of VI screening levels in overburden. Development with a building would require checking VI screening levels at that time.
Fish and Wildlife: Endangered and Threatened Species	NJAC 7:13-3.9	Location specific	Identifies endangered and threatened species and species of special concern.	Relevant and Appropriate	Threatened or endangered species habitat has been identified at the Site and is being addressed under OU2

Table 10
Summary of Applicable or Relevant and Appropriate Requirements
Groundwater Focused Feasibility Study
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Standard, Requirement, or Criterion	Citation or Reference	Type	Description	Status	Comments
Groundwater: New Jersey Primary Drinking Water Standards	NJAC 7:10-5	Chemical specific	Maximum permissible concentrations in water that is delivered to any user of a public water system.	TBC	Applicable to determining whether groundwater if used from the Site for drinking would require treatment to meet the MCLs. Groundwater at the site is not anticipated to be used.
Groundwater Quality Standards	NJAC 7:9C	Chemical specific	Lists groundwater quality standards	Applicable	Applicable to groundwater remedial alternatives
Underground Injection Control Program	NJAC 7:14A-8	Action specific	Establishes controls for injection practices	Relevant and Appropriate	Potentially applicable if the remedial activities include injection for remediation
Hazardous and Solid Waste: Identification and Listing of Hazardous Waste	NJAC 7:26G-5	Chemical specific	Describes methods for identifying hazardous wastes and lists known hazardous wastes.	Applicable	Applicable to determining whether wastes are hazardous. Not likely to be applicable to groundwater.
Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities	NJAC 7:26G-8	Action specific	Establishes permit requirements and construction and operations standards.	Applicable	Applicable if remedial activities include the treatment, storage, and/or disposal of hazardous waste. Not likely to be applicable to groundwater
Land Disposal Restrictions	NJAC 7:26G-11	Action and chemical specific	Identifies hazardous wastes that are subject to land disposal restrictions	Applicable	Applicable if remedial activities include the disposal of hazardous waste. Not likely to be applicable to groundwater

Table 10
Summary of Applicable or Relevant and Appropriate Requirements
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Standard, Requirement, or Criterion	Citation or Reference	Type	Description	Status	Comments
Transportation of Hazardous Materials	NJAC 16:49	Action specific	Regulates shipping/ transport of hazardous materials.	Applicable	Applicable if action includes off-site transport of hazardous materials. Not likely to be applicable to groundwater
Solid Waste Regulations	NJAC 7:26	Action specific	Regulates non-hazardous waste management.	Applicable	Applicable if action includes generation or management of solid wastes. Not likely to be applicable to groundwater
Surface Water: Storm Water Management	NJAC 7:8	Action specific	Establishes requirements for managing and controlling storm water from the site.	Applicable	Applicable if conditions are altered for remedial activities
Surface Water Standards	NJAC 7:9B	Chemical specific	Sets standards for the restoration and maintenance of chemical, physical and biological characteristics of surface water.	Applicable/ TBC	Applicable to certain remedial technologies (e.g., surface water discharge)
Flood Hazard Area Control	NJAC 7:13	Location specific	Controls and limits development in flood plains	Applicable	Applicable to remedial activities in a flood plain
New Jersey Pollutant Discharge Elimination System Rules	NJAC 7:14A	Action and chemical specific	Establishes standards for surface water discharge for site remediation projects. Takes precedence over National Pollutant Discharge Elimination System regulations (40 CFR 122 and 125)	Applicable	Potentially applicable if remedial activities include discharge to groundwater or surface water
Treatment Works Approval	NJAC 7:14A-22,23	Action and chemical specific	Regulates the construction and operation of industrial and domestic wastewater collection, conveyance, and treatment facilities.	Relevant and Appropriate	Potentially applicable if remedial activities include a treatment plant or pre-treatment plant

Table 10
Summary of Applicable or Relevant and Appropriate Requirements
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Standard, Requirement, or Criterion	Citation or Reference	Type	Description	Status	Comments
Soil: Soil Erosion and Sediment Control	NJAC 7:13-3.3, 3.4	Action specific	Requires controls for erosion and sediment transport.	Applicable	Applicable to construction activities that disturb soils greater than the regulatory threshold
Remediation Standards	NJAC 7:26D	Chemical specific	Soil site-specific cleanup levels. Includes guidance on development of impact to groundwater soil remediation standards.	Applicable	Not likely to be applicable to groundwater
Wetlands: Freshwater Wetland Protection Act Rules	NJAC 7:7A	Location specific	Establishes requirements for the protection of freshwater wetlands.	Applicable	Applicable to remedial actions that affect wetland areas (e.g., installation of wells, land disturbance)
Other: Noise Control	NJAC 7:29	Action specific	Limits the noise generated from any industrial, commercial, public service or community service facility.	Applicable	Limits the noise that can be generated during remedial activities
Technical Requirements for Site Remediation	NJAC 7:26E	Action specific	Specifies requirements for remedial activities within New Jersey.	Applicable	State program for implementation of remedial activities and part of Licensed Site Remediation Professional program.
Well Construction and Maintenance, Sealing of Abandoned Wells	NJAC 7:9D	Action specific	Specifies requirements for installation and abandonment of wells.	Applicable	Applicable to remedial action that involve construction or abandonment of wells.
NJDEP Site Remediation Guidance Library	NJAC 7:26C	Action and/or location specific	Provides technical guidance for various aspects of site remediation	Relevant	State program for implementation of remedial activities and part of Licensed Site Remediation Professional program

Table 10
Summary of Applicable or Relevant and Appropriate Requirements
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Standard, Requirement, or Criterion	Citation or Reference	Type	Description	Status	Comments
Flood Hazard Area Control	NJAC 7:13	Action and/or location specific	Establishes requirements for work in a flood hazard area and protection of riparian zones	Applicable	Applicable to remedial actions in a flood hazard area or riparian zone of Park Brook (e.g., installation of wells, land disturbance)

Table 11
Remedial Action Alternative Screening Summary
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

Alternative	Description	Effectiveness	Implementability	Relative Cost	Retained/Not Retained for Detailed Analysis
Peters Mine Pit Area					
No Action	No activities, including no monitoring.	Not effective in meeting RAOs of exposure control and aquifer restoration.	Implementable as no activities are included.	No cost.	Retained as a baseline for comparison of other alternatives.
Monitored Natural Attenuation (MNA) with a CEA/WRA	Employs naturally occurring attenuation from advection, dispersion, and biodegradation with a monitoring program and administrative controls.	Meets RAOs of exposure control and aquifer restoration to the extent practicable through administrative controls and natural attenuation mechanisms.	Readily implementable with routine monitoring and typical administrative controls (CEA/WRA) from the NJDEP.	Low, but long-term costs associated with monitoring.	Retained – effective, implementable, and low cost.
Enhanced MNA Treatment Barrier with a CEA/WRA	Enhances naturally occurring attenuation from advection, dispersion, and biodegradation through addition of an electron acceptor in a barrier style approach, with a monitoring program and administrative controls.	Meets RAOs of exposure control and aquifer restoration to the extent practicable through administrative controls and enhancement of natural attenuation mechanisms.	Readily implementable with routine monitoring and typical administrative controls (CEA/WRA) from the NJDEP. Addition of electron acceptor accomplished with conventional technology.	Moderate due to construction of treatment barrier and multiple injections of electron acceptor, and long-term monitoring.	Retained – effective, implementable, and moderate cost.

Table 11
Remedial Action Alternative Screening Summary (continued)
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

Alternative	Description	Effectiveness	Implementability	Relative Cost	Retained/Not Retained for Detailed Analysis
In-situ Chemical Oxidation (ISCO)	Introduction of a commercially available oxidant in a barrier approach down-gradient of the PMP Area.	Would meet the RAO of exposure control through administrative controls. Unlikely to achieve aquifer restoration due to absence of a discrete source, and substantial oxidant sinks.	Implementable with commercially available technology and typical administrative controls (CEA/WRA) and permitting (injection permit by rule) from NJDEP.	High due to need for multiple injections to attempt to reduce contaminant mass with substantial oxidant sinks and absent a discrete source.	Not retained due to ineffectiveness, potential to mobilize COCs, and high costs without added benefit.
Air Sparge/Soil Vapor Extraction	Injection of air in the aquifer down-gradient of the PMP Area using a barrier approach, and collection of sparged air/volatiles through vapor extraction. Air sparging promotes aerobic biodegradation and volatilization (e.g., benzene).	Would meet the RAO of exposure control through administrative controls. Unlikely to effectively distribute air in heterogeneous environment and achieve contaminant reduction for aquifer restoration.	Implementable with commercially available technology, however, requires a long power drop because of remote location. Typical administrative controls (CEA/WRA) and permitting (wells) from NJDEP.	Moderate to high cost because of continuous operation and long power drop.	Not retained due to ineffectiveness, likelihood of not addressing 1,4-dioxane, difficulty of achieving uniform air distribution and recovery, and high cost.

Table 11
Remedial Action Alternative Screening Summary (continued)
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

Alternative	Description	Effectiveness	Implementability	Relative Cost	Retained/Not Retained for Detailed Analysis
Groundwater Extraction, Treatment and Discharge	Groundwater extraction wells placed down gradient of the PMP Area to create a hydraulic capture zone. Extracted groundwater treated by physical/chemical means with discharge to surface water.	Would meet the RAO of exposure control through administrative controls. Would contribute to meeting the RAO of aquifer restoration by removing mass; however, this technology is inefficient at mass removal.	Implementable with commercially available technology and typical administrative controls (CEA/WRA) and permitting (wells, NJPDES) from NJDEP. Difficult to maintain capture in the low yield fractured bedrock.	High due to capital cost of extraction and treatment system, requirement for power, and ongoing operation and maintenance that would be complicated by fouling problems from high iron and manganese.	Not retained – primarily for migration control and potential risk is not significant under existing conditions, inefficient, questionable effectiveness, with high cost and no significant incremental benefit.
Groundwater Extraction, Treatment and Recirculation	Groundwater extraction wells placed down gradient of the PMP Area to create a hydraulic capture zone. Extracted groundwater treated by physical/chemical means and recirculated to the aquifer to aid in aquifer restoration.	Would meet the RAO of exposure control through administrative controls. Would contribute to meeting the RAO of aquifer restoration by flushing; however, this technology is inefficient at mass removal. Recirculation unlikely to be effective because of low bedrock hydraulic conductivity.	Implementable with commercially available technology and typical administrative controls (CEA/WRA) and permitting (wells, NJPDES-DGW) from NJDEP. Likely difficult to maintain capture and recirculation in the low yield fractured bedrock.	High due to capital cost of extraction and treatment system, requirement for power, and ongoing operation and maintenance that would be complicated by fouling problems from high iron and manganese, including in recirculation wells.	Not retained – primarily for migration control and potential risk is not significant under existing conditions, inefficient, questionable effectiveness, with high cost and no significant incremental benefit.

Table 11
Remedial Action Alternative Screening Summary (continued)
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

Alternative	Description	Effectiveness	Implementability	Relative Cost	Retained/Not Retained for Detailed Analysis
PMP Air Shaft					
No Action	No activities, including no monitoring.	Not effective in meeting RAOs of exposure control and aquifer restoration; however, COC source could include mine workings which is not the subject of the remediation.	Implementable as no activities are included.	No cost.	Retained as a baseline for comparison of other alternatives, and a stand-alone alternative.
Oxygen Diffusion via Chemical Addition	Introduction of oxygen via slow release oxygen compound to promote biodegradation of COCs.	Contributes to enhanced biodegradation of benzene, possibly 1,4-dioxane; however, source is not definitive and treatment may be only in stored water in the Air Shaft.	Implementable with conventional technology.	Low to moderate, with likelihood of continuing replacement of oxygen release compound.	Retained – concerns over disrupting geochemistry of the Air Shaft are more limited with the minimally disruptive technology such as oxygen release compound.
In-Situ Chemical Oxidation	Introduction of a commercially available oxidant into the Air Shaft to oxidize COCs.	Competition from oxidant sinks in the air shaft limit effectiveness. No discrete source to target, may treat only water stored in the Air Shaft.	Implementable with conventional technology and permitting (injection permit by rule) from NJDEP.	Moderate to high cost due to need to continuously introduce oxidant and competition from oxidant sinks present in the Air Shaft.	Not retained – unlikely to be effective because of oxidant sinks, disruptive to Air Shaft geochemistry, high cost with no added benefit.

Table 11
Remedial Action Alternative Screening Summary (continued)
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

Alternative	Description	Effectiveness	Implementability	Relative Cost	Retained/Not Retained for Detailed Analysis
Biosparging	Introduction of air to the Air Shaft via sparging wells to promote biodegradation of COCs.	Contributes to enhanced biodegradation of benzene, possibly 1,4-dioxane; however, source is not definitive and treatment may be only in stored water in the Air Shaft.	Implementable with conventional technology, however, requires a long power drop.	Low to moderate with higher end of costs driven by power drop and ongoing operation.	Not retained – similar to oxygen release compound but at higher cost with more difficulty of maintenance without added benefit.
Closure/Treatment	Introduction of adsorbents in base of the Air Shaft followed by closure of the Sir Shaft.	Would provide potential adsorption of COCs at the base of the Air Shaft and then isolate the Air Shaft from the surrounding environment.	Implementable with conventional mine shaft closure technology. No ongoing operation or maintenance.	Moderate, driven primarily by Air Shaft closure.	Retained – isolates the Air Shaft from the surrounding environment with the added benefit of eliminating potential future safety hazard.
Cannon Mine Pit Area					
No Action	No activities, including no monitoring.	Not effective in meeting RAOs of exposure control and aquifer restoration.	Implementable as no activities are included.	No cost.	Retained as a baseline for comparison of other alternatives.

Table 11
Remedial Action Alternative Screening Summary (continued)
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

Alternative	Description	Effectiveness	Implementability	Relative Cost	Retained/Not Retained for Detailed Analysis
Monitored Natural Attenuation (MNA) with a CEA/WRA	Employs naturally occurring attenuation from advection, dispersion, and biodegradation with a monitoring program and administrative controls.	Meets RAOs of exposure control and aquifer restoration to the extent practicable through administrative controls and natural attenuation mechanisms.	Readily implementable with routine monitoring and typical administrative controls (CEA/WRA) from the NJDEP.	Low, but long-term costs associated with monitoring.	Retained – effective, implementable, and low cost.
O'Connor Disposal Area					
No Action	No activities, including no monitoring.	Not effective in meeting RAOs of exposure control and aquifer restoration.	Implementable as no activities are included.	No cost.	Retained as a baseline for comparison of other alternatives.
Monitored Natural Attenuation (MNA) with a CEA/WRA	Employs naturally occurring attenuation from advection, dispersion, and biodegradation with a monitoring program and administrative controls.	Meets RAOs of exposure control and aquifer restoration to the extent practicable through administrative controls and natural attenuation mechanisms.	Readily implementable with routine monitoring and typical administrative controls (CEA/WRA) from the NJDEP.	Low, but long-term costs associated with monitoring.	Retained – effective, implementable, and low cost.

Table 12
Detailed Evaluation of Alternatives Summary, Threshold Criteria
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

Alt. No.	Alternative	Threshold Criteria	
		Protection of human health and the environment	**Compliance with ARARs**
1	Site-Wide Groundwater, No Action	Potential human health risks not significant under existing conditions. No significant potential ecological risks.	Would comply with ARARs with a CEA/WRA. Not expected to achieve groundwater standards in near term.
2	Site-Wide Groundwater, Monitored Natural Attenuation (MNA)	Potential human health risks not significant under existing conditions. No significant potential ecological risks. MNA monitoring increases data to confirm potential risks have not changed.	Would comply with ARARs through permit equivalent process. Not expected to achieve groundwater standards in near term.
3	OCDA/PMP Area Enhanced Monitored Natural Attenuation Treatment Barrier	Potential human health risks not significant under existing conditions. No significant potential ecological risks. MNA monitoring increases data to confirm potential risks have not changed.	Would comply with ARARs through permit equivalent process. Not expected to achieve groundwater standards in near term, but enhancement of MNA may shorten term of CEA/WRA
4	PMP Air Shaft No Action	Potential human health risks not significant under existing conditions. No significant potential ecological risks.	Would comply with ARARs with a CEA/WRA for site-wide groundwater. Mine water not expected to meet groundwater standards in near term.
5	PMP Air Shaft Oxygen Diffusion via Chemical Addition	Potential human health risks not significant under existing conditions. No significant potential ecological risks.	Would comply with ARARs through permit equivalent process. Oxygen diffusion may reduce flux from mine water to groundwater, and if so, have potential beneficial impact on Site-wide groundwater.
6	PMP Air Shaft Closure/Treatment	Potential human health risks within USEPA acceptable thresholds. No significant potential ecological risks.	Would comply with ARARs through permit equivalent process. Treatment/closure would isolate shaft from the aquifer, and thus, may reduce flux from mine water to groundwater, and if so, have potential beneficial impact on Site-wide groundwater.

Table 13
Detailed Evaluation of Alternatives Summary, Balancing Criteria
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site,

Alt. No.	Alternative	Balancing Criteria				
		Long-Term Effectiveness and Permanence	**Reduction of Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Implementability**	**Cost (NPW, 30 years, 7% discount rate)**
1	Site-Wide Groundwater, No Action	**Effective long-term but not permanent.** The CEA/WRA would be of indeterminate duration because GWQS are not met and a definitive source has not been identified. For as long as the CEA/WRA is in effect, this alternative would be protective in the long term. The CEA/WRA requires ongoing certifications. There is limited monitoring per the CEA/WRA to demonstrate that concentrations of COCs on Site do not change over time and alter the absence of significant risks under current conditions.	**Does not reduce toxicity, mobility or volume.** Natural attenuation processes are expected to continue over time; however, there is only limited monitoring to demonstrate that concentrations of COCs on Site do not change over time and alter the absence of significant risks under current conditions.	**No short-term impacts.** No remedial or construction activities occur. Implementation time to obtain the CEA/WRA is weeks to one-two months.	**Readily implemented.** CEA/WRA readily implemented through regulatory coordination.	**$622,000**
2	Site-Wide Groundwater, Monitored Natural Attenuation (MNA) with CEA/WRA	**Effective long-term but not permanent.** The CEA/WRA would be of indeterminate duration because GWQS are not met and a definitive source has not been identified. For as long as the CEA/WRA is in effect, this alternative would be protective in the long term. MNA is functioning to reduce concentrations of COCs in groundwater naturally. The CEA/WRA requires ongoing certifications.	**Reduces the toxicity and mobility of COCs present on Site through natural attenuation**. Natural attenuation processes of biodegradation, advection, and dispersion would continue. Monitoring would be conducted to confirm these processes continue.	**Minimal short-term impacts.** Remedial construction limited to installation of additional wells. Health and safety of workers and the public would be maintained with a Site-specific health and safety plan. Implementation time to obtain the CEA/WRA and permit equivalents and install the new wells is on the order of six months.	**Readily implemented.** Conventional equipment and materials available in the marketplace (e.g., for well installations). CEA/WRA readily implemented through regulatory coordination. Impediments to obtaining permit equivalents are not anticipated.	**$1,439,000**

Table 13
Detailed Evaluation of Alternatives Summary, Balancing Criteria
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site,

Alt. No.	Alternative	Balancing Criteria				
		Long-Term Effectiveness and Permanence	**Reduction of Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Implementability**	**Cost (NPW, 30 years, 7% discount rate)**
3	OCDA/PMP Area Enhanced Monitored Natural Attenuation Treatment Barrier with CEA/WRA	**Effective long-term but not permanent.** The CEA/WRA established would be of indeterminate duration because GWQS are not met and a definitive source has not been identified. As such, for as long as the CEA/WRA is in effect, these alternatives would be protective in the long term. MNA is functioning to reduce concentrations of COCs in groundwater naturally. The CEA/WRA requires ongoing certifications. Enhanced MNA requires routine addition of ORC and nutrients to continue to support and enhance the MNA process.	**Reduces the toxicity and mobility of COCs present on Site through natural attenuation**. Natural attenuation processes of biodegradation, advection, and dispersion would continue and be enhanced. Monitoring would be conducted to confirm these processes continue. Enhanced MNA introduces oxygen and nutrients to provide additional steps of supporting and enhancing the natural attenuation processes, which also aids in the positive effects of redox conditions.	**Minimal short-term impacts.** Remedial construction limited to installation of additional wells. Health and safety of workers and the public would be maintained with a Site-specific health and safety plan. Placement of ORC requires limited effort, and would be in accordance with manufacturer's instructions and the health and safety plan. Implementation time to obtain the CEA/WRA and permit equivalents, install the new wells and install the ORC is one-year to 18 months.	**Readily implemented**. Conventional equipment and materials available in the marketplace (e.g., for well installations, ORC). CEA/WRA readily implemented through regulatory coordination. Impediments to obtaining permit equivalents are not anticipated.	**$2,815,000**
4	PMP Air Shaft No Action	**Effective long-term but not permanent.** The Site-wide groundwater CEA/WRA would include the area adjacent to and downgradient of the PMP Air Shaft. The CEA/WRA requires ongoing certifications. There would not be a mechanism to demonstrate that concentrations of COCs at the PMP Air Shaft do not change overtime.	**Does not reduce toxicity, mobility or volume.** No action would be taken to reduce concentrations of COCs in the PMP Air Shaft	**No short-term impacts.** No remedial or construction activities occur.	**Not applicable.** No action does not require implementation of any remedial construction or obtaining permit equivalents.	**No cost.**

Table 13
Detailed Evaluation of Alternatives Summary, Balancing Criteria
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site,

Alt. No.	Alternative	Balancing Criteria				
		Long-Term Effectiveness and Permanence	**Reduction of Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Implementability**	**Cost (NPW, 30 years, 7% discount rate)**
5	PMP Air Shaft Oxygen Diffusion via Chemical Addition	**Effective long-term but not permanent.** The Site-wide groundwater CEA/WRA would include the area adjacent to and downgradient of the PMP Air Shaft. The CEA/WRA requires ongoing certifications. ORC can be placed in the PMP Air Shaft indefinitely, and therefore, the effectiveness can be maintained for the long term.	**Reduces the toxicity and volume of COCs present in the Air Shaft.** Introduction of oxygen and essential nutrients would promote aerobic biodegradation of COCs. As a discrete, definitive source of COCs has not been identified, concentrations of COCs in the PMP Air Shaft are in the parts per billion range, and the bedrock aquifer has limited hydraulic conductivity, a substantial reduction in toxicity or volume of COCs is not anticipated.	**Minimal short-term impacts.** Remedial construction limited to installation of the concrete cap on the PMP Air Shaft. Health and safety of workers and the public would be maintained with a Site-specific health and safety plan. Placement of ORC requires limited effort, and would be in accordance with manufacturer's instructions and the health and safety plan. Implementation time to obtain the permit equivalents, install concrete cap and install the ORC is six months to one-year.	**Readily implemented.** Conventional equipment, materials, means and methods available in the marketplace.	**$352,000**

Table 13
Detailed Evaluation of Alternatives Summary, Balancing Criteria
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site,

Alt. No.	Alternative	Balancing Criteria				
		Long-Term Effectiveness and Permanence	**Reduction of Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Implementability**	**Cost (NPW, 30 years, 7% discount rate)**
6	PMP Air Shaft Closure/Treatment	**Effective long-term and permanent.** COCs adsorbed to the GAC and resin would remain as there would not be a mechanism to regenerate the carbon or resin and release the COCs. The Air Shaft would be permanently sealed with grout to isolate it from the surrounding environment.	**Reduces the mobility of COCs present in the Air Shaft.** GAC and resin placed in the PMP Air Shaft would adsorb COCs. Grout used to permanently seal the entire shaft will isolate it from the surrounding environment, also reducing mobility through encapsulation. As a discrete, definitive source of COCs has not been identified, concentrations of COCs in the PMP Air Shaft are in the parts per billion range, and the bedrock aquifer has limited hydraulic conductivity, a substantial reduction in mobility of COCs is not anticipated.	**Minimal short-term impacts.** Remedial construction is limited to installation of GAC and resin in the base of PMP Air Shaft and closure of the shaft. Health and safety of workers and the public would be maintained with a Site-specific health and safety plan. Implementation time to obtain the permit equivalents and perform the closure/treatment is one-year to 18 months. The placement of stone, GAC, and resin in the base of the Air Shaft has the potential to disturb sediments and debris, which could in turn alter the geochemistry and groundwater quality in the base of the shaft and down gradient on a short-term basis. However, absent an identifiable source the risk is considered low/moderate.	**Readily implemented.** Conventional equipment, materials, means and methods available in the marketplace.	**$598,000**

Table 14
Alternative 1, Site-Wide Groundwater, No Action
Cost Estimate
Groundwater Focused Feasibility Study, Ringwood Mines/Landfill Superfund Site

Item	Unit	Unit Price	Quantity	Amount
Capital Costs				
Institutional Control (CEA/WRA)	LS	$15,000	--	$15,000
Subtotal Capital				***$15,000***
Contingencies (25%)				$3,800
Total Capital				***$18,800***
Annual Operation, Maintenance, and Monitoring Costs				
Groundwater Monitoring, Biennial*	LS	$25,000	--	$25,000
CEA/WRA Biennial Certification	LS	$5,000	--	$5,000
Reporting/Five-Year Reviews*	LS	$5,000	--	$5,000
Misc. Well Maintenance, Security, etc.	LS	$500	--	$500
Subtotal Annual OM&M				***$36,000***
Engineering & Administration (10%)				$3,600
Contingencies (25%)				$9,000
Total Annual OM&M				***$48,600***
Present Worth Annual OM&M (7%, 30 yrs)				***$603,000***
Total 30-Year Net Present Worth				***$622,000***

*Intermittent activities converted to estimated annual cost for calculation purposes.

Table 15

Alternative 2, Site-Wide Groundwater, Monitored Natural Attenuation with CEA/WRA

Cost Estimate

Groundwater Focused Feasibility Study, Ringwood Mines/Landfill Superfund Site

Item	Unit	Unit Price	Quantity	Amount
Capital Costs				
Mobilization/Demobilization	LS	$2,500	--	$2,500
Miscellaneous (HASP, Survey, Well Permits, etc.)	LS	$15,000	--	$15,000
Site Preparation/Access Agreements	LS	$10,000	--	$10,000
Well Installations				
Site Access	LS	$20,000	--	$20,000
Bedrock Sentinel Wells	Ea	$22,000	3	$66,000
IDW Classification and Disposal	LS	$5,000	--	$5,000
Institutional Controls (CEA/WRA, Deed Notice)	LS	$15,000	--	$15,000
Well Installation FHA and FWW Permit Equivalents & Mitigation	LS	$50,000	--	$50,000
Subtotal Capital				***$183,500***
Engineering & Administration (10%)				$18,000
Contingencies (25%)				$46,000
Total Capital				***$248,000***
Annual Operation, Maintenance, and Monitoring Costs				
Groundwater/Surface Water Monitoring	LS	$50,000	--	$50,000
Institutional Controls, Biennial Certifications*	LS	$10,000	--	$10,000
Reporting/Five-Year Reviews*	LS	$10,000	--	$10,000
Misc. Well Maintenance, Security, etc.	LS	$1,000	--	$1,000
Subtotal Annual OM&M				***$71,000***
Engineering & Administration (10%)				$7,100
Contingencies (25%)				$18,000
Total Annual OM&M				***$96,000***
Present Worth Annual OM&M (7%, 30 yrs)				***$1,191,000***
Total 30-Year Net Present Worth				***$1,439,000***

*Intermittent activities converted to estimated annual cost for calculation purposes.

Table 16
Alternative 3, PMP/OCDA Enhanced Monitored Natural Attenuation Treatment Barrier
Cost Estimate
Groundwater Focused Feasibility Study, Ringwood Mines/Landfill Superfund Site

Item	Unit	Unit Price	Quantity	Amount
Capital Costs				
Mobilization/Demobilization	LS	$5,000	--	$5,000
Miscellaneous (HASP, Survey, Well Permits, etc.)	LS	$15,000	--	$15,000
Site Preparation/Access	LS	$50,000	--	$50,000
Well Installations				
Site Access	LS	$40,000	--	$40,000
Bedrock Sentinel Wells	Ea	$22,000	3	$66,000
Bedrock Injection Wells	Ea	$22,000	4	$88,000
Overburden Injection Wells	Ea	$3,000	21	$63,000
IDW Classification and Disposal	LS	$20,000	--	$20,000
Well Installation FHA and FWW Permit Equivalents & Mitigation	LS	$50,000	--	$50,000
Institutional Controls (CEA/WRA, Deed Notice)	LS	$15,000	--	$15,000
Oxygen Release Compound	LS	$50,000		$50,000
Installion of ORC	LS	$5,000	--	$5,000
Subtotal Capital				***$467,000***
Engineering & Administration (10%)				$47,000
Contingencies (25%)				$117,000
Total Capital				***$631,000***
Annual Operation, Maintenance, and Monitoring Costs				
Groundwater/Surface Water Monitoring	LS	$50,000	--	$50,000
Institutional Controls, Biennial Certifications*	LS	$10,000	--	$10,000
Oxygen Release Compound (annual replacement)	LS	$50,000	--	$50,000
Annual Installation of ORC	LS	$5,000	--	$5,000
Reporting/Five-Year Reviews*	LS	$10,000	--	$10,000
Misc. Well Maintenance, Security, etc.	LS	$5,000	--	$5,000
Subtotal Annual OM&M				***$130,000***
Engineering & Administration (10%)				$13,000
Contingencies (25%)				$32,500
Total Annual OM&M				***$176,000***
Present Worth Annual OM&M (7%, 30 yrs)				***$2,184,000***
Total 30-Year Net Present Worth				***$2,815,000***

*Intermittent activities converted to estimated annual cost for calculation purposes.

Table 17
Alternative 5, PMP Air Shaft, Oxygen Diffusion via Chemical Addition
Cost Estimate
Groundwater Focused Feasibility Study, Ringwood Mines/Landfill Superfund Site

Item	Unit	Unit Price	Quantity	Amount
O&M				
Mobilization	LS	$5,000	--	$5,000
Miscellaneous (e.g., HASP)	LS	$3,000	--	$3,000
Site Preparation/Access	LS	$2,500	--	$2,500
Cap on Air Shaft Opening	LS	$50,000	--	$50,000
Oxygen Release Compound (ORC)	LS	$5,000	--	$5,000
Installation of ORC Canisters	LS	$1,000	--	$1,000
Subtotal Capital				$66,500
Engineering & Administration (10%)				$7,000
Contingencies (25%)				$17,000
Total Capital				***$91,000***
Annual Operation, Maintenance & Monitoring Costs				
Oxygen Release Compound (semi-annual replacement)	LS	$6,000	--	$6,000
Installation of ORC Canisters	LS	$1,000	--	$1,000
Misc. (Supplies, Mine Shaft Inspections)	LS	$1,000	--	$1,000
Mine Water Sampling (semi-annual)	LS	$7,500	--	$7,500
Groundwater Monitoring Performed Under Site-Wide Groundwater				$0
Subtotal Annual OM&M				$15,500
Engineering & Administration (10%)				$1,600
Contingencies (25%)				$3,900
Total Annual OM&M				$21,000
Present Worth Annual OM&M (7%, 30 yrs)				***$261,000***
Total 30-Year Net Present Worth				***$352,000***

Table 18
Alternative 6, PMP Air Shaft, Treatment/Closure
Cost Estimate
Groundwater Focused Feasibility Study, Ringwood Mines/Landfill Superfund Site

Item	Unit	Unit Price	Quantity	Amount
Capital Costs				
Mobilization/Demobilization	LS	$15,000	--	$15,000
Miscellaneous (e.g., HASP)	LS	$3,000	--	$3,000
Site Preparation/Access				
Stone Pad and Accessway	LS	$50,000	--	$50,000
Geotextile, Mats, etc. for Equipment	LS	$15,000	--	$15,000
Air Shaft Closure/Treatment				
Granular Activated Carbon (GAC)	Lbs	$2	2,000	$4,000
Resin	Kgs	$160	100	$16,000
Installation of GAC and Resin (e.g., cable, socks, etc.)	LS	$10,000	--	$10,000
Coarse Angular Stone	Tons	$40	1,500	$60,000
Fast Setting, Low-Slump Grout	CY	$125	100	$12,500
Low-Strength Fly Ash Cement Grout	CY	$100	2,200	$220,000
Concrete Cap and Marker	LS	$5,000	--	$5,000
Treatment of Displaced Mine Shaft Water	Gals	$0.05	450,000	$22,500
Site Restoration	LS	$10,000	--	$10,000
Subtotal Capital				***$443,000***
Engineering & Administration (10%)				$44,000
Contingencies (25%)				$111,000
Total Capital				***$598,000***
Annual Operation, Maintenance, and Monitoring Costs				
Groundwater Monitoring Performed Under Site-Wide Groundwater				$0
Total Remedy Cost				***$598,000***

Table 19
Comparative Analysis of Alternatives
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

Evaluation Criteria / Site Remedy	Overall Protection of Human Health and the Environment	Compliance with Applicable or Relevant and Appropriate Requirements	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume	Short-Term Effectiveness	Implementability	Cost (NPW, 30 years, 7% discount rate)	Total Relative Scale[1]
Site-Wide Groundwater								
Alternative 1 – Site-Wide Groundwater, No Action	Protective of human health and the environment under current conditions. Relative Scale = 5	Partially complies with ARARs. Relative Scale = 5	Effective long-term through implementation and maintenance of the CEA/WRA. Relative Scale = 5	Does not reduce toxicity, mobility or volume. Relative Scale = 1	No short-term impacts. Implementation time weeks to one-two months. Relative Scale = 5	Readily implemented. Relative Scale = 10	$622,000 Relative Scale = 10	41
Alternative 2 – Site-Wide Groundwater, Monitored Natural Attenuation (MNA) with CEA/WRA	Protective of human health and the environment. Relative Scale = 8	Able to comply with ARARs with permit equivalents. Unlikely to meet GWQS in the near term. Relative Scale = 7	Effective long-term through implementation and maintenance of the CEA/WRA. MNA monitoring would allow the continued evaluation of groundwater to confirm COCs are decreasing and not migrating off-site. Relative Scale = 7	Reduces the toxicity and mobility of COCs through the natural attenuation processes. Relative Scale = 6	Minimal short-term impacts from remedial construction, implemented with a Site-specific health and safety plan. Implementation time six months. Relative Scale = 7	Readily implemented with conventional equipment and materials available in the marketplace (e.g., for well installations). Relative Scale = 7	$1,439,000 Relative Scale = 8	50

Table 19
Comparative Analysis of Alternatives
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

Evaluation Criteria / Site Remedy	Overall Protection of Human Health and the Environment	Compliance with Applicable or Relevant and Appropriate Requirements	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume	Short-Term Effectiveness	Implementability	Cost (NPW, 30 years, 7% discount rate)	Total Relative Scale[1]
Alternative 3 – OCDA/PMP Area Enhanced Monitored Natural Attenuation Treatment Barrier with CEA/WRA	Protective of human health and the environment. Relative Scale = 8	Complies with ARARs. Unlikely to meet GWQS in the near term. Enhanced MNA Treatment Barrier may reduce time to meet GWQS. Relative Scale = 9	Effective long-term through implementation and maintenance of the CEA/WRA. MNA monitoring would allow the continued evaluation of groundwater to confirm COCs are decreasing and not migrating off-site. Relative Scale = 8	Reduces the toxicity and mobility of COCs through the natural attenuation processes. Introduction of oxygen and nutrients supports and enhances the natural attenuation processes. Relative Scale = 8	Minimal short-term impacts from remedial construction, implemented with a Site-specific health and safety plan. Implementation time one-year to 18 months. Relative Scale = 7	Readily implemented with conventional equipment and materials available in the marketplace (e.g., for well installations, ORC). Relative Scale = 7	$2,815,000 Relative Scale = 5	52
PMP Air Shaft								
Alternative 4 – PMP Air Shaft No Action	Protective of human health and the environment under current conditions. Relative Scale = 5	Partially complies with ARARs. Relative Scale = 5	Controlled by Site-wide CEA/WRA. Relative Scale = 5	Does not reduce toxicity, mobility or volume. Relative Scale = 1	No short-term impacts, no action. Relative Scale = 5	Not applicable, no action. Relative Scale = 10	None. Relative Scale = 10	41

Table 19
Comparative Analysis of Alternatives
Groundwater Focused Feasibility Study
Ringwood Mines/Landfill Superfund Site

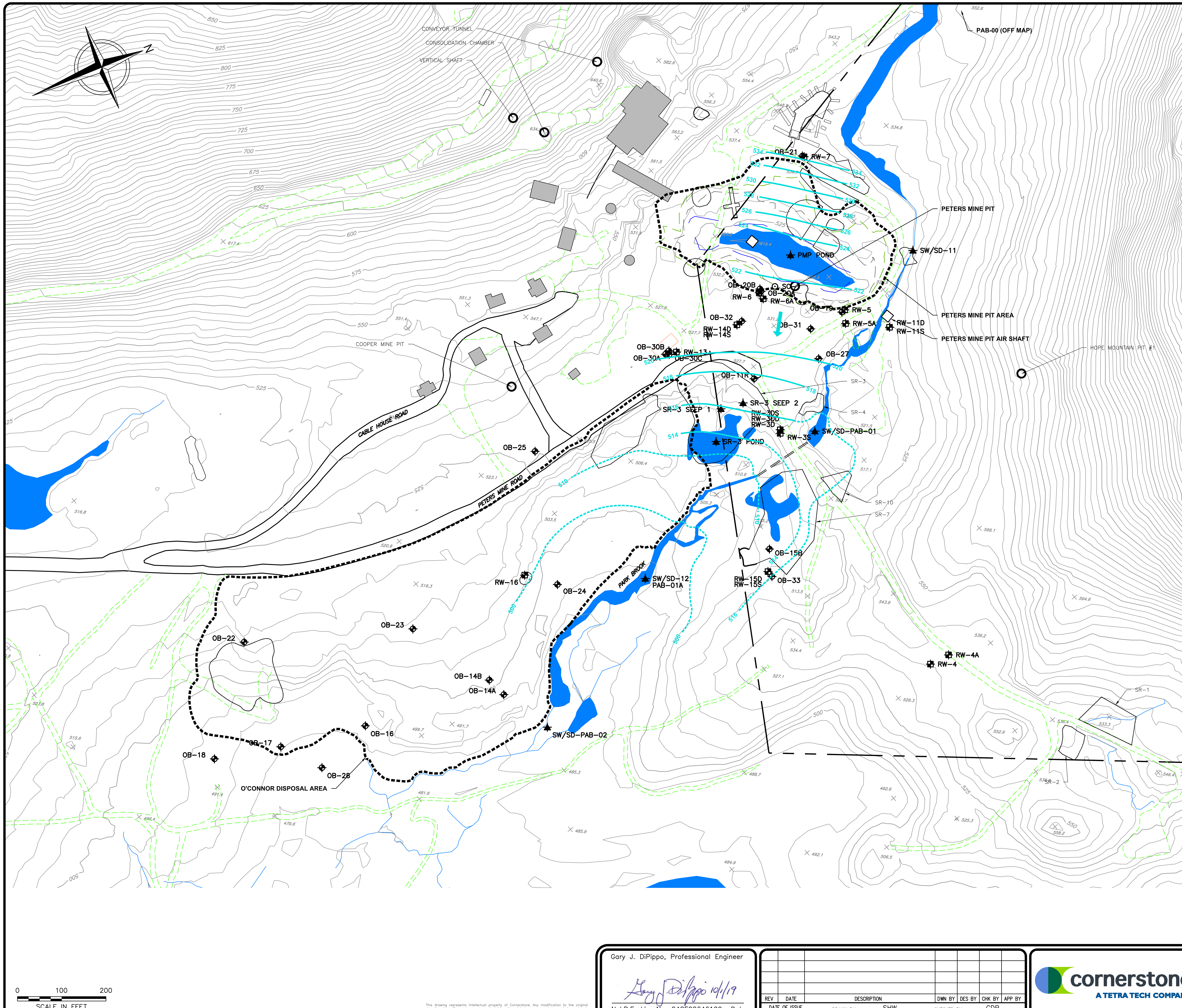
Evaluation Criteria / Site Remedy	Overall Protection of Human Health and the Environment	Compliance with Applicable or Relevant and Appropriate Requirements	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume	Short-Term Effectiveness	Implementability	Cost (NPW, 30 years, 7% discount rate)	Total Relative Scale[1]
Alternative 5 – PMP Air Shaft Oxygen Diffusion via Chemical Addition	Protective of human health and the environment. Relative Scale = 7	Able to comply with ARARs through permit equivalents. May reduce time to meet GWQS Relative Scale = 8	Can be maintained for the long term through introduction of oxygen. Relative Scale = 7	Addition of ORC and nutrients may reduce toxicity and volume, but not substantially. Relative Scale = 5	Minimal short-term impacts from remedial construction, implemented with a Site-specific health and safety plan. Implementation time six months to one-year. Relative Scale = 7	Readily implemented with conventional equipment, materials, means and methods available in the marketplace. Relative Scale = 7	$352,000 Relative Scale = 8	49
Alternative 6 – PMP Air Shaft Closure/Treatment	Protective of human health and the environment. Relative Scale = 9	Able to comply with ARARs through permit equivalents. May reduce time to meet GWQS Relative Scale = 9	Can be maintained for the long term. Closure of the PMP Air Shaft is permanent and essentially isolates the air shaft from the surrounding environment. Relative Scale = 10	Addition of GAC/resin would reduce mobility, but not substantially. Relative Scale = 8	Minimal short-term impacts from remedial construction, implemented with a Site-specific health and safety plan. May temporarily disturb geochemistry and groundwater quality of Air Shaft and down gradient. Implementation of one-year to 18 months. Relative Scale = 6	Readily implemented with conventional equipment, materials, means and methods available in the marketplace. Relative Scale = 6	$598,000 Relative Scale = 5	53

Relative Scale: 1 ◄——————► 10
Worse Than Other Remedies Better

Note:
[1] Total Relative Scale represents the sum of the individual criteria relative scale ratings. Remedies with higher Total Relative Scale meet requirements of the individual evaluation criteria better than remedies with lower Total Relative Scale (Maximum Total Relative Scale = 70, Minimum = 7)

FIGURES

Attached Separately, 24" x 36" Sheets



LEGEND:

- STATE PARK BOUNDARY
- 1360 — EXISTING INDEX CONTOUR
- EXISTING BUILDING
- EXISTING EDGE OF PAVED ROAD
- EXISTING EDGE OF GRAVEL ROAD
- EXISTING WATER COURSE
- EXISTING WATER BODY
- SR-1 — LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
- 500 — GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
- 510 — INFERRED GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
- GROUNDWATER FLOW DIRECTION
- EXISTING MINE STRUCTURE
- OB-2 — EXISTING BEDROCK GROUNDWATER MONITORING WELL
- OB-27 — EXISTING OVERBURDEN GROUNDWATER MONITORING WELL
- SW/SD-MRB-01 — EXISTING SURFACE WATER MONITORING LOCATION
- SC-2 — EXISTING SOIL BORING LOCATION

NOTES:

1. GROUNDWATER ELEVATION DATA POINTS NOT SHOWN FOR CLARITY.
2. GROUNDWATER CONTOURS SHOWN ARE FOR THE UPPER, SHALLOW BEDROCK WATER-BEARING ZONE.
3. GROUNDWATER CONTOURS TAKEN FROM AUGUST 2016 GROUNDWATER, MINE WATER, AND SURFACE WATER SAMPLING DATA REPORT (CORNERSTONE, 2016) AND EXTRAPOLATED INTO OCDA BASED ON DATA AT RW-16.

Gary J. DiPippo, Professional Engineer
Gary J DiPippo 10/1/19
N.J.P.E. Lic. No. 24GE02646100 Date

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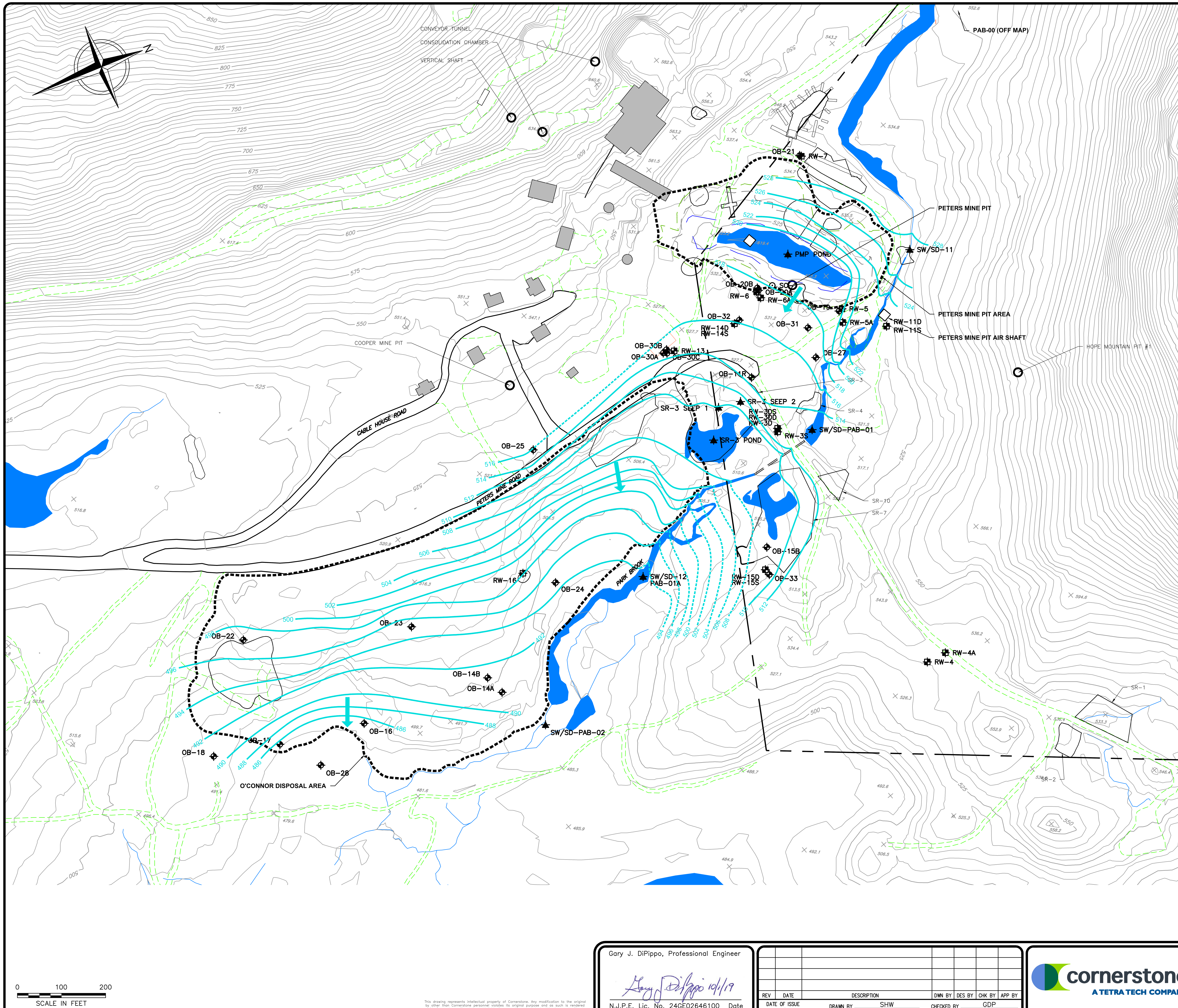
RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

PMP/OCDA WELL AND SURFACE WATER SAMPLE LOCATIONS & SHALLOW BEDROCK GROUNDWATER MAP
(AUGUST 2016 DATA)

FIGURE NO. 1
PROJECT NO. 170101



LEGEND:

- STATE PARK BOUNDARY
- 1360 — EXISTING INDEX CONTOUR
- EXISTING BUILDING
- EXISTING EDGE OF PAVED ROAD
- EXISTING EDGE OF GRAVEL ROAD
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- EXISTING WATER BODY
- SR-1 — LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
- 500 — GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
- 510 — INFERRED GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
- GROUNDWATER FLOW DIRECTION
- EXISTING MINE STRUCTURE
- OB-2 — EXISTING BEDROCK GROUNDWATER MONITORING WELL
- OB-27 — EXISTING OVERBURDEN GROUNDWATER MONITORING WELL
- SW/SD-MRB-01 — EXISTING SURFACE WATER MONITORING LOCATION
- SC-2 — EXISTING SOIL BORING LOCATION

NOTES:

1. GROUNDWATER ELEVATION DATA POINTS NOT SHOWN FOR CLARITY.
2. GROUNDWATER CONTOURS TAKEN FROM AUGUST 2016 GROUNDWATER, MINE WATER, AND SURFACE WATER SAMPLING SAMPLING DATA REPORT (CORNERSTONE, 2016) AND ADJUSTED TO INTEGRATE PMP AREA AND OCDA DATA.

Gary J. DiPippo, Professional Engineer
N.J.P.E. Lic. No. 24GE02646100 Date 10/1/19

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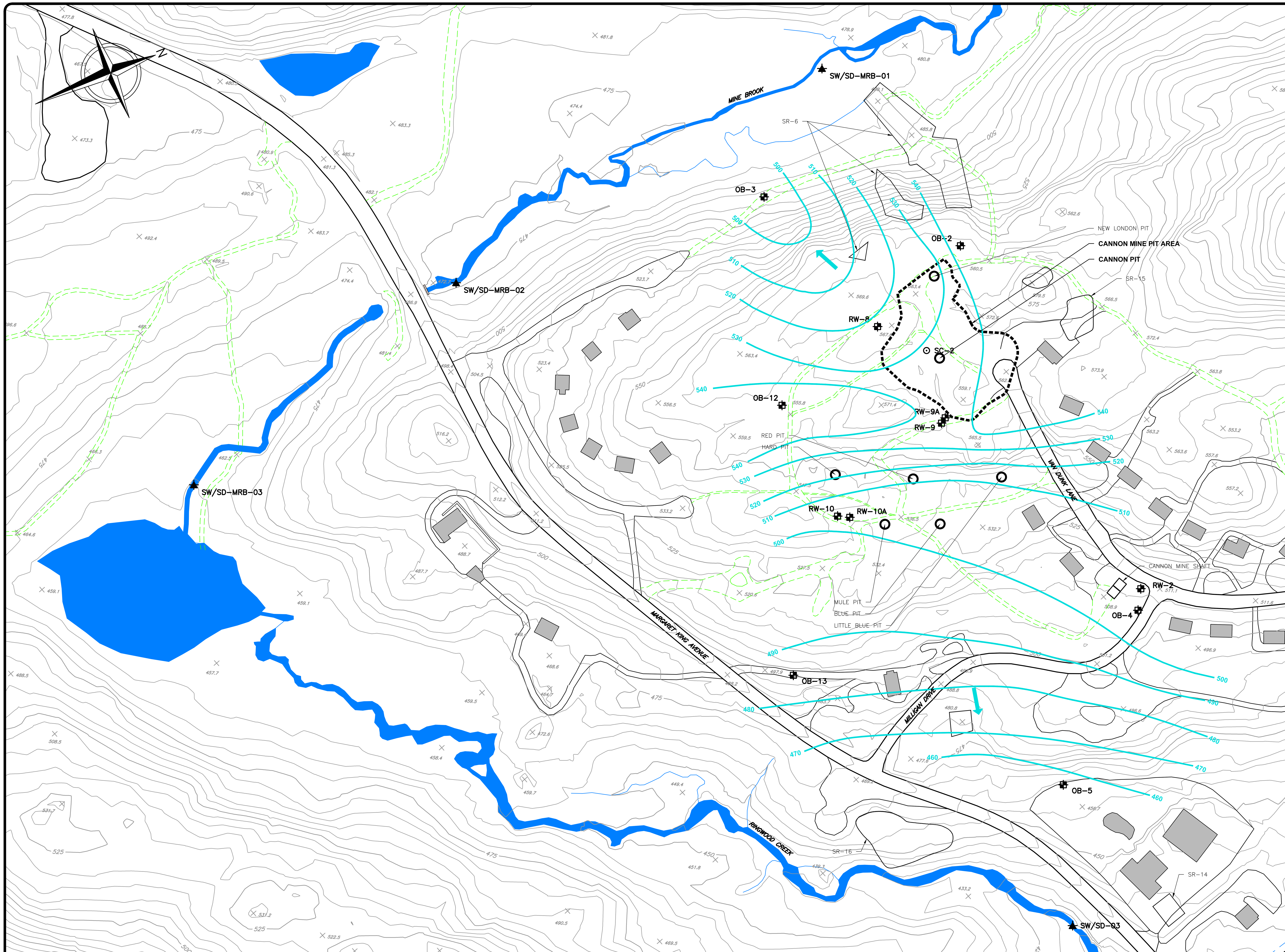
RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

PMP/OCDA WELL AND SURFACE WATER SAMPLE LOCATIONS & OVERBURDEN GROUNDWATER CONTOUR MAP
(AUGUST 2016 DATA)

FIGURE NO. 2
PROJECT NO. 170101



LEGEND:

- STATE PARK BOUNDARY
- 1360 — EXISTING INDEX CONTOUR
- EXISTING BUILDING
- EXISTING EDGE OF PAVED ROAD
- EXISTING EDGE OF GRAVEL ROAD
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- EXISTING WATER BODY
- SR-1 — LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
- 500 — GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
- 510 — INFERRED GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
- GROUNDWATER FLOW DIRECTION
- EXISTING MINE STRUCTURE
- OB-2 — EXISTING BEDROCK GROUNDWATER MONITORING WELL
- SW/SD-MRB-01 — EXISTING SURFACE WATER MONITORING LOCATION
- SC-2 — EXISTING SOIL BORING LOCATION

NOTES:

1. GROUNDWATER ELEVATION DATA POINTS NOT SHOWN FOR CLARITY.
2. GROUNDWATER CONTOURS TAKEN FROM AUGUST 2016 GROUNDWATER, MINE WATER, AND SURFACE WATER SAMPLING DATA REPORT (CORNERSTONE, OCTOBER 2016).

0 100 200
SCALE IN FEET

Gary J. DiPippo, Professional Engineer
N.J.P.E. Lic. No. 24GE02646100 Date 10/1/19

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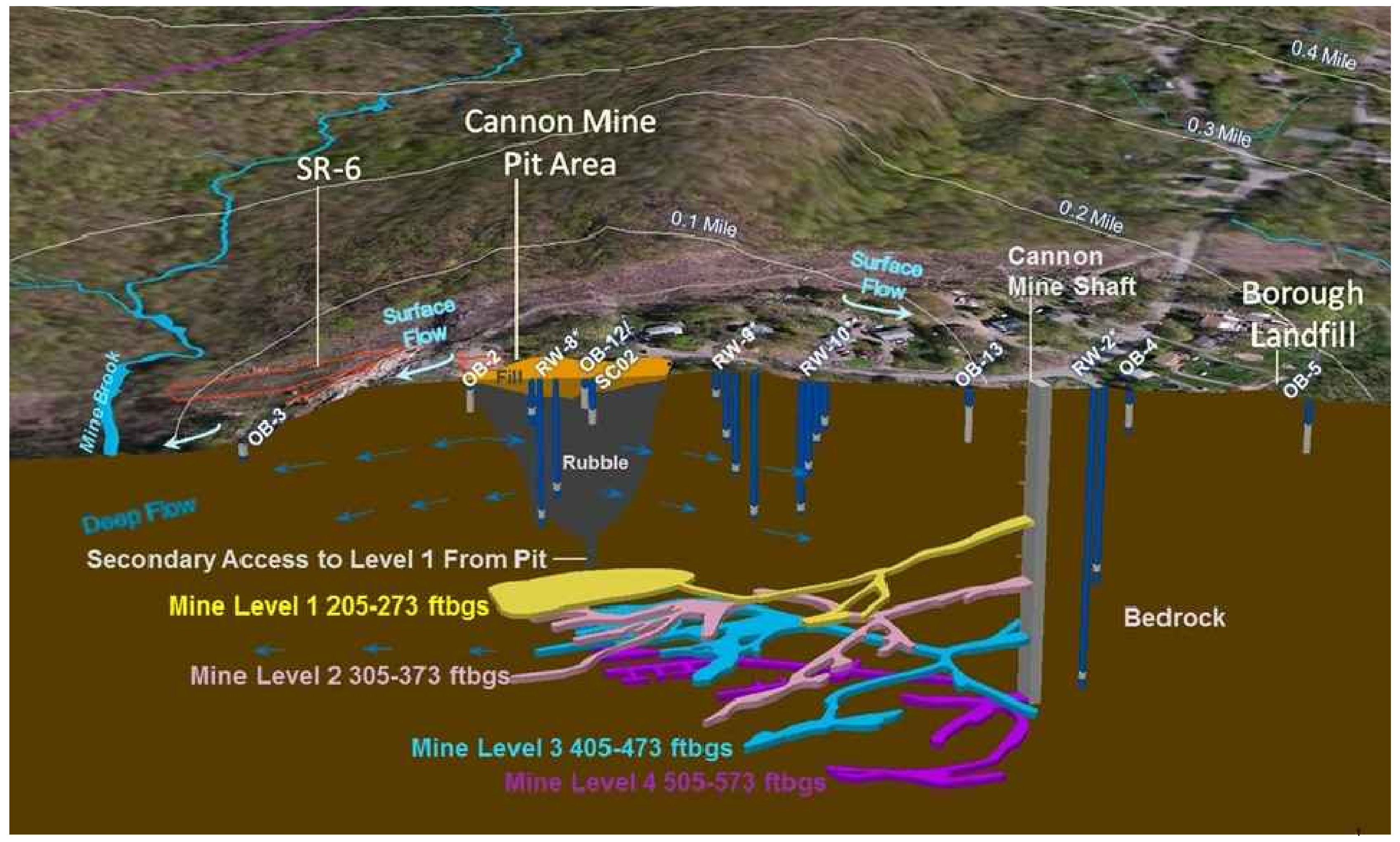
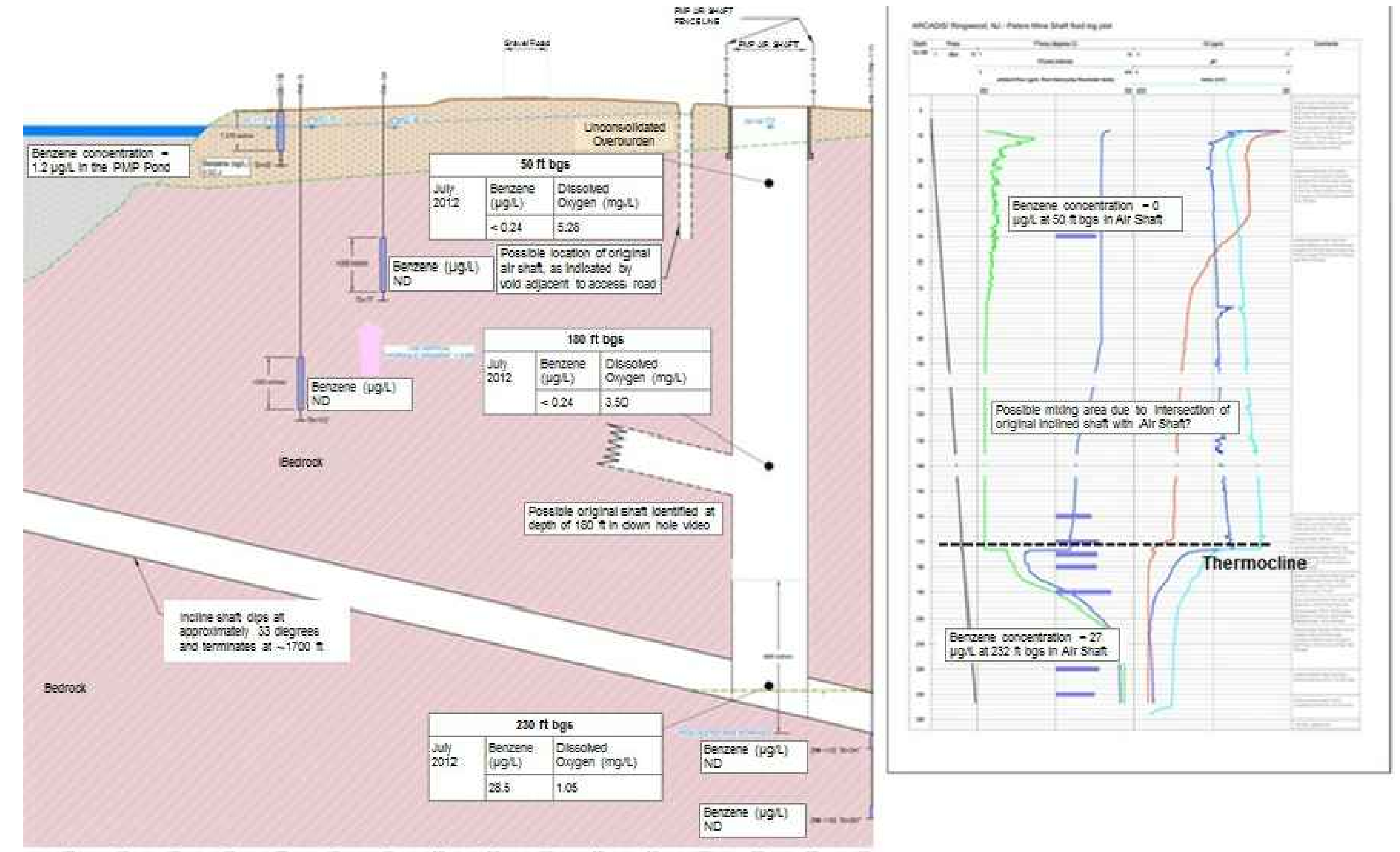
RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

CMP WELL AND SURFACE WATER SAMPLE LOCATIONS & SHALLOW BEDROCK GROUNDWATER CONTOUR MAP
(AUGUST 2016 DATA)

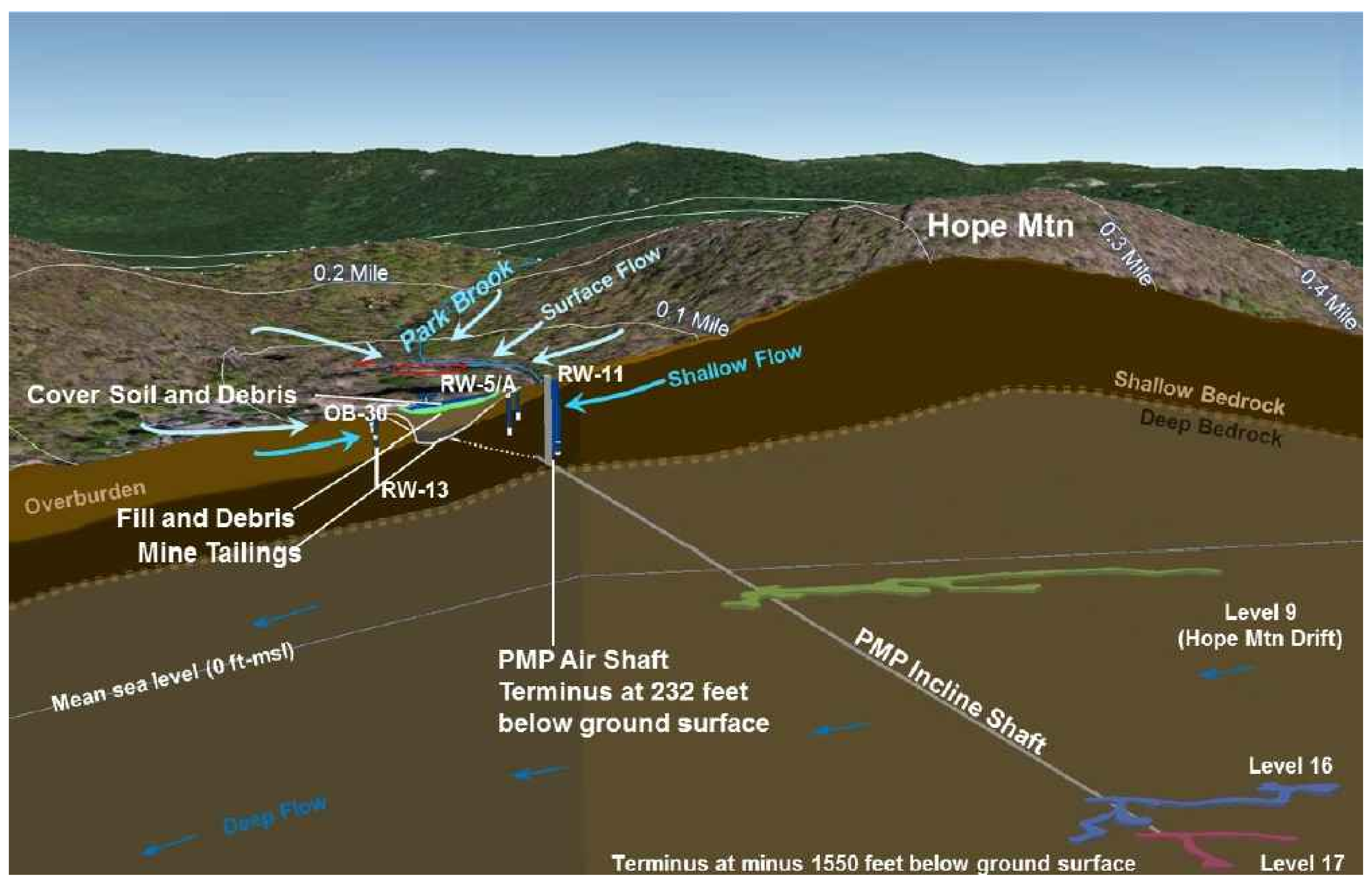
FIGURE NO. 3
PROJECT NO. 170101



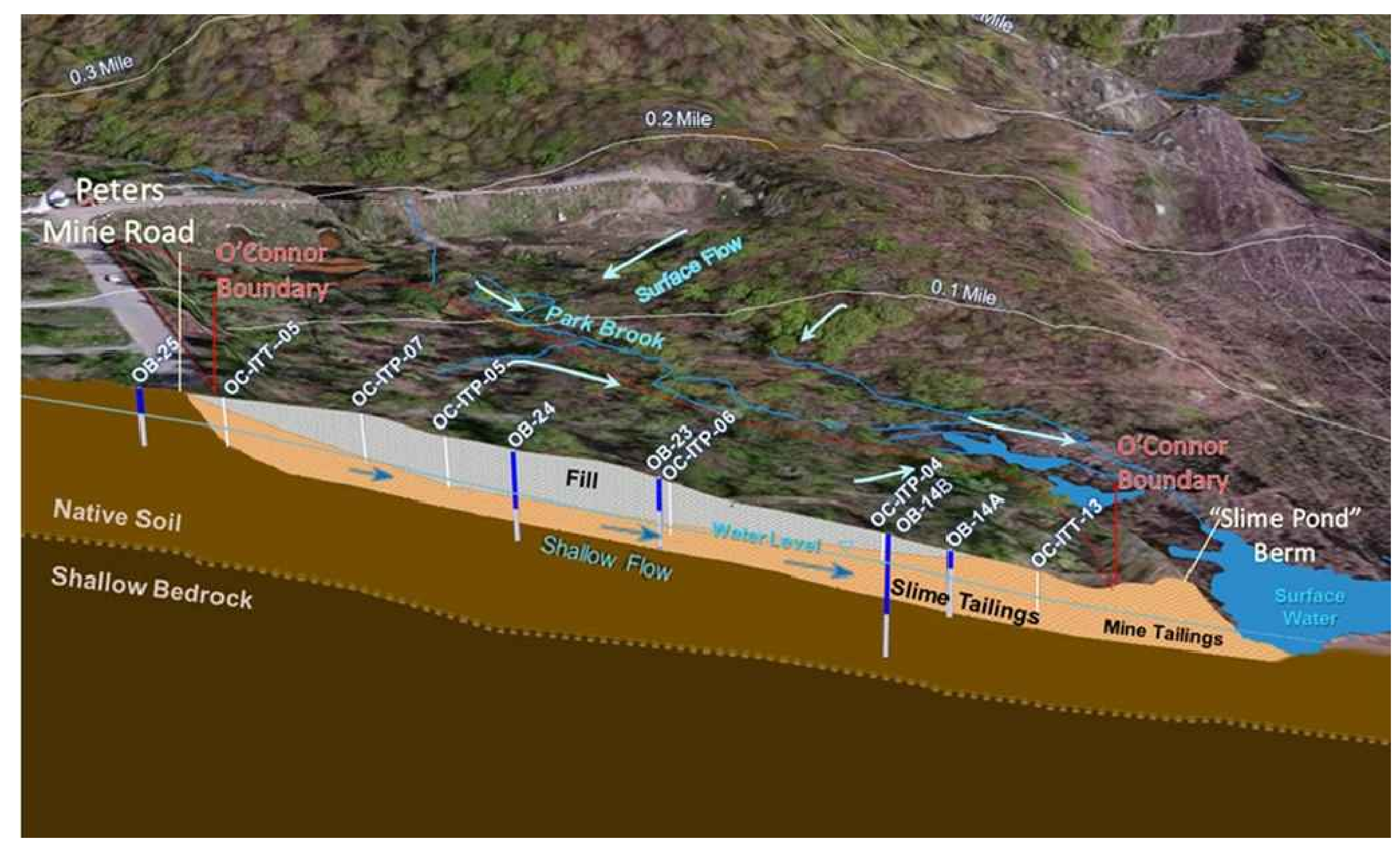
4A
CANNON MINE PIT
SITE MODEL
SCALE: N.T.S.



4B
PETERS MINE PIT
AIR SHAFT MODEL
SCALE: N.T.S.



4C
PETERS MINE PIT
SITE MODEL
SCALE: N.T.S.



4D
O'CONNOR DISPOSAL AREA
SITE MODEL
SCALE: N.T.S.

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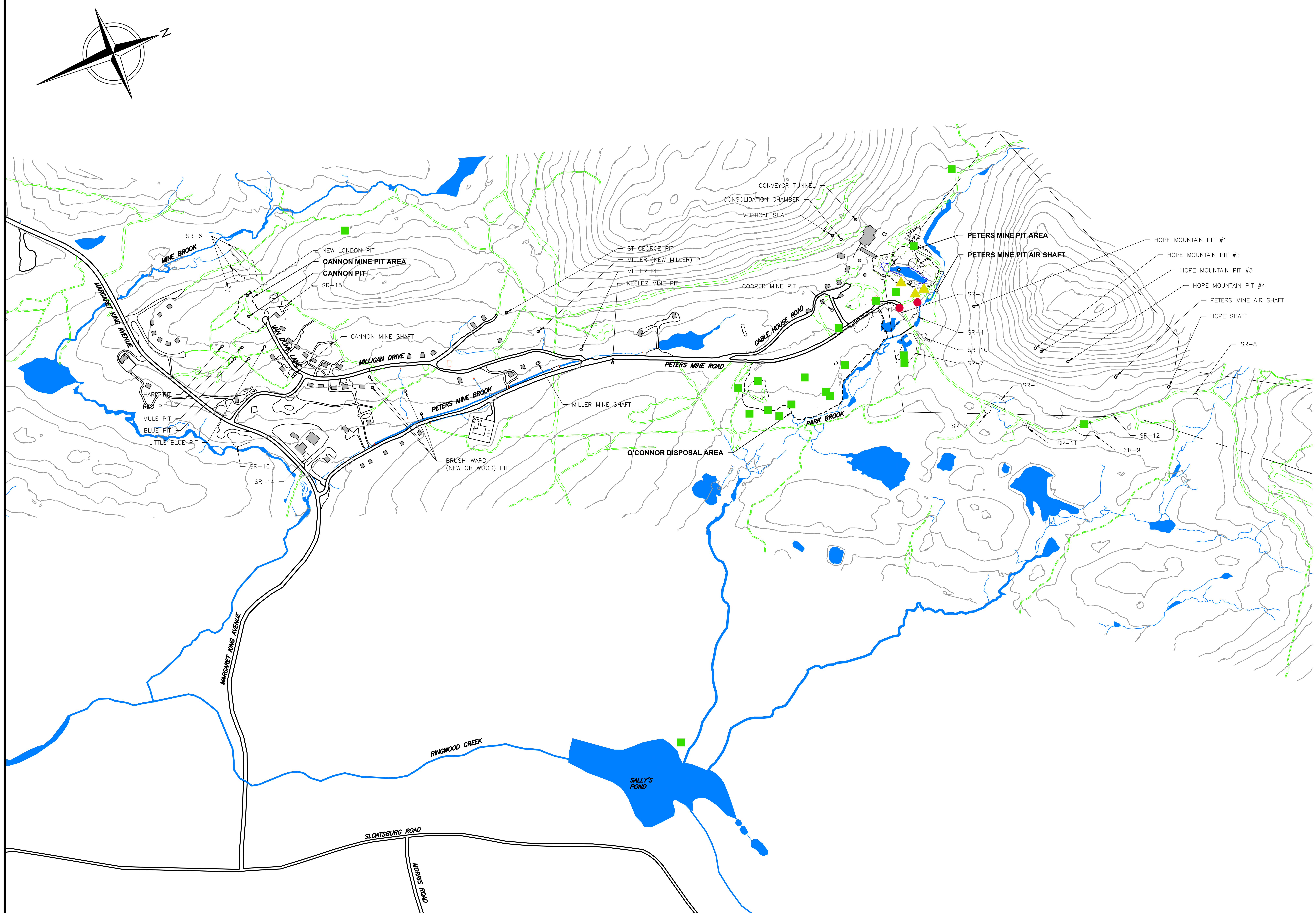
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

CONCEPTUAL SITE MODELS

FIGURE NO. 4
PROJECT NO. 170101



LEGEND:

	STATE PARK BOUNDARY
1360	EXISTING INDEX CONTOUR
	EXISTING BUILDING
	EXISTING EDGE OF PAVED ROAD
	EXISTING EDGE OF GRAVEL ROAD
	EXISTING WATER COURSE
	EXISTING WATER BODY
SR-1	LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
●	BENZENE >GWQS IN OVERBURDEN GROUNDWATER
▲	BENZENE <GWQS IN OVERBURDEN GROUNDWATER
■	BENZENE UNDETECTED IN OVERBURDEN GROUNDWATER
GWQS	NEW JERSEY GROUNDWATER QUALITY STANDARD

NOTES:

1. MAP SOURCE: "SITE PLAN DEPICTING TOPOGRAPHIC FEATURES," RINGWOOD MINES/LANDFILL SITE, SITE RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT, MAP LATEST REVISION DATE 11/24/14.
2. AUGUST 2016 DATA ARE REPRESENTATIVE OF DISTRIBUTION OF BENZENE AT THE SITE IN OVERBURDEN GROUNDWATER.
3. FOR ADDITIONAL DATA DETAILS SEE THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT (ARCADIS, 2015) AND THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT ADDENDUM (CORNERSTONE, 2017).

0 400 800
SCALE IN FEET

Gary J. DiPippo, Professional Engineer

10/1/19

N.J.P.E. Lic. No. 24GE02646100 Date

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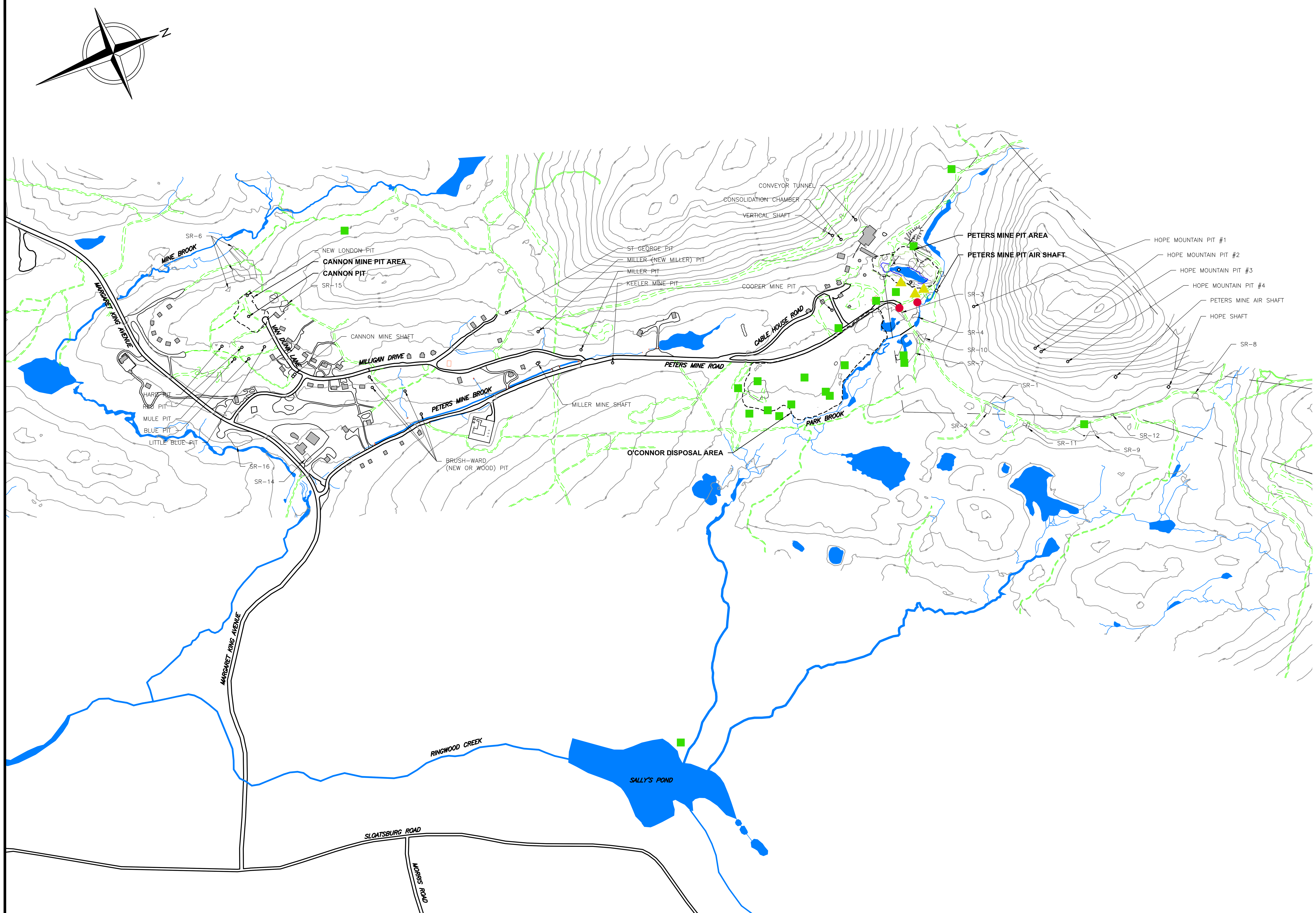
RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

OVERBURDEN GROUNDWATER BENZENE DETECTION MAP

(AUGUST 2016 DATA)

FIGURE NO. 5

PROJECT NO. 170101



LEGEND:

STATE PARK BOUNDARY

1360 — EXISTING INDEX CONTOUR

EXISTING BUILDING

EXISTING EDGE OF PAVED ROAD

EXISTING EDGE OF GRAVEL ROAD

EXISTING WATER COURSE

EXISTING WATER BODY

SR-1 — LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS

CHLOROETHANE >IGGWQC IN OVERBURDEN GROUNDWATER

CHLOROETHANE <IGGWQC IN OVERBURDEN GROUNDWATER

CHLOROETHANE UNDETECTED IN OVERBURDEN GROUNDWATER

IGGWQC — NEW JERSEY INTERIM GENERIC GROUNDWATER QUALITY CRITERION (SEE NOTE 4)

NOTES:

1. MAP SOURCE: "SITE PLAN DEPICTING TOPOGRAPHIC FEATURES," RINGWOOD MINES/LANDFILL SITE, SITE RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT, MAP LATEST REVISION DATE 11/24/14.
2. AUGUST 2016 DATA ARE REPRESENTATIVE OF DISTRIBUTION OF CHLOROETHANE AT THE SITE IN OVERBURDEN GROUNDWATER.
3. FOR ADDITIONAL DATA DETAILS SEE THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT (ARCADIS, 2015) AND THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT ADDENDUM (CORNERSTONE, 2017).
4. AS AN ADDITIONAL POINT OF COMPARISON, THE USEPA REGIONAL SCREENING LEVEL (RSL) FOR TAP WATER IS 21,000 ug/l. ALL DETECTIONS ARE LESS THAN THE RSL.

Gary J. DiPippo, Professional Engineer

10/1/19

N.J.P.E. Lic. No. 24GE02646100 Date

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RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

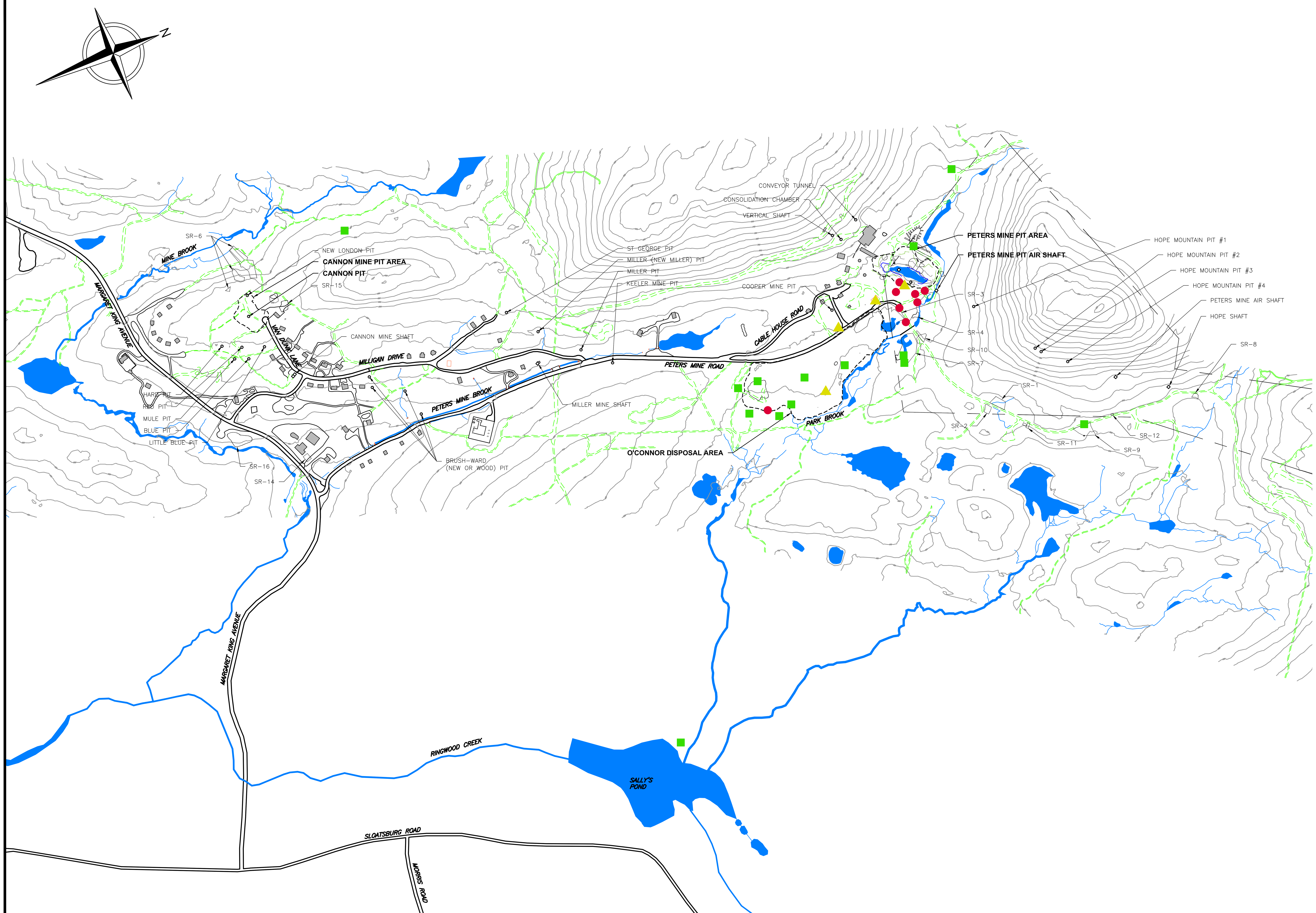
OVERBURDEN GROUNDWATER CHLOROETHANE DETECTION MAP

(AUGUST 2016 DATA)

FIGURE NO. 6

PROJECT NO. 170101

File: K:\PROJECTS\FORD MOTOR COMPANY\170101 - REDESIGN SAMPLING CTW_Project Drawings\170101-FS-06-OVERBURDEN CHLOROETHANE MAP.dwg Layout: FIGURE 6 User: sam.wilzenegger Sep 28, 2018 - 3:28pm



LEGEND:

Dashed line	STATE PARK BOUNDARY
1360	EXISTING INDEX CONTOUR
	EXISTING BUILDING
	EXISTING EDGE OF PAVED ROAD
	EXISTING EDGE OF GRAVEL ROAD
	EXISTING WATER COURSE
	EXISTING WATER BODY
SR-1	LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
Red circle	1,4-DIOXANE >ISGWQS IN OVERBURDEN GROUNDWATER
Yellow triangle	1,4-DIOXANE <ISGWQS IN OVERBURDEN GROUNDWATER
Green square	1,4-DIOXANE UNDETECTED IN OVERBURDEN GROUNDWATER
ISGWQS	NEW JERSEY INTERIM SPECIFIC GROUNDWATER QUALITY STANDARD

NOTES:

1. MAP SOURCE: "SITE PLAN DEPICITING TOPOGRAPHIC FEATURES," RINGWOOD MINES/LANDFILL SITE, SITE RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT, MAP LATEST REVISION DATE 11/24/14.
2. AUGUST 2016 DATA ARE REPRESENTATIVE OF DISTRIBUTION OF 1,4-DIOXANE AT THE SITE IN OVERBURDEN GROUNDWATER.
3. FOR ADDITIONAL DATA DETAILS SEE THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT (ARCADIS, 2015) AND THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT ADDENDUM (CORNERSTONE, 2017).

Gary J. DiPippo, Professional Engineer

N.J.P.E. Lic. No. 24GE02646100 Date 10/1/19

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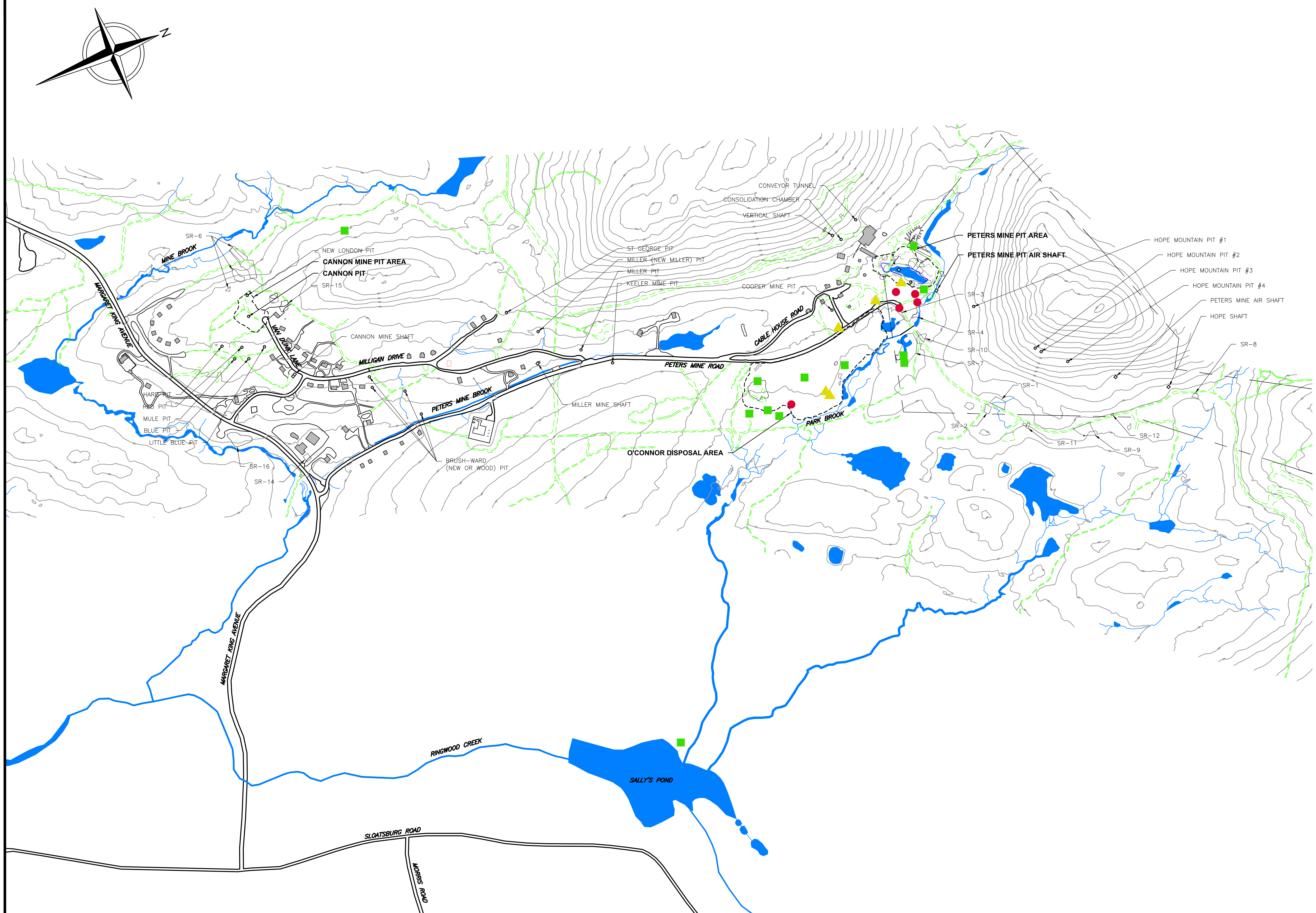
RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

OVERBURDEN GROUNDWATER 1,4-DIOXANE DETECTION MAP

(AUGUST 2016 DATA)

FIGURE NO. 7

PROJECT NO. 170101



LEGEND:

(long dash line)	STATE PARK BOUNDARY
1360	EXISTING INDEX CONTOUR
(grey shape)	EXISTING BUILDING
(double black line)	EXISTING EDGE OF PAVED ROAD
(double green dashed line)	EXISTING EDGE OF GRAVEL ROAD
(blue line)	EXISTING WATER COURSE
(blue band)	EXISTING WATER BODY
SR-1	LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
(red circle)	ARSENIC >GWQS IN OVERBURDEN GROUNDWATER
(yellow triangle)	ARSENIC <GWQS IN OVERBURDEN GROUNDWATER
(green square)	ARSENIC UNDETECTED IN OVERBURDEN GROUNDWATER
GWQS	NEW JERSEY GROUNDWATER QUALITY STANDARD

NOTES:

1. MAP SOURCE: "SITE PLAN DEPICITING TOPOGRAPHIC FEATURES," RINGWOOD MINES/LANDFILL SITE, SITE RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT, MAP LATEST REVISION DATE 11/24/14.
2. AUGUST 2016 DATA ARE REPRESENTATIVE OF DISTRIBUTION OF ARSENIC AT THE SITE IN OVERBURDEN GROUNDWATER.
3. FOR ADDITIONAL DATA DETAILS SEE THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT (ARCADIS, 2015) AND THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT ADDENDUM (CORNERSTONE, 2017).

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Gary J. DiPippo, Professional Engineer
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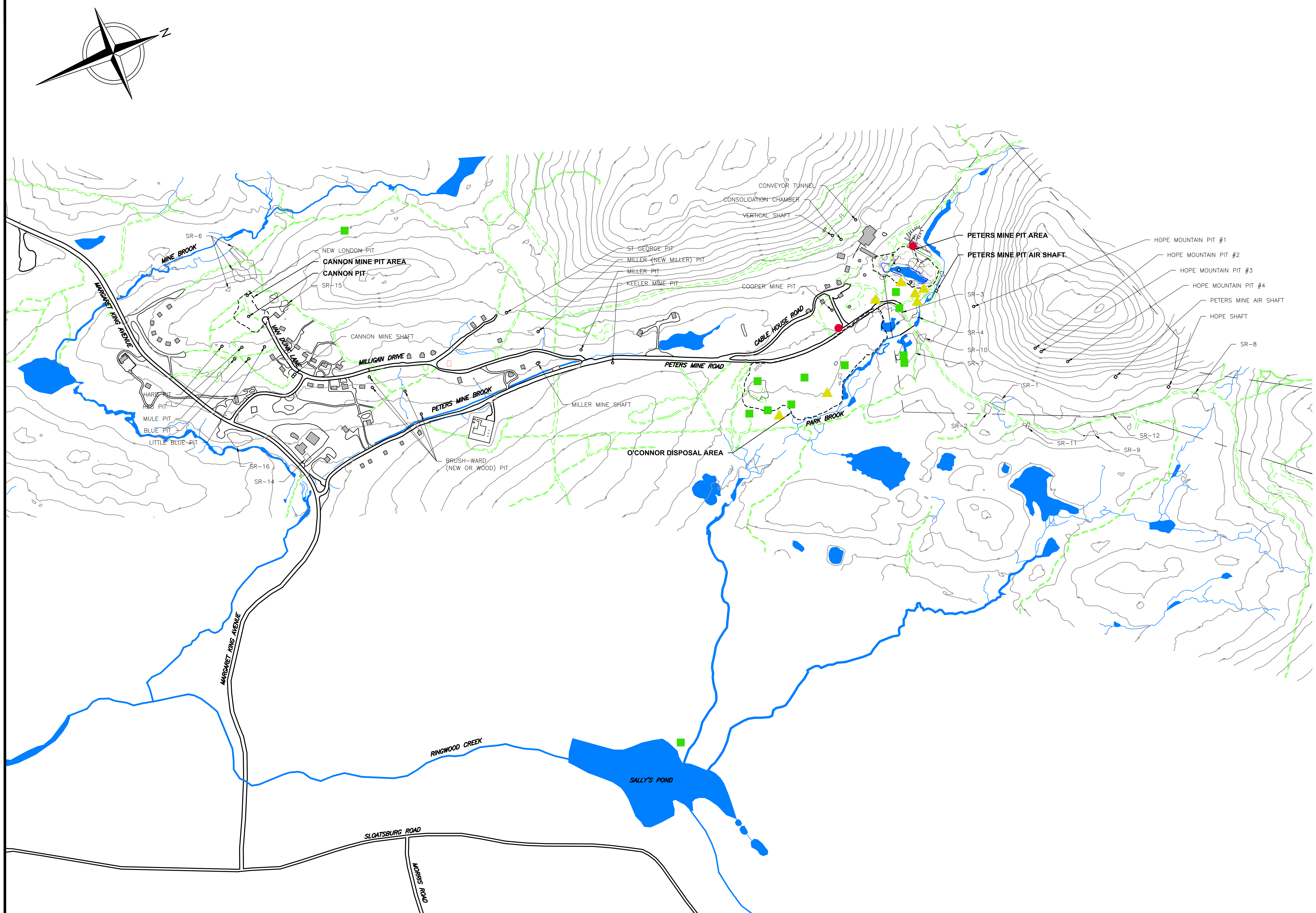
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

OVERBURDEN GROUNDWATER TOTAL ARSENIC DETECTION MAP

(AUGUST 2016 DATA)

FIGURE NO.
8
PROJECT NO.
170101



LEGEND:

- STATE PARK BOUNDARY
- 1360 — EXISTING INDEX CONTOUR
- EXISTING BUILDING
- EXISTING EDGE OF PAVED ROAD
- EXISTING EDGE OF GRAVEL ROAD
- EXISTING WATER COURSE
- EXISTING WATER BODY
- SR-1 — LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
- LEAD >GWQS LIMIT IN OVERBURDEN GROUNDWATER
- LEAD <GWQS LIMIT IN OVERBURDEN GROUNDWATER
- LEAD UNDETECTED IN OVERBURDEN GROUNDWATER
- GWQS — NEW JERSEY GROUNDWATER QUALITY STANDARD

NOTES:

1. MAP SOURCE: "SITE PLAN DEPICITING TOPOGRAPHIC FEATURES," RINGWOOD MINES/LANDFILL SITE, SITE RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT, MAP LATEST REVISION DATE 11/24/14.
2. AUGUST 2016 DATA ARE REPRESENTATIVE OF DISTRIBUTION OF LEAD AT THE SITE IN OVERBURDEN GROUNDWATER.
3. FOR ADDITIONAL DATA DETAILS SEE THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT (ARCADIS, 2015) AND THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT ADDENDUM (CORNERSTONE, 2017).

Gary J. DiPippo, Professional Engineer
Gary J DiPippo 10/1/19
N.J.P.E. Lic. No. 24GE02646100 Date

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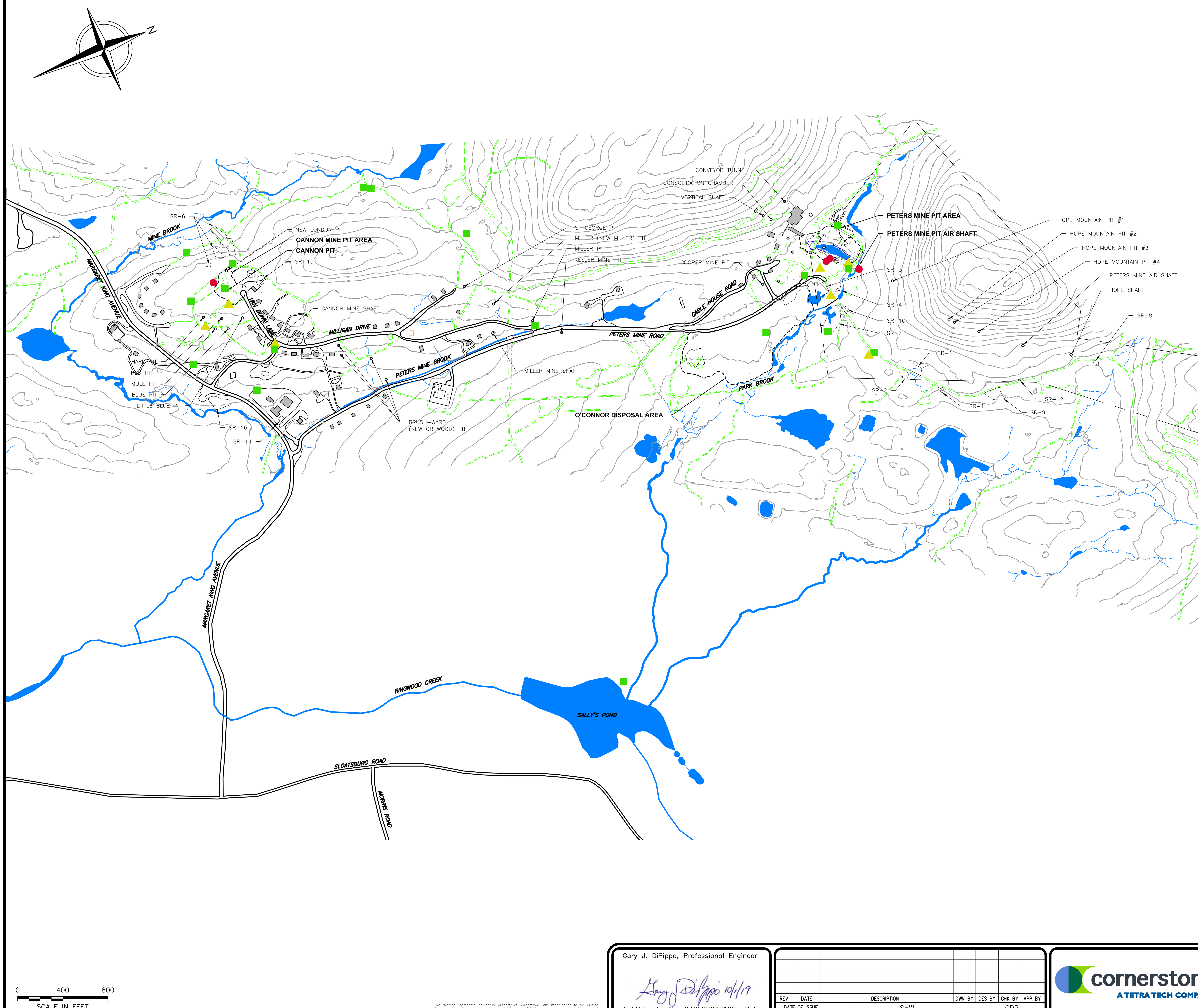
RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

OVERBURDEN GROUNDWATER TOTAL LEAD DETECTION MAP

(AUGUST 2016 DATA)

FIGURE NO. 9

PROJECT NO. 170101



LEGEND:

	STATE PARK BOUNDARY
1360	EXISTING INDEX CONTOUR
	EXISTING BUILDING
	EXISTING EDGE OF PAVED ROAD
	EXISTING EDGE OF GRAVEL ROAD
	EXISTING WATER COURSE
	EXISTING WATER BODY
SR-1	LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
	BENZENE >GWQS IN BEDROCK GROUNDWATER
	BENZENE <GWQS IN BEDROCK GROUNDWATER
	BENZENE UNDETECTED IN BEDROCK GROUNDWATER
GWQS	NEW JERSEY GROUNDWATER QUALITY STANDARD

NOTES:

1. MAP SOURCE: "SITE PLAN DEPICTING TOPOGRAPHIC FEATURES," RINGWOOD MINES/LANDFILL SITE, SITE RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT, MAP LATEST REVISION DATE 11/24/14.
2. ROCK WELL CLUSTERS ARE SHOWN AS A SINGLE LOCATION.
3. AUGUST 2016 DATA ARE REPRESENTATIVE OF DISTRIBUTION OF BENZENE AT THE SITE IN BEDROCK GROUNDWATER.
4. FOR ADDITIONAL DATA DETAILS SEE THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT (ARCADIS, 2015) AND THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT ADDENDUM (CORNERSTONE, 2017).

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10/1/19
N.J.P.E. Lic. No. 24GE02646100 Date

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GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

BEDROCK GROUNDWATER BENZENE DETECTION MAP

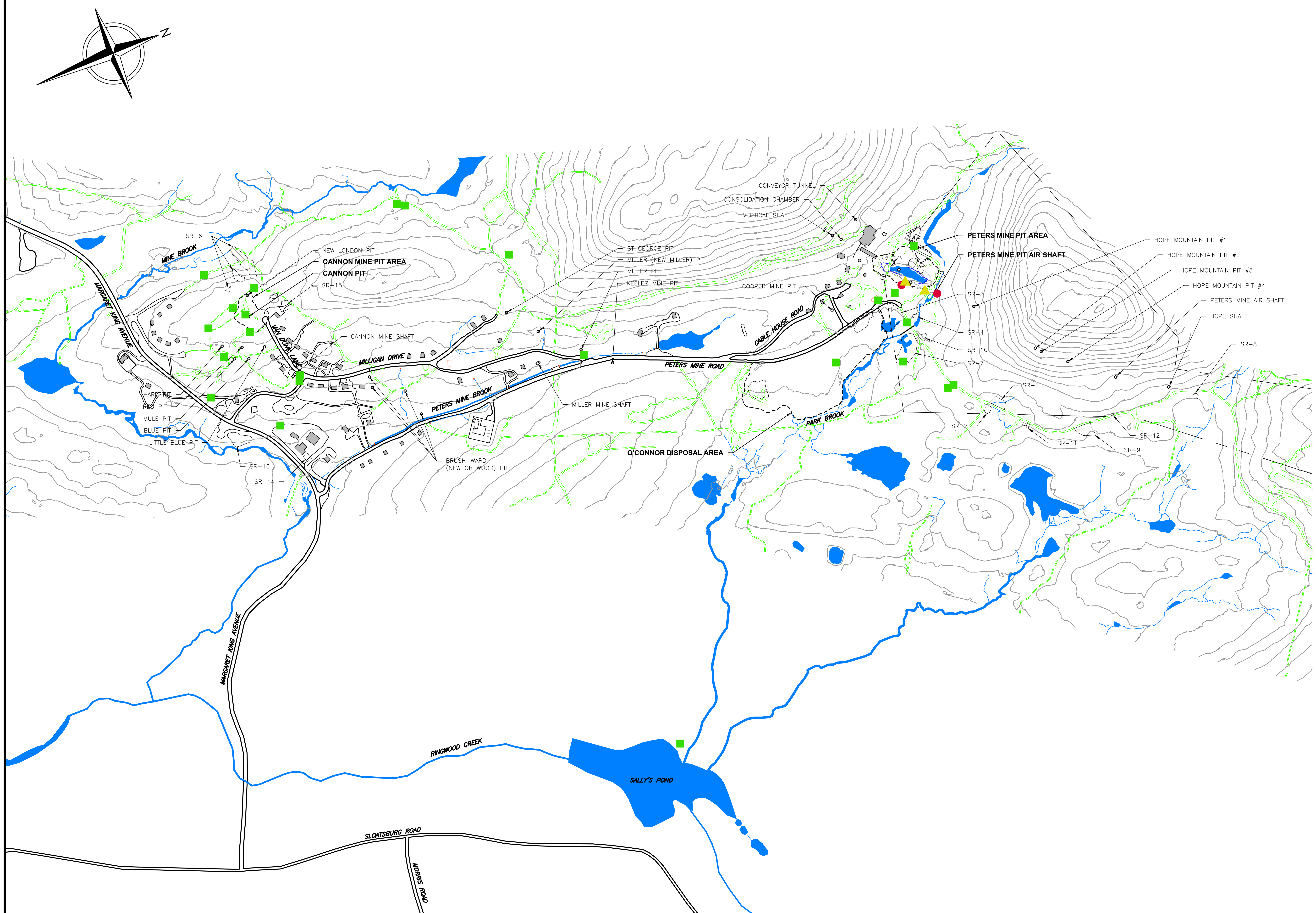
(AUGUST 2016 DATA)

FIGURE NO.
10

PROJECT NO.
170101

1" 1/2" 0" 1"

File: X:\PROJECTS\FORD MOTOR COMPANY\170101 - REDESIGN SAMPLING CTM_Project Drawings\170101-FS-10-BEDROCK BENZENE MAP.dwg Layout: FIGURE 10 User: sam.waizenegger Sep 28, 2018 - 3:29pm



LEGEND:

	STATE PARK BOUNDARY
1360	EXISTING INDEX CONTOUR
	EXISTING BUILDING
	EXISTING EDGE OF PAVED ROAD
	EXISTING EDGE OF GRAVEL ROAD
	EXISTING WATER COURSE
	EXISTING WATER BODY
SR–1	LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
● (red)	CHLOROETHANE >IGGWQC IN BEDROCK GROUNDWATER
▲ (yellow)	CHLOROETHANE <IGGWQC IN BEDROCK GROUNDWATER
■ (green)	CHLOROETHANE UNDETECTED IN BEDROCK GROUNDWATER
IGGWQC	NEW JERSEY INTERIM GENERIC GROUNDWATER QUALITY CRITERION (SEE NOTE 5)

NOTES:

1. MAP SOURCE: "SITE PLAN DEPICITING TOPOGRAPHIC FEATURES," RINGWOOD MINES/LANDFILL SITE, SITE RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT, MAP LATEST REVISION DATE 11/24/14.
2. ROCK WELL CLUSTERS ARE SHOWN AS A SINGLE LOCATION.
3. AUGUST 2016 DATA ARE REPRESENTATIVE OF DISTRIBUTION OF CHLOROETHANE AT THE SITE IN BEDROCK GROUNDWATER.
4. FOR ADDITIONAL DATA DETAILS SEE THE SITE–RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT (ARCADIS, 2015) AND THE SITE–RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT ADDENDUM (CORNERSTONE, 2017).
5. AS AN ADDITIONAL POINT OF COMPARISON, THE USEPA REGIONAL SCREENING LEVEL (RSL) FOR TAP WATER IS 21,000 ug/l. ALL DETECTIONS ARE LESS THAN THE RSL.

0 400 800
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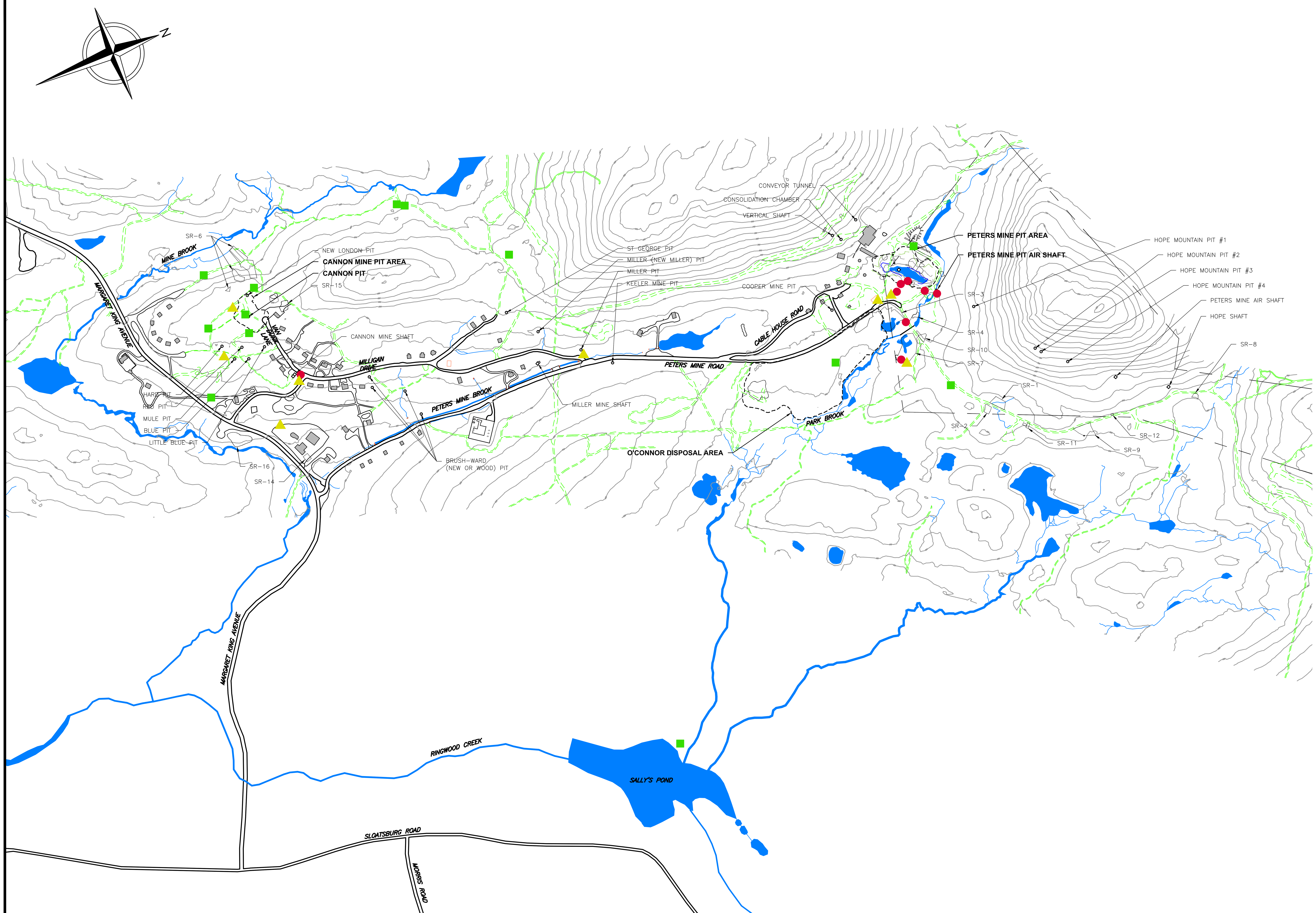
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

BEDROCK GROUNDWATER CHLOROETHANE DETECTION MAP

(AUGUST 2016 DATA)

FIGURE NO. **11**

PROJECT NO. 170101



0 400 800
SCALE IN FEET

LEGEND:

- STATE PARK BOUNDARY
- 1360 — EXISTING INDEX CONTOUR
- EXISTING BUILDING
- EXISTING EDGE OF PAVED ROAD
- EXISTING EDGE OF GRAVEL ROAD
- EXISTING WATER COURSE
- EXISTING WATER BODY
- SR-1 — LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
- ● 1,4-DIOXANE >ISGWQS IN BEDROCK GROUNDWATER
- ▲ 1,4-DIOXANE <ISGWQS IN BEDROCK GROUNDWATER
- ■ 1,4-DIOXANE UNDETECTED IN BEDROCK GROUNDWATER
- ISGWQS — NEW JERSEY INTERIM SPECIFIC GROUNDWATER QUALITY STANDARD

NOTES:

1. MAP SOURCE: "SITE PLAN DEPICITING TOPOGRAPHIC FEATURES," RINGWOOD MINES/LANDFILL SITE, SITE RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT, MAP LATEST REVISION DATE 11/24/14.
2. ROCK WELL CLUSTERS ARE SHOWN AS A SINGLE LOCATION.
3. AUGUST 2016 DATA ARE REPRESENTATIVE OF DISTRIBUTION OF 1,4-DIOXANE AT THE SITE IN BEDROCK GROUNDWATER.
4. FOR ADDITIONAL DATA DETAILS SEE THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT (ARCADIS, 2015) AND THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT ADDENDUM (CORNERSTONE, 2017).

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Gary J DiPippo 10/1/19
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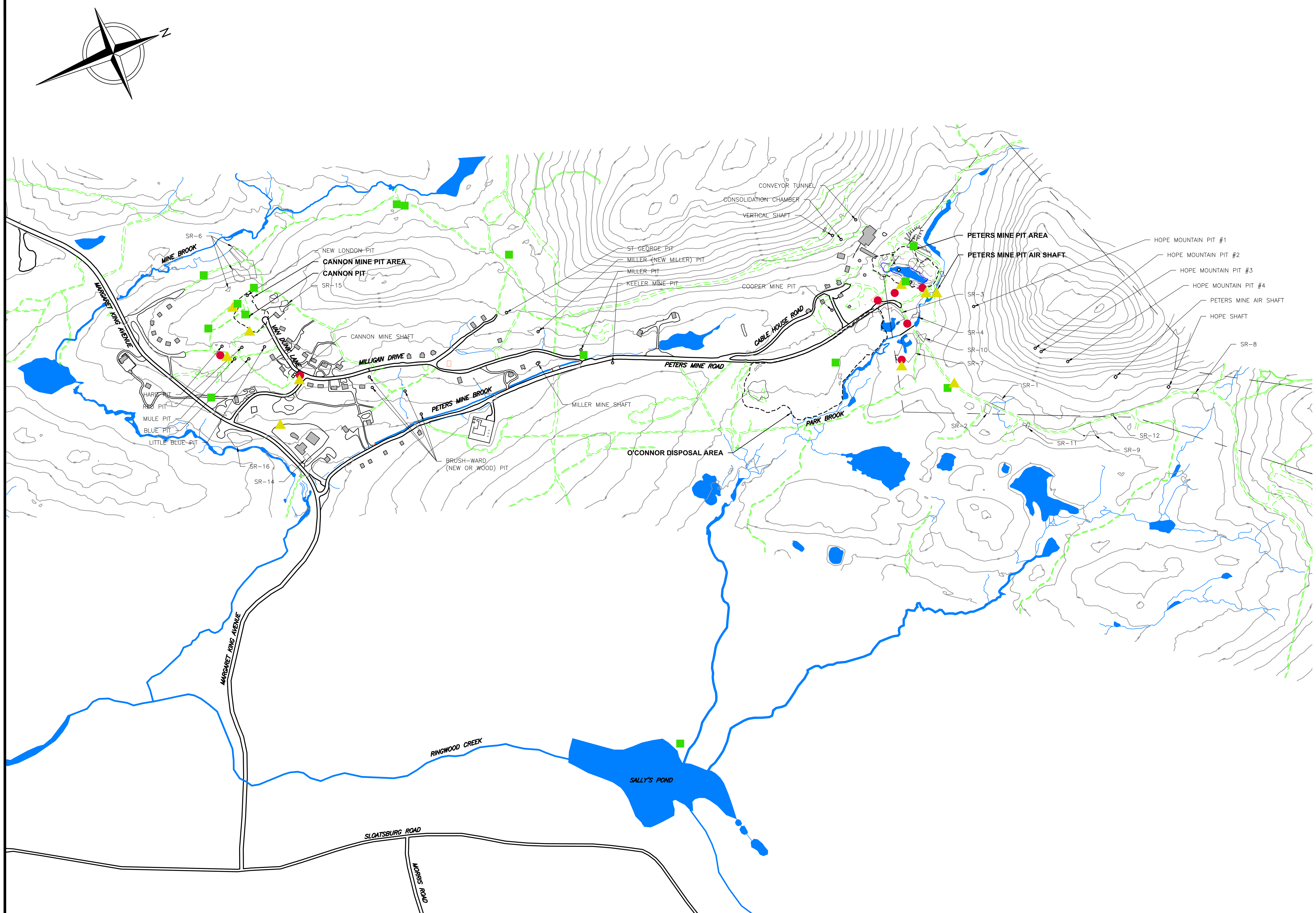
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

BEDROCK GROUNDWATER 1,4-DIOXANE DETECTION MAP
(AUGUST 2016 DATA)

FIGURE NO. 12
PROJECT NO. 170101



0 400 800
SCALE IN FEET

LEGEND:

- STATE PARK BOUNDARY
- 1360 EXISTING INDEX CONTOUR
- EXISTING BUILDING
- EXISTING EDGE OF PAVED ROAD
- EXISTING EDGE OF GRAVEL ROAD
- EXISTING WATER COURSE
- EXISTING WATER BODY
- SR-1 LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
- ARSENIC >GWQS LIMIT IN BEDROCK GROUNDWATER
- ARSENIC <GWQS LIMIT IN BEDROCK GROUNDWATER
- ARSENIC UNDETECTED IN BEDROCK GROUNDWATER
- GWQS NEW JERSEY GROUNDWATER QUALITY STANDARD

NOTES:

1. MAP SOURCE: "SITE PLAN DEPICITING TOPOGRAPHIC FEATURES," RINGWOOD MINES/LANDFILL SITE, SITE RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT, MAP LATEST REVISION DATE 11/24/14.
2. ROCK WELL CLUSTERS ARE SHOWN AS A SINGLE LOCATION.
3. AUGUST 2016 DATA ARE REPRESENTATIVE OF DISTRIBUTION OF ARSENIC AT THE SITE IN BEDROCK GROUNDWATER.
4. FOR ADDITIONAL DATA DETAILS SEE THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT (ARCADIS, 2015) AND THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT ADDENDUM (CORNERSTONE, 2017).

Gary J. DiPippo, Professional Engineer
Gary J DiPippo 10/1/19
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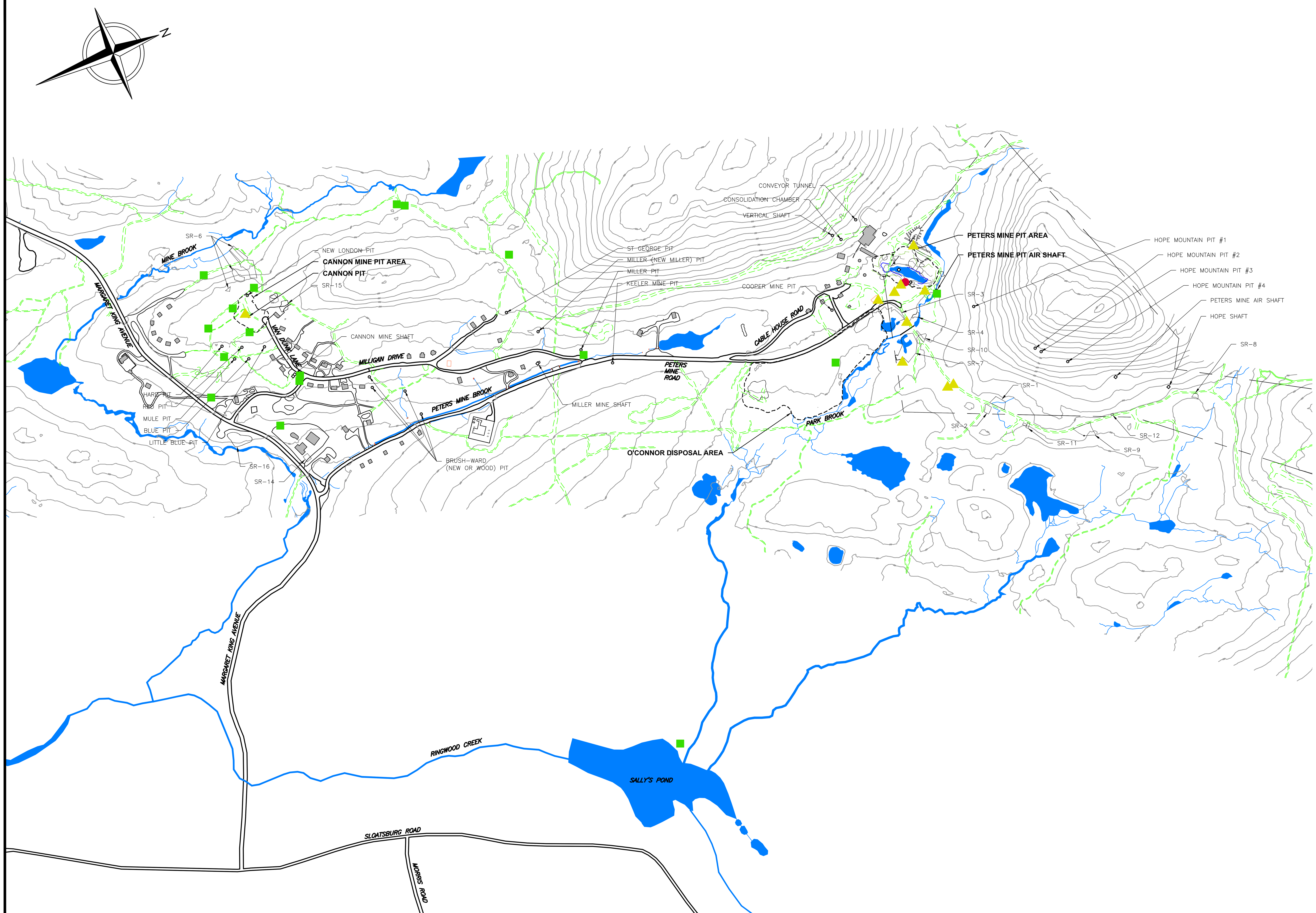
RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

BEDROCK GROUNDWATER TOTAL ARSENIC DETECTION MAP

(AUGUST 2016 DATA)

FIGURE NO.
13
PROJECT NO.
170101



LEGEND:

(long dash line)	STATE PARK BOUNDARY
1360	EXISTING INDEX CONTOUR
(grey shape)	EXISTING BUILDING
(double black line)	EXISTING EDGE OF PAVED ROAD
(green dashed line)	EXISTING EDGE OF GRAVEL ROAD
(blue line)	EXISTING WATER COURSE
(blue fill)	EXISTING WATER BODY
SR-1	LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
(red dot)	LEAD >GWQS IN BEDROCK GROUNDWATER
(yellow triangle)	LEAD <GWQS LIMIT IN BEDROCK GROUNDWATER
(green square)	LEAD UNDETECTED IN BEDROCK GROUNDWATER
GWQS	NEW JERSEY GROUNDWATER QUALITY STANDARD

NOTES:

1. MAP SOURCE: "SITE PLAN DEPICITING TOPOGRAPHIC FEATURES," RINGWOOD MINES/LANDFILL SITE, SITE RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT, MAP LATEST REVISION DATE 11/24/14.
2. ROCK WELL CLUSTERS ARE SHOWN AS A SINGLE LOCATION.
3. AUGUST 2016 DATA ARE REPRESENTATIVE OF DISTRIBUTION OF LEAD AT THE SITE IN BEDROCK GROUNDWATER.
4. FOR ADDITIONAL DATA DETAILS SEE THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT (ARCADIS, 2015) AND THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT ADDENDUM (CORNERSTONE, 2017).

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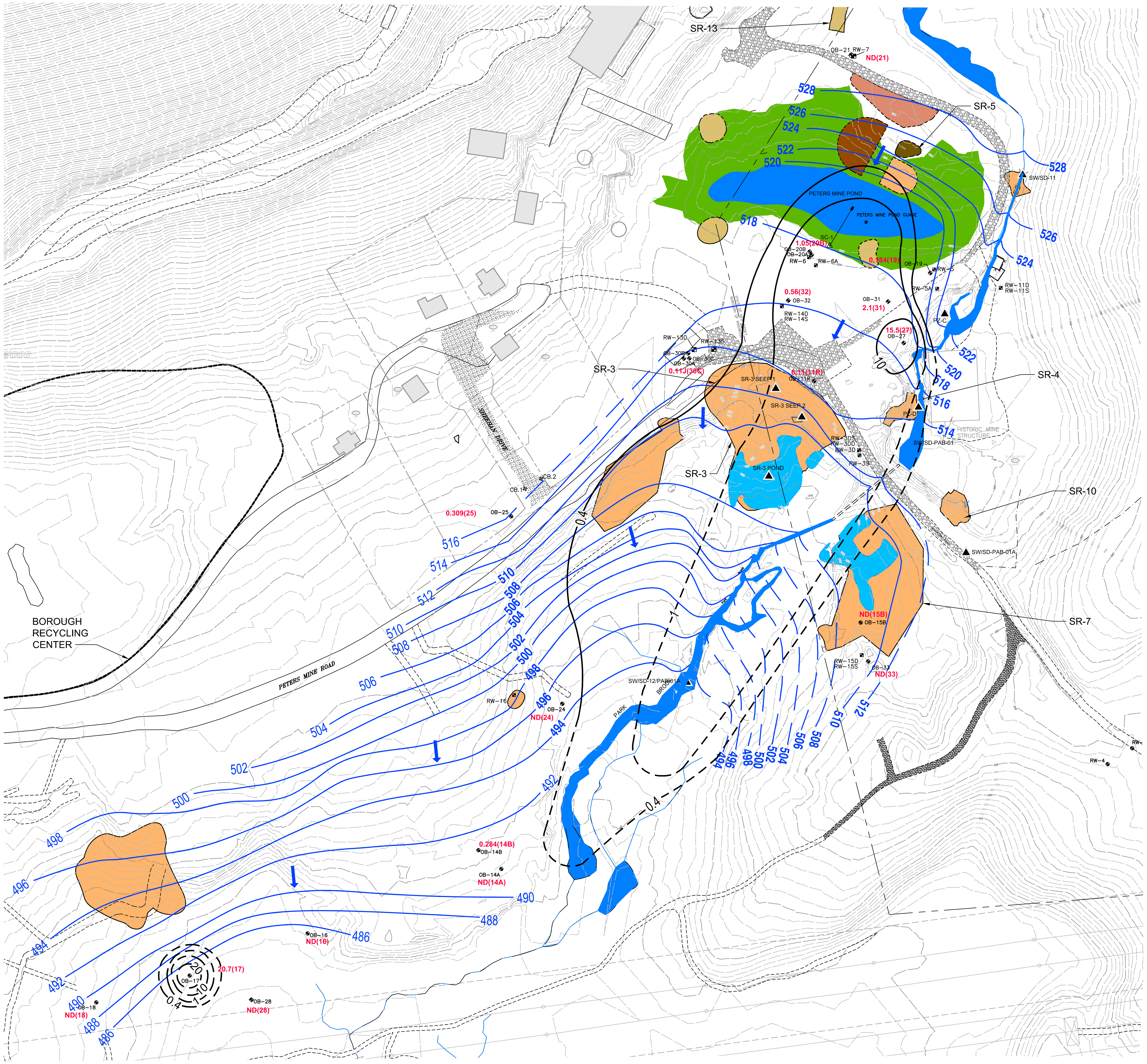
RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

BEDROCK GROUNDWATER TOTAL LEAD DETECTION MAP
(AUGUST 2016 DATA)

FIGURE NO.
14
PROJECT NO.
170101

File: K:\PROJECTS\FORD MOTOR COMPANY\170101 - BEDROCK SAMPLING CTM_Project Drawings\170101-FS-14-BEDROCK LEAD MAP.dwg Layout: FIGURE 14 User: sam-wolzenegger Sep 28, 2018 - 3:30pm

1" 1/2" 0" 1"



LEGEND:

530	EXISTING CONTOUR
OB-19	OVERBURDEN MONITORING WELL
RW-5	BEDROCK MONITORING WELL
2.1(33)	1,4- DIOXANE CONCENTRATION (WELL #)
1	1,4- DIOXANE ISOCONCENTRATION LINE (DASHED WHERE INFERRED)
505	GROUNDWATER ELEVATION CONTOUR – OVERBURDEN (DASHED WHERE INFERRED)
	GROUNDWATER FLOW DIRECTION OF OVERBURDEN
SW/SD-11	SURFACE WATER AND SEDIMENT – SAMPLE LOCATION/ STAFF GUAGE
SW/SD-PMB-01	SURFACE WATER AND SEDIMENT – SAMPLE LOCATION FROM PETERS MINE BROOK/ STAFF GUAGE
	APPROXIMATE LIMITS OF REMOVAL AREAS – SOIL, PAINT SLUDGE, AND DRUM REMNANTS
	APPROXIMATE LIMITS OF REMOVAL AREA – SOIL AND DRUM REMNANTS
	APPROXIMATE LIMITS OF REMOVAL AREA – SOIL, DRUMS, AND DRUM REMNANTS
	APPROXIMATE LIMITS OF REMOVAL AREAS – SOIL AND PAINT SLUDGE
	APPROXIMATE LIMITS OF SURFICIAL SOIL SCRAPING
	HISTORICAL FILL AREA SURROUNDING PETERS MINE POND (AREA 1)
	INDICATES VERNAL CONDITIONS TYPICALLY OBSERVED IN THE SPRING AND FALL SEASONS
	WATER BODY
	STREAM

NOTES:

1. ALL RESULTS IN ug/l.
2. ND = NOT DETECTED.
3. "J" = ESTIMATED VALUE.
4. ISOCONCENTRATION LINES MAPPED TO NJGWQS OF 0.4 mg/l.

0 60' 120'
GRAPHIC SCALE

Gary J. DiPippo, Professional Engineer
N.J.P.E. Lic. No. 24GE02646100 Date

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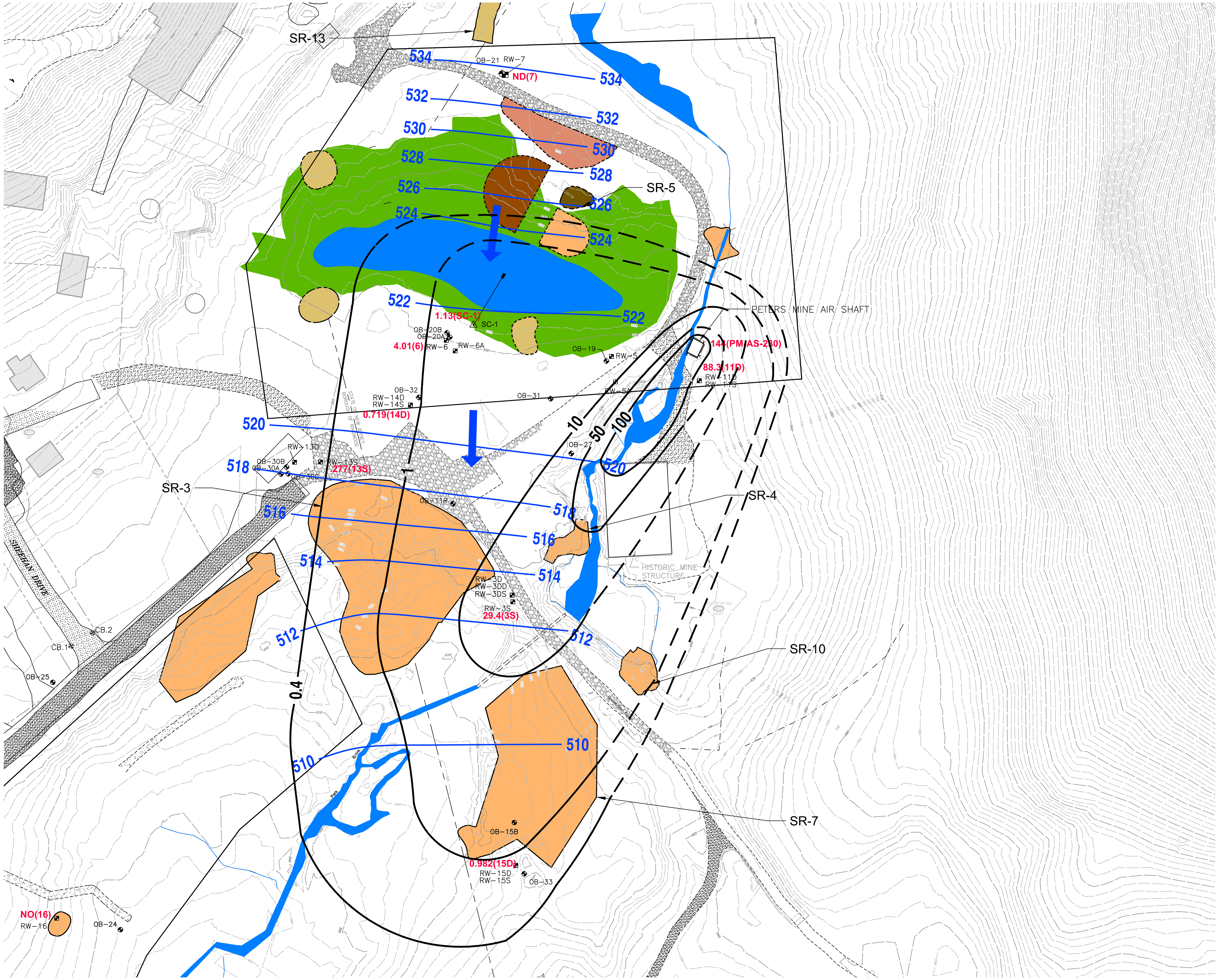
RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

OVERBURDEN GROUNDWATER 1,4 DIOXANE ISOCONCENTRATION MAP - AUGUST 2017 DATA

FIGURE NO. 15
PROJECT NO. 170101



LEGEND:

530	EXISTING CONTOUR
OB-27	OVERBURDEN MONITORING WELL
RW-5	BEDROCK MONITORING WELL
SC-1	DIRECTIONAL MONITORING WELL
4.01(6)	1,4- DIOXANE CONCENTRATION (WELL #)
1	1,4- DIOXANE ISOCONCENTRATION LINE (DASHED WHERE INFERRED)
520	GROUNDWATER ELEVATION CONTOUR – SHALLOW BEDROCK
	GROUNDWATER FLOW DIRECTION OF SHALLOW BEDROCK INTERVAL 100' (2-FT CONTOUR INTERVAL)
	APPROXIMATE LIMITS OF REMOVAL AREAS – SOIL, PAINT SLUDGE, AND DRUM REMNANTS
	APPROXIMATE LIMITS OF REMOVAL AREA – SOIL AND DRUM REMNANTS
	APPROXIMATE LIMITS OF REMOVAL AREA – SOIL, DRUMS, AND DRUM REMNANTS
	APPROXIMATE LIMITS OF REMOVAL AREAS – SOIL AND PAINT SLUDGE
	APPROXIMATE LIMITS OF SURFICIAL SOIL SCRAPING
	HISTORICAL FILL AREA SURROUNDING PETERS MINE POND (AREA 1)
	INDICATES VERNAL CONDITIONS TYPICALLY OBSERVED IN THE SPRING AND FALL SEASONS
	WATER BODY
	STREAM

NOTES:

1. ALL RESULTS IN ug/l.
2. ND = NOT DETECTED.
3. ISOCONCENTRATION LINES BASED ON MAXIMUM MEASURED 1,4-DIOXANE CONCENTRATION AT ANY DEPTH INTERVAL.
4. ISOCONCENTRATION LINES MAPPED TO NJGWQS OF 0.4 mg/l.

0 60' 120'
GRAPHIC SCALE

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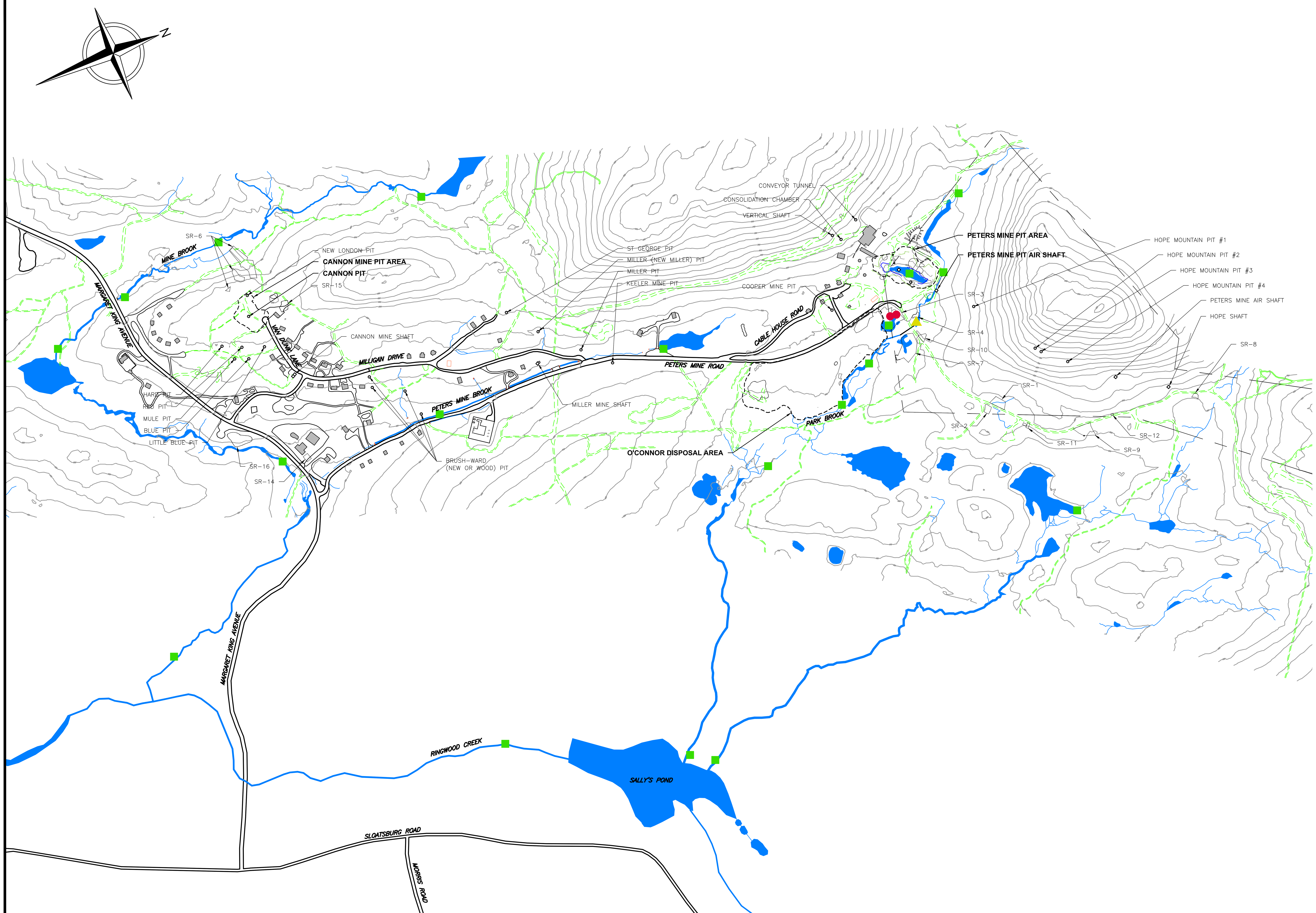
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

BEDROCK GROUNDWATER AND MINE WATER 1,4 DIOXANE ISOCONCENTRATION MAP - AUGUST 2017 DATA

FIGURE NO.
16
PROJECT NO.
170101



LEGEND:

STATE PARK BOUNDARY	
1360	EXISTING INDEX CONTOUR
	EXISTING BUILDING
	EXISTING EDGE OF PAVED ROAD
	EXISTING EDGE OF GRAVEL ROAD
	EXISTING WATER COURSE
	EXISTING WATER BODY
SR-1	LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
	BENZENE >SWQS IN SURFACE WATER
	BENZENE <SWQS IN SURFACE WATER
	BENZENE UNDETECTED IN SURFACE WATER
SWQS	NEW JERSEY SURFACE WATER QUALITY STANDARD

NOTES:

1. MAP SOURCE: "SITE PLAN DEPICTING TOPOGRAPHIC FEATURES," RINGWOOD MINES/LANDFILL SITE, SITE RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT, MAP LATEST REVISION DATE 11/24/14.
2. AUGUST 2016 DATA ARE REPRESENTATIVE OF DISTRIBUTION OF BENZENE AT THE SITE IN SURFACE WATER.
3. FOR ADDITIONAL DATA DETAILS SEE THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT (ARCADIS, 2015) AND THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT ADDENDUM (CORNERSTONE, 2017).

Gary J. DiPippo, Professional Engineer
10/1/19
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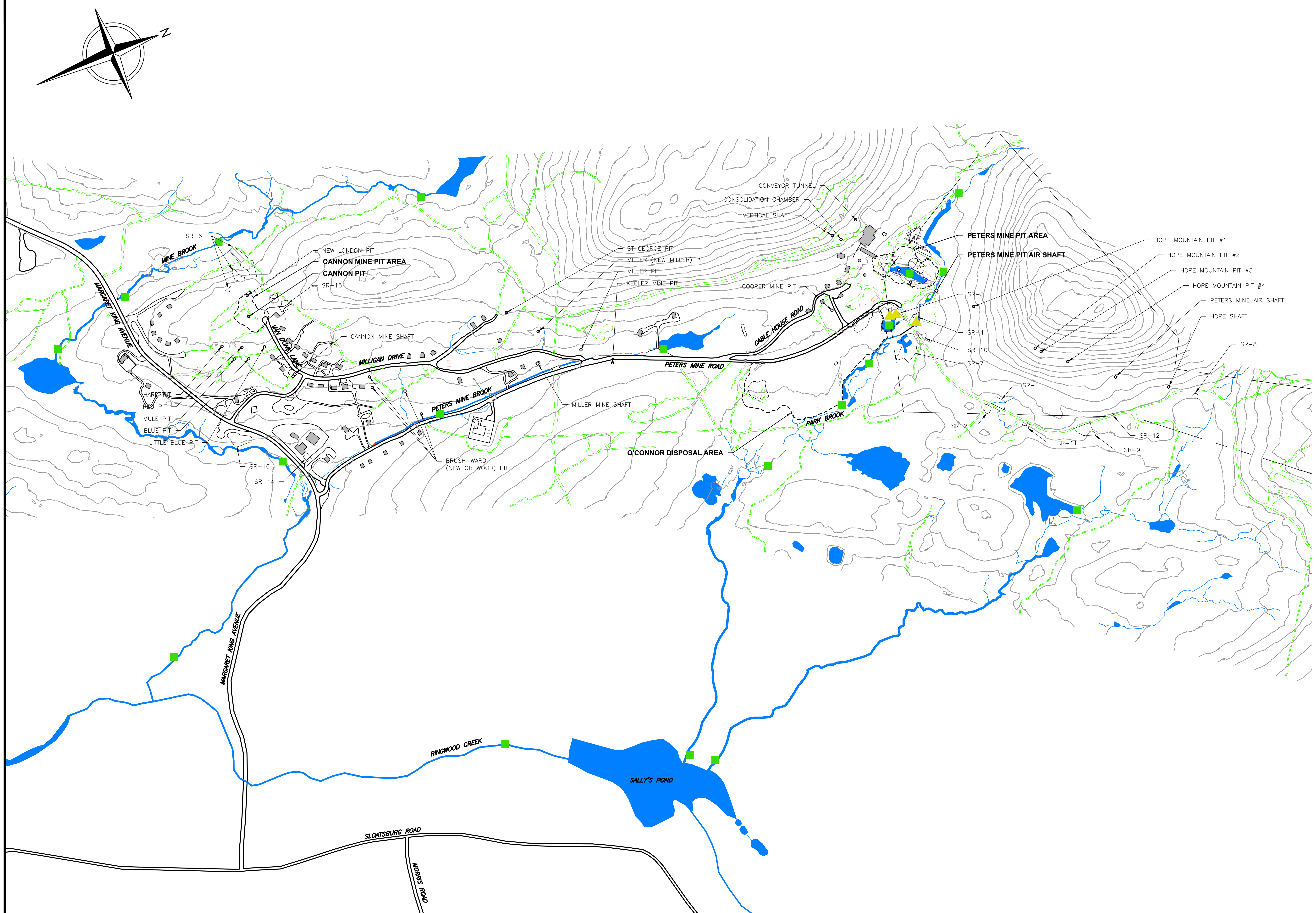
RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

SURFACE WATER BENZENE DETECTION MAP
(AUGUST 2016 DATA)

FIGURE NO. **17**
PROJECT NO. 170101

File: X:\PROJECTS\FORD MOTOR COMPANY\170101 - REDESIGN SAMPLING CTM_Project Drawings\170101-FS-17-SURFACE BENZENE MAP.dwg Layout: FIGURE 17 User: scm.wildenegger Sep 28, 2018 - 3:30pm



LEGEND:

- STATE PARK BOUNDARY
- EXISTING INDEX CONTOUR (1360)
- EXISTING BUILDING
- EXISTING EDGE OF PAVED ROAD
- EXISTING EDGE OF GRAVEL ROAD
- EXISTING WATER COURSE
- EXISTING WATER BODY
- SR-1 LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
- CHLOROETHANE DETECTED IN SURFACE WATER (SEE NOTE 3)
- CHLOROETHANE UNDETECTED IN SURFACE WATER (SEE NOTE 3)

NOTES:

1. MAP SOURCE: "SITE PLAN DEPICTING TOPOGRAPHIC FEATURES," RINGWOOD MINES/LANDFILL SITE, SITE RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT, MAP LATEST REVISION DATE 11/24/14.
2. AUGUST 2016 DATA ARE REPRESENTATIVE OF DISTRIBUTION OF CHLOROETHANE AT THE SITE IN SURFACE WATER.
3. NEW JERSEY DOES NOT HAVE A SURFACE WATER QUALITY STANDARD FOR CHLOROETHANE.
4. FOR ADDITIONAL DATA DETAILS SEE THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT (ARCADIS, 2015) AND THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT ADDENDUM (CORNERSTONE, 2017).
5. THE MAXIMUM CONCENTRATION OF CHLOROETHANE DETECTED IN SURFACE WATER IN AUGUST 2016 IS 4.1 ug/l AT THE SR-3 SEEP AREA.

Gary J. DiPippo, Professional Engineer
[signature] 10/1/19
N.J.P.E. Lic. No. 24GE02646100 Date

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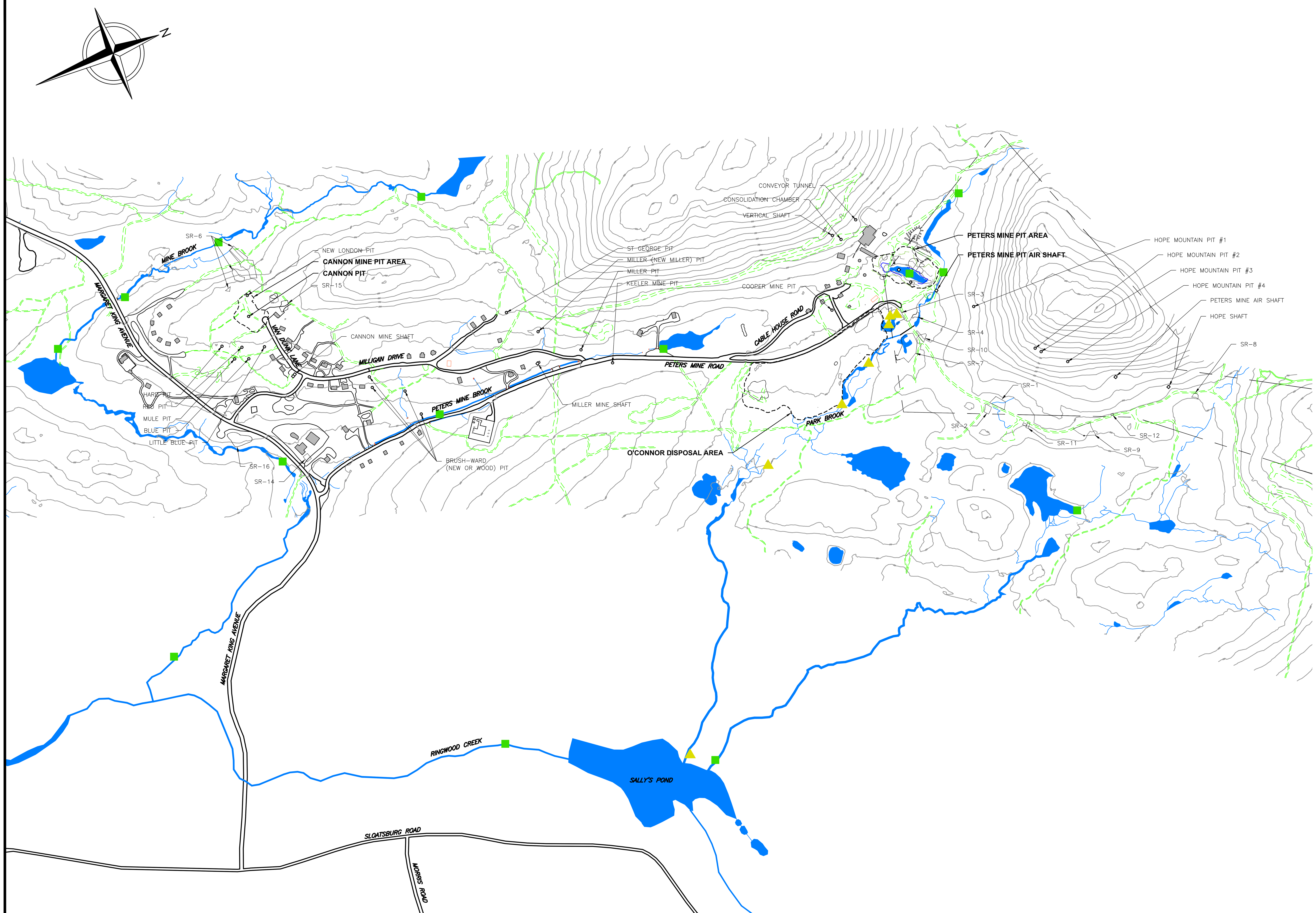
RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

SURFACE WATER CHLOROETHANE DETECTION MAP

(AUGUST 2016 DATA)

FIGURE NO. 18

PROJECT NO. 170101



LEGEND:

- STATE PARK BOUNDARY
- 1360 — EXISTING INDEX CONTOUR
- EXISTING BUILDING
- EXISTING EDGE OF PAVED ROAD
- EXISTING EDGE OF GRAVEL ROAD
- EXISTING WATER COURSE
- EXISTING WATER BODY
- SR-1 — LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
- 1,4-DIOXANE >EBSL IN SURFACE WATER
- 1,4-DIOXANE <EBSL IN SURFACE WATER
- 1,4-DIOXANE UNDETECTED IN SURFACE WATER
- EBSL — ECOLOGICALLY-BASED SCREENING LEVEL (SEE NOTE 4)

0 400 800
SCALE IN FEET

NOTES:

1. MAP SOURCE: "SITE PLAN DEPICTING TOPOGRAPHIC FEATURES," RINGWOOD MINES/LANDFILL SITE, SITE RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT, MAP LATEST REVISION DATE 11/24/14.
2. AUGUST 2016 DATA ARE REPRESENTATIVE OF DISTRIBUTION OF 1,4-DIOXANE AT THE SITE IN SURFACE WATER.
3. FOR ADDITIONAL DATA DETAILS SEE THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT (ARCADIS, 2015) AND THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT ADDENDUM (CORNERSTONE, 2017).
4. NEW JERSEY DOES NOT HAVE A SURFACE WATER QUALITY STANDARD FOR 1,4-DIOXANE. FOR THE PURPOSE OF COMPARING DETECTIONS AN ECOLOGICALLY-BASED SCREENING LEVEL (EBSL) OF 22,000 ug/l FROM THE MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY IS USED, WITH ESEPA CONCURRENCE.

Gary J. DiPippo, Professional Engineer
10/1/19
N.J.P.E. Lic. No. 24GE02646100 Date

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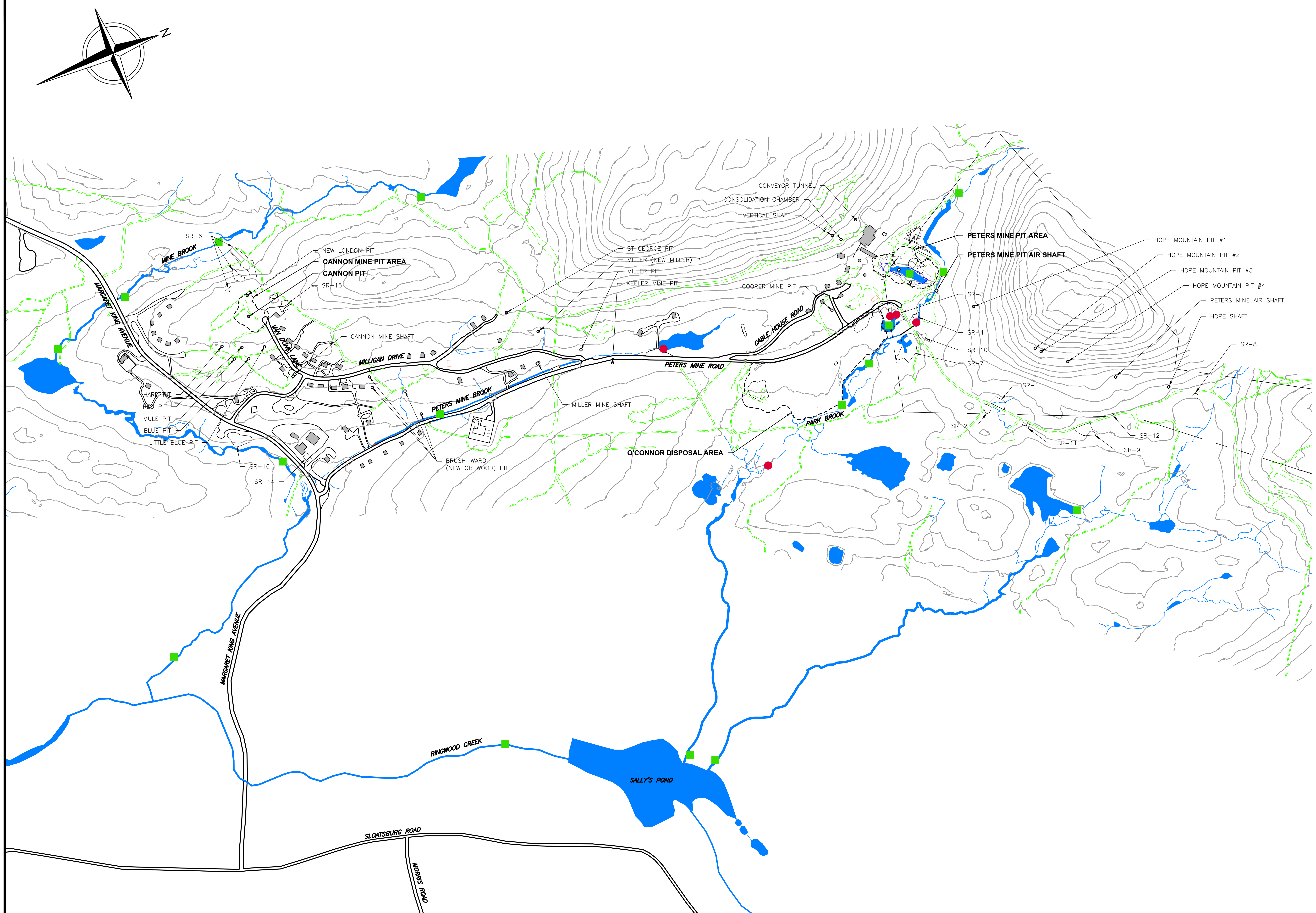
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

SURFACE WATER 1,4-DIOXANE DETECTION MAP

(AUGUST 2016 DATA)

FIGURE NO. **19**

PROJECT NO. 170101



0 400 800
SCALE IN FEET

LEGEND:

(heavy dashed line)	STATE PARK BOUNDARY
(line) 1360	EXISTING INDEX CONTOUR
(grey shape)	EXISTING BUILDING
(double line)	EXISTING EDGE OF PAVED ROAD
(green dashed lines)	EXISTING EDGE OF GRAVEL ROAD
(blue line)	EXISTING WATER COURSE
(blue band)	EXISTING WATER BODY
SR-1	LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
(red circle)	ARSENIC >SWQS IN SURFACE WATER
(yellow triangle)	ARSENIC <SWQS IN SURFACE WATER
(green square)	ARSENIC UNDETECTED IN SURFACE WATER
SWQS	NEW JERSEY SURFACE WATER QUALITY STANDARD

NOTES:

1. MAP SOURCE: "SITE PLAN DEPICTING TOPOGRAPHIC FEATURES," RINGWOOD MINES/LANDFILL SITE, SITE RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT, MAP LATEST REVISION DATE 11/24/14.
2. ROCK WELL CLUSTERS ARE SHOWN AS A SINGLE LOCATION.
3. AUGUST 2016 DATA ARE REPRESENTATIVE OF DISTRIBUTION OF ARSENIC AT THE SITE IN SURFACE WATER.
4. FOR ADDITIONAL DATA DETAILS SEE THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT (ARCADIS, 2015) AND THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT ADDENDUM (CORNERSTONE, 2017).

Gary J. DiPippo, Professional Engineer
10/1/19
N.J.P.E. Lic. No. 24GE02646100 Date

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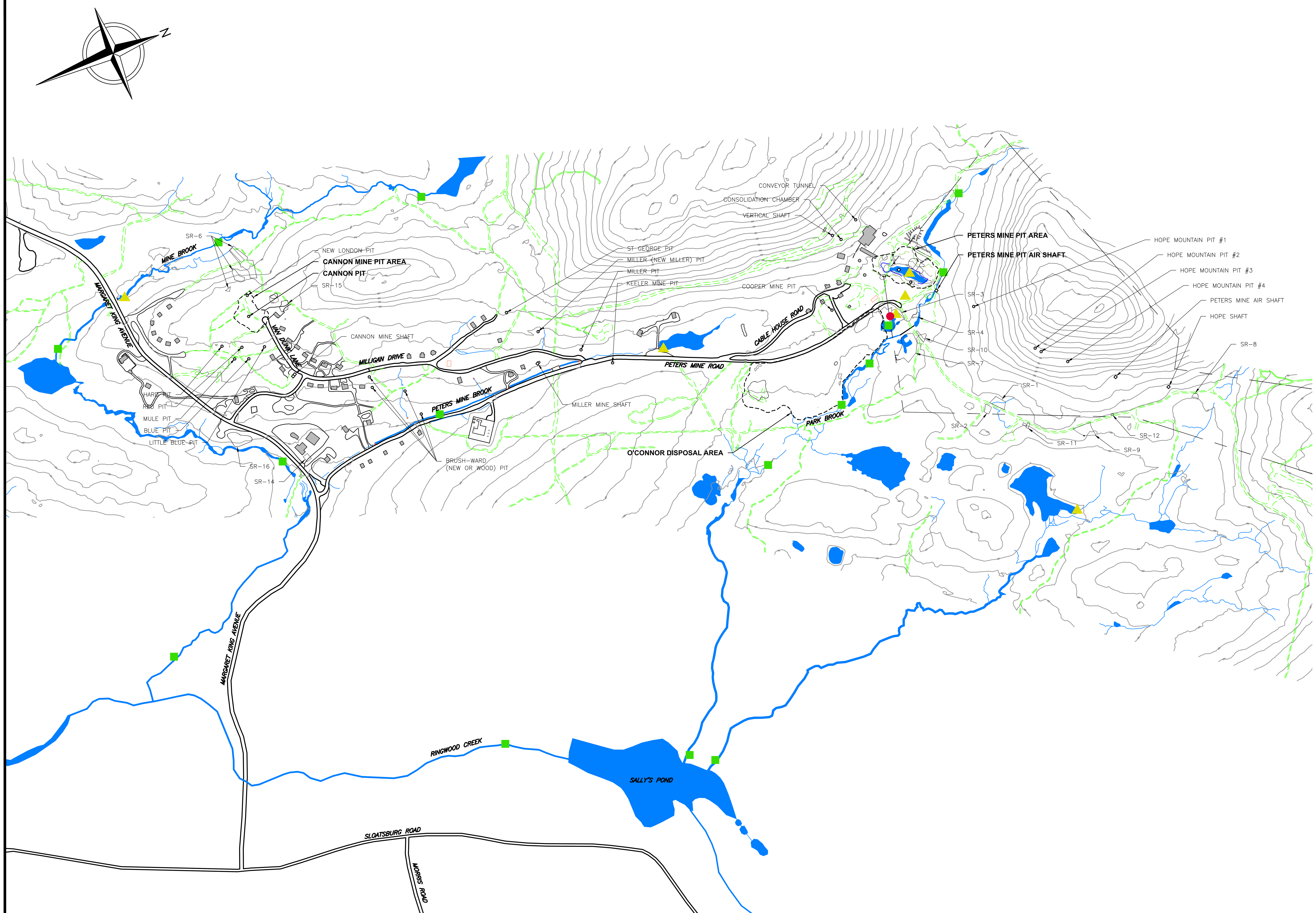
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

SURFACE WATER TOTAL ARSENIC DETECTION MAP

(AUGUST 2016 DATA)

FIGURE NO. 20

PROJECT NO. 170101



LEGEND:

(dashed line)	STATE PARK BOUNDARY
1360	EXISTING INDEX CONTOUR
(grey shape)	EXISTING BUILDING
(black line)	EXISTING EDGE OF PAVED ROAD
(green dashed line)	EXISTING EDGE OF GRAVEL ROAD
(blue line)	EXISTING WATER COURSE
(blue band)	EXISTING WATER BODY
SR-1	LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
(red circle)	LEAD >SWQS IN SURFACE WATER
(yellow triangle)	LEAD <SWQS IN SURFACE WATER
(green square)	LEAD UNDETECTED IN SURFACE WATER
SWQS	NEW JERSEY SURFACE WATER QUALITY STANDARD

NOTES:

1. MAP SOURCE: "SITE PLAN DEPICITING TOPOGRAPHIC FEATURES," RINGWOOD MINES/LANDFILL SITE, SITE RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT, MAP LATEST REVISION DATE 11/24/14.
2. AUGUST 2016 DATA ARE REPRESENTATIVE OF DISTRIBUTION OF LEAD AT THE SITE IN SURFACE WATER.
3. FOR ADDITIONAL DATA DETAILS SEE THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT (ARCADIS, 2015) AND THE SITE-RELATED GROUNDWATER REMEDIAL INVESTIGATION REPORT ADDENDUM (CORNERSTONE, 2017).

0 400 800
SCALE IN FEET

Gary J. DiPippo, Professional Engineer
10/1/19
N.J.P.E. Lic. No. 24GE02646100 Date

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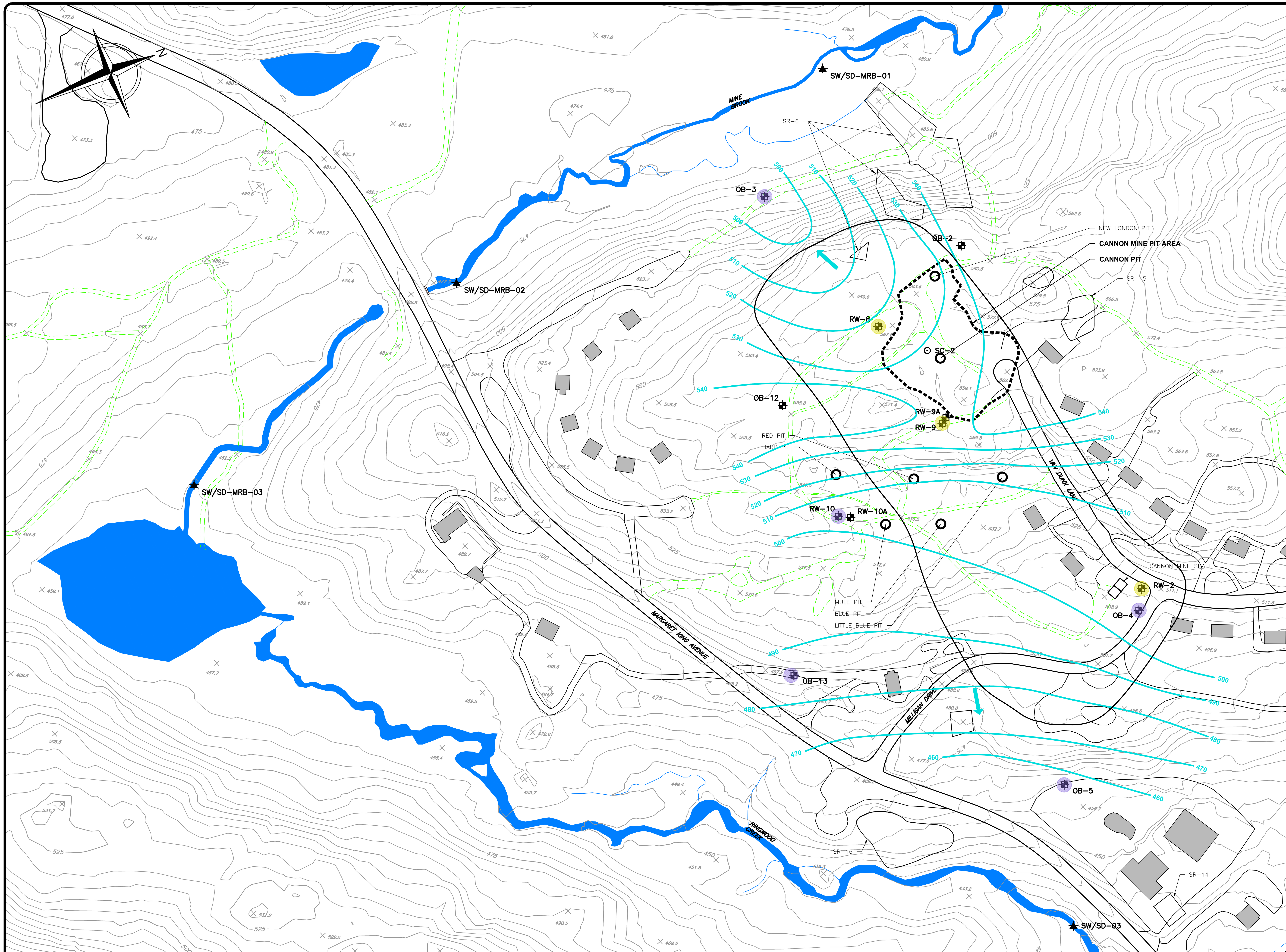
RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

SURFACE WATER TOTAL LEAD DETECTION MAP
(AUGUST 2016 DATA)

FIGURE NO. 21
PROJECT NO. 170101

File: X:\PROJECTS\FORD MOTOR COMPANY\170101 - REDESIGN SAMPLING CTM_Project Drawings\170101-FS-21-SURFACE LEAD MAP.dwg Layout: FIGURE 21 User: sam.waizenegger Sep 28, 2018 - 3:31pm

1" 1/2" 0" 1"



0 100 200
SCALE IN FEET

LEGEND:

	STATE PARK BOUNDARY
1360	EXISTING INDEX CONTOUR
	EXISTING BUILDING
	EXISTING EDGE OF PAVED ROAD
	EXISTING EDGE OF GRAVEL ROAD
	EXISTING WATER COURSE
	EXISTING WATER BODY
SR-1	LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
500	GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
510	INFERRED GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
	GROUNDWATER FLOW DIRECTION
	EXISTING MINE STRUCTURE
OB-2	EXISTING BEDROCK GROUNDWATER MONITORING WELL
SW/SD-MRB-01	EXISTING SURFACE WATER MONITORING LOCATION
SC-2	EXISTING SOIL BORING LOCATION
RW-3	EXISTING MNA BEDROCK GROUNDWATER MONITORING WELL
RW-16	EXISTING SENTINEL BEDROCK MONITORING WELL
	ESTIMATED BEDROCK GROUNDWATER CEA/WRA BOUNDARY

NOTES:

1. GROUNDWATER ELEVATION DATA POINTS NOT SHOWN FOR CLARITY.
2. GROUNDWATER CONTOURS TAKEN FROM AUGUST 2016 GROUNDWATER, MINE WATER, AND SURFACE WATER SAMPLING SAMPLING DATA REPORT (CORNERSTONE, 2016).

Gary J. DiPippo, Professional Engineer
N.J.P.E. Lic. No. 24GE02646100 Date 10/1/19

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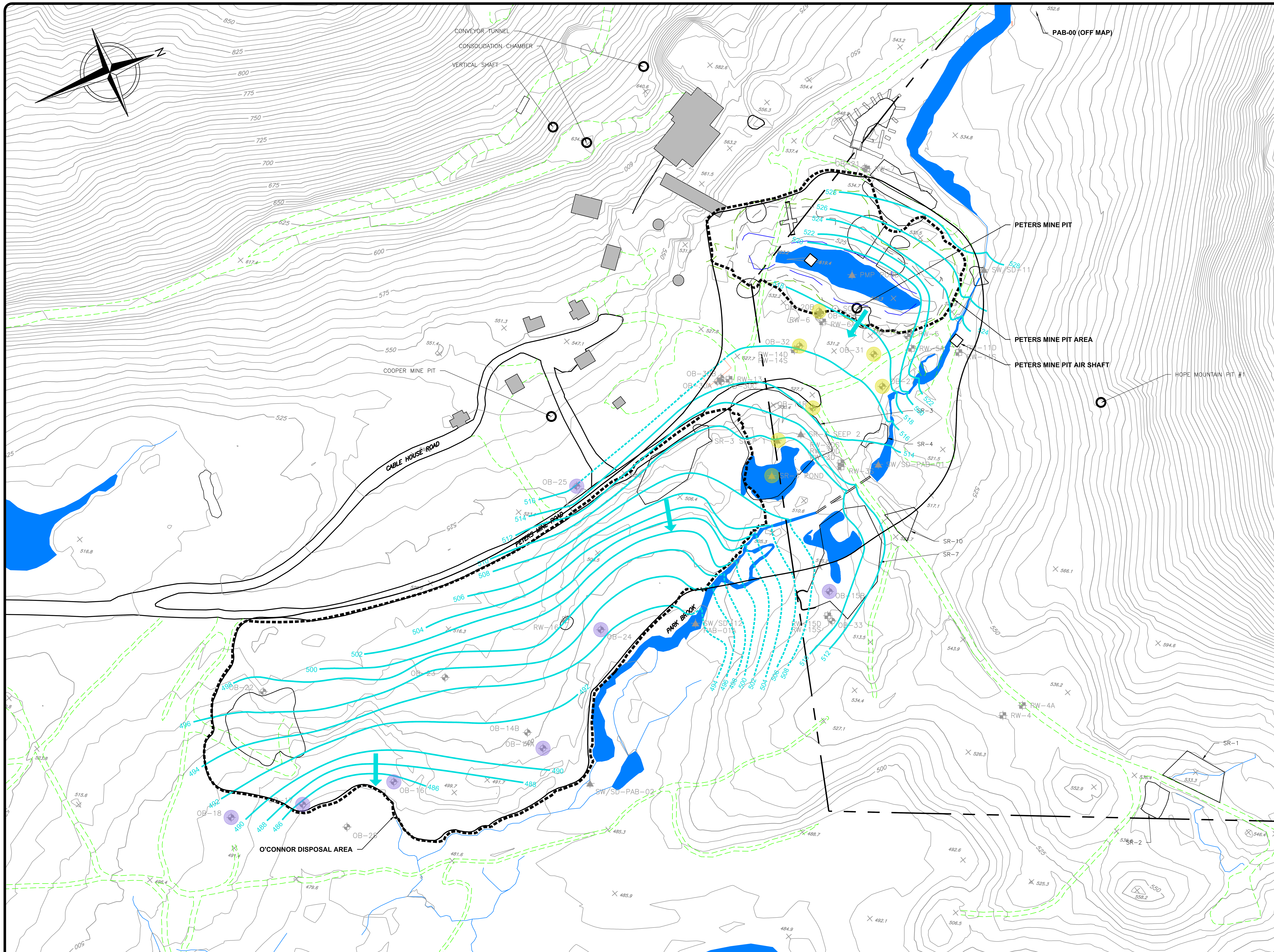
RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

ALTERNATIVE 2, SITE-WIDE GROUNDWATER MONITORED NATURAL ATTENUATION SITE PLAN (CMP AREA)
(SUPERIMPOSED ON SHALLOW BEDROCK GROUNDWATER CONTOURS)

FIGURE NO. 22
PROJECT NO. 170101



LEGEND:

- STATE PARK BOUNDARY
- 1360 — EXISTING INDEX CONTOUR
- EXISTING BUILDING
- EXISTING EDGE OF PAVED ROAD
- EXISTING EDGE OF GRAVEL ROAD
- EXISTING WATER COURSE
- EXISTING WATER BODY
- SR-1 — LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
- 500 — GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
- 510 — INFERRED GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
- GROUNDWATER FLOW DIRECTION
- EXISTING MINE STRUCTURE
- OB-2 — EXISTING BEDROCK GROUNDWATER MONITORING WELL
- OB-27 — EXISTING OVERBURDEN GROUNDWATER MONITORING WELL
- SW/SD-MRB-01 — EXISTING SURFACE WATER MONITORING LOCATION
- SC-2 — EXISTING SOIL BORING LOCATION
- OB-27 — EXISTING MNA OVERBURDEN GROUNDWATER MONITORING WELL
- OB-24 — EXISTING SENTINEL OVERBURDEN MONITORING WELL
- ESTIMATED OVERBURDEN GROUNDWATER CEA/WRA BOUNDARY

NOTES:

1. GROUNDWATER ELEVATION DATA POINTS NOT SHOWN FOR CLARITY.
2. GROUNDWATER CONTOURS TAKEN FROM AUGUST 2016 GROUNDWATER, MINE WATER, AND SURFACE WATER SAMPLING DATA REPORT (CORNERSTONE, 2016) AND ADJUSTED TO INTEGRATE PMP AREA AND OCDA DATA

0 100 200
SCALE IN FEET

Gary J. DiPippo, Professional Engineer
N.J.P.E. Lic. No. 24GE02646100 Date 10/1/19

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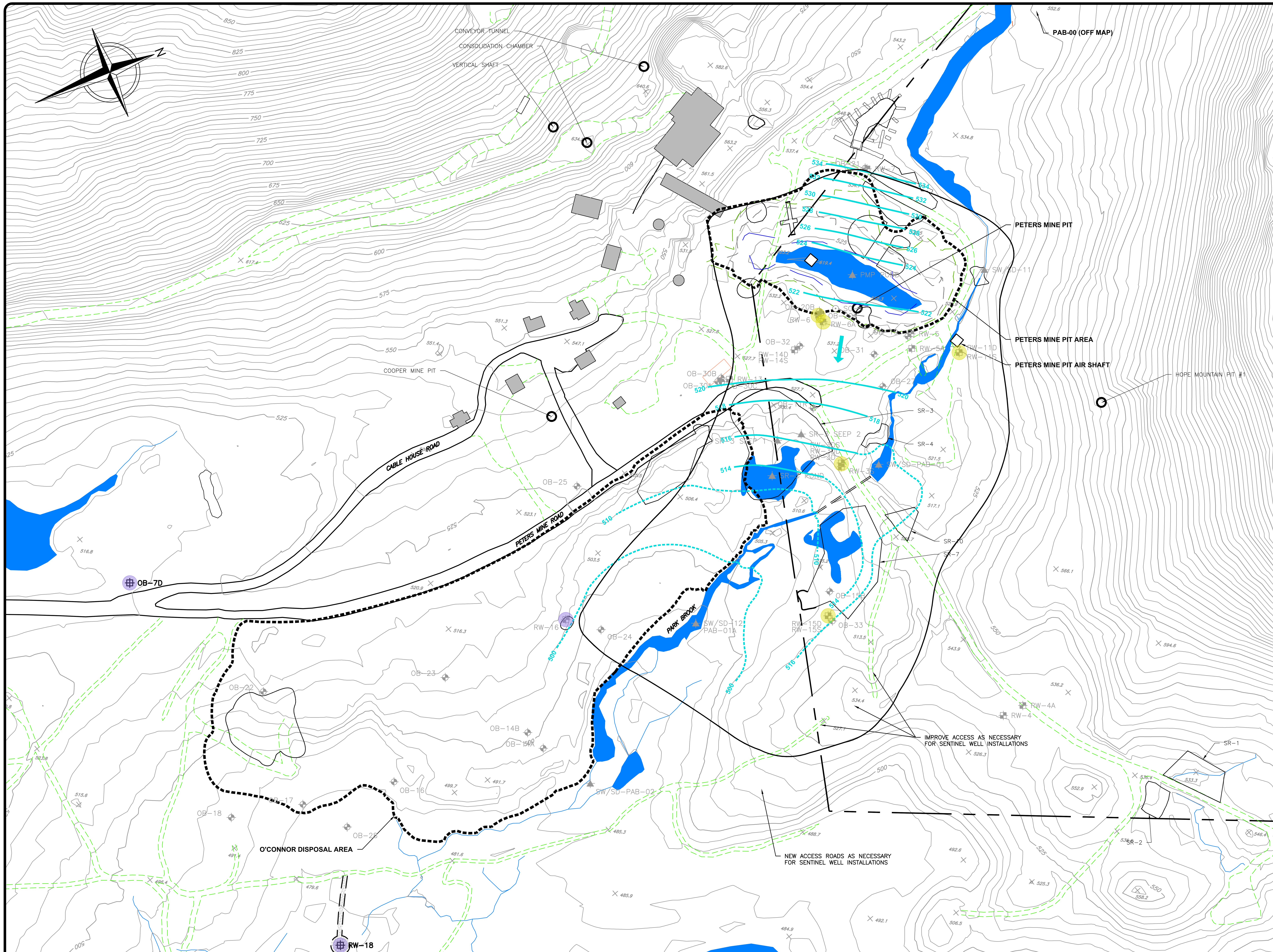
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

ALTERNATIVE 2, SITE-WIDE GROUNDWATER MONITORED NATURAL ATTENUATION SITE PLAN (PMP/OCDA AREA)

(SUPERIMPOSED ON OVERBURDEN GROUNDWATER CONTOURS)

FIGURE NO. 23
PROJECT NO. 170101



LEGEND:

- STATE PARK BOUNDARY
- 1360 EXISTING INDEX CONTOUR
- EXISTING BUILDING
- EXISTING EDGE OF PAVED ROAD
- EXISTING EDGE OF GRAVEL ROAD
- EXISTING WATER COURSE
- EXISTING WATER BODY
- SR-1 LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
- 500 GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
- 510 INFERRED GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
- GROUNDWATER FLOW DIRECTION
- EXISTING MINE STRUCTURE
- OB-2 EXISTING BEDROCK GROUNDWATER MONITORING WELL
- OB-27 EXISTING OVERBURDEN GROUNDWATER MONITORING WELL
- SW/SD-MRB-01 EXISTING SURFACE WATER MONITORING LOCATION
- SC-2 EXISTING SOIL BORING LOCATION
- RW-3 EXISTING MNA BEDROCK GROUNDWATER MONITORING WELL
- RW-16 EXISTING SENTINEL BEDROCK MONITORING WELL
- RW-17 PROPOSED SENTINEL BEDROCK MONITORING WELL
- ESTIMATED BEDROCK GROUNDWATER CEA/WRA BOUNDARY

NOTES:

1. GROUNDWATER ELEVATION DATA POINTS NOT SHOWN FOR CLARITY.
2. GROUNDWATER CONTOURS SHOWN ARE FOR THE UPPER, SHALLOW BEDROCK WATER–BEARING ZONE.
3. GROUNDWATER CONTOURS TAKEN FROM AUGUST 2016 GROUNDWATER, MINE WATER, AND SURFACE WATER SAMPLING SAMPLING DATA REPORT (CORNERSTONE, 2016) AND EXTRAPOLATED INTO OCDA BASED ON DATA AT RW–16.

Gary J. DiPippo, Professional Engineer
10/1/19
N.J.P.E. Lic. No. 24GE02646100 Date

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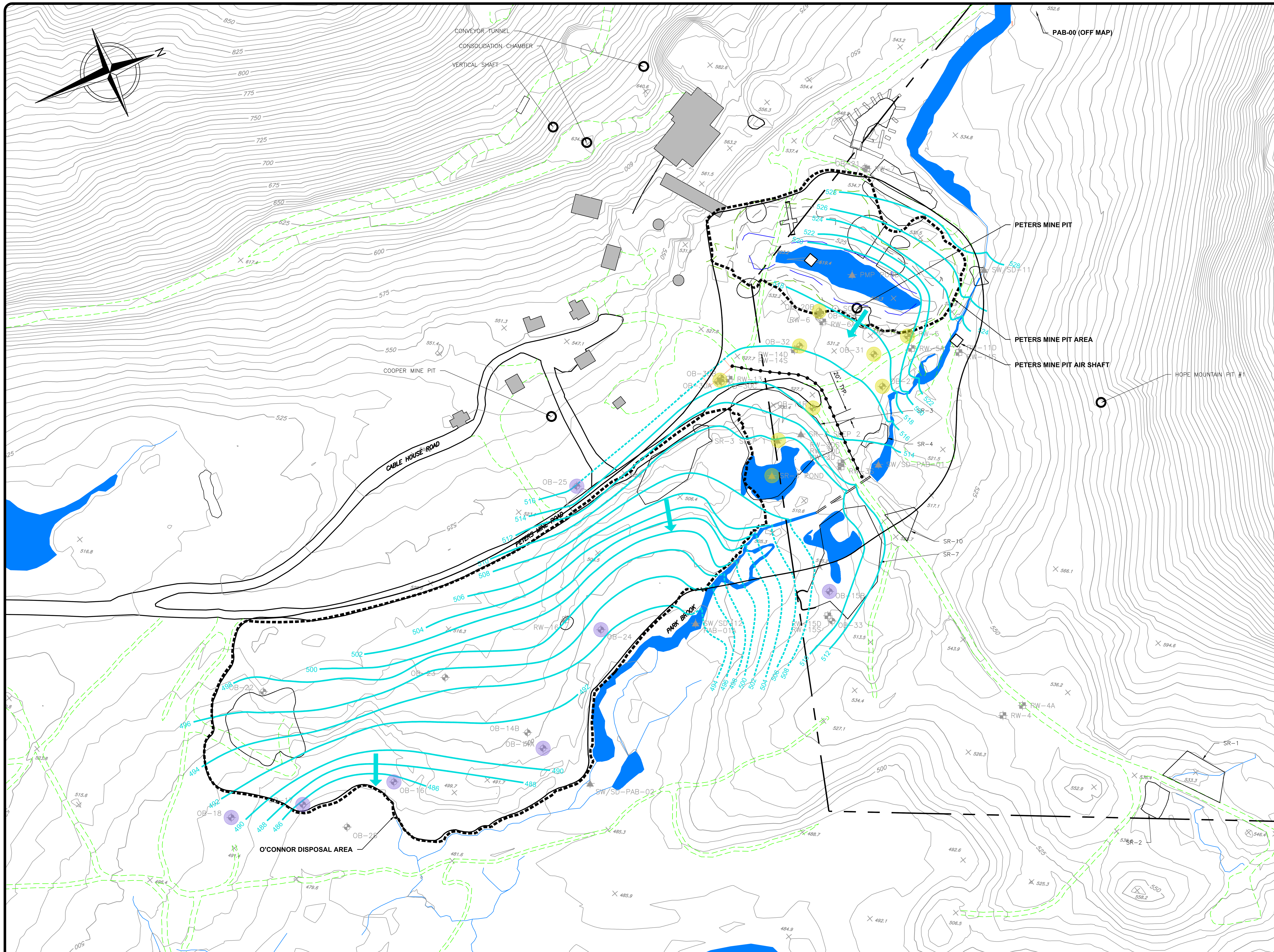
RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

ALTERNATIVE 2, SITE-WIDE GROUNDWATER MONITORED NATURAL ATTENUATION SITE PLAN (PMP/OCDA AREA)

(SUPERIMPOSED ON BEDROCK GROUNDWATER CONTOURS)

FIGURE NO. **24**

PROJECT NO. 170101



LEGEND:

	STATE PARK BOUNDARY
1360	EXISTING INDEX CONTOUR
	EXISTING BUILDING
	EXISTING EDGE OF PAVED ROAD
	EXISTING EDGE OF GRAVEL ROAD
	EXISTING WATER COURSE
	EXISTING WATER BODY
SR-1	LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
500	GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
510	INFERRED GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
	GROUNDWATER FLOW DIRECTION
	EXISTING MINE STRUCTURE
OB-2	EXISTING BEDROCK GROUNDWATER MONITORING WELL
OB-27	EXISTING OVERBURDEN GROUNDWATER MONITORING WELL
SW/SD-MRB-01	EXISTING SURFACE WATER MONITORING LOCATION
SC-2	EXISTING SOIL BORING LOCATION
OB-27	EXISTING MNA OVERBURDEN GROUNDWATER MONITORING WELL
OB-24	EXISTING SENTINEL OVERBURDEN MONITORING WELL
	PROPOSED OVERBURDEN WELLS FOR PLACEMENT OF OXYGEN RELEASE COMPOUND (21 WELLS TOTAL, IN-WELL CANISTERS)
	ESTIMATED OVERBURDEN GROUNDWATER CEA/WRA BOUNDARY

NOTES:

1. GROUNDWATER ELEVATION DATA POINTS NOT SHOWN FOR CLARITY.
2. GROUNDWATER CONTOURS TAKEN FROM AUGUST 2016 GROUNDWATER, MINE WATER, AND SURFACE WATER SAMPLING DATA REPORT (CORNERSTONE, 2016) AND ADJUSTED TO INTEGRATE PMP AREA AND OCDA DATA

0 100 200
SCALE IN FEET

Gary J. DiPippo, Professional Engineer
N.J.P.E. Lic. No. 24GE02646100 Date 10/1/19

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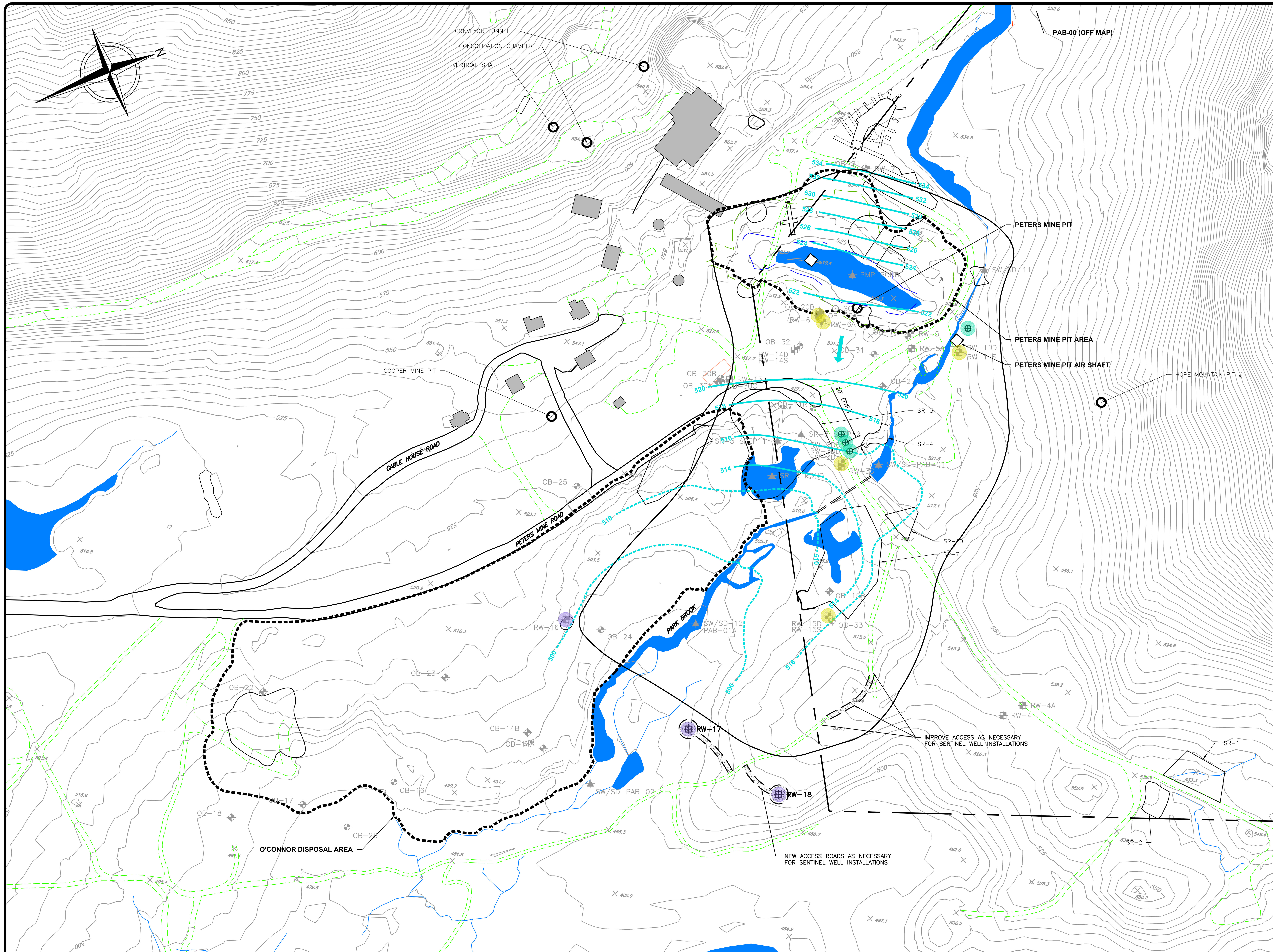
RINGWOOD MINES/LANDFILL SUPERFUND SITE
GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

ALTERNATIVE 3, ENHANCED MONITORED NATURAL ATTENUATION TREATMENT BARRIER SITE PLAN (PMP/OCDA AREA)
(SUPERIMPOSED ON OVERBURDEN GROUNDWATER CONTOURS)

FIGURE NO. 25
PROJECT NO. 170101



0 100 200
SCALE IN FEET

LEGEND:

- STATE PARK BOUNDARY
- 1360 EXISTING INDEX CONTOUR
- EXISTING BUILDING
- EXISTING EDGE OF PAVED ROAD
- EXISTING EDGE OF GRAVEL ROAD
- EXISTING WATER COURSE
- EXISTING WATER BODY
- SR-1 LIMITS OF PRIOR PAINT WASTE REMOVAL AREAS
- 500 GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
- 510 INFERRED GROUNDWATER ELEVATION CONTOUR, AUGUST 2016
- GROUNDWATER FLOW DIRECTION
- EXISTING MINE STRUCTURE
- OB-2 EXISTING BEDROCK GROUNDWATER MONITORING WELL
- OB-27 EXISTING OVERBURDEN GROUNDWATER MONITORING WELL
- SW/SD-MRB-01 EXISTING SURFACE WATER MONITORING LOCATION
- SC-2 EXISTING SOIL BORING LOCATION
- RW-3 EXISTING MNA BEDROCK GROUNDWATER MONITORING WELL
- RW-16 EXISTING SENTINEL BEDROCK MONITORING WELL
- RW-17 PROPOSED SENTINEL BEDROCK WELLS
- PROPOSED BEDROCK WELLS FOR OXYGEN RELEASE COMPOUND (IN-WELL CANISTER)
- ESTIMATED BEDROCK GROUNDWATER CEA/WRA BOUNDARY

NOTES:

1. GROUNDWATER ELEVATION DATA POINTS NOT SHOWN FOR CLARITY.
2. GROUNDWATER CONTOURS SHOWN ARE FOR THE UPPER, SHALLOW BEDROCK WATER-BEARING ZONE.
3. GROUNDWATER CONTOURS TAKEN FROM AUGUST 2016 GROUNDWATER, MINE WATER, AND SURFACE WATER SAMPLING SAMPLING DATA REPORT (CORNERSTONE, 2016) AND EXTRAPOLATED INTO OCDA BASED ON DATA AT RW-16.

Gary J. DiPippo, Professional Engineer
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GROUNDWATER FOCUSED FEASIBILITY STUDY
RINGWOOD, PASSAIC COUNTY, NEW JERSEY

ALTERNATIVE 3, ENHANCED MONITORED NATURAL ATTENUATION TREATMENT BARRIER SITE PLAN (PMP/OCDA AREA)

(SUPERIMPOSED ON BEDROCK GROUNDWATER CONTOURS)

FIGURE NO. 26
PROJECT NO. 170101