September 20, 2019

Mr. Todd Caffoe, P.E.
Project Manager
Division of Environmental Remediation
New York State Department of Environmental Conservation
6274 East Avon-Lima Road
Avon, NY 14414

Subject: Final Feasibility Study Report, Arch Chemicals, Inc., Site No. 828018a

Dear Mr. Caffoe:

On behalf of Arch Chemicals, Inc., a wholly-owned subsidiary of Lonza, Amec E & E (PC) is pleased to provide this Final Feasibility Study Report for the Arch Chemicals, Inc. site in Rochester, New York.

Sincerely,

AMEC E & E (PC)

Nelson Breton
Project Manager

encl.
cc : Melissa Doroski, NYSDOH – Albany (email transmission)
Jean Robert Jean, USEPA Region II (email transmission)
Richard Hampson, Lonza (email transmission)
Francien Trubia, Lonza (email transmission)
City of Rochester Public Library - Lyell Avenue Branch (hardcopy)

AMEC E & E PC.
511 Congress Street
Portland, ME 04101

2019

FEASIBILITY STUDY REPORT
ARCH CHEMICALS, INC.
SITE NO. 828018a

Prepared for:

Arch Chemicals, Inc.
(A Wholly-Owned Subsidiary of Lonza)

ARCH
is now a part of
Lonza
www.lonza.com

Prepared by:

AMEC E & E (PC).
Portland, Maine

PROJECT NO: 3616196075

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SEPTEMBER 2019

STUART C. PEARSON
088066

9/20/19

Nelson Breton
Project Manager

Stuart C. Pearson, PE
Senior Associate Engineer

Nathan Lewis
Project Engineer

I Stuart C. Pearson certify that I am currently a NYS registered professional engineer as defined in 6 NYCRR Part 375 and that this Report was prepared to document background and remedy evaluations in support for the Record of Decision (NYSDEC, 2019) in general accordance the DER Technical Guidance for Site Investigation and Remediation (DER-10).

TABLE OF CONTENTS

FIGURES

TABLES

APPENDICES

EXECUTIVE SUMMARY

This report presents the findings of a Feasibility Study (FS) conducted for the Arch Chemicals, Inc. (Arch) manufacturing facility in Rochester, New York (the Site). Arch performed this FS to evaluate remedial alternatives capable of destroying or removing on-site source area contaminants of concern (COCs) and containing the off-site migration of COCs to protect human health and the environment.

Arch initially completed an FS in January 2000 (Arch Chemicals, Inc., 2000) to develop and evaluate remedial alternatives intended to protect human health and the environment. An addendum to the FS was submitted to the New York State Department of Environmental Conservation (NYSDEC) in April 2015 (Arch Chemicals, Inc., 2015). The addendum specifically reevaluated source area treatment in light of new remediation technologies and approaches that may be able to destroy source area contamination or increase the rate of contaminant mass removal. This FS is intended to address both potential human health and environmental exposures to contaminated media and source removal and containment of groundwater. More specifically, remedial action objectives are identified to prevent:

1) Ingestion of groundwater with contaminant levels exceeding drinking water standards,

2) contact with, or inhalation of volatile organic compounds, from contaminated groundwater, and

3) discharge of contaminants to surface water.

Soil remedial and soil vapor remedial action objectives are identified to mitigate impact to public health for soil vapor exposure and to prevent:

1) Ingestion/direct contact with contaminated soil and

2) inhalation of or exposure from contaminants volatilizing from

   contaminants in soil, and

3) migration of contaminants that would result in groundwater or surface water contamination.

Ongoing remedial actions at the Site (groundwater extraction, treatment, and discharge to publicly owned treatment works) in addition to groundwater use limitations and monitoring are protective of human health and provide a remediation strategy for affected media (groundwater).

Technologies were identified and screened to assess their effectiveness in removing or treating contaminated on-site groundwater in the contaminant source areas and provide protection to off-site receptors. Three alternatives were selected for further evaluation:

- Alternative 1, Groundwater Extraction, involves no further action to reduce groundwater contamination beyond operating the existing groundwater extraction and treatment system and was developed as a baseline against which to compare the other remedial alternatives.

- Alternative 2, Horizontal Groundwater Extraction Wells, includes installation of up to two horizontal groundwater extraction wells, continued long-term groundwater monitoring, and operation, maintenance, and monitoring of the groundwater extraction system. One horizontal well would be installed along an east-west alignment and would target the source areas beneath the manufacturing building and near monitoring well B-17. A second well, if deemed necessary, would be installed along the western property boundary in a north-south alignment to aid in groundwater capture and control. The inclusion of horizontal groundwater extraction wells would accelerate the removal and treatment of remaining groundwater contamination.

- Alternative 3, Hydraulic Fracturing and Additional Groundwater Extraction Wells, would use hydraulic fracturing, commonly referred to as fracking, to increase groundwater flow through the bedrock fractures and increase contaminant mass removal. Fracking uses pressurized fluid to open and develop fractures within bedrock. Alternative 3 consists of fracking the shallow bedrock zone along three alignments within the contaminant source area, installation of one vertical groundwater extraction well within each fractured alignment, long term groundwater monitoring, and operation, maintenance, and monitoring of the enhanced groundwater extraction system. Fracking the shallow bedrock zone and expanding the network of groundwater extraction wells is intended to accelerate the removal and treatment of remaining groundwater contamination. As part of the evaluation of Alternative 3, Arch contracted Nothnagle Drilling, Inc. (Nothnagle) to perform a hydraulic fracturing pilot test in September 2012. The objective of the pilot test was to observe if hydraulic fracturing would improve the bulk permeability and connectivity of fractures within a historically low yield portion of the shallow bedrock. Overall, the pilot test demonstrated inconsistent results at improving bedrock permeability between wells and has not resulted in increased performance at extraction wells within the pilot test area, PW-14 and PW-15.

All remedial alternatives were retained for detailed analysis. As a result of the detailed analysis and comparison of alternatives, it is recommended that Arch and the NYSDEC select Alternative 2, Install Horizontal Groundwater Extraction Wells, as the preferred remedy for the Site. While Alternative 3 is comparable in nature and cost to Alternatives 1 and 2, the hydraulic fracturing pilot test demonstrated inconsistent results at increasing connectivity between wells on site. Furthermore, the pilot test did not increase groundwater extraction rates from wells PW-14 and PW-15, suggesting limited potential for Alternative 3 to increase mass removal rates from the shallow bedrock zone. Alternative 3 would offer limited benefit at a comparatively higher cost. While Alternative 2 is similar to Alternative 1 in approach, Alternative 2 would allow for installation of hundreds of additional feet of well screen in zones of contamination while only requiring the installation of one or two wells. The well lengths, sizes, and locations proposed for purposes of evaluation and costing in this report would be further refined as part of the design phase based on a more detailed evaluation of field conditions. Overall, Alternative 2 provides the best balance of all the evaluation criteria and offers the best opportunity to increase source area contaminant mass removal and protect human health and the environment in the most cost-effective manner.

To address potential exposure to contaminants in soil, soil vapor, and groundwater on-site, Arch will provide for institutional controls. These institutional controls will be documented in a Site Management Plan and would be consistent with the recommended Alternative S2 that was identified in the 2000 FS (Arch Chemicals Inc., 2000).

Specifically, institutional controls in the form of an environmental easement for the property will consist of the following elements:

- a periodic certification of institutional and engineering controls in accordance with Title 6 of New York Codes, Rules and Regulations Part 375-1.8 (h)(3);
- allow the use and development of the property for industrial use as defined by Part 375-1.8(g);
- restrict the use of groundwater as a source of potable or process water, without necessary water quality treatment as determined by the New York State Department of Health (NYSDOH) or County DOH; and
- require compliance with a Site Management Plan to be approved by the NYSDEC.

1.0 INTRODUCTION

This report presents the findings of a Feasibility Study (FS) conducted for the Arch Chemicals, Inc. (Arch) manufacturing facility in Rochester, New York (the Site). Arch Chemicals is a wholly-owned subsidiary of Lonza, a leading supplier to the global life sciences, healthcare and pharmaceutical industries headquartered in Basel, Switzerland. Arch performed this FS to evaluate remedial alternatives capable of destroying or removing on-site source area contamination as well as containing the off-site migration of these contaminants to protect human health and the environment. The primary contaminants of concern (COCs) in the source area include chloropyridines and volatile organic compounds (VOCs).

Arch initially completed an FS in January 2000 (Arch Chemicals, Inc., 2000) to fulfill part of the requirements of the Consent Order between the New York State Department of Environmental Conservation (NYSDEC) and Olin (Index No. B8-0343-90-08), dated 23 August 1993. That FS developed and evaluated remedial alternatives intended to protect human health and the environment. Alternatives protected human health and the environment by controlling, treating, or removing contaminated soil and groundwater. The recommended alternatives primarily addressed off-site groundwater through hydraulic control of contamination using extraction systems, treatment, discharge to publicly owned treatment works (POTW), and groundwater monitoring.

In the January 2000 FS, more aggressive approaches to destroy source area contamination were not recommended due to the infeasibility of oxidizing, degrading, or volatilizing chloropyridines. A draft FS Addendum (Arch Chemicals Inc., 2015) was prepared to specifically reevaluate source area treatment in light of new remediation technologies and approaches that may have been able to destroy source area contamination or increase the rate of contaminant mass removal. In accordance with NYSDEC Division of Environmental Remediation (DER)-10's (NYSDEC, 2010) preferred hierarchy of remediating contaminant sources, the alternatives evaluated in the FS Addendum emphasized removal and/or treatment of grossly contaminated on-site groundwater to the greatest extent feasible. This FS is intended to address both removal and/or treatment and containment of groundwater to protect human health and the environment.

1.1 Purpose of Report

This FS Report presents changes to the conceptual site model since the January 2000 FS, identifies a complete set of Remedial Action Objectives (RAOs) to protect public health and the environment, and presents remedial alternatives to satisfy the RAOs.

1.2 Site Background

The Site includes a chemical manufacturing plant located at 100 McKee Road, Rochester, Monroe County, New York (**Figure 1-1**). The plant property occupies approximately 19.5 acres (see **Figure 1-2**).

The Site has been the subject of various environmental investigations since the early 1980s, including, but not limited to, a groundwater investigation conducted in 1990, a two-phase remedial investigation (RI) conducted in 1994-96, and an FS conducted in 2000. A prior Consent Order was executed in August 1993, between Olin Corporation (the former owner) for the implementation of an RI and FS. Arch implemented a portion of the previously recommended remedial alternative in the 2000 FS for the Site after Arch entered into a new Consent Order with the NYSDEC to implement the requirements of the NYSDEC's Record of Decision (ROD) in August 2003. The recommended remedial alternative included groundwater extraction and treatment to maintain hydraulic control of groundwater at the property boundary. Groundwater extraction system operations, maintenance, and upgrades have occurred as needed from August 2000 to the present. Extracted groundwater is conveyed by pipeline to a treatment system prior to discharge to the Monroe County Pure Waters POTW. The recommended remedial alternative also included a provision for installing and operating a downgradient extraction well near the Dolomite Products quarry on Buffalo Road; however, subsequent monitoring and an updated risk evaluation have demonstrated that potential exposure risks at the quarry are below levels of concern. The NYSDEC has indicated that installation of the downgradient extraction well is no longer required (MACTEC, 2005).

1.3 Report Organization

Arch structured this FS report in general accordance with NYSDEC DER-10 (NYSDEC, 2010) guidance for remedy selection. The following is an outline and summary of the FS report sections:

Section 2.0 Physical Setting:

Section 2.0 briefly summarizes the physical characteristics of the Site as presented in the 2000 FS (Arch Chemicals Inc, 2000).

Section 3.0 Nature and Extent of Contamination:

Section 3.0 briefly summarizes the nature and extent of contamination as presented in the 2000 FS along with an update to the understanding of the nature and extent of contamination. This update is based on sampling and monitoring programs from January 2000 to May 2018.

Section 4.0 Contaminant Fate and Transport:

Section 4.0 briefly summarizes the fate and transport of the site contaminants.

Section 5.0 Human Health Risk Assessment:

Section 5.0 summarizes previous risk evaluations for human health and the environment and presents a qualitative human health risk assessment for current and future land use.

Section 6.0 Development of Remedial Action Objectives and General Response

Actions:

Section 6.0 presents the RAOs and General Response Actions targeted in this FS.

Section 7.0 Identification of Technologies and Alternatives:

Section 7.0 identifies potential remedial technologies and alternatives. This FS does not repeat the conventional FS process of comprehensively identifying and screening technologies, combining retained technologies into remedial alternatives, and then screening those alternatives. In part, this FS uses the 2015 FS Addendum to help screen out technologies that were deemed infeasible, allowing the FS to focus on a limited number of technologies and alternatives that have the potential to reduce source area contamination and protect human health and the environment.

Section 8.0 Development and Preliminary Screening of Alternatives:

In **Section 8.0,** technologies retained from Section 7 are assembled into potential site-specific remedial alternatives capable of achieving the RAOs. Alternatives that cannot achieve RAOs are screened out.

Section 9.0 Detailed Analysis of Alternatives:

Section 9.0 presents the detailed analyses of remedial alternatives for the Site. The detailed analysis provides decision-makers with relevant information to aid in selecting a supplementary Site remedy.

Section 10.0 Comparative Analysis of Alternatives:

In **Section 10.0**, the relative performance of each alternative is evaluated using the same criteria from the detailed analysis of alternatives. The comparative analysis identifies advantages and disadvantages of each alternative relative to one another to aid in selecting a supplementary Site remedy.

Section 11.0 Recommended Alternative:

Section 11.0 summarizes the conclusions of the comparative analysis and presents the recommended alternative.

Section 12.0 Glossary of Acronyms and Abbreviations:

Section 12.0 defines acronyms and abbreviations used in the text of this report.

Section 13.0 References:

Section 13.0 lists the references used in the preparation of this report. Supporting information is included in the Appendices attached to this Report.

2.0 SITE PHYSICAL SETTING

The physical characteristics especially relevant to remediation of the contamination source area are presented in this section. Additional information on site physical characteristics is available in the 2000 FS.

2.1 Geology

Glacially deposited sands and silty sands constitute local surface geology. Local fill, interpreted as recompacted glacial sediments, covers the sand and silty sands. This report refers to the undisturbed sediment and fill as overburden. Overburden thickness ranges from approximately 10 to 20 feet.

Lockport Dolomite bedrock underlies the overburden. The bedrock surface elevation ranges from approximately 520 to 530 feet above mean sea level. A fractured upper bedrock zone ranges in thickness from 11 to 40 feet (or 27 to 54 feet below ground surface [bgs]). Fractures within the upper zone appear to be primarily near-horizontal. Below the upper zone, the bedrock becomes less fractured and more competent.

2.2 Hydrogeology

Groundwater flow occurs primarily in the saturated portions of the overburden and the uppermost 10 feet of bedrock. No significant barrier to flow between the overburden and the upper bedrock has been identified. However, the degree of hydraulic communication between the overburden and bedrock units varies locally due in large part to heterogeneities in the shallow bedrock.

The groundwater table in the overburden is generally less than 10 feet bgs throughout the property. Overburden groundwater exists beneath the site but is absent in areas west and southwest of the site in the direction of the Erie Barge Canal. The presence of a drainage area along the railroad right-of-way just east of the Arch site serves as a significant recharge area for groundwater that results in a mound along the eastern property boundary. This is the primary feature that controls overburden and bedrock groundwater flow at the Site. Other factors that influence flow include: bedrock surface topography, the location of the canal, the nature and distribution of water-bearing fractures, and flow direction in bedrock.

Historical piezometric contours indicate that overburden groundwater flows primarily west and south from the plant toward the Erie Barge Canal and Buffalo Road. An easterly and southeasterly flow component is also present along the east and the southeast corner of the site. Groundwater in shallow and deeper bedrock flows primarily west and south toward the Dolomite Products Quarry in the Town of Gates. Groundwater discharges into quarry the along vertical bedrock seepage faces. The driving force for groundwater appears to be ongoing dewatering in the quarry.

Historical overburden piezometric contours suggest a southerly horizontal component of flow near the southern boundary of the plant. However, when compared to shallow bedrock piezometric contours, the data also indicate a strong downward vertical gradient beneath the plant, suggesting a downward flow path for overburden groundwater.

Hydraulic conductivity estimates calculated from the Phase I RI for the water bearing zones range as follows:

- Overburden: 1.9 x 10^{-5} to 7.7 x 10^{-3} centimeters per second (cm/sec)
- Shallow bedrock: 4.0 x 10^{-5} to 1.17 x 10^{-2} cm/sec
- Deeper bedrock: 1 x 10^{-6} to 2.4 x 10^{-4} cm/sec.

While the overburden and shallow bedrock ranges are similar, experience with pumping well operations at this site over the past 25 to 30 years indicates that the transmissivity of the shallow bedrock is noticeably greater than the saturated overburden zone.

3.0 NATURE AND EXTENT OF CONTAMINATION

This section summarizes the results of the field investigations performed at the Site prior to the FS and the current nature and extent of contamination. Summarized results are provided for treatment and containment alternatives analyzed in this FS. For more detailed characterization of off-site media, refer to the 2000 FS.

3.1 Surface Soil

Surface soil samples were collected from several areas at the facility as part of the RI. Analytical results were presented in **Table 4-2** as part of that report (ABB, 1995).

Constituents exceeding site cleanup objectives (SCOs) or background levels included metals, semi-volatile organic compounds (SVOCs including chloropyridine isomers), and one VOC (chloroform). The location of the maximum concentration of chloroform and many of the SVOCs (including chloropyridines) was in the Well B-17 Area, shown on **Figure 3-1**. SVOCs exceeding SCOs were noted sporadically in surface soils and mercury was detected in the former Lab Sample Disposal Area in surface soil within a small central portion of the Site. These locations are currently under asphalt pavement or part of an existing railway bed located on site.

3.2 Subsurface Soil

Soil boring samples were collected across the Site as part of the RI from over 25 soil borings. Subsurface soil investigation was focused on six different potential source areas, shown on **Figure 3-1**:

- Well B-17 Area
- Former Lab Sample Disposal Area
- Sodamide Area
- Former Tank Farm Area
- TDA Area
- Well BR-5 Area

The highest concentrations of VOCs, chloropyridines, and other SVOCs in soil were detected in the paved alcove located immediately east of the main plant building in the Well B-17 Area. This was noted as the main source area of groundwater contamination as the result of underground sewer leaks from the main plant. Most of the soil contamination is confined to depths between 8 and 18 feet bgs. Given this result and several plant expansions over the years, it is most likely that contamination extends beneath the footprint of the main plant. **Table 3-1** provides a summary of analytical results for key chemical constituents (chlorinated VOCs and chloropyridines) in soil from each of these areas. The approximate limits of the Well B-17 source area are shown on **Figures 3-1 and 3-2**.

3.3 On-site Groundwater

SVOCs (mainly chloropyridines), VOCs, and inorganic analytes were detected in overburden and bedrock groundwater beneath the Site. Chloropyridines were the most frequently detected organic chemicals in both overburden and bedrock groundwater. The distribution of chloropyridines is believed to represent the greatest extent of site-derived constituents in the groundwater and is considered representative of SVOC distribution at the Site – further references in the report to the extent of SVOC contamination will simply refer to the extent of the chloropyridines.

Figures 3-1 and 3-2 show the extent of VOC and chloropyridine contamination in groundwater based on the May 2018 sampling event. Refer to the full Spring 2018 Groundwater Monitoring Report (Arch Chemicals, Inc., 2018) for a current summary of contaminant concentrations and distributions.

In general, maximum chloropyridine and VOC concentrations are near the main plant building in both overburden and shallow bedrock wells. Total chloropyridine concentrations are lower in deep bedrock wells than in adjacent shallow bedrock wells.

3.4 Off-site Groundwater

Sampling completed as part of the Phase II RI in the 1990’s in addition to ongoing monitoring of downgradient wells, seeps, and surface water provides data to support an understanding of the distribution of chemicals that have migrated off site. The bulk of dissolved VOC and chloropyridines in groundwater migrate into bedrock groundwater to the west and southwest and toward the Dolomite Products Quarry in the Town of Gates.

Ongoing monitoring indicates that VOCs in overburden and shallow bedrock groundwater extend a few hundred feet off site from the plant. Chloropyridines are present in overburden and shallow bedrock in the area of the Site but have migrated into deep groundwater along a migration pathway that ends at a seep at the Dolomite Products Quarry. The driving force for chloropyridines moving to the quarry appears to be ongoing dewatering in the quarry. The migration pathway to deeper zones in bedrock may be caused by preferential pathways due to fracture patterns. Alternatively, it could be the result of historical groundwater pumping at locations between the Site and the quarry that have drawn groundwater to the southwest. **Figure 3-3** from Spring 2018 shows the interpreted groundwater flow for deep bedrock groundwater and the location of the quarry seepage face.

At the Dolomite quarry, sampling has been conducted since the mid-1990’s from the quarry seep where groundwater discharges along the eastern face of the quarry wall (see **Figure 3-3**). Sampling has also been conducted from water discharged from the quarry.

A time-series plot for total chloropyridines representing the sum of 2-chloropyridine, 2,6-dichloropyridine, 3-chloropyridine, 4-chloropyridine, p-fluoroaniline, and pyridine for the quarry seep is provided on **Figure 3-4**. The time-series plot also shows the total volume of groundwater extracted from on-site wells each year since 2000. The chart provides an indicator of the impact of groundwater extraction over the years.

3.5 Soil Vapor

Soil gas sampling was performed as part of the Phase 1 RI (the analytical results of which can be found in **Table 4-1** of that report). The results of the sampling suggested that the concentration of VOCs in soil gas mimicked the distribution of VOCs in the overburden groundwater (ABB, 1995). Additional on- and off-site soil vapor sampling was performed in 2006 to evaluate the impacts to indoor air at the Site and adjacent properties.

On-site indoor air was evaluated at three locations: the Office Area, the Warehouse Area, and the Production Area. Each area had contaminants present in indoor air that pose cancer risks in excess of the New York State Department of Health (NYSDOH) point of departure ($1x10^{-6}$), but comparison of soil vapor and indoor air data suggested that the primary source of indoor air contamination is not soil gas (Arch Chemicals, Inc., 2006a). Chloropyridine compounds are produced in the facility, acting as another potential source.

Off-site indoor air was evaluated at the neighboring American Recycling and Manufacturing and Firth Rixon buildings. Potential complete vapor migration pathways were identified in both facilities, but again, comparison of soil vapor and indoor air sample suggest that soil gas is not the sole, or even the primary source of indoor air contamination (Arch Chemicals, Inc., 2006b). Additional information from the facility owners would be necessary to determine whether the compounds identified are present in indoor air as a result of current occupational uses.

4.0 CONTAMINANT FATE AND TRANSPORT

This section summarizes the fate and transport of source area contaminants as presented in the 2000 FS (Arch Chemicals Inc., 2000).

4.1 Fate of VOCs and Chloropyridines

The physical-chemical properties of VOCs and chloropyridines were previously evaluated to assess the importance of biodegradation, adsorption, volatilization, and dissolution as fate processes. Dissolution and degradation were identified as the most significant fate processes for VOCs. Biodegradation, photo-oxidation, and to a lesser degree volatilization were identified as the most important fate processes for pyridines, although in general chloropyridines are more persistent than pyridine and increasing the number of halogen substituents increases the persistence of the pyridine ring (ABB, 1995).

Given the high dissolved phase concentrations of VOCs and chloropyridines in on-site wells, Arch cannot discount the possibility that residual dense non-aqueous-phase liquid (DNAPL) may exist in bedrock fractures and prior to the 1990s separate phase product was observed in two bedrock wells. However, routine semiannual screening of groundwater monitoring and extraction wells continues to show no accumulation of DNAPL in the on-site wells. DNAPL may also be present within bedrock as a result of matrix diffusion.

4.2 Migration of VOCs and Chloropyridines

Based on the physical-chemical properties of site-related constituents presented in the Phase I RI Report, dissolved-phase transport in groundwater is considered the primary migration pathway.

The active groundwater extraction and treatment system limits off-site migration of contamination in groundwater. With the exception of well BR-127, located near the eastern property boundary, all of the bedrock recovery wells extract groundwater from the primary source area or from along the site boundary to the west of this area, intercepting the primary contaminant migration pathway.

Although contamination is also present in the overburden, the comparatively low permeability of this unit and the observed strong downward vertical gradients minimize the potential for significant off-site migration within the overburden. In addition, there is an absence of saturated overburden to the west of the Site.

Contaminants have migrated to the bedrock beneath the facility and are acting as an ongoing source for the groundwater contamination; no barrier to flow between the overburden and the upper bedrock has been identified (ABB, 1995). As discussed in **Section 3.3**, chloropyridines have also migrated to the Dolomite Products Quarry east of the Site. The quarry serves as the endpoint for the chloropyridine plume where groundwater cascades down into a holding pond that mixes with stormwater that is then pumped to a surface ditch that discharges into the Erie Canal.

5.0 HUMAN HEALTH RISK ASSESSMENT

Potential human health risks at the Site were identified in the 2000 FS and Phase I and Phase II RI Reports as follows:

- populations of humans that may be present at and in the vicinity of the Site were identified;
- exposure pathways by which those humans may be exposed to Site contamination were identified; and
- the significance of exposure that may occur through the potential exposure pathways were evaluated.

The results of the previous human health risk assessment are used to establish site-wide RAOs that were utilized in the selection of the remedial action for the site. Where applicable, those risks are assessed in **Section 9** of this report, along with other factors, such as effectiveness in accomplishing contaminant mass reduction, technical and administrative implementability, and cost.

A quantitative exposure assessment was conducted as part of the Phase I RI and was summarized in the 2000 FS. A qualitative human risk exposure assessment is provided as part of this FS. The purpose of a qualitative human risk exposure assessment is to evaluate and document how people might be exposed to site-related contaminants and to identify and characterize the potentially exposed populations now and under the reasonably anticipated future use of the Site.

Site-related chemicals (VOCs and chloropyridines) have been detected in on-site samples of soil vapor, surface soil, subsurface soil, and in both on-site and off-site groundwater. The distribution of these constituents is believed to be the result of leaching of chemicals from materials at the plant by infiltrating precipitation or former percolation of materials through the unsaturated overburden to the groundwater. The highest concentrations of the contaminants have been observed in on-site groundwater in the shallow bedrock zone. Concentrations in groundwater have historically been high enough that they suggest the presence of DNAPL, and a separate phase liquid was observed in two bedrock wells prior to the 1990's, but none was been observed during the Phase I and II RIs in the 1990's or during routine monitoring since that time.

The fate and transport analysis provided in the Phase I RI identified dissolved-phase transport in groundwater as the primary mode of transport for contaminants; soils are not expected to migrate off-site, and only one sample of soil vapor was observed slightly above the air standard within the facility. Within the shallow bedrock zone, groundwater flows primarily south and west, but is strongly influenced by bedrock pumping wells located at the boundaries of the Site.

Given the location and behavior of the contaminants and the industrial/commercial use of the Site, the 2000 FS identified a limited number of potential exposure pathways: on-site facility and non-facility commercial/industrial workers may contact contaminated surface soils; older children and adult recreational boaters/swimmers and adult recreational anglers may be exposed to surface water in the Erie Barge Canal, a major surface water feature where chloropyridines have historically been observed at levels just above or below the detection limit; and workers at the Dolomite Products Quarry, located downgradient of the Site where chloropyridines have historically been observed, may be exposed to groundwater seeps. Future use of the Site and the surrounding properties are anticipated to be the same as current use; future exposure pathways may include on-site construction workers exposed to surface soil and overburden groundwater, off-site construction workers exposed to overburden groundwater, and off-site commercial/industrial workers who may be exposed to groundwater used as industrial process water.

Based on additional investigations and monitoring conducted since the 2000 FS, the anticipated routes of exposure have changed. On-site subsurface soils still exceed standards, criteria, and guidance (SCG) values (presented in **Appendix A**) but are located below pavement near the soil/bedrock interface. A potential exposure pathway exists for commercial/industrial and construction workers in the event that future construction activity unearths the contaminated soil, allowing for direct contact and incidental ingestion.

Contaminants have been observed in both on- and off-site groundwater exceeding SCG values, but the site and surrounding area are served by public water that is unaffected by this contamination. The groundwater is otherwise not potable and the downgradient properties potentially affected by the off-site contamination are all commercial and industrial, so it is unlikely that a private well will be installed that would expose residents or workers to contaminated groundwater. Monitoring performed subsequent to the 2000 FS has not observed contaminants at the Erie Barge Canal, which is no longer believed to be a potential exposure pathway, and a risk assessment was performed at the Dolomite Products Quarry that determined that there was no risk to quarry workers from exposure to the quarry seep (MACTEC, 2005). However, there does still exist a potential exposure pathway for commercial/industrial and construction workers who may have direct contact with groundwater in the event of future construction work that excavates below the water table at the Site.

Soil vapor sampling has been conducted at the western and southern edges of the Site annually from 2006 to 2009, and an off-site soil vapor intrusion study was performed in 2006 on the American Recycling and Manufacturing and Firth Rixson facilities. Elevated concentrations of contaminants have been observed in on-site soil vapor, but indoor air sampling has not identified concentrations exceeding Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs) for occupational exposure. Off-site soil vapor samples did identify several contaminants resulting in $1\text{x}10^{-6}$ or greater excess lifetime cancer risk or a hazard index of 1 or greater for non-cancer risks, calculated consistent with United States Environmental Protection Agency (USEPA) guidance. However, soil vapor intrusion was not definitively identified as the sole or primary source of contamination and the observed concentrations were well below OSHA PELs (Arch Chemicals, Inc., 2006b). This monitoring suggests there is no current risk to off-site workers because indoor air concentrations both on- and off-site were observed below applicable

OSHA PELs. However, there is still a potential for inhalation of contaminants for commercial/industrial and construction workers who may be exposed due to future construction activity or change in use of the buildings.

The results of this qualitative human health exposure assessment are summarized in **Table 5-1**.

6.0 DEVELOPMENT OF REMEDIAL ACTION OBJECTIVES, AND GENERAL RESPONSE ACTIONS

6.1 Identification of Remedial Action Objectives

RAOs are the specific goals that must be achieved by the remedial actions evaluated in this FS. RAOs therefore form the basis for identifying remedial technologies and developing remedial alternatives. Remedial alternatives are intended to restore the Site to pre-disposal conditions to the extent feasible and to conform to promulgated standards and criteria that are directly applicable or that are relevant and appropriate. Selection of remedies is influenced by their ability to achieve RAOs and to conform to applicable standards and criteria and must take into account appropriate standards, criteria, and guidance (hereafter called SCGs). NYSDOH and NYSDEC have developed media-specific SCGs to identify whether contaminant concentrations pose a risk to the environment; they are included as **Appendix A**.

Conventionally, RAOs are medium-specific or operable unit-specific goals established to protect public health and the environment. The RAOs are risk-based in that they are selected to address specific potential exposure pathways for each of the identified media of concern, as identified in the risk assessment. This FS has developed RAOs that represent a comprehensive set of goals to evaluate alternatives for the protection of public health and the environment.

Soil RAOs

- Prevent ingestion/direct contact with contaminated soil
- Prevent inhalation of or exposure from contaminants volatilizing from contaminants in soil
- Prevent migration of contaminants that would result in groundwater or surface water contamination.

Groundwater RAOs

- Prevent ingestion of groundwater with contaminant levels exceeding drinking water standards
- Prevent contact with, or inhalation of volatiles, from contaminated groundwater.
- Prevent the discharge of contaminants to the surface water
- Remove the source of ground or surface water contamination.

Soil Vapor RAOs

- Mitigate impacts to public health resulting from existing, or the potential for, soil vapor intrusion into buildings at the Site

Implementation of the selected remedial alternative(s), along with institutional controls are planned to control risks for potential exposure to contaminants in soil, soil vapor, and groundwater on site. Institutional controls will be documented in a Site Management Plan and will be consistent with the recommended Alternative S2 that was identified in the 2000 FS (Arch Chemicals, Inc, 2000).

Specifically, institutional controls in the form of an environmental easement for the controlled property will consist of the following elements:

- a periodic certification of institutional and engineering controls in accordance with Title 6 of the New York Codes, Rules and Regulations (NYCRR) Part 375-1.8 (h)(3);
- allow the use and development of the property for industrial use as defined by Part 375-1.8(g);
- restrict the use of groundwater as a source of potable or process water, without necessary water quality treatment as determined by the NYSDOH or County DOH; and
- require compliance with a Site Management Plan to be approved by the NYSDEC.

6.2 Identification of General Response Actions

General response actions describe those actions that will satisfy the RAOs (USEPA, 1988). General response actions may include treatment, containment, excavation, disposal, institutional actions, or a combination of these. Like RAOs, general response actions are medium-specific. General response actions include those applicable to human health and environmental exposure as well as groundwater source control and migration at the Site. The following general response actions would address the RAOs identified for the Site:

- no further action – continued groundwater containment, extraction, and treatment (groundwater migration)
- enhanced extraction (groundwater migration with source control)
- in-situ groundwater treatment (groundwater source control)
- institutional controls (soil, soil vapor, and groundwater exposure)

No further action would involve no additional measures beyond operation and maintenance of the current system to extract and treat contaminated groundwater. Enhanced extraction would extract more contaminated groundwater using additional pumping wells to supplement the existing extraction and treatment system. In-situ groundwater treatment would treat contaminated groundwater in-place, within the saturated overburden and bedrock.

6.3 Extent of Media Requiring Remedial Action

This subsection identifies the extent of contaminated media to which the RAOs and general response actions identified above, and the remedial alternatives to be developed in **Section 8.0**, will apply. Due to lower VOC concentrations off site, the horizontal extent of VOC contamination targeted by the active portions of remedial action focuses on the areas on site having the highest VOC mass (e.g. in the Well B-17 Area and other areas on site). These areas are generally within the 1,000 microgram per liter (µg/L) concentration contour as shown on **Figure 3-1**. Other media and areas where on-site groundwater concentrations are greater than SCGs (presented in **Appendix A**) outside of the 1,000 µg/L concentration contour will be addressed with institutional controls to prevent exposure. Specific locations of concern for VOC contamination include wells PZ-106, PZ-107, PW-15, PW-17 and B-17.

The horizontal extent of chloropyridine contamination targeted by the active portions of remedial action focuses on the areas of highest chloropyridine mass. These areas are generally within the 10,000 µg/L concentration contour as shown on **Figure 3-2**. Areas of on-site groundwater concentrations greater than SCGs (presented in **Appendix A**) outside of the 10,000 µg/L concentration contour will be addressed with institutional controls to prevent exposure. Specific locations of concern for chloropyridine contamination include wells B-17, BR-8, PW-15, PW-16, and PZ-106.

The vertical extent of groundwater contamination for both VOCs and chloropyridines extends throughout the saturated zone and into bedrock. Remedies will generally target the saturated overburden and the first five to ten feet of underlying bedrock. The significant fracturing of this upper zone of weathered bedrock contains the majority of bedrock contamination.

The horizontal extent of soil contamination subject to RAOs for both VOCs and chloropyridines is shown on **Figures 3-1 and 3-2**. In the RI, the extent of soil contamination was evaluated in six different potential release areas indicated on **Figure 3-1**, but active treatment alternatives focus on what has been identified as the main source area by well B-17. Soil contamination outside the source area will be addressed with institutional controls to prevent exposure.

The vertical extent of soil contamination for both VOCs and chloropyridines is primarily confined to depths between 8 and 18 feet below ground surface as identified in the RI (ABB, 1995). Active remedy components will target this interval; contaminated soils outside of the treatment interval will be addressed with institutional controls to prevent exposure.

Soil gas sampling performed as part of the RI suggested that concentrations of VOCs in soil vapor mimicked the distribution of VOCs in the overburden groundwater (ABB, 1995). Subsequent indoor air and subslab sampling identified that soil vapor potential migration pathways were present in on- and off-site buildings but that soil vapor was not the sole or primary source of indoor air contamination (Arch Chemicals, Inc., 2006b). As a result, no immediate risk is posed by soil vapor, which will be addressed by institutional controls to prevent exposure.

Remedial alternatives will be developed in **Section 8.0** with consideration for the horizontal and vertical distribution of the contaminants.

7.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES

This section describes the identification and screening of potential remedial technologies. Technologies are identified for the purpose of attaining the RAOs established in **Subsection 6.1**. Identified technologies correspond to the categories of general response actions described in **Subsection 6.2**.

Following identification, candidate technologies are screened based on applicability to site- and contaminant-limiting characteristics. Potential technologies representing the range of general response actions are considered. The screening produces an inventory of suitable technologies that can be assembled into remedial alternatives capable of mitigating actual or potential risks at the Site.

The 2000 FS (Arch Chemicals, Inc., 2000) and subsequent indoor air sampling on and off site (Arch Chemicals, Inc., 2006a) has shown that there is no risk posed by soil vapor unless workers are disturbing the building slab. Rather than generate several candidate technologies for screening, institutional controls was selected as the presumptive technology to address soil vapor.

7.1 Technology Identification

Remedial technologies presumed to be effective at treating common contaminant groups were identified to generate the list of applicable remedial technologies and associated process options presented in **Table 7-1**.

7.2 Technology Screening

The technology screening process reduces the number of potentially applicable technologies and process options by evaluating factors that may influence process-option effectiveness and implementability. This overall screening is consistent with guidance for developing and evaluating remedial alternatives for an FS under DER-10 (NYSDEC, 2010). Effectiveness and implementability are incorporated into two screening criteria: waste- and site-limiting characteristics. Waste-limiting characteristics consider the suitability of a technology based on contaminant types, individual compound properties (e.g., volatility, solubility, specific gravity, adsorption potential, and biodegradability), and interactions that may occur between mixtures of compounds. Site-limiting characteristics consider the effect of site-specific physical features on the implementability of a technology, such as site topography and geology, the location of buildings and underground utilities, available space, and proximity to sensitive operations. Technology screening serves the two-fold purpose of screening out technologies whose applicability is limited by waste- or site-specific considerations while retaining as many potentially applicable technologies as possible.

Table 7-1 presents the technology-screening process. Technologies and process options judged ineffective or prohibitively difficult to implement were eliminated from further consideration. Among those technologies in this table that were eliminated from further evaluation was in-situ treatment which was evaluated and considered in the FS Addendum (Arch Chemicals Inc., 2015). The technologies retained following screening represent an inventory of technologies considered most suitable for remediation of soil at the Site and may be used alone or integrated with other technologies to develop remedial alternatives.

8.0 DEVELOPMENT AND PRELIMINARY SCREENING OF ALTERNATIVES

The retained technologies identified in **Table 7-1** are considered technically feasible and applicable to the waste types and physical conditions at the Site. These medium-specific technologies were assembled into potential site-specific remedial alternatives capable of achieving the RAOs for the contaminated soil, groundwater and soil vapor requiring remediation.

8.1 Development of Remedial Alternatives

The retained remedial technologies for groundwater have been composed into the following remedial alternatives:

- Alternative 1: Groundwater Extraction
- Alternative 2: Horizontal Groundwater Extraction Wells
- Alternative 3: Hydraulic Fracturing and Additional Groundwater Extraction Wells

Instititional controls would be required for and be a component of each alternative to mitigate potential exposure to other contaminated media (i.e., soil and soil vapor).

8.1.1 Alternative 1: Continued Groundwater Extraction

Alternative 1 was developed as a baseline against which to compare the other remedial alternatives. This alternative involves no further action to reduce groundwater contamination beyond operation, maintenance, and monitoring of the existing groundwater extraction and treatment system.

As discussed in the 2000 FS, Arch has operated a groundwater extraction system since 1983 to intercept and contain contaminants on site. Initially the extraction system addressed on-site overburden groundwater, but was subsequently expanded to capture on-site shallow bedrock groundwater as well. Presently, nine pumping wells are operated within the site property boundary: BR-5A, BR-7A, BR-9, PW-13, PW-14, PW-15, PW-16, PW-17, and BR-127. The average total extraction flow rate from these wells generally ranges from 25 to 30 gallons per minute (gpm). Extracted groundwater is treated by granular activated carbon prior to discharge to the Monroe County Pure Waters POTW.

Arch personnel operate the existing groundwater extraction system, performing periodic or as-needed maintenance. Long-term monitoring activities include collection of groundwater samples from 28 on-site monitoring and extraction wells, 17 off-site groundwater monitoring wells, and three off-site surface water sample points for VOC and/or SVOC laboratory analysis. Semiannual reports are prepared describing the results of the long-term monitoring.

Institutional and management controls would be put in place to prevent exposure to on-site contaminated soil and soil vapor. Arch institutes a safety plan that protects workers engaging in activities where exposure is a risk, but further institutional controls restricting access to contaminated media will be needed under this alternative to eliminate potential exposure pathways. These controls would be developed as part the site management plan to be implemented once the final remedy is in place.

8.1.2 Alternative 2: Install Horizontal Groundwater Extraction Wells

Alternative 2 consists of:

- installation of up to two horizontal groundwater extraction wells
- long-term groundwater monitoring
- operation, maintenance, and monitoring of the groundwater extraction system
- institutional and management controls

Alternative 2 includes installation of up to two horizontal groundwater extraction wells to improve groundwater capture at the western property boundary and to increase contaminant mass removal rates. The use of horizontal extraction wells as part of an expanded network of groundwater extraction wells will accelerate the removal and treatment of remaining groundwater contamination.

Figure 8-1 shows the conceptual layout of the proposed horizontal groundwater extraction wells. One horizontal extraction well would be oriented approximately east-west to improve contaminant mass removal by targeting areas of high chloropyridine concentrations generally found between monitoring well PZ-106 and the rear of the main operating facility building near monitoring well B-17. Historically, extraction well PW-10 operated near well B-17 but ceased to be productive and no longer extracts groundwater; replacing this well with capture influence from a horizontal well would be consistent with previous efforts to capture contaminants near well B-17, which historically has exhibited the highest chloropyridine concentrations. Installing the well near PZ-106 would target an area of high chloropyridine concentrations and target the high concentrations of VOCs in that area, and would supplement former extraction well PW-14, which was taken out of service due to poor performance, and BR-127 which is intended to capture groundwater to the east. The horizontal well would extract groundwater from beneath the Arch facility and directly target the suspected chloropyridine source area. This well would be a 6-inch diameter screened well along an interval of approximately 400 feet and installed approximately 5 feet below the top of bedrock, or approximately 25 feet bgs.

If deemed necessary, a second well would be oriented north-south along the western property boundary to better intercept groundwater flow off the site and to improve contaminant mass removal by targeting high concentrations of chloropyridines near well BR-8. This alternative assumes a 6-inch diameter screened well along an interval of approximately 370 feet and installed approximately 5 feet below the top of bedrock, or 20-30 feet bgs. The well would be installed by drilling a pilot bore through an entrance point approximately 125 feet from the start of the well screen, allowing a five-to-one slope for the boring from ground surface to target well depth. The pilot bore would proceed along the target well depth and length before ascending to the ground surface, again at a five-to-one ratio. Walkover locating technology would track the location of the drill head throughout installation of the boring. The permanent high density polyethylene well screen and casing would then be pulled through the exit point back to the entrance, and a 50 gpm submersible pump would be installed in the well screen. **Appendix B** provides calculations for estimated early time groundwater yield in the extraction well and pump sizing to deliver extracted groundwater to a groundwater treatment system. Early time flow estimates were calculated assuming a drawdown of 5 feet at flow rates of 20, 30 and 50 gpm. While these flow rate estimates may not be valid for longer term steady-state flow, they are useful in providing baseline estimates for a single horizontal well with the given dimensions. Longer term flow rates for a single horizontal well intended to achieve hydraulic capture would not be expected to exceed the range of early time flow estimates (20 to 50 gpm).

The east-west well may be more challenging to install than the north-south well. Walkover location technology would be difficult to use due to interference from piping, control circuits, and other industrial infrastructure present on top of the well path. This would require use of a navigation system such as a gyroscopic steering tool, in turn requiring a larger rig to support use of the tool. The surface obstructions to setting up both entrance and exit points for the east-west well would likely require this well to be installed blind, using a single well-end. Blind wells are technically more challenging to install than double-ended wells.

The well lengths, sizes, and locations proposed above are for purposes of evaluation and costing in this report. Actual dimensions and locations would need to be finalized as part of the design phase. These design details would be based on a more detailed evaluation of field and geologic conditions than is within the scope of this report.

The addition of the horizontal wells may either supplement or eliminate the need for the current array of extraction wells. Therefore, a new or upgrade of the current groundwater treatment system has been assumed using two granular activated carbon (GAC) vessels in series to accommodate increased flow. Usage rates and change out frequencies are assumed to be similar to current system usage for costing purposes. Given the higher yield expected for each extraction well, it is assumed that approximately 500 feet of new above ground discharge piping would be required to transport water from the well pumps to the on-site treatment plant. Operation, monitoring, and maintenance of the groundwater extraction system would be similar to that described for Alternative 1.

Additional groundwater monitoring wells may be added to the existing network of locations that are sampled semiannually. Average daily extraction flow rates would also be recorded to evaluate extraction well performance. This combination of flow and analytical data would allow Arch to estimate increased contaminant mass removal rates. Long-term monitoring and reporting would be similar to that described for Alternative 1.

Similar to Alternative 1, institutional and management controls would be put in place to prevent exposure to on-site contaminated soil and soil vapor.

8.1.3 Alternative 3: Hydraulic Fracturing and Additional Groundwater Extraction Wells

Alternative 3 consists of:

- hydraulic fracturing along three alignments within the contaminant source area
- installation of one groundwater extraction well within each fractured alignment
- long term groundwater monitoring
- operation, maintenance, and monitoring of the enhanced groundwater extraction system
- institutional and management controls

Alternative 3 includes hydraulic fracturing, commonly referred to as fracking, of shallow bedrock along three alignments within the contaminant source area. Fracking uses pressurized fluid to open and develop fractures within bedrock to increase flow through the fractures. Hydraulic fracturing offers a significant advantage over the use of explosives at the Site because it can be used in close proximity to structures and operational areas with less risk of adverse (structural) impacts.

Fracking for this alternative would use water injected at low volumes and lower pressures to further open and develop existing fractures in bedrock, contrasted with fracking associated with the oil and natural gas industries, which typically uses chemical additives at greater depths under higher fluid volumes and pressures. Fracking for this alternative more closely resembles a packer test than the fracking done by the oil or natural gas industries. High pressure buildup is assumed to be unlikely given the shallow fracking depth into weathered bedrock. It is assumed that health and safety concerns would be minimal given the low fluid volume and pressure.

To assist with the evaluation of the feasibility of hydraulic fracturing at the Site, Arch contracted Nothnagle Drilling, Inc. (Nothnagle) to conduct a hydraulic fracturing pilot test. The objective of the pilot test was to observe if hydraulic fracturing would improve the bulk permeability and connectivity of fractures within a historically low yield portion of the shallow bedrock. From September 17 through September 27, 2012, Nothnagle installed 12 shallow bedrock borings on site, as shown on Figure 8-2. At each of these 12 locations, Nothnagle drilled a boring at a depth ranging from 35 to 40 feet and installed a packer system to segregate a portion of the bedrock for testing. Nothnagle then performed packer testing and hydraulic fracturing to observe how the local bedrock formation would respond and if communication occurred at other nearby wells or borings. Pumping rates and pressures were increased incrementally at each well from 10 pounds per square inch (psi) up to typically 40 psi to observe possible communication with other wells and how well yield increased with pressure. Select wells were then pumped at lower pressures again to observe if the higher pressures had increased the formation's permeability. Drilling forms, field notes, and a table summarizing the observations during fracking field activities are provided in **Appendix C**.

The results of the pilot test suggest that hydraulic fracturing at the Site could improve communication between existing and future groundwater extraction wells and that hydraulic fracturing could improve the pumping yield for groundwater extraction wells on site. However, the heterogeneous nature of the existing fractures in shallow bedrock creates uncertainty in terms of how effective hydraulic fracturing will be at any given well point. Of the 12 borings, six demonstrated communication with other nearby wells when drilling and testing. Tests at borings HF-5, HF-7, HF-10, HF-11, and HF-1 in particular resulted in strong and sometimes violent reactions at nearby wells; however, this may have been due to pre-existing fractures in the shallow bedrock zone. **Figure 8-3** shows the extent of influence observed at each boring. Of the five borings installed that were retested at lower pressures after fracturing, four indicated a likely increase in formation permeability. Boring HF-5 pumping rates increased by 41%, Boring HF-1 and boring HF-3 pumping rates increased by 50%, and boring HF-12 pumping rates increased by 76%. One boring, HF-6, showed a likely decrease in permeability with a pumping rate drop of 25%.

Despite the increase in pumping rates during the pilot test, the fracturing appears to have had no observable effect on the performance of pumping wells PW-14 (no longer in use as of Spring 2016) and PW-15, both located adjacent to the fracked borings. **Figures 8-4** and 8-5 show weekly pumping quantities for wells PW-14 and PW-15 from December 2008 to May 2014. The fracking pilot test in September 2012 did not increase pumping rates at wells PW-14 and PW-15 above historical trends since December 2008. In addition, well PW-17, which was installed to help control migration of groundwater in the fractured zone during the pilot test, has performed poorly since installation, averaging less than 1 gpm throughout its operation history. Operations and maintenance issues related to pumps, well scaling, etc., historically have and continue to influence extraction rates more than poor connectivity within the bedrock, and the fracking pilot test has likely played little or no part in affecting groundwater extraction performance.

Overall, the pilot test suggests that hydraulic fracturing on site could improve hydraulic communication between bedrock wells and possibly improve the performance of the groundwater extraction system. However, the lack of improved performance at PW-14 and PW-15, combined with the inconsistent results within the pilot test borings themselves, create uncertainty in estimating how individual wells or borings would respond to fracking. Also, it is not feasible to control the propagation of fractures, and there is the potential of increasing vertical flow within bedrock that could lead to possible increases in off-site migration of site contaminants through deeper fracture zones in the rock. This alternative would require a high factor of safety in estimating how many fracturing points are required to achieve improve well yields and hydraulic communication in the target extraction zones, which could increase the risk of vertical fracturing and potentially increased off-site migration.

For the conceptual design of a hydraulic fracturing program, two new alignments would be proposed: a northern alignment on a 125-foot east-west lateral along well B-17 and a middle 125-foot alignment west of the pretreatment building. The pilot test alignment would serve as a third alignment approximately between wells BR-3 and PZ-106. **Figure 8-6** shows the conceptual design layout for Alternative 3. Based on the inconsistent influence observed in the pilot test at 20-foot intervals, a spacing interval of 10 feet would be used in the preferential east-west groundwater flow direction for the north and middle alignments. The target depth for fracking is the upper 10 to 15 feet of weathered bedrock, where groundwater flow is already higher due to existing fractures. Temporary coreholes would be installed and fracked along the additional alignments. New groundwater extraction wells would be installed within each alignment to capture groundwater from these fractured zones.

This expanded network of fractured coreholes and groundwater extraction would be intended to accelerate the removal of remaining groundwater contamination. New extraction wells would be installed in bedrock as 6-inch diameter corehole wells to an average depth of 30 feet into bedrock, or 50 feet total below ground surface.

It is assumed that the on-site treatment plant capacity will not have to be expanded to accommodate these three new wells. Operation, monitoring, and maintenance of the enhanced groundwater extraction system would be similar to that described for Alternative 1.

Three additional groundwater extraction wells will be added to the existing network of locations that are sampled semiannually. Average daily extraction flow rates would also be recorded to evaluate extraction well performance. This combination of flow and analytical data will allow Arch to estimate increased contaminant mass removal rates. Long-term monitoring and reporting would be similar to that described for Alternative 1.

Institutional and management controls would be institutued to prevent exposure to on-site contaminated soil and soil vapor and would be similar to those described for Alternative 1.

8.2 Preliminary Screening of Alternatives

This Subsection presents a preliminary screening of the developed remedial alternatives. Consistent with DER-10, the developed remedial alternatives are screened on the basis of whether they are technically implementable (Implementability) for the Site and whether they can meet the RAOs (Effectiveness). Additionally, based upon available information, the relative cost of each remedial alternative is also evaluated. Those remedial alternatives which are not technically implementable, would not achieve RAOs, or would incur costs significantly higher than other remedial alternatives without providing greater effectiveness or implementability are not evaluated further in the FS.

Screening of remedial alternatives is presented in **Table 8-1**. The No Further Action alternative is not evaluated according to the screening criteria; it passes through screening to be evaluated during the detailed analysis as a baseline for other retained alternatives.

Alternative 2: One or two horizontal groundwater extraction wells would be effective in the long-term at reducing the concentration of chloropyridines and VOCs in the contaminant source area and at property boundaries. and Historically, the groundwater extraction system has removed significant quantities of contaminant mass. For example, approximately 82 pounds of VOCs and 2,400 pounds of chloropyridines were removed between December

2017 and June 2018 (Arch Chemicals, Inc., 2018). This alternative uses similar methods as the current remediation system at the Site and would have limited impact on facility operations. Technical issues with implementing this alternative primarily include the installation of the horizontal wells to capture groundwater in bedrock with predominantly horizontal fractures. Since the wells and fractures would need to intersect on the same horizontal plane, it is possible a horizontal well could miss significant water bearing zones. In effect the vertical capture zone is likely to be limited by the vertical hydraulic conductivity, which is expected to be lower than horizontal conductivity in shallow bedrock.

There is an inherent risk of bore-hole collapse when installing a horizontal well and this is particularly the case for single-ended wells since the hole is left unprotected between borehole completion and well screen/casing installation.

Costs associated with installing horizontal groundwater extraction wells are expected to be moderate.

Alternative 3: Hydraulic Fracturing and Additional Groundwater Extraction Wells would be effective in the long term at reducing the concentration of chloropyridines and VOCs, although the potential benefit of hydraulically fracturing bedrock within the contaminant source area is difficult to evaluate. This alternative would also continue to extract contaminated groundwater from the existing extraction wells. While a successful fracturing program could achieve significant short-term increases in contaminant mass removal, the pilot test indicates uncertainty with respect to the effectiveness of hydraulic fracturing. There is also a risk of increased vertical fracturing, which could lead to unwanted pathways for off-site migration of site contaminants through deeper bedrock fractures. This alternative could be readily implemented, as it uses known and readily available technology along with the existing extraction and treatment system; however, existing facility infrastructure would limit the amount of site area that could be accessed for hydraulic fracturing. Costs associated with this alternative are relatively moderate with a high contingency risk based on the uncertain number of hydraulic fracturing wells required to achieve communication between the developed bedrock fractures and the new extraction wells.

The remaining remedial alternatives have been retained for detailed analysis in **Section 9.0** to at least provide an estimated cost analysis comparison between the alternatives.

9.0 DETAILED ANALYSIS OF ALTERNATIVES

This section presents the detailed analyses of remedial action at the Site. The detailed analysis is intended to provide decision-makers with the relevant information needed for selection of a site remedy. The detailed description of technologies or processes used for each alternative includes, where appropriate, a discussion of limitations, assumptions, and uncertainties for each component. The descriptions provide a conceptual design of each alternative and are intended to support alternatives-comparison and cost-estimation.

The detailed analysis of each alternative includes evaluation using the first eight evaluation criteria identified in DER-10 (NYSDEC, 2010) and §375-1.8(f) (New York State [NYS], 2006), as presented in the following paragraphs.

Compliance with Standards, Criteria, and Guidance. Compliance with SCGs considers whether or not a remedy will meet applicable environmental laws, regulations, standards, and guidance. SCGs for the Site are identified along with a discussion of whether or not the remedy will achieve compliance. For those SCGs that will not be met, a discussion and evaluation of subsequent impacts and whether waivers are necessary is presented. Location- and Action-specific SCGs are identified for each alternative in this Section and in **Table 9.1**, and chemical-specific SCGs are presented in **Appendix A**.

Overall Protection of Public Health and the Environment. This criterion is an evaluation of the remedy's ability to protect public health and the environment, assessing how risks posed through each existing or potential pathway of exposure are eliminated, reduced, or controlled through removal, treatment, engineering controls, or institutional controls. The remedy's ability to achieve each of the RAOs is evaluated.

Short-term Effectiveness. The potential short-term adverse impacts and risks of the remedy upon the community, the workers, and the environment during the construction and/or implementation are evaluated. How the identified adverse impacts and health risks to the community or workers at the Site will be controlled, and the effectiveness of the controls, are considered. Engineering controls that will be used to mitigate short term impacts (e.g., dust control measures) are described. The length of time needed to achieve the remedial objectives is estimated.

Long-term Effectiveness and Permanence. This criterion evaluates the long-term effectiveness of the remedy after implementation. If wastes or treated residuals remain on site after the selected remedy has been implemented, the following items are evaluated:

1. magnitude of remaining risk
2. adequacy of the engineering and institutional controls intended to limit the risk
3. reliability of these controls
4. ability of the remedy to continue to meet RAOs in the future.

Reduction of Toxicity, Mobility, or Volume with Treatment. The remedy's ability to reduce the toxicity, mobility or volume of site contamination is evaluated. Preference should be given to remedies that permanently and significantly reduce the toxicity, mobility, or volume of site wastes.

Implementability. The technical and administrative feasibility of implementing the remedy is evaluated. Technical feasibility includes the difficulties associated with remedy construction and the ability to monitor the remedy's effectiveness. For administrative feasibility, the availability of the necessary personnel and material is evaluated along with potential difficulties in obtaining specific operating approvals, access for construction, or other issues.

Land Use. The current, intended, and reasonably anticipated future land uses of the Site and its surroundings will be considered in the evaluation of remedial alternatives.

Cost. Capital and Operation, Maintenance and Monitoring costs are estimated for the remedy and presented on a present worth basis.

9.1 Cost Analysis Procedures

Costs presented in this FS are intended to be within the target accuracy range of minus 30 to plus 50 percent of actual cost (USEPA, 1988). Costs are presented as a present worth and as a total cost for a 30-year period.

A summary of the costs for each alternative identifying capital and net present worth (NPW) as originally estimated in 2015 are included in each alternative's cost description. In order to update these costs to 2019 dollars, a total inflation factor of 6.5 percent should be applied over these 4 years. This factor is calculated based on financial requirements for hazardous waste management facilities (NY State 6 CRR-NY 373-2.8) using Implicit Price Deflator for Gross National Product published by the U.S. Department of Commerce in its Survey of Current Business.

Each cost estimate includes a present worth analysis to evaluate expenditures that occur over different time periods. The analysis discounts future costs to a NPW and allows the cost of remedial alternatives to be compared on an equal basis. NPW represents the amount of money that, if invested now and disbursed as needed, would be sufficient to cover costs associated with the remedial action over its planned life. A discount rate of 5 percent was used to prepare the cost estimates per NYSDEC guidance (USEPA 1988).

Consistent with USEPA FS cost estimating guidance (USEPA, 2000), the remedial alternative cost estimates include costs for project management, remedial design, construction management, technical support, and scope contingency.

Project management includes planning and reporting, community relations support during construction or operations and maintenance (O&M), bid or contract administration, permitting (not already provided by the construction or O&M contractor), and legal services outside of institutional controls.

Remedial design applies to capital cost and includes services to design the remedial action. Activities that are part of remedial design include pre-design collection and analysis of field data, engineering survey for design, treatability study/pilot-scale testing, and the various design components such as design analysis, plans, specifications, cost estimate, and schedule.

Construction management applies to capital cost and includes services to manage construction or installation of the remedial action, except any similar services provided as part of regular construction activities. Activities include review of submittals, design modifications, construction observation or oversight, engineering survey for construction, preparation of O&M manual, documentation of quality control/quality assurance, and record drawings.

Technical support during O&M includes services to monitor, evaluate, and report progress of remedial action. This includes oversight of O&M activities, update of O&M manual, and progress reporting and is generally between 10 percent and 20 percent of total annual O&M costs depending on complexity of the remedial action (USEPA, 2000).

Scope contingency represents project risks associated with the feasibility-level of design presented in this Report. This type of contingency represents costs, unforeseeable at the time of estimate preparation, which are likely to become known as the remedial design proceeds. Scope contingency ranges from 10 to 25 percent, with higher values appropriate for alternatives with greater levels of cost growth potential (USEPA, 2000).

Project management, remedial design, and construction management costs presented in this Report are based upon the following matrix presented in the USEPA FS cost estimating guidance (USEPA, 2000).

Professional and Technical Costs as Percentage of Direct Costs					
Indirect Cost	< $100K (%)	$100K-$500K (%)	$500K-$2M (%)	$2M-$10M (%)	>$10M (%)
Project Management	10	8	6	5	5
Remedial Design	20	15	12	8	6
Construction Management	15	10	8	6	6

The following subsections present a conceptual design and cost estimate for each of these remedial alternatives and a discussion of each alternative relative to the evaluation criteria as set forth in NYCRR Part 375 (NYS, 2006).

9.2 Alternative 1: Continued Groundwater Extraction

This alternative would continue to operate the existing groundwater extraction and treatment system.

Compliance with Standards, Criteria, and Guidance. This alternative does not meet chemical-specific SCGs in the short term because it does not address all groundwater contamination in excess of 6 NYCRR Parts 700-706 Water Quality Standards (NYSDEC, 1998). However, in the long term this alternative is expected to ultimately achieve class GA groundwater standards.

Overall Protection of Public Health and the Environment. The existing groundwater extraction and treatment system already provides protection of human health and the environment by controlling migration of groundwater contaminants from the source area and eliminating and controlling potential exposure pathways through removal and treatment of contaminated groundwater. Institutional and management controls will mitigate risks for contaminants in soil and soil vapor that are above SCGs. This remedial alternative is expected to achieve the RAOs in the long term.

Short-term Effectiveness. This alternative does not include construction or other activities that would result in potential short-term adverse impacts and risks to the community, workers, or the environment during implementation. Due to the complexity of the hydrogeologic setting, fate and transport models are not likely to be effective in projecting remediation timeframes, particularly for chloropyridines, which are not expected to naturally attenuate over time, and have therefore not been attempted as part of this FS.

Long-term Effectiveness and Permanence. This remedy is only expected to meet RAOs for VOCs with continued extraction of contaminant mass; this is supported by the observed reduction of the VOC plume over time. Once the groundwater has met RAOs for VOCs, it is unlikely to rebound. Management controls will remain in place to eliminate the potential for exposure to contaminants for future site use, including during construction activities at the Site, but the potential for off-site exposure to contaminated groundwater exists. The Site and surrounding areas are served by public water and the groundwater is otherwise not potable, so it is unlikely that a downgradient site installs a private well and creates an exposure pathway, but it remains a possibility.

Reduction of Toxicity, Mobility, or Volume with Treatment. This alternative would reduce the mobility and volume of contaminants through groundwater extraction and ex-situ treatment with granular activated carbon.

Implementability. No additional actions would be conducted. Therefore, there are no added technical difficulties associated with this alternative.

Land Use. Given the existing management controls, groundwater containment, and anticipated continued operation of the chemical manufacturing facility, this alternative would be compatible with current and foreseeable future land use.

Cost. Alternative 1 has no additional capital costs. Expected annual operation, maintenance, and monitoring costs related to the extraction wells total approximately $325,000, assuming that 2013 O&M costs and annually budgeted monitoring costs represent future system costs. The NPW of this Alternative is $4,996,000. A summary of the costs associated with this alternative is presented in **Table 9-2**. These costs assume 30 years of further operation. Detailed cost analysis backup is provided in **Appendix D**.

9.3 Alternative 2: Horizontal Groundwater Extraction Wells

Alternative 2 consists of the following components:

- design and installation of up to two horizontal groundwater extraction wells
- long-term groundwater monitoring
- operation, maintenance, and monitoring of the groundwater extraction system
- institutional and management controls

Design and Installation of up to Two Horizontal Groundwater Extraction Wells. In order to improve hydraulic control at the western property boundary and increase contaminant mass removal rates at the source area, the current network of groundwater extraction wells would be replaced or expanded with the addition of up to two new horizontal wells as shown on **Figure 8-1**. Based on early time flow estimate calculations for a conservative well screen length of 500 feet (**Appendix B**) and current total extraction rates of up to 40 gpm for the site, flow rates ranging from 20 to 50 gpm are expected along the western property line. To conservatively estimate equipment sizing and cost, this alternative assumes that equipment should be sized to handle flows of up to 50 gpm per well, or up to 100 gpm total. Prior to design of the wells, a pre-design investigation including packer testing and borehole geophysical logging of open corehole wells BR-9, BR-102, PW-16, BR-8, PW-13, and BR-7A would be completed for the north-south well alignment. Similarly, logging and packer tests would be completed for wells BR-127, PW-15, and PW-17 along the east-west alignment. Additional bedrock boreholes may also be needed to evaluate the bedrock surface topography. These investigations would serve to identify the primary water bearing zones and support decision making for final elevation of the horizontal wells.

Long Term Groundwater Monitoring. The new groundwater extraction wells will be incorporated into the existing network of wells that are monitored and sampled semiannually. Additional vertical monitoring wells will be installed to perform long term monitoring - the exact number and placement of the wells will be decided during design. Groundwater samples will be analyzed for VOCs and chloropyridines. Average daily extraction flow rates will be recorded to evaluate extraction well performance. This combination of data will be used to estimate the increased contaminant mass removal from the source area. Semiannual reports will be prepared detailing the results of the long-term monitoring.

Operation, Maintenance, and Monitoring of the Groundwater Extraction Wells. While it may be possible to connect the new wells to the existing on-site treatment plant, this alternative conservatively assumes that separate piping and treatment systems will be installed. New above ground piping would convey extracted groundwater from the wells to GAC vessels for treatment prior to sewer discharge. While the availability of space for new GAC vessels in an existing on-site building or for a newly constructed treatment building is unknown, this alternative assumes that a new building will be constructed on site. Opportunities to reduce system footprint and costs by using the existing on-site buildings and treatment equipment would be evaluated during the design phase. In addition, the high anticipated flow rates from the horizontal wells may result in a substantial decrease in flow from the existing vertical extraction wells. For the purposes of this evaluation, it is assumed that the flow from existing wells will be reduced by 50 percent, resulting in a decrease in operating costs for the existing GAC treatment system.

Institutional and Management Controls. The risk evaluation determined that there are no current exposure pathways to contaminated media on site; the purpose of the institutional and management controls is to eliminate potential exposure pathways (Arch Chemicals, Inc., 2000). Controls may include continued adherence to the plant's existing health and safety policies and implementation of deed restrictions, but the exact scope of the controls will be documented in a Site Management Plan after remedy implementation.

Compliance with Standards, Criteria, and Guidance. Similar to Alternative 1, this alternative does not meet chemical-specific SCGs in the short term because it does not address all groundwater contamination in excess of 6 NYCRR Parts 700-706 Water Quality Standards (NYSDEC, 1998). However, in the long term this alternative is expected to achieve class GA groundwater standards.

Overall Protection of Public Health and the Environment. This remedial alternative protects public health and the environment by controlling migration of groundwater contaminants from the source area and eliminating and controlling potential exposure pathways through removal and treatment of contaminated groundwater and institutional controls for soil and soil vapor. This remedial alternative is expected to achieve the RAOs for groundwater, soil, and soil vapor in the long term.

Short-term Effectiveness. This alternative includes activities that would result in potential short-term adverse impacts and risks to workers during installation of the new extraction wells. However, proper health and safety practices can control these risks. The time period to fully implement this alternative is estimated to be approximately one year, but the complexity of the hydrogeologic setting and the nature of the contaminants make it difficult estimate remediation time frames (as in Alternative 1). The increased extraction rate should decrease the time required to meet RAOs, so the length of time needed to achieve remedial objectives is expected to be shorter than Alternative 1.

Long-term Effectiveness and Permanence. This remedy is expected to meet RAOs in the future due to enhanced extraction of contaminant mass and improved hydraulic containment of the contaminant plumes; this is supported by the observed reduction of the VOC plume over time. The ability of Alternative 2 to extract groundwater directly from the areas of highest contaminant concentration should reduce the time to meet RAOs and the remaining risk before meeting RAOs. Once the groundwater has met RAOs for VOCs, it is unlikely to rebound. Institutional and management controls will be put in place to eliminate the potential for exposure to contaminants for future site use, including during construction activities at the site, but the potential for off-site exposure to contaminated groundwater from a private well remains, as in Alternative 1.

Reduction of Toxicity, Mobility, or Volume with Treatment. This alternative would reduce the mobility and volume of contaminants through groundwater extraction and ex-situ treatment with granular activated carbon.

Implementability. The continued operation, maintenance, and monitoring of the groundwater extraction system would not be technically difficult to implement. Issues with implementing this alternative primarily include the installation of one or two horizontal wells. Drilling rates in fractured rock can be slow, and the possibility of borehole collapse exists both for fractured zones and for heterogeneous glacial till in the overlying soils. Installation of an east-west well would be difficult due to the existing industrial infrastructure overlying the proposed well path and limited space for well entrance and exit points. In addition, since the wells and fractures would need to intersect on the same horizontal plane, it is possible a horizontal well could miss significant water bearing zones.

Land Use. Given the existing management controls, groundwater containment, and anticipated continued operation of the chemical manufacturing facility, this alternative would be compatible with current and foreseeable future land use.

Cost. The capital cost of Alternative 2 is $1,094,000, for the installation of twonew horizontal groundwater extraction wells and a groundwater treatment system. Annual operation, maintenance, and monitoring costs related to the new extraction wells total approximately $452,000 for years 1 through 20, assuming that 2010 operations and maintenance costs and annually budgeted monitoring costs represent future system costs, and $97,000 for years 21 through 30, assuming that extraction could be shut down after 20 years and only semiannual monitoring costs remain. Assuming that the horizontal wells yield a 50% reduction in flow from the existing wells, operations and maintenance costs of the existing system have been reduced to one carbon changeout per year instead of two. The NPW of this Alternative is $7,011,000. A summary of the costs associated with this alternative is presented in **Table 9-3**. Remediation timeframes are difficult to accurately estimate for the complex hydrogeologic setting and the mixture of contaminants at the site; RAOs will not necessarily be achieved after that time, but using 20 years as an assumed O&M duration for the cost estimate should project a relative cost difference reflective of the anticipated difference between alternatives 1 and 2, which is anticipated to have a shorter duration due to the increased contaminant mass extraction. Detailed cost backup is provided in **Appendix D**.

9.4 Alternative 3: Hydraulic Fracturing and Additional Groundwater Extraction Wells

Alternative 3 consists of the following components:

- hydraulic fracturing along two alignments within contaminant source area
- design and installation of one groundwater extraction well per alignment

- long-term groundwater monitoring
- operation, maintenance, and monitoring of the enhanced groundwater extraction system
- institutional and management controls

Hydraulic Fracturing Along Two Alignments within Contaminant Source Area. To increase groundwater flow through the contaminant source area and facilitate increased contaminant mass removal rates, the hydraulic fracturing pilot test would be expanded with two alignments fracked within the contaminant source area. A northern alignment would extend approximately 125 feet eastward from well PW10. A southern alignment would extend approximately 125 feet west from pretreatment building. The proposed alignments target the areas of highest VOC and chloropyridine concentration that are both accessible by a drill rig and do not obstruct facility activities. Boreholes will be drilled 10 feet into bedrock along each alignment, spaced at the most cost-effective interval determined from the pilot test. This FS assumes a distance of 10 feet would be used in the preferential east-west groundwater flow direction for the north and middle alignments. Proposed fracturing alignments are shown in **Figure 8-6**.

Design and Installation of Groundwater Extraction Wells for each Alignment. To increase contaminant mass removal rates at the source area, the current network of groundwater extraction wells would be expanded with three new wells located at the western and hydraulically downgradient end of each fracking alignment. The northern alignment well would be adjacent to well PW10, the middle alignment well would be approximately between wells PW-10 and PW-15, and the southern alignment well would be adjacent to well BR-3. Assuming that fracking increases groundwater flow through the source area, the three extraction wells would increase contaminant mass removal near both the VOC and chloropyridine source areas, including contamination underneath the facility. 6-inch diameter corehole wells would be installed to a depth of 50 feet below ground surface. Well yield rates are assumed to be slightly higher than previous wells installed in this part of the Site due to the fracturing, and are estimated to range from 5 to 10 gpm each. Proposed groundwater extraction well locations are shown in **Figure 8-6.**

Long-Term Groundwater Monitoring. The new groundwater extraction wells will be incorporated into the existing network of wells that are monitored and sampled semiannually. Groundwater surface elevation measurements and groundwater samples will be taken semiannually; groundwater samples will be analyzed for VOCs and chloropyridines. Average daily extraction flow rates will be recorded to evaluate extraction well performance. This combination of data will be used to estimate the increased contaminant mass removal from the source area. Semiannual reports are prepared detailing the results of the long-term monitoring.

Operation, Maintenance, and Monitoring of the Enhanced Groundwater Extraction Wells. It is assumed that the on-site treatment plant will not have to be expanded or modified to accommodate the new extraction wells. While the pumping and conveyance system at sump P-WT-30 may need to be modified to increase its pumping capacity. This alternative assumes that the pumping and conveyance system will also not have to be expanded or modified to accommodate the new extraction wells.

Institutional and Management Controls. The risk evaluation determined that there are no current exposure pathways to contaminated media on site; the purpose of the institutional and management controls is to eliminate potential exposure pathways (Arch Chemicals Inc., 2000). Controls may include continued adherence to the plant's existing health and safety policies and implementation of deed restrictions, but the exact scope of the controls will be determined during remedial design.

Compliance with Standards, Criteria, and Guidance. Similar to Alternatives 1 and 2, this alternative does not meet chemical-specific SCGs in the short term because it does not address all groundwater contamination in excess of 6 NYCRR Parts 700-706 Water Quality Standards (NYSDEC, 1998). However, in the long term this alternative is expected to achieve class GA groundwater standards.

Overall Protection of Public Health and the Environment. This remedial alternative protects public health and the environment through controlling migration of groundwater contaminants from the source area and eliminating and controlling potential exposure pathways through removal and treatment of contaminated groundwater and institutional controls for soil and soil vapor. This remedial alternative is expected to achieve the RAOs for groundwater, soil, and soil vapor in the long term.

Short-term Effectiveness. This alternative includes activities that would result in potential short-term adverse impacts and risks to workers during the fracking program and installation of new groundwater extraction wells. However, proper health and safety practices can control these risks. There is also the potential that hydraulic fracturing could create additional pathways for off-site migration of contaminated groundwater, resulting in short-term increases in contaminant concentrations in downgradient areas. The time period to fully implement this alternative is estimated to be approximately one year, but the time period required to meet RAOs is difficult to predict, especially considering the inconsistent and uncertain results of the pilot test. Assuming the fracturing is able to achieve some measure of increased extraction, the time period is expected to be shorter than Alternative 1 and may be similar to or longer than Alternative 2.

Long-term Effectiveness and Permanence. This remedy is expected to meet RAOs in the future due to increased extraction of contaminant mass and improved hydraulic containment of the contaminant plumes; this is supported by the observed reduction of the VOC plume over time. However, the location of the contamination beneath the building and the limited access to initiate fractures inhibit the ability of the remedy to target the source area, increasing the estimated treatment time and the remaining risk. As in Alternative 2, institutional and management controls will be put in place to eliminate the potential for exposure to contaminants for future site use, including during construction activities at the site, but the potential for off-site exposure to contaminated groundwater from a private well remains, as in Alternative 1. In addition, there is the potential of increasing vertical flow within bedrock that could lead to possible increases in off-site migration of site contaminants through deeper fracture zones in the rock. There is no way to eliminate the risk of uncontrolled fracturing, as there is no way to control the propagation of fractures, but it can be mitigated by being conservative in estimating the necessary number of fracture points to increase connectivity in the area.

Reduction of Toxicity, Mobility, or Volume with Treatment. This alternative would reduce the mobility and volume of contaminants through groundwater extraction and ex-situ treatment with granular activated carbon.

Implementability. Fracking the shallow bedrock on site, installing new extraction wells, and continued operation, maintenance, and monitoring of the groundwater extraction system would not be technically difficult to implement, although it is limited to accessible areas of the Site.

Land Use. Given the existing management controls, groundwater containment, and anticipated continued operation of the chemical manufacturing facility, this alternative would be compatible with current and foreseeable future land use.

Cost. The capital cost of Alternative 3 is $224,000 for hydraulic fracturing of bedrock and new groundwater extraction wells. Annual operation, maintenance, and monitoring costs related to the new extraction wells total approximately $325,000 for years 1 through 25, assuming that 2010 operations and maintenance costs and annually budgeted monitoring costs represent future system costs, and $97,000 for years 26 through 30, assuming that only semiannual monitoring costs remain. The NPW of this Alternative is $4,805,000. A summary of the costs associated with this alternative is presented in **Table 9-4**. These costs assume 25 years of further operation, maintenance and monitoring, and an additional 5 years of semiannual monitoring after that. Remediation timeframes are difficult to accurately estimate for the complex hydrogeologic setting and the mixture of contaminants at the site; RAOs will not necessarily be achieved after that time, but using 25 years as an assumed O&M duration for the cost estimate should project a relative cost difference reflective of the anticipated difference between Alternatives 1, 2, and 3, which is anticipated to have a shorter duration than Alternative 1 due to the increased contaminant mass extraction, but potentially longer than Alternative 2 due to the inconsistent results of the fracking pilot test. Detailed cost backup is provided in **Appendix D**.

10.0 COMPARATIVE ANALYSIS OF ALTERNATIVES

This section presents a summary of the relative performance of each of the candidate alternatives based on the criteria evaluated in **Section 9**. The purpose of the comparative analysis is to identify the advantages and disadvantages of each alternative relative to one another to aid in selecting an overall remedy for the Site.

The comparative analysis includes a narrative discussion of the strengths and weaknesses of the alternatives relative to one another with respect to each criterion, and how reasonable variations of key uncertainties could change the expectations of their relative performance, as applicable. The comparative analysis presented in this document uses a qualitative approach to comparison, with the exceptions of comparing alternative costs and the required time to implement each alternative.

A comparison of the capital and long-term costs associated with the remedial alternatives is presented in **Table 10-1**. Detailed cost analysis backup is provided in **Appendix D**.

10.1 Comparative Analysis of Remedial Alternatives

The following paragraphs present a comparison of the remedial alternatives which were evaluated in detail in **Section 9.0**, relative to the following evaluation criteria (an assessment of Community Acceptance will be made after the public comment period is complete, as part of the Responsiveness Summary). The comparative analysis is also presented in tabular form in **Table 10-2**.

Compliance with Standards, Criteria, and Guidance. None of the alternatives would meet chemical-specific SCGs for the Site in the near term because they do not remove or treat all Site contamination which exceeds applicable SCG values. Instead, these alternatives are compared with respect to their ability to accelerate the reduction of contaminant mass in the short term for the source area and to achieve SCGs in the long term for residual on-site contamination.

Alternatives 1, 2, and 3 would not meet chemical-specific SCGs in the short term for groundwater contamination. However, by removing source area contamination they would help satisfy chemical-specific SCGs in the long term. Qualitatively, Alternative 2 would satisfy chemical-specific SCGs more rapidly than Alternative 1 by accelerating mass removal through increased groundwater extraction. The results of the hydraulic fracturing pilot test do not suggest hydraulic fracturing may have limited effectiveness at improving mass removal, and Alternative 3 therefore ranks below Alternative 2 in compliance with SCGs.

Implementation of the alternatives would be conducted in accordance with applicable municipal, state, and federal guidance and regulations. **Table 9-1** presents a summary of location- and action-specific SCGs associated with the alternatives evaluated in this Section.

Overall Protection of Public Health and the Environment.

In all alternatives, protection of public health and the environment is accomplished principally through the operation of a groundwater extraction and treatment system on site along with implementation of institutional and management controls for potential exposure to contaminants in each media (soil, soil vapor and groundwater). Therefore, under this criterion the alternatives vary only in how long they rely on groundwater containment to provide the necessary protection of public health and the environment, with Alternative 1 requiring the most time to achieve SCGs site wide, and Alternative 2 potentially requiring the least time. Existing controls and health and safety practices would also continue to be implemented until RAOs were met for all three alternatives.

Short-term Effectiveness. Because no actions would be taken, Alternative 1 would not result in short-term adverse impacts and risks to the community, site workers, and the environment.

Alternatives 2 and 3 include activities that would result in potential short-term adverse impacts and risks to workers during implementation. However, the risks could be mitigated through coordination and communication with the facility personnel, erosion, sedimentation and dust control where applicable, preparation and implementation of a comprehensive contractor health and safety plan, and continued adherence to existing health and safety practices at the facility. It is estimated that Alternatives 2 and 3 could be fully implemented in less than one year.

Long-term Effectiveness and Permanence. Alternatives 1and 2 are expected to meet RAOs in the future due to increased extraction of contaminant mass and improved hydraulic containment of the contaminant plumes, although the time period required to meet RAOs is difficult to predict. Remaining contamination would pose a low risk to human health and the environment, and existing health and safety practices on-site would further mitigate residual risks. Alternative 2 is more effective than Alternative 1 in the long term by accelerating contaminant mass removal and targeting the areas of highest contaminant concentration for removal and treatment. Alternative 2 is also considered to be more effective than Alternative 3 based on the hydraulic fracturing pilot test results, which suggest hydraulic fracturing may have limited benefit. Alternatives 2 and 3 also create the potential for increased off-site migration of contaminated groundwater as a result of uncontrolled vertical fracturing, which could increase connectivity to deeper fractures.

Reduction of Toxicity, Mobility, or Volume with Treatment. Alternatives 1, 2, and 3 would reduce the mobility and volume of contaminants on site through groundwater extraction and ex-situ treatment with granular activated carbon. All three of these alternatives would likely achieve similar levels of reduction.

Implementability. No additional actions would be conducted under Alternative 1; therefore there are no technical difficulties associated with this alternative. As Alternative 1 is an existing remedy, no new administrative obstacles or concerns are anticipated other than implementation of institutional and management controls.

Alternative 2 includes the installation of up to two horizontalextraction wells and continued operation, maintenance, and monitoring of the groundwater extraction system. This alternative would include technical challenges. Drilling rates in fractured rock can be slow, and the possibility of borehole collapse does exist both for fractured zones and for heterogeneous glacial till in the overlying soils. As discussed in **Section 8**, installation of an east-west well would be difficult due to the existing industrial infrastructure overlying the proposed well path and limited space for well entrance and exit points. However, based on conversations with horizontal well drillers and engineering experience with horizontal well installation, these challenges can be addressed through the use of appropriate drilling methods and practices. As an implementation of the existing remedy, administrative obstacles or concerns are not anticipated.

Alternative 3 includes hydraulic fracturing of the shallow bedrock on site, installing new extraction wells, and continued operation, maintenance, and monitoring of the groundwater extraction system. This alternative would not be technically difficult to implement. As an enhancement of the existing remedy, administrative obstacles or concerns are not anticipated. Because the hydraulic fracturing to be used in this alternative is different from the fracturing used in the petroleum industry in that it only uses clean water as a fracturing medium with no chemical additives, regulatory approvals are not expected to be a major issue.

Land Use. The current and reasonably anticipated future land use of the Site is for continued commercial and industrial use. Alternatives 1, 2, and 3 would be compatible with current land use and with reasonably anticipated future land use, given the existing management and engineering controls.

Cost. A comparison of estimated capital and long-term costs associated with the remedial alternatives is presented in **Table 10-1**. In general, Alternatives 1 and 3 have similar net present worth costs, since the bulk of the cost is associated with the long-term operation, monitoring, and maintenance of the existing groundwater extraction and treatment system. Alternative 2 has higher capital costs than Alternatives 1 and 3 and higher annual O&M costs due to the assumed expansion of groundwater treatment capacity. These higher costs are partially offset by the shorter assumed duration of operation, but Alternative 2 remains the most expensive alternative considered.

11.0 RECOMMENDED ALTERNATIVE

Based on the detailed analysis and comparison of alternatives, it is recommended that Arch and the NYSDEC select Alternative 2, Horizontal Groundwater Extraction Wells, as the preferred remedy. As with each of the other alternatives, this alternative includes institutional and management controls to prevent human health and environmental exposure to contaminants in groundwater and other media. The use of horizontal wells in Alternative 2 allows for hundreds of additional feet of well screen to intercept areas of contaminant migration and source areas. The additional influence of a horizontal groundwater extraction well or wells will improve hydraulic control and accelerate contaminant mass removal more effectively than using vertical wells alone as with Alternative 1 or using technologies of uncertain effectiveness in Site-specific conditions as with Alternative 3. Although Alternative 2 is more expensive than the other alternatives, this is outweighed by the likelihood for improved containment and capture of contaminant mass and the shorter expected timeframe to achieve RAOs.

Alternative 3 is not recommended at this time due to uncertain performance. The pilot test did not convincingly demonstrate that fracking technology could be effectively applied to the site’s specific conditions. The pilot test demonstrated inconsistent results with no long-term benefit observed to date from the existing extraction wells in the vicinity of the test.

Based on these considerations, Alternative 2 provides the best balance of all the evaluation criteria. Alternative 2 continues using a proven extraction system that has removed contaminant mass and controlled contaminant migration within the source area, introduces a new extraction technology to improve existing hydraulic control and contaminant source removal, and does not risk the uncertainty of new technologies that did not perform convincingly on-site during the pilot tests.

12.0 GLOSSARY OF ACRONYMS AND ABBREVIATIONS

Arch	Arch Chemicals, Inc.
bgs	below ground surface
cm/sec	centimeter(s) per second
COC	contaminant of concern
DER	Division of Environmental Remediation
DNAPL	dense non-aqueous phase liquid
FS	Feasibility Study
GAC	granular activated carbon
gpm	gallon(s) per minute
µg/L	micrograms per liter
Nothnagle	Nothnagle Drilling, Inc.
NPW	net present worth
NYCRR	New York Codes, Rules and Regulations
NYS	New York State
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
O&M	Operation and Maintenance
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
POTW	Publicly Owned Treatment Works
psi	pounds per square inch
RAO	Remedial Action Objective
ROD	Record of Decision
RI	Remedial Investigation
SCO	site cleanup objective
Site	Arch Chemicals, Inc. manufacturing facility in Rochester, NY
SCG	standards, criteria and guidance values
SVOC	semi volatile organic compound
USEPA	United States Environmental Protection Agency
VOC	volatile organic compound

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FIGURES

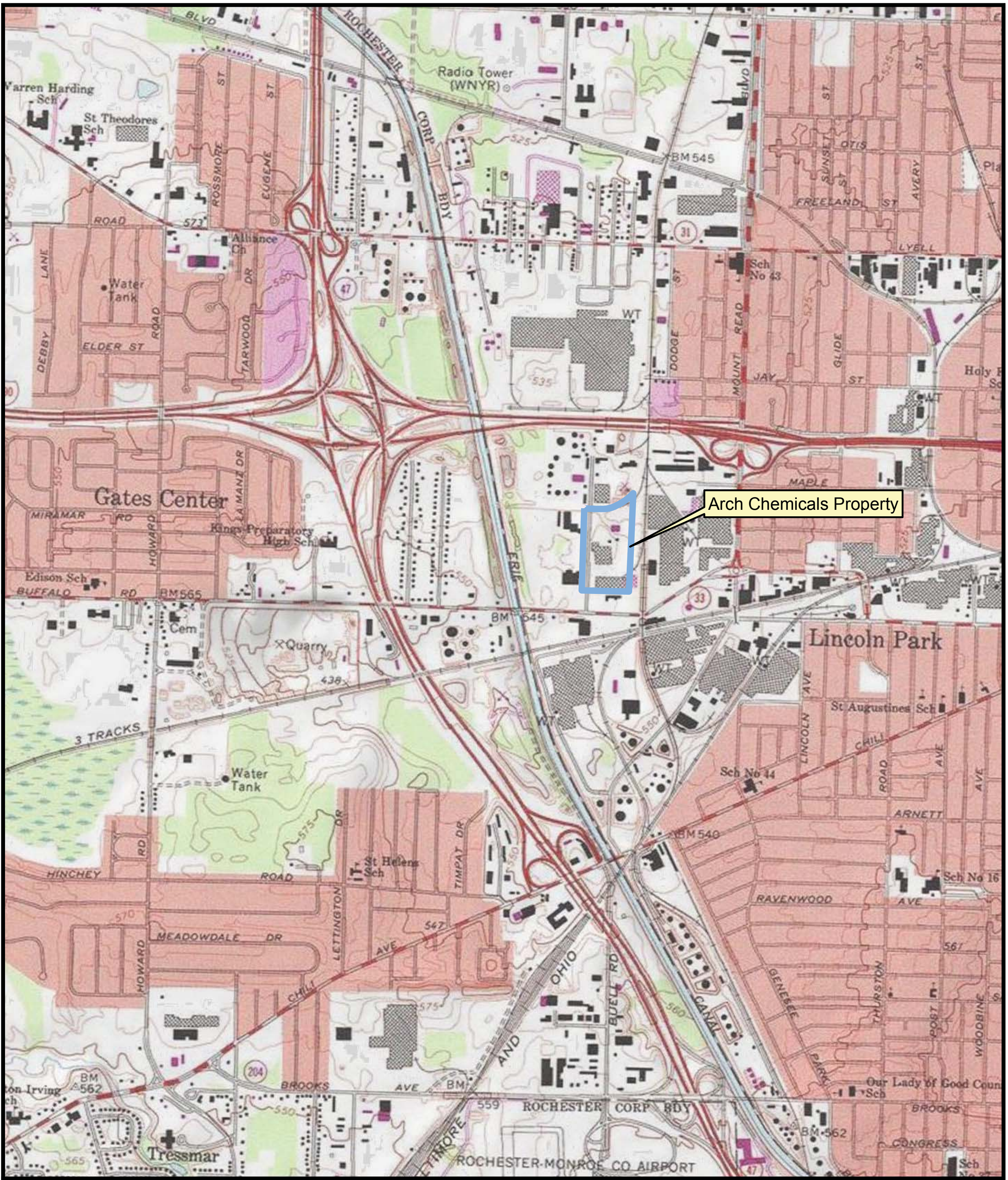

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Figure 1-1
Site Location

Legend

▬ Arch Property Boundary

N

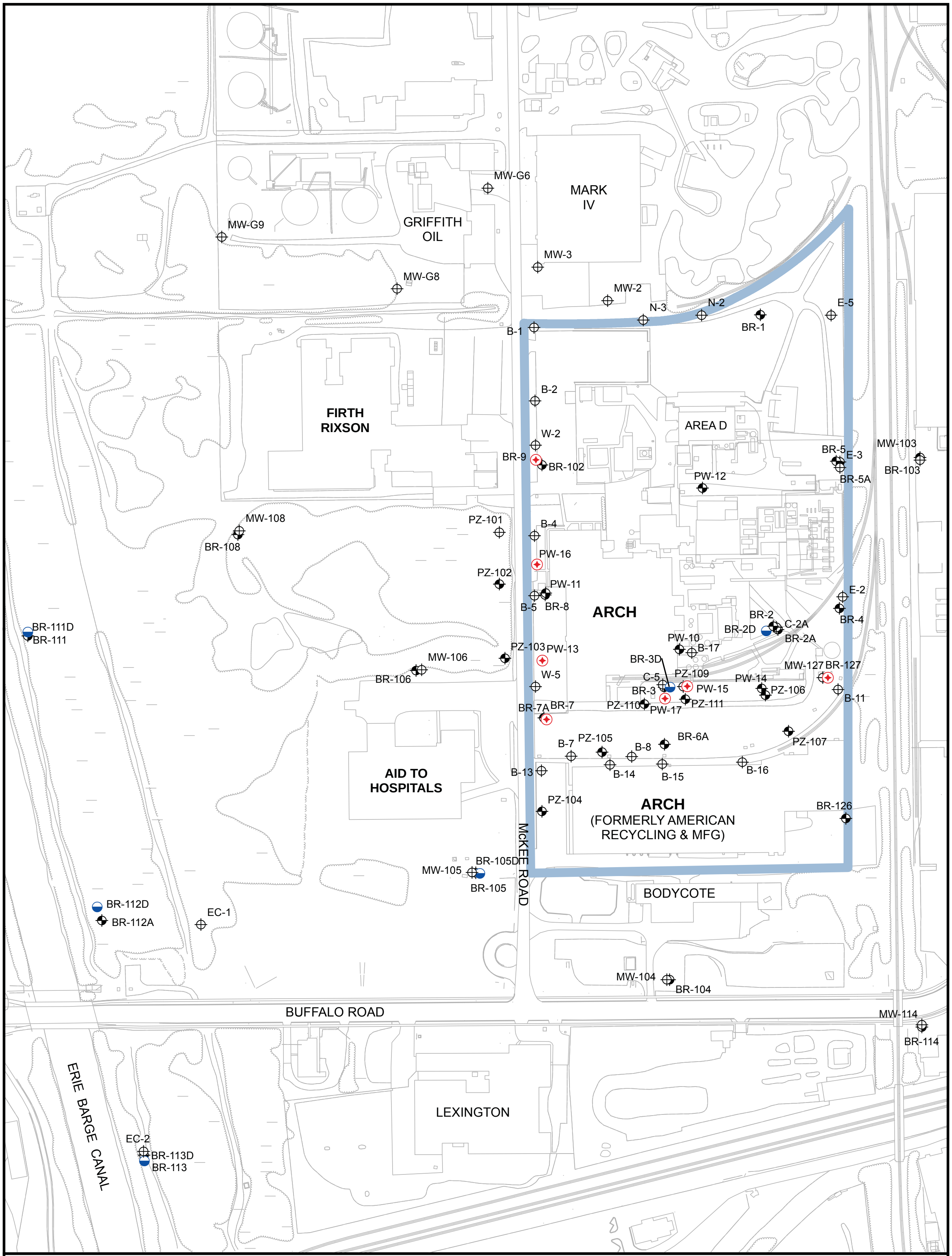
0 1,000 2,000
Feet

Arch Chemicals
Rochester, New York

Prepared/Date: BRP 03/04/19 | Checked/Date: NL 03/04/19

amec

Document: P:\Projects\Arch\Rochester\GIS\MapDocuments\FS Addendum\Site_Location.mxd PDF: P:\Projects\Arch\4.0 Deliverables\4.1 Reports\FSA\2019 Update\Figure 1-1 - Site Location.pdf 03/04/2019 10:52 AM brian.peters



Legend

- Active Pumping Well
- Overburden Monitoring Well
- Bedrock Monitoring Well
- Deep Bedrock Monitoring Well
- Outline of Arch Property Boundary

N

0 100 200 400 Feet

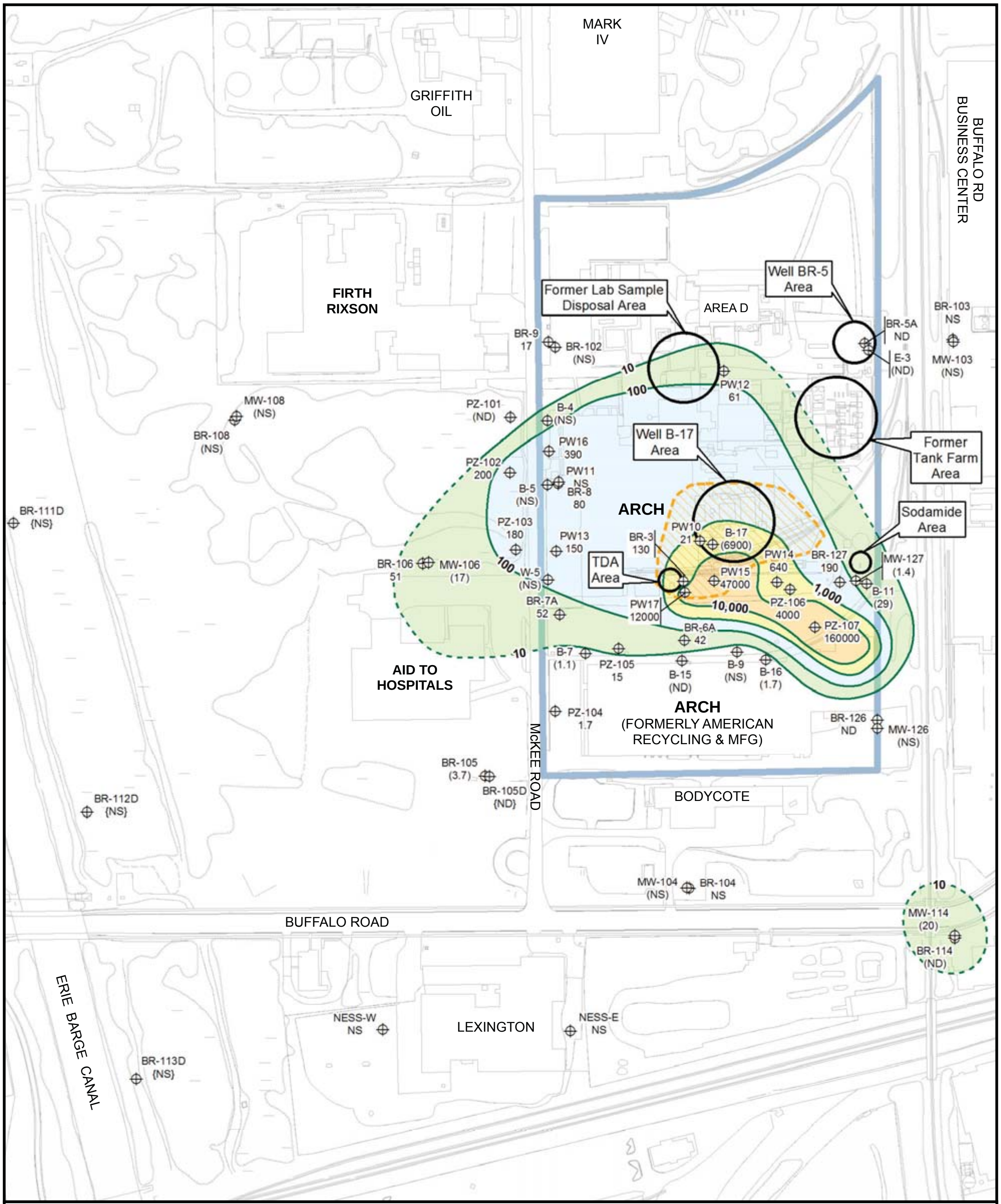
Figure 1-2
Monitoring Well Locations

Arch Chemicals
Rochester, NY

Prepared/Date: BRP 03/04/19	Checked/Date: NL 03/04/19

amec

Document: P:\Projects\Arch\Rochester\GIS\MapDocuments\FS Addendum\FSA_11x17P.mxd PDF: P:\Projects\Arch\4.0 Deliverables\4.1 Reports\FSA\2019 Update\Figure 1-2 - Onsite Monitoring Well Locations.pdf 03/04/2019 10:54 AM brian.peters



Legend

B-17 (6900) ⊕ Monitoring Location with Concentration

100 — VOC Concentration Contour

— Outline of Arch Property Boundary

▨ Approximate Source Area

{1000}	Deep Bedrock Well
(1000)	Overburden Well
1000	Bedrock Well
NS	Not Sampled
ND	Not Detected

0 100 200 Feet N

NOTES:

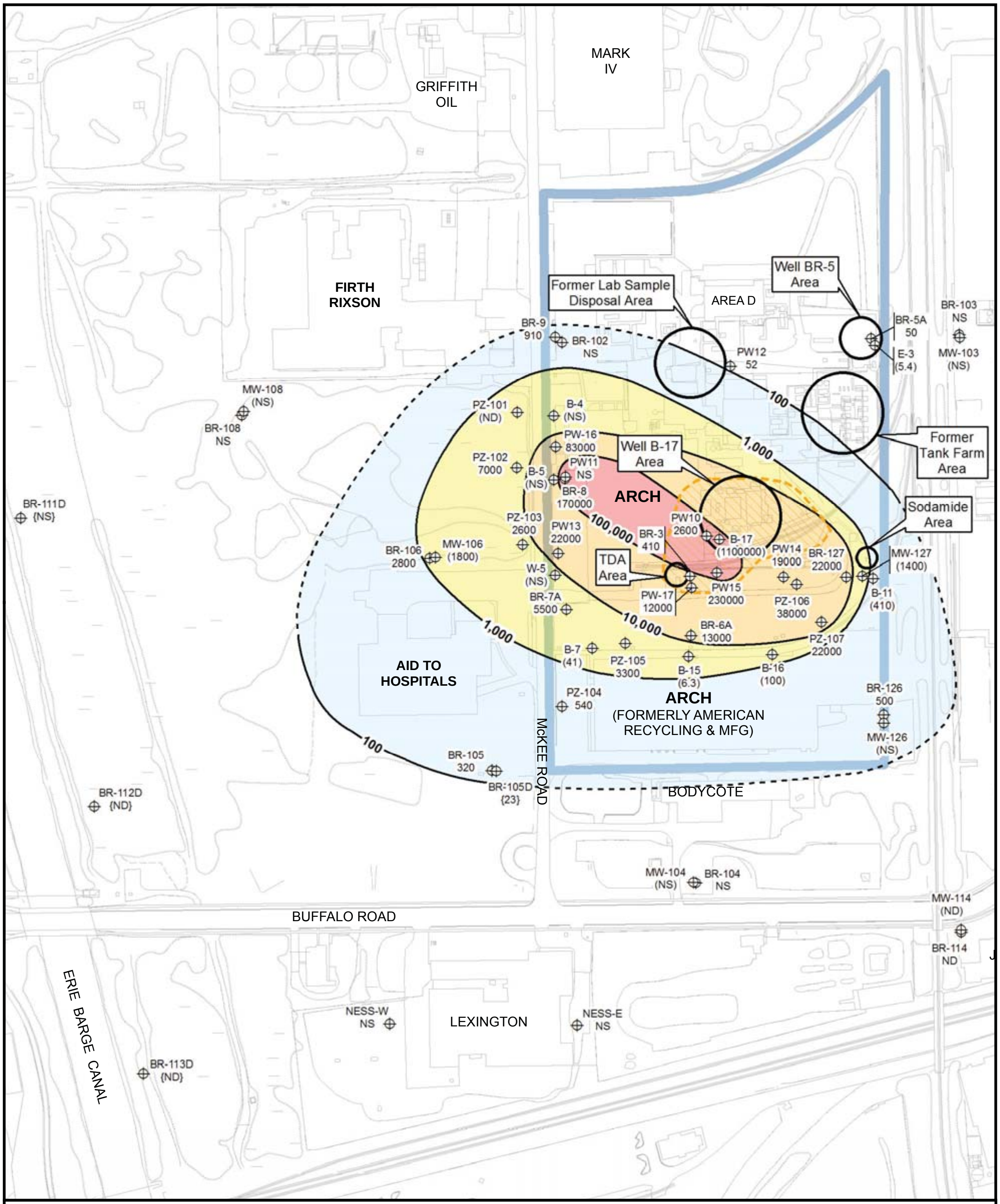
1. Samples Collected May 9-16, 2018
2. Original Select VOCs consist of Carbon tetrachloride, Methylene chloride Chloroform, TCE, PCE, and Chlorobenzene.
3. Concentration contours represented for Bedrock Wells and selected Overburden and Deep Bedrock Wells.
4. Dashed concentration contours represent inferences from historical analytical results.
5. Concentrations are in µg/L

Figure 3-1
Spring 2018
Selected Volatile Organic Compound Concentration Contours

Arch Chemicals
Rochester, NY

Prepared/Date: BRP 06/28/19	Checked/Date: NL 06/28/19

amec



Legend

MW-106 (22000) ⌖ Monitoring Location with Concentration

Outline of Arch Property Boundary

100 — Chloropyridine Concentration Contour

Approximate Source Area

{1000}	Deep Bedrock Well
(1000)	Overburden Well
1000	Bedrock Well
NS	Not Sampled
ND	Not Detected

NOTES:

1. Samples Collected May 9-16, 2018
2. Selected chloropyridines consist of 2,6-dichloropyridine, 2-chloropyridine, 3-chloropyridine, 4-chloropyridine, and P-fluoroaniline.
3. Concentration contours represented for Bedrock Wells and selected Overburden and Deep Bedrock Wells.
4. Dashed concentration contours represent inferences from historical analytical results.
5. Concentrations are in μg/L.

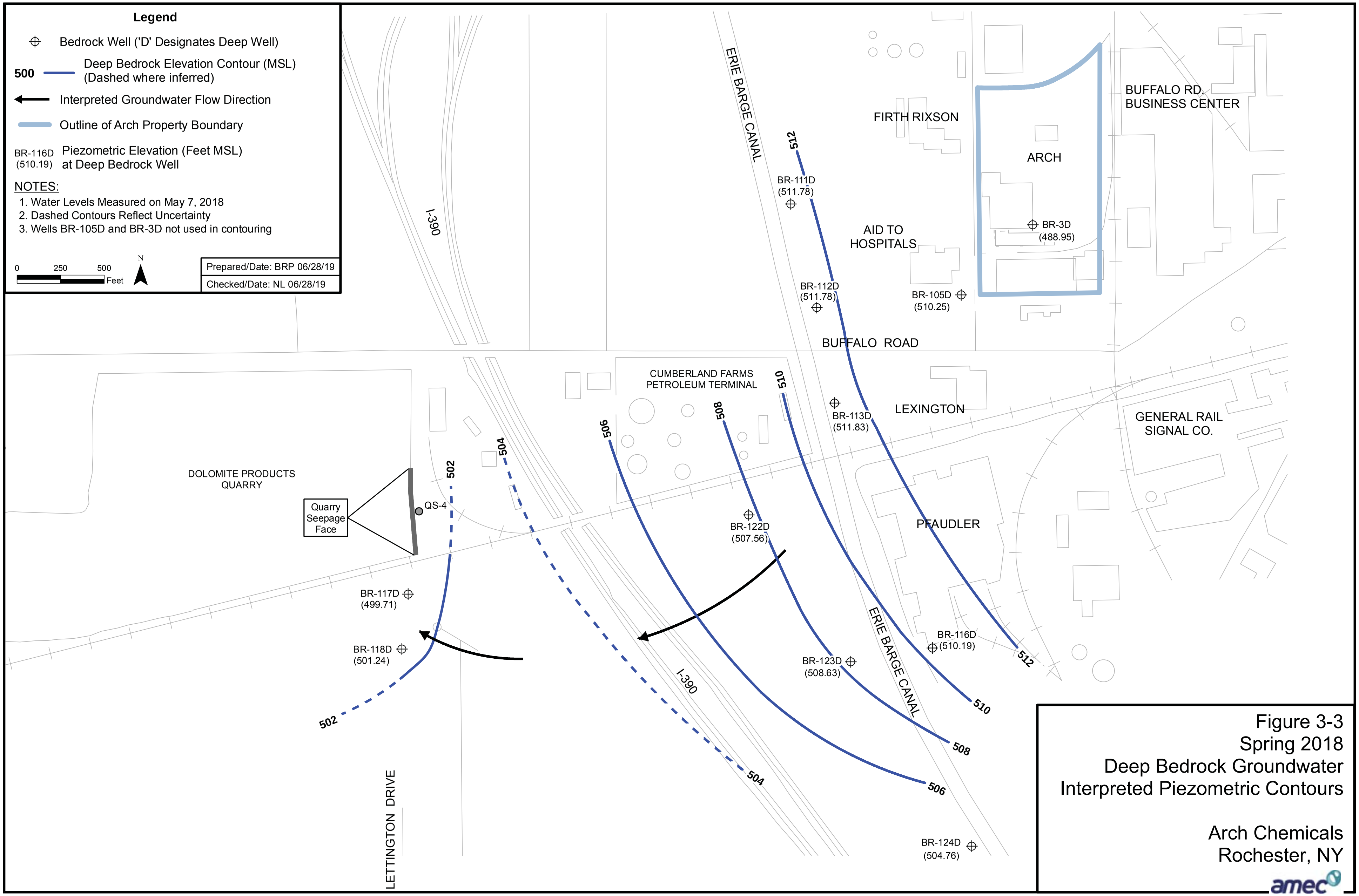
0 100 200
Feet
N

Prepared/Date: BRP 06/28/19 | Checked/Date: NL 06/28/19

Figure 3-2
Spring 2018
Selected Chloropyridine Concentration Contours

Arch Chemicals
Rochester, NY

amec



Legend

⌖ Bedrock Well ('D' Designates Deep Well)

500 — Deep Bedrock Elevation Contour (MSL) (Dashed where inferred)

← Interpreted Groundwater Flow Direction

— Outline of Arch Property Boundary

BR-116D (510.19) Piezometric Elevation (Feet MSL) at Deep Bedrock Well

NOTES:
1. Water Levels Measured on May 7, 2018
2. Dashed Contours Reflect Uncertainty
3. Wells BR-105D and BR-3D not used in contouring

Prepared/Date: BRP 06/28/19
Checked/Date: NL 06/28/19

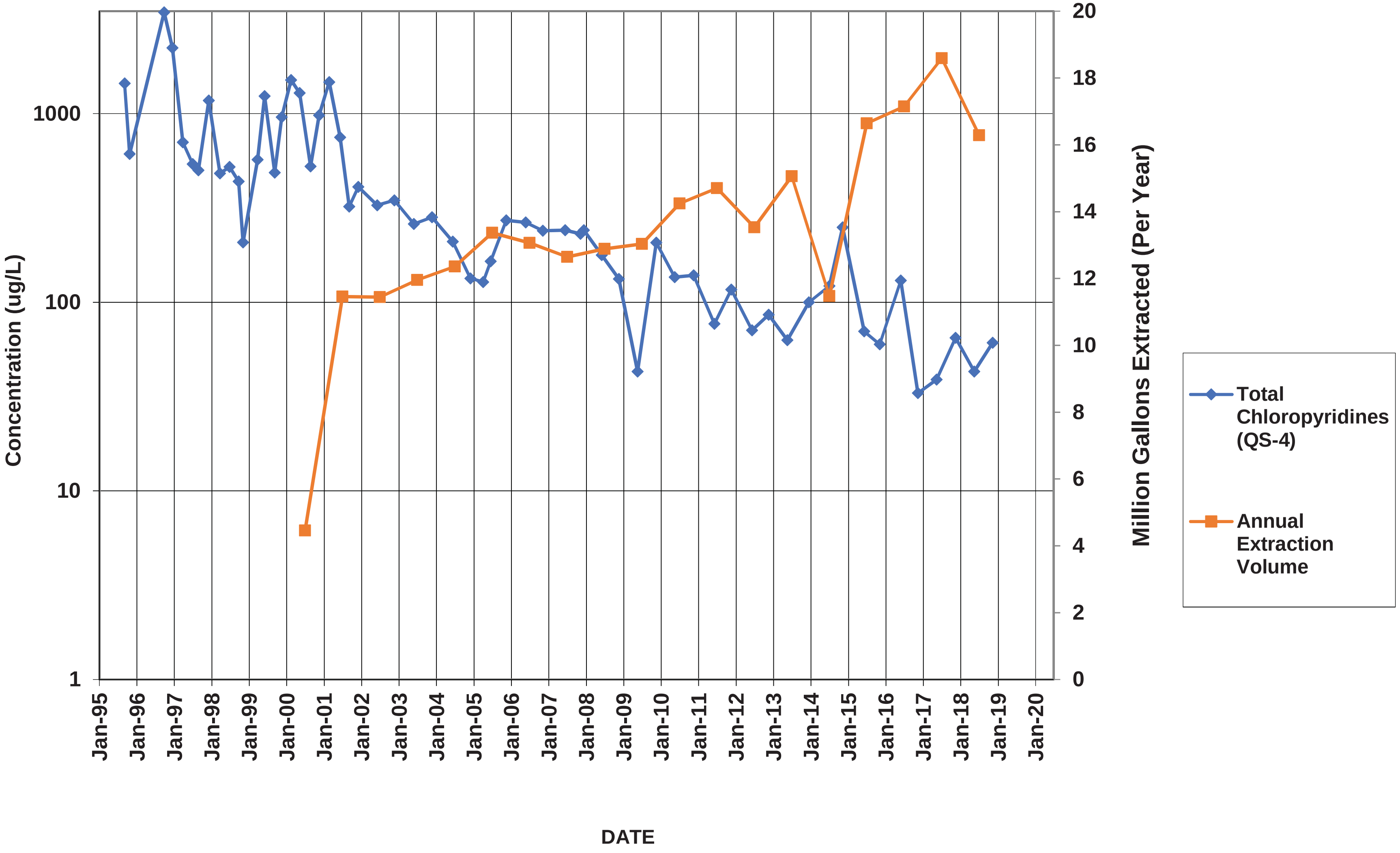
Figure 3-3
Spring 2018
Deep Bedrock Groundwater Interpreted Piezometric Contours

Arch Chemicals
Rochester, NY

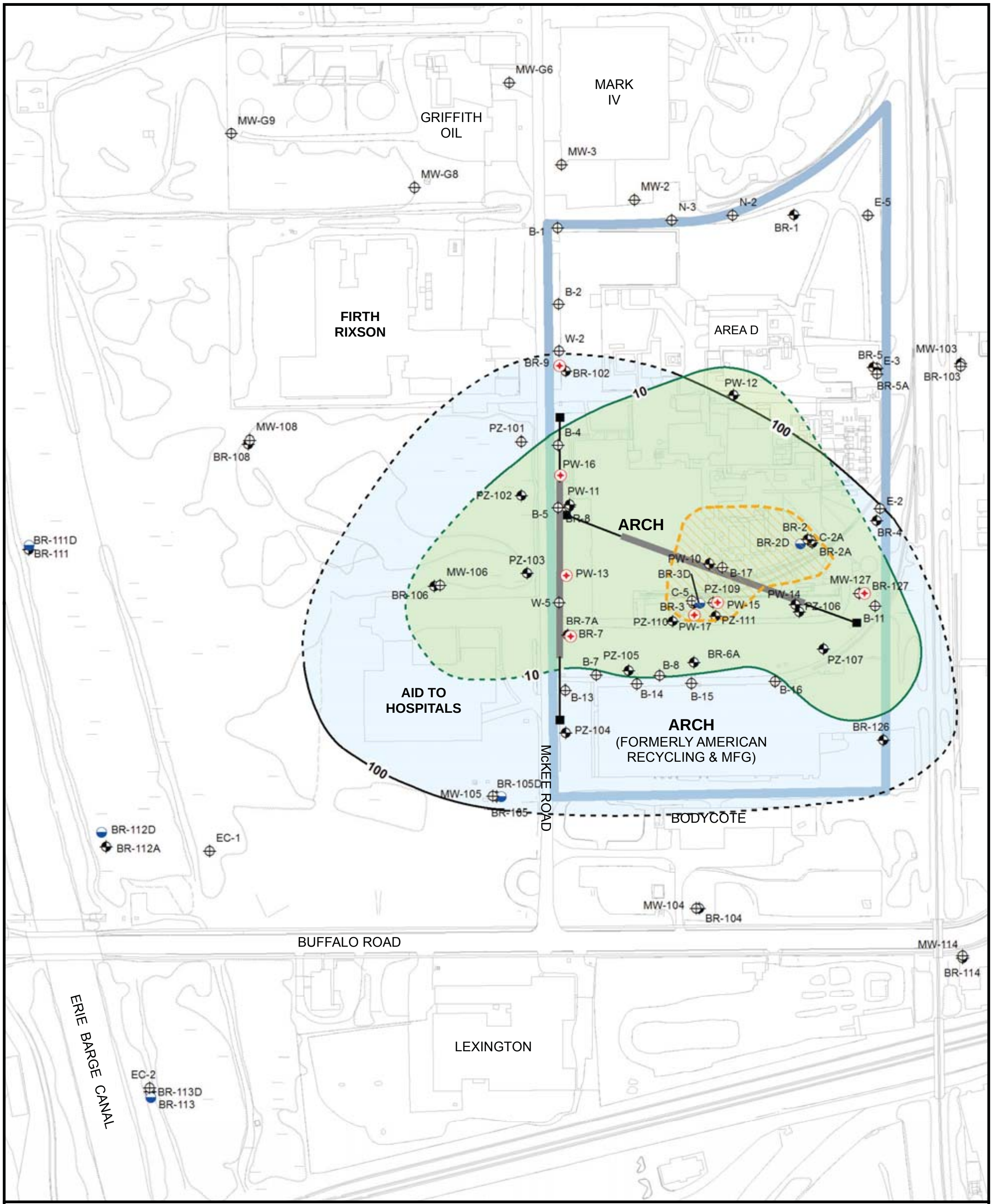
amec

Document: P:\Projects\Arch\Rochester\GIS\MapDocuments\Spring 2018\FS_Deep_BedrockGW.mxd PDF: P:\Projects\Arch\4.0 Deliverables\4.1 Reports\FSA\2019 FS\Figures\Figure 3-3 - Deep Bedrock GW Contours.pdf 06/28/2019 3:19 PM brian.peters

FIGURE 3-4
ON-SITE GROUNDWATER EXTRACTION WITHDRAWALS vs QUARRY SEEP CONCENTRATIONS



Prepared by: jar
Reviewed by: nmb



Legend

—	Well Casing
▬	Well Screen
■	Well Vault
⊕	Active Pumping Well
⊕	Overburden Monitoring Well
◆	Bedrock Monitoring Well
◓	Deep Bedrock Monitoring Well
▬	Outline of Arch Property Boundary
▨	Approximate Source Area
100 —	Chloropyridine Concentration Contour (Spring 2018)
10 —	VOC Concentration Contour (Spring 2018)

NOTES:

1. Samples Collected May 9-16, 2018
2. Original Select VOCs consist of Carbon tetrachloride, Methylene chloride Chloroform, TCE, PCE, and Chlorobenzene.
3. Selected chloropyridines consist of 2,6-dichloropyridine, 2-chloropyridine, 3-chloropyridine, 4-chloropyridine, and P-fluoroaniline.
4. Concentration contours represented for Bedrock Wells and selected Overburden and Deep Bedrock Wells.
5. Dashed concentration contours represent inferences from historical analytical results.
6. Concentrations are in µg/L.

0 100 200
Feet
N

Figure 8-1
Horizontal Groundwater Extraction Well Layout

Arch Chemicals
Rochester, NY

Prepared/Date: BRP 07/17/19 | Checked/Date: NL 07/17/19

amec

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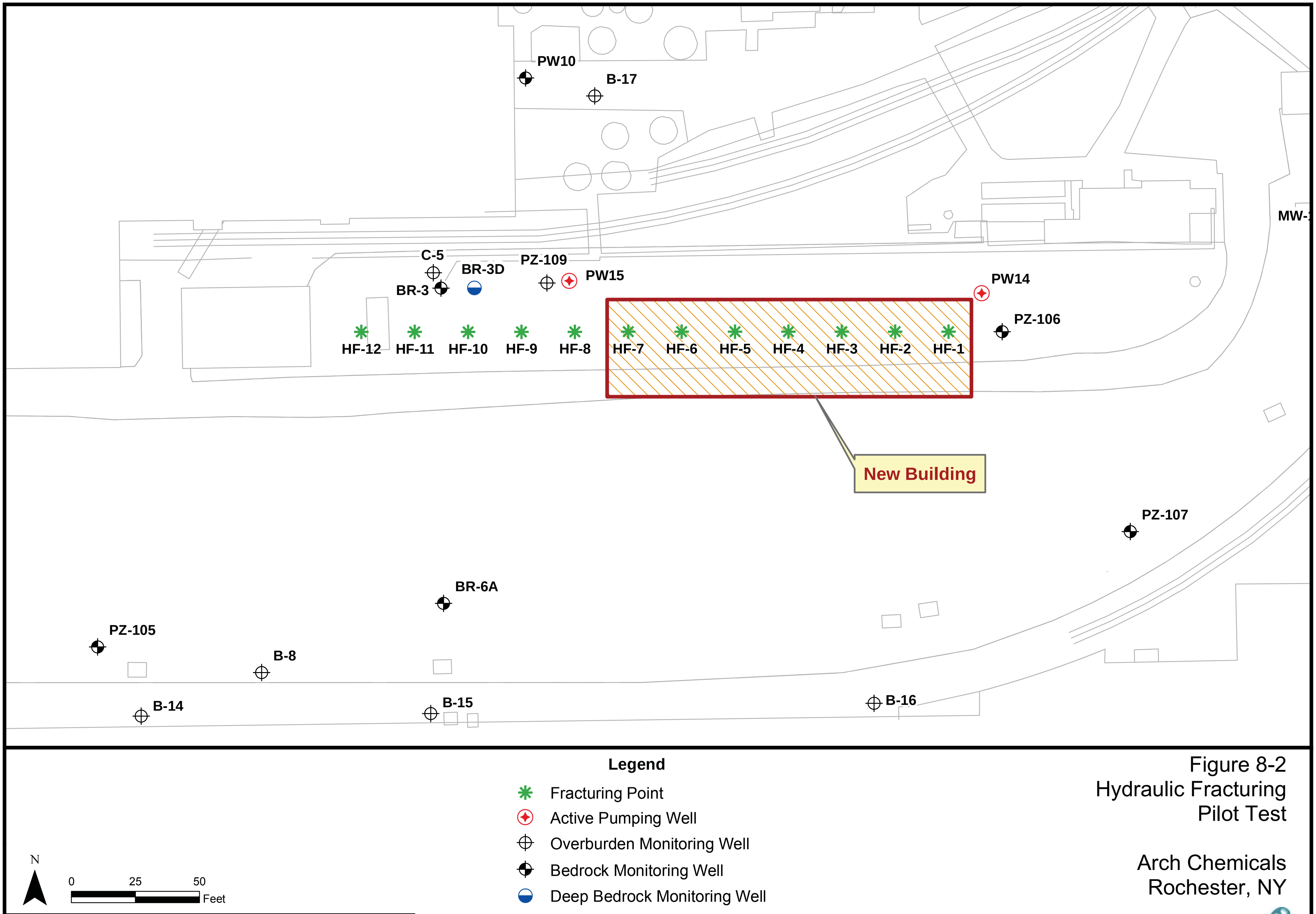

Figure 8-2
Hydraulic Fracturing Pilot Test

Arch Chemicals
Rochester, NY

Prepared/Date: BRP 03/04/19	Checked/Date: NL 03/04/19

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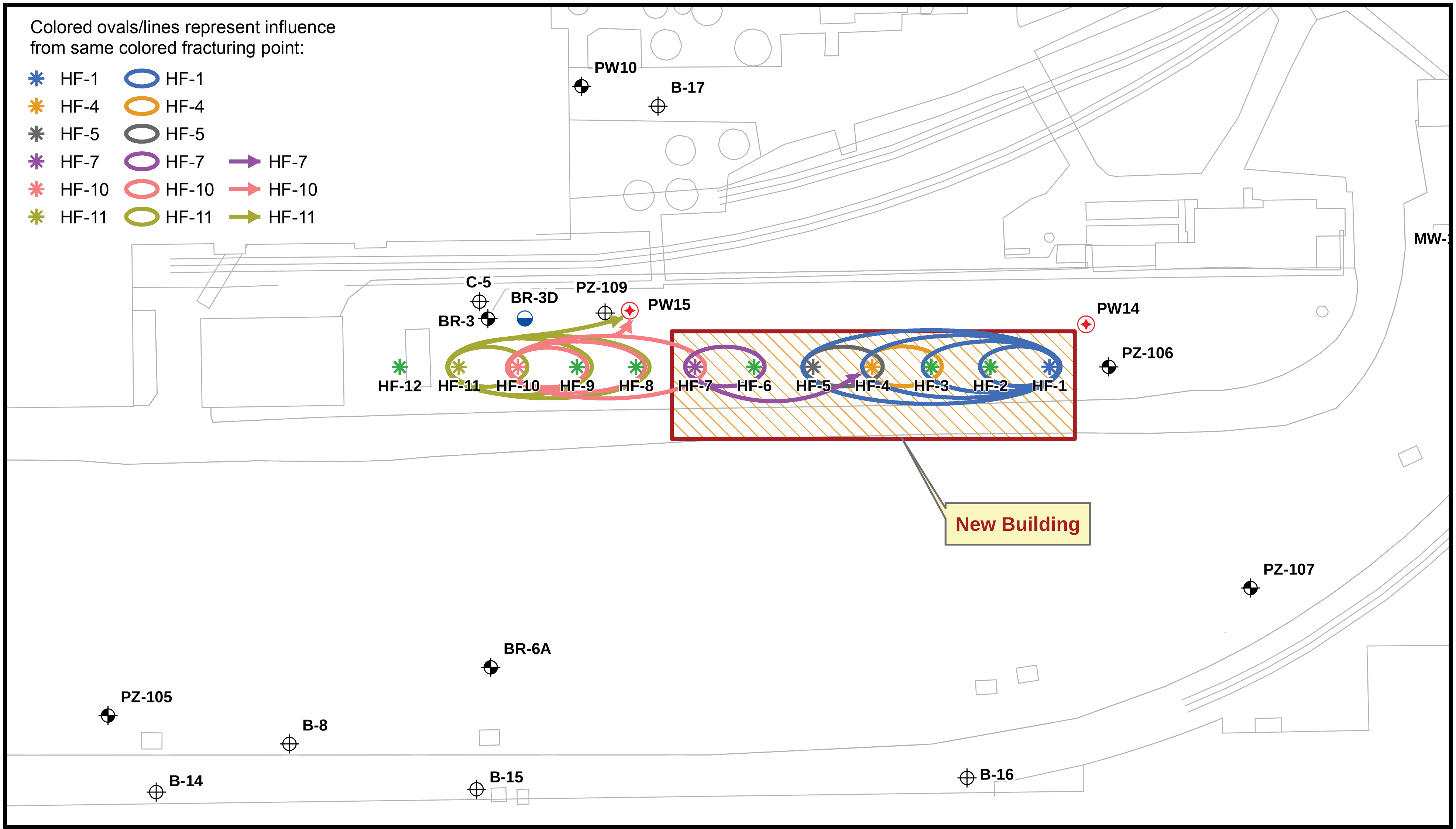


Legend

- ✳ Fracturing Point
- ⊕ Active Pumping Well
- ⊕ Overburden Monitoring Well
- ⊕ Bedrock Monitoring Well
- ◒ Deep Bedrock Monitoring Well

N

0 25 50 Feet

Prepared/Date: BRP 03/04/19 | Checked/Date: NL 03/04/19

Figure 8-3
Hydraulic Fracturing Well Influence

Arch Chemicals
Rochester, NY

amec

Document: P:\Projects\Arch\Rochester\GIS\MapDocuments\FS Addendum\Fracturing_8.5x11LS.mxd PDF: P:\Projects\Arch\4.0 Deliverables\4.1 Reports\FSA\2019 Update\Figure 8-3 - Hydraulic Fracturing Well Influence.pdf 03/04/2019 2:18 PM brian.peters

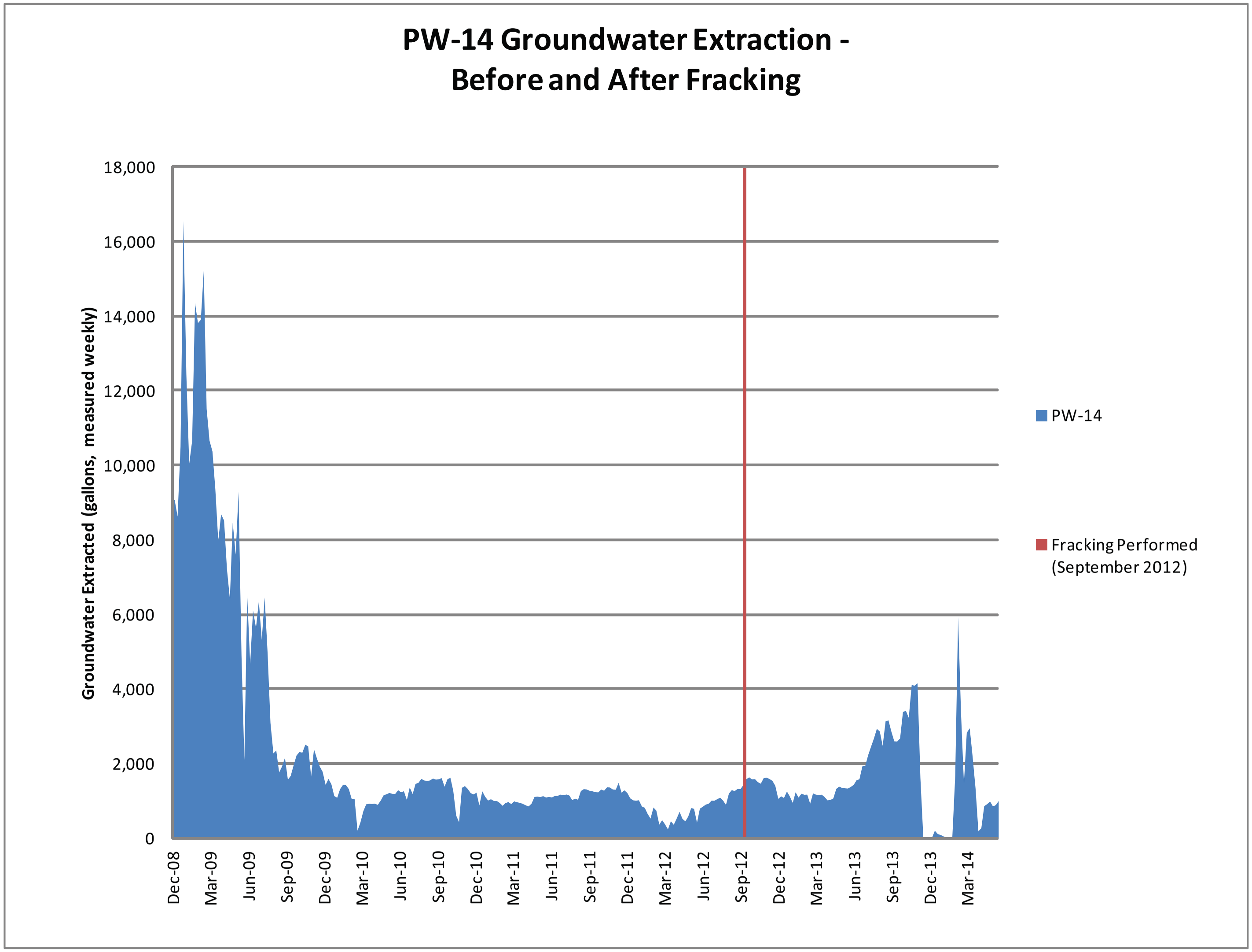


Figure 8-4
PW-14 Groundwater Extraction -
Before and After Fracking

Arch Chemicals
Rochester, NY

Prepared/Date: BRP 10/20/14	Checked/Date: BPN 10/20/14

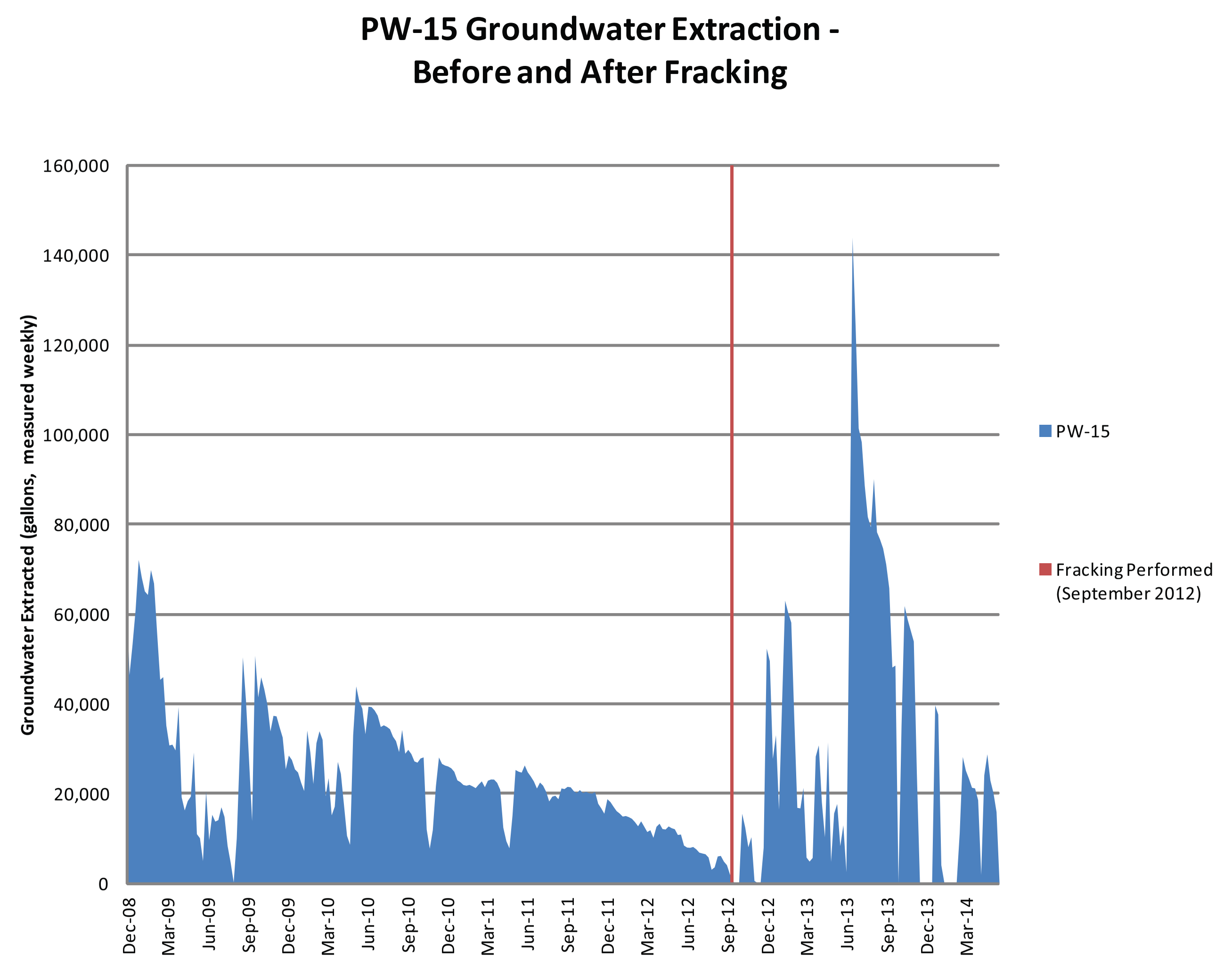
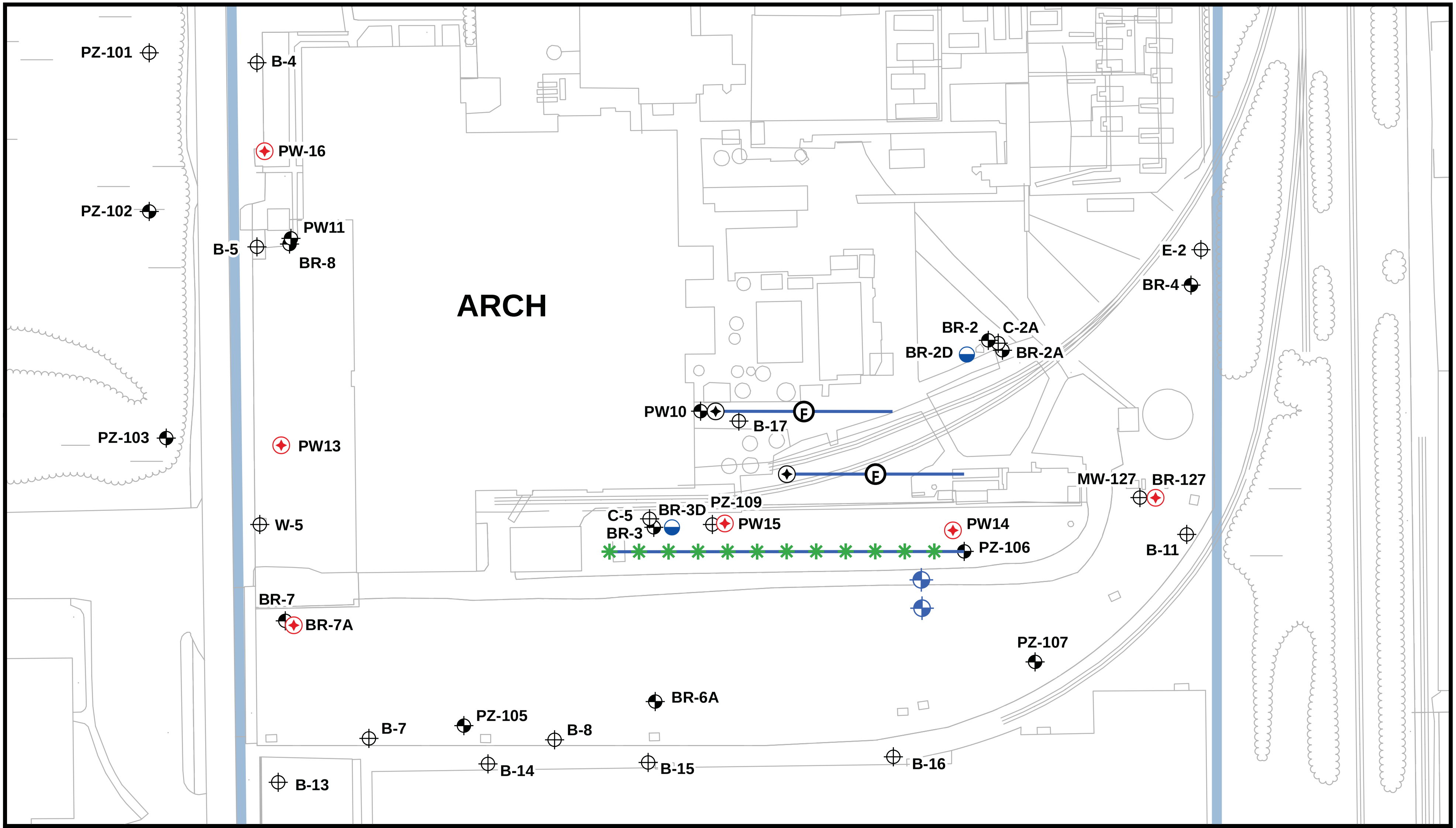


Figure 8-5
PW-15 Groundwater Extraction - Before and After Fracking

Arch Chemicals
Rochester, NY

Prepared/Date: BRP 10/20/14	Checked/Date: BPN 10/20/14



NOTES:
1. Proposed alignments are assumed to be Hydraulically fractured at points spaced 22 feet apart.
2. A new well will be installed at the west end of each alignment.

Legend

- ✳ Pilot Test Fracturing Point
- ⊕ Pilot Test Bedrock Monitoring Well
- ⊛ Proposed Pumping Well
- —Ⓕ— Proposed Hydraulic Fracturing Alignment
- ✦ Active Pumping Well
- ⊕ Overburden Monitoring Well
- ⊕ Bedrock Monitoring Well
- ◒ Deep Bedrock Monitoring Well
- ▬ Outline of Arch Property Boundary

Figure 8-6
Proposed Hydraulic Fracturing Program

Arch Chemicals
Rochester, NY

amec

Prepared/Date: BRP 03/05/19 | Checked/Date: NL 03/05/19

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TABLES

Table 3-1: Soil Data Summary

Chem Class	Parameter	Area	Units	Detects	Samples	Mean*	Maximum
SVOCs	2-Chloropyridine	Well B-17 Area	MG/KG	13	19	**37**	**300**
		Lab Sample Area	MG/KG	5	10	1.5	3.4
		Sodamide Area	MG/KG	2	8	0.49	2.8
		Tank Farm Area	MG/KG	2	10	0.11	0.11
		TDA Area	MG/KG	5	5	26	67
		Well BR-5 Area	MG/KG	2	10	0.094	0.081
	2,6-Dichloropyridine	Well B-17 Area	MG/KG	17	19	**12**	**170**
		Lab Sample Area	MG/KG	0	10	0.08	ND
		Sodamide Area	MG/KG	4	8	0.13	0.24
		Tank Farm Area	MG/KG	4	10	0.13	0.49
		TDA Area	MG/KG	5	5	3.8	9.5
		Well BR-5 Area	MG/KG	5	10	0.101	0.32
	3-Chloropyridine	Well B-17 Area	MG/KG	6	19	**4.1**	**2.9**
		Lab Sample Area	MG/KG	0	10	ND	ND
		Sodamide Area	MG/KG	1	8	0.89	0.038
		Tank Farm Area	MG/KG	0	10	ND	ND
		TDA Area	MG/KG	0	5	ND	ND
		Well BR-5 Area	MG/KG	0	10	ND	ND
VOCs	Carbon tetrachloride	Well B-17 Area	MG/KG	11	19	**222**	**4,200**
		Lab Sample Area	MG/KG	1	10	0.002	0.0023
		Sodamide Area	MG/KG	4	8	0.04	0.14
		Tank Farm Area	MG/KG	2	10	0.003	0.0092
		TDA Area	MG/KG	1	5	0.08	0.0056
		Well BR-5 Area	MG/KG	1	10	0.002	0.0014
	Chloroform	Well B-17 Area	MG/KG	12	19	**21**	**380**
		Lab Sample Area	MG/KG	0	10	ND	ND
		Sodamide Area	MG/KG	3	8	0.06	0.49
		Tank Farm Area	MG/KG	2	10	0.008	0.06
		TDA Area	MG/KG	3	5	0.34	1
		Well BR-5 Area	MG/KG	1	10	0.002	0.0013
	Methylene chloride	Well B-17 Area	MG/KG	6	19	0.60	2.4
		Lab Sample Area	MG/KG	0	10	ND	ND
		Sodamide Area	MG/KG	1	8	0.012	0.0092
		Tank Farm Area	MG/KG	2	10	0.002	0.0026
		TDA Area	MG/KG	3	5	**0.615**	**2.8**
		Well BR-5 Area	MG/KG	3	10	0.004	0.011

Mean concentration calculated using 1/2 of detect limit for non-detects
MG/KG = milligrams per kilogram
Bold number reflects highest mean or maximum concentration among the 6 areas

Prepared/Date: NMB 07/06/19
Checked/Date: NRL 07/10/19

Table 5-1: Qualitative Human Health Exposure Assessment

Environmental Media & Exposure Route	**Human Exposure Assessment**
Direct contact with surface soils (and incidental ingestion)	• The public is not coming into contact with contaminated surface soils because access to the site is restricted by fencing. • People can come into contact with contaminated surface soils if they trespass on the site. • Workers can come into contact with uncovered contaminated surface soils.
Direct contact with subsurface soils (and incidental ingestion)	• Workers can come into contact if they complete ground-intrusive work at the site; however, the Arch Plant has a mandatory policy that requires the use of PPE in hazardous conditions.
Ingestion of groundwater	• Contaminated groundwater is not being used for drinking water because bedrock groundwater is non-potable due to high concentrations of salts, sulfide, and dissolved gasses • The area area is served by the public water supply and is required for new developments of more than five houses. • There are no known domestic water supply wells in the area.
Direct contact with groundwater	• Workers can come into contact if they complete ground-intrusive work at the site; however, the Arch Plant has a mandatory policy that requires the use of PPE in hazardous conditions. • People can come into contact if private wells are installed in the area; however, bedrock groundwater is non-potable and public water is available and required in new developments of more than five houses.
Direct contact with surface water (and incidental ingestion)	• Anyone wading or swimming in the Erie Barge Canal downgradient from the site can come into contact with surface water.
Inhalation of air (exposures related to soil vapor intrusion)	• The public is not coming into contact with soil vapor on-site because access to the site is restricted by fencing. • Workers can come into contact with contaminated soil vapor; however, only one soil gas sample slightly exceeded the air standard and was considered to pose no substantial health risk by the prior risk assessment.

Prepared/Date: NRL 02/06/19
Checked by: NMB 03/01/19

Table 7-1: Identification and Screening of Remedial Technologies

Environmental Media	General Response Action	Remedial Technology	Process Option	Applicability to		Screening Status	Comments
				Site-Limiting Characteristics	Waste-Limiting Characteristics		
Groundwater	No Further Action	Groundwater Extraction and Treatment	Extraction by groundwater pumps and treatment by granular activated carbon.	Not Applicable	Not Applicable	Retained.	Retained to be carried through detailed analysis of alternatives for comparison to alternatives that satisfy RAOs.
	Enhanced Extraction	Blasted Bedrock Trench	Extraction wells.	Limited surface access due to site buildings and features. Further, the proximity of the contaminant source areas to the facility buildings my prohibit the use of explosives and the applicability of blasted bedrock trenching.	None.	Eliminated.	Initial evaluation of the site and source area contamination by a blasting contractor advised that this technology would not be feasible for this site. There is insufficient clearance from the site buildings to employ explosives without risking disturbance or damage to facility structures or operations.
		Hydraulic Fracturing	Extraction wells.	Limited surface access due to site buildings and features.	None.	Retained.	
		Groundwater Extraction Wells	Extraction wells.	Limited surface access due to site buildings and features. Surface access issues may be mitigated through the installation of horizontal wells.	None.	Retained.	Given the known effectiveness and limitations of vertical wells on-site, alternatives using groundwater extraction wells will evaluate the use of horizontal groundwater extraction wells where practicable.
	In-Situ Treatment	Biological Treatment	Enhanced Biodegradation	Surface access for injections may be difficult given presence of actively used buildings and facility components. Distribution of applied biodegradation materials into bedrock matrix may be difficult and ineffective. The variable fractures in the bedrock could make uniform distribution of bioremediation materials unlikely.	Would not effectively treat relatively high concentrations of VOC contaminants or chloropyridines. Presently, results of groundwater monitoring do not demonstrate chloropyridines are readily biodegrade at this site. Treatability tests would be required to demonstrate if chloropyridines can be readily biodegraded.	Eliminated.	No evidence of biodegradation of chloropyridines on-site.
		Physical Treatment	Permeable Reactive Barrier	Installation of a permeable reactive barrier would be severely restricted due to the chemical manufacturing equipment and facility buildings, as well as the treatment depth required into bedrock.	Treatability tests may be required to demonstrate if chloropyridines could be immobilized and then degraded by a permeable reactive barrier.	Eliminated.	
			Air Sparging	Limited surface access for sparging and recovery wells due to site buildings and features.	Would removes VOC contaminants from the soil in the saturated zone and bedrock, but may require additional technology to treat off-gases. Relatively low volatility of chloropyridines suggests this technology would not be effective at treating both contaminant groups	Eliminated.	

Prepared/Date: NRL 02/06/19
Checked/Date: NMB 03/01/19

Table 7-1: Identification and Screening of Remedial Technologies

Environmental Media	General Response Action	Remedial Technology	Process Option	Applicability to		Screening Status	Comments
				Site-Limiting Characteristics	**Waste-Limiting Characteristics**		
		Thermal Treatment	In-Situ Thermal Desorption	May not be cost-effective for the extensive horizontal extents of contamination (i.e. more probe points required to heat media). Site buildings and features would restrict installation locations. Installation locations are not recommended for any use except the treatment system throughout treatment, potentially preventing facility activities in the treatment area. Infeasibility of cutting off groundwater flow to source area may inhibit effectiveness due to heat required to boil off water before heating contaminants to higher temperatures, or else require the installation of steam wells upgradient to preheat water before it arrives in the treatment area. Could not treat underneath building without disrupting building operations or raising indoor air temperatures to nearly unbearable levels.	Requires capture of off-gases for contaminants that are not destroyed by heating. Low volatility and high solubility of chloropyridines may restrict technology's ability to reduce contamination to the low parts per million range.	Eliminated.	Reviewed technology is patented by Terratherm.
		Chemical Treatment	Oxidation/Reduction	Surface access for injections may be difficult given presence of actively used buildings and facility components. Distribution of applied reagent into bedrock matrix may be difficult and ineffective. The variable fractures in the bedrock could make uniform distribution of bioremediation materials unlikely.	Chloropyridines did not respond to chemical oxidation using Fenton's reagent and potassium permanganate in previous FS. Catalyzed persulfate may prove effective, but treatability tests would be required to demonstrate effectiveness.	Retained.	Will test treatment approach with alkaline activated sodium persulfate, patented by VeruTEK.

Prepared/Date: NRL 02/06/19
Checked/Date: NMB 03/01/19

Table 8-1: Preliminary Screening of Remedial Alternatives

Remedial Alternative	Effectiveness	Implementability	Cost	Comments
Alternative 1: No Further Action: Continued Groundwater Extraction	Not evaluated.	Not evaluated.	No cost.	Retained as a baseline for comparison.
Alternative 2: Install Horizontal Groundwater Extraction Wells	In the long term, this alternative would be effective at reducing the concentration of chloropyridines and VOCs near existing extraction wells and new extraction wells in the contaminant source area. In the short term, this alternative would achieve significant additional mass removal in the source area.	Technical issues with implementing this alternative primarily include the installation of a horizontal well to capture groundwater in bedrock with predominantly horizontal fractures. Since the wells and fractures would need to intersect on the same horizontal plane, it's possible a horizontal well could miss significant water bearing zones. Additional implementability concerns include drilling in fractured bedrock, which carries the risk of boring collapse. Drill bit navigation may be difficult due to the facility infrastructure at the site's gorund surface. Identifying entrance/exit points for the wells that won't interfere with facility operations will also be difficult	Costs associated with this alternative are moderate. The primary cost items include bedrock extraction well installation, above ground pipe installation, groundwater treatment system installation, and continued operations, maintenance, and monitoring of the extraction system. Drilling costs may be high given the long horizontal runs of the wells and the lower production rates in bedrock compared to other soils.	Retained.
Alternative 3: Hydraulic Fracturing and Additional Groundwater Extraction Wells	In the long term, this alternative would be effective at reducing the concentration of chloropyridines and VOCs in hydraulically fractured bedrock within the contaminant source area. In the short term, this alternative could achieve significant additional mass removal from the source area.	Technical issues with implementing this alternative include the unknown effectiveness of hydraulic fracturing in the weathered bedrock. The pilot test results suggest uncertainty with the potential effectiveness of this technology, raising concerns that the varied fractures in bedrock could affect implementability.	Costs associated with this alternative are moderate. The primary cost items include the fracking pilot test, fracking program, bedrock extraction well installation and long term operations, maintenance, and monitoring of the enhanced extraction system. However, these costs would carry a high contingency risk based on the uncertain number of hydraulic fracturing wells required to achieve communication between the developed bedrock fractures and the new extraction wells.	Retained.
Alternative 4: In-Situ Source Treatment - Chemical Oxidation	This alternative would not effectively oxidize groundwater contaminants in the short term. While VOC and chloropyridine degradation was successfully demonstrated during laboratory bench test analyses, the pilot study indicated oxidant transport and dispersion did not promote sufficient contact and oxidant permanency to target contamination within the fracted bedrock matrix, and contaminant concentrations were reduced either inconsistently or ineffectively in observed monitoring wells.	In-situ chemical oxidation can be implemented using readily available technologies. Depending on the chemical used, its dosage, and ability for chemical distribution, this alternative can provide relatively quick results. Technical issues with implementing this alternative derive from the limited surface access given the active facility, as well as the varied fractures in bedrock which would likely limit contact between the chemical oxidant and the contaminants.	Costs associated with this alternative are moderate. The primary cost items include the chemical oxidant bench test, pilot study, and the chemical oxidant injection program. However, these costs would carry a high contingency risk based on the uncertain ability to contact contaminants with the oxidant.	Eliminated.

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Table 9-1: Applicable Location- and Action-Specific Standards, Criteria, and Guidance

Requirement	**Consideration in the Remedial Response Process**
29 CFR Part 1910.120 - Hazardous Waste Operations and Emergency Response	Applicable to implementation of Health and Safety implementation, enforcement, and emergency response.
6 NYCRR Part 371 - Identification and Listing of Hazardous Wastes (November 1998)	Applicable to the characterization, handling, transportation, and treatment/disposal of soils to be removed from the Site.
6 NYCRR Part 372 - Hazardous Waste Manifest System and Related Standards for Generators, Transporters and Facilities (November 1998)	Applicable to the handling, transportation, and treatment/disposal of soils to be removed from the Site.
6 NYCRR Part 375 - Environmental Remediation Programs (as amended December 2006)	Applicable to the development and implementation of remedial programs.
6 NYCRR Part 376 - Land Disposal Restrictions	Applicable to disposal of hazardous wastes. Identifies those wastes that are restricted from land disposal.
6 NYCRR Part 750 through 758 - Implementation of NPDES Program in NYS (“SPDES Regulations”)	Applicable to construction in and adjacent to water bodies and discharge of treated wastewater.
DER-10 Technical Guidance for Site Investigation and Remediation	Applicable to the development and implementation of remedial programs.
Citizen Participation in New York’s Hazardous Waste Site Remediation Program: A Guidebook (June 1998)	Applicable to the development and implementation of remedial programs.
TOGS 1.1.1 - Ambient Water Quality Standards & Guidance Values and Groundwater Effluent Limitations	Applicable to discharge of treated wastewater.
Solidification/Stabilization and its Application to Waste Materials	Applicable to disposal of wastes generated during implementation of remedial program.

Prepared/Date: NRL 02/06/2019
Checked by: NMB 03/01/19

Table 9-2: Cost Summary for Alternative 1 - Continued Groundwater Extraction

ITEM		COST
DIRECT CAPITAL COSTS		
Direct Cost Subtotal	$	-
INDIRECT CAPITAL COSTS		
Project Management (@ 10 Percent)	$	-
Remedial Design (none included)	$	-
Construction Management (none included)	$	-
Contingency (@ 15 Percent)	$	-
Indirect Cost Subtotal	$	-
TOTAL CAPITAL COSTS	**$**	**-**
ANNUAL OPERATION AND MAINTENANCE COSTS		
OM&M of the Existing Groundwater Extraction System (years 1-30)	$	228,000
Semiannual Monitoring and reporting (years 1-30)	$	97,000
PRESENT WORTH OF ANNUAL AND PERIODIC COSTS (30 yrs)	**$**	**4,996,000**
TOTAL PRESENT WORTH OF ALTERNATIVE 1 (30 yrs)	**$**	**4,996,000**

NOTES:

Costs have been rounded to the nearest thousand.
Costs based on annual inspection and reporting.

Table 9.3: Cost Summary for Alternative 2 – Install Horizontal Groundwater Extraction Wells

ITEM		**COST**
DIRECT CAPITAL COSTS		
General Conditions	$	39,000
Extraction Well Installation	$	685,000
Direct Cost Subtotal	$	724,000
INDIRECT CAPITAL COSTS		
Project Management (@ 6 Percent)	$	44,000
Remedial Design (@ 12 Percent)	$	87,000
Contingency (@ 15 Percent)	$	58,000
Contingency (@ 25 Percent)	$	181,000
Indirect Cost Subtotal	$	370,000
TOTAL CAPITAL COSTS	**$**	**1,094,000**
ANNUAL OPERATION AND MAINTENANCE COSTS		
Annual Groundwater Extraction System OM&M (1-25)	$	355,000
Semiannual Monitoring (Years 1-30)	$	97,000
PRESENT WORTH OF ANNUAL AND PERIODIC COSTS (30 yrs)	**$**	**5,917,000**
TOTAL PRESENT WORTH OF ALTERNATIVE 2 (30 yrs)	**$**	**7,011,000**

NOTES:

Costs have been rounded to the nearest thousand.

Table 9.4: Cost Summary for Alternative 3 - Hydraulic Fracturing and Additional Groundwater Extraction Wells

ITEM		**COST**
DIRECT CAPITAL COSTS		
Hydraulic Fracturing Field Program	$	64,300
Extraction Well Installation	$	77,982
Direct Cost Subtotal	$	142,282
INDIRECT CAPITAL COSTS		
Project Management (@ 8 Percent)	$	11,000
Remedial Design (@ 15 Percent)	$	21,000
Contingency (@ 15 Percent)	$	14,000
Contingency (@ 25 Percent)	$	36,000
Indirect Cost Subtotal	$	82,000
TOTAL CAPITAL COSTS	**$**	**224,282**
ANNUAL OPERATION AND MAINTENANCE COSTS		
Annual Groundwater Extraction System OM&M (1-20)	$	228,000
Semiannual Monitoring (Years 1-30)	$	97,000
PRESENT WORTH OF ANNUAL AND PERIODIC COSTS (30 yrs)	**$**	**4,581,000**
TOTAL PRESENT WORTH OF ALTERNATIVE 3 (30 yrs)	**$**	**4,805,000**

NOTES:
Costs have been rounded to the nearest thousand.
Costs based on annual inspection and reporting.

Table 10.1: Summary of Remedial Alternative Costs

Item	**Description**	**Alternative 1**	**Alternative 2**	**Alternative 3**
1	Capital Costs	$ -	$ 1,094,000	$ 224,282
2	Present Worth of Annual and Periodic Costs	$ 4,996,000	$ 5,917,000	$ 4,581,000
3	**Total Present Worth (Item 1 plus 2)**	**$ 4,996,000**	**$ 7,011,000**	**$ 4,805,000**
4	Annual Costs Years 1 through 15 Contingency (@ 15 Percent)	$ 325,000	$ 452,000	$ 325,000
5	Annual Costs Years 16 through 20	$ 325,000	$ 452,000	$ 325,000
6	Annual Costs Years 21 through 25	$ 325,000	$ 97,000	$ 325,000
7	Annual Costs Years 26 through 30	$ 325,000	$ 97,000	$ 97,000
8	Remedial Timeframe (yrs) (Note 3)	30	30	30

Notes:

1. Present Worth costs shown above are based upon the assumed Remedial Timeframe.
2. Annual and Periodic Costs (Item 2, 4 - 7) presented are non-discounted (future) costs.
3. Estimated costs presented in this table are intended to be within the target accuracy range of minus 30 to plus 50 percent of actual cost.

Alternative Descriptions:

1 = Continued Groundwater Extraction
2 = Install Horizontal Groundwater Extraction Wells
3 = Hydraulic Fracturing and Additional Groundwater Extraction Wells

Table 10-2: Comparative Analysis of Remedial Alternatives

Remedial Alternative	Alternative 1: Continued Groundwater Extraction	Alternative 2: Install Horizontal Groundwater Extraction Wells	Alternative 3: Hydraulic Fracturing and Additional Groundwater Extraction Wells
Compliance with New York State SCGs	Alternative 1 does not meet chemical-specific SCGs in the short term because it does not remove or treat groundwater contamination in excess of 6 NYCRR Parts 700-706 Water Quality Standards (NYSDEC, 1998). However, in the long term this alternative will assist remediating groundwater to meet class GA groundwater standards.	Alternative 2 does not meet chemical-specific SCGs in the short term because it does not remove or treat groundwater contamination in excess of 6 NYCRR Parts 700-706 Water Quality Standards (NYSDEC, 1998). However, in the long term this alternative will assist remediating groundwater to meet class GA groundwater standards faster than Alternatives 1 or 3.	Alternative 3 does not meet chemical-specific SCGs in the short term because it does not remove or treat groundwater contamination in excess of 6 NYCRR Parts 700-706 Water Quality Standards (NYSDEC, 1998). However, in the long term this alternative will assist remediating groundwater to meet class GA groundwater standards. The pilot test results for this technology suggest this alternative may be ineffective at reaching SCGs significantly faster than Alternative 1 alone.
Overall Protection of Human Health and the Environment	Alternative 1 protects public health and the environment through controlling migration of groundwater contaminants from the source area and eliminating and controlling potential exposure pathways through removal and treatment of contaminated groundwater. This remedial alternative may achieve the RAOs for groundwater in the long term.	Alternative 2 protects public health and the environment through controlling migration of groundwater contaminants from the source area and eliminating and controlling potential exposure pathways through removal and treatment of contaminated groundwater. This remedial alternative may achieve the RAOs for groundwater in the long term and would likely achieve RAOs faster than Alternatives 1 or 3.	Alternative 3 protects public health and the environment through controlling migration of groundwater contaminants from the source area and eliminating and controlling potential exposure pathways through removal and treatment of contaminated groundwater. This remedial alternative may achieve the RAOs for groundwater in the long term, but would likely not achieve RAOs faster than Alternative 2 and would be comparable to Alternative 1
Short-term Impacts and Effectiveness	Alternative 1 does not include construction or other activities that would result in potential short-term adverse impacts and risks to the community, workers, or the environment during implementation.	Alternative 2 includes activities that would result in potential short-term adverse impacts and risks to workers during installation of the new extraction wells. However, proper health and safety practices can control these risks. It is estimated that this alternative could be fully implemented in approximately one year.	Alternative 3 includes activities that would result in potential short-term adverse impacts and risks to workers during the fracking pilot test, fracking program, and installation of new groundwater extraction wells. However, proper health and safety practices can control these risks. It is estimated that this alternative could be fully implemented in approximately one year.

Prepared/Date: NRL 02/06/19
Checked/Date: NMB 03/01/2019

Table 10-2: Comparative Analysis of Remedial Alternatives

Remedial Alternative	Alternative 1: Continued Groundwater Extraction	Alternative 2: Install Horizontal Groundwater Extraction Wells	Alternative 3: Hydraulic Fracturing and Additional Groundwater Extraction Wells
Long-term Effectiveness and Permanence	Alternative 1 may meet RAOs in the future due to natural attenuation of contaminants and continued extraction of contaminant mass, although the time period required to meet RAOs is likely significant. Remaining contamination would pose a low risk to human health and the environment, and existing health and safety practices on-site further mitigate the residual risks.	Alternative 2 may meet RAOs in the future due to natural attenuation of contaminants and continued extraction of contaminant mass, although the time period required to meet RAOs is likely significant. Remaining contamination would pose a low risk to human health and the environment, and existing health and safety practices on-site further mitigate the residual risks. This remedial alternative would likely achieve RAOs faster than Alternatives 1 or 3 due to increased contaminant mass extraction rates.	Alternative 3 may meet RAOs in the future due to natural attenuation of contaminants and increased extraction of contaminant mass, although the time period required to meet RAOs is likely significant. Remaining contamination would pose a low risk to human health and the environment, and existing health and safety practices on-site further mitigate the residual risks. This remedial alternative would likely achieve RAOs comparably to Alternative 1 due to the ineffective pilot test results.
Reduction of Toxicity, Mobility, and Volume	Alternative 1 would reduce the mobility and volume of contaminants on-site through groundwater extraction and ex-situ treatment with granular activated carbon.	Alternative 2 would reduce the mobility and volume of contaminants on-site through groundwater extraction and ex-situ treatment with granular activated carbon.	Alternative 3 would reduce the mobility and volume of contaminants on-site through groundwater extraction and ex-situ treatment with granular activated carbon.
Implementability	Alternative 1 does not include additional actions. Therefore, there are no technical difficulties associated with this alternative. As the existing remedy, regulatory approval of this alternative is not anticipated to be difficult.	Alternative 2 includes the installation of new extraction wells and continued operation, maintenance, and monitoring of the groundwater extraction system. This alternative would not be technically difficult to implement. As an enhancement of the existing remedy, regulatory approval of this alternative is not anticipated to be difficult.	Alternative 3 includes hydraulic fracturing of the shallow bedrock on-site, installing new extraction wells, and continued operation, maintenance, and monitoring of the groundwater extraction system. This alternative would not be technically difficult to implement. As an enhancement of the existing remedy, regulatory approval of this alternative is not anticipated to be difficult.
Land Use	Alternative 1 would be compatible with current and foreseeable future land use given the existing institutional controls, groundwater containment, and anticipated continued use of the land as an active chemical manufacturing facility.	Alternative 2 would be compatible with current and foreseeable future land use given the existing institutional controls, groundwater containment, and anticipated continued use of the land as an active chemical manufacturing facility.	Alternative 3 would be compatible with current and foreseeable future land use given the existing institutional controls, groundwater containment, and anticipated continued use of the land as an active chemical manufacturing facility.

Prepared/Date: NRL 02/06/19
Checked/Date: NMB 03/01/2019

APPENDIX A

MEDIA-SPECIFIC STANDARDS, CRITERIA, AND GUIDANCE

Appendix A: Media-Specific Standards, Criteria, and Guidance

Constituent	**Groundwater SCG[a] (ppb)[b]**	**Soil SCG[c] (ppm)[d]**	**Surface Water SCG[e] (ppb)[b]**
VOCS			
Carbon Tetrachloride	5	0.76	ND
Chlorobenzene	5	ND	ND
Chloroform	7	0.37	ND
1,1-Dichloroethene	ND	0.33	ND
Methylene Chloride	5	0.05	ND
Tetrachloroethene	5	1.3	ND
Trichloroethene	5	0.47	ND
SVOCs			
2,6-dichloropyridine	NS	NS	NS
2-chloropyridine	NS	0.9[f]	NS
3-chloropyridine	NS	0.8[f]	NS
4-chloropyridine	NS	NS	ND
p-fluoroaniline	NS	ND	ND
Pyridine	50	ND	ND
Benzo(a)pyrene	ND	1	ND
Indeno(1,2,3-cd)pyrene	ND	11	ND
Inorganics			
Mercury	ND	5.7	ND

a - Ambient Water Quality Standards and Guidance Values (TOGs 1.1.1), 6 NYCRR Part 703: Surface Water and Groundwater Quality Standards, and Part 5 of the New Tork State Sanitary Code (10 NYCRR Part 5)
b - ppb: parts per billion, which is equivalent to micrograms per liter, ug/L, in water
c - Part 375-6.8(b), Restricted Use Soil Cleanup Objectives for the Protection of Groundwater
d - ppm: parts per million, which is equivalent to milligrams per kilogram, mg/kg, in soil
e - Ambient Water Quality Standards and Guidance Values (TOGs 1.1.1), and 6 NYCRR Part 703: Surface Water and Groundwater Quality Standards
f - As used in March 2002 ROD

NS - no standard of guidance value
ND - Constituent not detected in media

Prepared/Date: NRL 02/06/2019
Checked by: NMB 03/01/19

APPENDIX B

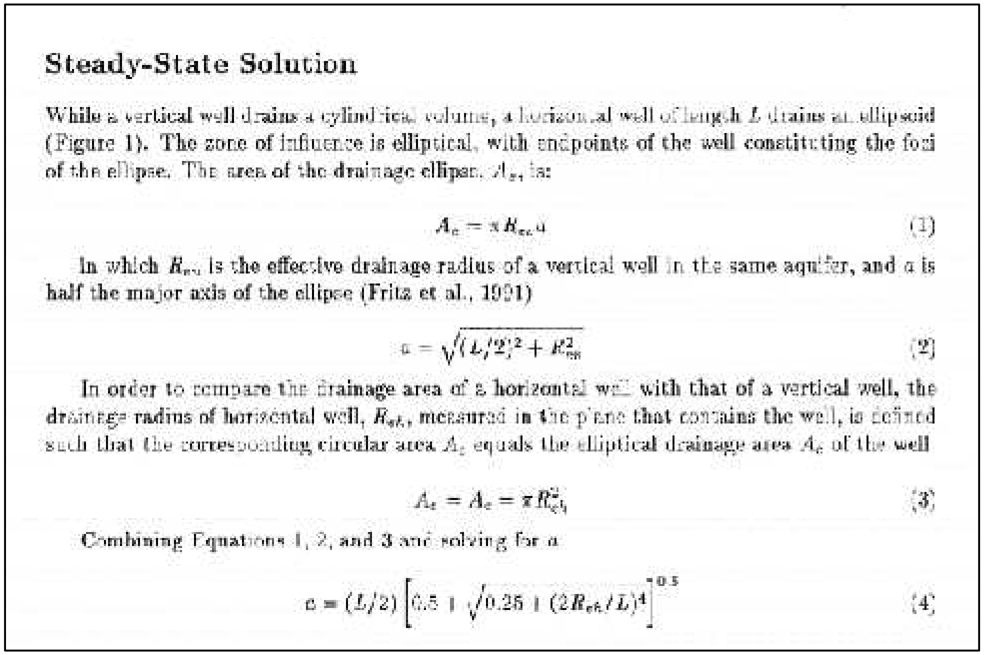
CALCULATIONS

Job No. 3616146046
Job Name Arch Chemicals FSA
By Nelson Breton Date 1/8/15
Checked By Brandon Newman Date 1/14/15

amec
511 Congress Street
Portland, ME 04101
+1 (207) 775-5401

Purpose: Estimate the yield of a 500’ long horizontal groundwater extraction well installed at the Arch Chemicals Facility in Rochester, NY.

Method:



Steady-State Solution

While a vertical well drains a cylindrical volume, a horizontal well of length L drains an ellipsoid (Figure 1). The zone of influence is elliptical, with endpoints of the well constituting the foci of the ellipse. The area of the drainage ellipse, A_e, is:

$$A_e = \pi R_{ev} a \tag{1}$$

In which R_{ev} is the effective drainage radius of a vertical well in the same aquifer, and a is half the major axis of the ellipse (Fritz et al., 1991)

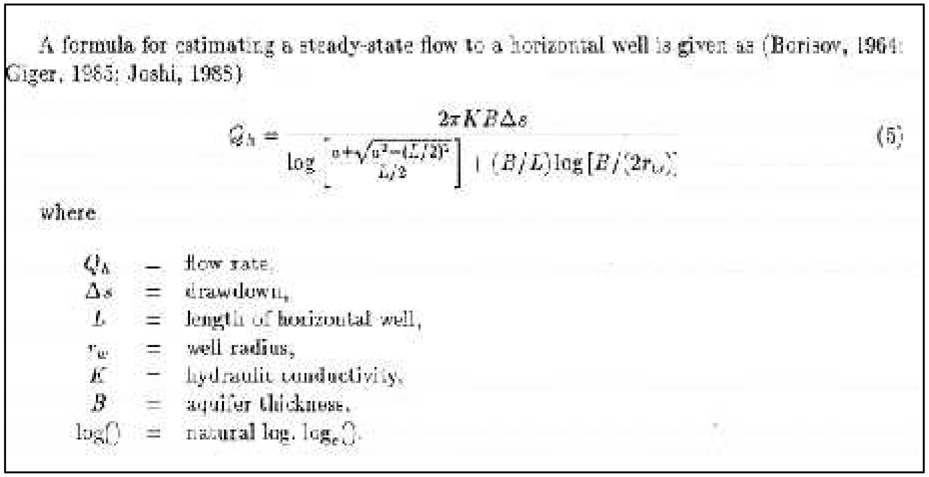
$$a = \sqrt{(L/2)^2 + R_{ev}^2} \tag{2}$$

In order to compare the drainage area of a horizontal well with that of a vertical well, the drainage radius of horizontal well, R_{eh}, measured in the plane that contains the well, is defined such that the corresponding circular area A_c equals the elliptical drainage area A_e of the well

$$A_c = A_e = \pi R_{eh}^2 \tag{3}$$

Combining Equations 1, 2, and 3 and solving for a

$$a = (L/2)\left[0.5 + \sqrt{0.25 + (2R_{eh}/L)^4}\right]^{0.5} \tag{4}$$



A formula for estimating a steady-state flow to a horizontal well is given as (Borisov, 1964; Giger, 1985; Joshi, 1988)

$$Q_h = \frac{2\pi K B \Delta s}{\log\left[\frac{a+\sqrt{a^2-(L/2)^2}}{L/2}\right] + (B/L)\log[B/(2r_w)]} \tag{5}$$

where

Q_h = flow rate,
Δs = drawdown,
L = length of horizontal well,
r_w = well radius,
K = hydraulic conductivity,
B = aquifer thickness,
$\log()$ = natural log, $\log_e()$.

Assumptions: Homogeneous isotropic conditions with no other hydraulic influences.

Constants and Inputs: Rising Head Slug Tests - Phase I RFI

BR-101	2.20E-03	cm/s

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Job Name	Arch Chemicals FSA		
By	Nelson Breton	Date	1/8/15
Checked By	Brandon Newman	Date	1/14/15

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Portland, ME 04101
+1 (207) 775-5401

BR-102	4.90E-03	cm/s				
BR-103	2.00E-04	cm/s				
BR-104	1.90E-03	cm/s				
BR-105	3.90E-05	cm/s		1.70E-02	max	cm/s
BR-106	1.70E-02	cm/s		3.55E-03	median	cm/s
BR-107	1.10E-02	cm/s		1.70E-04	max	m/sec
BR-108	1.60E-02	cm/s		3.55E-05	median	m/sec

a	300	91.44	m	based on 500 ft long screen w/ variable drawdown radius
R_{eh}	100	30.48	m	Drawdown radius = 50
Δs	5	1.524	m	
L	500	152.4	m	
R_w	0.5	0.1524	m	
K	0.00017	3.55E-05	m/s o	0.00355 cm/s median K 3.07E+00
B	10	3.048	m	

References: http://info.ngwa.org/gwol/pdf/920156009.pdf

Calculations:

Expected flow using K_{median}:

264.2 gal/m3

Q_h = 0.00155 m^3/s 0.001036115 0.017 min/sec

24.6 gpm 0.668414206 Unit conv factor

0.00155011 m3/sec x 264 gal/m3 / 0.017 min /sec = 15847

Expected flow using K_{max}:

Q_h = 0.00742 m^3/s

118 gpm

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amec

511 Congress Street
Portland, ME 04101
+1 (207) 775-5401

Conclusion: Using a median value of hydraulic conductivity for 8 on-site bedrock wells, expected flow for a 500 foot long trench are approximately 25 gallons per minute. Flows up to 118 gpm were estimated assuming a maximum uniform hydraulic conductivity from BR-106. While actual flow rates will likely not approach 118 gpm due to variation in conductivity values along the well alignment, an intermediate flow rate of 50 gpm should be assumed to conservatively size and price the extraction and treatment equipment. Design flow rates will need to be informed by pre-design packer testing along the proposed alignments. Also, note that initial flow rates may be much higher when the system is first turned on to meet the drawdown objective.

PIPE RUN NO.		0-1		1-2							
RUN LENTH (FT.)		1000		0							
FLOW (GPM)		50		50							
PIPE SIZE (IN.)		3		2							
PIPE I.D. (IN.)		2.9		1.656							
VELOCITY (FT./S)		2.43		7.4485111							
REYNOLDS NUMBER		58696.322		102789.45							
FLOW REGIME		transition		transition							
FRICTION FACTOR (SMOOTH PIPE)		0.0200881		0.0177657							
FITTINGS	K	No.	Hf	No.	Hf	No.	Hf	No.	Hf	No.	Hf
90° ELLS STANDARD	0.9	6	0.4946479		0		0		0		0
90° ELLS MEDIUM SWEEP	0.75		0		0		0		0		0
90° ELLS LONG SWEEP	0.6		0		0		0		0		0
45° ELLS	0.4		0		0		0		0		0
90° MITER BEND (WITHOUT VANES)	1.1		0		0		0		0		0
90° MITER BEND (WITH VANES)	0.2		0		0		0		0		0
TEE-STRAIGHT	0.9		0		0		0		0		0
TEE-BRANCH	1.8		0		0		0		0		0
CLOSE RETURN BEND	2.2		0		0		0		0		0
SQUARE-EDGED ENTRANCE	0.5		0		0		0		0		0
REENTRANT ENTRANCE	0.8		0		0		0		0		0
WELL ROUNDED ENTRANCE	0.03	1	0.002748		0		0		0		0
PIPE EXIT	1		0		0		0		0		0
ORIFACE PLATE (1.5 TO 1 AREA RATIO)	0.85	1	0.0778612		0		0		0		0
ORIFACE PLATE (2 TO 1 AREA RATIO)	3.4		0		0		0		0		0
ORIFACE PLATE (4 TO 1 AREA RATIO)	29		0		0		0		0		0
GENERAL CONTRACTION (30° INCLUDED ANGLE)	0.02		0		0		0		0		0
GENERAL CONTRACTION (70° INCLUDED ANGLE)	0.07		0		0		0		0		0
REDUCER (2 TO 1 AREA RATIO)	0.25		0		0		0		0		0
REDUCER (5 TO 1 AREA RATIO)	0.41		0		0		0		0		0
REDUCER (10 TO 1 AREA RATIO)	0.46		0		0		0		0		0
INCREASER (1 TO 2 AREA RATIO)	0.25		0		0		0		0		0
INCREASER (1 TO 5 AREA RATIO)	0.64		0		0		0		0		0
INCREASER (1 TO 10 AREA RATIO)	0.81		0		0		0		0		0
VALVE-GATE FULLY OPEN	0.2	2	0.0366406		0		0		0		0
VALVE-GATE HALF OPEN	5.6		0		0		0		0		0
VALVE-GATE ONE QUARTER OPEN	24		0		0		0		0		0
VALVE-GLOBE FULLY OPEN	6.4		0		0		0		0		0
VALVE-GLOBE HALF OPEN	9.5		0		0		0		0		0
VALVE- BALL FULL OPEN	0.05		0		0		0		0		0
VALVE- ANGLE FULLY OPEN	5		0		0		0		0		0
VALVE -SWING CHECK FULLY OPEN	2.5		0		0		0		0		0
VALVE - 3-WAY STRAIGHT THROUGH	0.51		0		0		0		0		0
VALVE- CHECK	0.25	2	0.0458007		0		0		0		0
TOTAL FITTING HEAD (FT.)			0.6576985		0		0		0		0
TOTAL PIPE LENGTH (FT.)			1000		0		0		0		0
CALCULATED C VALUE FROM FRICTION FACTOR			151.41298		155.56289		#DIV/0!		#DIV/0!		#DIV/0!
C VALUE USED IN HAZEN-WILLIAMS			140		110		80		100		100
PIPE FRICTION HEAD (FT.) (HAZEN-WILLIAMS)			8.8116133		0		#DIV/0!		#DIV/0!		#DIV/0!
CONTROL VALVE FRICTION HEAD (FT.)			0		0		0		0		0
EQUIPMENT FRICTION HEAD (FT.)			0		0		0		0		0
TOTAL FRICTION HEAD (FT.)			9.4693118		0		#DIV/0!		#DIV/0!		#DIV/0!
CUMULATIVE FRICTION HEAD (FT.)			9.4693118		9.4693118		#DIV/0!		#DIV/0!		#DIV/0!

FLUID

LIQUID	water	%BD
CONSISTENCY	100	%
SOLIDS	unknown	
MAX. PARTICLE SIZE	unknown	
ABRASIVE	unknown	
SPECIFIC GRAVITY	1	
TEMPERATURE	45	°F
pH	7.5	
KINEMATIC VISCOSITY	1E-05	FT^2/SEC

CAPACITY

SOLIDS FLOW	-	BDT/D
CONSISTENCY	-	%BD
VOLUME FLOW	10	USGPM
ALLOWANCE	-	%
TOTAL VOLUME FLOW	10	USGPM

HEAD

+ DISCHARGE STATIC	545.00	FT.
- SUCTION STATIC	510.00	FT.
= NET STATIC	35.00	FT.
+ SUCTION FRICTION	9.47	FT.
+ DISCHARGE FRICTION	0.00	FT.
= TOTAL FRICTION	9.47	FT.
- SUCTION VESSEL PRESS	0.00	FT. ABS
+ DISCHARGE VESSEL PRESS	0.00	FT. ABS
= TOTAL PRESS	0.00	FT.
PUMP TDH	44.47	FT.

PUMP Arch Horizontal Extraction Wells - Typical

NPSHa/MIN SUCT HEAD

+SUCTION VESSEL PRESS		FT. ABS
- LIQUID VAPOR PRESS		FT. ABS
+ SUCTION STATIC		FT.
- SUCTION FRICTION		FT.
= NPSHA		FT.
SUBMERGENCE		FT.

2/19/2015	BPN	Draft	
DATE	BY	STATUS	CHK. BY

AMEC Environment & Infrastructure

PROJECT
329313533.4100.410001

DATE	BY	JOB
2/19/2015	BPN	Arch Chemicals FSA

APPENDIX C

HYDRAULIC FRACTURING PILOT TEST FIELD FORMS, NOTES, AND OBSERVATIONS

Packer Testing at Lonza Manufacturing Facility
Rochester, New York

During the period of September 17 through September 27, 2012, AMEC Environment and Infrastructure, Inc. (AMEC) oversaw the installation of 12 shallow bedrock borings at the Lonza Manufacturing Facility (Lonza) in Rochester, New York. The borings were installed by Nothnagle Drilling, Inc. (Nothnagle) of Scottsville, New York. The objective of the borings was to increase the bulk permeability and connectivity of fractures within the shallow bedrock to improve the performance of a groundwater containment extraction system. The locations of the borings identified as HF-1 through HF-12 and as shown on Figure 1, coincide with the areas of highest groundwater contamination levels. This area has also historically exhibited low yields or rapidly declining yields in the nearby extraction wells.

The 12 borings were installed as shown on Figure 1 to produce an East-West alignment extending to the west from PZ-106. The borings were placed at roughly 22-foot intervals. Because of the location of an existing building, borings HF-11 and HF-12 were offset approximately 12 feet south of the alignment of the other borings. Also, Lonza will be constructing a new wastewater treatment building, containment dike, and covered ramp as shown on Figure ___. Accordingly, borings HF-1 through HF-7 were placed where the proposed new building will be located.

At each of the 12 boring locations, Nothnagle used 4-1/4" inside diameter hollow stem augers to drill down to the top of bedrock. Using the augers as a temporary casing, bedrock borings 3-3/4" in diameter were air hammered to approximately 20 feet into the bedrock (approximately 35' – 40' below ground surface). Rates of drilling, noted fracturing or depths exhibiting soft drilling, as well as other observations were recorded on field sheets as each boring was advanced. These sheets are included in Appendix A. Once termination depths were obtained, a packer system was installed into the bedrock borehole to segregate a portion of the borehole in which packer testing and hydraulic fracturing were performed. Typically, a single packer was installed prior to conducting the test, with the packer placed at top of what was interpreted as being the most competent section of borehole. With the packer inflated to segregate the test section of bedrock, water was pumped at increasingly higher rates of pressures to observe how the formation responded as well as to see if the bedrock could be hydraulically fractured. A rule of thumb for the hydraulic pressures needed to produce fractures in bedrock is that one pound per square inch of pressure is needed for each foot below ground surface. Therefore, for depths of up to 30 feet below ground surface, hydraulic pressures of at least 30 pounds per square inch would be necessary to initiate fracturing in the bedrock. The intent of the pressure testing was to either initiate new fractures or to increase the conductivities of the existing fractures in the shallow bedrock to improve total groundwater movement and potential contaminant movement to any existing or proposed pumping wells. Only at HF-5 were two packers used; these were installed to segregate an approximately six foot section of bedrock from 22’ to 28’ below ground surface. Field forms were completed to identify the testing parameters, and these forms are included in Appendix B. Actual test results were recorded in the field notebook which has been photocopied and included in Appendix C. After the testing was performed, all borings were backfilled with pea stone from termination depths to the ground surface. Temporary piezometers were installed in the shallow bedrock and overburden interface in the HF-4 and HF-8 locations. These temporary piezometers were installed to observe water level fluctuations or signs of hydraulic communication as the other borings were installed.

At the completion of the drilling and packer testing, two piezometers were installed in bedrock at the HF-12 and HF-8 locations and were completed with flush-to-ground protective road boxes. These piezometers (identified as PZ-110 and PZ-111, respectively) were placed to monitor the shallow bedrock. The two piezometer diagrams are included in Appendix D. Additionally, an open-hole bedrock boring was installed at the HF-10 location, this being identified as PW-17. This well was completed with an above ground protective stick up casing. The installation diagram for this well is also included in Appendix D.

A summary of the drilling and testing observations are presented in Table 1.

DETAILS AND OBSERVATIONS OF PACKER BORINGS
LONZA MANUFACTURING FACILITY
ROCHESTER, NEW YORK

Location ID	Date of Installation	Date of Packer Testing	ID of Installed Piezometer or Well	Depth to Top of Bedrock (ft. bgs)	Depth to Bottom of Borehole (ft. bgs)	Single (S) or Double (D) Packers	Packer Test Interval (ft. bgs)	Observed Communication With Other Borings or Wells?	Notes, Observations, Comments
HF-2	9/17/2012	9/18/2012	-	13'	33'	S	25'-33'	-	packer tests at: 10 psi = 4.2 gpm; 25 psi = 9 gmp; 40 psi = 14.8 gpm: total pumping time of about 10 minutes
HF-3	9/18/2012	9/18/2012	-	14.2'	35'	S	28'-35'	-	packer tests at: 10 psi = 0.4 gpm; 25 psi = 1.4 gmp; 40 psi = 2.3 gpm; then 10 psi again = 0.6 gpm: apparent increase of permeability as seen in the 10 psi tests of before and after higher psi's: total pumping time of 14 minutes
HF-4	9/18/2012	9/18/2012	-	12.8'	33'	S	26'-33'	in first 5' of drilling HF-4, notice reaction in HF-3	packer tests at: 10 psi = 0 gpm; 25 psi = 0.4 gpm; 40 psi = 0.4 gpm; 100 psi = from a low of 3 up to around 7 gpm; only at higher pressures did the formation take much water: total pumping time of 12 minutes
HF-5	9/19/2012	9/19/2012	-	15'	35'	D	22'-28'	water violently shoots out of HF-4 piezometer when drilling at depths of 15' and 34' in HF-5	packer tests at: 10 psi = 2.2 gpm; 25 psi = 6.8 gpm; 40 psi = 10.4 gpm; and 10 psi again at 3.1 gpm: apparent increase of permeability as seen in the 10 psi tests before and after higher psi's: total pumping time of 12 minutes
HF-6	9/19/2012	9/19/2012	-	16'	36'	S	25'-36'	-	packer tests at: 10 psi = 5.1 gpm; 25 psi = 8.3 gpm; 40 psi = 12 gpm; and 10 psi again = 3.8 gpm: reduction of permeability seen in the two 10 psi test results: total pumping time of 11.5 minutes
HF-7	9/20/2012	9/20/2012	-	15.6'	36'	S	28'-36'	when drilling at around 18' in HF-7, water and air shoots out of HF-4 and HF-6	numerous pressures applied during testing: packer tests at: 10 psi = 2.3 gpm; 25 psi = 5.8 gmp; 40 psi = 9.2 gpm, then turn off pump and notice water released back into the boring from the formation after water pump shut off; then, conducted tests again at 10 psi = 3.2 gpm; 60 psi = 17.2 gpm; 90 psi = 24.8 gpm, and water still comes back from formation after water pump shut off; this is only boring showing this feature: total pumping time of 21 minutes
HF-8	9/20/2012	9/20/2012	PZ-111	16.4'	36'	S	28'-36'	-	packer tests at: 10 psi = 2.2 gpm; 25 psi = 4 gpm; 40 psi = 5.6 gpm; 80 psi = 9.7 gpm: total pumping time of 20 minutes
HF-9	9/24/2012	9/24/2012	-	15.4'	36'	S	26'-36'	-	packer tests at: 10 psi = 5.1 gpm; 25 psi = 8.3 gpm; 40 psi = 12.7 gmp; bumped pump up to approx. 105 psi and formation took as much water as could be pumped: total pumping time of 16 minutes
HF-10	9/24/2012	9/24/2012	PW-17	17'	37'	S	27'-37'	while drilling down to 20' in HF-10, have water and air coming out of HF-9, HF-8 and HF-7; also lot of air and muddy water coming out of PW-15	packer tests at: 10 psi = 6+ gpm; 25 psi = 10.3 gmp; 40 psi = 13.3 gpm; 62 psi = 18.9 gpm: total pumping time of 17 minutes
HF-11	9/24/2012	9/25/2012	-	13.7'	34'	-	-	during the drilling of HF-11, have water and air coming out of HF-8, HF-9, HF-10, and PW-15	packer testing not performed in this boring due to poor seal at top or rock caused by poor rock quality; potential to damage/lose packer from loose rocks falling into hole above packer
HF-12	9/25/2012	9/25/2012	PZ-110	18.7'	39'	S	29'-39'	-	packer tests at: 10 psi = 2.5 gpm; 25 psi = 3.9 gpm; 40 psi = 7.8 gpm; 60 psi = 13.8 gpm; then again at 10 psi = 4.4 gpm: apparent increase in permeability based on the two 10 psi tests: total pumping time of 20 minutes
HF-1	9/26/2012	9/26/2012	-	12.5'	33'	S	25'-33'	during drilling of this boring down to around 17', noticed sometimes violent reactions in HF-2, HF-3, HF-4, HF-5, and a 14" dia. well located 15' north of HF-1; drilling of HF-1 caused most observed reactions in other borings	packer tests at: 10 psi = 0.3 gpm; 25 psi = 0.4 gpm; 40 psi = 0.6 gpm; 63 psi = 1 gpm; 80 psi = 13.6 gpm; then again at 25 psi = 0.6 gpm: total pumping time of 22 minutes

"-" = not applicable or not observed

Arch Chemicals, Rochester, NY
Drilling Progress
Hydrofracking Test Boreholes

Borehole ID: HF-2
Date Drilled: 9-17-12
Driller: Neal Short
Time Start: 13:46
Time End: 14:49

Drill Firm: Nothnagle
Dia. Of Borehole (in.): ~3 3/4" IN Rock (≈8" soil)
Drilling Technique: AIR HAMMER
Rig: CME-75

Time	Depth	Drilling Observations, Etc.
13:46	13'	START @ 13' on Rock 20+13 = 33' TARGET depth
	14.5'	FRACTURE : PID = 0.0 ppm
13:54	~18'	ADD 5' Rod (18'-23') Skunk ODOR TO Returns
14:00		18.5' bgs ; ▽ ≈ 18' bgs : STOP @ 14:00 to add rubber bands/deflectors
14:08	18.5'	START AGAIN
14:13	~~23'~~ 21'	STOP - ADD ROD TDL (~~23'-28'~~)(21'-26')
14:22	~~START~~ 21'.	START SOFT @ ~24½-25'
14:30	26'	STOP. Small FRAC. @ TDL ~~29'~~ 24' : ADD ROD (26'-31')
14:33	26'	START (26'-31')
14:41	31'	END Ream ; will add Rod
14:47	31'	START @ 31'-33'
14:49	33'	END @ 33'
		— Get Ready to FRACTURE ~23'-33' zone =
		bottom 10' of HOLE

FRAC 24'
Set bottom of packer @ 25'

Notes: DRILLER HAS 3" & 3 3/4" O.D. drill bits (coring bits) & 3 3/4" AIR HAMMER
SPUN AUGERS TO 13' on ROCK

Arch Chemicals, Rochester, NY
Drilling Progress
Hydrofracking Test Boreholes

Borehole ID: HF-3
Date Drilled: 9-18-12
Driller: Neal Short
Time Start: 0943
Time End: 10:19

Drill Firm: Nothnagle
Dia. Of Borehole (in.): ~ 3 3/4"
Drilling Technique AIR HAMMER
Rig : CME-75

14.2' - (SOIL)
20 - (ROCK)
34.2' = TARGET, SAY 35'

Time	Depth bgs	Drilling Observations, Etc.
09:43		START AT 14.2' : GOING TO 17' end of Rod
0944	15'	AT 15'
09:47	16.5'	SMALL FRAC.
09:48	17'	END - WILL ADD 5' Rod
09:50	17'	START 17'-22' RUN
0953	18'	SMALL FRACTURE ; ~~19.2~~
0955	19.2'	FRACTURE
0957	21.5'	FRACTURE 0958 END RUN @ 22'
0959	22'	START 22'-27'
1002	23.5'	FRACTURE
10:02:30	24'	SOFT & FRAC.
10:04	25'	FRAC., 25.8' FRAC., 26.5' FRAC/SOFT;
10:06	27'	END RUN ; START 27'-32' @ 10:08
10:13	31'	FRAC. - SOFT - DILLED FAST
10:14:30	32'	END RUN : ADD ROD
10:16	32'	START NEXT RUN
10:18:30	34.5'	34.5' SOFT
10:19	35'	END RUN

Set bottom of packer @ 28'

Notes: Augers (4.25") drilled to 14.2' onto Rock

Arch Chemicals, Rochester, NY
Drilling Progress
Hydrofracking Test Boreholes

Borehole ID: HF-4
Date Drilled: 9-18-12
Driller: Neal Short
Time Start: 13:43
Time End: 14:24

Drill Firm: Nothnagle
Dia. Of Borehole (in.): ~3¾" in Rock : ~8" in soiL
Drilling Technique HSA in Soil : AIR HAmmer in Rock
Rig : CME-75

TARGET = 12.8' + 20' = 32.8'
SAY 33'

Time	Depth	Drilling Observations, Etc.
		13:04→13:15 Spun augers to Rock @ 12.8' bgs
13:43	12.8'	START @ 12.8' w/ air hammer
13:46	15'	~~STOP TO ADD 5' ROD~~
13:49	16	STOP TO ADD 5' ROD
13:52	17'	FRACTURE
13:55	18.5'	FRACTURE
13:57	21'	END RUN: ADD 5' ROD
13:59	21'	START 21'-26' RUN
14:02	23'	FRACTURE
14:03	24'	FRACTURE
14:05	25.5'	FRACTURE
14:06:30	26'	END RUN
14:07	26'	Begin next Run to 31'
14:15	29.5'	FRACTURE
14:16	30.5'	Small FRACTURE
14:17	31'	END RUN
14:19	31'	Go To 33'
14:24	33'	END @ 33' : last 0.2' Very soft

Set bottom of packer @ 26'

(4.25")

Notes: H.S.A. Advanced to Rock; ≈8" DIA. Borehole w/ augers in soil 13:04→13:15/Rock @ 12.8' bgs

STARTED TO GET GOOD water production @ ~21'

Arch Chemicals, Rochester, NY
Drilling Progress
Hydrofracking Test Boreholes

Borehole ID: HF-5
Date Drilled: 9-19-12
Driller: Neal Short
Time Start: 08:28
Time End:

Drill Firm: Nothnagle
Dia. Of Borehole (in.): 3 3/4" in Rock
Drilling Technique: Air Hammer
Rig: CME-75

TARGET = 15'+20' = 35'

Time	bgs Depth	Drilling Observations, Etc.
0828	15'	START DRILLING in Rock
0832	16.5	END 16.5': ADD ROD ← HF-4 Bubbles
0835	16.5	START RUN from 16.5'
0835+	17.5	FRACTURE; hole making lot of water
0837	18'	FRACTURE/or SOFT
0838	20.5'	FRACTURE/SOFT
0840	21.5'	END RUN: ADD ROD FOR ~~21.5'~~ 21.5'–26.5'
0842		START RUN
0843	22.2'	FRACTURE/SOFT
0844	23'	FRACTURES & 23.8'
0847	26'	FRACTURE/SOFT
0848	26.5'	END RUN: ADD ROD for 31.5'
	27.5'	FRACTURE/SOFT
	30.5'	FRACTURE/SOFT
0856	31'	FRACTURE/SOFT
0856	31.5'	END RUN
0859	31.5'	START 31.5'-35' RUN
0906	34.5'	AT 34.5' ← HF-4 Bubbles
0908	35'	END DRILLING here

Notes:
H.S.A. drilled to Rock @ 15' bgs
Water shoots out of PIEZO. in HF-4 when drilling 15'-16.5' in HF-5: Then NOT AGAIN 'TIL LATER.
Hole HF-4 bubbling @ 0903 VIOLENTLY! @ 33.5' TO ~~35'~~ TDL 34', then stops ~~to~~ TDL
Bubbling in HF-4 noted when drilling in HF-5 @ 2 Depths of 15'-16.5' & 33.5'-34'

33.5
16.5
17.0

~~17~~ 16.5
\+ 8.5
25.0 min of 2 zones

Arch Chemicals, Rochester, NY
Drilling Progress
Hydrofracking Test Boreholes

Borehole ID: HF-6
Date Drilled: 9-19-12
Driller: Neal Short
Time Start: 14:34
Time End:

Drill Firm: Nothnagle
Dia. Of Borehole (in.): 3¾" in Rock
Drilling Technique AIR HAMMER
Rig : CME-75

TARGET = 16+20 = 36'

Time	Depth	Drilling Observations, Etc.
14:34	13'	START 1st Run
14:42	16'	VERY SOFT drilling to 16'; need to advance augers to 16' To
—	—	Case the borehole; bedrock apparently @ 16', not 13'
15:12	16'	START Hammering
15:18	17.5'	FRACTURE
15:20	19.5'	FRACTURE
15:22	20.8'	FRACTURE & 21.7' FRACTURE
15:23	~22'	END of Run
15:25	22'	BEGIN NEXT Run
15:28	23.5'	FRACTURE & 24.3' FRACTURE & 25'
15:32	26.5'	END of Run
15:34	26.5'	START NEXT Run
15:35	28.5'	FRACTURE
15:40	32.5'	END OF Run @
15:42	32.5'	START NEXT Run
15:46	33.5'	FRACTURE
15:47	34.5'	FRACTURE
15:51	36'	END HERE

Notes: H.S.A. drilled to Rock @ 13' bgs

Arch Chemicals, Rochester, NY
Drilling Progress
Hydrofracking Test Boreholes

Borehole ID: HF-7
Date Drilled: 9-20-12

Driller: Neal Short

Time Start: 09:02
Time End: 10:07

Drill Firm: Nothnagle

Dia. Of Borehole (in.): 3 3/4" in Rock

Drilling Technique AIR HAMMER

Rig : CME 75

TARGET 20 + 15.6' = 35.6', say 36'

Time	Depth	Drilling Observations, Etc.
~~08~~09:02	15.6'	START hammering
0905	16.5'	STOP - need to check on compressor w/ Shop about oil use
		18' - have connection w/ HF-4 & HF-6; air/water venting
		20.5' FRACTURE/SOFT
		21' FRACTURE/SOFT
0940	21.5	END - ADD Rod
0943	21.5'	START Run
0944	22.5'	FRACTURE/SOFT
0946	24'	FRACTURE/SOFT
0947	24.8'	" "
0949	26'	" " Then END Run shortly after
0952	26.6'	START Run
0953	27.2'	FRACTURE/SOFT
0957	30.4	" " — 28'
0958	31.6'	END Run
10:00	31.6'	START Run
10:03	33.5'	FRACTURE/SOFT
10:04	34.3'	" "
10:07	36'	END BORING

Notes: Augered 4.25" HSA TO bedrock @ ~15.6' bgs 08:30 → 0843
Will set bottom of Single packer @ 28' bgs

Arch Chemicals, Rochester, NY
Drilling Progress
Hydrofracking Test Boreholes

Borehole ID: HF-8

Date Drilled: 9-20-12

Driller: Neal Short

Time Start: 13:19

Time End: 14:06

Drill Firm: Nothnagle

Dia. Of Borehole (in.): 3 3/4" in bedrock

Drilling Technique Air Hammer

Rig : CME-75

TARGET = 16.4 + 20 = 36.4
say = ~~37'~~ 36'

Time	Depth	Drilling Observations, Etc.
13:19	16.4'	START HAMMERING
13:21	17'	AT JOINT : ADD ROD
13:24	17'	START RUN
13:26	17.5'	FRACTURE/SOFT
13:27	19.5'	FRACTURE/SOFT
13:29	20.5'	FRAC./SOFT
13:31	22'	END RUN
13:33	22	START
13:35	22.5'	FRACTURE/SOFT
13:37	24'	" "
13:39	24.8'	" "
13:40	25.6'	" "
13:41	26.6'	" "
13:42	27'	END RUN
13:45	27'	START RUN
13:46	27.2'	FRAC./SOFT
13:53	32'	END RUN
13:56	32'	START RUN
14:01	33.5'	FRAC. SOFT
14:02	34	" "
14:03	35'	END RUN
14:04	35'	START
14:05	~~36~~ 35.3'	FRAC./SOFT
14:06	36'	END

Notes: 4.25" H.S.A drilled to bedrock @ 16.4'

Arch Chemicals, Rochester, NY
Drilling Progress
Hydrofracking Test Boreholes

Borehole ID: HF-9
Date Drilled: 9-24-12 (9-24-12)
Driller: Neal Short
Time Start: 0748
Time End: 0843

Drill Firm: Nothnagle
Dia. Of Borehole (in.): 3 3/4" in Rock
Drilling Technique AIR HAMMER
Rig : CME-75

THEOT = 20+15.4 = 35.4 ; SAY 36'

Time	Depth	Drilling Observations, Etc.
0748	15.4'	START DRILLING : $\underline{\nabla}$ = 8.82' B.TO.R. in HF-8
0751	16.5'	END : FRACTURED/SOFT @ ~16'-16.5'
0754	16.5'	START RUN
0755	17'	FRACTURED/SOFT
	17.5	" "
0759	19.2	" " @ 19.9' & 20.2'
08:05	21.5'	END RUN
08:07	21.5'	START RUN
08:10	22'	FRACTURED/SOFT : $\underline{\nabla}$ = 9.3' HF-8 (B.T.O.R.)
08:15	23.7'	FRACTURED/SOFT : $\underline{\nabla}$ = 9.4' HF-8
08:16	24.5'	" "
08:18	25.2'	" " & 25.8' & 26.4'
08:20	26.5'	END RUN : $\underline{\nabla}$ = 9.47' HF-8
08:23	26.5'	START RUN
08:31	30.2'	SOFT/FRACTURED : $\underline{\nabla}$ = 9.55' HF-8
08:32	31'	" "
08:33	31.5'	END RUN
08:34	31.5'	START RUN
08:37	33.3'	FRACTURED/SOFT : $\underline{\nabla}$ = 9.65' HF-8
08:338	34'	" "
08:43	36'	END $\underline{\nabla}$ = 9.75' HF-8

Notes: H.S.A. TO Rock @ 15.4'

Arch Chemicals, Rochester, NY
Drilling Progress
Hydrofracking Test Boreholes

Borehole ID: HF-10
Date Drilled: 9-24-12
Driller: Neal Short
Time Start: 11:11
Time End: 12:06

Drill Firm: Nothnagle
Dia. Of Borehole (in.): 3¾" in Rock
Drilling Technique Air Hammer
Rig : CME-75

TARGET 17'+20' = 37'

Time	Depth	Drilling Observations, Etc.
11:11	17'	START AIR HAMMERING
11:15	17.5'-18'	17.5'-18' LARGE FRACTURE - Communicates w/ HF-9
11:17	18.7'	FRACTURE/SOFT " " "/ " & HF-8
—	20'	" " - * PEA STONE in HF-8 settles 3' or more
11:24	20.6/21.5'	" " & 1-Ft. in HF 7
—	23'-24'	" "
11:37	25.3'	" " & 26.5 FRACTURE/SOFT
11:40	27'	END RUN
11:42	27'	START RUN
11:49	30.5'	FRACTURE/SOFT
11:52	32'	END RUN ∇ = 8.27' B.T.O.R in Pz-109
11:55	32'	START RUN
11:56	32.2'	FRACTURE/SOFT & 32.5' & 33.3' & 33.6'
11:60	34.5'	" "
12:06 ~~12:00~~	37'	END DRILLING ∇ = 8.38' B.T.O.R in PZ-109

Notes: H.S.A. (4.25") to Rock at 17' bgs

TOP FRACTURES communicate w/ HF-9 & HF-8

Arch Chemicals, Rochester, NY
Drilling Progress
Hydrofracking Test Boreholes

Borehole ID: HF - 11
Date Drilled: 9-24-12
Driller: Neal Short
Time Start: 15:00
Time End: 15:44
Drill Firm: Nothnagle
Dia. Of Borehole (in.): 3 3/4" in Rock
Drilling Technique AIR HAMMER
Rig : CME - 75

TARGET 13.7' + 20' = 33.7'; SAY 34'

Time	Depth	Drilling Observations, Etc.
15:00	13.7'	START AIR HAMMERING
15:07	17.2'	FRACTURE/SOFT
15:10	18.1'	" "
15:12	19.5	" "
15:13	20.6'	" "
15:15	21.5'	END RUN - START Getting water
15:20	22.5'	FRACTURE/SOFT : BAD ODOR : PID = Background
15:23	24'	" "
15:24	24.8'	" "
15:26	26.1'	" " END RUN AT 26.5'
15:28	26.5'	START RUN TO 31.5'
15:33	29'	FRACTURE/SOFT
15:38	31.3'	" " ; END RUN @ 31.5'
15:42	32.8'	" "
15:43	33.5'	" "
15:44	34'	END BORING @ 34'

Notes: H.S.A. drilled to top of Rock @ ~13.7'

Arch Chemicals, Rochester, NY
Drilling Progress
Hydrofracking Test Boreholes

Borehole ID: HF-12

Date Drilled: 9-25-12

Driller: Neal Short

Time Start: 12:58

Time End: 13:50

Drill Firm: Nothnagle

Dia. Of Borehole (in.): 3 3/4" in ~~Hol~~ Rock

Drilling Technique AIR HAMMER

Rig : CME-75

TARGET DEPTH = 20' + 18.7 = 38.7, say 39'

Time	Depth	Drilling Observations, Etc.
12:58	18.7'	START AIR HAMMERING
/	19.6'	FRACTURE/SOFT
13:02	20.8'	" " NO NOTICEABLE COMMUNICATION w/ other borings
13:04	22'	END RUN
13:06	22'	START RUN
13:08	22.2'	FRACTURE/SOFT @ 22.5' @ 24.2'
13:13	25.0'	" " @ 26.3'
13:15	27'	END RUN
13:17	27'	START RUN
13:19	27.5'	FRACTURE/SOFT
13:25	30.5'	" "
13:27	32'	END RUN
13:34	32'	START RUN
13:37	33'	FRACTURE/SOFT
13:39	33.6'	" " @ 34.8' @ 35.7'
13:43	37	END RUN
13:48	38.5	FRACTURE/SOFT
13:50	39'	END

Notes: H.S.A. drilled to rock @ 18.7'

Arch Chemicals, Rochester, NY
Drilling Progress
Hydrofracking Test Boreholes

Borehole ID: HF-1
Date Drilled: 9-26-12
Driller: Neal Short
Time Start: 09:32
Time End: 10:30

Drill Firm: Nothnagle
Dia. Of Borehole (in.): 8 3/4" in Rock
Drilling Technique: Air Hammer
Rig: CME-75

TARGET: 12.5' + 20 = 32.5', say 33'

Time	Depth	Drilling Observations, Etc.
09:32	12.5	START FIRST RUN
09:37	13.5	FRACTURE/SOFT
09:40	14.3'	" " pea stone in HF-2 settles out over last 1':
		air violently coming out of HF-2 & piezo @ HF-4
		& @ Well North of HF-1 (15' North) & HF-5; ~~All~~
09:48	16.3'	END of Run; All locations of HF-2 through HF-5 are
		reacting to drilling in HF-1, but PZ-106 NOT so much
09:53	17.5'	Fracture/Soft - water shoots up out of HF-4 Piezo.
0955	18'	FRACTURE/Soft: reactions are gone
0957	19.2'	" "
10:00	21'	" "
10:00:30	21.3'	END of RUN
10:06	22.8'	FRACTURE/SOFT
		at ~26' driller notes odd odor: "different smell"
10:20	28'	FRACTURE/Soft
10:23	29.2'	" "
10:26	31'	" "
10:30	33'	END of boring

Notes: H.S.A. TO 12.5' TOP OF Rock

In air hammering from ~14' through 17.5' got violent reactions from HF-2, HF-3, HF-4/piezo, HF-5 & well ~15' north of HF-1. PZ-106 demonstrated v. little reaction, comparatively.

* PW-14 did not bubble up either - behaved like PZ-106

Arch Chemicals, Rochester, NY
Single Packer Injection Testing

Date Drilled: 9-17-12

Date of Test: 9-18-12

Borehole ID: TDL ~~3 3/4" OD~~ HF-2

Dia. Of Borehole (in.): 3 3/4" OD

Depth to Bottom of Packer(~~s~~) (ft/bgs): TDL ~~23'~~ 25'

Height of Pressure Gage (pump) Above Mid-Point of Injection Zone (ft.) (H-1): 32.5' ~~28.5'~~ (~~23'+3.5'~~) TDL ~~25'~~ (29'+3.5') (28.5')

Static Water Level (ft. bgs) 6.15'

Length of Injection Interval (ft.): 8' (25'-33') ~~10'~~ (~~23'-33'~~)

Ⓧ Dia. Of Pipe (in.): 1.5" I.D. @ packer → using Drill Rods Above of 1.25"

Static Water Level to Mid-Point of Injection Zone (ft.) (H-2) TDL 29'-8' = 21'

Height of Pump Above Ground Surface (ft) 3.5'

Pumping is On

Start Time: 0737

End Time:

Time:	Gage Pressure (psi):	Water Flow (gpm)	Water Level Above Top Packer (ft. BTOR)
0737	10	~~0.2~~ 0.2	8.0
0738	10		
0740	20		
0741	15		
		See notebook	pages 5 & 6
		for readings	

PRE-FRAC.

(ft. bgs)

Top of Rock: 13'

Bottom of Borehole: 33'

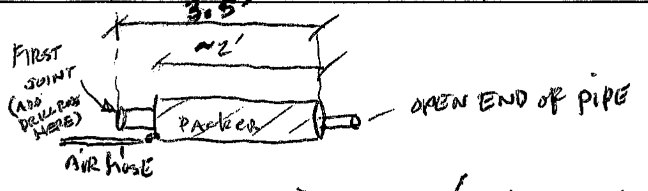
Packer:

[✓ single X]

~~double~~

Pressure to Packer(~~s~~) (psi) 120

Rubber packer ≈ 2' long



→ DOWN (packer assembly from bottom of packer to first joint = 3.5')

Notes:

9-17-12 ▽ = 6.15' bgs : BoB = 33' BGS : ▽ = 8' on 9-18-12

Ⓧ pipe dia. @ packer = 1.5" : Dia. of drill rods holding packer = 1.25"

Frac. @ 24' - want to get below this w/ packer ; Bottom packer @ 25' bgs

Rock did not Frac. - see notebook pp. 5 & 6 : It took water at different pressures at different gpm rates

Arch Chemicals, Rochester, NY
Single Packer Injection Testing

Date Drilled: 9-18-12
Date of Test: 9-18-12
Depth to Bottom of Packer(s) (ft/bgs): 28'
Static Water Level (ft. bgs) packer ~~1.5" I.D. / 1.25"~~ 5.5' TO 5.6'
④ Dia. Of Pipe (in.): 1.5" / 1.25"
Height of Pump Above Ground Surface (ft) 3.5'

Borehole ID: HF-3
Dia. Of Borehole (in.): 3.75"
Height of Pressure Gage (pump) Above Mid-Point of Injection Zone (ft.) (H-1): 31.5' + 3.5' = 35'
Length of Injection Interval (ft.): 28' - 35' = 7' MID = 31.5'
Static Water Level to Mid-Point of Injection Zone (ft.) (H-2) 31.5' TO 5.6' = 25.9'

Pumping is On
Start Time: 12:02
End Time: 12:16

(ft. bgs)
Top of Rock: 14.2'
Bottom of Borehole: 35'

Packer:
[✓ single] ✓
~~double~~

Pressure to Packer(s) (psi) 140.

Time:	Gage Pressure (psi):	Water Flow (gpm)	Water Level Above Top Packer (ft. BTOR)
12:02		START	5.6'
		See pages	
		8 & 9 in	
12:16		FIELD Book	5.5'

Set bottom packer @ 28' bgs.

Notes: ④ 1.5" To JUST Above packer, then 1.25" drill RODS
∇ = 5.6' bgs @ 11:48 & 5.5' bgs @ 12:16

Arch Chemicals, Rochester, NY
Single Packer Injection Testing

Date Drilled: 9-18-12

Date of Test: 9-18-12

Depth to Bottom of Packer(s) (ft/bgs): 26'

Static Water Level (ft. bgs): ~6'

Dia. Of Pipe (in.): 1.5" & 1.25"

Height of Pump Above Ground Surface (ft): 3.5'

Borehole ID: HF-4

Dia. Of Borehole (in.): ≈3 3/4" in Rock

Height of Pressure Gage (pump) Above Mid-Point of Injection Zone (ft.) (H-1): 3.5'+29.5'= 33'

Length of Injection Interval (ft.): 7' (33'-26') 29.5' mid point of zone

Static Water Level to Mid-Point of Injection Zone (ft.) (H-2): 29.5'-6'= 23.5'

Pumping is On

Start Time: 15:03

End Time: 15:15

(ft. bgs)

Top of Rock: 12.8'

Bottom of Borehole: 33'

Packer:

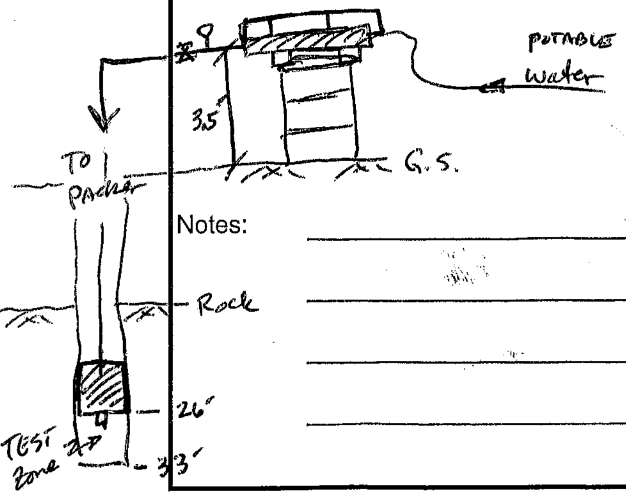
[✓ single]

~~double~~

Pressure to Packer(s) (psi): 140.

Time:	Gage Pressure (psi):	Water Flow (gpm)	Water Level Above Top Packer (ft. BTOR)
		SEE PAGES	
		10 & 11 in	
		Book	

33
-26
7'



Notes: ▽ ~8.6' B.T.O.C. (Augers)

8.8
2.6
6.2

Arch Chemicals, Rochester, NY
Single Packer Injection Testing

Date Drilled: 9-19-12
Date of Test: 9-19-12
Depth to Bottom of Packer(s) (ft/bgs): 30' & 22' (see below)
Static Water Level (ft. bgs): ~~7.8~~ TDL ~~~6.0~~' bgs 5.7bgs
Dia. Of Pipe (in.): 1.5" in packer; 1.25" Above packer
Height of Pump Above Ground Surface (ft): 3.5'

Borehole ID: HF-5
Dia. Of Borehole (in.): 3 3/4"
Height of Pressure Gage (pump) Above Mid-Point of Injection Zone (ft.) (H-1): 3.5' + 25' = 28.5' bgs
Length of Injection Interval (ft.): 6.2'
Static Water Level to Mid-Point of Injection Zone (ft.) (H-2): 25' - 5.7' = 19.3'

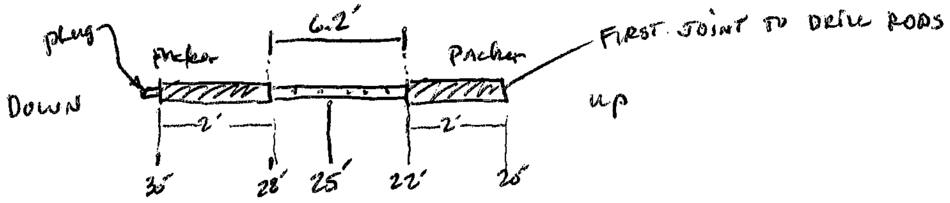
Pumping is On
Start Time: 13:01
End Time: 13:13

(ft. bgs)
Top of Rock: 15'
Bottom of Borehole: 35'

Packer:
~~single~~
double X

Pressure to Packer(s) (psi)
140
140

Time:	Gage Pressure (psi):	Water Flow (gpm)	Water Level Above Top Packer (ft. BTOR)
	See	pp. 16 in Field	book for readings
		9-19-12	



Notes: SET MID POINT of packer zone @ 25' bgs

Arch Chemicals, Rochester, NY
Single Packer Injection Testing

Date Drilled: 9-19-~~11~~ 12
Date of Test: 9-20-12

Borehole ID: HF-6
Dia. Of Borehole (in.): 3 3/4"

Depth to Bottom of Packer(~~s~~) (ft/bgs): 25'

Height of Pressure Gage (pump) Above Mid-Point of Injection Zone (ft.) (H-1): 3.5' + 30.5' = 34'

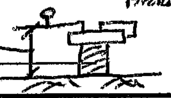
Static Water Level (ft. bgs) 5.6' obtained From piezo. in HF-4

Length of Injection Interval (ft.): 25'-36' = 11'

Static Water Level to Mid-Point of Injection Zone (ft.) (H-2) 30.5 - 5.6 = 24.9
~~5.6 + 30.5 = 36.1'~~ TDL

Dia. Of Pipe (in.): 1.5" in packer : 1.25" above Packer

Height of Pump Above Ground Surface (ft) 3.5'



Pumping is On
Start Time: 07:32
End Time: 07:43

(ft. bgs)
Top of Rock: 16
Bottom of Borehole: 36

Packer:
[✓ single] ✓
double

Pressure to Packer(~~s~~) (psi) 140

Time:	Gage Pressure (psi):	Water Flow (gpm)	Water Level Above Top Packer (ft. BTOR)
		See Book p. 19	
		FOR Readings	

Mid point of zone = 36 TOTAL DEPTH
25 packer
11 ÷ 2 = 5.5
25
Midpoint = 30.5
~~[illegible]~~ + 3.5 Height
34.0 gage

TDL
~~5.6 STATIC~~
~~+ 30.5 MID point zone~~
~~36.1 = H-2~~

30.5 ~~static~~ mid-point
- 5.6 STATIC
24.9

Notes: Pumped water @ pressures of 10, 25, 40 psi. Shut off & waited for 1-minute, then turned back on again @ 10 psi for comparison to initial 10 psi readings.

▽ = 5.6' bgs - obtained from piezo. in HF-4

Arch Chemicals, Rochester, NY
Single Packer Injection Testing

Date Drilled: 9-20-12
Date of Test: 9-20-12
Depth to Bottom of Packer(s) (ft/bgs): 28'
Static Water Level (ft. bgs) 5.6' (in HF-4 piez.)
Dia. Of Pipe (in.): 1.5" In Packer 1.25" Above Packer
Height of Pump Above Ground Surface (ft) 3.5'

Borehole ID: HF-7
Dia. Of Borehole (in.): 3 3/4" in Rock
Height of Pressure Gage (pump) Above Mid-Point of Injection Zone (ft.) (H-1): 3.5' + 32' = 35.5'
Length of Injection Interval (ft.): 36'-28' = 8'
Static Water Level to Mid-Point of Injection Zone (ft.) (H-2) 32'-5.6' = 26.4'

Pumping is On
Start Time: 10:35
End Time: 10:56

(ft. bgs)
Top of Rock: 15.6'
Bottom of Borehole: 36'

Packer:
single ✓
~~double~~

Pressure to Packer(s) (psi) 140

Time:	Gage Pressure (psi):	Water Flow (gpm)	Water Level Above Top Packer (ft. BTOR)
		See p.p. 20 & 22	IN NOTEBook
		for readings	
		JDJ	
		9-21-12	

Notes: MID point of injection zone: 36 -28 8'÷2=4   28+4=32'

Arch Chemicals, Rochester, NY
Single Packer Injection Testing

Date Drilled: 9-20-12
Date of Test: 9-20-12

Depth to Bottom of Packer(s) (ft/bgs): 28'

Static Water Level (ft. bgs): 7.5' (FROM PW-15)

Dia. Of Pipe (in.): 1.5" IN PACKER 1.25" ABOVE PACKER
Height of Pump Above Ground Surface (ft): 3.4'

Borehole ID: HF-8
Dia. Of Borehole (in.): 3 3/4"
Height of Pressure Gage (pump) Above Mid-Point of Injection Zone (ft.) (H-1): 3.4' + 32' = 35.4'

Length of Injection Interval (ft.): 8'
Static Water Level to Mid-Point of Injection Zone (ft.) (H-2): 32' - 7.5' = 24.5'

Pumping is On
Start Time: 14:33
End Time: 14:53

(ft. bgs)
Top of Rock: 16.4'
Bottom of Borehole: 36'

Packer:
single X ✓
~~double~~

Pressure to Packer~~(s)~~ (psi): 140

—

Time:	Gage Pressure (psi):	Water Flow (gpm)	Water Level Above Top Packer (ft. BTOR)
	See	NOTEBOOK pp. 23	& 24
		FOR READINGS	

9-20-12

Notes: Length of injection interval: 36 - 28 = 8'   MID POINT OF INJECTION INTERVAL = 28 + 4 = 32'

Because PW-15 is nearby, call STATIC water Level here the SAME FOR HF-8 STATIC Water Level

Arch Chemicals, Rochester, NY
Single Packer Injection Testing

Date Drilled: 9-24-12

Date of Test: 9-24-12

Borehole ID: HF-9

Dia. Of Borehole (in.): 3 3/4 in Rock

Depth to Bottom of Packer(~~s~~) (ft/bgs): 26'

Height of Pressure Gage (pump) Above Mid-Point of Injection Zone (ft.) (H-1): 3.4' + 31' = 34.4'

Static Water Level (ft. bgs): 6.8' HF-8 @ 07:00

Length of Injection Interval (ft.): 26'-36' = 10'

Dia. Of Pipe (in.): 1.5" IN Packer 1.25" ABOVE Packer

Static Water Level to Mid-Point of Injection Zone (ft.) (H-2): ~~34~~ 31-6.8 = 24.2'

Height of Pump Above Ground Surface (ft): 3.4

Pumping is On

Start Time: 09:14

End Time: 09:30

(ft. bgs)

Top of Rock: 15.4'

Bottom of Borehole: 36'

Packer:

single ✓

~~double~~

Pressure to Packer(~~s~~) (psi): 140

Time:	Gage Pressure (psi):	Water Flow (gpm)	Water Level Above Top Packer (ft. BTOR)
		See p-29 IN	
		Field Book for	
		READINGS	

9-24-12

9:14
16
0

Notes: MID Point Injection Zone: 26-36 = 10 : 26+5 = 31'

Arch Chemicals, Rochester, NY
Single Packer Injection Testing

HF-10

Date Drilled: 9-24-12
Date of Test: 9-24-12

Borehole ID: ~~3¾" in Rock~~
Dia. Of Borehole (in.): 3¾" in Rock
Height of Pressure Gage (pump) Above Mid-Point of Injection Zone (ft.) (H-1): 3.4' + 32' = 35.4'

Depth to Bottom of Packer(~~s~~) (ft/bgs): 27'

Static Water Level (ft. bgs): 6.8' in HF-8 @ 07:00

Length of Injection Interval (ft.): 27'-37' = 10'

Dia. Of Pipe (in.): 1.5" in Packer
1.25" Above Packer

Static Water Level to Mid-Point of Injection Zone (ft.) (H-2): 32' - 6.8' = 25.2'

Height of Pump Above Ground Surface (ft): 3.4'

Pumping is On
Start Time: 13:00
End Time: ~13:18

Top of Rock: 17' (ft. bgs)
Bottom of Borehole: 37'

Packer:
single ✓
double

Pressure to Packer(s) (psi): 140

Time:	Gage Pressure (psi):	Water Flow (gpm)	Water Level Above Top Packer (ft. BTOR)
		See FIELD Book	
		page 31 FOR	
		READINGS	
			9-24-12

Notes: MID-POINT INJECTION ZONE: 27'-37' = 27'+5' = 32'
∇ = 9.46' B.T.O.R. in HF-8 piezo. (~7.3' bgs)
See notes (p. 30) About communication w/ PW-15

Arch Chemicals, Rochester, NY
Single Packer Injection Testing

Date Drilled: 9-24-12

Date of Test: 9-25-12

Borehole ID: HF-11

Dia. Of Borehole (in.): 3¾" in Rock

Depth to Bottom of Packer~~(s)~~ (ft/bgs): 26'

Height of Pressure Gage (pump) Above Mid-Point of Injection Zone (ft.) (H-1): NM

Static Water Level (ft. bgs): 7' (HF-8 on 9-24-12)

Length of Injection Interval (ft.): 26'-34' = 8'

Dia. Of Pipe (in.): 1.5" in packer / 1.25" Above packer

Static Water Level to Mid-Point of Injection Zone (ft.) (H-2): ~~7~~ 30'-7' = 23'

Height of Pump Above Ground Surface (ft): 4.8' (on ~~pedestal of~~ the concrete walkway)

Pumping is On

Start Time:

End Time:

(ft. bgs)

Top of Rock: 13.7'

Bottom of Borehole: 34

Packer:

single ✓

~~double~~

Pressure to Packer~~(s)~~ (psi): 140

Time:	Gage Pressure (psi):	Water Flow (gpm)	Water Level Above Top Packer (ft. BTOR)
		See Field book	p. 35
		For Readings	~~No~~ DID NOT
		Conduct PERM.	TEST ON HF-11
			9-25-12

Notes:

Total Rock Depth

34.0
13.7
20.3

10.2 + 13.7 = 23.9 = 24 mid point of Rock

Mid Point Injection Interval = 4' + 26' = 30'

No Testing conducted

Arch Chemicals, Rochester, NY
Single Packer Injection Testing

Date Drilled: 9-26-12
Date of Test: 9-25-12
Borehole ID: HF-12
Dia. Of Borehole (in.): 3 3/4" in Rock
Depth to Bottom of Packer(s) (ft/bgs): 29'
Height of Pressure Gage (pump) Above Mid-Point of Injection Zone (ft.) (H-1): 4.3'+34'= 38.3'
Static Water Level (ft. bgs) 7' (in HF-8 piezo.@ 07:30)
Length of Injection Interval (ft.): 29'-39' = 10'
Dia. Of Pipe (in.): 1.5" in Packer 1.25" Above Packer
Static Water Level to Mid-Point of Injection Zone (ft.) (H-2) 34'-7'= 27'
Height of Pump Above Ground Surface (ft) 4.3'

Pumping is On
Start Time: 14:35
End Time: 14:55

(ft. bgs)
Top of Rock: 18.7'
Bottom of Borehole: 39'

Packer:
single ✓
~~double~~

Pressure to Packer(~~s~~) (psi) 140

Time:	Gage Pressure (psi):	Water Flow (gpm)	Water Level Above Top Packer (ft. BTOR)
	See	page 39 in	Field book
		for readings	
			9-25-12

Notes: Rock 18.7'-39' = 20.3'
20.3 ÷ 2 = 10.1'
18.7'+10.1' = 28.8, say 29' = MID-point of Section in Rock
MID-Point of injection zone: 29'-39' = 10'
29+5 = 34'

Arch Chemicals, Rochester, NY
Single Packer Injection Testing

Date Drilled: 9-26-12

Date of Test: 9-26-12

Depth to Bottom of Packer(s) (ft/bgs): 25'

Static Water Level (ft. bgs): (PIEZO P-106 Today) ~6 (Piezo. @HF-4 @ 7:55)

Dia. Of Pipe (in.): 1.5" in packer 1.25" Above packer

Height of Pump Above Ground Surface (ft): 3.7'

Borehole ID: HF-1

Dia. Of Borehole (in.): $3\frac{3}{4}$" in Rock

Height of Pressure Gage (pump) Above Mid-Point of Injection Zone (ft.) (H-1): 3.7' + 29' = 32.7'

Length of Injection Interval (ft.): 25' - 33' = 8'

Static Water Level to Mid-Point of Injection Zone (ft.) (H-2): ~ 29' - 6' = 23'

Pumping is On

Start Time: 10:52

End Time: 11:13

(ft. bgs)

Top of Rock: 12.5

Bottom of Borehole: 33'

Packer:

single ✓

~~double~~

Pressure to Packer~~(s)~~ (psi): 140

Time:	Gage Pressure (psi):	Water Flow (gpm)	Water Level Above Top Packer (ft. BTOR)
	See	notebook p. 44	for
		readings	
		9-26-12	

Notes: length of hole in Rock 33 − 12.5 = 20.5'

Mid point injection zone: 25' - 33' = 8' 25+4 = 29'

Projects LONZA / ARCH CHEMICALS
ROCHESTER, NY

JOB # 3616106029 / .02.01

This book belongs TO:
AMEC E & I
511 Congress ST.
PORTLAND, ME 04101
(207) 775-5401
ATTN: JEFF BRANDOW (207) 828-3459

① ③

9-17-12 3616106029/.02.01

08:00 Tom Longley on SITE - MONDAY
ZACH NOTHNAGLE arrives - we go through security & ATTEND H&S briefing. We will need to obtain daily work & EXCAVATION permits. Weather: PTLY cloudy, breezy, into ~~High 70s~~ MID 80s
Meet w/ FRANCIEN TRUBIA &
JOE FLORES

VIEW TRAINING VIDEO & TAKE TEST.
QUESTION ON MY WEDDING BAND - CAN'T TAKE it off & not allowed to wear jewelry of any kind - Not NO EXCEPTIONS - ABLE TO ALLOW IN MY CASE because can't physically take it off w/out cutting it - so as long as I wear gloves, can work here. So, I will wear NITRILE GLOVE(S) at ALL TIMES on-site, other than in office area.

Work this week will include drilling into bedrock (20' into rock or 35'-40' bgs) at 12 borings along an alignment near where a proposed bldg. will be built. We will attempt to hydro-fracture the borings to increase permeability in the shallow bedrock to assist in pumping water for treatment at a higher rate than presently able to do

Thom O. [illegible]

augh 10
re (±5')
will
10'
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PARATED
)
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DIA.
t.
:
- in
-

9-17-12 LONZA/ARCH 3616106029/.02.01
I will be able to use LONZA'S Camera &
FRANCIEN will be able to download &
send to office

11:03 PID = 11.7 eV LAMP # 06466 From PINE
Calibrate Instrument 100 ppm
SPAN Gas = Isobutylene, lot # 0621FB12
Part # GP11012
Use Before 07/2016

Meet Bob SCHELLINGER - ENGINEERING
to check for underground - He is OK
w/ plan except for Location #5 which
will be move ~ 4'/5' to the west;
all others will be as shown on p.3

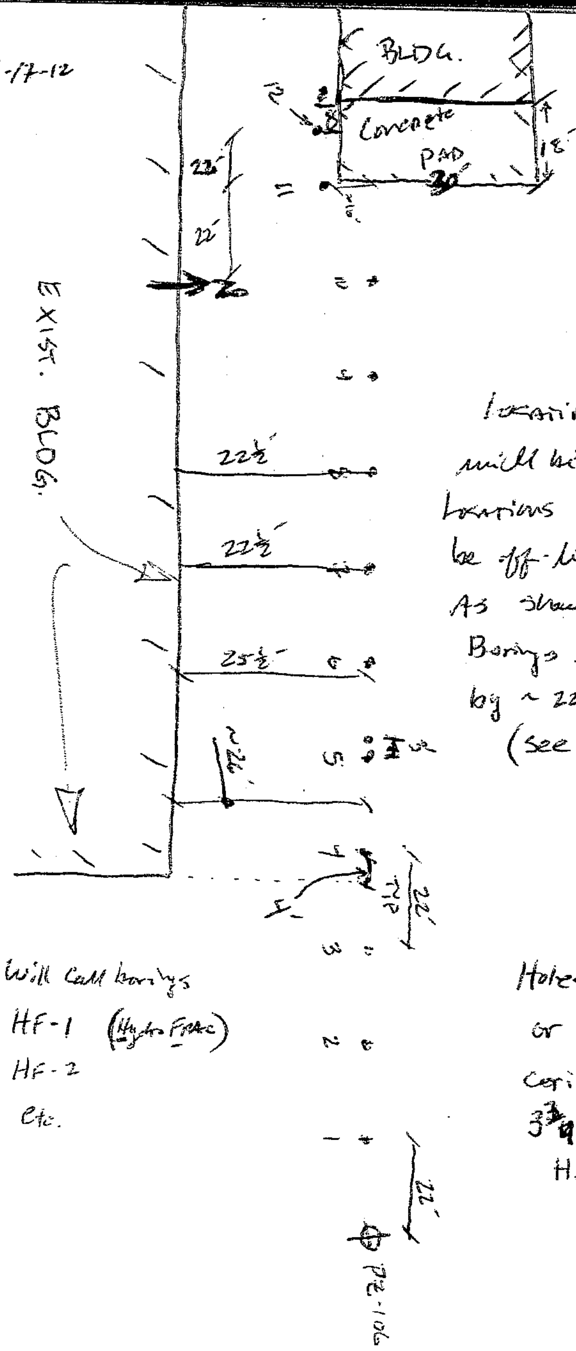
- Meet @ CAR Bldg. to have TAIL-GATE
Meetings & permits every day @ 07:00

— Regulator on PID calibration set up is
not working - PINE will send one out
to LONZA for tomorrow morning delivery

Because there are RAW-FOR-Rent FRAC
TANKS on site, HF-1 location is not
Accessible now - will have to get them
moved, so, Set up @ HF-2 FIRST.
Will drill w/ 4.25" HSA to bedrock, giving
≈ 8" dia borehole in soils. Rock hole
will be ~ 3½" (3" TOL) DIA. (or 3¾") & 3¾ AIR Hammer

The O. Tuly

9-17-12



Will call borings
HF-1 (Hydro Frac)
HF-2
etc.

Locations 1 through 10
will be in-line (±5')
Locations 11 & 12 will
be off-line by ≈ 10'
As shown. All
Borings are SEPARATED
by ~ 22' (TYP.)
(see p.32)

Holes ~~3½~~ 3" TOL DIA.
or 3¾" DIA.
coring bits &
3¾" DIA. AIR
HAMMER

④

9-17-12 ARCH/Amec 3616106029/.02.01
Drillers went to lunch after set up to drill
Drillers on site again
1305 START Spinning augers in **HF-2** (HYDROFRAC-2)
1306 AT 4' bgs (5")
Very Hard drilling @ 6'-10'
1314 may be on Rock @ ~ 12' bgs
1319 Switching over to air hammer - augers
Sitting on Rock @ ~13' ; 3 3/4" air bit
14:49 END drilling @ 33' (13'-33' Rock Hole)
FRACTURES @ 14.5' & 24' - NOTED BY DRILLER
TOLD NEAL we will FRACTURE BOTTOM 10'
of hole : ~ 23'-33' zone

GOT MOST ALL Set up to perform Perm &
FRAC TESTS - But drillers have to leave
site @ 4:00 p.m. So, will continue
tomorrow
16:00 All hands off site

9-18-12 HF-2 ⑤

0700 Arr. on Site - ATTEND HES Briefing & get work Permit
Tom Ingley AMEC ; NEAL SHORT & ZACH Nothnagle
of Nothnagle Drilling.
JOE Flores gives us a work permit
Weather: Rain, potentially heavy at Times, w/
Temps. into high 70's.
OBSERVED Small FRAC. @ 24' yesterday,
So, want to get below this w/ packer.
0729 ▽ = 8.01' Below Top of augers, 5.6' B.G.S.
Set bottom of packer @ 25' B.G.S.
START PRE-TEST of zone w/ inflated
packer but stopped - had to move
vehicle out of area.

PRE-FRAC water test of zone

	Time	Water Meter	(Totm)	PSI	▽ B.T.O.C.
	0:00	93.5	935.	10	
	0:30	93.7	937.	10	
	1:00	10x 93.92	939.2	10	~4 GPM
	1:30	94.15	941.5	10	(4.2)
4.2 gpm	2:00	94.39	943.9	10	
	2:30	94.61	946.1	10	
	3:00	94.81	948.1	10	Go To 25psi
	3:30	95.2	952.0	25	
	4:00	95 ~~96~~.7	957.0	25	
	4:30	96.2	962.0	25	

Water Meter = Badger Meter, Recordall, Model 35
PRESSURE Meter = Ashcroft, 0-200 psi

⑥

9-13-REPLACED

HF-2

	TOTAL GALS ~~USE~~	Time	GALLONS TOTAL	PSI	
	966.3	5:00	96.63	25	
	970.9	5:30	97.09	25	~10 gpm
9 GPM	975.5	6:00	97.55	25	9 GPM
	980	6:30	98.0	25	
	984.5	7:00	98.45	25	
	990	7:30	99.0	25	GO TO 40 psi
	994.8	8:00	102 99.48	40	
14.8 GPM	1002.0	8:30	100.20	40	
	1010.0	9:00	101.00	40	~ 14.8 GPm
	1016.8	9:30	101.68	40	~~34.0 GPM~~
	1022.4	10:00	1022.4	40	
		~~10:30~~	~~102~~		Shut off

Was reading wrong #'s

∇ = 8' BTOR

Must Read water gauge a little bit differently

Rock did not FRACTURE, but Accepted water at different pressures from ~4 GPM/10 psi, to ~14.8 gpm / 40 psi

08 28 Heavy Rain - will pull out, backfill w/ gravel & go to next boring location

Thomas C. Fogg

⑦

9-18-12 ARCH/LONZA 3616006024/02.01

0843 START Pulling augers from HF-2

Use Combination of this book & FIELD SHEETS for TOTAL picture of Hydro fracking process. FIELD Sheets contain measurements of set up & this book has readings AT LEAST for HF-2 boring

0854 Move to HF-3 location

AT HF-2, Generated 10 drums water & 1 DRUM soil

0905 START drilling w/ Augers AT HF-3

0915 AT Rock @ 14.2' bgs

Tool up to go w/ AIR HAMMER

09 43 START AIR HAMMERING AT HF-3

10:19 END AT 35' bgs; will switch over to FRAC.

10:40 TAKE A BREAK - call Jeff B. - discuss drillers working >8 hrs./day. Jeff to call Nothnagle. Also Jeff says to proceed as planned & discuss how HF-3 goes later.

11:44 ~~Back~~ at work ∇ = 5.6 bgs

Will set packer @ 28' - bottom of packer & take readings at Timed intervals & at different pressures & will read Flows in gpm off ~~of~~ a water ~~flow~~ meter.

Th C. Fogg

9-18-12

HF-3

	ELAPSED Time	TOTAL GALS.	PSI on gage	
	12:02	on Meter	10	
	:30	1058.9	10	
	1:00	1058.6	10	
0.4gpm	1:30	1050.0	10	
	2:00	1050.4	10	
	2:30	1050.9	10	go TO 25 psi
	3:00	1050.4	25	
	~~2:30~~			
	4:00	1052.0	25	
	4:30	1052.9	25	
1.4GPM	5:00	1053.7	25	
	5:30	1054.3	25	
	6:00	1055.1	25	
	6:30	1055.7	25	Go TO 40 psi
	7:00	1056.6	40	
	7:30	1057.7	40	
	8:00	1059.0	40	
	8:30	1059.9	40	
2.3GPM	9:00	1061.0	40	
	9:30	1062.2	40	
	10:00	1063.3	40	
	10:30	1064.5	40	
	11:00	1065.5	40	Go to 10 psi
	~~11:30~~			

HF-3 & HF-4

	ELAPSED TIME (min)	TOTAL GALS.	PSI	
	12:00	1066.3	10	$\underset{=}{\nabla}$ = 5.5' bgs
0.6 GPM	12:30	1066.6	10	
	13:00	1066.8	10	HF-3
	13:30	1067.2	10	
	14:00	1067.5	10	END TEST

So, got flows of ~ 0.4 gpm @ 10 psi
~ 1.4 gpm @ 25 psi, and
~ 2.3 gpm @ 40 psi.

Then dropped back down to 10 psi, &
get a flow of ~ 0.6 gpm @ 10 psi again

— END TESTING AT HF-3

Will fill boring w/ stone after pull out

12:51 Move rig up TO HF-4 location
Rain has lessened to showers/mist/or nothing
13:04 START H.S.A. in HF-4 boring
13:15 Spinning on rock @ 12.8' bgs
13:30 Becoming breezy w/ SCATTERED blue patches
& less humid
13:43 START AIR hammering from 12.8' in HF-4
14:24 END AIR hammering @ 33' in HF-4
Get ready for fracking process but flushing
out the hole first.

⑩

9-18-12 ARCH/LONZA 3616106029/.02.01 HF-4

14:50 ∇ in HF-4 ≅ 7' bgs

Tw ~~14:50~~

15:02 ∇ ≃ 6' bgs

Set bottom of packer @ 26' bgs

	ELAPSED TIME	TOTAL Flow Readings	PSI Water	B.T.O.R. ∇	HF-4
15:03	—	—	10	8.6'	START
0.06gpm	1:00	1069.0	10	-	
	1:30	1069.0	10	-	
	2:00	1069.0	10	-	
	2:30	—	—	8.55	
	3:00	1069.0	10	GO TO 25 psi	
	3:30	1070.0	25	-	
0.4GPM	4:00	1070.1	25	-	
	4:30	1070.3	25	8.5'	
	5:00	1070.5	25	—	
	5:30	1070.7	25	—	GO TO 40 psi
	6:00	—	—	—	
	6:30	1071.4	40	-	
0.4gpm	7:00	1071.9	40	-	
	7:30	—	—	8.45	
	8:00	1072.3	40	-	
	8:30	1072.5	40	GO TO 60 psi GO TO 80 psi GO TO 100 psi	

⑪

	ELAPSED TIME		TOTAL FLOW	psi	∇	HF-4
2.9gpm	09:30		1073.8	100	–	
	10:00		1075.2	100	–	
	10:30	4.4 gpm	1076.7	100	–	
-6.4gpm	11:00		1078.3	100	–	
	11:30		~~1080~~ 1081.1	100	–	
7.1gpm	12:00		1084.7	100	–	
	12:30		1088.2	100	7.7' ∇ B.T.O.C.	

~15:15 END TEST 15:03+12:30 ≐ 15.15

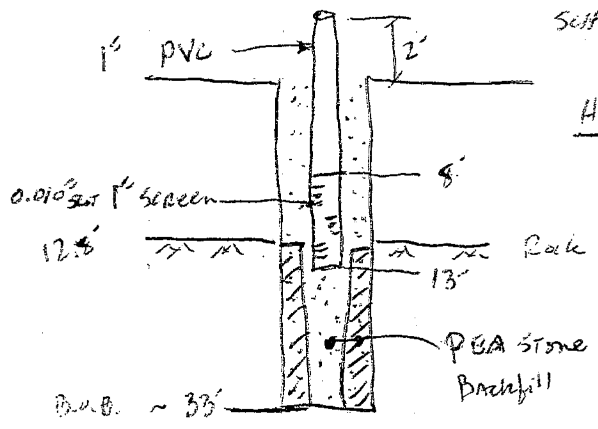
Had to go to 100 psi to get a good flow going. Pressures @ 60, 80 (+40) did not make the formation take water in a much improved manner. It wasn't until we pumped water @ 100 psi that the flow really appreciably increased.

FRANCIEN has scanned through today w/ this book & FIELD FORMS TO HERE

16:00 Drillers leave for the day at this point

FRANCIEN has sent PDF files of these notes & FIELD FORMS through today's work to JEFF B.

9-19-12 Arch/Lonza 3616006 029/.02.01
Weather: Predicted mostly sunny, cool, breezy, 60's
0700 Tom Ingly & Drillers enter site
$\underline{\nabla}$ ≅ 6.5' BGS in HF-4
Nem Short & Zach Nothnagle drillers w/
Nothnagle Drilling
Calibrate PID #06466 From Pine
GAS = 100 ppm Isobutylene lot# 062/FB12
Good to 07/2016
Background Air = 0.0 ppm
w/ CAL GAS, Reading = 100 ppm
B.O.B. = 31.5' BGS in HF-4
Told drillers to set ~~10~~ 5' Screen, 10' Riser in
HF-4 : Screen 13'-8', Riser 8'-2' AGS
07:46 HOLE IS backfilled w/ PIEZO INSTALLED w/
Screen @ ~13'-8' bgs, Riser 8' TO 2' AGS
Sch 40 PVC



HF-4 PIEZO.

9-19-12 HF-5

Moved HF-5 location ~3' WEST TO GET FARther
from buried drain pipes in area. ~~All other~~ JOF
07:58 START Spinning Augers in HF-5
08:10 Spinning augers on Rock @ ~15' bgs
Set up to air hammer to 35' bgs
Water is shooting up out of piezometer in HF-4
when drilling in HF-5 to 16.5'
08:47 PID up to 3.8 ppm at exhaust area, 0 ppm in
breathing zone - Good steady breeze from the West
0857 DRAGER TUBE FOR Chloroform @ 26.5'-31.5' run
gives 0.0 ppm Result at cuttings tub
PID in breathing zone = 0.0 ppm, up to 4.5 ppm
@ exhaust
0903 HF-4 bubbles/shoots water violently @
33.5'-34' when drilling HF-5
DRAGER TUBE FOR VINYL CHLORIDE = 0.0 ppm @
cuttings tub
— Definite communication between HF-4 & HF-5
Two zones in drilling HF-5 produced violent
reaction @ HF-4 from air/drilling activity,
these being @ 15'-16.5' & 33.5'-34'.
0925 Have to clear out HF-5 - lot of cuttings in hole,
likely gravel ~~gr~~ sized Rock bits from
shallow portion of Rock

9-19-12 ARCH/LONZA 3616106 029/.02.01

I think we can assume the top (5' or so) of bedrock is fractured & connected from boring-to-boring. Neal said (& I didn't notice) that in drilling HF-4, there was some reaction in HF-3 in the first 5' of drilling, just as seen in HF-4 while drilling HF-5.

10:41 DRAGER TUBE FOR carbon tetrachloride gives <1.0 ppm result - taken w/in overturned tub that collects water & cuttings from drilling operation.

10:05 TALK w/ Jeff Brenton about this boring: he suggests we use double packer to test middle portion of borehole HF-5: Tell drillers to make up double packer for testing. This needs set up time to perform

PID response in breathing zone < 1.0 ppm

10:54 $\underline{\nabla} \cong 5.7'$ bgs in HF-4
$\cong 6.1'$ bgs in HF-5

10:55 Drillers need to get fitting @ hardware to make up packer - go off site

12:03 $\underline{\nabla} = 5.7'$ bgs HF-4
$\underline{\nabla} = 5.9'$ bgs HF-5

13:03 DRILLERS Back on Site w/ FITTINGS To make double packer

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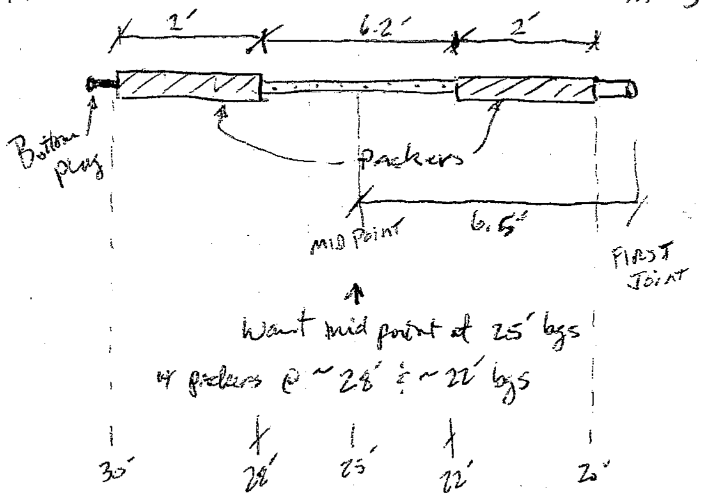
9-19-12



Want mid point at 25' bgs
w/ packers @ ~28' & ~22' bgs

Schematic of packers for HF-5 TEST

Conducted test in HF-5 from 13:04→13:13
SEE FIELD Sheet & next page for Results

9-19-12

(16) ARCH/LONZA 3616106029/.02.01

9-19-12 HF-5

	ELAPSED TIME	TOTAL FLOW Gallons	(PSI) Water Pressure	∇ Above packer
13.01	START			
	0:30	1095.7	10	8.7' Below TOP
2.1 gpm	1:00	1096.7	10	—
	1:30	1097.7	10	—
2.2gpm	2:00	1098.8	10	—
	2:30	1099.9	10	—
2.4 gpm	3:00	1101.1	10	8.7
	3:30	1102.3	10	Go TO 25
	4:00	1104.5	25	—
6.8 gpm	4:30	1108.0	25	—
	5:00	1111.3	25	—
6.7 gpm	5:30	1114.8	25	8.7'
~~4.3~~ gpm	6:00	1118.0	25	—
	6:30	~~1119.1~~	25	bad reading TOL 6.0 TO ~~60~~ 40
	7:00	1126.0	40	—
	7:30	1132.0	40	8.7'
10.4 gpm	8:00	1137.5	40	—
10.4 gpm	8:30	1142.4	40	—
	9:00	1147.9	40	8.7' TURN off; go TO 10 PSI
	11:00	1149.0	10	—
	11:30	1150.0	10	—
3.1 gpm	12:00	1151.6	10	—
13:13	12:30	1153.1	10	TURN off

---

(17)

9-19-12 HF-6

There was no movement in water levels in HF-4 during packer test in HF-5

13:14 Breaking down to move to next location

13:37 Move to HF-6 location

13:43 Begin Augering @ **HF-6**

13:55 Possibly on Rock @ ~13' bgs : yes

13:59 13' to BEDROCK - Switch over to air hammer

14:28 ∇ = 5.7' bgs in HF-4 piezo.

14:34 Begin air hammering HF-6

14:35 JIM CRAFT on SITE (NYSDEC)

14:42 AT 16' : Very soft 13'-16' : apparently not on Rock @ 13' : lot of gravel coming up : so, have to advance augers to 16' TO case off gravel section.

14:56 AT 16' : Switch back to hammer.

15:11 JIM CRAFT leaves site

— Getting PID Readings up to 2.5 in breathing zone — but typically 0.0 is norm.

15:57 FINISH drilling HF-6 @ 36' bgs

16:11 Picking up for the day

⑱ ARCH/Lonza 3616106029/.02.01

20
9-~~19~~-12

HF-6

0700 Attend H&S Briefing for Lonza

Tom Longly-Amec

Neal Short & Zack Vernagle - Drillers

Weather: Sunny, into low 60's

Calibrate PID w/ ~~[illegible]~~ background air &

100 ppm Isobutylene

Bkg. = 0.0 ppm

w/ Span Gas = 100 ppm

Using same meter & span gas as yesterday

▽ = 5.65 bgs in HF-4 - use this as static ▽ for test in HF-6

For the Test: Ran water pressures into packered zone at pressures of 10, 25, 40 psi. Then turned off pump for 1 minute, then back on again at 10 psi to compare readings w/ initial 10 psi readings. Used single packer

After test, filled up HF-6 w/ pea stone, pulled augers, moved to HF-7 location

⑲

9-20-12

HF-6

	Elapsed Time	Total Flow (Gal.)	(psi) Water Pressure	▽ Above Bladder
	07:32 Turn on Water Flow			8.5′
	0:30	1156.7	10	~~FD~~ -
	1:00	1159.2	10	—
	1:30	1161.8	10	~~5.3~~ 8.3′
5.1 gpm	2:00	1164.4	10	-
	2:30	1166.9	10	Go To 25
	3:00	1171.0	25	-
	3:30	1175.5	25	-
	4:00	1180.0	25	-
8.3 gpm	4:30	1184.2	25	8.25
	5:00	1188.3	25	
8.5 gpm	5:30	1192.6	25	
	6:00	1196.8	25	Go To 40
	6:30	1202.5	40	-
	7:00	1209.5	40	-
11 gpm	7:30	1214.5	40	-
	8:00	1220.5	40	-
12- gpm	8:30	1226.8	40	-
	9:00	1232.5	40	Turn off
	10:00	1234.5	10	On Again
	10:30	1235.5	10	
38 gpm	11:00	1237.4	10	
	11:30	1239.3	10	End Test - Turn off water flow

(20)

ARCH/Lonza 36116106029/.02.01 HF-7

9-20-12

0804 Move Rig to HF-7

0830 START Augering HF-7

0843 On Rock @ ~15.6' bgs

0902 START Air HAMMERING

In drilling in Rock @ HF-7, have communication w/ HF-6 & HF-4 when hit fracture @ 18'.

10:07 END Boring @ 36'

10:23 ($\underline{\nabla}$ = 5.8' bgs in HF-4)

	ELAPSED TIME	TOTAL FLOW (gal.)	(psi) Water Pressure	$\underline{\nabla}$ Above Packer
10:35	0:30	1241.6	10	8.4'
	1:00	1242.7	10	—
	1:30	1244.0	10	—
2.3 gpm	2:00	1245.0	10	—
	2:30	1246.2	10	—
	3:00	1247.3	10	up to 25
	3:30	1250.2	25	—
	4:00	1253.0	25	8.25'
	4:30	1256.0	25	—
	5:00	1258.9	25	—

(21)

9-20-12 HF-7

	ELAPSED TIME	TOTAL Flow Gal.	(psi) Water Pressure	Above Packer $\underline{\nabla}$
	5:30	1261.7	25	—
5.8 gpm	6:00	1264.7	25	—
	6:30	1267.5	25	Go to 40
	7:00	1272.0	40	8.2'
	7:30	1276.9	40	
	8:00	1281.2	40	
	8:30	1285.9	40	
	9:00	1290.3	40	
9.2 gpm	0930 ~~10:00~~	1295.0	40	
	10:00 ~~10:30~~	1299.5	40	
	10:30 ~~11:00~~	1304.2	40	TURN OFF

Water comes back out of the formation after turn off pressure

12:00 TURN on to 10 psi

	12:30	1299.7	10	—
3.2 gpm	13:00	1301.1	10	—
	13:30	1302.9	10	—

TURN up to ~~20 psi~~ 60 psi

	14:30	1315.7	60	—
	15:00	1324.8	60	8.2
17.2 gpm	15:30	1333.3	60	—
	16:00	1341.8	60	—
	17:00	1359.2	60	—

TURN off water

(22)

Arch/Lonza 3461060291.02.01

9-20-12 HF-7

Water still comes back after turn off water pressure; so, will add water @ higher pressure

	ELAPSED TIME	GALS.	PRESSURE PSI	
24.8 gpm	19:00	1373.0	90	90 psi
25.4 gpm	20:00	1397.8	90	
10:56	21:00	1423.2	90	END TEST

Water still bleeds out of formation after release pressure

Break down to move to next boring.

11:30 Move to next boring HF-8 - break for lunch

12:38 Back from break

12:41 START SPINNING Augers in HF-8

HITTING obstruction ~2' bgs; move rig to EAST just a bit

1300 ON Rock @ 16.4' bgs. Get ready to hammer

13:19 Begin hammering HF-8

14:06 END DRILLING AT 36' IN HF-8

1430 ▽ = 8.8' Below datum HF-8

= 8.2' Below Casing PW-15

9-20-12 HF-8 (23)

	ELAPSED TIME	TOTAL FLOW (GALS)	(psi) WATER PRESSURE		▽ BELOW POINT ABOVE PACKER HF-8	▽ BELOW POINT BELOW CASING PW-15
Clock Time 14:33	START		10			
	1:00	1416.2	10		8.8	8.1
	2:00	1418.2	10		—	—
2.2 gpm	3:00	1420.2	10		8.6	8.05
	4:00	1422.4	10		—	
	5:00	1424.5	10	Go up	—	8.0
	6:00	1428.3	25		—	—
	7:00	1432.5	25		8.4	7.9
4 gpm	8:00	1436.7	25		—	—
	9:00	1440.7	25		—	7.86
	10:00	1444.9	25		—	—
	11:00	1448.9	25	Go up	8.35	7.83
	12:00	1454.4	40		—	—
5.6 gpm	13:00	1460.0	40		—	7.77
	14:00	1465.6	40		—	—
	15:00	1470.9	40		—	7.72
	16:00	1476.3	40		8.2	—
	17:00	1481.3	40		—	7.7
9.7 gpm	18:30	1492.2	80		Go up	
9.0	19:30	1501.9	80		8.15	—
Clock Time 14:53	20:00	1506.7	80			

- Turn off - Water does not come back after pressure turned off (doesn't come back from formation)

(24) ARCH/Lonza 3616106029/.02.01 HF-8

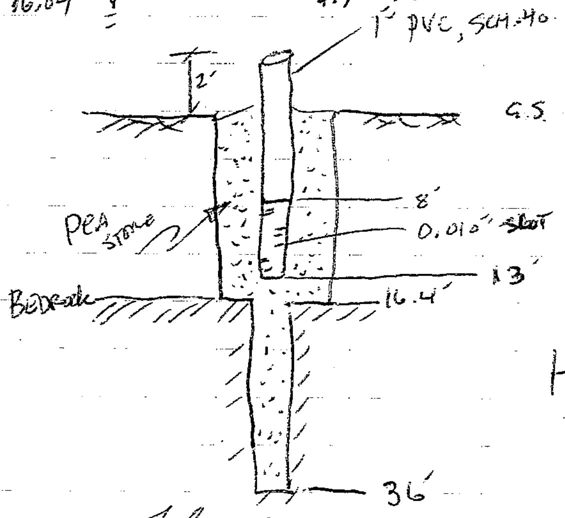
9-20-12

AT 22 min. elapsed Time, ∇ = 7.8' in PW-15

AT 23 min. elapsed Time, ∇ = 7.8' in PW-15
AT 24 min " " ∇ = 7.8 " "
AT 25 min. " " ∇ = 7.8 " "
AT 37 min " " ∇ = 7.95 " "

May have had some leakage above packer in HF-8 & may have had very slight communication w/ PW-15 based on water level readings, AS noted Above.

Will set a piezometer in HF-8
15:18 ∇ in PW-15 = 8.0' B.T.O.C.
16:04 ∇ " " " = 7.9' B.T.O.C.



HF-8 PIEZO.

Thomas O. Fagley

(25) 9-20-12 HF-9

15:52 Move rig to HF-9 Location
Pick up, clean up, drums, etc.
No more drilling for today

Make copies of notes
to PDF TO OFFICE/JEFF
TD HERE FROM
p. 11

Thomas O. Fagley

Arch/Longa

9-21-12   3616106029/.02.01

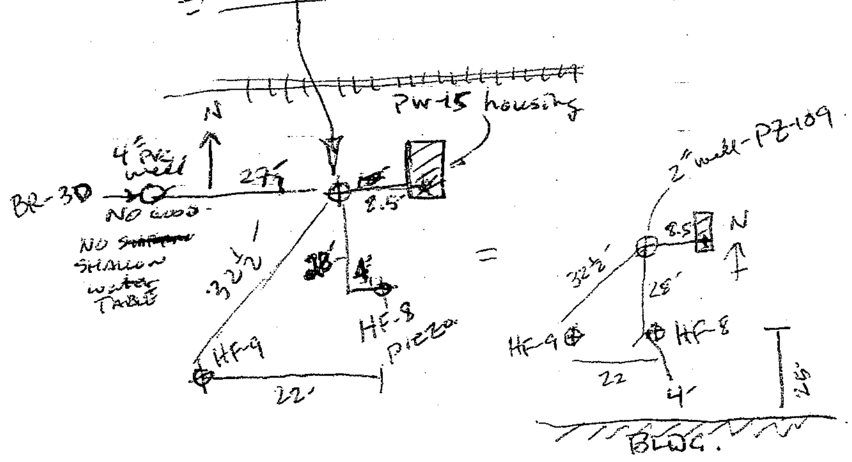
07.00 Tom Longly on Site AMEZ
Neal Silover & Zach Nothnagle of W. Drilling
ATTEND H & S meeting & go to work

0707 $\underline{\nabla}$ in PZ HF-8 = 6.7' bgs
$\underline{\underline{\nabla}}$ in PZ HF-4 = 5.8' bgs
Weather: Overcast, showers, low 70's
$\underline{\underline{\nabla}}$ = 6.7 bgs in PW-15 & 7.9' B.T.O.C.
Getting ready to drill HF-9
Breeze out of S-SW: warm, humid

0718 START Augering HF-9

0729 Broke drive chain on drill head / Kelly;
Chain Coupler is right Term,
May be able to fix w/ replacement
parts They have on hand, ~~/~~ no need to go to shop

0750 2" well, ~ ~~10~~ 8.5' west of PW-15, PVC,
$\underline{\underline{\nabla}}$ = 8' B.T.O.R. & 6' B.G.S. - PZ-109



9-21-12

08:50 Drillers have replacement part - will be drilling Shortly

0856 Drilling again w/ HSA
More than just what broke before, come
To find out, has been damaged - Much
more than what was apparent has
turned out to be broken. The replacement
Coupler broke again, & Kelly bar attachment
(Cap) also broke.
So, because parts need To be ordered, won't be
back until Monday.

09:10 Tom Longly leaves site - drillers are
right behind.

9-24-12 ARCH-LONZA 366106 029/.02.01 HF-9

07:00 Tom Longly (Amec) on [illegible]
NEAL SHORT, & Zach Nothnagle on site
ATTEND H&S meeting w/ Joe Places
Weather: Bright, cool, into 60's; breezy from SW
- $\underline{\nabla}$ = 8.14' B.T.O.R./PZ-109
- = = 8.82' B.T.O.R./HF-8 PIEZO./6.85' BGS.
- = 7.97' B.T.O.R. HF-4 PZ/5.90' BGS

07:25 Parts are on rig - ready to go: Down to ~ $\overset{13'}{8'}$ bgs
Calibrate 11.7 EV PID from Pine Env.
Background AIR = 0.0 ppm
100 Isobutylene gas = 100/99.7 ppm
— TOP of Rock ≈ 15' bgs (15.4')

08:44 In drilling HF-9, water level in HF-8 dropped from 8.82' to 9.75' B.T.O.R. from 07:48 to 08:43

08:51 $\underline{\nabla}$ = 8.51' B.T.O.R./PZ-109

09:14 psi @ 10. START at this pressure
at 5 minutes in, go up to 25 psi
AT 9 minutes in, go up to 40 psi
AT 14 minutes in, go up as high as we could, to ~105 psi.

9-24-12 HF-9

	ELAPSED TIME (MIN.)		TOTAL FLOW GALS	WATER PRESSURE (PSI)		$\underline{\nabla}$ ABOVE PACKER	$\underline{\nabla}$ B.T.O.R. HF-8
	09:14 pump is on		—	—			
	1:00		1519.4	10		—	
	3:00		1625.1	10		8.8	9.05
~ 5.1 gpm	4:00		1530.2	10		—	-
	5:00		1535.3	10	Go up	—	—
	6:00		1544.5	25		8.6	9.00
	7:00		1554.2	25		—	—
~ 8.3 gpm	8:00		1562.7	25		8.55	8.95
	9:00		1571.0	25	Go up	—	—
	10:00		1583.0	40		—	-
	11:00	24.9 gpm	1559.9	40		—	8.85
~ 12.7 gpm	12:00		1608.6	40		-	—
	13:00		1621.3	40		-	8.82
	14:00		1634.5	40	go up	—	—
24.8?	15:00		1649.2	55	go up	-	—
	16:00		1674.0	105	(End)	7.3	8.77

Water does not come back from formation after turn off pump

09:30 Turn off

Ran pressures from 10 to 40 psi over a few minutes each, then as high as could go for ~ 1 minute; formation took as much water as we could give it.

(30)

ARCH/Longa 3616106029/.02.01 HF-10

9.24.12

10:00 Pulling tools out of HF-9 & backfilling w/ pea gravel.

10:22 Move Rig to HF-10

▽ = 8.92' B.T.O.R. in HF-8 PIEZO.

10:33 START H.S.A. in HF-10: OFFSET DUE TO DEBRIS OBSTRUCTION

10:57 Augers at Rock at 17' bgs

11:11 START AIR HAMMERING

12:04 WIND out of W/SW

12:27 TAKE A BREAK -

12:50 DIDN'T notice, but @ PW-15, during drilling of HF-10, lot of water & air shot up & out of this well. Francisco took picture of aftermath of the mess of PW-15 - lots of mud shot out of well. Driller notes: @ 21' Neal notices when drilling, hit unnatural looking, smelling, & bubbly water in all borings (generally)

13:00 TURN on Water @ 10 psi

13:18 Test turned off after 17 min. elapsed time.

Pull out & backfill w/ pea gravel HF-10 boring

(31)

9.24.12

HF-10

▽

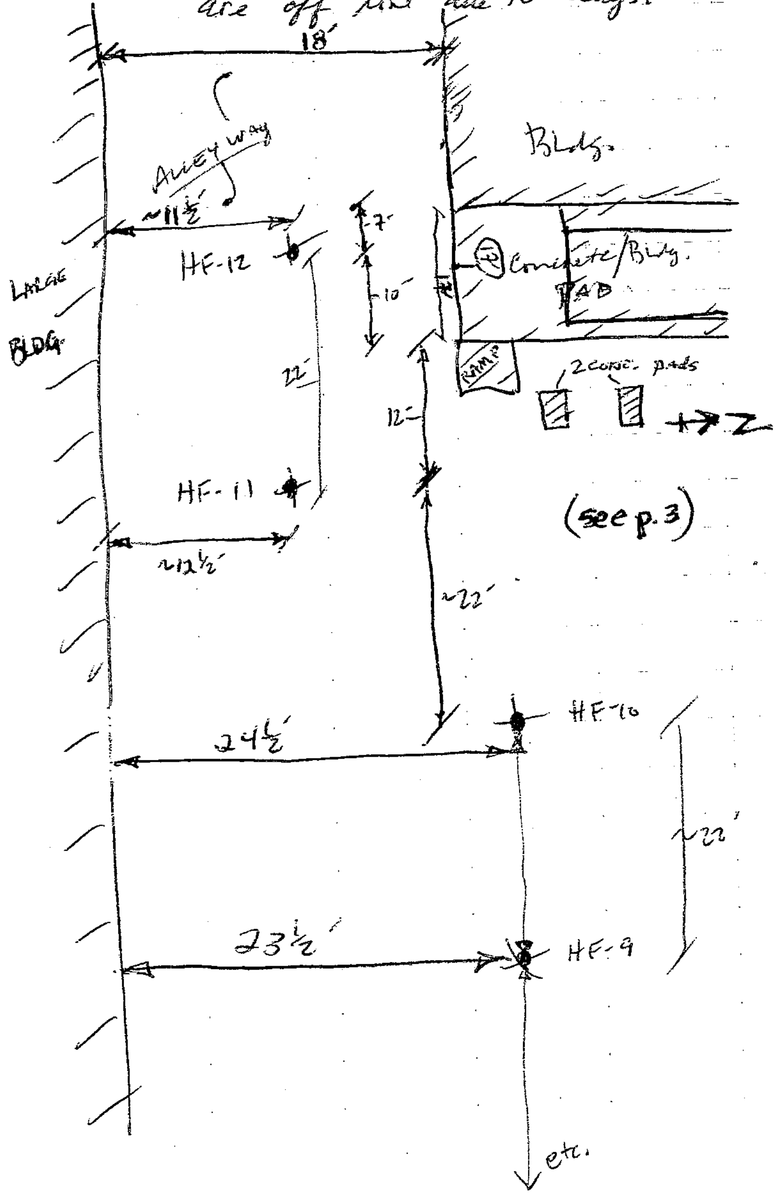
	ELAPSED TIME		TOTAL FLOW (GALS.)	Water Pressure (PSI)		Above Packer	B.T.O.R. HF-8 PIEZO
13:00	Packer @ 27'			10		9.2	9.10
	1:00		1689.2	10		–	–
	2:00		1696.6	10		–	8.9
	3:00		1703.5	10		8.95	8.95
6.5	4:00		1710.0	10		–	~~8.77~~ 8.77
6.0	5:00		1716.0	10	go up to 25	–	–
18.8	6:00		1726.7	25		TBC ~~8.7~~	TBC ~~8.7~~ (8.7)
	7:00		1737.5	25		–	–
10.3	8:00	10.1	1747.7	25		–	–
	9:00		1758.0	25		8.57	–
9.8	10:00		1767.8	25	go up to 40	–	–
	11:00		1782.0	40		–	8.47
	12:00		?.-1799.2	40		9.45	–
?.	13:00		?.-1781.0	40		–	8.4
	14:00	13.3 gpm	1823.8	40		–	–
13.3	15:00		1837.1	40	go up to 62	–	–
	15:30		1845.8	62		–	–
	16:00		1855.1	62		–	–
18.9	17:00		1874.0	62		–	8.31

~ 13:18 END

ARCH/LONZA 3616106029/.02.01

9-24-12

Next two borings, HF-11 & HF-12, are off line due to bldgs.



9-24-12 HF-11

14:23 START Spinning augers for HF-11

14:43 IN Rock @ 13.7'

15:00 START AIR HAMMERING

15:44 END DRILLING @ 34' bgs.

No noticeable communication w/ other wells/borings during...
($\underline{\nabla}$ = 9.43' B.T.O.R. in PIEZO. @ HF-8)
... the drilling of HF-11

Will end drilling activities AT This point for today

Copied to here To Send PDF to Jeff from p. 26

(34) ARCH/Longa 3616106029/.02.01

9-25-12

HF-11

0700 Tom Longly AMEC on site

Neil Short & Zach Nothnagle on site

All attend H&S briefing

Weather: Ptly, Sunny, Breezy, into high 60's

0730 ∇ = 9.04' B.T.O.R. @ PZ HF-8

≅ 7' BGS

Will perform Hydro Test in HF-11

This morning

∇ = 8.3' B.T.O.R. in PZ-109

Rock falling into hole giving us problems in getting packer into boring

Need to spin augers a bit to get a better seal @ Top of Rock

8:00 ∇ = 9.20' B.T.O.R. in HF-8 piezo. Water levels really fluctuate in This piezo. ??

Spin augers down an additional 3.5'/4'

0808 lower to seal off crumbly zone

0830 Cleaning out hole w/ hammer

(✳) HF-8, HF-9, HF-10 all settle out in hammering at HF-11. And, water, silt, mud, etc comes out of PW-15 again! lot of water

Also, water shoots out of piezo HF-8.

So, upper fractures communicate Very well w/ borings in this area (even HF-7 had settling of pea stone)

Tom O. Longly

9-25-12

HF-11 (35)

~~ELAPSED TIME~~	~~TOTAL Flow Gals.~~	~~Water Pressure (psi)~~	~~∇ Above Packer~~

JC 8

Decide not to continue w/ HF-11 ~~testing~~ - due to problems w/ hole, Jeff B. & Nelson B. & I agree to move on to HF-12 & HF-1 for now & not worry about testing @ HF-11 for now.

Calibrate PID w/ background air to get 0.0 ppm & 100 ppm Isobutylene: Final Reading = 99.8 ppm

PID = 11.7ev lamp #06466 from Pine Env.,

Span gas = Isobutylene, Lot #0621FB12, use before 07/2016.

Tom O. Longly 9-25-12

Arcadis/Lonza 3616106029/.02.01 HF-11

9-25-12

0855 HF-11 Boring has been hammered clean again but still have gravel, etc. falling into hole on top of drill bit! Having trouble pulling out tools

This is a bad hole! - Appears to be crooked from hitting an obstruction high up in the overburden. We may get tools stuck in hole if we continue to go down this boring. Also, afraid of damaging/getting stuck the packer: this already has some damage to it from rocks falling down around it during the first try this morning.

Am considering we abandon this hole

0916 Going back down w/ packer depth of 26' for bottom of packer

IT won't go into rock - gets stuck!

0930 Drillers off site for ~ 30 min.

Call & talk w/ Jeff B. & Nelson B. about situation. We agree to move on to drill HF-12, HF-1 & then call them to see how we will proceed at that point. Meanwhile, Jeff & Nelson to talk w/ Northrup to come up w/ plan on how to install an extraction well that will likely go at HF-10 location

9-25-12 HF-12

Decide, for now, to not continue w/ HF-11, but to fill w/ pea stone to surface.

10:47 Drillers are back on site

Bob Schellinger marks out the far West end of the proposed bldg. Right now, PZ in HF-8 is ~ 12' West of this line - We are OK if we want to place a piezo. at HF-8 location.

Tell drillers to pull out of HF-11, fill w/ pea stone

11:20 RIG IS moved to HF-12 location

11:38 START Spinning augers in HF-12

12:01 Spinning on top of Rock @ 18.7'

Weather: Cloudless, steady breeze out of S/SW, low 70's

Augers stopped @ 18.7' bgs on Rock

12:58 START air hammering in Rock

13:30 DRAGER TUBE FOR CHLOROFORM IS NON-DETECT

1338 " " " VINYL CHLORIDE IS NON-DETECT

13.50 " " " Carbon Tetrachloride is NON-DETECT

(*) Instream $\underline{\nabla}$ in HF-8 piezo. go from 9.3' TO 9.6' B.T.O.R. in 1 minute ?!! IS This effected by pumping of extraction well(s)? PW-15 doesn't appear to be pumping, so??? AIR HAMMER TO 39'.

14:20 JIM CRAFT (NYSDEC) on site

Getting ready TO set packer @ 29' bgs

9-25-12 ARCH/LONZA 3616106029/.02.01 HF-12

Ran Packer test in HF-12 at pressures of 10, 25, 40, & 60 psi. Then went back down to 10 psi. There was an increase in GPM flow at 10 psi from initial ~2.5 gpm to 4.4 gpm. So, the higher pressures opened the fractures to give an increase in flow when comparing pre- & after high pressures, or fractures. So, will pull out of hole & backfill w/ pea stone. During the test, did not observe communication w/ other borings/wells in the area.

15:06 Packer is out of the hole, Adding pea stone to boring as come out of hole

note: Jim Craft leaves site @ around 14:38 — sometime in the early part of the packer test.

16:00 Moved rig to HF-1 location

9-25-12 HF-12

14:35 Plug is on

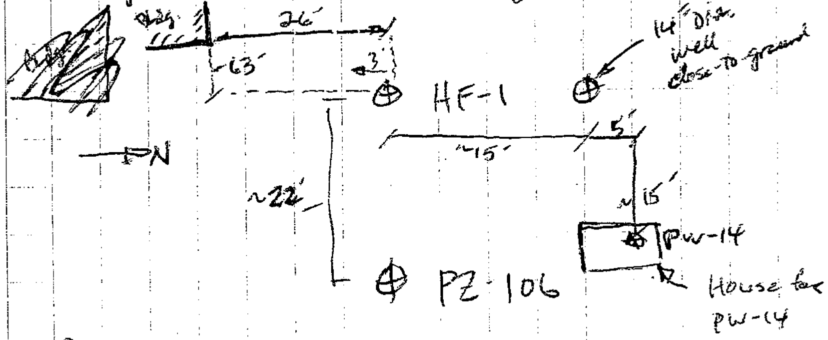
	ELAPSED TIME	TOTAL Flow (Gals.)	Water Pressure (psi)		from a convenient marker ∇ = Above Packer
	—	—	10		~~13.25~~ 11.05'
	1:00	1880.7	10		—
	2:00	1883.9	10		11.0'
2.5 gpm	3:00	1886.6	10		—
	4:00	1889.1	10		11'
	5:00	1891.5	10	go up to 25	—
	6:00	1895.6	25		10.95'
	7:00	1899.7	25		—
3.9 gpm	8:00	1903.8	25		~~9.5~~ 10.95'
	9:00	1907.7	25		—
	10:00	1911.5	25	go up to 40	—
	11:00	1918.6	40		10.95'
	12:00	1926.3	40		—
7.8 gpm	13:00	1934.0	40		10.95'
	14:00	1941.8	40		—
	15:00	1949.5	40	go up to 60	—
	16:00	1960.9	60		—
13.8	17:00	1974.9	60		10.55'
	18:00	1988.7	60	go to 10	—
4.4 gpm	19:00	1993.8	10		—
	20:00	1998.2	10	off	—
	14:55 off	—	—	—	10.55'

9-25-12 Arch/Lonza 3616106029/.02.01 HF-1

16:13 AT 12' bgs. - Spinning on rock
AT 12.5' bgs. - end here for the day.

9-26-12 HF-1

07:00 Tom Longley (Amec) on site
Zach Nothnagle - Drill Helper - we two attend H&S briefing w/ Lonza - Joe Flores - Neal Short to arrive later: getting well materials @ shop
Weather: Overcast, predicted showers, humid, into low 60's: Breeze from S/SW
Spun augers yesterday to top of Rock in HF-1 @ 12.5'.
Will plan to hammer to ~33' bgs



Calibrated PID, MiniRAE 2000: Ambient air = 0.0 ppm
& Isobutylene 100ppm = 98.9 ppm

07:55 ∇ = 8.26' B.T.O.R. in PIEZO. @ HF-4
≅ 6.2' B.G.S. " " "

07:57 ∇ = 9.25' B.T.O.R. in PIEZO. @ HF-8
≅ 7.2' B.G.S. " " " "

08:45 NEAL SHORT (Nothnagle) on site w/ supplies, etc. for extraction well & the 2 piezometers.

9-26-12 **HF-1**

∇ = 7.92' B.T.O.R. @ PZ-106; ≈6.2' BGS

0854 Rig is turned on; on rock @ 12.5': will
go w/ air hammer to ~ 33'
0932 Start hammering rock
Above 15' in HF-1, air, water come
violently out of HF-2, Piezo @ HF-4
& well? ~15' N of HF-1, HF-5

∇ = 7.45' B.T.O.R. PZ-106 - not reacting
too much to drilling @ HF-1, but HF-2
through HF-5 are reacting to drilling of HF-1
This settles down considerably after
Go below 16.3', but piezo in HF-4
still coughs up water
0955 ∇ = 7.5' B.T.O.R. PZ-106
PZ-106 does not react like HF-2/HF-5
or well N. of HF-1 (14' DIA.)
From ~14' to & through 17.5', reactions from
HF-2, HF-3, HF-4/piezo, HF-5, &
well 15' North of HF-1 all react to drilling.
• of ALL HF-locations, drilling in HF-1 caused
the most reactions over the site, by far

* NOTE: No water bubbled out of PW-14 well

9-26-12 **HF-1**

10:10 AT ~ 26' bgs, driller notes "different smell" in
air: PID = 0.2 ppm; "real pungent" odor:
he smelled it twice & went away below 27'.
10:15 DRAGER for VC = Non-detect.
DRAGER For Chloroform = non-detect
10:26 DRAGER FOR Carbon Tetrachloride = non-detect
10:30 Finish air hammering @ 33'
Will perform pressure testing
10:45 ∇ = 9.26' B.T.O.R. in PZ-106

11:16 Conducted Perm./Packer test (see p. 44)
then pulled out & backfilled w/ Pea stone

9-26-12

ARCH/LONZA 3616106029/.02.01

9-26-12

HF-1

START: 10:52

	ELAPSED TIME	TOTAL Flow (GALS.)	Water Pressure (PSI)	▽ Above PACKER
	1:00	2001.6	10	8.8
	2:00	2002.0	10	—
	3:00	2002.4	10	8.75
	4:00	2002.7	10 go up	—
0.5 - [	5:00	2003.3	25	—
	6:00	2003.8	25	8.7
	7:00			
0.4 - [	8:00	2004.9	25	—
	9:00	2005.3	25 go up	—
	10:00	2006.1	40	8.7
0.6 - [	11:00	2006.8	40	—
	12:00	2007.4	40 go up	—
	13:00	2008.5	~ ~~65~~63	—
1.0 [	14:00	2009.6	63	8.85
	15:00	2010.6	63	—
	16:00	2011.6	63 go up	—
	17:00	2017.8	80	8.5
13.6 - [	18:00	2028.3	80	—
	19:00	2041.9	80	—
11:10	End			
			~~40~~	
	—	2044.5	25	
0.6 [	1:00	2045.1	25	
11:13	2:00	2045.7	25	TURN off

9-26-12

EXTRACTION WELL PW-17

Formation took water @ very slow rates up to 63 psi. When pressure @ 80 psi, took water @ ~13.5 gpm. When back down to 25 psi, took water @ ~0.6 GPM versus @ ~0.5 gpm at earlier rate of 25 psi. - Don't knew how to evaluate that right away.
When turned off water pressure, there was no back pressure from the formation.

11:35 Hole is backfilled (HF-1) w/ pea stone - Will now set up @ HF-10 to drill to rock to set casing for Extraction Well

11:45 Rig moved to HF-10 Location

12:21 Clouds moving out of W/SW - humid, feels like rain

12:27 START Spinning 10¼" Augers AT HF-10 Location for setting 8" Casing for EXTRACTION well

12:32 1-Auger drilled (Augers make ~ 14" dia. hole)

12:37 2-Augers drilled

12:42 3-Augers drilled ~ 14.5 bgs

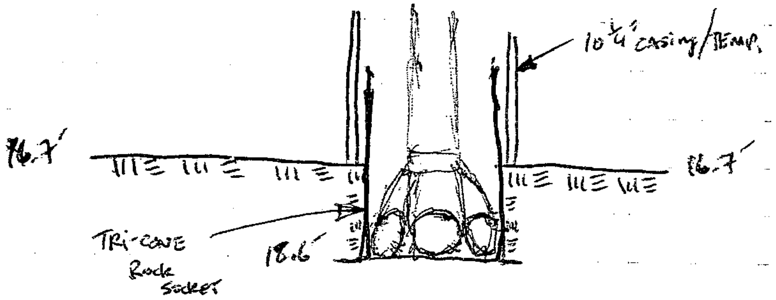
12:49 Spinning on Rock @ ~ 17' bgs; measured @ 16.7'. Will pull Augers to place 10¼" ID Temp. Casing in hole into which the drill bit, tri-cone/10" will go no more than 2' into Rock, to then be able to grout into the socket, an 8¼" ID permanent casing

ARCH/LONZA 361606029/.02.01

9-26-10

13:15 10¼" Temp. Casing driven/hammered to Top of Rock @ 16.7' (20'+16.7' = 36.7'/37' TARGET DEPTH) (SAY 36')

Getting ready to drill socket into bedrock
Will recirculate water
Drilling w/ Tri-cone ~~on rock~~ to clean
14:26 out casing
14:45 On rock now
14:52 Going to 18.7'
14:56 AT ~18.6' - END HERE w/ TRI-CONE



15:30 MIX cement/Bent. cement grout - will tremie through drill string ~45 gallons to set on bottom. Then will place permanent 8" casing into the grout to set/harden overnight
- Made ~45 gallons - pumped in hole, pulled tri-cone,
15:49 8" Casing sitting in the hole, in concrete
16:00 Pulling temp. 10¼" casing out of hole -

Thomas W.

9-26-10

16:12 Will mix another batch of concrete/bent. to place in the boring; ≈45 gallons - placed on outside of 8¼" casing, in annular space made by the temp. 10¼" casing - Hole is done - now wait for concrete to cure in the meantime & tomorrow will drill & install 2x2" piezometers in the HF-8 & HF-12 locations: Both will be Flush-to-ground completions. Then, will use an ~8" Tri-cone to drill the bedrock in the new extraction well to a depth of ~37' bgs (~20' in bedrock).

Give Jeff B. a call at the office - He will call DiLaura @ Northridge about remaining issues, such as development & capacity testing, etc.
17:00 All hands off site

Copied to here to send PDF to Jeff B.

ARCH/Longa 3616106029/.02.01

9-27-12

PIEZO.
AT HF-12
PZ-110

0720 Tom Longley (Amec) on site w/ Neal Short & Zach Northagle - Attend Longa Contractor's H&S briefing.
Weather: Ptly. Cloudy, highs predicted mid. 60's Slight breeze from W/SW (now mid 40's)

07:30 Setting up @ HF-12 TO place 2" PIEZO.

07:45 Down to Rock @ 18.7' w/ 4¼" Augers
Will go down w/ 3 15/16" bit to clean out hole to set bottom of Screen @ 31'. So, need to set up containment box around rig as though were drilling into rock in order to clean out the hole in the bedrock portion of the boring.
Plan is to set 2" PVC, 10-slot screen, 10' long from 31' - 21', sand pack up to 20', bent. seal 20' - 17' (Rock being @ 18.7'), then grout 17' to surface

0830 Going down w/ ~~hammer~~ Roller bit to Clean out hole

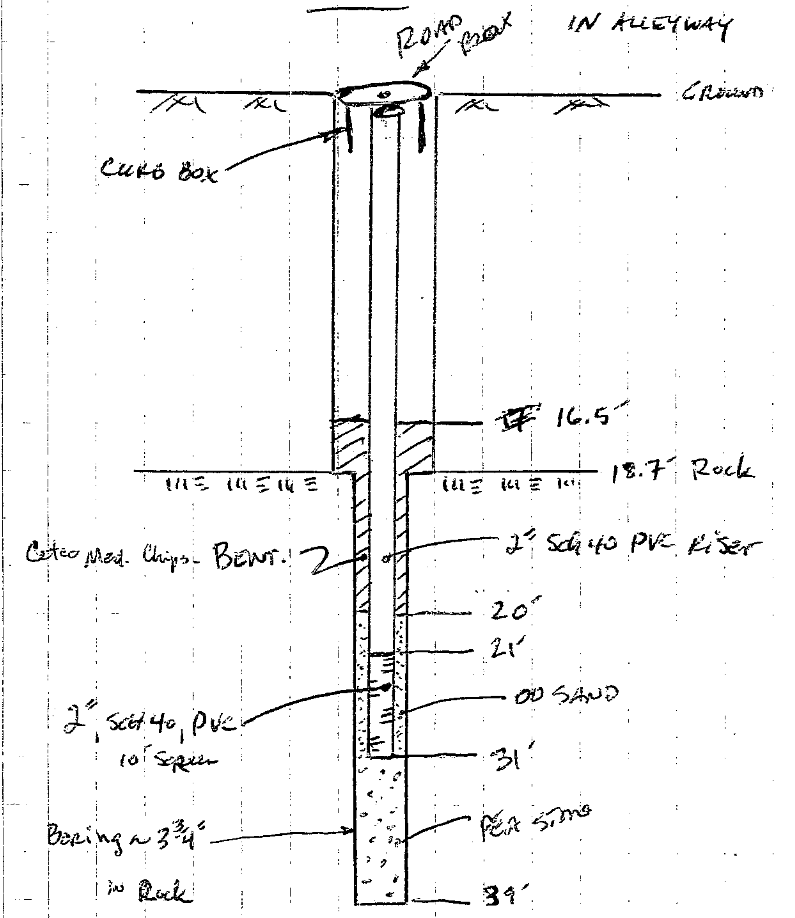
0843 Hole is clean - will build a well after pull out Rods

0936 Well is as shown on p. 49 - Still need to place grout to near surface

9-27-12

2" PIEZO.
AT HF-12 LOCATION
IN ALLEYWAY

PZ-110



(50) ARCH/LONZA 3616106029/03.01

9-27-12 PZ-111

10:10 Rig moved to HF-8 location to drill & place PZ-111 at this location

10:16 $\underline{\nabla}$ = 7.35' BGS. : Pull out 1" PIEZO.

10:24 START DRILLING out PZ-111

10:34 Augers are on Rock @ 16.5'
Will clean/ream out hole to ~28' w/ 2 15/16" Tri-cone roller bit, using air

10:58 Hole is cleaned out - pull tools to set well

11:23 Bentonite seal up to 14'

12:00 Take a break for lunch

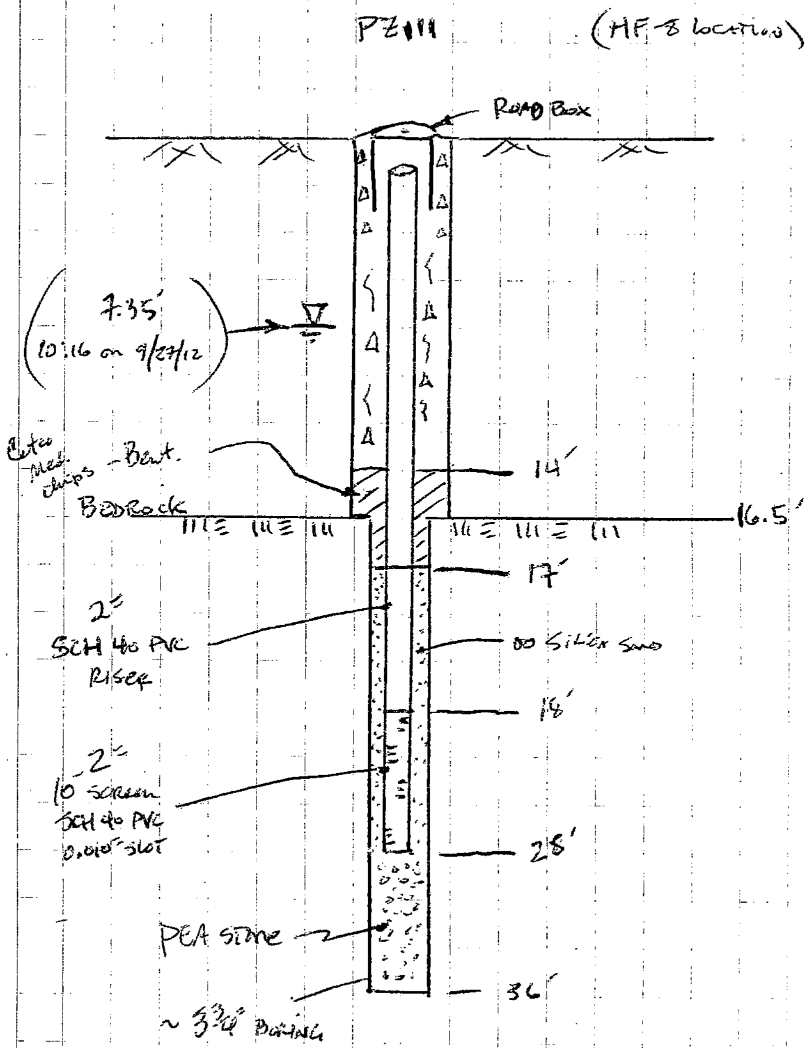
12:50 Jeff Brandow calls, drillers will likely not develop the two piezos of PZ-110 & PZ-111 but may develop the PW-17 by Venturi/air lift system, rather than gunk up a pump. This may be done either tomorrow or next week.

Breeze out of EAST - causes odor from pits to come right at us. No: The odor, says JOE, is from a neighboring company to the NE that manufactures high-tech insulating material.

- Pull rig back over PW-17 to drill out rock to depth by using a tri-core bit (7 7/8" DIA.)

(51)

9-27-12



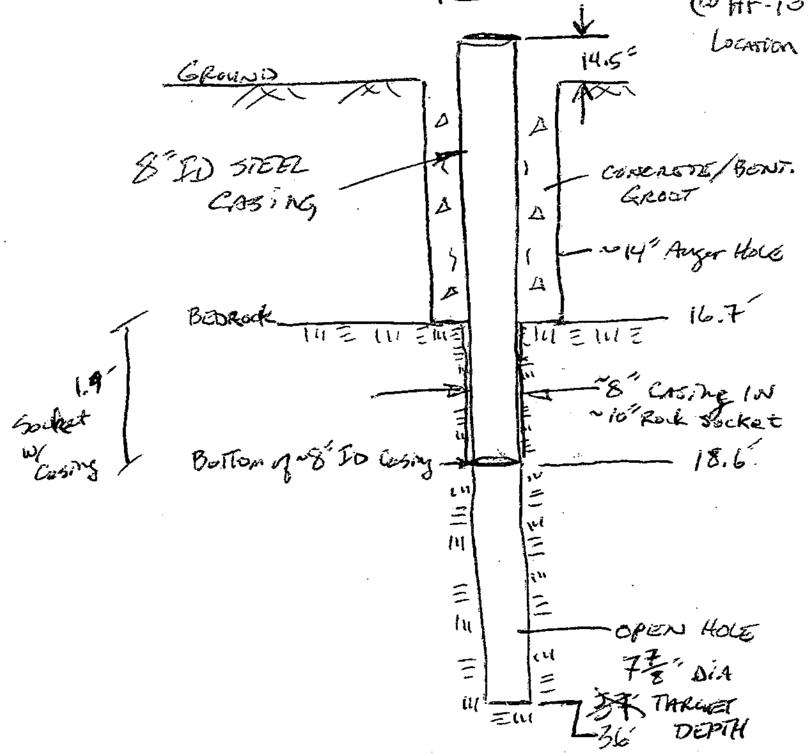
(52)

ARCH/LONZA 3616106029/.02.01

9-27-12

PW-17

PW-17
@HF-10
LOCATION



The ~8" permanent casing was set into rock socket yesterday w/ cement grout left to set overnight. Had to cut 8" casing to 14" AGS in order to drive over it, & attach their re-circulation tub for drilling.

13:51 Cement grout at ~3' bgs! Lot of drilling to do. Will be drilling w/ water

14:12 Down to rock now. Will be increasing the existing rock boring from $3\frac{3}{4}$" to $7\frac{7}{8}$" dia.

(53)

9-27-12

PW-17

15:00 Down to ? ~25'
15:33 Down to 31' : Have 5' more to go
15:57 Down TO 36' - end of EW/PW-17

Go to Hydrogeo. ppn
Look for LAGAN analysis?

for plotting Pressures vs. Flow

for Packer Testing - per Peter Thompson

APPENDIX D

DETAILED COST ANALYSIS BACKUP

Table 9-2: Cost Summary for Alternative 1 - Continued Groundwater Extraction

ITEM		COST
DIRECT CAPITAL COSTS		
Direct Cost Subtotal	$	-
INDIRECT CAPITAL COSTS		
Project Management (@ 10 Percent)	$	-
Remedial Design (none included)	$	-
Construction Management (none included)	$	-
Contingency (@ 15 Percent)	$	-
Indirect Cost Subtotal	$	-
TOTAL CAPITAL COSTS	**$**	**-**
ANNUAL OPERATION AND MAINTENANCE COSTS		
OM&M of the Existing Groundwater Extraction System (years 1-30)	$	228,000
Semiannual Monitoring and reporting (years 1-30)	$	97,000
PRESENT WORTH OF ANNUAL AND PERIODIC COSTS (30 yrs)	**$**	**4,996,000**
TOTAL PRESENT WORTH OF ALTERNATIVE 1 (30 yrs)	**$**	**4,996,000**

NOTES:

Costs have been rounded to the nearest thousand.

Costs based on annual inspection and reporting.

Alternative 1 - No Further Action: Continued Groundwater Extraction

Task	Description	Quantity	Unit of Measure	Material Unit Cost	Labor Unit Cost	Equipment Unit Cost	Extended Cost	Comments/ Assumptions
Subtask								
Assembly (1)								
CAPITAL COSTS								
None								
ALTERNATIVE ANNUAL AND PERIODIC COSTS								
Annual OM&M of Groundwater Extraction System: Years 1-30								
Eng. Estimate	Task Subtotal						$ 228,417.01	Assume 30 years until asymptotic mass removal rates or RAOs achieved.
Contingency (@ 15 Percent)								
Long-Term Monitoring - Semiannual Sampling and Reporting: Years 1-30								
Eng. Estimate	Task Subtotal						$ 97,000.00	Annual budgeted costs for semiannual monitoring and reporting.

Notes:
1) Assembly numbers presented indicate RACER/RS MEANS assembly code

PRESENT VALUE OF ANNUAL AND PERIODIC COSTS FOR ALTERNATIVE 1 (No Further Action: Continued Groundwater Extraction)

Year	Cost*	Number of Annual Periods	Annual Discount Rate	Number of 5-Year Periods	5-Year Discount Rate	Number of 10-Year Periods	10-Year Discount Rate	Total Non-Discounted Cost	Present Value Cost
Capital (Year 0)	$ -	1	0	NA	NA	NA	NA	$ -	$ -
Annual Groundwater Extraction System OM&M (1-30)	$ 228,000	30	0.05	NA	NA	NA	NA	$ 6,840,000.00	$ 3,504,918.83
Semiannual Monitoring (Years 1-30)	$ 97,000	30	0.05	NA	NA	NA	NA	$ 2,910,000.00	$ 1,491,127.75
Totals								**$ 9,750,000.00**	**$ 4,996,046.58**

*Annual and periodic costs include 10% for technical support and 25% contingency for unforeseen project complexities, including insurance, taxes, and licensing costs.
Capital costs include 25% contingency, as well as and project management, remedial design, and construction management costs per DER-10 guidance.

Discount rate of 5% (for 30-years) percent based on NYSDEC PRAP Outline / Instructions.

Table 9.3: Cost Summary for Alternative 2 – Install Horizontal Groundwater Extraction Wells

ITEM		**COST**
DIRECT CAPITAL COSTS		
General Conditions	$	39,000
Extraction Well Installation	$	685,000
Direct Cost Subtotal	$	724,000
INDIRECT CAPITAL COSTS		
Project Management (@ 6 Percent)	$	44,000
Remedial Design (@ 12 Percent)	$	87,000
Contingency (@ 15 Percent)	$	58,000
Contingency (@ 25 Percent)	$	181,000
Indirect Cost Subtotal	$	370,000
TOTAL CAPITAL COSTS	**$**	**1,094,000**
ANNUAL OPERATION AND MAINTENANCE COSTS		
Annual Groundwater Extraction System OM&M (1-25)	$	355,000
Semiannual Monitoring (Years 1-30)	$	97,000
PRESENT WORTH OF ANNUAL AND PERIODIC COSTS (30 yrs)	**$**	**5,917,000**
TOTAL PRESENT WORTH OF ALTERNATIVE 2 (30 yrs)	**$**	**7,011,000**

NOTES:

Costs have been rounded to the nearest thousand.

Alternative 2 – Install Horizontal Groundwater Extraction Wells

Task	Description	Quantity	Unit of Measure	Material Unit Cost	Labor Unit Cost	Equipment Unit Cost	Extended Cost	Comments/ Assumptions
Subtask				**Adj 2009 (3% /yr)**	**Adj 2009 (3% /yr)**	**Adj 2009 (3% /yr)**		**No localized factor added. 4% Tax on Materials**
ALTERNATIVE CAPITAL COSTS								
General Conditions								
Eng. Est	Site Superintendent	280	HR	$ -	$ 100.00	$ -	$ 28,000.00	Assume 35 days oversight for site preparation, trenching, drilling, pump installation, electrical and instrumentation.
Eng. Est	Temporary field office and utilities	1	LS	$ 1,000.00	$ -	$ -	$ 1,000.00	
Eng. Est	Contractor Workplan	1	LS	$ -	$ 10,000.00	$ -	$ 10,000.00	
	Task Subtotal						**$ 39,000.00**	
Extraction Well Installation								Extraction well installation costs are based on an extraction well replacement bid by Matrix Environmental Technologies at Arch Chemical (March, 2010) and quotes from Directed Technologies Drilling, Inc.
Site Preparation								
Contingency (@ 15 Percent)								
Vendor	Project Coordination	16	HR	$ -	$ 88.00	$ -	$ 1,408.00	
Vendor	Senior Remediation Technician	16	HR	$ -	$ 70.00	$ -	$ 1,120.00	
Vendor	Remediation Technician	16	HR	$ -	$ 60.00	$ -	$ 960.00	
Vendor	Service Vehicle	2	DAY	$ -	$ -	$ 150.00	$ 300.00	
Drilling and Installation of Discharge Piping and Electrical for Extraction Wells								Days 30
Vendor	Mobilization/Demobilization	1	LS	$ -	$ 25,000.00	$ -	$ 25,000.00	
Vendor	Project Coordination	8	HR	$ -	$ 88.00	$ -	$ 704.00	
Vendor	Geologist	280	HR	$ -	$ 70.00	$ -	$ 19,600.00	
Vendor	Senior Remediation Technician	280	HR	$ -	$ 70.00	$ -	$ 19,600.00	
Vendor	Remediation Technician	280	HR	$ -	$ 60.00	$ -	$ 16,800.00	
Vendor	Service Vehicle x2	35	DAY	$ -	$ -	$ 150.00	$ 5,250.00	
Vendor	Drilling	1270	FT		$ 240.00		$ 304,800.00	Assuming $230-275/foot, hovering somewhere around $240/ft. actual; 770' of well screen plus four 125-ft sloped bore holes to reach target well depth.
Vendor	Well seals and surface completion (w/ vault)	4	UNIT	$ 8,000.00			$ 32,000.00	
Vendor	Well Materials - screen	770	FT	$ 15.00	$ -	$ -	$ 11,550.00	
Vendor	Well Materials - casing	600	FT	$ 10.00	$ -	$ -	$ 6,000.00	
Vendor	Fuel - Estimated	35	DAY	$ 75.00	$ -	$ -	$ 2,625.00	
Vendor	Plumbing, Electrical Wire and Pump Ends	2	BUDGET	$ 1,500.00		$ -	$ 3,000.00	
Vendor	2'x2' aluminum valve box (flush mount)	2	UNIT	$ 1,100.00	$ -	$ -	$ 2,200.00	
Vendor	Freight	2	BUDGET	$ 100.00	$ -	$ -	$ 200.00	
Vendor	Concrete	4	BUDGET	$ 400.00	$ -	$ -	$ 1,600.00	
Eng. Est	Temporary Water Connection for drilling	1	BUDGET	$ 5,000.00	$ -	$ -	$ 5,000.00	
Pump Installation								
Vendor	Pump Installation	2	LS	$ 2,500.00	$ -	$ -	$ 5,000.00	

Alternative 2 – Install Horizontal Groundwater Extraction Wells

Task	Description	Quantity	Unit of Measure	Material Unit Cost	Labor Unit Cost	Equipment Unit Cost	Extended Cost	Comments/ Assumptions
Subtask				**Adj 2009 (3% /yr)**	**Adj 2009 (3% /yr)**	**Adj 2009 (3% /yr)**		**No localized factor added. 4% Tax on Materials**
Transportation and Disposal of Excavated Soil and Cuttings								Assume development water will be pumped to Arch's treatment plant from the driller provided frac tank.
Eng. Est.	Cutting T&D	62	TON	$ 115.88	$ -	$ -	$ 7,242.16	Assume non-hazardous industrial waste. 10" diameter cores, density of 2.9 g/cm3, conversion of .84 to tons per cy
Groundwater Treatment								
Eng Est.	Prefabricated treatment building	1500	SF	$ 45.26	$ 55.10	$ 15.63	$ 173,985.00	RS Means 2014 - 20' x 40' x 20' prefabricated steel building. Includes foundation, plumbing, mechanical and electrical
Eng Est.	Extraction Piping	1000	LF	$ 23.10	$ 15.63	$ -	$ 38,730.00	Assume above ground and heat traced. It is assumed that there is an existing overhead utility pipe rack structure that the pipe will be attached to.
	Task Subtotal						**$ 684,674.16**	
ALTERNATIVE ANNUAL AND PERIODIC COSTS								
Annual OM&M of Groundwater Extraction System: Years 1-20								
Eng Est.	Routine OM&M	1	LS	$ -	$ -	$ -	$ 206,667.01	Assume 20 years until asymptotic mass removal rates or RAOs achieved. Assumed 50% reduced flow from new wells --> one changeout per year instead of 2. Half of $43,500 for carbon change outs (2 in CY14) = 21,750
Eng Est.	Carbon Vessel Rental	12	MONTH	$ -	$ -	$ 1,500.00	$ 18,000.00	Estimate based on current facility costs
Eng Est.	Carbon Change Out	6	#/YEAR	$ 21,750.00	$ -	$ -	$ 130,500.00	Scaled based on 2 change outs / year at the current water treatment plant @ 30-35 gpm (New system flow assumed 100 gpm)
	Task Subtotal						**$ 355,167.01**	
Long-Term Monitoring - Semiannual Sampling and Reporting: Years 1-30								
Eng Est.	Task Subtotal						$ 97,000.00	Annual costs for semiannual monitoring and reporting.

Notes:

1) Assembly numbers presented indicate RACER/RS MEANS assembly code

PRESENT VALUE OF ANNUAL AND PERIODIC COSTS FOR ALTERNATIVE 2 – Install Horizontal Groundwater Extraction Wells

Year	Cost*	Number of Annual Periods	Annual Discount Rate	Number of 2-Year Periods	2-Year Discount Rate	Number of 4-Year Periods	4-Year Discount Rate	Total Non-Discounted Cost	Present Value Cost
Capital (Year 0)	$ 1,094,000	1	0	NA	NA	NA	NA	$ 1,094,000.00	$ 1,094,000.00
Annual Groundwater Extraction System OM&M (1-25)	$ 355,167	20	0.05	NA	NA	NA	NA	$ 7,103,340.20	$ 4,426,165.99
Semiannual Monitoring (Years 1-30)	$ 97,000	30	0.05	NA	NA	NA	NA	$ 2,910,000.00	$ 1,491,127.75
Totals								**$ 11,107,340.20**	**$ 7,011,293.73**

Capital costs include 25% contingency, as well as project management, remedial design, and construction management costs per DER-10 guidance.

Discount rate of 5% (for 30-years) percent based on NYSDEC PRAP Outline / Instructions.

Table 9.4: Cost Summary for Alternative 3 - Hydraulic Fracturing and Additional Groundwater Extraction Wells

ITEM		COST
DIRECT CAPITAL COSTS		
Hydraulic Fracturing Field Program	$	64,300
Extraction Well Installation	$	77,982
Direct Cost Subtotal	$	142,282
INDIRECT CAPITAL COSTS		
Project Management (@ 8 Percent)	$	11,000
Remedial Design (@ 15 Percent)	$	21,000
Contingency (@ 15 Percent)	$	14,000
Contingency (@ 25 Percent)	$	36,000
Indirect Cost Subtotal	$	82,000
TOTAL CAPITAL COSTS	**$**	**224,282**
ANNUAL OPERATION AND MAINTENANCE COSTS		
Annual Groundwater Extraction System OM&M (1-20)	$	228,000
Semiannual Monitoring (Years 1-30)	$	97,000
PRESENT WORTH OF ANNUAL AND PERIODIC COSTS (30 yrs)	**$**	**4,581,000**
TOTAL PRESENT WORTH OF ALTERNATIVE 3 (30 yrs)	**$**	**4,805,000**

NOTES:
Costs have been rounded to the nearest thousand.
Costs based on annual inspection and reporting.

Alternative 4 - Enhanced Multiphase Extraction

Task	Description	Quantity	Unit of Measure	Material Unit Cost	Labor Unit Cost	Equipment Unit Cost	Extended Cost	Comments/ Assumptions
Subtask								
Assembly (1)								
CAPITAL COSTS								
Hydraulic Fracturing Field Program								Assume 12 hydraulic fracturing points on northern alignment and 12 on middle alignment (one point per 10 feet).
General Conditions								
Eng. Est	Site Superintendent	120	HR	$ -	$ 100.00	$ -	$ 12,000.00	
Eng. Est	Temporary field office and utilities	1	LS	$ 1,000.00	$ -	$ -	$ 1,000.00	
Eng. Est	Contractor Workplan	1	LS	$ -	$ 10,000.00	$ -	$ 10,000.00	
Contingency (@ 15 Percent)								
Hydraulic Fracturing								
Vendor	Mobilization & Demobilization	1	EA	$ -	$ -	$ 500.00	$ 500.00	
Vendor	Crew Site Safety Training	1	DAY	$ -	$ 800.00	$ -	$ 800.00	
Vendor	Drill & Crew (8 hours on site)	15	DAY	$ -	$ -	$ 1,450.00	$ 21,750.00	Assume 2 points per day and 1 extra day per extraction well.
Vendor	Temporary 4" casing	540	FT	$ 15.00	$ -	$ -	$ 8,100.00	27 points - assume other 3 will be developed as extraction wells.
Vendor	Packer Equipment Rental	15	DAY	$ -	$ -	$ 150.00	$ 2,250.00	
Vendor	Temporary Decontamination Pad	1	EA	$ -	$ -	$ 100.00	$ 100.00	
Vendor	Steam Cleaner Rental	3	WK	$ -	$ -	$ 250.00	$ 750.00	
Vendor	Portland Cement	81	BAG	$ 20.00	$ -	$ -	$ 1,620.00	3 per temporary point.
Vendor	55 Gallon Drums	54	EA	$ -	$ -	$ 45.00	$ 2,430.00	
Vendor	1000 Gallon Frac Tank Rental	3	WK	$ -	$ -	$ 1,000.00	$ 3,000.00	
	Task Subtotal						$ 64,300.00	
Extraction Well Installation								Extraction well installation costs are based on an extraction well replacement bid by Matrix Environmental Technologies at Arch Chemical (March, 2010).
Site Preparation								
Vendor	Project Coordination	4	HR	$ -	$ 88.00	$ -	$ 352.00	
Vendor	Senior Remediation Technician	16	HR	$ -	$ 70.00	$ -	$ 1,120.00	
Vendor	Remediation Technician	16	HR	$ -	$ 60.00	$ -	$ 960.00	
Vendor	Service Vehicle	2	DAY	$ -	$ -	$ 150.00	$ 300.00	
Drilling and Oversight Associated with Extraction Well Installation								
Vendor	Project Coordination	8	HR	$ -	$ 88.00	$ -	$ 704.00	
Vendor	Geologist	40	HR	$ -	$ 70.00	$ -	$ 2,800.00	
Vendor	Service Vehicle	5	DAY	$ -	$ -	$ 150.00	$ 750.00	
Vendor	Drilling Subcontractor	1	LS	$ -	$ -	$ 4,971.00	$ 4,971.00	Based on Nothnagle budgetary estimate from August 3, 2011. Costs for mobilization and day rate already covered under hydrofracking field program.

Trenching and Installation of Discharge Piping and Electrical for Extraction Wells

Vendor	Mobilization/Demobilization	1	LS	$	-	$	750.00	$	-	$	750.00
Vendor	Project Coordination	8	HR	$	-	$	88.00	$	-	$	704.00
Vendor	Senior Remediation Technician	96	HR	$	-	$	70.00	$	-	$	6,720.00
Vendor	Remediation Technician	96	HR	$	-	$	60.00	$	-	$	5,760.00
Vendor	Service Vehicle x2	24	DAY	$	-	$	-	$	150.00	$	3,600.00
Vendor	Backhoe	3	WK	$	-	$	-	$	800.00	$	2,400.00
Vendor	Excavator	3	WK	$	-	$	-	$	1,000.00	$	3,000.00
Vendor	Tamper	3	WK	$	-	$	-	$	225.00	$	675.00
Vendor	Fuel - Estimated	12	DAY	$	75.00	$	-	$	-	$	900.00
Vendor	Backfill	3	BUDGET	$	400.00			$	-	$	1,200.00
Vendor	Plumbing, Electrical Wire and Pump Ends	3	BUDGET	$	1,500.00			$	-	$	4,500.00
Vendor	2'x2' aluminum valve box (flush mount)	3	UNIT	$	1,100.00	$	-	$	-	$	3,300.00
Vendor	Freight	3	BUDGET	$	100.00	$	-	$	-	$	300.00
Vendor	Concrete	3	BUDGET	$	400.00	$	-	$	-	$	1,200.00

Pump Installation

Vendor	Pump Installation	3	LS	$	-	$	9,900.00	$	-	$	29,700.00

Transportation and Disposal of Excavated Soil and Cuttings

Assume development water will be pumped to Arch's treatment plant from the driller provided frac tank.

Eng. Est.	Excavated Soil T&D	1	TON	$	115.88	$	-	$	-	$	115.88	Assume non-hazardous industrial waste.
Eng. Est.	Cuttings T&D	6	DRUM	$	200.00	$	-	$	-	$	1,200.00	Assume non-hazardous industrial waste.
	Task Subtotal									$	77,981.88	

ALTERNATIVE ANNUAL AND PERIODIC COSTS

Annual OM&M of Groundwater Extraction System: Years 1-25

Eng. Estimate	Task Subtotal	$	228,417.01	Assume 25 years until asymptotic mass removal rates or RAOs achieved.

Long-Term Monitoring - Semiannual Sampling and Reporting: Years 1-30

Eng. Estimate	Task Subtotal	$	97,000.00	Annual costs for semiannual monitoring and reporting.

Notes:

1) Assembly numbers presented indicate RACER/RS MEANS assembly code

PRESENT VALUE OF ANNUAL AND PERIODIC COSTS FOR ALTERNATIVE 3: Hydraulic Fracturing and Additional Groundwater Extraction Wells

Year	**Cost***	**Number of Annual Periods**	**Annual Discount Rate**	**Number of 5-Year Periods**	**5-Year Discount Rate**	**Number of 10-Year Periods**	**10-Year Discount Rate**	**Total Non-Discounted Cost**	**Present Value Cost**
Capital (Year 0)	$ 224,282	1	0	NA	NA	NA	NA	$ 224,281.88	$ 224,281.88
Annual Groundwater Extraction System OM&M (1-20)	$ 228,000	25	0.05	NA	NA	NA	NA	$ 5,700,000.00	$ 3,213,419.36
Semiannual Monitoring (Years 1-25)	$ 97,000	25	0.05	NA	NA	NA	NA	$ 2,425,000.00	$ 1,367,112.62
Totals								**$ 8,349,281.88**	**$ 4,804,813.87**

Capital costs include 25% contingency, as well as and project management, remedial design, and construction management costs per DER-10 guidance.
Discount rate of 5% (for 30-years) percent based on NYSDEC PRAP Outline / Instructions.

Table 10.1: Summary of Remedial Alternative Costs

Item	Description	Alternative 1	Alternative 2	Alternative 3
1	Capital Costs	$ -	$ 1,094,000	$ 224,282
2	Present Worth of Annual and Periodic Costs	$ 4,996,000	$ 5,917,000	$ 4,581,000
3	**Total Present Worth (Item 1 plus 2)**	**$ 4,996,000**	**$ 7,011,000**	**$ 4,805,000**
4	Annual Costs Years 1 through 15 Contingency (@ 15 Percent)	$ 325,000	$ 452,000	$ 325,000
5	Annual Costs Years 16 through 20	$ 325,000	$ 452,000	$ 325,000
6	Annual Costs Years 21 through 25	$ 325,000	$ 97,000	$ 325,000
7	Annual Costs Years 26 through 30	$ 325,000	$ 97,000	$ 97,000
8	Remedial Timeframe (yrs) (Note 3)	30	30	30

Notes:

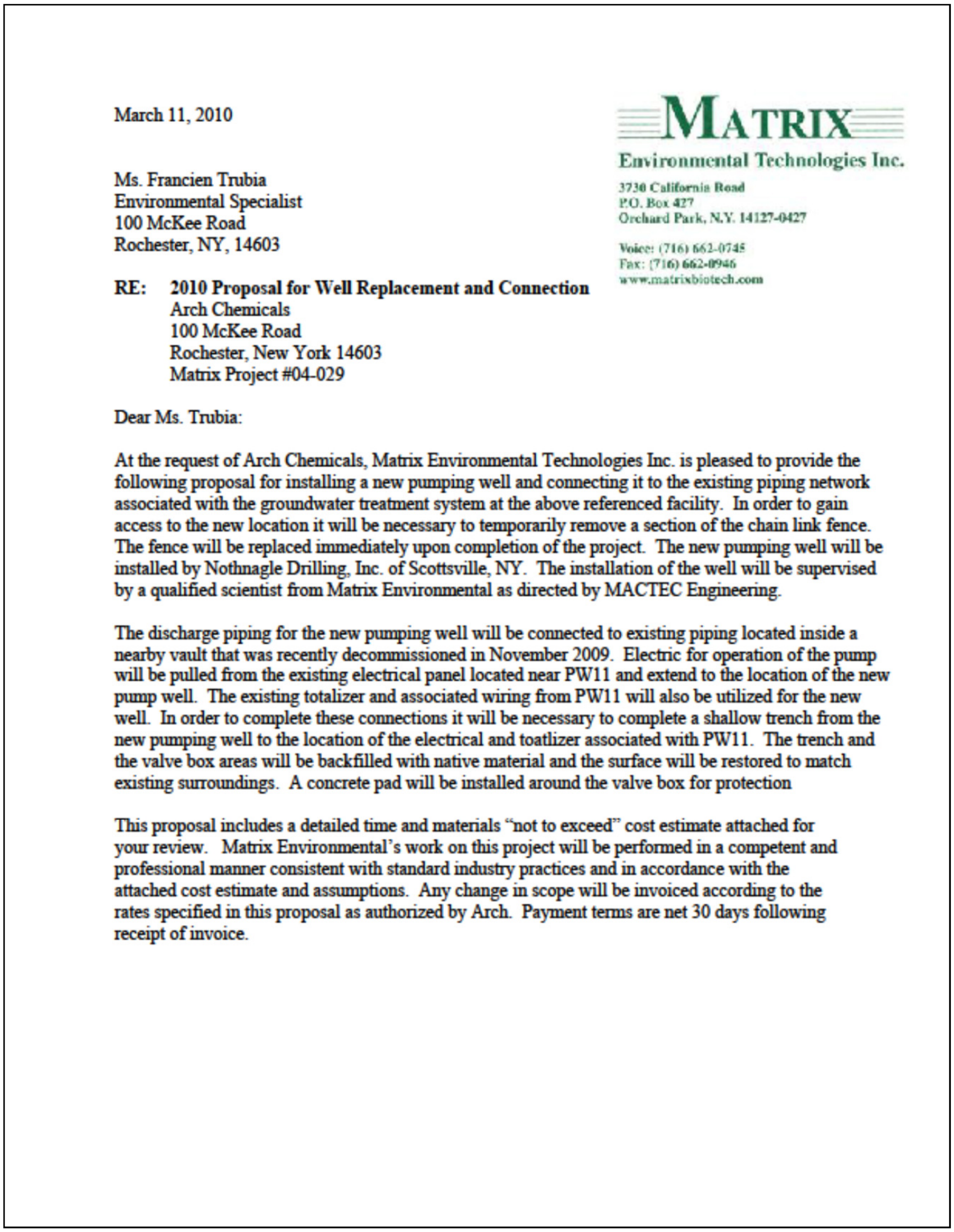
1. Present Worth costs shown above are based upon the assumed Remedial Timeframe.
2. Annual and Periodic Costs (Item 2, 4 - 7) presented are non-discounted (future) costs.
3. Estimated costs presented in this table are intended to be within the target accuracy range of minus 30 to plus 50 percent of actual cost.

Alternative Descriptions:

1 = Continued Groundwater Extraction
2 = Install Horizontal Groundwater Extraction Wells
3 = Hydraulic Fracturing and Additional Groundwater Extraction Wells

Groundwater

Net Total Costs	Act. cumulated	
5030050 SAFETY SUPPLIES	1.24	
5030060 POLLUTION SUPPLIES	66,624.98	calgon
5030090 SUPPLIES, INDIRECT	668.72	
5040010 MINOR MTLS(MIN.PROP)	1,016.78	
** SUPPLIES	68,311.72	
5055150 MAINT MATL -WH ISSUE	5,503.30	see tab
5325010 CONTR SVC-MAINTNANCE	9,385.06	see tab
9005020 Maintcont-w/o to cc	26,094.40	see tab
9005030 Maintsvcs-w/o to cc	31,209.75	see tab
9005040 Maintmat-w/o to cc	21,346.32	see tab
* MAINTENANCE MAT;CONT;SVC	Contingency (@ 15 Percent)	
** MAINTENANCE MAT;CONT;SVC	93,538.83	
5327990 CONTR SVC-OTHER	82,469.50	mactec reserve
** CONTRACT SERVICES	82,469.50	
5730010 DEPRECIATION	7,420.53	
** DEPRECIATION	7,420.53	
5712010 TAXES-MISCELLANEOUS	55,115.93	Groundwater Surcharge from Monroe County
** TAXES AND INSURANCES	55,115.93	
5810010 RENT-EQUIPMENT	4,800.00	rain for rent
** RENTALS	4,800.00	
5068010 DEMURRAGE - TRUCK	650.00	calgon
** DETENTION & SWITCHING CHGS	650.00	
5329010 LABORATORY FEES	(1,420.00)	
** OTHER EXPENSE	(1,420.00)	
*** TOTAL DIRECT SPENDING	310,886.51	



March 11, 2010

MATRIX
Environmental Technologies Inc.
3730 California Road
P.O. Box 427
Orchard Park, N.Y. 14127-0427

Voice: (716) 662-0745
Fax: (716) 662-0946
www.matrixbiotech.com

Ms. Francien Trubia
Environmental Specialist
100 McKee Road
Rochester, NY, 14603

RE: 2010 Proposal for Well Replacement and Connection
Arch Chemicals
100 McKee Road
Rochester, New York 14603
Matrix Project #04-029

Dear Ms. Trubia:

At the request of Arch Chemicals, Matrix Environmental Technologies Inc. is pleased to provide the following proposal for installing a new pumping well and connecting it to the existing piping network associated with the groundwater treatment system at the above referenced facility. In order to gain access to the new location it will be necessary to temporarily remove a section of the chain link fence. The fence will be replaced immediately upon completion of the project. The new pumping well will be installed by Nothnagle Drilling, Inc. of Scottsville, NY. The installation of the well will be supervised by a qualified scientist from Matrix Environmental as directed by MACTEC Engineering.

The discharge piping for the new pumping well will be connected to existing piping located inside a nearby vault that was recently decommissioned in November 2009. Electric for operation of the pump will be pulled from the existing electrical panel located near PW11 and extend to the location of the new pump well. The existing totalizer and associated wiring from PW11 will also be utilized for the new well. In order to complete these connections it will be necessary to complete a shallow trench from the new pumping well to the location of the electrical and toatlizer associated with PW11. The trench and the valve box areas will be backfilled with native material and the surface will be restored to match existing surroundings. A concrete pad will be installed around the valve box for protection

This proposal includes a detailed time and materials "not to exceed" cost estimate attached for your review. Matrix Environmental's work on this project will be performed in a competent and professional manner consistent with standard industry practices and in accordance with the attached cost estimate and assumptions. Any change in scope will be invoiced according to the rates specified in this proposal as authorized by Arch. Payment terms are net 30 days following receipt of invoice.

Optional equipment for previous pump installlation by Matrix:

One (1) Grundfos model 10E11 electric submersible well pump with ¾ HP 230V/1P motor; 10 GPM at 60 PSI
One (1) 65’ length of tow wire TEFZEL motor lead
One (1) 65’ length of steel support cable
One (1) 65’ length of 1” discharge hose with cam lock fittings
One (1) 4” well cap
One (1) Warrick level probe assembly:

- Neutral level probe with 55’ of wire
- High level pump control with 55’ of wire - *discrete output*
- Low level pump control with 55’ of wire - *discrete output*
- High level alarm with 55’ of wire - *discrete output*

Control System Module:
RELAY Series Relay Logic based control panel with the following features:

- UL certification
- NEMA4 lockable panel enclosure
- Inner swing panel
- Primary circuit protection using external fused main disconnect
- Surge and lightning protection for control system
- Main power block
- Branch circuit protection with circuit breakers for motors
- Motor starters with overload protection
- Branch circuit protection with circuit breakers for powered devices
- Warrick pump controller
- Wired and factory tested prior to shipping

Outside cover of inner swing panel to contain the following:

- HOA switches with green run lights
- Red alarm indicator lights
- Alarm reset button
- Emergency stop button

Total Cost of Optional Equipment:	$ 9,900.00

NOTHNAGLE ***DRILLING, INC.***

1821 Scottsville-Mumford Road
Scottsville, New York 14546
(585) 538-2328
Fax (585) 538-2357

July 26, 2011

AMEC Environment & Infrastructure
511 Congress St.
Portland, ME 04101

RE: Drilling Services
Rochester, NY

ATTN: Mr. Brandon Newman

Contingency (@ 15 Percent)

Dear Brandon:

Below please find applicable unit costs to perform drilling services at the above referenced location.

	EST. QTY.	COST	UNIT	EST. EXTENSION
1. Mobilization & Demobilization	1	$500.00	Ea	$ 500.00
2. Crew Site Safety Training	1	$800.00	Day	800.00
3. Drill & Crew (8 hours on site)	5	$1,450.00	Day	7,250.00
4. 6" pipe installed	60	$26.00	Ft	1,560.00
5. Packer Equipment Rental	5	$150.00	Day	750.00
6. Temporary Decontamination Pad	1	$100.00	Ea	100.00
7. Steam Cleaner Rental	1	$250.00	Week	250.00
8. Portland Cement	15	$20.00	bag	300.00
9. 55 Gallon Drums	6	$45.00	Ea	270.00
10. 1000 Gallon Frac Tank Rental	1	$1,000.00	Wk.	1,000.00
	TOTAL ESTIMATED COST :			$ 12,780.00

We have assumed that all borings are accessible to a truck mounted drill rig. All waste generated during the project will be left neatly on site for disposal by others.

We appreciate the opportunity to submit this proposal.

Sincerely,

Timothy M. Nothnagle
President

NOTHNAGLE *DRILLING, INC.*
1821 Scottsville-Mumford Road
Scottsville, New York 14546
(585) 538-2328
Fax (585) 538-2357

August 3, 2011

AMEC Environment & Infrastructure
511 Congress St.
Portland, ME 04101

RE: Drilling Services
Rochester, NY

ATTN: Mr. Brandon Newman

Contingency (@ 15 Percent)

Dear Brandon:

Below please find applicable unit costs to perform drilling services at the above referenced location.

	EST. QTY.	COST	UNIT	EST. EXTENSION
1. Mobilization & Demobilization	1	$900.00	Ea	$ 900.00
2. Drill & Crew (8 hours on site)	9	$1,500.00	Day	13,500.00
3. Temporary 10" Casing	60	$15.00	Ft.	900.00
3. 6" Pipe Installed	66	$26.00	Ft	1,716.00
4. Locking Royer Cap	3	$45.00	Ea	135.00
5. Temporary Decontamination Pad	1	$150.00	Ea	150.00
6. Steam Cleaner Rental	9	$50.00	Day	450.00
7. Portland Cement	36	$20.00	Bag	720.00
8. 55 Gallon Drums	20	$45.00	Ea	900.00
		TOTAL ESTIMATED COST :		$ 19,371.00

We propose to drill with 10.25" hollow stem augers, set a temporary 10" casing, drill a 9 7/8" rock socket, and grout in permanent 6' casing. After grout set time a 5 7/8" rotary hole shall be advanced to total depth.

We have assumed that all wells are available to truck mounted equipment. All waste generated during the project will be left neatly on site for disposal by others.

We appreciate the opportunity to submit this proposal.

Sincerely,

Timothy M. Nothnagle
President

NOTHNAGLE ***DRILLING, INC.***
1821 Scottsville-Mumford Road
Scottsville, New York 14546
(585) 538-2328
Fax (585) 538-2357

August 4, 2011

AMEC Environment & Infrastructure
511 Congress St.
Portland, ME 04101

RE: Drilling Services
Rochester, NY

ATTN: Mr. Brandon Newman

Contingency (@ 15 Percent)

Dear Brandon:

Below please find applicable unit costs to perform drilling services at the above referenced location.

	EST. QTY.	**COST**	**UNIT**	**EST. EXTENSION**
1. Supply and install pump plumbing flow meter, and electric for pump test	2	$320.00	Ea	$ 640.00
2. Remove pump & plumbing after test	2	$320.00	Ea	640.00
3. Generator rental / 8 hour shift	6	$95.00	Shift	570.00
4. Labor to conduct pump test (24 hour)	48	$75.00	Hr.	3,600.00
		TOTAL ESTIMATED COST :		$ 5,450.00

All waste generated during the project will be left neatly on site for disposal by others.

We appreciate the opportunity to submit this proposal.

Sincerely,

Timothy M. Nothnagle
President