Draft
Remedy Optimization Team Report for the Bethpage Groundwater Plume Remedy

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EXECUTIVE SUMMARY

In order to evaluate the effectiveness of the on-going remedy for the Bethpage plume and recommend potential future steps for optimizing the remedy, the Navy requested an optimization review of the Bethpage plume remedy by a team of independent nationally-recognized experts in chlorinated solvent impacts to groundwater. As part of the review, this Technical Team recognized that many of the tools (e.g., tracer testing or solute transport modeling) used routinely at smaller sites are subject to considerable limitations at a particularly large and complex site, such as Bethpage. Therefore, the Technical Team has used its best scientific judgment and experience to provide strategic recommendations that identify technical areas to *avoid* and technical areas to *emphasize* in future efforts. The Technical Team has not attempted to pinpoint exact locations for additional monitoring wells/vertical profile borings or determine exact locations and pumping rates of new extraction wells. Rather, the Technical Team leaves it to the project representatives to determine efficient methods that accomplish the technical objectives and guidance provided by the Technical Team members.

The Technical Team's key conclusions and recommendations are summarized as follows:

1. The general strategy of on-site source containment and off-site plume monitoring has succeeded in reducing the impacts to down-gradient public supply wells. However, the hot spot in the Eastern Plume contains much higher volatile organic compound (VOC) concentrations than the rest of the off-site plume. This hot spot needs to be effectively contained to reduce future impacts to the down-gradient aquifer.
2. The Eastern Plume hot spot can be contained in one of two ways:
    a. Use new extraction wells upgradient of the Bethpage public supply wells to capture a substantial portion of the hot spot. In this strategy, the VOC impacts to the Bethpage supply wells will decrease over time, but low VOC levels are expected to persist in the near future (next 20 or 30 years) due to residual contamination in the aquifer matrix.
    b. Supplement the on-going capture in Bethpage public supply wells with new extraction wells (if required) that capture additional horizontal or vertical intervals to prevent the hot spot from migrating further down-gradient. This strategy has the potential to leverage existing infrastructure, for example, by operating the Bethpage supply wells at maximum capacity throughout the year. If this strategy is followed, then additional protective measures (such as including sufficient factors of safety in the treatment design) are necessary in the Bethpage public supply wells to ensure that impacted groundwater is treated at all times and does not leave the plant above levels that the water district considers safe.
3. The Technical Team agrees with the general assessment of the USGS's technical memorandum (Misut, 2010) and report (Misut, 2011) outlining the inadequacies of the current groundwater model for the site. The Technical Team adds that some of these modeling inadequacies can be addressed by improved modeling techniques, but some of the inadequacies are likely to remain inherent limitations of any modeling effort at this large and complex site. Capturing the variations in aquifer properties at a scale

conducive to reliable modeling predictions of plume arrival times and concentrations in public water supply wells will continue to be a challenge. However, a well-constructed and properly calibrated model is likely to be useful in addressing a number of important questions, including:

   a. Evaluation of the target capture zones of public supply wells that would enable decision makers to better locate outpost (sentry) wells and manage impacts to drinking water;

   b. Validation of capture by the extraction wells in the On-Site Containment System and Interim Remedial Measure to help determine effectiveness of source containment; and

   c. Design of alternatives for capturing the Eastern Plume hot spot to help protect down-gradient public supply wells.

4. The off-site monitoring network needs to be augmented with vertical profile borings and multi-level monitoring wells at selected locations) in order to:

   a. Better quantify hydrogeologic parameters critical for improved groundwater flow modeling and particle tracking through the collection and analysis of time dependent water level or pressure transducer data;

   b. Better evaluate the on-site containment of sources by the On-Site Containment System and the Interim Remedial Measure, especially in the deeper aquifer zones;

   c. Better evaluate contributions to the plume from other non-Navy, non-Northrop Grumman Corporation sources;

   d. Better understand the overall plume's eastern and western boundaries and its leading edge; and

   e. Better monitor the plume's progress beyond its current leading edge.

5. The Technical Team recommends that an evaluation be conducted of the technical and economic feasibility of plume containment at its leading edge and of other alternatives, such as the potential future installation of treatment plants in currently un-impacted public water supply wells.

6. A comprehensive conceptual site model needs to be developed based on an integrated analysis of all available Western Plume and Eastern Plume information, kept updated, and used as a dynamic tool to guide each successive monitoring, modeling, and treatment step.

ACRONYMS AND ABBREVIATIONS

DNAPL	dense non-aqueous phase liquid
NAVFAC	Naval Facilities Engineering Command
NRC	National Research Council
NWIRP	Naval Weapons Industrial Reserve Plant
NYSDEC	New York State Department of Environmental Conservation
ROD	Record of Decision
TCE	trichloroethene
U.S. EPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	volatile organic compound

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1.0 BACKGROUND

The Naval Facilities Engineering Command (NAVFAC) Headquarters and the NAVFAC Mid-Atlantic requested an independent technical optimization study of the groundwater remedy at the Former Naval Weapons Industrial Reserve Plant (NWIRP) and Former Northrop Grumman Corporation in Bethpage, New York. Groundwater at Bethpage is impacted by volatile organic compounds (VOCs), primarily trichloroethene (TCE). The impacted aquifer at this site has been commonly referred to as the Bethpage Plume. The Navy is committed to implementing a remedy that protects Long Island's drinking water supplies and continues to implement the Operable Unit 2 remedy in accordance with the signed Record of Decision (ROD) [1]. Northrop Grumman Corporation is managing Operable Unit 3, which includes the Eastern Plume and associated sources. Additionally, Northrop Grumman Corporation has prepared a computerized model of the impacted aquifer to aid in understanding groundwater flow and plume migration. Recently, concern was voiced by United States Senator Charles E. Schumer, based on input from Massapequa Water District, questioning the accuracy of the current groundwater model and the sufficiency of this remedy for protecting groundwater supply wells. Therefore, the Southeast Nassau Water Committee has requested the Navy to look further into these concerns.

In response, the Navy convened an Optimization Review of the Bethpage remedy and assembled a Technical Team of nationally-renowned experts in chlorinated solvent impacts to groundwater, VOC fate and transport, remediation technologies, groundwater modeling, and hydrogeology. The goal of this team is to provide an independent evaluation of the groundwater remedy at the Bethpage site and recommend potential steps to optimize the remedy's implementation. The team is charged with making recommendations to Navy leadership on how best to evaluate (a) the effectiveness of previous and ongoing treatments and (b) the effectiveness of the current well network in monitoring the progress of the plume. Appendix A lists the team members and brief descriptions of their professional experience. A separate and more thorough evaluation of the computerized groundwater model of the VOC-impacted aquifer was concurrently conducted by the United States Geological Survey (USGS) and U.S. Environmental Protection Agency (U.S. EPA), and the results were considered during the development of this report.

The Technical Team met for a site visit and discussions from February 8–10, 2011 in Bethpage, NY. Prior to the meeting, the team members reviewed key documents including, but not limited to, the ROD for Operable Unit 2, the Remedial Investigation and Feasibility Study for Operable Unit 3, Quarterly and Annual Monitoring Reports, documents relating to the On-Site Containment System and hot spot treatment at well GM-38, correspondence regarding the USGS/U.S. EPA task to review Northrop Grumman Corporation's computerized groundwater model, and the USGS report [2] on its findings from the model review. The Technical Team held weekly conference calls during January and early February 2011 to discuss initial findings and to begin development of preliminary recommendations.

The first day of the on-site February meeting was used for information sharing among all stakeholders. Therefore, in addition to the technical team members, participants also included representatives from New York State Department of Environmental Conservation (NYSDEC), U.S. EPA Region 2, Northrop Grumman Corporation and their consultants from Arcadis and EMAGIN, and NAVFAC Headquarters. In the morning, this group visited the Navy and Northrop Grumman Corporation properties, several of the water district supply wells and associated wellhead treatment systems, some of the outpost monitoring wells, the On-Site Containment System on Operable Unit 2 (the Western Groundwater Plume), the Interim Remedial Measure treatment system on Operable Unit 3 (the Eastern Groundwater Plume), and the GM-38 hot spot treatment system in the Eastern Groundwater Plume. In the afternoon, the Technical Team presented its progress to date. Then, Northrop Grumman Corporation and its consultants presented their conceptual understanding of the plume, data from the On-Site Containment System and Interim Remedial Measure systems, modeling strategy, and the Operable Unit 3 recommended remedy.

The Technical Team members met on the second and third days following the site visit to develop conclusions and discuss recommendations. Discussions focused on four main topics: 1) evaluation of the on-site remedy, 2) evaluation of the remedy for the off-site hot spot and plume, 3) evaluation of the effectiveness of the monitoring network for the off-site plume, and 4) role of groundwater models and modeling. The Technical Team convened again on a conference call on March 31, 2011 to discuss and finalize the draft report. This report presents general observations on the progress of the remedy to date (Section 2.0) and general conclusions and recommendations on a future strategy for managing the Bethpage Plume (Section 3.0). Then, the report discusses the four main topics related to the remedy. Appendix B provides supporting graphics.

2.0 GENERAL OBSERVATIONS ON PAST PROGRESS AT THE SITE

The Technical Team noted that this large and deep plume in a highly complex geologic setting has posed and will continue to pose relatively unique challenges for decision makers. Figure B-1 provides the general site layout at Bethpage such as locations of the Navy's and Northrop Grumman Corporation's former facilities as well as current remedy locations. Although the "Bethpage Plume" is often referred to as a single plume, there are multiple plumes and/or plume fingers due in part to the permeability contrasts resulting from heterogeneous geology involved (see conceptual depiction of a typical plume and plume fingers in attached Figure B-2). The Technical Team noted that the east-west geologic cross-section C-C' is strikingly similar to the dispersed plume concept presented in Figure B-2 (see geologic cross-sections shown in Figures B-3 to B-6). Instead of a single, contiguous plume, there are multiple widely dispersed plumes or fingers. If finer resolution (and adequate plume characterization) were possible, several more fingers might become apparent in these already dispersed plumes. Given the size and depth of the impacted aquifer, there are inherent limitations at this site in adequately delineating and managing the plume. These inherent limitations create uncertainties for any plume monitoring, modeling, or capture efforts, whether in the northern portion near source areas or in the southern portion near the leading edge. These limitations need to be taken into account in planning plume management strategies. Although there are other sites (e.g., Hill Air Force Base or Massachusetts Military Reservation) with relatively large VOC plumes, the unique combination of deep aquifer, large plume, geologic complexities, persistent dense non-aqueous phase liquid (DNAPL), multiple sources, and proximity to public water supply wells makes this site somewhat unique.

A National Research Council (NRC) classification of impacted groundwater sites based on difficulty of cleanup would place the Bethpage site in Category 4 [3]. Category 4 sites, which are characterized by the type of heterogeneous geologic layers and DNAPL sources present at Bethpage, are the most difficult to clean up. Of the 42 sites in this category that the NRC panel examined, none had been able to achieve cleanup goals (usually drinking water standards). A NRC panel also concluded that "typical methods used to calculate clean-up time often result in underestimates because they neglect processes that can add years, decades, or even centuries to cleanup" [4]. These challenges have since been reinforced by other researchers, the most recent being Payne et al. [5], who have described the inherent limitations of delineating heterogeneous sites and the consequent implications for monitoring, modeling, and managing groundwater plumes. The difficulties of gaining access to land, operating large drill rigs, and installing monitoring wells for recurring sampling in primarily residential areas are major challenges. The Technical Team is mindful of these challenges and acknowledges the difficulties they pose for any future strategy.

While discussing options for paths forward, the Technical Team took note of the progress that has been made in the past in managing this large Bethpage plume under complex hydrogeologic conditions.

- The Technical Team appreciated past efforts made by the Navy and Northrop Grumman Corporation to protect the public water supply systems. Useful measures taken so far include construction of the On-Site Containment System for the Western Plume and the Interim Remedial Measure for the Eastern Plume, the water treatment plants installed at public supply wells, and the significant monitoring efforts (especially more recent ones) involved in delineating the plume.

- The removal of 13,000 lb in 2009 (and 150,000 lb cumulative since 1998) of source VOC mass from the aquifer by the Western Plume On-Site Containment System is a significant achievement. Operation of this system has reduced the VOC mass loading to the down-gradient plume.
- Bethpage Water District responded and installed well-head treatment facilities at its Plants 4, 5, and 6 for the protection of public health.
- Outpost groundwater monitoring wells (warning wells or “sentry” wells) at both South Farmingdale Water District Plant 1 and Plant 3 served their purpose and provided sufficiently early warning of the approaching plume, enabling the water districts to plan for well-head treatment in advance of VOC impacts to public supply wells. This indicates that the outpost wells, although not foolproof, have succeeded in providing early warning in some cases.
- The Navy’s increased reliance on gathering and using intensive field data (instead of relying solely on modeling) to direct future activities has been valuable in navigating some of the complexities of the site (see Figures B-3 to B-6). Although this empirical process could be improved, the several detailed vertical profile borings conducted in the field have helped site representatives better identify and manage the heterogeneously distributed plume.
- The time-series graphs for monitoring wells and the geologic cross-sections constructed by both Tetra Tech (Navy’s contractor) and Arcadis (Northrop Grumman Corporation’s contractor) are useful representations of field data and contributed greatly to the Technical Team’s understanding and analysis of subsurface conditions and On-Site Containment System effectiveness.
- The recent and increasingly deeper vertical profile borings have greatly expanded the site decision-makers’ understanding of the nature and depth of the Lower Magothy and Upper Raritan formations. Clay layers in the Raritan formation are now understood to be deeper than previously thought in this region.

3.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS ON A FUTURE STRATEGY

After much discussion, the Technical Team arrived at several broad conclusions and recommendations that relate to the future approach at this site. Further discussion of these general conclusions can be found in Sections 4 to 7 of the report.

1) Although the hydrogeologic system on a regional scale (Long Island footprint) is relatively well understood and has been discussed in USGS publications, the complexities on a local scale (Bethpage Plume footprint or smaller) are not well characterized, have posed a challenge in the past, and could continue to pose a challenge in the future. Even at smaller sites, heterogeneous porosity and permeability distributions that drive plume migration are difficult to understand, despite extensive characterization. These difficulties are magnified at this site with its large and deep volume of impacted aquifer and complex geology. Variable hydrologic stresses, including changes in pumping rates of the supply wells over time, exert considerable influence on groundwater flow and plume migration and add complexity to the site. Therefore, estimating the velocity and strength of groundwater flow and plume migration will continue to be a challenge at the Bethpage site.
2) Given the relative proximity of Operable Unit 2 and Operable Unit 3 and the possible intermingling of the Eastern and Western Plumes down-gradient, a more technically integrated approach among various stakeholders for managing groundwater impacts in Operable Unit 2 and Operable Unit 3 could provide many advantages at this site. Plumes from neighboring sources, such as Hooker/RUCO and American Dry Cleaners could also possibly be mingling with the composite "Bethpage Plume" and should be taken into account in an overall strategy for the site (see Figure B-7). Some of these smaller plumes, such as the perchloroethylene plume (possibly from the American Dry Cleaners site), are apparent in geologic cross-section C-C' that slices through the composite Bethpage Plume and could have an impact on the public water supply wells. The Technical Team recommends that a comprehensive conceptual site model be described in a report for the entire site, including Western and Eastern plumes (and any other comingling plumes), and used as a dynamic tool for future decision making. As more vertical profile borings and monitoring wells are installed, the conceptual site model should be updated periodically.
3) There is a lack of plume delineation in certain areas and this increases the challenge of developing an integrated strategy. The plume currently is not well defined along its eastern and western boundaries, especially down-gradient of the On-Site Containment System (see Figures B-8 and B-9 for shallow and deep trichloroethene plumes). Better definition of the width of the plume immediately down-gradient of the Western Plume On-Site Containment System would provide better guidance for down-gradient plume management. On the southern boundary (near the leading edge of the plume), understanding of the plume has been growing due to the recent vertical profile borings that have been drilled into much deeper zones than in the past. The Navy appears to already have planned additional vertical profile borings near the leading edge of the plume in an effort to determine additional outpost well locations for South Farmingdale Water District Plants 3 and 6.

4) The Technical Team recommends more coordination of data collection and sharing among various stakeholders to improve information exchange and decision making. For example, site-wide standard operating procedures could be developed for common items, such as monitoring well installation. A site-wide sampling and analysis plan could be developed and utilized by both Navy and Northrop Grumman Corporation to standardize sampling procedures and, perhaps, to synchronize certain site-wide monitoring events (e.g., water levels). The influent VOC analysis data collected by the water districts should be communicated to Navy and Northrop Grumman Corporation on a regular basis, as soon as it is acquired.

Other recommendations that elaborate on these general conclusions are in the following sections.

4.0 EVALUATION OF THE ON-SITE REMEDY

The On-Site Containment System for the Western Plume and the Interim Remedial Measure for the Eastern Plume consists of five and four extraction wells, respectively and associated water treatment plants. The purpose of both systems is to prevent VOC-impacted water from leaving the source zone and migrating south in the direction of groundwater flow.

The Technical Team reviewed the available data on the performance of these containment systems and arrived at the following conclusions and recommendations.

1) Available down-gradient monitoring data show that the On-Site Containment System for the Western Plume is reducing plume concentrations. The reduction in concentrations in immediately down-gradient wells (including well GM-75) indicates that upgradient sources have been considerably contained by the On-Site Containment System. The Interim Remedial Measure for the Eastern Plume has only been operating since 2009 (with periodic shutdowns for maintenance), so it is too early to evaluate its performance.

2) Containment of on-site sources is a critical component of the remedy. Although the Technical Team recognizes that the On-Site Containment System and Interim Remedial Measure are removing considerable VOC mass, their performance in deeper portions of the aquifer has not been established. Elevated VOC levels have been found in recent vertical profile borings/wells (VPB-126, GM-34D, and GM-34D2) in deeper aquifer zones in the off-site plume. Although the On-Site Containment System and Interim Remedial Measure extraction wells probably draw water both horizontally and vertically from the surrounding aquifer (thus extending their capture to depths deeper than their screened intervals), additional performance monitoring in deeper portions of the aquifer (immediately down-gradient of the containment systems) is required to determine whether or not the Eastern and Western Plume sources are being adequately contained. Horizontally, the extent of both the plume and its capture along its western edge of the Western Plume and eastern boundary of the Eastern Plume should be better defined to improve identification of down-gradient plume monitoring needs.

   To better evaluate on-site containment, the Technical Team recommends additional studies to better define the capture zones for the extraction wells that constitute the On-Site Containment System and the Interim Remedial Measure. These studies should involve a combination of hydrogeologic measurements (e.g., water levels or pressure transducers in surrounding wells) and groundwater flow modeling. The U.S. EPA [6] published a detailed scientific protocol titled "A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems". The Technical Team recommends that the Navy and Northrop Grumman apply the principles in this document to better understand the performance of the source containment wells. While Northrop Grumman may, in fact, be following several or all of the systematic steps to evaluate capture described in the U.S. EPA report, incomplete reporting of the comparison of water level data and modeling calculations enabled only limited peer review of their work. Capture analysis methodology and validation of modeling results with field data must be documented more thoroughly. See also Recommendations 1 and 2 in Section 7 that describes the role of modeling.

The Technical Team also recommends additional multi-level monitoring points (clustered wells or multi-level monitoring wells) immediately down-gradient of the flow divides at the On-Site Containment System and Interim Remedial Measure to better evaluate effectiveness of containment, especially in the deeper zones in the aquifer (below 500 ft below ground surface). The objective of this program would be to verify that the on-site sources have been contained laterally and at all depths in the Magothy Aquifer. The recommended starting point for locating these monitoring points are computational tools developed for the Department of Defense that are designed to answer questions concerning the distance and time of stabilization at sites where the concentrations of VOCs leaving a source area are reduced through engineered remedial action. It was noted that one potentially important VOC mass transport process called matrix diffusion (transport of VOCs trapped in less-permeable silts and clays into more-permeable soils) may delay the development of a down-gradient "clean" front for several years as VOCs that have diffused into clay and silt layers slowly bleed out. Therefore, the data from these new monitoring points should be interpreted carefully.

3) Source remediation (aggressive in-situ treatment of DNAPL sources) above and beyond the On-Site Containment System in the Western Plume source areas is not recommended. Source reduction will not be sufficient to remove the need for the On-Site Containment System in the near term (within 30 to 50 years). In addition, there is considerable uncertainty pertaining to the location of DNAPL sources at Operable Unit 2. The Technical Team noted the continuously elevated concentrations in containment wells and the technical impracticability of source investigation and remediation due to buildings and urban infrastructure. Historical experience at other sites with infrastructure indicates that in-situ source reduction is rarely successful at restoring VOC source zones to pre-release conditions (drinking water levels) [4, 7, 8, and 9]. The inability to restore source zones is due to several factors, the most important of which is that an aquifer is a geologically complex (heterogeneous) matrix that a) traps and stores VOCs (via "sorption" and "matrix diffusion"); and b) prevents effective contact between VOCs and injected treatment chemicals or other groundwater treatment measures. Also, source reduction projects will have no effect on plume migration at the leading edge of the plume (where the plume is a result of dissolved VOCs that left the source as many as 60 to 70 years ago). Therefore, source reduction is unlikely to provide any additional benefit above that already provided by the source containment systems.

   Source reduction currently planned in the Operable Unit 3 Feasibility Study targets shallower sources in the vadose zone and the uppermost region of the saturated zone, where there is potential risk to on-site surface or near-surface activities, such as recreation or construction. For this reason, the limited source treatment planned in the Feasibility Study will provide on-site benefits and should be done. The proposed thermal treatment remedy is a technology with a reasonably good track record of success in environments with shallow impacts and limited infrastructure constraints. Historically, removal (treatment) of discrete and well-delineated VOC source mass from the subsurface has resulted in reduced VOC mass flux and mass discharge from the source zone to the groundwater plume. However, from a down-gradient plume management perspective, source reduction may not eliminate the need for the Interim Remedial Measure in the near term. As with many other sites, treating the DNAPL threshold concentrations (greater than 10,000 mg/kg in soil or 10,000 µg/L in water planned to be treated in the Feasibility Study) suggests that some source mass will remain once the thermal application is complete. The assumption that DNAPL sources have been well delineated has proved optimistic at many other sites and may be especially uncertain at this relatively complex site. Any remaining source mass, therefore, will necessitate source containment in the foreseeable future (next 30 to 50 years) in Operable Unit 3 as well.

4) The Western Plume On-Site Containment System well RW-19 is currently recovering substantial VOC mass and is still showing an increasing trend in VOC concentrations in the groundwater that is being extracted. Alternative 3 in the Operable Unit 3 Feasibility Study [10] suggests scaling back the extraction rate of this well, in conjunction with increased capture of the plume further down-gradient (in the proposed new well RW-21). The Technical Team recommends that the pumping rate of RW-19 not be reduced in the near term (next 5 or 10 years), unless concentrations in this well drop significantly. The substantial VOC mass recovery in RW-19 is a current certainty, whereas potential tradeoffs between a lowered pumping rate in RW-19 and higher pumping rate in RW-21 currently are less clear to the Technical Team.

5.0 EVALUATION OF REMEDY FOR OFF-SITE HOT SPOT AND PLUME

This section addresses the VOC plume beyond the property boundaries. Multiple sources have contributed to this composite plume and include the Operable Unit 2 source areas (resulting in the “Western Plume”), the Operable Unit 3 source areas (resulting in the “Eastern Plume”), and other assorted sources (see attached Figure B-7 that shows possible other CERCLA/RCRA sources that may be contributing to the composite plume). This makes tracking the plume and evaluating the off-site remedy very challenging. Some of these challenges and possible approaches for resolving them are presented in this section.

Within the composite plume, reference is made in this report to a “hot spot”, which is the portion of the Eastern Plume down-gradient of the Interim Remedial measure and upgradient of Bethpage Water District Plants 4, 5, and 6. This hot spot has elevated VOC levels, reaching more than 10,000 parts per billion (ppb) in some places (compared to a typical drinking water standard for key VOCs of 5 ppb).

The Technical Team’s conclusions and recommendations for the hot spot and plume are described below.

1) It will not be possible to reduce concentrations throughout the existing plume to drinking water levels within a short (20 to 30 years) time frame and prevent further impacts to public water supply wells in the region. The sheer size of the TCE plume footprint (approximately 2,350 acres based on the 5 microgram per liter concentration contour) renders complete aquifer cleanup unachievable within a reasonable timeframe, even with the benefit of unlimited economic resources. Experience at other sites shows that geologic heterogeneities, plume migration, and matrix diffusion are significant technical constraints that will likely make large-scale, rapid restoration of groundwater in the down-gradient plume to pre-plume conditions impossible (for example, see [9]). Therefore, impacts to public water supply wells are unavoidable.

2) The hot spot in the Eastern Plume is a relatively higher-concentration portion of the off-site plume that the Technical Team believes should be prevented from moving further south, as it represents substantially higher concentrations of VOCs than in the rest of the plume. Although any off-site treatment is likely to involve significant challenges, the Technical Team recommends substantial treatment or containment of this hot spot. Reduction in VOC mass discharge by at least 90% should be a functional goal of the hot spot containment. Mass discharge is the mass (in grams per day) of VOCs moving with groundwater through a vertical cross-section of the aquifer proximally upgradient of the Bethpage Water District Plants 4, 5, and 6 and spanning the Eastern Plume. This can be accomplished in one of two ways:

    a) Demonstrate in a detailed report that the proposed new extraction well (RW-21) or wells will substantially contain the Eastern Plume hot spot and reduce mass discharge across a vertical cross-section at this location by at least 90%. If the current solute transport model is employed for this task, the model must first be calibrated to historical plume concentration data (see Recommendation 5 in Section 7). An alternative and recommended approach is quantifying mass discharge reduction using a well-calibrated groundwater flow model and particle tracking to demonstrate that the capture zone would extend horizontally and vertically across the portion of a well-characterized plume cross-section that represents 90% of the mass discharge through this cross-section. This would require adequate delineation of the hydraulic flow parameters (gradient and permeability distribution) and plume concentrations in the vicinity of the new containment well with the help of existing and (if required) new multi-level monitoring wells and the public water supply wells. The report should clearly explain how the model was set up, which field measurements were used for calibration, which field measurements were used to define the plume horizontally and vertically, and the pumping scenarios and associated target capture zones. Once this strategy is implemented, the Technical Team recommends that an adaptive process be used on a regular basis (e.g., quarterly or annually) to recalibrate the model based on new monitoring data. Annual reports should include all monitoring data collected, as well as an update on any model recalibration (and associated changes to target capture zones).

b) Demonstrate in a detailed report that the existing Bethpage Water District Wells (Plants 4, 5, and 6) or some combination of the proposed new extraction well (RW-21) or wells and Plants 4, 5, and 6 would capture at least 90% of the VOC mass discharge from a vertical cross-section proximally upgradient of the three supply wells. As mentioned in the recommendation above, the report should utilize a combination of enhanced plume delineation, a well calibrated flow model, and particle tracking. All the modeling, reporting, and adaptive process recommendations in (a) apply to this approach, too. If this approach is used, the report should also describe steps that will be taken to install sufficient safeguards in Plants 4, 5, and 6 to prevent exposure of the receiving population. These safeguards should include adequate safety factors in the design of the wellhead treatment, as well as engineering controls to ensure that VOC-laden water does not leave the plants above levels that the water district considers safe. The annual report should include monthly VOC data and pumping rate information provided by Bethpage Water District. In general, through a combination of the On-Site Containment System, Interim Remedial Measure and Eastern Plume Hot Spot containment, the Team recommends that VOC mass discharge to the down-gradient plume be substantially reduced.

3) Ways to leverage existing treatment plant infrastructure should be carefully explored. Reducing the extraction rate of On-Site Containment System well RW-19 may not be the best way to achieve desired efficiencies. The pumping rates of any new extraction wells (e.g., RW-21), GM-38, and Bethpage Water District Plants 4, 5, and 6 wells could be leveraged to obtain optimum capture of the Eastern Plume and meet the goal of 90% reduction in mass discharge. For example, the technical merits of maintaining the pumping rate of Plants 4, 5, and 6 at summer (maximum) levels throughout the year should be evaluated, and the feasibility of this approach should be explored with the Bethpage Water District.

4) "Arrival time" hand calculations by the Technical Team provided an estimated plume velocity of 275 ft/yr. This estimate is based on the first arrival of the plume in 2009 in the Aqua New York supply well (approximately 3 miles from the suspected source areas and 60 to 70 years after the first reported operations that could have led to VOC releases in the source areas). Assuming that the plume progresses with this same flow rate

beyond its current leading edge, the plume could arrive in the Massapequa District wells in approximately 20 years. Assuming that uncertainties (and unknowns) in these rough calculations are of the order of a factor of 2, the plume could be approximated to arrive in Massapequa supply wells, potentially between 10 to 40 years. This calculation contains a large assumption – that the geology, hydraulic gradient, and physical stressors encountered by the plume in its future trajectory are the same (spatially and temporally) as those on the last 3 miles covered by the current plume. This assumption may not hold. The plume would have to bypass capture by Aqua and South Farmingdale Water District supply wells and the plume's VOC content at the current leading edge would have to be strong enough to sustain plume expansion over the next 2 or 3 miles for the plume to reach the next major group of wells. Rather, the objective of this hand calculation is to emphasize that, given the lack of monitoring data to the south of the Aqua and SFWD supply, more rigorous groundwater flow and particle tracking modeling is unlikely to provide considerably more reliable estimates of arrival times and concentrations (discussed further in Recommendation 6 of Section 7). South Farmingdale Water District Plants 3 and 6 are closer to the leading edge of the plume and were not part of this calculation. Whether or not or when the plume arrives at these South Farmingdale Water District wells depends on local heterogeneities on a scale that is still being mapped.

In summary, this hand calculation indicates that there is some possibility that the plume could reach Massapequa Water District supply wells sometime between the next 10 to 40 years. This possibility was a factor in the Technical Team's Recommendation 5 in this section (evaluation of the technical and economic merits of a containment system along the leading edge of the current plume and other alternatives) and in Recommendation 4 in Section 6 (additional outpost wells midway between the current edge of the plume and the Massapequa supply wells).

5) The Technical Team recommends an evaluation be conducted of the technical and economic feasibility of a containment and treatment system, in conjunction with existing public water supply wells, at the current leading edge of the plume to prevent further plume expansion and impacts to currently non-affected public water supply wells. The technical feasibility and cost of this containment system should be evaluated in relation to other alternatives, such as eventual installation of treatment plants in down-gradient (currently non-impacted) public water supply wells. The possibility of leveraging existing public water supply wells (e.g., Aqua New York and South Farmingdale Water District Plants 3 and 1) by operating them at full capacity year–round could be discussed with the water districts. Lower pumping rates in winter months may be one reason why the plume has evaded greater capture by the supply wells so far.

Because measures beyond the current plume containment are likely to be costly and ineffective, monitored natural attenuation has been proposed for the long-term management of the source areas and plume. Monitored natural attenuation is a remediation approach where naturally occurring processes are relied upon for long-term treatment of VOCs. However, there has been no focused analysis of the effectiveness of monitored natural attenuation at this site through analysis of relatively easily measured parameters, such as total organic carbon, redox conditions, and by-products generation. In general, several attenuating mechanisms are likely to impact VOC concentrations near the leading edge of the plume that may serve to limit or slow further southward progress of the plume. These attenuation mechanisms include capture by the public water supply wells, diffusion into clay lenses, biotic and abiotic degradation, dispersion, and sorption on organic carbon. At some point in the future, understanding the rate of attenuation of the VOCs in the leading edge of the plume is of interest. The progress of the plume beyond its current leading edge will be the net result of these natural attenuation processes. The Technical Team recommends additional study of natural attenuation processes at the leading edge of the plume.

6.0 EVALUATION OF EFFECTIVENESS OF MONITORING NETWORK FOR OFF-SITE PLUME

The monitoring network for the off-site plumes (Eastern and Western) covers an area approximately 3 miles long and 1.5 miles wide, down-gradient of the Operable Unit 2 and Operable Unit 3 sources. In this large area, the Technical Team evaluated the existing monitoring network within and near the plume boundaries, as well as the strategy for selecting outpost monitoring well locations and their screened intervals. Several conventional and innovative tools (such as geophysics, multi-level samplers, pressure transducers, etc.) were discussed for their potential applicability at this site. Although numerous monitoring wells and vertical profile borings have been installed in the last two decades within and near the boundaries of the plume, the large distances and depths involved are a challenge for effectively monitoring the progress of the plume.

The Technical Team's conclusions and recommendations are discussed below.

1) Although there are numerous monitoring points (vertical profile borings and monitoring wells) throughout the site, plume delineation is lacking along the western and eastern boundaries, especially in the northern half of the plume. Contribution to the Western Plume from the Hooker/RUCO Superfund site also is not well defined. Along the southern boundary, efforts seem to be underway to improve the definition of the leading edge of the plume. The further away from the source, the more difficult plume definition becomes, as the plume fingers become more isolated and dispersed. The outpost wells have served their purposes in some cases (South Farmingdale Plants 1 and 3), but not in others (Aqua New York), where the plume appears to have bypassed Bethpage Outpost Well (BPOW) 3-1 and 3-2, before being detected in the Aqua New York supply wells. A recent vertical profile boring (VPB-126) was installed specifically for determining why the Bethpage outpost wells did not identify the approaching plume. The data from this boring indicate the presence of a plume finger below the screened intervals of the outpost wells, indicating that the outpost wells were screened at depth intervals that did not anticipate this deeper plume finger (leading to a "vertical miss"). More recently, vertical profile borings have been drilled to greater depths and future outpost wells are expected to include screened intervals at greater depths, if required. Therefore, the enhanced vertical definition of the plume is expected to result in better performance of future outpost wells. The Technical Team recommends an evaluation of cost-effective methods for incorporating multiple sampling depths in future outpost wells. Westbay Packers® and a string of passive diffusion bag samplers were discussed as two possibilities (potentially more cost efficient than well clusters).

2) Hydrogeologic understanding of the site should be improved through coordinated data collection and analysis that includes the public water supply wells, On-Site Containment System wells, Interim Remedial Measure wells, vertical profile borings (current and planned), and monitoring wells (current and planned). Data collection from these sources should include geologic data (boring logs), hydrologic data (any historical pump test data, hydraulic gradient data), and chemistry data (both VOCs and native geochemical parameters). In particular, the use of pressure transducers in multi-level monitoring wells located near public water supply wells should be implemented to collect time dependent water level data during periods when pumping is either increased or decreased. A

coordinated data analysis effort (discussed further in Recommendations 1 and 2 of Section 7) is required to:

a) Improve the groundwater flow model. Hydrogeologic parameters critical for improved simulation of groundwater flow (transmissivity, vertical hydraulic conductivity and aquifer storage parameters) can be quantified using time dependent water level data. These data can also be used as a means of better quantifying horizontal and vertical gradients in the impacted aquifer.

b) Analyze the capture zones of public supply wells. The capture zones of the public supply wells are an important planning and decision-making tool but are not well understood. Groundwater flow modeling can be used in conjunction with hydrogeologic data to evaluate capture zones. Because of limited water level data in the vicinity of the public water supply wells and the leading edge of the plume, the existing groundwater flow model is only a suitable starting point. Recommendation 2a and the U.S. EPA (2008) scientific protocol for the evaluation of capture zones should be followed to improve capture zone analysis.

c) Appropriately locate outpost wells using the capture zone analysis performed as part of the above recommendation (6.2.b). A supply well's capture zone is an important component of determining the location of future outpost wells. Additional outpost monitoring wells should be planned for South Farmingdale Plant 6 and Plant 4 at locations indicated by the improved hydrogeologic analysis in Item 1 and improved understanding from the planned vertical profile borings in this area. Outpost wells installed in the future should incorporate sampling of permeable zones throughout the entire vertical section of the aquifer and not just the currently VOC-impacted zones.

3) Non-Navy, non-Northrop Grumman sources of the groundwater plume are located within and near the Bethpage plume boundaries. Monitoring of any shallow or deep plumes resulting from these sources and mingling with the composite Bethpage plume is necessary, so that outpost well locations and screened intervals can be appropriately designed. An additional monitoring well on the western edge of the plume immediately down-gradient of the Western Plume source zones should be considered as a means of evaluating possible VOC bypass around the Western Plume On-Site Containment system and/or contribution from the Hooker/RUCO plume. A similar well on the eastern boundary should be considered to evaluate potential bypass (or additional sources) around the Interim Remedial Measure wells.

4) At least three additional multi-level monitoring wells should be installed approximately midway between Massapequa supply wells and the currently identified leading edge of the plume, to serve as an additional indicator of plume migration. The Southern State Parkway may provide potential access for such wells, which would be installed across a transverse (approximately east-west) cross-section along the potential path of the plume. These wells would supplement other efforts to monitor plume migration towards the next major series of public water supply wells (Massapequa Water District). Given the rough approximation of estimated arrival times described in Section 5 (Item #4), the halfway point between the current leading edge of the plume and the Massapequa supply wells would represent a conservative 5-year travel window.

7.0 ROLE OF MODELS AND MODELING

A Northrop Grumman Corporation managed computerized groundwater flow and solute transport model has been used at Bethpage for over a decade to predict plume trajectory, arrival times, and concentrations. Due to concerns regarding the model's ability to predict arrival time at outpost and public water supply wells, the USGS and the U.S. EPA have a parallel effort under way to review the current model used at the site. As part of this model review, USGS has prepared a technical memorandum [11] and a report [2] containing its evaluation of the groundwater model, as described in relevant site reports [10, 12]. The USGS memo and report seek to provide an assessment of factors contributing to inaccurate predictions of arrival times, including:

1) Lack of adequate calibration of the flow and solute transport models;
2) Limited representation of aquifer heterogeneity; and
3) Absence of techniques to model changes in hydrologic stress over time (the current model assumes "steady state" groundwater flow conditions).

The Technical Team agrees with this general assessment and adds that some of these inadequacies could be addressed, but some may be inherent limitations of any modeling effort at this large and complex site.

The Technical Team's conclusions and recommendations on the modeling approach at the site are described below.

1) Groundwater flow models can usually be calibrated well enough in the field to determine groundwater (and plume) flow path or trajectory. Therefore, a well-calibrated flow model (or models) combined with best practices for modeling groundwater flow will serve as a valuable tool to address the following objectives:
    a) Determining the target capture zones of On-Site Containment System and Interim Remedial Measure wells, so that the effectiveness of source containment can be evaluated.
    b) Determining the target capture zone of any new extraction wells planned (e.g., RW-21 and the recently installed GM-38), so that the effectiveness of hot-spot treatment can be evaluated.
    c) Determining the target capture zones of public water supply wells, so that outpost sentry wells can be appropriately located and decision makers can better anticipate potential impacts to the supply wells.
2) To achieve all items in Recommendation 1 above, additional monitoring locations and innovative monitoring strategies (multi-level wells, pressure transducers, etc.) are recommended by the Technical Team in Sections 4, 5, and 6. These would improve the calibration and validation of the groundwater flow model particularly in the vicinity of the public water supply wells. The Technical Team was unclear from the site reports reviewed as to how much of the recently collected vertical profile boring information had been incorporated into the model. Recent vertical profile borings have been drilled

deeper than in the past and the resulting geologic data would be important to use in calibrating and validating the model.

3) The current steady-state modeling approach assumes that hydraulic "stresses" are constant (e.g., a model that assumes a single annual pumping rate for public water supply wells). The variability in pumping rates at the public water supply wells to meet demand will cause changes in the direction that VOCs migrate in the groundwater in the vicinity of the pumping wells. This variability must be accounted for to reduce the current uncertainty associated with flow model interpretations (i.e., capture zone analyses).

4) Several recent publications [5, 13, and 14] have emphasized the need to have realistic expectations about what solute transport modeling can and cannot do. These experts have asserted that small-scale heterogeneities that control the rate and extent of groundwater plume migration are extremely difficult to characterize in the field at sites associated with large plumes and/or relatively heterogeneous aquifers. In other words, the average permeability and average hydraulic gradient measurements collected at most field sites do not adequately capture the small-scale flow and plume migration factors that ultimately determine plume arrival times and concentrations. This is especially true at Bethpage, where the goal in the past has been to predict the first arrival of extremely low solute concentrations (0.5 ppb of total VOC) in distant wells (up to 3 miles distant from the source).

5) Calibrating the solute transport model to historical plume concentration data would improve confidence in the modeling results associated with the Operable Unit 3 feasibility study and could be one way of evaluating mass discharge (and mass discharge reduction from any Eastern Plume hot spot capture efforts). Modeling results were used to evaluate several strategies for the Eastern Plume [15]. However, the report indicates that the solute transport model was never evaluated relative to current site conditions. This is a fundamental step in any modeling investigation [16] to demonstrate the validity of the site model to simulate VOC concentrations in groundwater. However, given the limitations of adequately characterizing such a large and complex site, the resulting predictions of concentrations in capture wells and public water supply wells associated with the Eastern plume remedy may still have relatively low reliability (see also, Recommendation 4 in Section 5). As such, the Technical Team recommends an adaptive process used on an annual basis to recalibrate the model based on new monitoring data to reduce uncertainty and improve performance of the remedy.

6) Use of modeling to predict plume travel time and concentrations, especially beyond the leading edge of the plume (towards Massapequa wells), is not recommended. There are several reasons for this:

    a) The leading edge of the plume cannot be clearly defined in this large and complex aquifer (at a distance of 3 miles from the source, the "plume" probably is present in the form of several dispersed fingers).

    b) Data for calibrating the groundwater flow and solute models will always be limited, given the size of the plume. Particularly at this site, the scale of the desired modeling volume (several miles of a 700-ft deep aquifer) does not lend itself well to capturing the driving heterogeneities of the site and predicting the arrival of 0.5-ppb level trigger VOC concentrations. Even if the model is calibrated to the known extent of the current plume, it is unlikely that the geologic and hydrologic complexities beyond the current plume extent can be characterized and captured in a model well enough to provide an accurate prediction.

7) The use of a solute transport model for estimating cleanup times (e.g., due to pumping of RW-21 or GM-38) is not recommended, especially if the goal is to achieve extremely low target levels (0.5 ppb of total VOCs). A solute transport model is likely to provide optimistic estimates of cleanup time because: a) it does not entirely account for potential matrix diffusion effects, which become significant when VOC concentrations fall below approximately 100 ppb; and b) the factors described in Recommendation 4 above. More complex modeling approaches (such as a dual-domain modeling technique that has been recently employed at the site) might ameliorate some of the problems discussed in this section, but cleanup time and concentration predictions will still be uncertain.

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GLOSSARY OF TERMS

Conceptual Site Model (CSM) – a characterization, basic description or diagram of the key overall dynamics of a site which provide the necessary understanding of the site as a basis for remedial strategy development; the model identifies source and release information; contaminant distribution, transport, and fate; geologic and hydrogeologic information; and receptors, pathways, and other risk-related information.

Feasibility Study (FS) – (1) the analysis of a proposal's practicality, often of proposed cleanup alternatives for a specific site. A recommendation for a cost-effective alternative is commonly included. The FS is often begun jointly with the Remedial Investigation (RI), and they are often referred to jointly as the RI/FS; (2) a small-scale investigation to determine whether a proposed research approach is likely to provide useful data.

Heterogeneous – nonuniform, consisting of dissimilar items (geologic units).

Interim Remedial Action (IRA) – a response action under CERCLA to mitigate fire and safety hazards and to prevent further migration of the contaminant(s). It may be identified and implemented at any time during the study or design phase; limited in scope and addresses only areas or media for which a final remedy will be developed by the RI/FS process; should be consistent with the final remedy for a site.

Mass discharge – the total mass of any solute conveyed by a plume at a given location per time. Mass discharge is a scalar quantity, expressed as mass/time.

Matrix Diffusion – contaminant diffusion into and out of the aquifer matrix.

Monitored Natural Attenuation (MNA) – a remedial option that monitors the naturally occurring physical, chemical, and biological processes which reduce contaminant levels to effectively protect human health and the environment and ultimately achieves remedial goals within a time frame that is reasonable compared to alternative technologies, without human intervention.

Perchloroethylene (PCE) – chlorinated solvent used for a variety of operations such as degreasing, maintenance, and dry cleaning.

Record of Decision (ROD) – an official U.S. EPA final remedial action plan for a site or operable unit that records the decisions and rationales for selecting specific remediation processes for a contaminated site(s). An ROD summarizes the problems posed by the conditions at a site, the alternative remedies considered for addressing those problems, the comparative analysis of those alternatives against nine evaluation criteria, and the selected remedy and rationale for selection.

Sampling and Analysis Plan (SAP) – a document that combines a field sampling plan and a quality assurance protection plan.

Solute Transport Model – a numerical model which simulates contaminant fate and transport.

Sorption – (1) the process whereby dissolved contaminants partition to the solid matrix (i.e., soil, rock) in contact with the groundwater, resulting in the slowing (retardation) of the contaminant movement relative to the rate of groundwater flow; (2) a general term used to encompass the processes of adsorption, absorption, desorption, ion exchange, ion exclusion, ion retardation, chemisorption, and dialysis; (3) the slowing or attenuation of a moving contaminant plume due to sorption onto soil solids.

Steady State Groundwater Flow Model – a numerical model which solves the governing groundwater flow equation typically using a finite element approach and site specific boundary conditions. A steady state groundwater model is used to analyze sites where the flow field is independent of time.

Transient Groundwater Flow Model a numerical model which solves the governing groundwater flow equation typically using a finite element approach and site specific boundary conditions. A transient groundwater model is used to analyze time-dependent situations.

Trichloroethene (TCE) – chlorinated solvent used for a variety of operations such as degreasing, maintenance, and dry cleaning.

Volatile Organic Compound (VOC) – an organic compound that is best identified and quantified by using U.S. EPA SW-846 Method 8260B.

Appendix A

Technical Team Member Curriculum Vitae

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Naval Facilities Engineering Service Center
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EDUCATION
B.E., Vanderbilt University, Civil and Environmental Engineering, 1992
M.B.A., Graziadio School of Business and Management, Pepperdine University, 2001

RELEVANT PROFESSIONAL EXPERIENCE

2010 - Current. Head, Environmental Restoration Technology Applications Branch, Naval Facilities Engineering Service Center (NAVFAC ESC), Port Hueneme, CA

- Oversee ten engineers, geologists, and biologists to provide assistance to remedial project managers across NAVFAC with technical challenges, disseminate information on innovative technologies, and optimize planned and existing remedies.
- Principle Investigator for an ESTCP project on Quantifying Life Cycle Environmental Footprints of Soil and Groundwater Remedies.
- Member of the Federal Remediation Technologies Roundtable.

2003-2010. Team Lead, Environmental Restoration Technology Transfer, NAVFAC ESC

- Facilitated clean-up review teams and conducted optimization evaluations for over 15 sites.
- Developed NAVFAC's strategic plan to overcome barriers to the use innovative environmental remediation technologies.
- Led the NAVFAC Optimization Workgroup and Alternative Restoration Technology Team (ARTT). These teams are responsible for developing guidance, tools, and case studies on optimizing remedial actions and innovative technologies.
- Principal Investigator for two ESTCP projects. One project to demonstrate software for improving effectiveness of long term monitoring programs. The other project to assess the benefits of using computer algorithms for optimizing groundwater flow and transport models.
- Active team member with the Interstate Regulatory Technology Council (ITRC) Remedial Process Optimization (RPO) and Remedial Risk Management (RRM) teams.

2001-2003. Team Lead, Environmental Acquisitions, NAVFAC ESC. Led a 5-member team in contracting for $10M per year in environmental services for the Environmental Restoration Division.

1994-2001. Environmental Engineer, NAVFAC ESC. Coordinated pilot demonstrations and technical evaluations of innovative environmental technologies. Resolved concerns of community members, Navy project managers, and federal and state regulators.

SELECT CONFERENCE PAPERS / PRESENTATIONS
Harre, K. and Chaudhry, T. Optimizing Remedial Action Operations and Long Term Management Programs, *Navy CECOS Course on Optimizing Remedy Selection and Site Closeout, 2003 – Present.*

Harre, K. et al. Adaptive Long-Term Monitoring at Environmental Restoration Sites - LTM Optimization Workshop, *Partners In Environmental Technology Technical Symposium and Workshop, December 2009.*

Greenwald, R., Y. Zhang, K. Harre, L. Yeh, K. Yager, D. Becker, B. Minsker, C. Zheng, and R. Peralta. Results of Transport Optimization Demonstration Project for Three DoD Sites. *2003 MODFLOW and More: Understanding through Modeling, Golden, Colorado, September 2003.*

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EDUCATION

BS, Chemical Engineering, 1984
MS, Environmental Science/Technology, 1986

RELEVANT PROFESSIONAL EXPERIENCE

25 years of experience in soil and groundwater remediation with particular expertise in DNAPL and chlorinated solvent plumes, an area in which Mr. Gavaskar has led several large cleanup and innovative technology demonstration projects, authored several publications, and served on expert panels at high-profile sites, such as Hill Air Force Base, Kelly Air Force Base, and former Naval Air Station Brunswick

2008 – Current. Head, Technology Applications Branch, Environmental Restoration Department, Naval Facilities Engineering Command Atlantic, Norfolk, VA

- Supervise technical support to Navy's field engineering commands in continental U.S.
- Provided technical and regulatory expertise at over 60 CERCLA and RCRA sites across the country on issues, with particular expertise in DNAPL/chlorinated solvent contamination
- Member of Interstate Technologies Regulatory Commission's (ITRC) Permeable Barriers Workgroup. Authored section on longevity of permeable barriers in ITRC's 2011 guidance.

1985-2008. Associate Manager, Environmental Restoration Product Line, Battelle, Columbus, OH.

- Supervised a staff of 30 engineers, geologists, and chemists involved in environmental restoration support to the US EPA, Army, Navy, Air Force, NASA, DOE, and private industries.
- Project manager for several large soil, groundwater, and sediment remediation projects at sites, such as NWS Seal Beach, Cape Canaveral Air Station, and Dover Air Force Base.
- Chaired the International Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, CA) in 2000, 2002, and 2004.

AWARDS

- NAVFAC Atlantic's Employee of the Year 2010 award at the ER Conference, Oxnard, CA.
- NASA's Honor Award 2003 for Groundwater Treatment Technology Development.
- US EPA's STAR Award, 1996 for the antifreeze recovery technology development project.

SELECTED PUBLICATIONS

Hood, E., D. Major, J. Quinn, W-S. Yoon, A. Gavaskar, and E.Edwards. 2008. Demonstration of Enhanced Bioremediation in a TCE Source Area at Launch Complex 34, Cape Canaveral Air Force Station. *Ground Water Monitoring & Remediation* 28(2):98–107.

Gavaskar, A.R 1999. "Design and Construction Techniques for Permeable Reactive Barriers". *Journal of Hazardous Materials*, 68 (1999) 41-71.

RICHARD W. HUMANN, P.E., V.P.

EDUCATION

- B.S., Mechanical Engineering, New York Institute of Technology, 1991
- Certificate in Technical Writing, New York Institute of Technology
- Trained in Dynflow, Dyntrack and Dynplot groundwater modeling software, 2002

RELEVANT PROFESSIONAL EXPERIENCE

- Chief Water Resources Engineer for H2M (employed for 23 years) and responsible for managing the water resources division. Client manager for several of H2M's water supply clients, including the Bethpage Water District. Duties include water system and aquifer evaluation, planning and studies, design of source supply and treatment systems, and assessment of groundwater quality for drinking water.
- Extensive experience in hydrogeology, groundwater and aquifer assessments, water quality and regulatory requirements including:

  o VOC Removal Systems: Treatment system designs for public water supplies of Bethpage, Dix Hills, Garden City, Garden City Park, Greenlawn, Hicksville, Plainview, South Farmingdale, South Huntington and West Hempstead. Responsibilities included groundwater and aquifer contamination assessments, review of available remedial engineering studies, reports, and plans, engineering report preparation, treatment system design, and regulatory permits.

  o Groundwater Modeling: Managed several groundwater modeling projects, including evaluation of new well locations and evaluation of groundwater contamination plumes impacting public supply wells in Bethpage, Garden City, Hicksville, Manhasset-Lakeville, Plainview and South Farmingdale.

PROFESSIONAL ASSOCATIONS and CERTIFICATIONS

- Licensed Professional Engineer: New York (1998), New Jersey (2000)
- American Consulting Engineers Counsel, National Society of Professional Engineers
- American Society of Civil Engineers, American Society of Heating, Refrigeration and Air Conditioning Engineers
- American Society of Mechanical Engineers
- American Water Works Association (AWWA), New York Section Program Committee Member
- Long Island Water Conference, Drinking Water Standards and Comprehensive Planning Committee Member
- National Groundwater Association

AUTHORED PRESENTATIONS

- "Dealing with Groundwater Plumes – What to Know", presented to the Edwin C. Tifft, Jr. Water Supply Symposium, New York State Section AWWA, November 2008
- "Water Treatment System O&M – Lessons Learned", presented to the New York State Section AWWA, April 2008
- "Pilot Program for Nitrate Treatment Technology", presented to the New York State Section AWWA April 2007
- "Water Supplies Collaborate to Investigate Perchlorate Treatment", presented to the New York State Section AWWA, April 2006
- "Approaches for Treatment of MTBE Groundwater Contamination", presented to the New York State Section AWWA, April 2004
- "UV Disinfection of Groundwater Supplies", presented to the Long Island Water Conference, December 2002
- "Optimizing Treatment Efficiencies of VOC Treatment Systems", presented to the New York State Section AWWA, October 2001

EXPERT TESTIMONY

- Index No. 9975/01 – Supreme Court – State of New York, Plainview Water District, Plaintiff vs. Exxon Mobil Corporation, f/k/a Exxon Corporation,…, Defendants – 2007
- Case No. 07-cv-5244 – United States District Court – Eastern District of New York, Inc. Village of Garden City, Plaintiff vs. Genesco, Inc., and Gordon-Atlantic Corp., Defendants – USEPA Superfund Site 150 Fulton Avenue, Garden City Park,

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EDUCATION

B.S., Cornell University, Philosophy and Mathematics, 1988
M.S., SUNY Stony Brook, Earth and Space Sciences, 1991
M.E., Cooper Union, Civil Engineering, 1995

RELEVANT PROFESSIONAL EXPERIENCE

DATES: From: 02/2008 To:10/2013
PROJECT TITLE: Estimation of Hydraulic Properties at Well Fields, Suffolk County, N.Y.
BACKGROUND: Suffolk County Water Authority supplies ground water to over 1 million people on Long Island. Improved understanding aquifer hydraulics near wellfields benefits supply management.
RESULTS: A scientifc investigations report documented one of the aquifer tests conducted during this study; other tests were placed in an aquifer test archive. This project is described further at http://ny.cf.er.usgs.gov/nyprojectsearch/projects/2457-BEE00.html

DATES: From: 10/2009 To:10/2010
PROJECT TITLE: Evaluation of Manufactured Gas Plants, Suffolk County, N.Y.
BACKGROUND: A massive manufactured gas plant in Bayshore, New York was being remediated with oxygen injection. The local department of health voiced concerns about the saftey of these operations.
RESULTS: For the first time in North America, OxyPAHs were established in groundwater samples. The USGS toxic substances hydrology program provided funding to present these results at a national conference. This project is described further at http://ny.cf.er.usgs.gov/nyprojectsearch/projects/2457-BEE00.html

DATES: From: 02/2001 To: present
PROJECT TITLE: Simulation of Ground-Water Flow and Chemistry to Evaluate Water-Management Alternatives in Kings and Queens Counties, New York
BACKGROUND: New York City experiences exceptional problems of water supply to its 8 million people, most living on islands. Water is mainly sourced from upstate reservoirs; however, novel approaches to integration with groundwater resources are treated in this project with complex research methods. Methods included application of coupled geochemical/ solute transport modeling to evaluate feasibility of storage and recovery in a previously-unexplored deep aquifer. Deep cores were obtained and subject to mineralogical and and microbiological analysis.
RESULTS: Highly controversial and novel results were nationally publicized in *The New York Times.* This project is described further at http://ny.cf.er.usgs.gov/nyprojectsearch/projects/2457-A3K-2.html

DATES: From: 02/2009 To:10/2011
PROJECT TITLE: Simulation of saltwater intrusion, Manhasset Neck, Nassau County, N.Y.
BACKGROUND: The Manhasset Neck Peninsula has experienced intrusion of salt water. New modeling techniques were applied to predict future salt water intrusion.
RESULTS: Acceptable saltwater intrusion predictions were generated for a highly complex site which was previously unyielding.This project is described further at http://ny.cf.er.usgs.gov/nyprojectsearch/projects/2457-BEE00.html

SELECT CONFERENCE PAPERS / PRESENTATIONS

Misut, P.E., and Feldman, S., 1995, Simulation of sources of water to wells in central Suffolk County, N.Y., USGS OFR 95-703.

Misut, P.E., and Busciolano, R., 2010, Hydraulic Properties of the Magothy and Upper Glacial Aquifers at Centereach, Suffolk County, New York, USGS SIR 2009-5190, 22p.

Yager, R.M., Misut, P.E., Langevin, C.D., and Parkhurst, D.L., 2009, Brine migration from a flooded salt mine in the Genesee Valley, Livingston County, New York: Geochemical modeling and simulation of variable-density flow: U.S. Geological Survey Professional Paper 1767, 59 p.

Misut, P.E. and Voss, C.I., 2007, Freshwater-saltwater transition zone movement during aquifer storage and recovery cycles in Brooklyn and Queens, New York City, USA: Journal of Hydrology.

Misut, P.E., and Brown, C.J., 1996, Solute transport along ground-water flowpaths near the Nassau/Suffolk County border, Long Island, New York, in “Hydrology and Hydrogeology of Urban and Urbanizing Areas, AIH.

Charles J. Newell, Ph.D., P.E., BCEE

GSI Environmental Inc.

2211 Norfolk, Suite 1000, Houston, TX 77098; Phone: (713) 522-6300; Fax: (713) 522-8010; Email: cjnewell@gsi-net.com

Education

Ph.D., Environmental Engineering, Rice University, Houston, Texas, 1989.

M.S., Environmental Engineering, Rice University, Houston, Texas, 1981.

B.S., Chemical Engineering, Rice University, Houston, Texas, 1978.

Professional Background

Vice President - Environmental Engineer, GSI Environmental Inc., Houston, Texas. 1989 – present.

Adjunct Professor of Environmental Science and Engineering, Rice University. 1993 – present.

Office Manager-Project Engineer, F. X. Browne Associates, Kansas City. 1980 – 1984.

Selected Professional Affiliations / Awards

American Academy of Environmental Engineers.

Certified Ground Water Professional, Association of Ground Water Scientists and Engineers.

2001 Wesley W. Horner Award, American Society of Civil Engineers (awarded for paper in ASCE journal).

Hanson Excellence of Presentation Award, American Association of Petroleum Geologists, 1996

Outstanding Presentation Award, American Institute of Chemical Engineers, June 1994, Denver, Colorado.

2008 Outstanding Engineering Alumni Award, Rice University.

Areas of Expertise

Site characterization, groundwater modeling, groundwater vulnerability, surface water impacts, non-aqueous phase liquids, risk assessment, natural attenuation, remediation performance, bioremediation, matrix diffusion, non-point source studies, environmental software development, environmental decision making, and long-term monitoring optimization.

Selected Publications

Bedient, P. B., H.S. Rifai, C.J. Newell, 1999. Groundwater Contamination: Transport and Remediation, 2nd Edition, Prentice-Hall, 1999.

McGuire, T.M., J.M. McDade, and C.J. Newell, 2006. "Performance of DNAPL Source Depletion Technologies at 59 Chlorinated Solvent-Impact Sites", Ground Water Monitoring and Remediation, Vol 26, No. 1, pg 73-84.

Newell, C.J., and R.R. Ross, 1992. *Estimating Potential for Occurrence of DNAPL at Superfund Sites*, U.S. Environmental Protection Agency, R.S. Kerr Environmental Research Laboratory, January 1992.

Newell, C.J., H.S. Rifai, J.T. Wilson, J.A. Connor, and J.J. Aziz, M.P. Suarez, 2002. *Calculation and Use of First-Order Rate Constants For Monitored Natural Attenuation Studies*, U.S. EPA Remedial Technology Fact Sheet, U.S. Environmental Protection Agency. EPA/540/S-02/500, Nov. 2002.

Newell, C.J. and C.E. Aziz, 2004. "Long-Term Sustainability of Reductive Dechlorination Reactions at Chlorinated Solvents Sites", Biodegradation, 15: 387-394, 2003.

U.S. Environmental Protection Agency; 2003. *The DNAPL Remediation Challenge: Is There a Case for Source Depletion?* National Risk Mgt. Research Laboratory, Ada, OK, EPA/600/R-03/143, Dec. 2003.

Wiedemeier, T.H., Rifai, H.S., Newell, C.J., and Wilson, J.W., 1999. Natural Attenuation of Fuels and Chlorinated Solvents, John Wiley & Sons, New York

Other Information

Selected by Federal Judge (Judge Marcia Crone, U.S. District Court for Eastern District of Texas) as the Court's independent expert for groundwater litigation matter (Lyondell Chemical Co. v. Occidental Chemical Corp).

Principal Investigator or Co-Principal Investigator for 45 research/development/tech transfer projects for Dept. of Energy, Dept. of Defense, U.S. EPA, and others. Cumulative funding: $12 million.

Project coordinator for two multi-party projects: Galveston Bay Estuary Program Mgt. Plan & Los Angles LNAPL Workgroup.

Author/co-author of 15 peer-reviewed articles, 9 environmental software tools, 2 patents, 5 US EPA publications, and 2 books.

Heather Veith Rectanus, Ph.D.
Principal Research Scientist
Battelle

Education

Ph.D. Civil Engineering, Geoenvironmental Emphasis, Virginia Tech, October 2006
Co-Advisors: John T. Novak and Mark A. Widdowson
M.S. Civil Engineering, Geoenvironmental Track, Virginia Tech, Dec 2000
Co-Advisors: John T. Novak and Mark A. Widdowson
B.S. Nuclear Engineering and **B.A. German,** Kansas State University, May 1998

Professional Experience and Qualifications

Ten (10) years experience in environmental research and development projects for government and industrial clients specializing in bioremediation and monitored natural attenuation remedial strategies at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Underground Storage Tank (UST) hazardous waste sites.

Co-chair for the Tenth International In Situ and On-Site Bioremediation Symposium (May 2009).

Remediation Innovative Technology Seminars (RITS)

- Manages task orders (TO) for outreach support and development of Environmental Restoration technology transfer efforts in concert with NAVFAC ESC. Task orders exceed $1.8M across three sets of seminar series.

Clean Up Review Teams (CURTs)

- Managed CURT for MCAS Cherry Point OU1 Chlorinated Solvent Plume to identify additional site characterization data and evaluate technologies for addressing a chlorinated solvent groundwater plume over a mile long.
- Managed CURT for the evaluation of treatment options to address 1,4-dioxane in the 100 ppb range as well as volatile organic compounds in the Eastern Groundwater Plume at Naval Air Station Brunswick, Maine.

Sustainability of reductive dechlorination at chlorinated solvent contaminated sites: Methods to evaluate biodegradable natural organic carbon

- Developed and validated a method to estimate the potentially bioavailable organic carbon in sediments as Ph.D. Research Assistant at Virginia Tech under ER-1349
- Developed and maintained anaerobic consortium for bioaugmentation of laboratory scale microcosms to monitor organic carbon utilization and reductive dechlorination

Fellowships

Graduate Assistance in Areas of National Need (GAANN) Fellowship for Biogeochemistry, 2002-2004
National Science Foundation Fellowship, 1998-2001

Selected Presentations and Publications

Rectanus, H.V., C.A. Kelly, M.A. Widdowson, J.T. Novak and F.H. Chapelle. "Evaluation of potentially bioavailable organic carbon at a chloroethene-contaminated site." Remediation of Chlorinated and Recalcitrant Compounds, May 19-22, 2008, Monterey, CA.

Rectanus, H.V., Widdowson, M.W., Chapelle, F.H., Kelley, C.A., and J.T. Novak. 2007. Investigation of Reductive Dechlorination Supported by Natural Organic Carbon. Groundwater Monitoring and Review. 27: 53-62.

H.V. Rectanus, C.A. Kelly, M.A. Widdowson, J.T. Novak and F.H. Chapelle. "Application of Potentially Bioavailable Organic Carbon at Active Reductive Dechlorination Sites" Oral presentation, Ninth International In Situ and On-Site Bioremediation, May 2007, Baltimore, MD.

H.V. Rectanus, M.A. Widdowson, J.T. Novak and F.H. Chapelle. "Method Development for Quantifying Bioavailable Organic Carbon in Aquifer Sediments." Poster presentation, Eighth International In Situ and On-Site Bioremediation, June 2005, Baltimore, MD.

M.A. Widdowson, F. H. Chapelle, **H.V. Rectanus**, and J.S. Brauner. "Relationship Between NAPL Mass and Remediation Time Using Monitored Natural Attenuation." First International Congress on Petroleum Contaminated Soils, Sediments & Water, August 2001, London, England.

Mark A. Widdowson

EDUCATION

Ph.D., Civil Engineering, Auburn University, 1987.
MS, Water Resources Engineering, University of Kansas, 1984.
BSCE, Civil Engineering, University of Cincinnati, 1982.

PROFESSIONAL EXPERIENCE

The Charles E. Via, Jr. Department of Civil & Environmental Engineering, Virginia Tech

- Professor of Civil Engineering, Virginia Tech, 2004 - present
- Assistant Department Head, , 2009 - present
- Coordinator, Environmental & Water Resources Engineering Graduate Program, 2004 - 2008
- Associate Professor of Civil Engineering (with tenure), Virginia Tech, 1993 – 2004

Professional Engineer Registration, #14257, South Carolina, 1991.
Assistant Professor, Department of Civil Engineering, University of South Carolina, 1988-92.
Post-Doctoral Fellow/Instructor, Department of Civil Engineering, Auburn University, 1988.

PROFESSIONAL ACTIVITIES, HONORS AND NOTABLE RECOGNITIONS

American Society of Civil Engineers; National Ground Water Association
Samuel Arnold Greeley Award, ASCE, 2011
College of Engineering Teaching Award, Virginia Tech, 2011
Outstanding Civil Engineering Faculty, ASCE Student Chapter, 1996
Graduate Summer Fellowship, University of Kansas, 1983

PATENTS AND SOFTWARE PUBLISHED

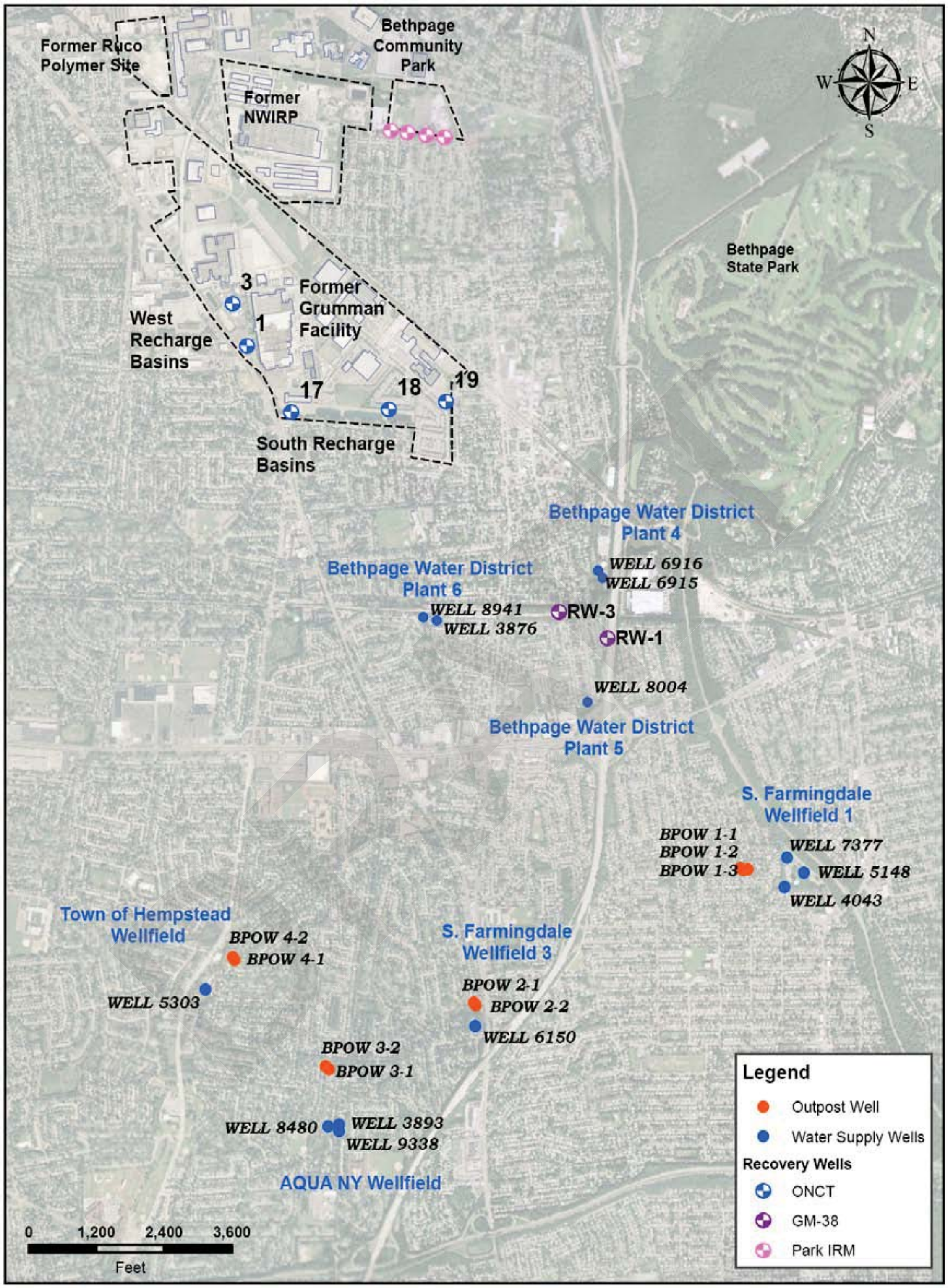
NAS: Natural Attenuation Software, 2002.
SEAM3D: Sequential Electron Acceptor Model for 3D Transport, 2000.
U.S. Patent No. 5,293,931, "Modular Multi-Level Sampling Device", 1994.

SELECTED PUBLICATIONS

1. Parker, J.C, Kim, U., Widdowson, M., Kitanidis, P., and Gentry, R. "Effects of model formulation and calibration data on uncertainty in predictions of DNAPL source dissolution rate", *Water Resources Research*, in press.
2. Chaplin, B.P., Schnobrich, M.R., Widdowson, M.A., Semmens, M.J., and Novak, P.J. "Stimulating in situ hydrogenotrophic denitrification with membrane-delivered hydrogen under passive and pumped groundwater conditions", *ASCE Journal of Environmental Engineering* 135(8), 666-676, 2009.
3. Rectanus, H.V., M. Widdowson, F. Chapelle, C. Kelly, and J. Novak. "Investigation of reductive dechlorination supported by natural organic carbon", *Ground Water Monitoring and Remediation*, 27(4), 53-62, 2007.
4. Chapelle, F.H., J.T. Novak, J.C. Parker, B.B. Campbell and M.A. Widdowson. "A framework for assessing the sustainability of monitored natural attenuation", accepted for publication by the U.S. Geological Survey Circular Series, C-1303, 2007.
5. Widdowson, M.A., S. Shearer, R. Andersen, J.T. Novak. "Remediation of polycyclic aromatic hydrocarbon compounds in groundwater using poplar trees", *Environmental Science and Technology*, 39(6), 1598-1605, 2004.
6. Widdowson, M.A. "Modeling natural attenuation of chlorinated ethenes under spatially-varying redox conditions". *Biodegradation*, 15, 435-451, 2004.
7. Waddill, D.W. and M.A. Widdowson. "A three-dimensional model for subsurface transport and biodegradation", *ASCE J. of Environmental Engineering*, 124(4), 336-344, 1998.

Appendix B

Figures



General site layout at Bethpage such as locations of the Navy's and Northrop Grumman Corporation's former facilities as well as current remedy locations (Source: Northrop Grumman Optimization Presentation, February 8, 2010).

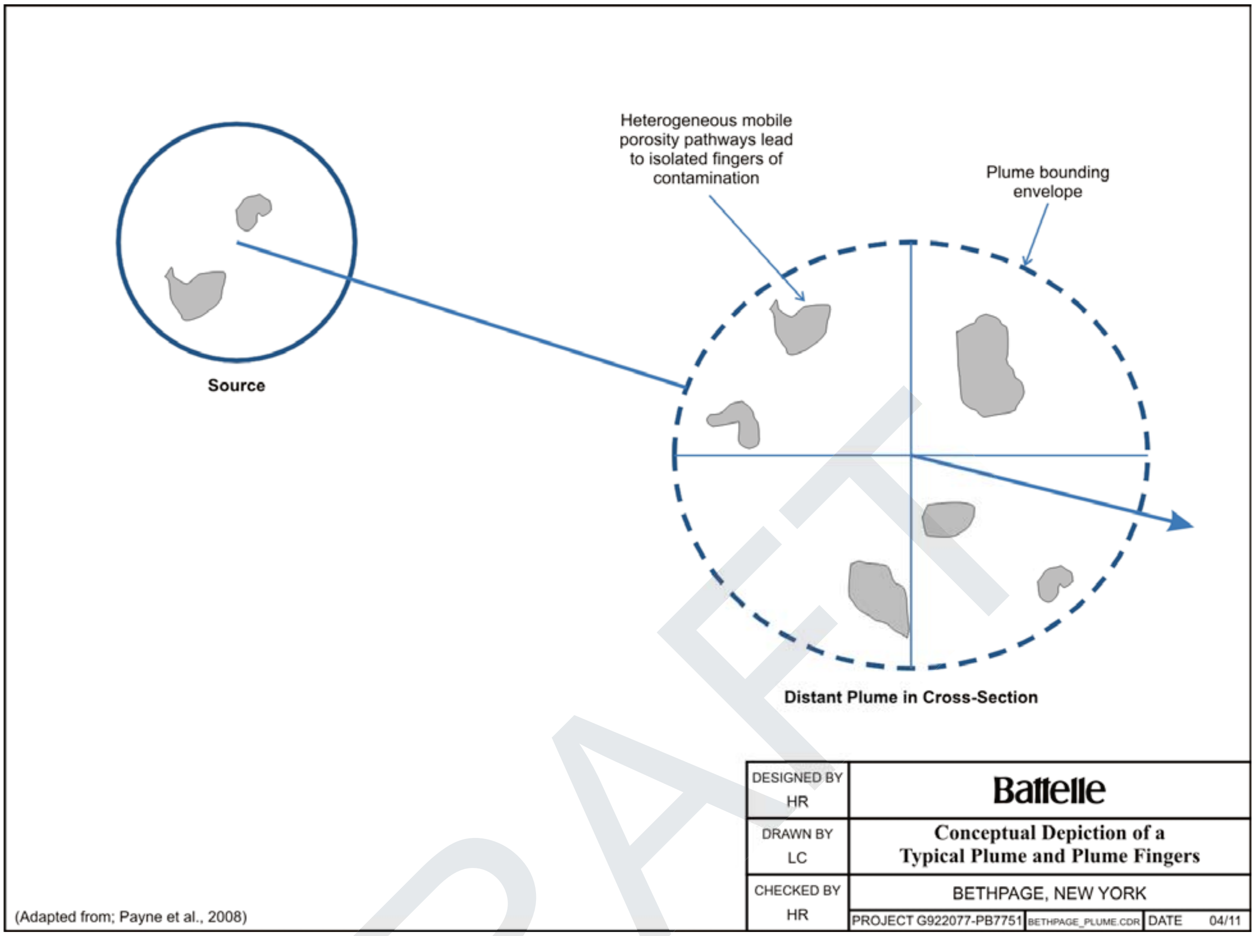
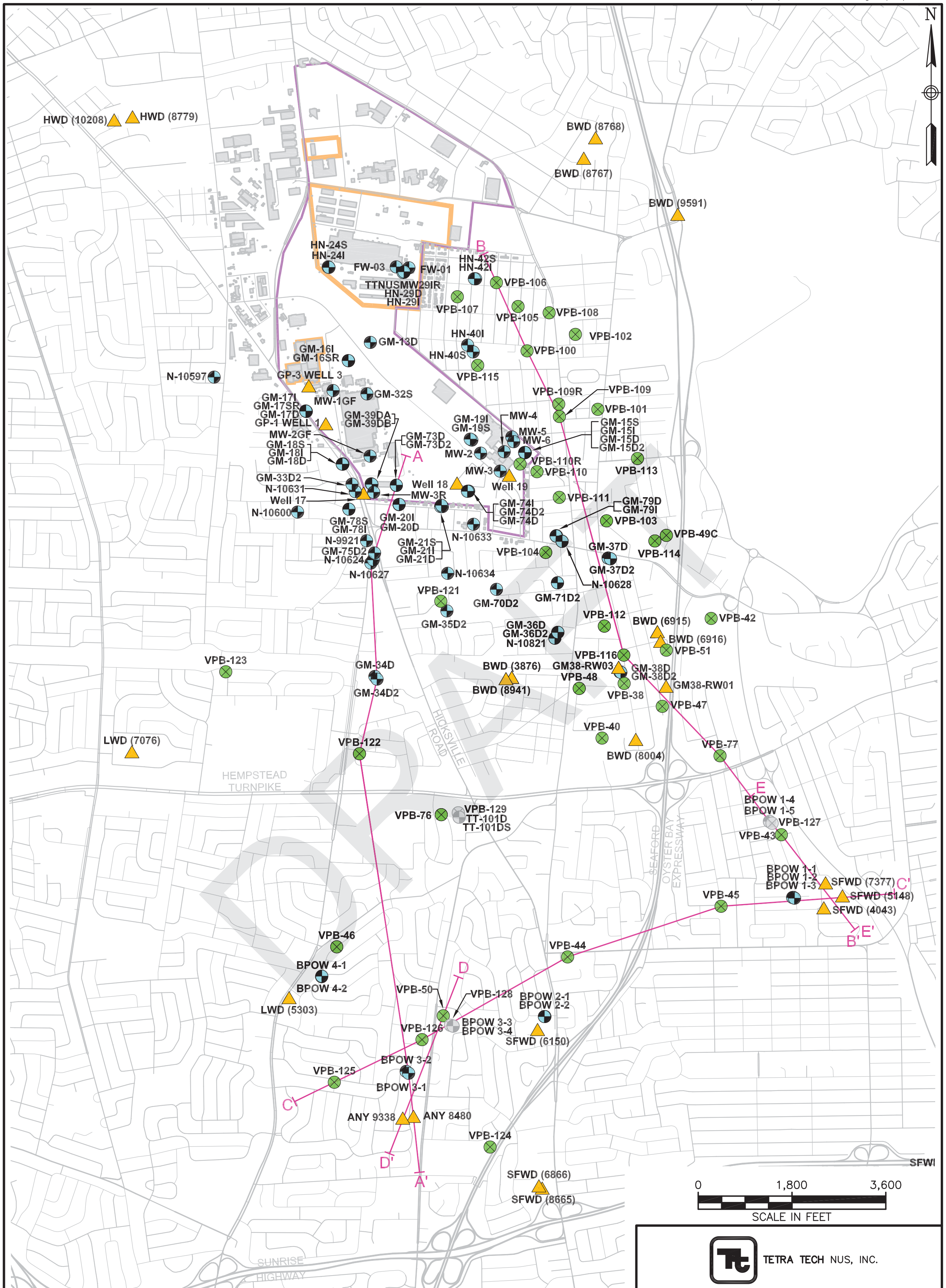

Heterogeneous mobile porosity pathways lead to isolated fingers of contamination
Plume bounding envelope
Source
Distant Plume in Cross-Section
DESIGNED BY
HR
DRAWN BY
LC
CHECKED BY
HR
Battelle
Conceptual Depiction of a Typical Plume and Plume Fingers
BETHPAGE, NEW YORK
PROJECT G922077-PB7751
BETHPAGE_PLUME.CDR
DATE
04/11
(Adapted from; Payne et al., 2008)

Figure B-2



LEGEND

- MONITORING WELL LOCATION
- PROPOSED MONITORING WELL LOCATION
- VERTICAL PROFILE BORING
- PROPOSED VERTICAL PROFILE BORING
- WATER SUPPLY WELL
- 1997 NORTHROP-GRUMMAN BETHPAGE BOUNDARY
- 1997 NWIRP BETHPAGE BOUNDARY
- BUILDING
- HIGHWAY
- MAJOR LOCAL ROAD
- MINOR LOCAL ROAD

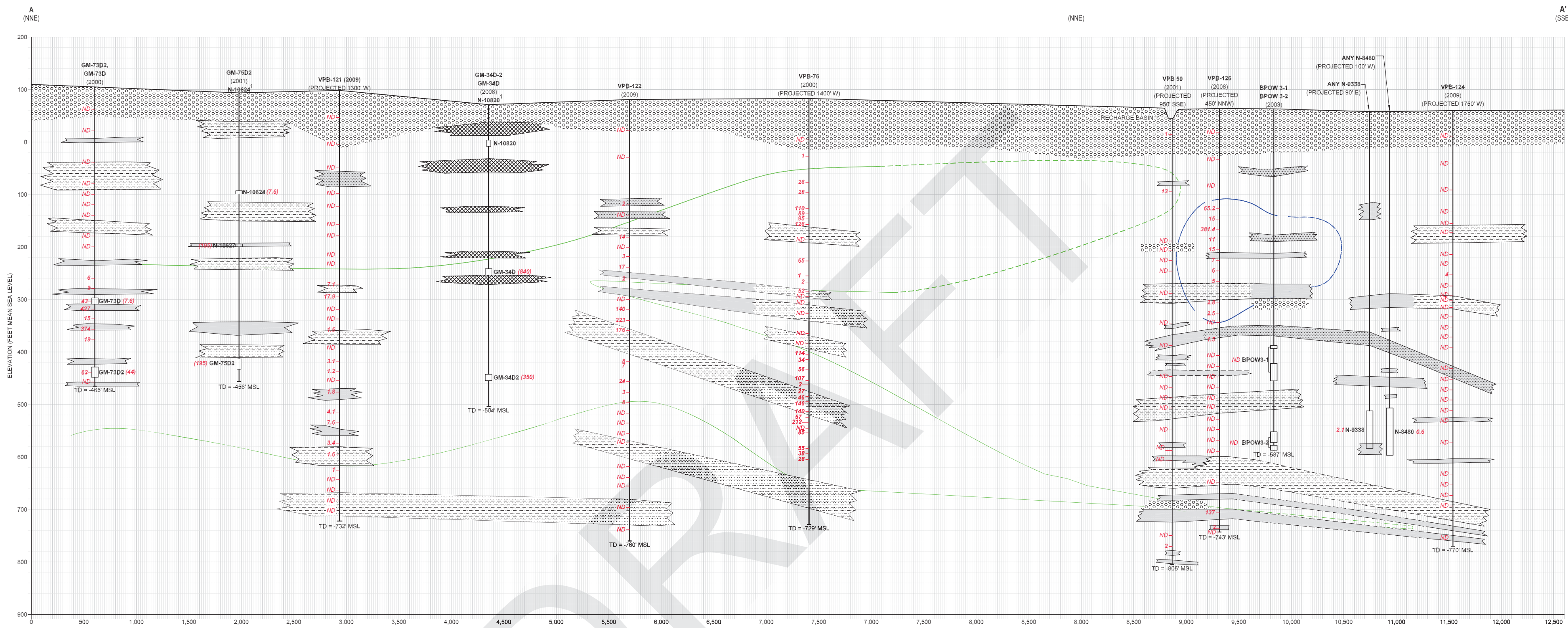
TETRA TECH NUS, INC.

OPERABLE UNIT 2 (SITE 1)
CROSS SECTION MAP
NAVAL WEAPONS INDUSTRIAL
RESERVE PLANT
BETHPAGE, NEW YORK

FILE	SCALE
112G01041GM02	AS NOTED

FIGURE NUMBER	REV	DATE
FIGURE OU2TT–G2	0	01/07/11

Figure B-3



LEGEND

- SAND AND GRAVEL
- F-M SAND WITH VARYING AMOUNTS OF SILT, CLAY, AND C. SAND

CONFINING UNITS

- INTERBEDDED CLAY AND SAND
- SANDY CLAY
- CLAY
- CONFINING UNIT FROM ARCADIS CROSS-SECTION, NO SPECIFIC LITHOLOGY GIVEN
- [1] ARCADIS CROSS SECTION (2004)
- * TVOC DATA FROM ARCADIS

BPOW 3-2	MONITORING WELL ID
(2003)	INSTALLATION YEAR
(PROJECTED 450' ESE)	PROJECTION
	CONFINING UNIT (DASHED WHERE INFERRED)
	MONITORING WELL SCREEN
374	VERTICAL PROFILE BORING TVOC RESULTS IN ug/L
ND	NOT DETECTED
	MIXED VOC PLUME (5 ug/L CONTOUR LINE)
	PCE PLUME (5 ug/L CONTOUR LINE)
TD = -743' MSL	TOTAL DEPTH (MEAN) SEA LEVEL

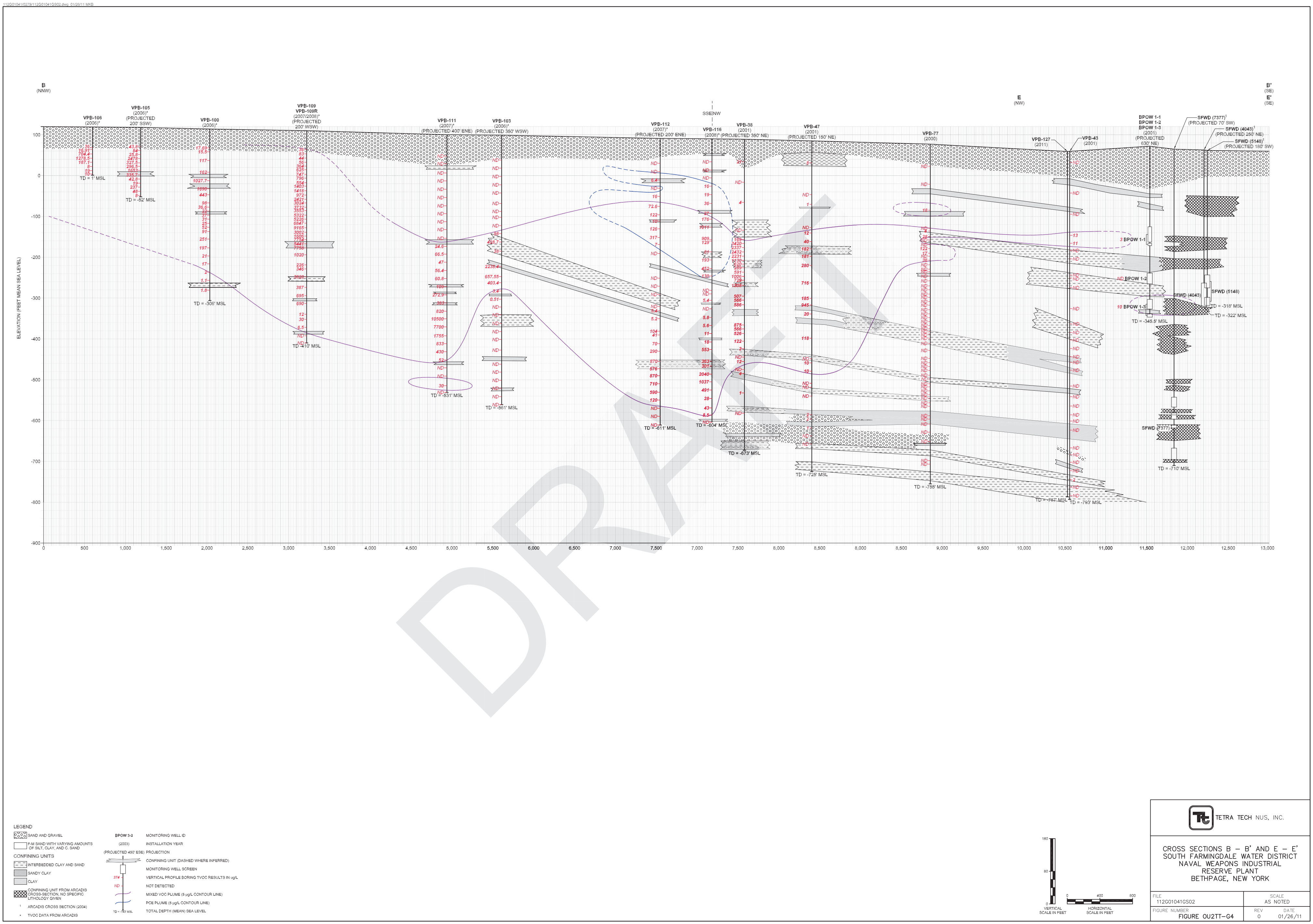
TETRA TECH NUS, INC.

CROSS SECTION A – A'
SOUTH FARMINGDALE WATER DISTRICT
NAVAL WEAPONS INDUSTRIAL
RESERVE PLANT
BETHPAGE, NEW YORK

FILE	SCALE
112G01041GS03	AS NOTED

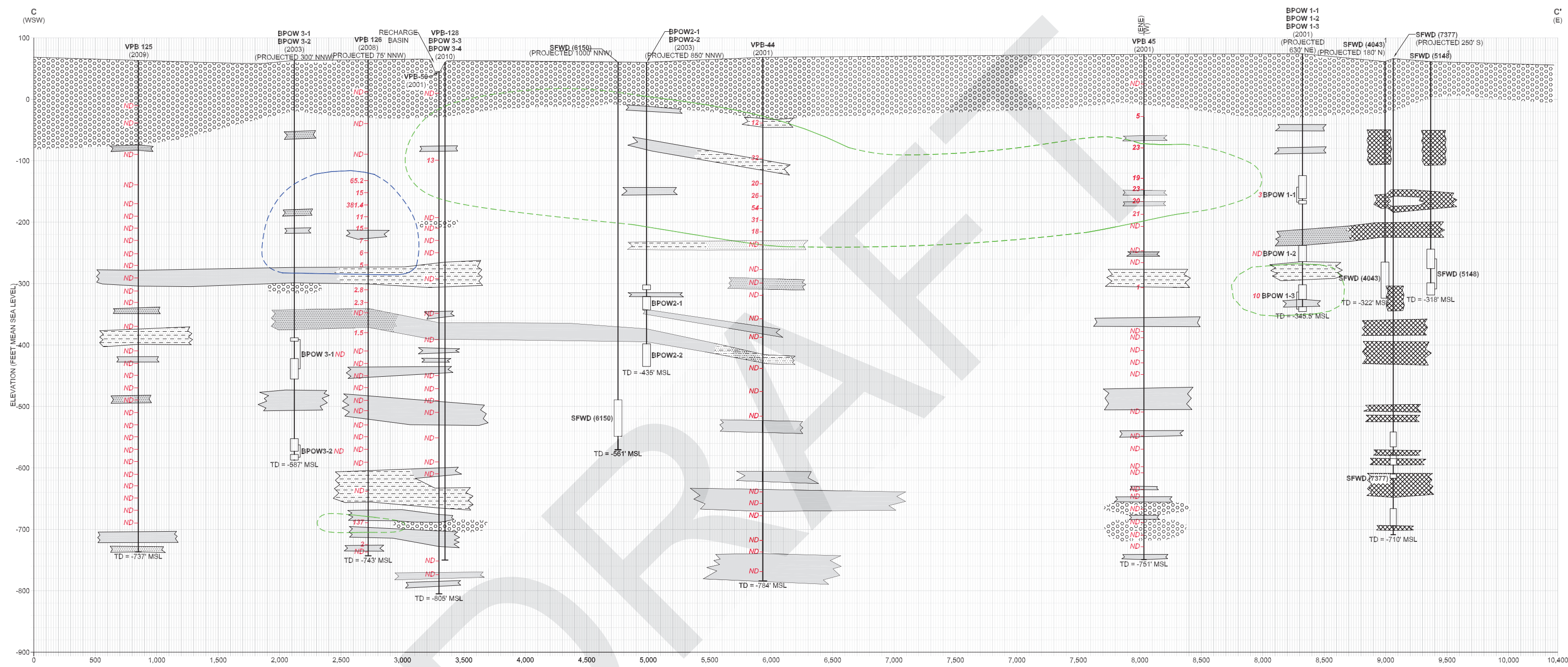
FIGURE NUMBER	REV	DATE
FIGURE OU2TT–G3	0	01/26/11

Figure B-4



112G01041/0279/112G01041GS02.dwg 01/26/11 MKB
B (NNW)
B' (SE)
E' (SE)
E (NW)
SSE|NW
VPB-106 (2006)*
VPB-105 (2006)* (PROJECTED 200' SSW)
VPB-100 (2006)*
VPB-109 VPB-109R (2007/2008)* (PROJECTED 200' WSW)
VPB-111 (2007)* (PROJECTED 400' ENE)
VPB-103 (2006)* (PROJECTED 350' WSW)
VPB-112 (2007)* (PROJECTED 200' ENE)
VPB-116 (2008)*
VPB-38 (2001) (PROJECTED 350' NE)
VPB-47 (2001) (PROJECTED 150' NE)
VPB-77 (2000)
VPB-127 (2011)
VPB-43 (2001)
BPOW 1-1 BPOW 1-2 BPOW 1-3 (2001) (PROJECTED 630' NE)
SFWD (7377)[1] (PROJECTED 70' SW)
SFWD (4043)[1] (PROJECTED 250' NE)
SFWD (5148)[1] (PROJECTED 180' SW)
TD = 1' MSL
TD = -52' MSL
TD = -306' MSL
TD = -410' MSL
TD = -531' MSL
TD = -561' MSL
TD = -611' MSL
TD = -604' MSL
TD = -673' MSL
TD = -725' MSL
TD = -758' MSL
TD = -787' MSL
TD = -793' MSL
TD = -345.5' MSL
TD = -318' MSL
TD = -322' MSL
TD = -710' MSL
ELEVATION (FEET MEAN SEA LEVEL)
DRAFT
LEGEND
SAND AND GRAVEL
F-M SAND WITH VARYING AMOUNTS OF SILT, CLAY, AND C. SAND
CONFINING UNITS
INTERBEDDED CLAY AND SAND
SANDY CLAY
CLAY
CONFINING UNIT FROM ARCADIS CROSS-SECTION, NO SPECIFIC LITHOLOGY GIVEN
[1] ARCADIS CROSS SECTION (2004)
* TVOC DATA FROM ARCADIS
BPOW 3-2 MONITORING WELL ID
(2003) INSTALLATION YEAR
(PROJECTED 450' ESE) PROJECTION
CONFINING UNIT (DASHED WHERE INFERRED)
MONITORING WELL SCREEN
374 VERTICAL PROFILE BORING TVOC RESULTS IN ug/L
ND NOT DETECTED
MIXED VOC PLUME (5 ug/L CONTOUR LINE)
PCE PLUME (5 ug/L CONTOUR LINE)
TD = -143 MSL TOTAL DEPTH (MEAN) SEA LEVEL
VERTICAL SCALE IN FEET
HORIZONTAL SCALE IN FEET
TETRA TECH NUS, INC.
CROSS SECTIONS B – B' AND E – E'
SOUTH FARMINGDALE WATER DISTRICT
NAVAL WEAPONS INDUSTRIAL RESERVE PLANT
BETHPAGE, NEW YORK
FILE 112G01041GS02
SCALE AS NOTED
FIGURE NUMBER FIGURE OU2TT–G4
REV 0
DATE 01/26/11

Figure B-5



LEGEND

- SAND AND GRAVEL
- F-M SAND WITH VARYING AMOUNTS OF SILT, CLAY, AND C. SAND

CONFINING UNITS

- INTERBEDDED CLAY AND SAND
- SANDY CLAY
- CLAY
- CONFINING UNIT FROM ARCADIS CROSS-SECTION, NO SPECIFIC LITHOLOGY GIVEN
- ¹ ARCADIS CROSS SECTION (2004)
- ² TVOC DATA FROM ARCADIS

BPOW 3-2	MONITORING WELL ID
(2003)	INSTALLATION YEAR
(PROJECTED 450' ESE)	PROJECTION
	CONFINING UNIT (DASHED WHERE INFERRED)
BPOW 3-2	MONITORING WELL SCREEN
374	VERTICAL PROFILE BORING TVOC RESULTS IN µg/L
ND	NOT DETECTED
	TCE PLUME (5 µg/L CONTOUR LINE)
	PCE PLUME (5 µg/L CONTOUR LINE)
TD = -743' MSL	TOTAL DEPTH (MEAN) SEA LEVEL

VERTICAL SCALE IN FEET: 0, 80, 160

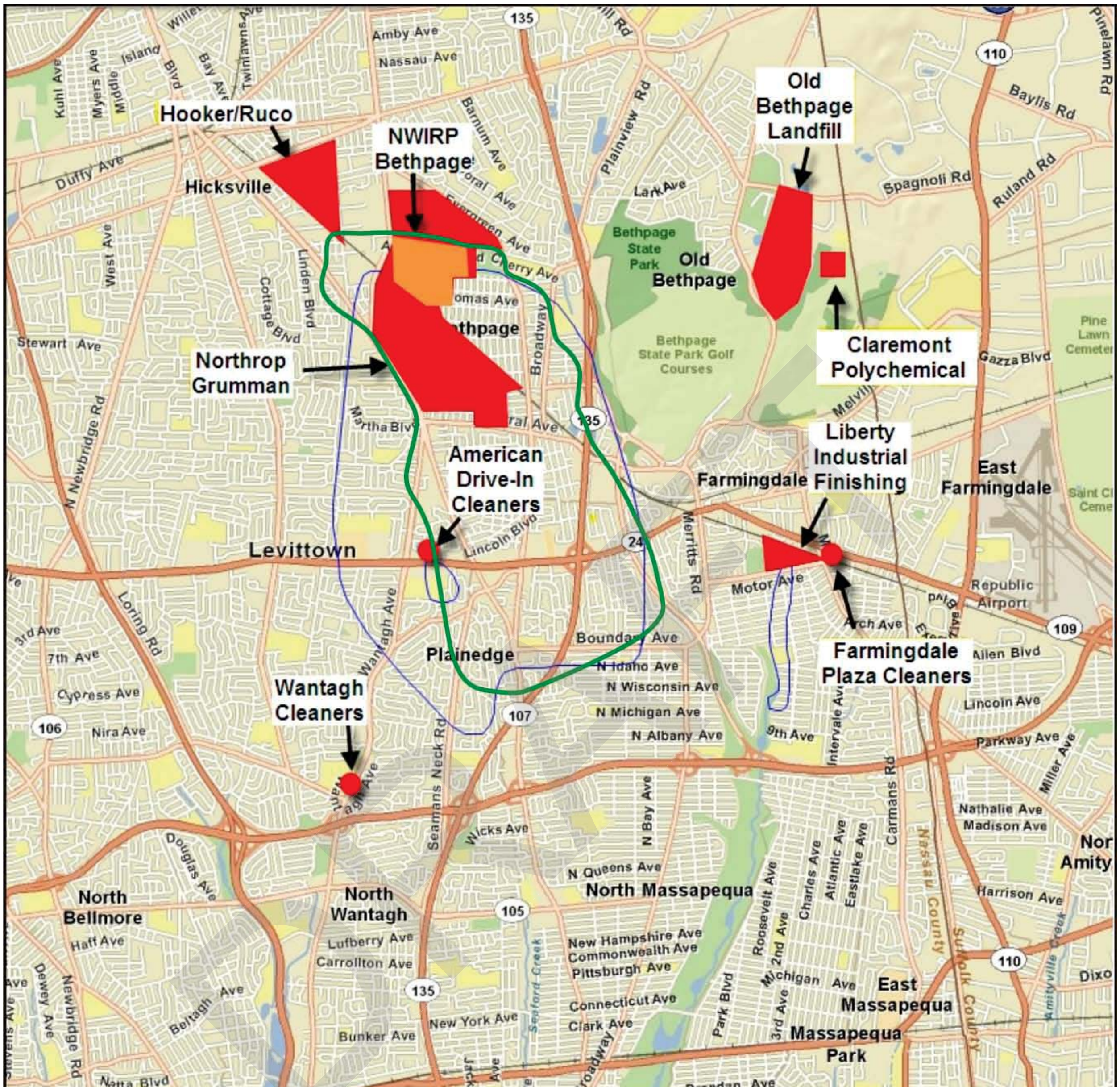
HORIZONTAL SCALE IN FEET: 0, 400, 800

TETRA TECH NUS, INC.

CROSS SECTION C – C'
SOUTH FARMINGDALE WATER DISTRICT
NAVAL WEAPONS INDUSTRIAL
RESERVE PLANT
BETHPAGE, NEW YORK

FILE	SCALE	
112G01041GS06	AS NOTED	
FIGURE NUMBER	REV	DATE
FIGURE OU2TT-G5	0	01/26/11

Figure B-6



0 0.5 1

APPROXIMATE SCALE IN MILES

N

Explanation

- ~5 ppb VOC Concentration Contour in Groundwater (OU2 and OU3)
- Plume from Other Sources
- NWIRP Bethpage
- Potential Sources of Contamination in the Bethpage Area

DESIGNED BY HR	Battelle		
DRAWN BY LC	**NWIRP Bethpage Potential Sources of Contamination**		
CHECKED BY HR	BETHPAGE, NEW YORK		
	PROJECT G922077-PB7751	BETHPAGE.CDR	DATE 04/11

Figure B-7

P: GIS files/Bethpage/MapDocs/BP OU2 2011 BP TCE SHALLOW 01172011 MMC 02032011

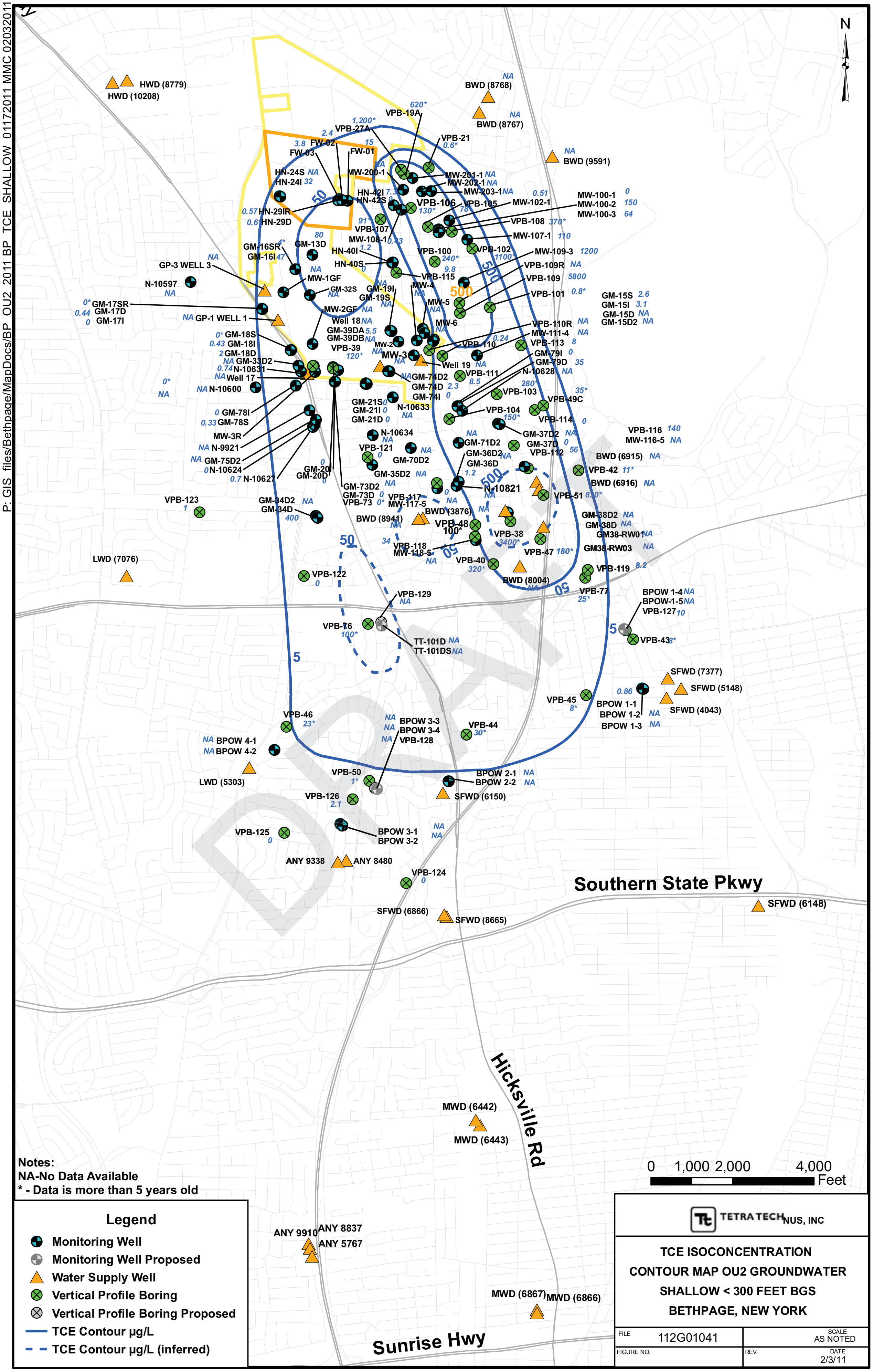


Figure B-8

P: GIS_files/Bethpage/MapDocs/BP_OU2_2011_BP_TCE_DEEP_01192011 MMC 02072011

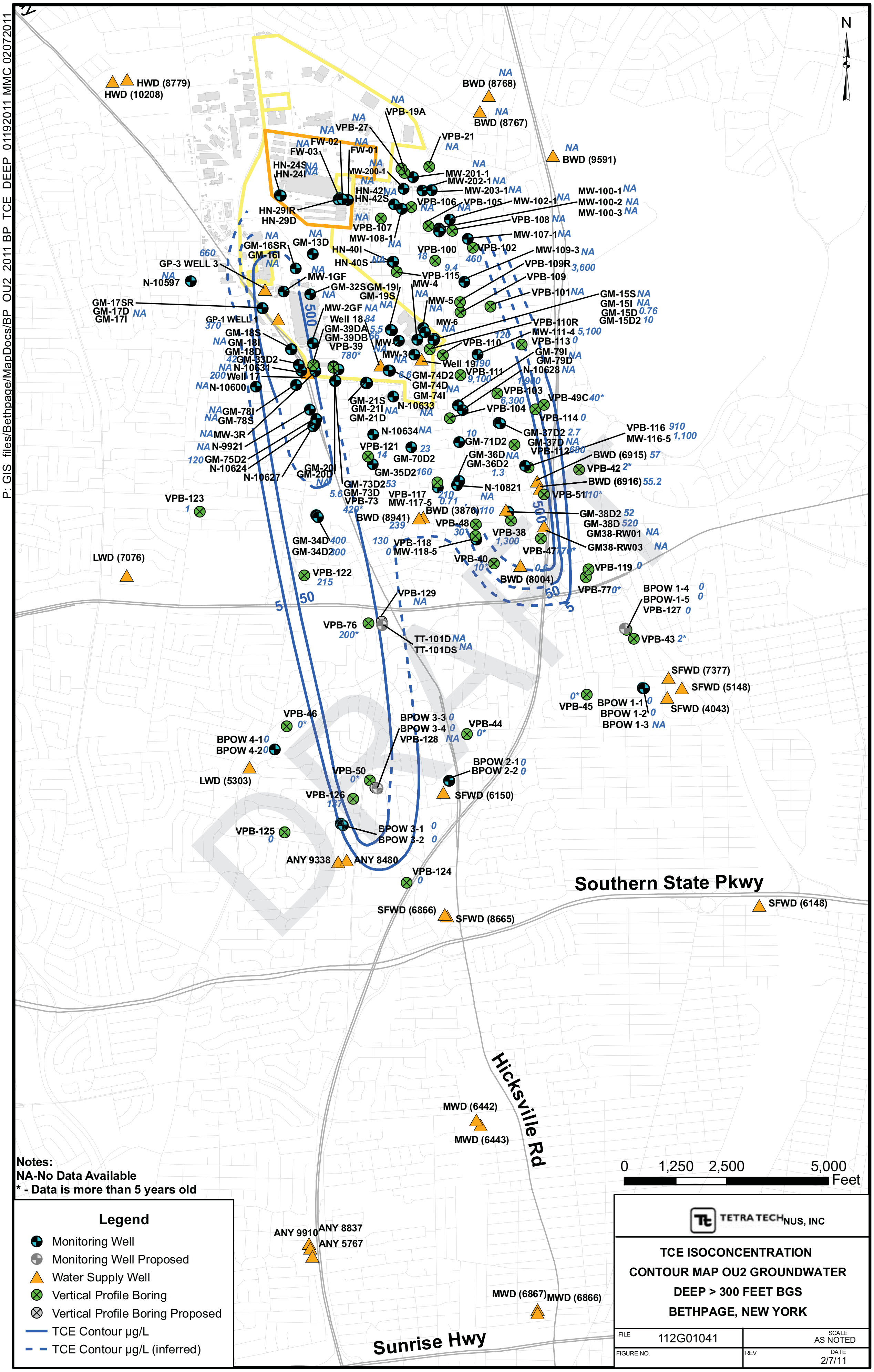


Figure B-9