LMS/PIN/N01673

Pinellas County, Florida, Site Environmental Restoration Project

Draft Building 100 Area Plume Management Alternatives Analysis

March 2012

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Abbreviations

1,1-DCE	1,1-dichloroethene
bls	below land surface
cDCE	*cis*-1,2-dichloroethene
COPC	contaminant of potential concern
CTL	cleanup target level
DOE	U.S. Department of Energy
FDEP	Florida Department of Environmental Protection
ft	feet
gpm	gallons per minute
IC	institutional control
µg/L	micrograms per liter
mg/L	milligrams per liter
NAM	natural attenuation with monitoring
NAPL	nonaqueous phase liquid
O&M	operation and maintenance
PCU	Pinellas County Utilities
RBCA	Risk-Based Corrective Action
RC	restrictive covenant
RCRA	Resource Conservation and Recovery Act
RMO	Risk Management Option
ROI	radius of influence
STAR Center	Young - Rainey Science, Technology, and Research Center
TCE	trichloroethene
tDCE	*trans*-1,2-dichloroethene
TPOC	temporary point of compliance
VC	vinyl chloride
WPSC	Walter Pownall Service Center

Executive Summary

The objective of this alternatives analysis is to determine the best approach for managing the onsite and offsite groundwater contaminant plumes at the Building 100 Area at the Young - Rainey Science, Technology, and Research Center (STAR Center) in Largo, Florida.

The U.S. Department of Energy (DOE) Office of Legacy Management, which is responsible for environmental restoration of the STAR Center, is coordinating with the Florida Department of Environmental Protection (FDEP) to identify the most appropriate approach. According to FDEP, remediation starts with contaminant source removal, but FDEP and DOE have agreed that delineation and complete remediation or removal of the source from beneath the occupied, 11-acre Building 100 is not currently possible. The contaminant source probably occurs as either (1) pools of nonaqueous phase liquids or (2) residual nonaqueous phase liquids dispersed throughout the aquifer matrix in the areas where releases from leaking drain lines or the drum storage pad occurred.

With the assumption that the source will remain in place, this study focused on determining how best to manage the two separate plumes, which have migrated beyond the property boundaries and onto adjacent properties. The contaminants of potential concern are 1,4-dioxane, vinyl chloride, trichloroethene, *cis*-1,2-dichloroethene, *trans*-1,2-dichloroethene, and 1,1-dichloroethene. The east plume extends from under the eastern edge of Building 100, east under Belcher Road, and onto private property. The extent of this plume is currently unknown, but additional delineation is planned for late March 2012. The south plume extends from under the south edge of Building 100, southeast under Bryan Dairy Road, and onto three separate privately owned parcels. The offsite portion of this plume is approximately 775 feet long.

Assuming that no one is accessing the contaminated groundwater at the offsite areas, the contamination presents no apparent adverse impacts to human health, public safety, or the environment. However, no restrictions are in place to deter access to the contaminated groundwater. Therefore, a graded approach to plume management is appropriate, with preference given to more passive alternatives unless future monitoring results or other conditions warrant otherwise.

DOE has inferred from conversations with FDEP that natural attenuation with monitoring, a passive approach with very low cost, could be an option for the Building 100 Area. Natural attenuation with monitoring is a regulated strategy for site rehabilitation (Chapter 62-780.200 *Florida Administrative Code*) and relies on natural processes to decrease the concentrations of contaminants in groundwater and stop plume movement; this strategy consists mainly of a monitoring program to demonstrate that natural attenuation is occurring. Natural attenuation with monitoring would not have a legally enforceable mechanism to prevent the installation of shallow wells that could be used to access contaminated groundwater, but it does require that property owners receive notification of contamination every 5 years. In addition, institutional controls, in the form of a restrictive covenant, could be implemented to ensure that contaminated groundwater is not accessible.

Institutional controls by themselves are a viable option for the offsite plumes as well, although landowner acceptance and actual cost to implement are relatively unknown factors at this point.

DOE has coordinated recently with STAR Center representatives to develop institutional controls for the STAR Center in the form of a draft declaration of restrictive covenant.

The most aggressive action would be active remediation of groundwater at the offsite areas, but this should not be considered unless required. The goal of this active approach would be to decrease contaminant concentrations in groundwater to levels that are below cleanup target levels. Active offsite remediation would require onsite plume control because continuous movement of contaminated groundwater onto the offsite areas would increase the time needed for offsite remediation and re-contaminate areas at which cleanup has been completed.

All commercially-available remediation technologies are screened during this study, and three active remediation technologies are chosen for detailed evaluation: groundwater pumping, the ART well system (a combination of in-well sparging, stripping, and vapor extraction), and chemical oxidation. Groundwater pumping with ex situ treatment is most likely to be effective, is the easiest to implement, and is the most cost effective.

Without source removal, and in consideration of the groundwater velocity of a few feet per year, this study used the assumption that any action to control the plume from moving offsite, if needed, would need to function for at least 50 years. Groundwater pumping with ex situ treatment is also the best option for plume control.

Groundwater pumping at the STAR Center has been effective for plume control but has had limited effectiveness at achieving cleanup target levels because contaminant source remained in the subsurface. But groundwater pumping as a means to meet cleanup target levels would be much more effective if the plume was isolated from the source by plume control.

It is assumed that the STAR Center will accept disposal of treated groundwater from offsite locations into the STAR Center wastewater facility. If not, groundwater pumping would not be a viable alternative unless another water disposal option could be found.

If implementation of one of the other two active remediation alternatives, ART well system and chemical oxidation, was considered, a pilot test would be required to demonstrate that these technologies could be effective given the specific conditions at the site.

1.0 Objective

The objective of this alternatives analysis is to determine how best to manage the groundwater contaminant plumes at the Building 100 Area at the Young - Rainey Science, Technology, and Research Center (STAR Center) that extend offsite beyond the STAR Center property boundaries. The U.S. Department of Energy (DOE) is coordinating with the Florida Department of Environmental Protection (FDEP) to identify the most appropriate approach for managing these plumes until the contaminant sources beneath Building 100 can be removed.

The east plume extends from under Building 100, under Belcher Road, and onto the Walter Pownall Service Center (WPSC) at 11111 Belcher Road. The south plume extends from under the south edge of Building 100, under Bryan Dairy Road, and onto the Harrod, Rally Stores, and Better Business Forms properties located at 8040 Bryan Dairy Road, 10980 Belcher Road, and 10950 Belcher Road, respectively (Plate 1). Except for the right-of-way for the two adjacent roadways, the impacted offsite properties are currently commercial or administrative office space and associated grounds.

2.0 Background

The Pinellas Plant was constructed in the mid-1950s and primarily manufactured neutron generators for nuclear weapons for about 40 years. On March 17, 1995, DOE sold the Pinellas Plant to the Pinellas County Industry Council. Ownership changed to the Pinellas County government on July 1, 1999. The sales contract included clauses to ensure continued compliance with federal, state, and local environmental regulations. Site cleanup activities by DOE have progressed during Pinellas County ownership of the site and continue currently. The former Pinellas Plant is now known as the Young - Rainey STAR Center (Figure 1).

Building 100 is the most notable feature of the STAR Center, covering approximately 11 acres in the southeastern corner of the STAR Center (Figure 1). Waste-handling activities during DOE ownership resulted in releases of organic solvents to the soil and groundwater under and near the building, and plumes of contaminants dissolved in groundwater have been transported off the property to the south and east for several hundred feet. Site background information relevant to this plume management alternatives analysis is provided in the following sections.

2.1 Summary of Remediation Activities

The Comprehensive Environmental Assessment and Response Program *Phase I: Installation Assessment Pinellas Plant* (DOE 1987) identified the Old Drum Storage Site (located near the northwest corner of Building 100) and the Industrial Drain Leaks beneath Building 100 as areas potentially requiring remediation based on past waste storage and handling activities. A 1991 Resource Conservation and Recovery Act (RCRA) Facility Investigation (DOE 1991) confirmed that corrective measures would be necessary, and because of proximity and similar contaminants, the Old Drum Storage Site (SWMU PIN06) and Industrial Drain Leaks (SWMU PIN12) were combined into the Building 100 Area.

Current contaminants of potential concern (COPCs) for groundwater are trichloroethene (TCE), *cis*-1,2-dichloroethene (cDCE), *trans*-1,2-dichloroethene (tDCE), 1,1-dichloroethene (1,1-DCE),

vinyl chloride (VC), 1,4-dioxane, and arsenic. Monitoring for arsenic is no longer conducted because concentrations are below the cleanup target level (CTL) for groundwater designated as poor quality. The use of poor groundwater quality CTLs is discussed in Section 2.2. COPCs and their CTLs are listed in Table 1.

The Corrective Measures Study Report for the Building 100 Area (DOE 1994) determined that installation of two groundwater recovery wells near the northwest corner of Building 100 would be sufficient to clean up the contamination identified during the RCRA Facility Investigation. Operation of the two recovery wells began in October 1997 and continued until August 2006.

Additional groundwater sampling in 1995 (DOE 1996a and DOE 1996b) demonstrated that significant contaminant concentrations in groundwater were present beneath other areas of the building and that lower levels of contamination were present south and east of the building. The *Building 100 Area Corrective Measures Implementation Plan Addendum* (DOE 1998a) recommended the installation of two additional recovery wells at the southeast corner of Building 100 to address the additional contamination, but implementation was deferred pending results of evaluation of other potential remedial options.

Biosparging was considered, but a biosparging project that began operation in November 1999 at the 4.5 Acre Site, located adjacent to the western edge of the STAR Center, proved unsuccessful at treating contaminants similar in type and concentration to those at the Building 100 Area. A pilot test study to evaluate enhancing natural reductive bioremediation processes was conducted at the Building 100 Area in 2003 and showed a decrease in contaminant concentrations, but CTLs were not achieved. However, implementation of full-scale enhanced reductive bioremediation using emulsified soybean oil at the 4.5 Acre Site and the Northeast Site (located north of the Building 100 Area) in 2010 has been successful at significantly decreasing concentrations of chlorinated ethene contaminants at most areas. At some locations, contaminant concentrations have decreased to levels below CTLs for poor-quality groundwater (DOE 2011a and DOE 2011b). Source removal was conducted at both sites prior to the soybean oil injection, so that project treated only contaminants dissolved in groundwater. Enhanced reductive bioremediation will not treat 1,4-dioxane, as explained in Section 3.2.

An interim remedial action using a single recovery well to collect hydraulic information for use in this study began in July 2009. Located in the south plume near the southern STAR Center property boundary, recovery well PIN12-RW03 has a radius of influence (ROI) that likely captures the entire south plume as it exits the property (Figure 2).

In 2007 DOE learned that Pinellas County Utilities (PCU) and Pinellas County Public Works planned major water line replacement and road construction, respectively, along both Bryan Dairy and Belcher Roads adjacent to the Building 100 Area. For this work, dewatering (extraction of shallow groundwater) would be conducted in areas where trenching was needed, and some of the trenching would be conducted in areas near the contaminant plumes. To evaluate potential worker exposure to contaminants, monitoring wells were installed in offsite areas in October 2007 and in January and February 2008 to determine plume depth and lateral extent. This investigation confirmed that the plume was offsite south of Bryan Dairy Road, on the county right-of-way. Additional delineation in 2009, 2010, and 2011 has confirmed that the contaminant plume extends south of Bryan Dairy Road onto property at 8040 Bryan Dairy Road (owned by Harrod Properties), 10980 Belcher Road (owned by Rally Stores), and 10950 Belcher

Road (owned by Better Business Forms). The results of these investigations were reported in DOE 2010, DOE 2011c, and DOE 2011d. Figure 3 shows the south plume.

Additional delineation east of Building 100 in 2011 showed that a separate contaminant plume extends from under the east side of Building 100, across Belcher Road, and onto 11111 Belcher Road (the WPSC). The results of this investigation were reported in DOE 2011e; the east plume is shown on Figure 4. During this work, chlorinated ethene contaminants were measured at concentrations that exceed CTLs, but 1,4-dioxane was also measured offsite at maximum concentrations ranging from 50 to 100 times its CTL. Previously, sampling of monitoring wells in this area showed very low to nondetect concentrations of 1,4-dioxane. As a result of this investigation, 1,4-dioxane was added as a COPC for the Building 100 Area. The east dioxane plume is shown on Figure 5. Additional delineation to determine the extent of contamination on the WPSC property is planned for March 2012.

PCU and Pinellas County Public Works conducted shallow dewatering activities for their water line and road construction work adjacent to the STAR Center intermittently from July 2011 to January 2012. DOE accumulated, treated, and disposed of this water as a best management practice to prevent potential worker contact with contaminants. Most of this water transfer and treatment infrastructure remains in place, and is described in Section 2.4.

2.2 Regulatory Setting

The Building 100 Area is included as a Solid Waste Management Unit under the RCRA Hazardous and Solid Waste Amendments Permit that was reissued on January 9, 2012, under the authority of FDEP. The permit incorporates the provisions of the Risk-Based Corrective Action (RBCA) regulations, which are discussed in detail below. The permit requires the investigation and remediation, if necessary, of any releases of hazardous waste or hazardous constituents at the facility. Any action taken to remediate the Building 100 groundwater plume would be covered under the RCRA permit.

The primary regulatory driver for cleanup at Building 100 is Chapter 62-780, *Florida Administrative Code* (F.A.C.), “Contaminated Site Cleanup Criteria” and accompanying “Contaminated Site RBCA Flow Process Flow Charts.” The objective of the RBCA process is to meet site cleanup criteria for a “No Further Action” determination, meaning that site cleanup is complete (62-780.680 F.A.C.). If the most stringent default site CTLs are met, and no restrictions are required to be placed on future site use (i.e., No Further Action without Controls), the site meets criteria for Risk Management Option I (RMO I). If less stringent, alternate CTLs are met, some type of institutional control (IC) is needed to ensure site protectiveness in the future (NFA with controls—RMO II or RMO III, depending on plume size and concentrations). If a site does not meet appropriate criteria for an NFA determination (either with or without controls), additional remediation is likely warranted. This remediation can be either passive (62-780.690) or active (62-780.700).

Distinction is made in RBCA between cleanup standards that apply to “source properties” (or what would be considered “onsite”) and those that apply to properties outside the site boundary. Under RMOs II and III, it is assumed that some type of IC will be implemented on the source property. Because restrictions can be placed on groundwater use, less stringent standards can be applied to onsite groundwater; default CTLs only need to be met offsite. RBCA also allows for

the use of offsite ICs under RMO III, though the use of ICs on non-source property is discouraged. Under RMO III, default CTLs only need to be met in areas outside the IC boundary (which, in theory, could be established well beyond the site boundary).

Based on a comprehensive review of background data for the site (DOE 2003), DOE determined that aluminum and iron levels in the shallow groundwater in the site vicinity are naturally elevated and far exceed State of Florida secondary drinking water standards (Chapter 62-550 F.A.C.). The ambient shallow groundwater in the area is therefore designated as "poor quality" as defined in Chapter 62-780.200 (35) F.A.C. Thus, the applicable groundwater CTLs are those for groundwater of "low yield/poor quality" provided in Table 1 of Chapter 62-777 F.A.C. In essence, these CTL values for poor-quality groundwater are a factor of 10 higher than the default CTL values for drinking water. FDEP has allowed the use of the poor groundwater quality CTLs onsite but requires adherence to drinking water CTLs for site-related constituents in offsite areas (or areas outside the IC boundary as discussed above).

The need for this alternatives analysis is largely driven by the identification of the offsite groundwater plumes and by the fact that offsite groundwater must meet more stringent standards than onsite groundwater (or requires the implementation of formal ICs). The need to meet different CTLs is why the evaluation of alternatives (Sections 5 and 7) considers offsite and onsite contamination separately.

FDEP has said that final closure of the Building 100 Area will not be an option until source removal can be addressed, and it is not known when that can be accomplished. However, for the purposes of this document, alternatives are evaluated with respect to their ability to meet final closure objectives. RMO III is the only potential closure option at Building 100 (regardless of whether source removal can be accomplished) based on the size of the groundwater plume (>0.25 acre in size). Despite FDEP's position that final closure will not be approved without source removal, RBCA does allow for final closure if source removal is not feasible and it can be demonstrated that the groundwater plume is stable or shrinking. This is the endpoint that is used for the evaluation of alternatives in this document. RBCA contains some criteria for evaluating plume stability (e.g., "leveling-off"); however, this determination is subject to interpretation and to State approval. The stability of the Building 100 plumes is discussed in Section 3.4.

In addition to requirements of RCRA and RBCA, any cleanup remedy must meet all applicable regulations governing emissions, discharges, and waste management (e.g., Clean Air Act, Clean Water Act, National Environmental Policy Act).

2.3 Utility Locations

Figure 6 shows the locations of known above- and below-ground utilities at the Building 100 Area and the offsite properties. Underground utilities on the STAR Center have been identified only in areas in which work was planned in the past; the full extent of some utilities is unknown, and completely unknown utilities may exist in areas that have not been investigated. Limited utility location work has been conducted in the offsite areas, so unknown utilities likely exist there as well. Location of all utilities will be needed prior to any significant remedial activities.

As can be seen on Figure 6, a significant number of utilities are present under and along the margins of Belcher and Bryan Dairy Roads, as well as along the eastern edge of Building 100.

The presence of these utilities must be evaluated to determine the implementability of various remedial alternatives.

2.4 Existing Remediation Infrastructure

The existing remediation infrastructure at the Building 100 Area is shown on Figure 7. The main features are recovery well RW03, the water transfer line, the under-road pipelines, and the ex situ groundwater treatment system.

The water transfer line and the under-road pipelines were installed to convey groundwater from the water line replacement and road construction activities conducted by the County in 2011 and early 2012. Groundwater recovered by RW03 also is conveyed by the water transfer line. The transmission line can accommodate a maximum flow rate of 55 gallons per minute (gpm).

The water is conveyed to the treatment system area located west of Building 100. The treatment system area consists of two air strippers. The smaller air stripper has a capacity of 20 gpm and treats water from RW03, and the larger air stripper has a 100 gpm capacity and is used to treat water from the County activities. Treated water from the air strippers is discharged to the STAR Center's wastewater neutralization facility where it is mixed with other wastewater from the STAR Center, and all the wastewater is subsequently discharged to the local sewer system.

The pump in recovery well RW03 is powered by electricity. When the electric lines for this well were installed in 2009, capacity for three other potential recovery wells was included.

3.0 Current Conditions

This section describes the hydrology and geochemistry of the Building 100 Area, the location of the onsite and offsite contaminant plumes, and the site conceptual model.

3.1 Hydrogeology

The uppermost sediments at the site consist of unconsolidated, silty, fine-grained sands with some shell and organic-rich layers. These surficial sediments generally range in thickness from approximately 35 feet (ft) to 40 ft. Underlying the surficial sediments is the Hawthorn Group, a 70 ft thick layer composed mainly of clay. With an average vertical hydraulic conductivity of 0.0011 ft/day, the Hawthorn Group forms an aquitard between the surficial aquifer and the underlying Floridan aquifer.

Shallow groundwater in the Building 100 Area flows to the southeast under a very slight gradient of about 0.002 ft/ft. Based on approximations of 1 ft/day for hydraulic conductivity and 0.3 for effective porosity, groundwater flow velocity is estimated to be about 2.4 ft per year.

Depth to groundwater ranges from 0 to 5 ft below land surface (bls), varying by season and recent rainfall. Based mainly on water level differences in wells screened at shallow and deep intervals in the surficial aquifer, this aquifer has been divided into shallow and deep units. The division between the two units is at about 15 to 20 ft bls and is the result of a discontinuous, organic-rich, silty sand that has a much lower hydraulic conductivity than 1 ft/day. Water level

maps for the shallow and deep surficial aquifer in August 2009 are included as Figures 8 and 9. These maps are the most recent maps to show ambient flow conditions; subsequent water levels were affected by pumping of recovery well RW03 (Figure 2) or dewatering for road construction.

Groundwater flow in the shallow surficial aquifer is affected by the presence of the South Pond and the Southwest Pond (Figure 8), both of which are located about 100 ft from Building 100. The South Pond provides irrigation water for the STAR Center property, and pumping from the pond can induce groundwater flow toward and discharge into the pond. The South and Southwest Ponds typically act as discharge points for the shallow surficial aquifer in both the wet and dry seasons. The South Pond was constructed in 1984, and the Southwest Pond was constructed in 1999.

The pond on the WPSC property apparently acts as a hydraulic barrier to ambient groundwater flow, as evidenced by the deflection of the east plume to the northeast (Figure 4). Water levels in the pond are consistently higher than the water levels in the nearby wells, allowing the pond to act as a barrier to groundwater flow.

In July 2009, an aquifer drawdown and recovery test was conducted in the area around recovery well PIN12-RW03 to estimate the hydraulic conductivity (K) of the surficial aquifer in the vicinity of the well. RW03, which is fully screened through the surficial aquifer from 3 to 38 ft bls, was used as the pumping well. Water levels were measured in six nearby monitoring wells that were all located between 75 and 200 ft from the pumping well. The results of the aquifer test estimated the K value of the surficial aquifer in the area around RW03 to be about 7 ft/day, which is greater than K values previously estimated for other parts of the STAR Center. Aquifer tests and slug tests conducted at the 4.5 Acre Site, Northeast Site, and around Building 100 have typically estimated K values for the surficial aquifer of about 1 ft/day. While proximity to the South Pond may play some part in the higher K value determined during the RW03 aquifer test, it appears likely that this well is located in a preferential flow pathway.

As part of an interim action to control the plume at the southern property boundary, groundwater recovery using recovery well PIN12-RW03 began in July 2009, stopped from June 2011 through February 2012 for road construction dewatering, and is scheduled to restart in April 2012. This well appears to influence water levels in monitoring wells located south of Bryan Dairy Road (Figure 2).

3.2 Geochemistry

This section describes the chemistry of the contaminants found in the subsurface (Section 3.2.1) and the subsurface geochemical conditions (Section 3.2.2).

3.2.1 Contaminant Chemistry

Current COPCs for groundwater at the Building 100 Area are TCE, cDCE, tDCE, 1,1-DCE, VC, 1,4-dioxane, and arsenic. Monitoring for arsenic is no longer conducted because concentrations are below the poor groundwater quality CTL, so arsenic is not addressed in this study. The addition of 1,4-dioxane as a COPC in October 2011 was a result of elevated concentrations detected during delineation of the east plume earlier in 2011.

The COPCs can be divided chemically into two categories: a cyclic ether (1,4-dioxane) and chlorinated ethenes (TCE, cDCE, tDCE, 1,1-DCE, and VC). These two categories of contaminants have different chemical properties, resulting in different behavior in the subsurface. The basic differences, explained in more detail in subsequent paragraphs, can be summarized as follows.

- 1,4-dioxane is a very stable molecule, is completely soluble in water and therefore is transported conservatively with groundwater movement, is not significantly susceptible to any natural attenuation process except dilution, and can be treated using a limited number of remediation methods.
- The chlorinated ethenes are less soluble in water and are transported slower than groundwater movement, are susceptible to naturally occurring biotic and abiotic degradation processes, and can be treated using several different types of remediation methods.

The most likely use of 1,4-dioxane at the Pinellas Plant was as a stabilizer for chlorinated solvents such as TCE or 1,1,1-trichloroethane. Typically, 1,4-dioxane would have been present in these solvents at a concentration of about 1–4 percent (Mohr et al. 2010). Therefore, 1,4-dioxane likely was present in the solvents when they leaked into the subsurface. This compound is miscible with water, meaning that it will completely dissolve into water at any concentration. This very high solubility causes the contaminant to be transported conservatively with groundwater but also causes the contaminant to be very difficult to strip from the groundwater.

The 1,4-dioxane molecule is not susceptible to natural biodegradation under reducing conditions such as those at the Building 100 Area. It is susceptible to biodegradation under oxidizing conditions, but this biodegradation has only been demonstrated in lab tests; no in situ oxic biodegradation of 1,4-dioxane has been reported (Mohr et al. 2010). This contaminant is readily degraded by chemical oxidants, and chemical oxidation is a well-established method for ex situ treatment of 1,4-dioxane in recovered groundwater (Mohr et al. 2010). In situ chemical oxidation of 1,4-dioxane has been conducted, but mostly in pilot-scale studies.

TCE, DCE, and VC may biodegrade via anaerobic reductive dechlorination, and VC may degrade via aerobic oxidation as well (EPA 2000). During the anaerobic reductive dechlorination process, a compound like TCE accepts electrons, loses a chlorine atom, gains a hydrogen atom, and thus is transformed into DCE (Figure 10). Further, DCE can accept electrons and transform to VC, which can also accept electrons and transform to ethene, ethane, or other compounds. At the Building 100 Area, TCE was most likely the solvent released into the subsurface, and the DCE isomers and VC probably result from biodegradation of TCE.

Reductive dechlorination of the chlorinated ethenes probably is occurring naturally in the subsurface at the Building 100 Area. However, based on the extent and concentrations of VC in the plumes, biodegradation of VC to ethene is a relatively slow process and may not be occurring at all at VC concentrations of roughly 50 micrograms per liter (μg/L) or less. This slowing or cessation of VC biodegradation at low concentrations is well documented in the literature and is due simply to the fact that the microorganisms responsible for the degradation do not gain enough energy from the process to survive. It is possible to force VC to degrade at low concentrations by adding various amendments and microorganisms (enhanced bioremediation), but this occurs under reducing conditions in which 1,4-dioxane is not affected.

3.2.2 Subsurface Conditions

Geochemical conditions in the subsurface at the Building 100 Area are moderately reducing, as evidenced by values of dissolved oxygen that generally are less than 1 milligram per liter (mg/L) and an average oxidation-reduction potential value of –60 millivolts. These conditions allow moderate, natural reductive dechlorination of the chlorinated ethene contaminants. The microorganism necessary for complete reductive dechlorination, *Dehalococcoides ethenogenes*, is present naturally at most areas of the site in moderate abundance. Approximately 50 percent of the *Dehalococcoides ethenogenes* contain the VC reductase gene, which is necessary for dechlorination of VC to the innocuous compound ethene. Reductive dechlorination is occurring at the site, as evidenced by the presence of biodegradation products (cDCE, tDCE, 1,1-DCE, VC, and ethene). However, complete reductive dechlorination to ethene is limited, as evidenced by large dilute plumes of the dichloroethene isomers and VC.

3.3 Locations of the Contaminant Plumes

As discussed in Section 2.2, FDEP allows use of the poor groundwater quality CTLs on the STAR Center but requires use of the regular drinking water CTLs offsite. COPCs and CTLs are listed in Table 1. The contaminant plumes are defined by the COPC concentrations in monitoring wells; if the concentration of any COPC exceeds its CTL, the well is included within the plume.

The contaminant plume under Building 100 is defined by the small number of existing monitoring wells and a few additional wells that have been abandoned. The highest contaminant concentrations at the Building 100 Area are measured under Building 100, indicating that the source of contamination is under the building. In general, the contaminant plume starts at the source area where the contaminants dissolve into the groundwater, and these dissolved contaminants are transported in the direction of groundwater movement. The distance the dissolved-phase plume moves depends on the groundwater velocity, the time at which the contaminant release occurred, and other factors such as sorption, degradation, and dilution. The exact boundaries of the plume under the building are unknown, and the possibility exists that multiple plumes from multiple source areas could be present under the building. Contaminant source areas appear to be limited to the area under the building; potential contaminant source areas are discussed in detail in Appendix A. Currently, two distinct plumes, the south plume and the east plume, exist hydraulically downgradient from the building.

Plate 1 shows the estimated plume under the building, the extent of the south plume, the defined and estimated extent of the east plume, existing monitoring wells, and temporary sampling points used during plume delineation. Maximum contaminant concentrations measured since delineation began in 2007 are listed in Table 1. Detailed plume delineation and monitoring well data are included in several data reports and the semiannual report (DOE 2010, DOE 2011a, DOE 2011c, DOE 2011d, and DOE 2011e).

As described in Section 2.1, DOE has conducted detailed delineation of both the onsite and offsite contaminant plumes at the Building 100 Area since 2007. The south plume, defined as the plume exiting from the south side of Building 100 and extending off the STAR Center under Bryan Dairy Road and onto the Harrod, Rally Stores, and Better Business Forms properties (Figure 3), has been delineated, and permanent monitoring wells have been installed.

Delineation is not complete for the east plume, defined as exiting from the east side of Building 100 and extending off the STAR Center under Belcher Road onto the WPSC property (Figures 4 and 5). Additional delineation of the east plume on the WPSC property is planned for late March 2012; results of that investigation will not be available for this Alternatives Analysis study, which must be completed by the end of March. Therefore, to complete this study, the extent of the plume on the WPSC property has been estimated based on the available data (Plate 1).

The location and extent of the east plume on the WPSC property is a significant assumption for this study. The plume could be smaller or larger than the estimated plume. This study assumes that remediation under the WPSC building will not be necessary, but if the plume is larger and extends under the building (or perhaps even past the east or south sides of the building), some of the conclusions made in this study could be invalid due to the complications of remediation under a large, occupied, privately owned building.

The data in Table 1 demonstrate the differences between the south and east plumes. In the east plume, only VC and 1,4-dioxane exceed CTLs. In the south plume, several contaminants exceed CTLs, and 1,4-dioxane is present at relatively low levels.

In the south plume, 1,4-dioxane was not analyzed in the temporary sampling points installed for plume delineation, instead being analyzed only in samples from monitoring wells. Concentrations of 1,4-dioxane have exceeded the 3.2 μg/L CTL at only two well locations: once at 3.5 μg/L in well 12-0569-2 (out of six sampling events) and once at 3.5 μg/L in well 12-0575-2 (out of two sampling events) (Plate 1). These exceedances are relatively minimal, but the possibility exists that slightly higher 1,4-dioxane concentrations could be present at other areas because the data density is relatively low. Therefore, the assumption was made for this study that remediation of 1,4-dioxane would be necessary for the south plume. The current south 1,4-dioxane plume is shown on Figure 11.

For both the south and east plumes, the highest contaminant concentrations are found in the deep surficial aquifer, at 20 ft bls or deeper, and lower contaminant concentrations (but still in excess of CTLs) are found in the shallow surficial aquifer. Plume cross sections are included as Appendix B. These vertical cross sections show the distribution of each of the COPCs (if detected) at (1) the south and east sides of Building 100, (2) the eastern property boundary, and (3) the western edge of the WPSC property.

3.4 Plume Stability

A stable plume is defined as a plume that is not advancing at any of its boundaries, and monitoring wells in the plume show level or declining concentration trends. An unstable plume is one in which contaminant concentrations that exceed CTLs are expanding laterally or vertically or in which significant, increasing contaminant concentrations are observed.

The stability of the contaminant plumes is a critical component of this study because the applicability of several alternatives depends on whether or not the plumes are stable. However, sufficient data are not yet available to determine if the offsite plumes are stable. Delineation of the east plume offsite has not been completed, and no monitoring wells have been installed. Most

wells in the offsite south plume were installed in May 2011 and have been sampled only twice, and two data points are insufficient to establish a definitive trend because they cannot account for potential seasonal effects on contaminant concentrations.

A few wells in the offsite south plume were installed in 2008 and 2009, and these wells have been sampled several times, but the contaminant concentrations in the wells have been influenced by pumping of recovery well RW03. Many of the onsite monitoring wells have existed for several years, but none of these wells are in the core of the plume, as demonstrated by the detailed plume delineation conducted in 2010 and 2011. Review of the data from these wells suggests that the plume boundaries are not expanding, but the concentration trends vary from decreasing to stable to increasing. Several time-concentration plots are included in Appendix C.

Evaluation of contaminant concentration trends must account for transformation processes such as biodegradation. For example, biodegradation of cDCE to VC could cause an interim increase in VC concentrations before VC degrades to ethene.

3.5 Risk Evaluation of Groundwater Contamination

There are no current exposures to groundwater (some groundwater naturally discharges to the South Pond, but any contaminants dissipate to the atmosphere or are diluted by the dominance of rain/storm water in the pond) except during groundwater monitoring events or activities requiring excavation below the water table (e.g., recent utility replacement activities). Because groundwater concentrations exceed drinking water standards (primarily for VC and dioxane), it is assumed that use of shallow groundwater for drinking water purposes would be unacceptable. The area encompassing and surrounding the groundwater is serviced by PCU, which provides water to homes and businesses. The natural quality of shallow groundwater in the vicinity of the site is generally poor; this discourages the use of shallow groundwater in the area even for irrigation purposes.

The quitclaim deed conveying the Pinellas site (including the Building 100 Area) to the County stated that the County (the Buyer) recognized the potential for contamination beneath Building 100; the awareness of the presence of contamination is a further deterrent to the use of shallow groundwater by the County. Where the plume has migrated off site, property owners were notified of the presence of contamination upon discovery; this awareness should discourage the use of offsite shallow groundwater. Because of these factors, the current conditions at and surrounding the Building 100 Area are protective of human health and the environment.

3.6 Site Conceptual Model

The sources of contamination at the Building 100 Area are releases from a former drum storage pad located near the northwest corner of Building 100 and leaks from drain lines beneath the building. The timeframe for potential releases and leaks starts with initial operations in 1956 and extends until the underground drain lines were repaired for the second time in 1989. The released contaminants could have been dissolved in water, and could also have been pure solvents that formed NAPLs in the subsurface. Groundwater flowing to the southeast past the contaminant source areas has resulted in two distinct contaminant plumes hydraulically downgradient from the building. The south plume exits the south side of the building and continues offsite south of Bryan Dairy Road onto private property for several hundred feet. The east plume exits the east

side of the building and extends east across Belcher Road onto the WPSC property. The east plume appears to have been deflected to the northeast by the pond on the WPSC property. Groundwater velocity is a few feet per year, but preferential flow pathways with a higher groundwater velocity likely exist.

The COPCs for groundwater are TCE, cDCE, tDCE, 1,1-DCE, VC, and 1,4-dioxane. The highest contaminant concentrations are found in the deep surficial aquifer (about 20–40 ft bls), but contaminant concentrations that slightly exceed CTLs are also found in the shallow surficial aquifer (generally 12–20 ft bls). The Hawthorn clay below the surficial aquifer precludes significant contaminant transport in the downward direction, so the surficial aquifer is the only contaminated groundwater of concern.

The onsite portions of the contaminant plumes generally appear to be stable in terms of both concentration trends and plume boundaries. There are some exceptions, in particular well 0524 in the south plume near the building. Monitoring of the south plume offsite has not been in progress long enough to determine stability. Delineation of the east plume offsite has not been completed, so its boundaries and stability are unknown.

4.0 Description of Alternatives

This section describes and screens potential alternatives for managing the plumes at the Building 100 Area. The alternatives are as follows.

1. No action
2. Long-term monitoring
3. Natural attenuation with monitoring (NAM)
4. ICs
5. Groundwater remediation
6. Plume control
7. Source removal

4.1 Description of Alternatives

No action
The no-action alternative means no active remediation and no monitoring.

Long-Term Monitoring
Long-term monitoring would involve routine sampling of a monitoring well network and reporting the results of the sample analysis, similar to the current sampling program. No active remediation of any kind would be conducted, and no remediation goals would be set. Long-term monitoring is somewhat similar to NAM, but NAM has specific goals and requirements, as discussed in the following section.

NAM
According to the definition in 62-780.200(29) F.A.C., "natural attenuation means a verifiable approach to site rehabilitation that allows natural processes to contain the spread of contamination and reduce the concentrations of contaminants in contaminated groundwater and soil. Natural attenuation processes may include sorption, biodegradation, diffusion, dispersion, volatilization, and chemical reactions with subsurface materials."

ICs
FDEP defines ICs as "the restriction on use of, or access to, a site to eliminate or minimize exposure to petroleum products' chemicals of concern, dry cleaning solvents, or other contaminants." ICs are non-engineering land use controls intended to affect human activities in such a way as to prevent or reduce exposure to contamination.

Groundwater Remediation
For this study, groundwater remediation is defined as any type of action that is taken to decrease contaminant concentrations to CTLs in the offsite plumes. This includes extractive technologies, such as groundwater pumping with ex situ treatment, as well as in situ treatment, such as injection of amendments to enhance contaminant biodegradation. Many different groundwater remediation options exist, and these are identified, described, and evaluated in Sections 5, 6, and 7.

Groundwater remediation has been conducted in various forms on the STAR Center property for over 2 decades, as described in Section 2.1. These actions have reduced contaminant mass in the subsurface and provided a measure of plume control, but attainment of drinking water CTLs has been difficult mainly due to the presence of a source of contamination in the subsurface. Attainment of these CTLs will also be difficult in the offsite plume unless the contaminant source is isolated from the plume. Therefore, this study has assumed that any type of active remediation offsite would be accompanied by onsite plume control.

Plume Control
Plume control, for the purposes of this study, is defined as controlling the plume on the STAR Center property such that contaminant concentrations do not exceed offsite CTLs in groundwater moving off the site. Plume control will be required if any groundwater remediation alternative is implemented offsite. If plume control was not implemented with offsite groundwater remediation, contaminated groundwater would continue to flow off the site, and the remediated areas would eventually become contaminated again. Many different plume control options exist, and these are identified, described, and evaluated in Sections 5, 6, and 7.

Source Removal
Source removal is the remediation or removal of the source of contamination in the subsurface. The sources of contamination at the Building 100 Area, as described in Appendix A, are releases from the former drum storage pad location that currently is under the northwest corner of Building 100 and leaks from drain lines under the building. Building 100 covers approximately 11 acres. The contaminant source probably is either (1) pools of nonaqueous phase liquid (NAPL) or (2) residual NAPL dispersed throughout the aquifer matrix in the areas where releases occurred.

4.2 Screening of Alternatives

This section screens the seven alternatives described in Section 4.1. The evaluation criterion is "effectiveness at meeting FDEP requirements." FDEP requirements are that the offsite plumes must be remediated to CTLs or that the plume must be stable, and some type of IC must be applied to the offsite properties to limit potential exposure to the contaminated groundwater.

No action and long-term monitoring do not meet the screening criterion because applying either of these alternatives would not result in contaminant concentrations meeting CTLs or limiting exposure to contaminants. Therefore, these two alternatives were dropped from consideration.

NAM could result in contaminant concentrations decreasing to levels below CTLs, but this likely would require a significant amount of time (at least several decades). A source of contamination likely remains under Building 100, so the mass flux of contaminants from the source areas into the groundwater would continue until the source is depleted. This contaminated groundwater would continue to flow from under the building and onto the offsite properties. While the chlorinated ethene contaminants are susceptible to biodegradation, 1,4-dioxane is not biodegradable under reducing conditions that naturally occur in the aquifer, so the only attenuation process that affects this contaminant is dilution. NAM will not control exposure to contaminated groundwater. However, DOE has inferred from conversations with FDEP that NAM may be a viable alternative for the Building 100 Area. Therefore, NAM was retained for detailed evaluation.

Application of ICs meets the FDEP requirements and was retained for detailed evaluation.

Groundwater remediation meets the FDEP requirements (with the assumption that active remediation can meet CTLs) and was retained for detailed evaluation.

Plume control could result in contaminant concentrations in the offsite areas decreasing to levels below CTLs by simply stopping the mass flux of contaminants off the site and allowing the remaining offsite plumes to naturally attenuate, but this could require a significant amount of time given the recalcitrant nature of 1,4-dioxane. However, onsite plume control would be a requirement for any type of offsite remedial action because cleaning up the offsite plumes would be pointless without stopping the mass flux of contamination off the site (i.e., the clean offsite areas would be recontaminated by contaminated groundwater moving off the site). Therefore, plume control was retained for detailed evaluation.

According to FDEP, remediation preferably starts with contaminant source removal, but both FDEP and DOE have agreed that complete remediation or removal of the source from beneath the occupied 11-acre Building 100 is not currently possible (DOE 2005). Therefore, source removal was dropped from consideration.

4.3 Summary of Alternatives Screening

The alternatives that passed this screening are NAM, ICs, plume control, and groundwater remediation. Section 5 presents further screening of the specific plume control and groundwater remediation technologies.

5.0 Screening of Groundwater and Plume Control Technologies

The purpose of this section is to screen all commercially available groundwater remediation and plume control technologies to select a subset that will be evaluated in detail in Section 7.

5.1 Screening Criteria

The screening criteria for groundwater remediation technologies are as follows:

- Effectiveness of remediating the plume to CTLs
- Implementability
- Cost (qualitative)

The screening criteria for plume control technologies are as follows.

- Effectiveness at controlling the contaminant plume
- Implementability
- Cost (qualitative)

5.2 Groundwater Remediation Technology Screening

The commercially available technologies for groundwater remediation are described in Table 2. The screening of these technologies using the criteria listed in Section 5.1 is presented in Table 3. The technologies that passed this screening are groundwater pumping, ART in-well system, and chemical oxidation. The detailed evaluation of these alternatives is presented in Section 7.4.

5.3 Plume Control Technology Screening

The commercially available technologies for plume control are described in Table 2. The screening of these technologies using the criteria listed in Section 5.1 is presented in Table 4. The technologies that passed this screening are groundwater pumping, ART in-well system, and chemical oxidation. The detailed evaluation of these alternatives is presented in Section 7.5.

6.0 Detailed Description of Alternatives

The screening conducted in Section 4 produced four alternatives for detailed evaluation, and the screening conducted in Section 5 identified three specific technologies for both groundwater remediation and plume control for detailed evaluation. This section presents detailed descriptions of the alternatives and proposed layouts for the active remediation alternatives.

6.1 NAM

NAM allows contaminant concentrations in groundwater to naturally degrade to appropriate CTLs over time. According to the definition in 62-780.200(29) F.A.C., “natural attenuation

means a verifiable approach to site rehabilitation that allows natural processes to contain the spread of contamination and reduce the concentrations of contaminants in contaminated groundwater and soil. Natural attenuation processes may include sorption, biodegradation, diffusion, dispersion, volatilization, and chemical reactions with subsurface materials." Use of NAM permits the establishment of a temporary point of compliance (TPOC), which is defined as "the boundary represented by one or more designated monitoring wells at which groundwater CTLs may not be exceeded while site rehabilitation is proceeding" (62-780.200[48] F.A.C.). The TPOC is established at the time that NAM is proposed as a rehabilitation strategy. The plume boundary must not expand relative to the TPOC after selection of NAM, or a reevaluation of the groundwater remediation approach is triggered.

NAM only applies outside the contaminant source area. NAM would only apply to groundwater where the primary contaminant source has been removed or stabilized. NAM would only be applicable to the portion of a plume downgradient of a stabilized source area that is dissipating over time.

Provided that human health and the environment are protected, NAM is a permissible strategy for site rehabilitation if the following are met:

- Free product is not present, or removal is not technologically feasible and no explosive hazard exists.
- Contaminated soil is not present in the unsaturated zone or does not pose a continuing source of contamination to groundwater.
- Contaminants at concentrations above applicable CTLs are not migrating beyond the TPOC or vertically.
- The physical, chemical, and biological characteristics of each contaminant and transformation products are conducive to natural attenuation.
- Data show an overall decline in contaminant concentrations.

In addition, for NAM to be an allowable strategy for site rehabilitation, one of the following must be met: (1) it must be demonstrated that NAM will meet remediation goals within 5 years and that groundwater concentrations do not exceed 100 times the default CTLs, **or** (2) an evaluation must be provided establishing that NAM is scientifically and technically defensible; the NAM evaluation must include estimates of annual contaminant reductions and the time required to meet CTLs. For this evaluation, NAM would need to result in meeting poor groundwater quality CTLs for onsite contamination and default CTLs for the offsite plumes. NAM is often used after the application of a more aggressive remediation approach (e.g., pump-and-treat) as a step to further reduce groundwater concentrations to their final goals.

NAM includes a notification every 5 years of the presence of offsite contamination to affected property owners (out to the plume boundary and TPOC). A Natural Attenuation with Monitoring plan is required to be submitted to FDEP for review and approval.

6.2 ICs

FDEP defines ICs as "the restriction on use of, or access to, a site to eliminate or minimize exposure to petroleum products' chemicals of concern, dry cleaning solvents, or other

contaminants." According to the Florida Statutes, ICs are non-engineering legal and legislative controls intended to affect human activities in such a way as to prevent or reduce exposure to contamination (FDEP 2010). Such restrictions may include, but are not limited to, deed restrictions, restrictive covenants (RCs), or conservation easements. This is the definition used for the IC alternative throughout this document. This definition differs from DOE's definition of ICs, which is broader and also includes engineered structures (e.g., fences, caps). FDEP's IC guidance notes that that government controls such as zoning, local ordinances, permits, and FDEP consent orders are also considered to be ICs. However, these controls are not permanent and are not sufficiently protective of human health and the environment over the long term (FDEP 2010).

The most common form of IC used by the FDEP Division of Waste Management is the RC. The RC is a two-party legal agreement executed between FDEP and the owner of the contaminated property, then properly recorded in the public records of the county in which the property is located. This process ensures proper public notice and continued effectiveness of the control. Any IC that requires the recording of a document affecting the title to, and use of, the property (such as an RC) must be authorized by the owner of the contaminated property. FDEP cannot unilaterally impose restrictions on the use of the property. Property encumbered with a recorded IC must be entered onto the FDEP's Institutional Controls Registry so that the controls can be audited and enforced. An RC is attached to the property deed and remains in effect even if property ownership changes. An RC may only be removed if the owner and the appropriate program of FDEP execute a termination of the RC, and the signed termination is recorded in the public records of the county in which the property is located.

The use of formal ICs eliminates the need to meet numerical standards for groundwater within the IC boundary, unless some uses of groundwater are permitted. If all groundwater use is prohibited, concentrations are irrelevant as long as exposure is prevented. If an IC permits some uses of groundwater, alternate CTLs that are protective of those uses (e.g., CTLs protective of irrigation) would need to be established.

FDEP does not generally recommend placing ICs on offsite non-source properties (FDEP 2010). However, closure under RMO III does allow for this possibility as long as a groundwater plume is demonstrated to be stable or shrinking, CTLs are not exceeded at the IC boundary, and the property owner agrees to the placement of restrictions on the subject property. In order to obtain approval for final site closure, ICs are required for any sites with residual contamination that does not allow for unrestricted use (RMO II or III—no further action with controls).

6.3 Groundwater Remediation Alternatives

6.3.1 Groundwater Pumping

The goal of groundwater pumping for offsite remediation would be to decrease contaminant concentrations to levels below CTLs in the offsite plumes. The groundwater pumping system would extract contaminated groundwater, transfer it to the treatment system on the STAR Center property, treat the water until it meets discharge standards, and then discharge the treated water to the municipal sewer system. Construction of the groundwater pumping system would consist of installation of groundwater recovery wells in the offsite plumes, installation of additional piping to connect these wells to the existing groundwater treatment infrastructure, and

installation of additional ex situ treatment system components to treat 1,4-dioxane. The system layout is shown in Figure 12; additional details are shown on Plate D1 in Appendix D.

It was assumed that the existing recovery well (RW03), under-road pipelines, water transfer pipeline, and one of the air strippers would be reused for this alternative (Figure 7). When the electric lines for RW03 were installed in 2009, capacity for three other potential recovery wells was included.

A conservative estimated ROI of recovery wells is about 100 ft, so three new recovery wells in the east plume and four new recovery wells in the south plume spaced roughly 150 ft apart would be sufficient to capture all the contaminated groundwater (Figure 12). Each recovery well is estimated to extract about 4 gpm on average, so the total groundwater extraction rate from the east and south plumes would be about 12 gpm and 16 gpm, respectively.

Each recovery well would have an effluent pipe and electrical conduit. Effluent pipes would all be connected to a single transmission pipeline. The transmission pipeline and electrical conduits would be routed inside the existing 6-inch-diameter HDPE pipe underneath Belcher Road for the east plume or Bryan Dairy Road for the south plume. The transmission pipeline would connect to the existing onsite water transfer line (which consists of double containment pipe), located along the south property line of the STAR Center. The new electrical conduits would connect to the existing electrical power source, located adjacent to the east side of Building 100.

Two air strippers are currently in place at the treatment system area, and these devices are very efficient at treating the chlorinated ethene contaminants. However, air stripping will not remove 1,4-dioxane from groundwater, so a supplemental treatment method is necessary. A review of the literature and discussion with vendors indicated that a flow-through system using any of several types of advanced oxidation processes would be the best option for the supplemental treatment. Ex situ chemical oxidation of chlorinated ethenes and 1,4-dioxane is a mature technology and is standard practice at many water treatment plants (Mohr et al. 2010). As an example of an ex situ chemical oxidation treatment system, the HiPOx technology was chosen for this study.

The HiPOx technology is an advanced oxidation process using hydrogen peroxide and ozone (a process flow diagram is shown on Plate D1 in Appendix D). Contaminated groundwater would flow continuously through a reaction chamber into which hydrogen peroxide and ozone would be injected. An ozone generator would use oxygen to create ozone. The ozone and hydrogen peroxide react to form hydroxyl radicals, which then degrade the contaminants in the groundwater. All the reactions occur rapidly, enabling the use of the flow-through system.

The approximate dimensions of the HiPOx unit would be 7.5 ft high × 8 ft long × 4.5 ft wide. The unit would be mounted on a metal skid and placed inside a new air-conditioned building at the treatment system area, within the existing concrete containment area and downstream of the existing air strippers. The building would be about 10 ft high × 15 ft long × 12 ft wide. The HiPOx unit would be sized to have sufficient capacity to reduce the 1,4-dioxane concentration from its maximum detected value of 440 μg/L in the east plume groundwater to below 0.012 mg/L at a maximum flow rate of 55 gpm (which is the maximum flow rate of the existing groundwater transmission line). 1,4-dioxane does not have an established wastewater discharge standard, but discussion of the issue with PCU determined that DOE should notify PCU if the level exceeded 0.012 mg/L.

6.3.2 ART Wells

The ART in-well process is a combined, continuous operation of air sparging, air stripping, soil vapor extraction, enhanced bioremediation/oxidation, and dynamic subsurface circulation in a single, large-diameter well. The system layout is shown in Figure 13; additional details are shown on Plate D2 in Appendix D. Within each well, groundwater would be pumped from the bottom of the well to the top of the well and then sprayed into the headspace in the well, causing volatile contaminants to partition from the water into the air. Air would be pumped into the bottom of the well to sparge the water column, causing volatile contaminants to partition into the air and be transported into the headspace of the well. The vapor extraction component then would extract the air containing the vapors from the well and transfer it to the STAR Center where it would be discharged into the air. The vapor extraction component would also lower the pressure inside the well, facilitating the air-stripping and sparging processes.

The water that would be pumped from the bottom of the well and sprayed in at the top of the well would infiltrate from the well back into the aquifer at the top of the water table. Continuous pumping from the bottom of the well would cause some of the water to circulate from the top of the well back to the bottom of the well, resulting in multiple passes through the system. Because 1,4-dioxane is very difficult to strip from water, multiple treatment cycles would be necessary to meet CTLs. The water infiltrating back into the aquifer would contain high concentrations of dissolved oxygen, and some of this oxygenated water would move away from the well. The resulting zone of oxygenated water around the well would potentially facilitate aerobic biodegradation of contaminants.

A review of case studies has shown that a typical ART well has a ROI of about 75 ft (based mainly on dissolved oxygen measurements; the ROI of groundwater recirculation is less). At each ART well location, two ART wells would be required to treat the entire surficial aquifer due to the semiconfining layer discussed in Section 3.1. This layer could limit or preclude complete recirculation of groundwater. Therefore, one ART well would be installed to a depth of 20 ft bls in the shallow surficial aquifer, and the second well would be installed at roughly 20 to 40 ft bls (soil cores at each location would define the exact depth of the confining layer, and well depth adjusted accordingly). Each well would contain a pneumatic water pump, a pipe for air sparging, and a pipe for vapor extraction.

A requirement of the ART well system is that some headspace be present in the well at all times for the stripping process. The water table at the site can be at the surface during the wet season, so the ART wellheads would be placed 6 ft above ground surface. A 2 ft diameter enclosure would be placed over each pair of 6-inch-diameter ART wells to minimize visual impact and four concrete bollards would be installed around the enclosure to protect the wells from vehicle traffic. The installed horizontal dimension, including concrete bollards, would be about 5 ft × 5 ft, and the 2 ft diameter enclosure would be about 7 ft tall.

The controls, instrumentation, vacuum blowers, air compressors, tanks, and piping for all the wells would be located in a single new building with an approximate dimension of 11 ft high × 20 ft wide × 24 ft long. The new building would be located adjacent to the east side of Building 100. Three sets of 4-inch-diameter trunk lines for the vapor extraction and a 1.5-inch-diameter trunk line for air sparging would exit this building underground and extend to

the onsite wells (for plume control) and through the 6-inch-diameter under-road pipelines to the east and south offsite plumes (Figure 13).

Based on the estimated ROI, 10 ART well pairs would be located in the core of the east plume, and 11 ART well pairs would be located in the core of the south plume (Figure 13). Each ART well would have a line for air sparging and a line for vapor extraction connected to the trunk lines originating at the control building on the STAR Center.

A pilot test would be required to determine actual ROI and the resulting well spacing before full-scale implementation.

6.3.3 Chemical Oxidation

Chemical oxidation for groundwater remediation involves injection of a strong oxidizing agent (or combination of agents) into the subsurface. When the oxidizing agent contacts the contaminant, the contaminant is degraded to innocuous species such as carbon dioxide and chloride. The oxidizing agent is not selective for the contaminants, and it would therefore also react with the aquifer matrix and naturally occurring dissolved species. This natural oxidant demand can be considerable and can often drive the project cost. Evaluation of the natural oxidant demand is critical for full-scale design and must be determined by laboratory soil analysis or an in situ pilot test. For this study, an average natural oxidant demand was estimated from the literature.

Several different oxidizing agents are available for groundwater remediation, and injection of the agent can be accomplished by a few different methods (ITRC 2005). After review of the literature and discussion with chemical oxidation technology vendors, persulfate injection was selected for evaluation during this study.

This chemical oxidation alternative would involve injection of persulfate using direct-push technology in a grid pattern covering the entirety of the offsite plumes. The system layout is shown in Figure 14; additional details are shown on Plate D3 in Appendix D. The spacing between injection points is highly dependent upon the hydrogeologic characteristics of the subsurface, and a pilot test is commonly conducted to determine this value before full-scale implementation. A review of the literature suggested that an injection point spacing of 25 ft would be sufficient, and that value was used in the study.

At each injection point location, a direct-push rig would be used to inject persulfate over the full vertical extent of the contaminant plume. The rig would then move to the next location and repeat the injection procedure. A single injection event would involve 118 injection points in the east plume and 112 injection points in the south plume.

Based on case studies, it was assumed that a total of two injection events scheduled 1 year apart would be sufficient. After the first injection event, monitoring of contaminant concentrations using monitoring wells would be conducted for a year, followed by the second injection event, then another year of groundwater monitoring. The second injection event would use a similar grid, except that the second grid would be offset from the first by half a grid cell to ensure that the maximum subsurface area was contacted. If contaminant concentrations remained above

CTLs after the second injection event, additional injection events could be required (but these additional events are not included in this study).

6.4 Plume Control Alternatives

Plume control is defined as controlling the plume on the STAR Center such that contaminant concentrations do not exceed offsite CTLs in groundwater moving off the site. Plume control would be required if any groundwater remediation alternative is implemented. For this study, it was assumed that plume control would need to continue for 50 years, until the contaminant source under Building 100 could be removed or remediated in place. Plume control would still be required after offsite remediation was completed because the contaminant source areas under the building would remain in place, and contaminated groundwater would continue to flow off the property if left uncontrolled.

The basics of the plume control technologies identified in Section 5.3 are identical to the basics of the groundwater remediation technologies identified in Section 5.2 and described in detail in Section 6.3. Therefore, only the layouts for plume control and any other significant differences are discussed in this section.

6.4.1 Groundwater Pumping

Groundwater pumping for plume control would involve four recovery wells onsite: three new recovery wells and the existing recovery well RW03 (Figure 12). The three new recovery wells would be installed in the plume cores adjacent to the south side of Building 100, adjacent to the east side of Building 100, and along the west side of Belcher Road. New effluent piping and electrical conduits to each new recovery well would be required. The new effluent piping would connect to the existing onsite water transfer piping, located along the STAR Center southern property line. The existing electrical power source, located adjacent and east of Building 100, would power the pumps in the wells. Each recovery well would extract up to an estimated 4 gpm of groundwater for a total of 16 gpm, although RW03 likely could be pumped at a higher rate, as discussed in Section 3.1.

6.4.2 ART Wells

ART wells would be placed in a barrier configuration to prevent offsite migration of groundwater contaminants (Figure 13). At each ART well location, two ART wells would be required to treat the entire surficial aquifer due to the semiconfining layer discussed in Section 3.1. In the south plume, three ART well pairs would be installed between the South Pond and the southern property boundary. In the east plume, five ART well pairs would be installed just west of the eastern property boundary.

6.4.3 Chemical Oxidation

Two rows of temporary injection points oriented perpendicular to groundwater flow direction would be used to create a reactive barrier wide enough to ensure complete treatment of contaminants to levels below CTLs before the groundwater moves off the property (Figure 14). An annual persulfate injection frequency would be sufficient to ensure that contaminants are

degraded to CTLs. Direct-push technology would be used for the injection, and the injection point locations would vary slightly from event to event to ensure complete treatment.

In the south plume, 11 injection points staggered in two rows along the width of the groundwater plume would be installed between the South Pond and the southern property boundary. In the east plume, 15 injection points staggered in two rows along the width of the groundwater plume would be installed just west of the property boundary.

7.0 Detailed Evaluation of Alternatives

This section presents the detailed evaluation of the plume management alternatives identified in Section 5 and described in Section 6:

- NAM
- ICs
- Groundwater remediation using either groundwater pumping, ART in-well system, or chemical oxidation
- Plume control using groundwater pumping, ART in-well system, or chemical oxidation

The criteria for the detailed evaluation are described in Section 7.1, and the evaluations are conducted in the subsequent sections.

7.1 Evaluation Criteria

The criteria used to evaluate remedial alternatives, as listed in 62-780.700 F.A.C., were used for this study and are described below.

Long-term and short-term human health and environmental effects
This criterion addresses risks to workers and the general public associated with installation and operation of the alternative. Long-term effects (i.e., those associated with the final cleanup goal) are not addressed for plume control, as this is not the final solution for the site, but are addressed for offsite remediation, NAM, and ICs. Ecological effects (those associated with local plants and animals) were not evaluated because the location is an urban area consisting mostly of parking lots, buildings, and roads.

Implementability
This criterion addresses the ability to construct and operate the alternative, including ease of construction, site access and access agreements, site infrastructure, regulatory and permitting aspects, and public and property owner acceptance or approval.

Operation and maintenance requirements
This criterion includes known and predictable requirements for operating and maintaining the alternative.

Reliability
This criterion addresses the predicted reliability of the alternative during operations, and also addresses potential problems that the system could have based on the knowledge of how the technology works.

Feasibility
This criterion addresses the predicted effectiveness of the alternative at achieving CTLs (for groundwater remediation and NAM), controlling contaminant movement off the site (for plume control), or limiting access to contaminated groundwater (ICs). The criterion also considers the permanence of the effects of the alternative.

Estimated time for alternative to be effective
This criterion is an estimate of the length of time required for the alternative to meet CTLs (groundwater remediation or NAM), to contain the plume (plume control), or to limit access to contaminated groundwater (ICs).

Cost-effectiveness of installation, operation, and maintenance compared to other alternatives
Detailed cost estimates will determine actual capital, construction, and operation and maintenance (O&M) costs for the alternatives. Appendix E contains summaries of the cost estimates and lists the assumptions used for the estimates.

7.2 NAM

NAM is a permissible option that doesn't require formal ICs, other than a notice to the property owner every 5 years. The assumption is that regular monitoring along with regular notifications would serve as de facto ICs for unacceptable groundwater use while natural attenuation is occurring. The applicability of this option would depend on how stable the leading edge of the plume is. The extent of the plume would be defined at the time that NAM is proposed as the site remedy. Monitoring would need to demonstrate that CTLs continue to be met at the downgradient edge of the plume (concentrations should actually be declining, according to RBCA). If CTLs are exceeded, a supplemental groundwater assessment would be required and possible remedial action considered.

Long-term and short-term human health and environmental effects
The risk associated with groundwater contamination at the Building 100 Area is summarized in Section 3.5. The use of NAM for site rehabilitation would not involve the exposure of workers or the public to contaminated groundwater in either the short term or long term; thus, conditions at the site would be expected to remain protective under this alternative.

The use of NAM does not require formally recorded ICs for properties undergoing NAM, so there would be no legally enforceable mechanism to prevent the installation of shallow wells that could be used for drinking water purposes. However, NAM does require that property owners receive notification every 5 years that groundwater contamination exists on their properties (and that certain uses of groundwater are not advisable, e.g., drinking water). This notification would serve as a further deterrent to improper groundwater use. Use of NAM would likely be protective of human health and the environment in both the short term and long term given the multiple deterrents to use of shallow groundwater, though it would not eliminate the possibility that some uncontrolled exposures to groundwater could occur.

Implementability
In order to justify that the application of NAM is appropriate, it would be necessary to demonstrate plume stability—that contaminants do not exceed CTLs beyond the TPOC and that concentrations are declining—to get regulatory approval from the State. FDEP implied that NAM could be a possible option for the Building 100 Area; therefore, it is assumed that the State is willing to consider this option. In practice, this remedy is already implemented, in that natural processes are already working to degrade contaminants.

The remedy wouldn't require any additional construction, though adequate delineation of the east plume and identification of an appropriate TPOC in this area would need to be completed. It is possible that property owners or other stakeholders could have objections to taking a passive approach to groundwater remediation. It is also possible that NAM could be more easily approved for the offsite portion of the plumes if it was combined with groundwater remediation, plume control, or ICs.

Operation and maintenance requirements
Monitoring would be required for NAM. After delineation of the east plume is completed, this remedy probably would require monitoring similar to what is currently planned, as long as the plume is stable or shrinking. DOE would need to continue to demonstrate that CTLs are met at TPOC and that groundwater concentrations are declining (or at least not increasing) in the offsite plumes. If CTLs should be exceeded at the established plume boundary, a supplemental site assessment and evaluation of remedial action would be needed. The likelihood of this occurring would be decreased if NAM were selected in combination with groundwater remediation and/or plume control.

This option would require notification of property owners every 5 years that contamination exists on their properties. DOE would want to track any construction activities on the affected properties to determine if pumping or other exposure to shallow groundwater will occur.

Reliability
If the contaminant plume is stable, NAM would likely be reliable over the long term (i.e., contaminant concentrations would be maintained [or be declining] at the TPOC). However, stability of the offsite plumes has not yet been established, as discussed in Section 3.4.

The reliability of maintaining CTLs at the established plume boundary would be increased if NAM were combined with groundwater remediation and/or plume control. NAM would be a good follow-up option if groundwater remediation did not reach CTLs.

Feasibility
No time limitation is imposed with NAM. It is likely that it would take a prolonged period of time to meet default CTLs (particularly for dioxane), if they are met at all. For the offsite plumes, it is possible that CTLs could be met, particularly if NAM was combined with groundwater remediation and/or plume control. This would result in a finite amount of offsite contamination that would require attenuation.

Estimated time for alternative to be effective
NAM relies solely on natural processes to decrease contaminant concentrations to CTLs. Given the apparent low degradability of cDCE and VC at low concentrations and the documented recalcitrant nature of 1,4-dioxane, dilution would be the most effective natural attenuation process and it is likely that a few to several decades would be required to reach CTLs for the offsite plumes. This relatively long time frame is due to the contaminant source remaining under Building 100 and the slow groundwater velocity. The time frame for NAM to be effective would be much shorter if monitoring was combined with onsite plume control.

Cost
The only costs associated with NAM are monitoring costs. It is likely that additional analytical parameters beyond what is currently analyzed would be necessary to evaluate natural attenuation processes. Potential costs would include a reassessment if CTLs are exceeded at the TPOC.

7.3 ICs

The detailed evaluation of ICs assumes that controls would be placed on **all** properties where groundwater concentrations exceed default CTLs (i.e., drinking water standards). If this alternative were implemented today, properties affected would include all of those within current plume boundaries. The evaluation below is based on the assumption that the extent of contamination is stable and that the plumes are not expanding. However, if this assumption of plume stability is incorrect, properties downgradient of the IC boundary could be impacted by groundwater containing contaminant concentrations above CTLs. The likelihood of this occurring can be reduced by establishing IC boundaries with a buffer zone. Use of groundwater remediation and/or plume control would improve the stability of the plume.

Long-term and short-term human health and environmental effects
The risk associated with groundwater contamination at the Building 100 Area is summarized in Section 3.5. The use of ICs for site rehabilitation would not involve the exposure of workers or the public to contaminated groundwater to implement the remedy in either the short term or long term; thus, conditions at the site would be expected to remain protective under this alternative. The use of ICs, such as an RC , would require formal recording specific controls in the IC registry and would be enforced by the State. The use of ICs would likely be protective of human health and the environment in both the short term and long term, given the legal mechanism to ensure that restrictions placed on a property can be enforced.

Implementability
FDEP has indicated that if the groundwater plumes cannot be remediated to CTLs, then an RC will be required for the STAR Center property as well as for each of the five other properties that have been affected by contaminated groundwater originating on the STAR Center property. Since 2008, DOE has assisted the STAR Center in developing an RC by researching requirements, coordinating with FDEP, discussing the approach with STAR Center personnel, and preparing a draft Declaration of Restrictive Covenant for the STAR Center. Dialogue with the STAR Center and Pinellas County legal counsel regarding the implementation of the document is ongoing.

With respect to obtaining final site closure, it is more acceptable to the State to put ICs on source property than on non-source property.

Operation and maintenance requirements
Groundwater monitoring would not formally be required if ICs were selected as the sole alternative for the site. However, the State would likely require some monitoring; this probably would not require anything more than is currently being done (after delineation of the east plume). The State would be responsible for enforcing the IC. DOE could provide additional IC monitoring as a best management practice.

Reliability
The State of Florida has maintained its IC registry for a number of years and has gained experience in the enforcement of ICs, making them highly reliable—as long as the plume is stable and ICs cover the maximum extent required. The Bureau of Waste Cleanup within FDEP implements the IC/EC [engineering control] Audit Program and conducts audits of all non-petroleum sites subject to IC/EC (FDEP 2010). If a violation of an IC is found, FDEP will pursue enforcement action. Further deterrents to shallow groundwater use, such as poor water quality, zoning restrictions, and availability of alternate water sources reinforce their reliability.

The most significant issue with regard to reliability is in the stability of the leading edge of the plume. As long as the plume is not still expanding at the time ICs are established, the remedy should be quite reliable. A buffer zone between the current leading edge of contamination and the IC boundary would increase the long-term reliability.

Feasibility
If implemented and enforced, RCs should be highly effective in preventing unacceptable exposures to contaminated groundwater. Concentrations of groundwater within the IC boundary would not be relevant to the effectiveness of the remedy as long as the plume remains contained within the IC boundary.

Estimated time for alternative to be effective
Exposures to groundwater are already effectively prevented through existing deterrents to water use. Acquiring formal approvals of ICs from property owners and the State could be a lengthy process. Several years would not be an unreasonable estimate of time. Implementation of ICs allows for final site closure (a “no further action” determination and “site rehabilitation complete order” under RBCA).

Cost
FDEP has suggested that DOE should either clean up to CTLs or implement an IC on each contaminated property. Considering the resources that DOE has spent on developing an IC at the STAR Center, it would be prudent to evaluate the estimated total cost of developing an RC for all of the contaminated properties compared to the cost of conducting active remediation to meet CTLs. If any one of the six property owners refuses to implement an IC, then DOE could be required to implement a different alternative for that property. If active remediation is conducted for a single property, it will likely be more cost effective to conduct the remediation for all six properties, assuming that CTLs can be met.

According to an article in *The Appraisal Journal* (Jackson and Sowinski 2006), “limitations on the use of groundwater as drinking water (potable water) when the groundwater will not be used

for this purpose regardless of contamination would not limit the property's highest and best use, and would not result in an adverse use effect on value."

The exact cost of ICs is impossible to determine currently.

7.4 Groundwater Remediation Technologies

This section describes the detailed evaluation of the three offsite groundwater remediation technologies described in Section 6.3: groundwater pumping, the ART well system, and chemical oxidation.

7.4.1 Groundwater Pumping

The groundwater pumping approach used for this evaluation is described in Section 6.3.1 and shown on Figure 12.

Long-term and short-term human health and environmental effects
Groundwater pumping with ex situ treatment requires the extraction, treatment, and discharge of contaminated groundwater while the system is being operated. Operation of the system requires that adequate personal protective equipment is worn and safety practices are observed to control worker exposures. Treatment system effluent monitoring conducted during operations ensures that concentrations of regulated chemicals in the treatment system effluent are within the STAR Center's wastewater discharge permit limits, thereby protecting the general public as well.

Trenching for the electrical power and water transfer lines would expose shallow, uncontaminated soil. Well installation would result in small amounts of soil saturated with contaminated groundwater being brought to the surface, resulting in some small risk to worker health, but breathing zone monitoring would be conducted to determine if any type of worker protection is needed.

Operation of the system would reduce contaminant concentrations in groundwater in the offsite plume. If combined with onsite plume control, concentrations should decline to levels below CTLs in the offsite plume, reducing the area over which controls (formal or informal) would be needed to restrict the use of groundwater. When operating properly, this alternative would be protective of human health and the environment. Overall long-term risks are reduced by shrinking the size of the plume that must be controlled.

The need to treat groundwater with potentially hazardous chemicals in an ex situ environment would increase the potential for accidental exposures during short-term operation of the system, though the potential risks associated with such an exposure would be low. Hydrogen peroxide is considered a potential hazard due to inhalation, skin/eye contact, and ingestion. Ozone is considered a potential hazard due to inhalation.

Implementability
As shown on Figure 7, a considerable fraction of the groundwater remediation infrastructure is already in place and could be used for this alternative: existing recovery well RW03, under-road pipelines, water transfer piping, and an air stripper. When the electric power lines for RW03 were installed in 2009, capacity for three other potential recovery wells was included.

Construction of the groundwater pumping and ex situ treatment system involves the following. The largest anticipated construction equipment required would be a drill rig and backhoe for installation of the recovery wells and a single utility trench for both the effluent and electrical lines. Installation conflicts with existing buried utilities could be easily avoided by pressurized pipes, electrical conduits, and recovery wells with an ROI of 100 ft. Minimal construction footprint would be required for installation of the recovery wells, concrete vaults, and utility trenching. The construction laydown area would be located outside the paved areas. Because of a minimal construction footprint, minimal pavement removal, and a short duration of construction, installation would be expected to have a low impact to parking lot traffic.

Well vaults would be installed flush with the existing ground surface, and pipes/conduits would be placed underground. The treatment system would be located at the current treatment system area west of Building 100. Once completed, the recovery well system and the treatment system would have no visual impact to private properties or the STAR Center and would not be a hazard for vehicle traffic.

New or revised access agreements would be required for the offsite properties for recovery well installation, trenching, and O&M. In addition, access to the Belcher Road right-of-way would be required to run piping to the east end of the existing pipeline under Belcher Road.

It is likely that the private property owners would accept groundwater pumping because it would have minimal negative impact to property use during construction and almost no impact during operations.

Groundwater pumping requires an ex situ groundwater treatment system that would discharge treated water to the STAR Center's wastewater facility. The PCU Industrial Wastewater Discharge Permit for the STAR Center, No. IE-3002-09/12, allows the STAR Center to discharge treated wastewater through the wastewater facility into the Pinellas County Publicly Owned Treatment Works system. The permit establishes maximum constituent concentrations for discharges into the sewer. DOE has agreed with the STAR Center that any DOE wastewater discharged to the STAR Center's system will meet the standards defined in the STAR Center's wastewater discharge permit. Total toxic organics must not exceed 1.37 mg/L, arsenic must not exceed 0.1 mg/L, total suspended solids must not exceed 650 mg/L, and pH must be in the range of 5.5–11.

The permit does not list 1,4-dioxane as a contaminant, and this constituent does not have an established discharge standard. DOE notified PCU of this contaminant when it was discovered in the wastewater and later inquired as to whether the PCU planned to establish a discharge standard. PCU notified DOE they did not plan to establish a standard but requested that DOE notify PCU if the level exceeded 0.012 mg/L.

It is assumed that the STAR Center would accept disposal of treated groundwater from offsite locations into the STAR Center wastewater facility. DOE would need to pay the STAR Center for disposal of the treated water. If the STAR Center refused to accept the treated water that originated from offsite locations, groundwater pumping would not be a viable alternative unless another water disposal option could be found. A potential option is treatment and disposal of the

water on the offsite properties, but this has not been discussed with the property owners and is not evaluated in this study.

An air permit would not be required to operate the air stripper because it would meet the generic unit exemption under 62-210.300 F.A.C. All wastewater that would be released to the STAR Center's wastewater facility would have to meet the contaminant levels specified in the permit. The permit requires that the STAR Center submit formal written notification to PCU 30 days before the introduction of new wastewater or pollutants to the system and 48 hours before the discharge of treated groundwater to the sewer. The wells would have to meet the well installation requirements of the Southwest Florida Water Management District.

Operation and maintenance requirements

This would be a continuous pumping operation requiring O&M site access at least twice weekly, quarterly, and annually for preventive and corrective maintenance. This would have some visual impact and would require the occasional traffic diversion at the recovery wells, but the durations would be short.

O&M requirements for the groundwater pumping system are as follows.

Recovery Well Pumps

1. Minimum twice weekly:
    - Condition inspection of well vaults, flow meters, check valves, pipes, fittings and tubing.
    - Record operational data (flows, pressures) to ensure correct performance of the recovery wells.
2. Minimum quarterly O&M:
    - Assess the performance of the recovery wells. Consistently poor performance may indicate fouling of the pump impeller chamber or integral check valve. If required, pull fouled pumps for cleaning.
3. Annual O&M:
    - As part of a preventive maintenance program, pull the recovery well pumps and stand pipe sections for cleaning. Redevelop or clean well screen as needed.

Air Stripper #2

1. Minimum twice weekly:
    - Condition inspection of all air stripper components, including pumps, blowers, valves, pipes, fittings, and tanks.
    - Inspect system wye strainer, clean if needed.
    - Record operational data (flows, pressures) to ensure correct performance, adjust system parameters if needed.

2. Monthly O&M:
    - Clean the system wye strainer.
    - Inspect and clean the system flow meter if needed.
    - Inspect and clean the air stripper discharge line air release vacuum breaker.
3. Quarterly O&M:
    - Inspect the air stripper tray assembly, door gasket, and door fittings. Remove, clean, and replace as needed.
    - Inspect and clean the surge tank of scale and biofouling if required.
    - Inspect for condition and function the air-stripper-level switches. Clean and replace as needed.
4. Annual O&M:
    - Replace the air compressor tip seals annually as recommended by the manufacturer.

HiPOx Reactor System

1. Minimum twice weekly:
    - Inspect the injection points, hydrogen peroxide injection pump, oxygen generator, ozone generator, air compressor, flow meters, pipes, fittings, and tubing.
    - Record operational data (flows, pressures, chemical volumes) to ensure correct performance; adjust as necessary to meet operational design criteria.
    - Inspect the hydrogen peroxide storage tank and injection pump.
2. Monthly O&M:
    - Inspect the air compressor air filter and moisture separator, replace as needed per manufacturer's instructions.
    - Replenish the hydrogen peroxide storage tank.
3. Quarterly O&M:
    - Assess the performance of the hydrogen peroxide injection pump. Clean and/or replace the diaphragm assembly as needed.
    - Inspect all flow meters and pressure gauges for proper operation, replace and clean as needed.
4. Semiannual O&M:
    - Assess the performance of the air compressor. Inspect and clean the scroll compressor vane assembly if required.
5. Annual O&M:
    - Replace the air compressor tip seals annually as recommended by the manufacturer.

Reliability

Groundwater pumping is a mature, basic technology and is generally accepted to be operationally reliable. It is common for groundwater pumping systems to exceed operational run

times >80 percent with minimal downtime due to equipment failure. System components are easily serviceable, and replacement parts are generally readily available.

The existing groundwater pumping system at the site consists of recovery well RW03 and an air stripper that operated from December 2009 to May 2011. During its operation, the system achieved an average run time of 83 percent, with one major unplanned shutdown due to equipment failure (failed recovery well pump that was subsequently replaced). The system was intentionally shut down in May 2011 due to the temporary dewatering effluent treatment project.

A HiPOx reactor system would be installed in series, downstream from the air stripper, for the treatment of 1,4-dioxane. Three major components make up the HiPOx reactor system: an oxygen generator, an ozone generator, and a hydrogen peroxide dosing system. A conventional scroll or rotary air compressor is also incorporated to drive the system. The oxygen and ozone generator systems are mature technologies that are widely used in a variety of industries. A chemical dosing system would meter hydrogen peroxide using a positive displacement pump. Reliability would be expected to be very good with these systems, although the success of the HiPOx reaction is dependent on all three technologies operating correctly together. A failure in any one of the HiPOx reactor systems could lead to a failure in the process. To minimize any potential downtime, the air stripper and the HiPOx system would incorporate a telemetry auto dialer function that would alert an operator if a system failure occurred.

Feasibility

To remediate the offsite plumes, three groundwater recovery wells would be installed within the east plume, and four wells would be installed within the south plume (Figure 12). Based on the performances of RW03 and historical recovery wells on other sites at the STAR Center and the 4.5 Acre Site, these new recovery wells should each yield a minimum of 4 gpm and thus produce an ROI large enough (at least 100 ft) to capture all offsite impacted groundwater for transmission to the onsite treatment system. Based on the data obtained during the East Plume Delineation project in the summer of 2011, the east plume is estimated to be about 150 ft wide on the east side of Belcher Road, and the south plume is estimated to be about 150 ft wide on the south side of Bryan Dairy Road.

Again using the results from RW03 as a pilot study, the contaminant concentrations in monitoring wells within the ROI were reduced significantly during the time RW03 was pumped from July 2009 until May 2011. Figure 3 shows the locations of monitoring wells close to RW03 (within 75 ft). The concentrations of all contaminants in these wells decreased to levels near or below CTLs (or even to concentrations below the detection limit) within a year or two after RW03 began pumping. Even more significantly, contaminant concentrations in the 0552 triple-well cluster (located about 145 ft south of RW03) and the 0569 triple-well cluster (located about 220 ft south of RW03) also decreased significantly during RW03 operations. For example, in well 0552-2, VC concentration decreased from 57 μg/L to 1 μg/L between March 2009 and March 2011, and cDCE concentration decreased from 310 μg/L to 2 μg/L during this same time period. These results demonstrate that groundwater pumping can decrease contaminant concentrations to levels below CTLs. The concentration of 1,4-dioxane is very low in the south plume and decreased to levels below detection limit in all monitoring wells within the ROI of RW03.

Estimated time for alternative to be effective
Based on contaminant geochemistry and the observed reductions in contaminant concentrations in wells PIN12-0530 and -0543 during RW03 operation, it is conservatively estimated that five pore volumes would need to be removed from the east and south plumes to reduce the offsite contaminant concentrations to levels below CTLs. The offsite recovery wells proposed in the east and south plumes, assuming an extraction rate of 4 gpm per well, should extract a pore volume approximately every year. Thus, it is conservatively estimated that contaminant concentrations, including concentrations of 1,4-dioxane, could be reduced to levels below CTLs in about 5 years using the pump-and-treat method, if RW03 and the proposed onsite recovery wells are pumped concurrently to control the plumes from continuing to migrate offsite.

Cost
The estimated cost for 5 years of groundwater pumping is $604,000 for the east plume and $664,000 for the south plume. Additional cost information is included in Appendix E.

7.4.2 ART In-Well System

The ART in-well system is described in detail in Section 6.3.2.

Long-term and short-term human health and environmental effects
The ART in-well system does not require the extraction, treatment, or discharge of contaminated groundwater while the alternative is being implemented. Trenching for the air sparging and vapor extraction lines would expose shallow, uncontaminated soil. Well installation would result in small amounts of soil saturated with contaminated groundwater being brought to the surface, resulting in some small risk to worker health, but breathing zone monitoring would be conducted to determine if any type of worker protection is needed.

During operation of the system, there would be little chance for worker exposure to contaminants because most of the treatment is in situ. The vapor extraction component of the system would transfer contaminant vapors through piping from the offsite plumes onto the STAR Center, where the vapors would be discharged into the air at the control building. The vapors would discharge from a stack through the roof of the building, above the breathing zone. Monitoring conducted during operations ensures that any emissions are within permissible limits, thereby protecting the general public as well.

Operation of the system should reduce contaminant concentrations in groundwater in the offsite plume and also cause the plume to shrink. Eventually concentrations should decline to levels below CTLs in the offsite plume, eliminating any risk.

During implementation and operations, this alternative should be protective of human health and the environment. Overall long-term risks would be reduced by shrinking the size of the plume that must be controlled.

Implementability
During construction of the ART well system, the largest anticipated construction equipment required would be a drill rig and backhoe for installation of the ART wells and a single utility trench for both the air-sparging and vapor extraction lines. Minimal construction footprint would be required for the installation of the ART wells and utility trench. The construction laydown

area would be located outside the paved areas. The construction footprint would be minimal, and installation would have a low impact to parking lot traffic and involve minimal pavement removal. The air sparging and vapor extraction lines would be placed underground, and any conflict with existing buried utilities could be avoided.

For each installation location, two ART wells would be constructed, one for the shallow and one for the deep portions of the surficial aquifer (Plate D2 in Appendix D). The wellhead of each ART well would be 6 ft above ground to provide headspace for the sparging, stripping, and vapor extraction processes. Each pair of 6-inch-diameter ART wells would be inside a 2 ft diameter enclosure to minimize visual impact and protected from vehicle traffic with four concrete bollards. The installed horizontal dimension, including concrete bollards, would be about 5 ft × 5 ft, and the 2 ft diameter enclosure would be about 7 ft tall. The wells must meet the well installation requirements of the Southwest Florida Water Management District.

Figure 13 shows the optimal locations for the ART wells based on the plume location. Most of these well locations are in access roads and parking spaces, and a few of them are in the landscaping features. Although some of the wells could be repositioned slightly to be in parking lot islands or within the landscaped areas, most cannot be moved to those locations without causing incomplete plume treatment. A 2 ft diameter enclosure 6 ft above the ground creates a negative visual impact for private property owners and a possible hazard to vehicle traffic. Thus, the ART well system may have significant limitations in terms of implementability.

The ART well system is a continuous remediation operation that would require O&M site access at least twice weekly, quarterly, and annually for preventive and corrective maintenance. A new or revised site access agreement would be required for construction, operation, and maintenance of the ART well system. In addition, access to the Belcher Road right-of-way would be needed to run piping to the east end of the existing pipeline under Belcher Road.

The ART well system would emit contaminant vapors into the air. The FDEP guidance document *Considerations of Air Emissions from Hazardous Waste Cleanup Sites* (FDEP 2008) specifies the following limits. An air permit would not be required as long as the maximum air emissions do not exceed 2.7 pounds per day for any single hazardous air pollutant or 6.8 pounds per day for total hazardous air pollutants. The Generic Unit Exemption under 62-210.300 F.A.C. would apply because the emissions from the unit would not have the potential to emit lead compounds in excess of 500 pounds per year; 1,000 pounds per year of any hazardous air pollutant; 2,500 pounds per year of total hazardous air pollutants; or 5 tons per year of any other regulated pollutants. Calculations using average concentrations were performed to estimate the total mass of contaminants in the offsite plumes. The east plume contains approximately 4 pounds and the south plume contains approximately 16 pounds. Based on the mass estimates, the air emissions from the remediation would not exceed any of the above limits and therefore would not require an air permit. A Remedial Action Plan or similar documentation prepared for the chosen remedial option would document the potential air emissions and verify that they would be below regulatory limits.

Operation and maintenance requirements

The ART well system would have the following O&M requirements.

1. At least twice weekly:
    - Condition inspection of the above-grade well casings, well vaults, flow meters (if installed), vacuum gauges (if installed), and tubing.
    - Record wellhead operational data (flows and vacuum) to ensure correct performance of the in-well air strippers.
2. Quarterly O&M:
    - Assess the operational performance of each ART in-well stripper system. Consistently poor performance may indicate fouling of the well screens and pneumatic pumps that may require chemical and/or physical cleaning.
3. Annual O&M:
    - As part of a preventive maintenance program, check and clean as needed all ART well pneumatic pumps.
    - As part of a preventive maintenance program, clean the ART well screens.

ART system treatment building components (three systems housed in a centralized treatment building) would have the following requirements.

1. At least twice weekly:
    - Record operational data from each ART well system to ensure correct performance (flows, temperature, vacuum, and pressures); adjust as necessary to meet operational design criteria.
    - Condition inspection of all system components, including instrumentation, for proper operation.
    - Check the knock-out tank systems for correct operation.
2. Monthly O&M:
    - Inspect the air filters and moisture separators of the air compressors, replace as needed per the manufacturer's instructions.
    - Inspect the in-line air filter of the vacuum blower; clean as needed.
3. Quarterly O&M:
    - Inspect the oil level of the air compressors; top off as needed.
4. Semiannual O&M:
    - As part of a preventive maintenance program, inspect the vanes of the air compressors; replace if needed as recommended by the manufacturer.
    - As part of a preventive maintenance program, replace the oil in the air compressors as recommended by the manufacturer.
    - As part of a preventive maintenance program, replace all air compressor air filters as recommended by the manufacturer.

Reliability
ART technology incorporates three systems: in situ air stripping, air sparging, and vapor extraction. An onsite centralized equipment building would house air compressors, vacuum blowers, and air/water separator systems for each treatment zone (local plume, east plume, and south plume). Each treatment zone would incorporate a number of ART wells that would be connected to the central equipment building via underground pipelines (for compressed air feed and vacuum extraction). Conventional rotary vane air compressors and regenerative vacuum blowers would be used for air sparge, air stripping, and ART well vapor extraction systems. Reliability of these systems has been established in the environmental industry as good, although a major mechanical failure of either an air compressor or vacuum blower would render a zone inactive until it is repaired or replaced. To minimize any potential downtime, an auto-dialer telemetry function would be incorporated to alert an operator if a system failure occurred.

Each ART well is an in situ air stripper with vapor extraction. The addition of forced air into the subsurface via in-well stripper circulation and air sparging creates favorable conditions for iron fouling of well screens, stripper spray nozzles, and pneumatic pumps if dissolved iron is present at significant concentrations. Background concentrations of dissolved iron are relatively high at the Pinellas site, and the potential is therefore present for ART well fouling that may require regular cleaning. The vendor has confirmed that one of the most important O&M requirements of ART well systems is periodic cleaning (chemical and/or physical) of the well screens and equipment to maintain operational reliability.

Feasibility
The ART well vendor, Specialty Systems Integrators, Inc., has proposed a plan for the use of ART wells to control the east and south plumes onsite and treat the offsite plumes. The design of the ART wells would be the same both onsite and offsite, and their operation should allow for their use for both plume control and groundwater remediation.

The ART wells would be installed as shallow and deep pairs because of the discontinuous but common low-permeability layer present in the surficial aquifer, typically at about 20 ft bls. For a single ART well installed over the entire depth of the surficial aquifer, this low-permeability layer would likely prevent the recirculated water at the top of the water column from traveling downward vertically to the depth of the pump, thus short-circuiting the designed operation of the ART well.

A review of case studies has shown that a typical ART well has a ROI of about 75 ft, and that value was used for this study. In addition, this technology has had success at removing contaminant mass (volatile organic compounds and 1,4-dioxane) in a relatively short period of time (90 days or less). However, most of the documented reductions in concentrations do not typically end with final concentrations below CTLs. It is unclear whether this is a result of the relatively short case history times or an inability of the ART well design to reduce concentrations of volatile organic compounds and 1,4-dioxane to levels below CTLs. The 1,4-dioxane is of particular interest in the east plume, and no full-scale project that was reviewed showed that concentrations of this compound can be reduced below the CTL of 3.2 µg/L with the use of ART wells. One pilot test, however, suggests that the CTL for 1,4-dioxane can be met. Based on these case studies, therefore, it is not possible to estimate, with any degree of confidence, the feasibility of ART wells to reduce site COPCs to CTLs.

The ART well system significantly increases dissolved oxygen concentrations in groundwater, potentially resulting in some degree of aquifer clogging due to oxidation of dissolved species such as iron and subsequent precipitation of solids (such as iron oxides).

Estimated time for alternative to be effective
Assuming that the ART well system would operate as effectively as the vendor claims, the estimated time for the system to decrease contaminant concentrations to CTLs is 10 years. ART well case studies show significant decreases in contaminant concentrations over time frames of a year or less, but nearly all of these are decreases from very high concentrations to concentrations in the hundreds or thousands of micrograms per liter. As discussed under the Feasibility criterion above, there is very limited evidence that the ART well system can meet CTLs. Thus, a very conservative estimate of time required to meet CTLs was necessary.

Cost
The estimated cost for 10 years of operation of the ART well system is $2,270,000 for the east plume and $2,682,000 for the south plume. Additional cost information is included in Appendix E.

7.4.3 Chemical Oxidation

This section evaluates chemical oxidation using persulfate injection, described in Section 6.3.3.

Long-term and short-term human health and environmental effects
Persulfate would be injected into the subsurface using direct-push technology in two annual events. Each injection event would require several weeks to complete. Implementation of persulfate injection would require that adequate personal protective equipment is worn and safety practices are observed to control worker exposures to persulfate, a very strong oxidant. Persulfate is considered a potential hazard due to inhalation, skin/eye contact, and ingestion. Mishandling of persulfate could cause a significant injury.

Operation of the system would reduce contaminant concentrations in groundwater in the offsite plumes. Concentrations should eventually decline to levels below CTLs. Overall long-term risks would be reduced by shrinking the size of the plume that must be controlled.

Implementability
During implementation of persulfate injection, the largest anticipated equipment used for the direct-push technology would be a Geoprobe. A 1.5-inch-diameter rod would be driven into the ground to inject persulfate at 118 injection points in the east plume and at 112 injection points in the south plume. This small-diameter rod allows much flexibility when working around underground utilities, but the Geoprobe rig would be limited by trees and overhead utilities. The project laydown area would be located outside the paved areas to limit disruption to site users.

Because of the number of injection points and pavement patch/repair at each injection point, installation would create a considerable impact to parking lot traffic.

Site access would be required daily for several weeks during the two annual injection events, and semiannually for sampling of monitoring wells. New or revised access agreements would be required for each of the offsite properties.

This alternative involves underground injection. FDEP provided a letter of acceptance for the proposal to inject persulfate, allowing an approved Remedial Action Plan to function as an injection well permit. The letter specifies that an injection zone of discharge must be determined. Within this zone of discharge, the injected persulfate may cause temporary exceedances of CTLs for certain chemicals (e.g., sulfate and sodium). However, CTLs must be met with the zone of discharge at the end of the project. This requirement to meet CTLs for all injected chemicals could limit the implementability of persulfate injection because it is unknown if concentrations of conservative chemicals like sodium would be sufficiently diluted after the estimated 4-year duration of the project.

The use of chemicals required for in situ oxidation would involve storage, regulatory, and reporting requirements. Sodium persulfate is considered a RCRA hazardous waste with the waste code of D001 (ignitable waste) when disposed of. Sodium persulfate is an oxidizer, and certain storage and safety issues would apply to the use of this chemical.

Property owner acceptance of a project of this type has not been determined. An assumption in the system design was that the parking lots would be repaved after project completion because of the large number of holes installed through the pavement.

Operation and maintenance requirements
No O&M would be required for this alternative because the only action is the injection of the persulfate. Monitoring wells would be sampled semiannually.

Reliability
The only reliability issues with persulfate injection are associated with the equipment used during the injection. A subcontractor would conduct the injection using a direct-push rig. The use of direct-push rigs and the associated injection equipment (tanks, pumps, etc.) for injection of various amendments is a mature technology. Equipment problems can typically be fixed in less than a day, and the local subcontractor typically would have backup equipment nearby that could be brought onsite within an hour or two.

Feasibility
Chemical oxidation has not been implemented previously at the STAR Center for a number of reasons, but the recently identified presence of 1,4-dioxane has resulted in a reevaluation of the applicability of this technology. Because of the recalcitrant nature of 1,4-dioxane in groundwater, extractive technologies and strong oxidants are the only methods that can significantly reduce the concentrations of this contaminant. The chlorinated ethene contaminants can also be degraded by strong oxidants, as demonstrated by a bench-scale test conducted in 1999 using permanganate to destroy contaminants in site soil and groundwater (DOE 2000).

Persulfate was chosen as the oxidant for this study based on a review of case studies and the use of a design tool entitled In Situ Chemical Oxidation for Groundwater Remediation (ESTCP 2010). According to the literature, injection of persulfate should be effective at degrading both the chlorinated ethenes and 1,4-dioxane.

However, the ability of full-scale application of chemical oxidation to decrease contaminant concentrations to levels below the offsite CTLs is questionable for the following reasons.

- The relatively small particle size and heterogeneity of the aquifer matrix results in preferential flow pathways for both groundwater and any injected fluid such as a chemical oxidant. Having the oxidant and the groundwater in the same flow pathway should degrade most of the contaminants, but the contaminants diffuse and disperse into the parts of the aquifer outside the preferential flow pathways. The persulfate oxidant, as with most oxidants, is very reactive, lasting only for a few days, and therefore does not persist long enough to diffuse or disperse into the contaminated areas outside the pathways. Thus, contaminated parts of the aquifer may be untreated.
- The naturally reducing geochemical conditions in the subsurface would cause high oxidant demands. Natural organic matter, metals such as iron, and other inorganics all will use up part of the injected oxidant. A pilot test would have to be conducted to quantify the natural oxidant demands prior to full-scale application.
- Oxidation of iron, sulfur, and other species could result in precipitation of solids in the aquifer pore space, potentially clogging parts of the aquifer. Clogging could lead to incomplete treatment of the contaminants.
- Chemical oxidation would change the redox conditions in the subsurface, potentially causing mobilization of metals from soil.
- Sulfate and sodium remain behind after persulfate reacts in the aquifer and can potentially cause an exceedance of the sulfate or sodium CTL. A temporary exceedance of the CTL is allowed by FDEP, but the CTL must be met at the end of the project.

In addition, it was assumed that blocking Bryan Dairy Road and Belcher Road to inject a chemical oxidant into the plumes under the roadways would not be possible, so this approach would not treat the section of plumes under the roadways.

If a chemical oxidation approach to remediation of the offsite plumes was chosen for full-scale application, an in situ pilot test would be required to determine the natural oxidant demand, estimate the ROI of the injection, and demonstrate that CTLs could be achieved.

Estimated time for alternative to be effective

Studies of persulfate injection at other sites suggest that two separate injection events could be sufficient to degrade the contaminants to CTLs. Figure 14 shows the layout of the injection locations for the initial injection event. The second injection event would use a similar grid, except that the second grid would be offset from the first by half a grid cell to ensure that the maximum subsurface area was contacted. A year of monitoring would follow each injection event to evaluate effectiveness at meeting CTLs. Therefore, the current estimate of time to reach CTLs is about 4 years after the initial injection.

Due to the various factors described under the feasibility criterion above, such as clogging and short persistence of the oxidant, it is possible that additional injection events could be necessary, and this could result in an additional few years before CTLs are met.

Cost
The estimated cost for 4 years of chemical oxidation is $2,201,000 for the east plume and $2,158,000 for the south plume. Additional cost information is included in Appendix E.

7.5 Plume Control Technologies

This section describes the detailed evaluation of the three plume control technologies described in Section 6.4: groundwater pumping, the ART well system, and chemical oxidation. The assumption for this study was that plume control would be required for 50 years.

The basics of the plume control technologies are identical to the basics of the groundwater remediation technologies evaluated in Section 7.4. Therefore, only the significant differences are discussed in this section.

7.5.1 Groundwater Pumping

This alternative is described in detail in Section 6.4.1.

Long-term and short-term human health and environmental effects
For this criterion, the evaluation of groundwater pumping for plume control is the same as the evaluation of groundwater pumping for groundwater remediation (Section 7.4.1).

Implementability
For this criterion, the evaluation of groundwater pumping for plume control is the same as the evaluation of groundwater pumping for groundwater remediation (Section 7.4.1).

Operation and maintenance requirements
For this criterion, the evaluation of groundwater pumping for plume control is the same as the evaluation of groundwater pumping for groundwater remediation (Section 7.4.1).

Reliability
For this criterion, the evaluation of groundwater pumping for plume control is the same as the evaluation of groundwater pumping for groundwater remediation (Section 7.4.1).

Feasibility
Recovery well RW03 has been in operation since July 2009; the well has essentially operated continuously from March 2010 until May 2011 and has served as a pilot test for plume control. During this 15-month period, more than 3.4 million gallons of water were pumped from the well at an average flow rate of over 5 gpm. At peak performance, RW03 yielded between 7 and 8 gpm. During these times of peak performance, the ROI created by RW03 in the surficial aquifer was estimated to be about 200 ft, based on site flow maps (Figure 2).

Significant decreases in contaminant concentrations were observed in monitoring wells within the ROI of the well after it began groundwater pumping, demonstrating that the well captured the plume. These decreases were observed as far away as the 0569 triple-well cluster on Harrod property south of Bryan Dairy Road, a distance of about 220 ft (Plate 1). <u>This demonstrates one of the significant advantages of groundwater pumping for plume control: it would pull back the</u>

plume from under roads, significantly facilitating the application of NAM, ICs, or active offsite remediation.

RW03 is constructed of 4-inch-diameter, Schedule 40 PVC, with 0.01-inch slot screen set from 3 to 38 ft bls (i.e., screened through the entire vertical length of the surficial aquifer). It is expected that recovery wells constructed similarly to RW03 would produce ROIs in the Building 100 area similar to that estimated around RW03. Based on this capture zone, it is expected that pumping groundwater from an additional three recovery wells should control the offsite migration of dissolved contaminants to the south and east. The proposed locations of the additional recovery wells are shown on Figure 12. For the south plume, one additional recovery well would be installed immediately south of the building to prevent the accelerated movement of the contaminants from beneath the building toward RW03. For the east plume, a pair of recovery wells would be installed in the same manner as to the south, with one well near the building and one near the property line.

Estimated time for alternative to be effective
Based on evidence from recovery well RW03 and many other recovery wells that have operated at the STAR Center, groundwater pumping would capture and control the plume within days of startup.

Cost
The estimated cost for 50 years of groundwater pumping for plume control is $1,831,000 for the east plume and $1,609,000 for the south plume. Additional cost information is included in Appendix E.

7.5.2 ART In-Well System

The ART well system for plume control is described in Section 6.4.2.

Long-term and short-term human health and environmental effects
For this criterion, the evaluation of the ART well system for plume control is the same as the evaluation of the ART well system for groundwater remediation (Section 7.4.2).

Implementability
For this criterion, the evaluation of the ART well system for plume control is the same as the evaluation of the ART well system for groundwater remediation (Section 7.4.2).

Operation and maintenance requirements
For this criterion, the evaluation of the ART well system for plume control is the same as the evaluation of the ART well system for groundwater remediation (Section 7.4.2).

Reliability
For this criterion, the evaluation of the ART well system for plume control is the same as the evaluation of the ART well system for groundwater remediation (Section 7.4.2).

Feasibility
For this criterion, the evaluation of the ART well system for plume control is the same as the evaluation of the ART well system for groundwater remediation (Section 7.4.2).

Estimated time for alternative to be effective
As discussed in Section 7.4.2, there is little evidence that the ART well system can decrease contaminant concentrations to CTLs, so an estimate of time to control the plume is unknown.

Cost
The estimated cost of using the ART well system for plume control for 50 years is $3,956,000 for the east plume and $2,467,000 for the south plume. Additional cost information is included in Appendix E.

7.5.3 Chemical Oxidation

Chemical oxidation using persulfate injection for plume control, described in Section 6.4.3, is evaluated in this section.

Long-term and short-term human health and environmental effects
For this criterion, the evaluation of chemical oxidation for plume control is the same as the evaluation of chemical oxidation for groundwater remediation (Section 7.4.3).

Implementability
For this criterion, the evaluation of chemical oxidation for plume control is the same as the evaluation of chemical oxidation for groundwater remediation (Section 7.4.3).

Operation and maintenance requirements
For this criterion, the evaluation of chemical oxidation for plume control is the same as the evaluation of chemical oxidation for groundwater remediation (Section 7.4.3).

Reliability
For this criterion, the evaluation of chemical oxidation for plume control is the same as the evaluation of chemical oxidation for groundwater remediation (Section 7.4.3).

Feasibility
For this criterion, the evaluation of chemical oxidation for plume control is the same as the evaluation of chemical oxidation for groundwater remediation (Section 7.4.3).

Estimated time for alternative to be effective
For this criterion, the evaluation of chemical oxidation for plume control is the same as the evaluation of chemical oxidation for groundwater remediation (Section 7.4.3).

Cost
The cost of using persulfate injection for plume control for 50 years is $21,043,000 for the east plume and $16,728,000 for the south plume. Additional cost information is included in Appendix E.

8.0 Summary of Detailed Evaluation of Alternatives

8.1 Summary

This section summarizes the detailed evaluation conducted in Section 7. Table 5 lists the evaluation criteria and the alternatives for comparison.

NAM
DOE inferred from discussions with FDEP that NAM could be an option for the Building 100 Area, and the evaluation conducted in Section 7 demonstrated that NAM could be a viable option. However, NAM requires a stable contaminant plume, and that has not yet been confirmed. For final closure of the entire Building 100 Area, NAM would also require FDEP concurrence that complete source removal under Building 100 is infeasible. NAM would not limit potential access to contaminated groundwater, making it less protective than ICs. The only NAM cost is that for monitoring.

ICs
ICs also appear to be a viable option, but unknown factors such as plume stability, landowner acceptance, and actual cost to implement would need to be considered. FDEP has suggested ICs as an option for the offsite plumes. ICs would be more protective than NAM because the controls to limit access to contaminated groundwater are enforceable by FDEP.

Offsite Groundwater Remediation
Remediation of the offsite plumes to CTLs would best be accomplished by groundwater pumping. Combined with onsite plume control, this alternative has the best chance for success and is the least costly. It is assumed that the STAR Center will accept disposal of treated groundwater from offsite locations into the STAR Center wastewater facility. If not, groundwater pumping would not be a viable alternative unless another water disposal option could be found.

The ART well system may be able to decrease contaminant concentrations, but the ability to meet the 1,4-dioxane CTL is unknown, and this alternative is costly. The required 6 ft stickup for the ART well system would have a negative visual impact and would probably impede traffic and/or potentially other site activities.

Application of chemical oxidation in a reducing aquifer that contains preferential flow pathways likely would have significant limitations that could prevent complete treatment of the contaminants; this alternative is also costly.

Onsite Plume Control
Groundwater pumping is the best option for plume control. Existing groundwater recovery well RW03 has been shown to control the south plume, and additional recovery wells would control the east plume as well. This alternative has no impact to human activities after installation, and is also the least costly plume control alternative. Groundwater pumping also has a distinct advantage over the other plume control alternatives in that it can pull back the contaminant plumes from under the roadways, greatly facilitating any active offsite remediation or implementation of NAM.

As with the ART well system for groundwater remediation, it is unknown if the ART well system can achieve the 1,4-dioxane CTLs and control the plume. This alternative is costly.

Injection of any type of chemical oxidant to control the plumes for 50 years has a very poor chance for success due to clogging by mineral precipitates. This alternative is costly.

8.2 Combinations of Alternatives

Various combinations of alternatives could be applicable for plume management in a number of aspects. As mentioned previously, plume control would be required in combination with active offsite remediation. Plume control would be advantageous combined with NAM and would almost ensure that NAM would be the final solution for the offsite plumes. Table 6 lists the alternatives and their compatibility.

The two plumes could quite likely be managed using completely different alternatives. For example, the south plume offsite contains very little 1,4-dioxane, as described in Section 3.3, potentially leading to use of a different approach than for the east plume, which has 1,4-dioxane at 50 times the CTL. If FDEP was not concerned about 1,4-dioxane in the south plume, injection of emulsified soybean oil would be a good option for the chlorinated ethenes if active remediation were required. Another potential scenario is application of groundwater pumping in the east plume offsite to decrease 1,4-dioxane concentrations to acceptable levels, followed by NAM or ICs for the remaining contaminants (which are less recalcitrant than 1,4-dioxane).

The final selection of plume management alternatives cannot be completed until the east plume is fully delineated and stakeholder input is compiled.

9.0 Comprehensive Plume Management Approach

The scope of this alternatives analysis was to determine how best to manage the contaminant plumes at the Building 100 Area. Evaluation of contaminant source removal under the building was not part of this scope, so the study addressed only management of the contaminant plumes to the south and east of Building 100.

Based on previous studies and modeling, the known contamination beneath the building does not present a health risk to tenants or workers in the building. The contaminants present in the two groundwater plumes that extend beyond the footprint of Building 100 are characterized by relatively low concentrations at depths of about 15 ft or more below land surface, which present no apparent adverse impacts to human health, public safety, or the environment. Although controls are not in place to prohibit access to the contaminated groundwater, the water is of poor quality, and there are no known users in the area. For these reasons, there is merit in taking a graded approach to plume management, with preference given to more passive alternatives unless future monitoring results or other conditions warrant otherwise. The simplified RBCA decision flow process for NAM, ICs, and active remediation is shown in Figure 15.

DOE has already taken action during the past few years by coordinating with STAR Center representatives to develop ICs for the STAR Center in the form of a draft declaration of restrictive covenant, which currently is being reviewed by Pinellas County officials. ICs are a

viable option for the offsite plumes as well, although landowner acceptance and actual cost to implement are relatively unknown factors at this point. If ICs can be applied to all the offsite properties and the plumes do not expand beyond the IC boundaries, no additional action would be necessary.

NAM may be an option for the Building 100 Area, and this alternative is the most cost effective. NAM would not have a legally enforceable mechanism to prevent the installation of shallow wells that could be used to access contaminated groundwater, but would require that property owners receive notification of contamination every 5 years. It is evident that some variation of the current groundwater monitoring program will be required for the foreseeable future, and this monitoring program can be modified as needed to meet the requirements of Chapter 62-780.690 F.A.C. (NAM) with an offsite TPOC. The monitoring would need to demonstrate that the plume is stable or shrinking and that natural attenuation processes are occurring. ICs and NAM are mutually compatible for implementation both onsite and offsite.

If monitoring results show that the NAM or IC requirements were not being met, then a more aggressive alternative could be implemented. The logical next step, if needed, would be implementation of a plume control technology onsite to prevent or minimize continued contaminant migration beyond the STAR Center property boundary or offsite TPOC. NAM could continue as the final solution but would be supplemented by plume control. The onsite plume control alternative is also compatible with offsite ICs.

The last resort and most aggressive alternative would be active remediation of groundwater at the offsite areas. The goal of this active approach would be to decrease contaminant concentrations in groundwater to levels below CTLs. Active offsite remediation would require onsite plume control because continuous movement of contaminated groundwater onto the offsite areas would increase the time needed for offsite remediation and re-contaminate areas at which cleanup had been completed.

If active offsite remediation was conducted for a period of time, but CTLs were not met at all areas, the reductions in contaminant mass and plume size could allow subsequent use of NAM or ICs without additional active remediation.

The ultimate solution for managing the contaminant plumes at the Building 100 Area is to remove the sources of contamination under the building. A follow-on study should be conducted to evaluate current state-of-the-art source delineation and remediation methods. As a high-level planning document, this study would determine if any cost-effective methods were available for (1) partial source remediation or (2) plume control under the building, and would confirm or refute the infeasibility of source removal beneath an occupied building.

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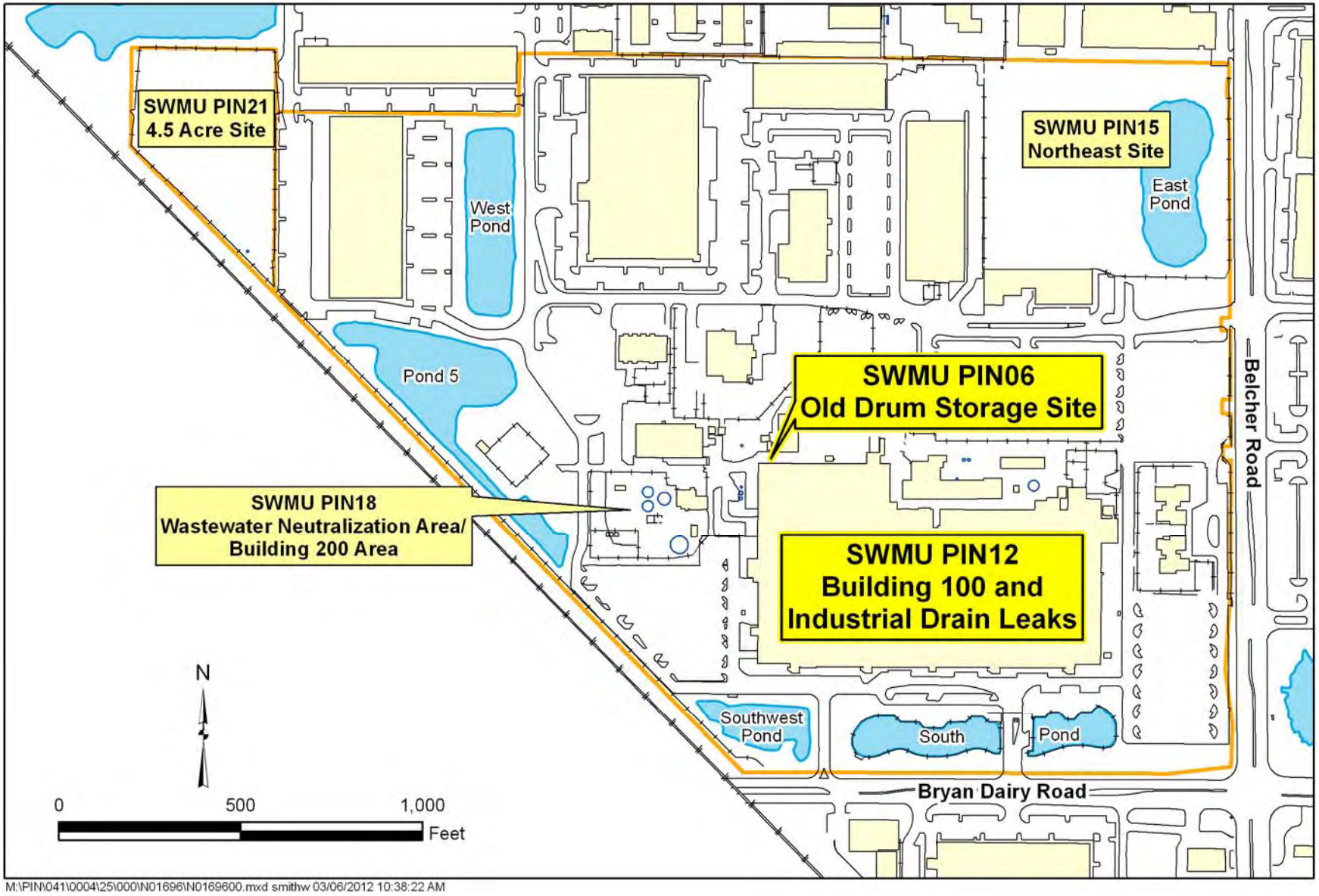

Figure 1. STAR Center Map

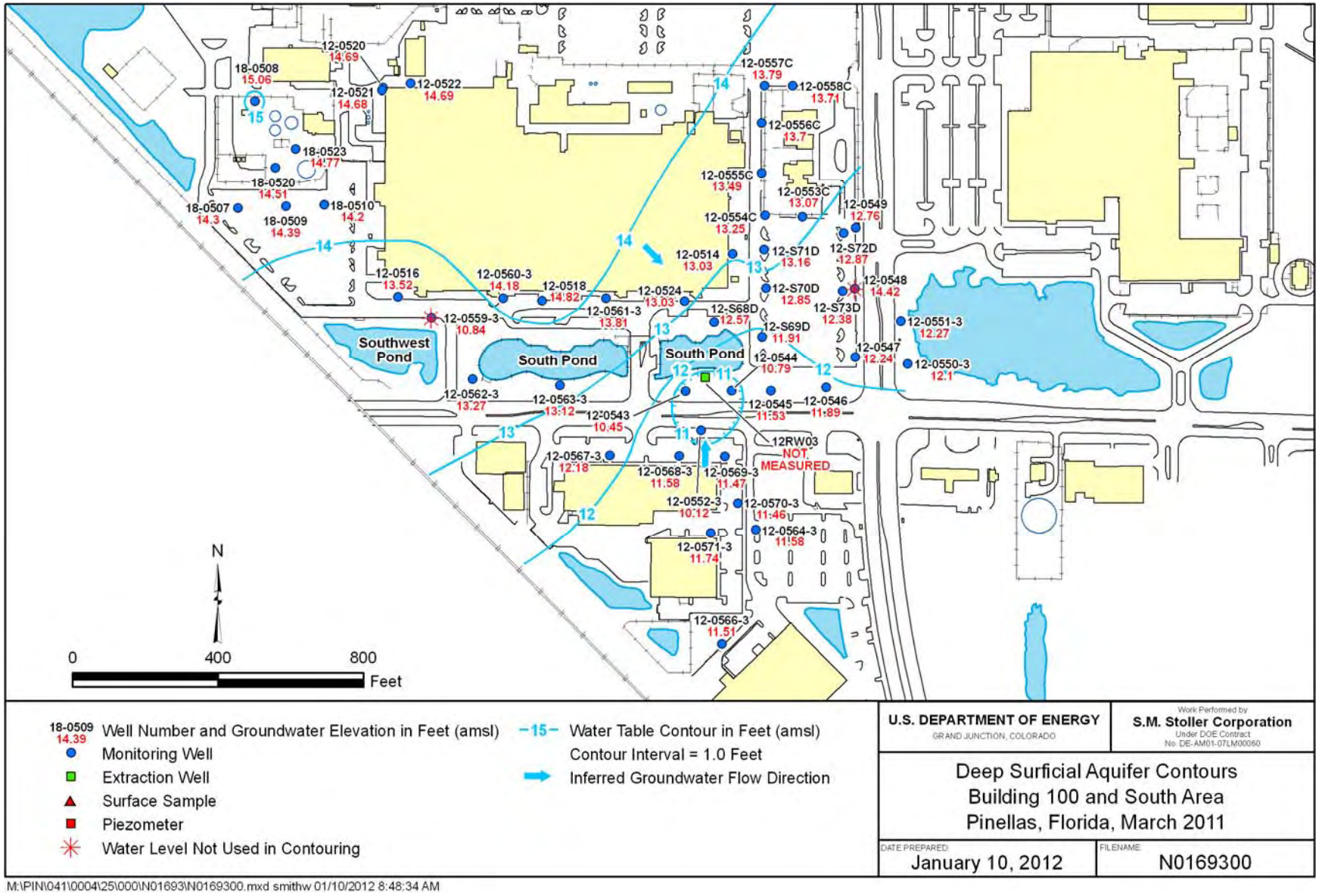

Figure 2. Deep Surficial Aquifer Flow March 2011

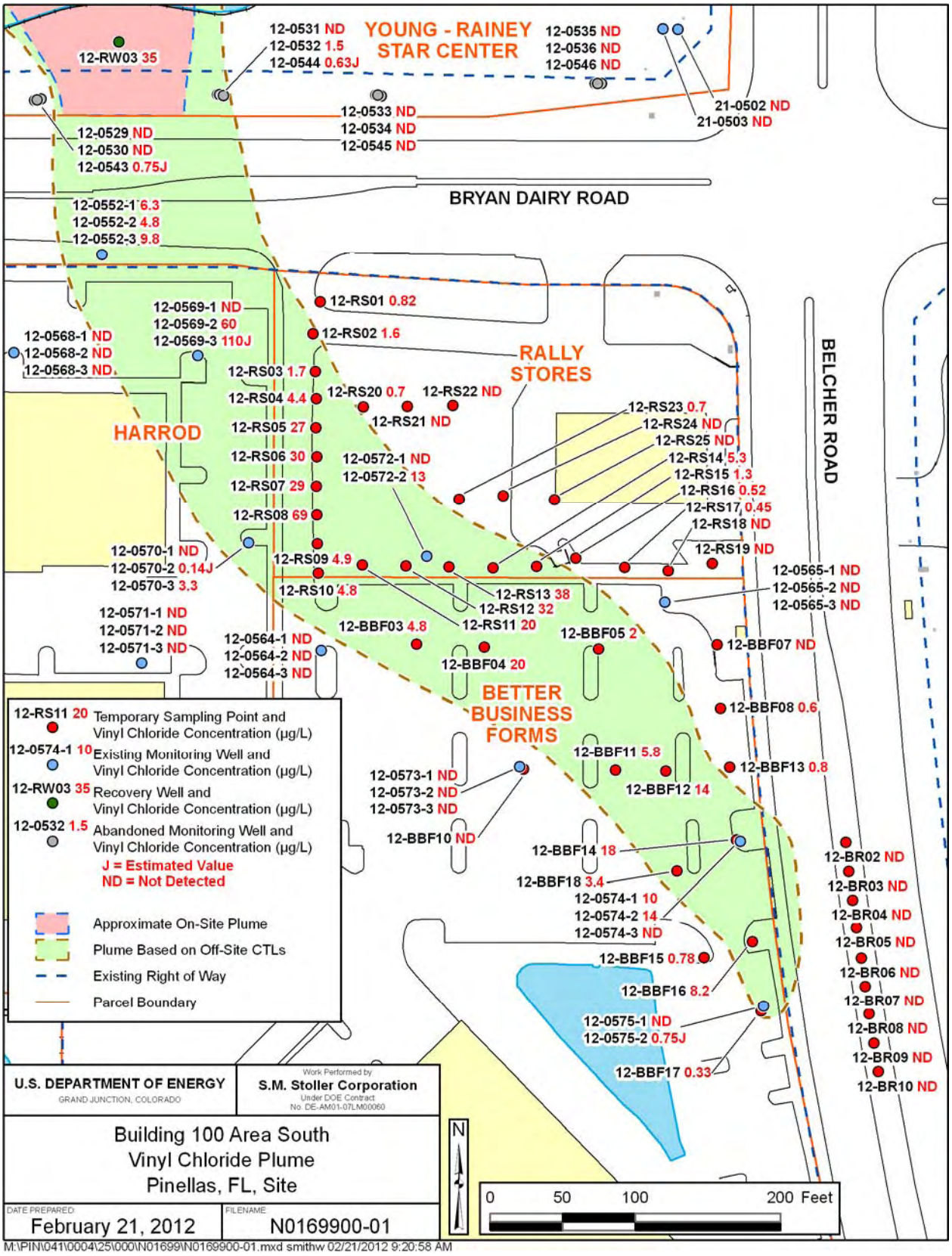

Figure 3. Building 100 Area South Plume—VC

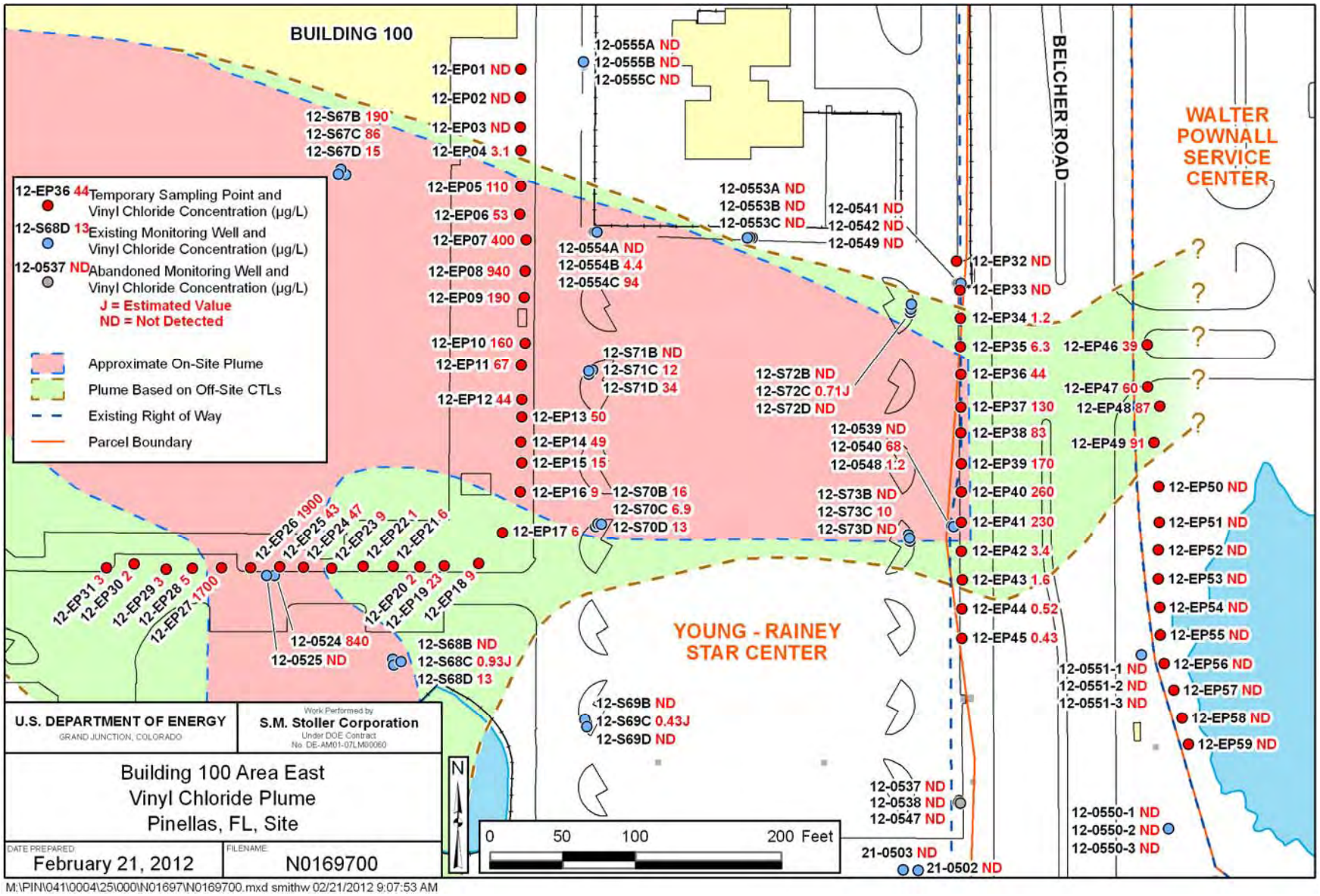

Figure 4. Building 100 Area East Plume—VC

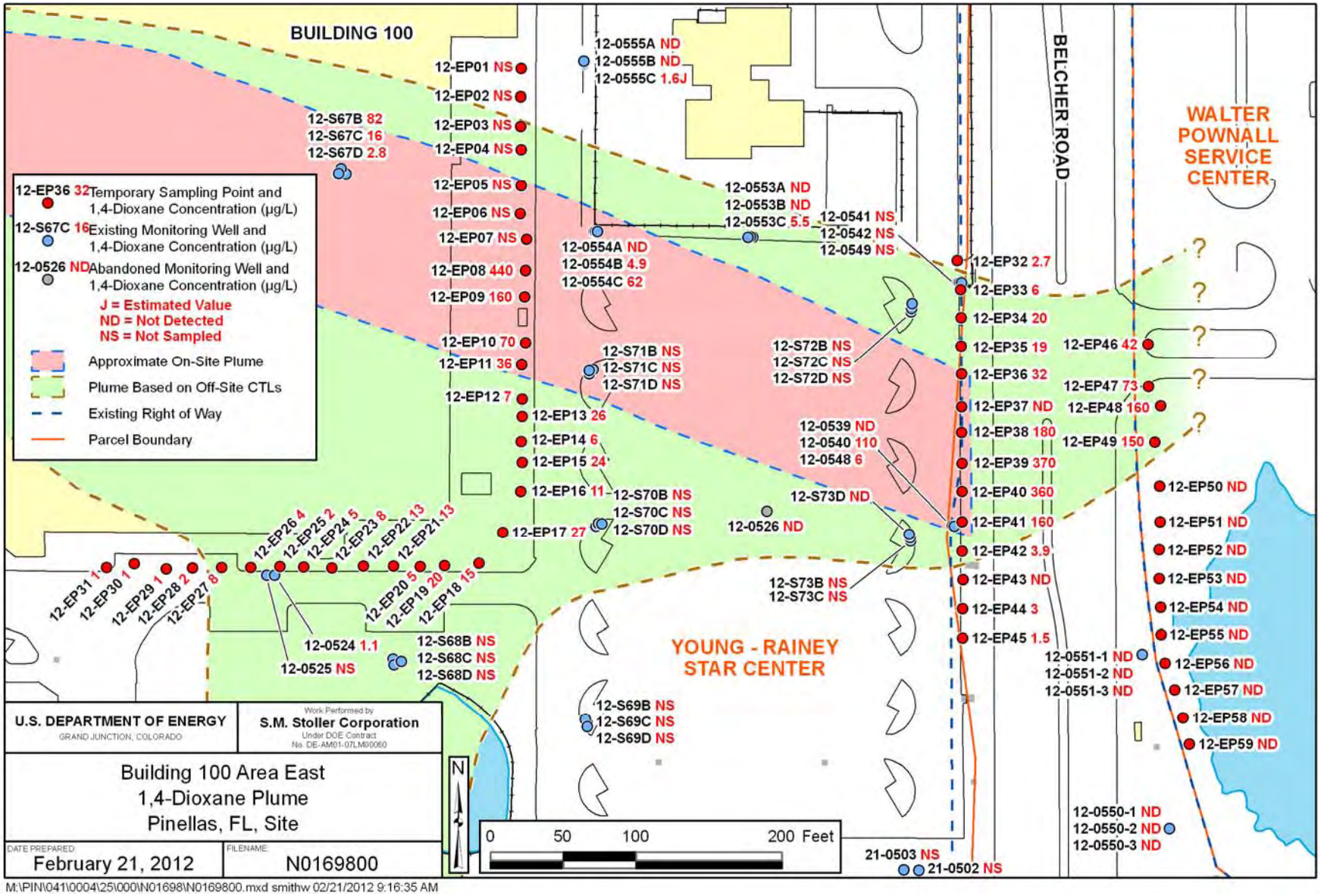

Figure 5. Building 100 Area East Plume—1,4-dioxane

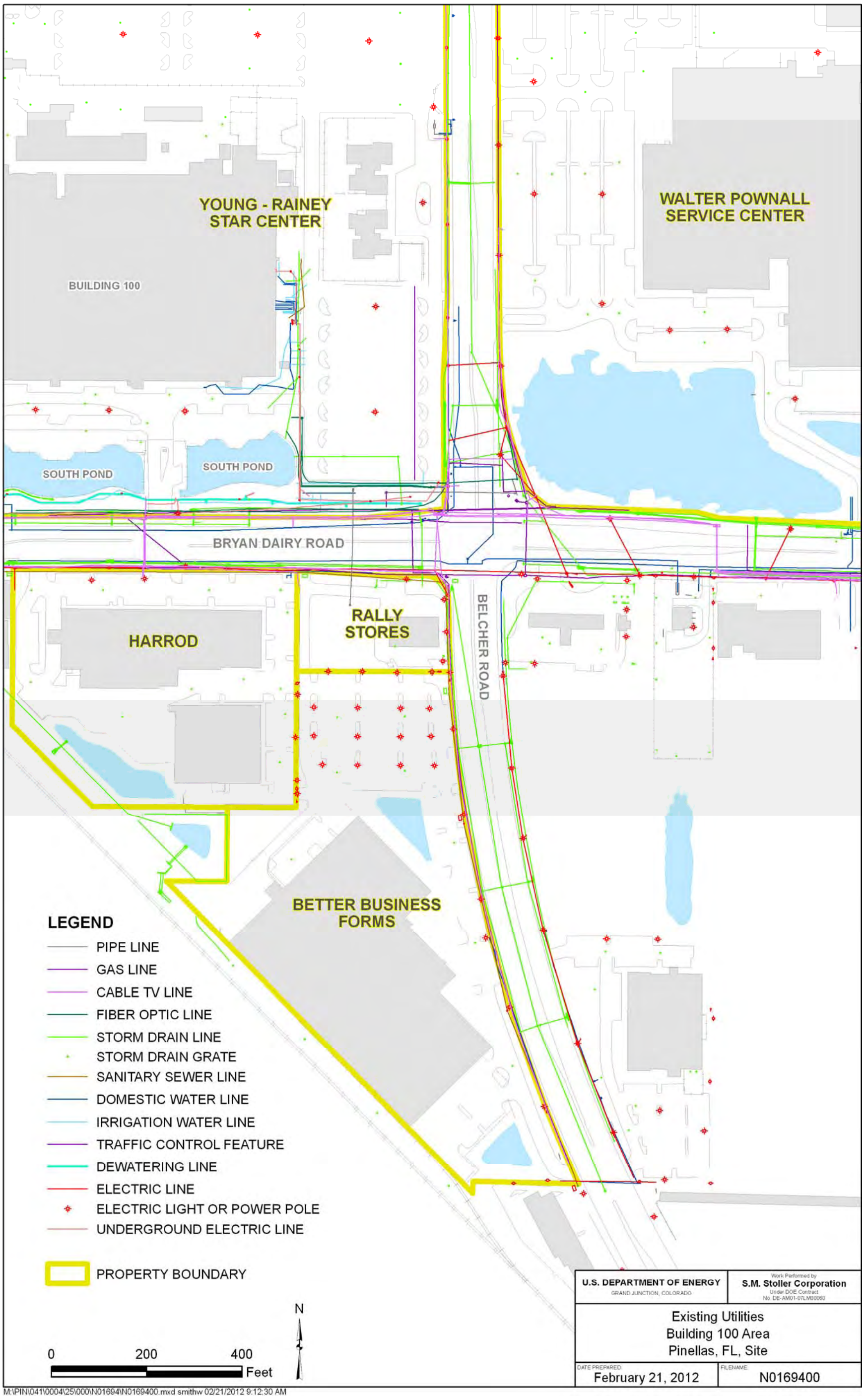

Figure 6. Location of Utilities at the Building 100 Area

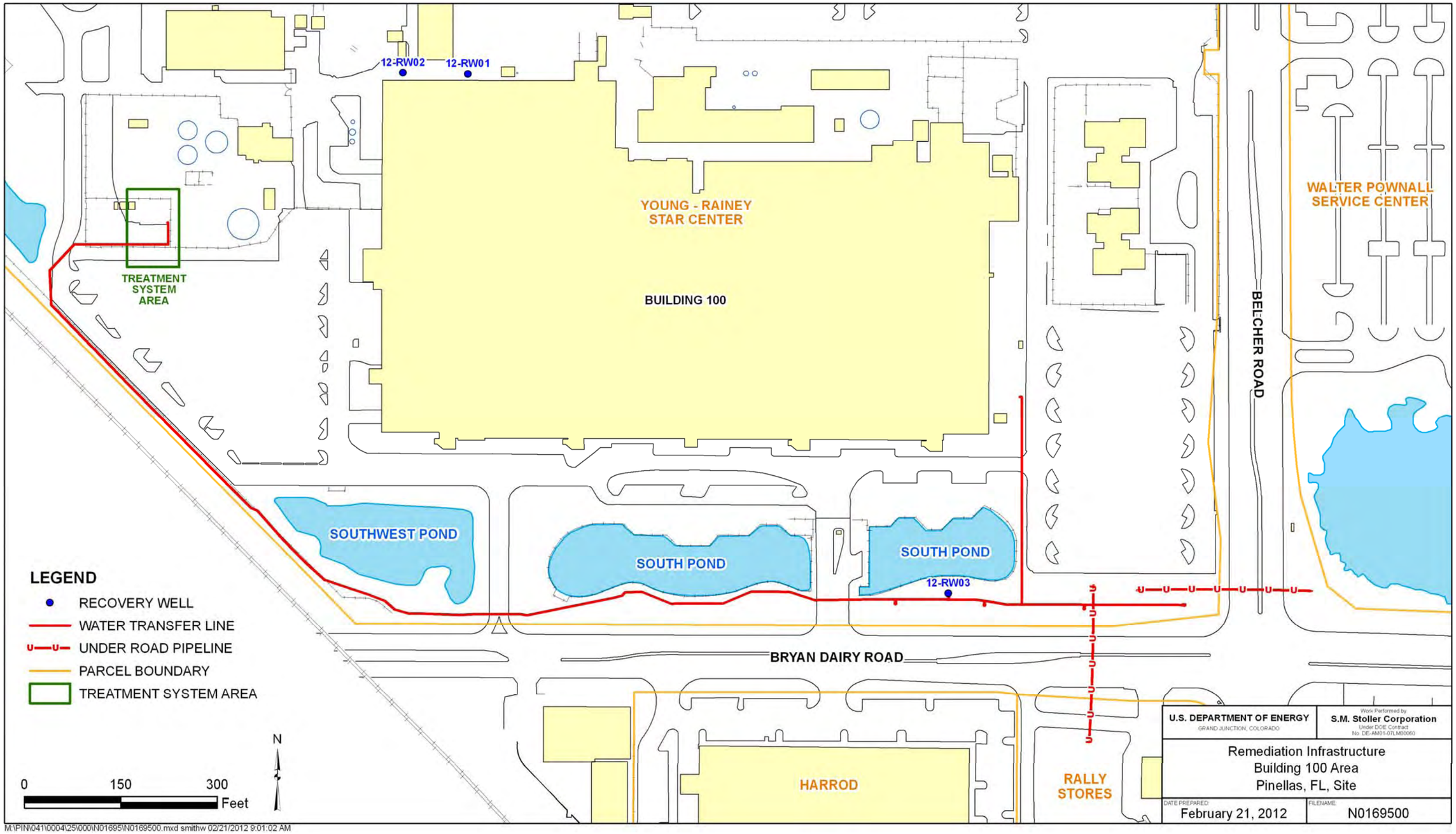

Figure 7. Existing Remediation Infrastructure

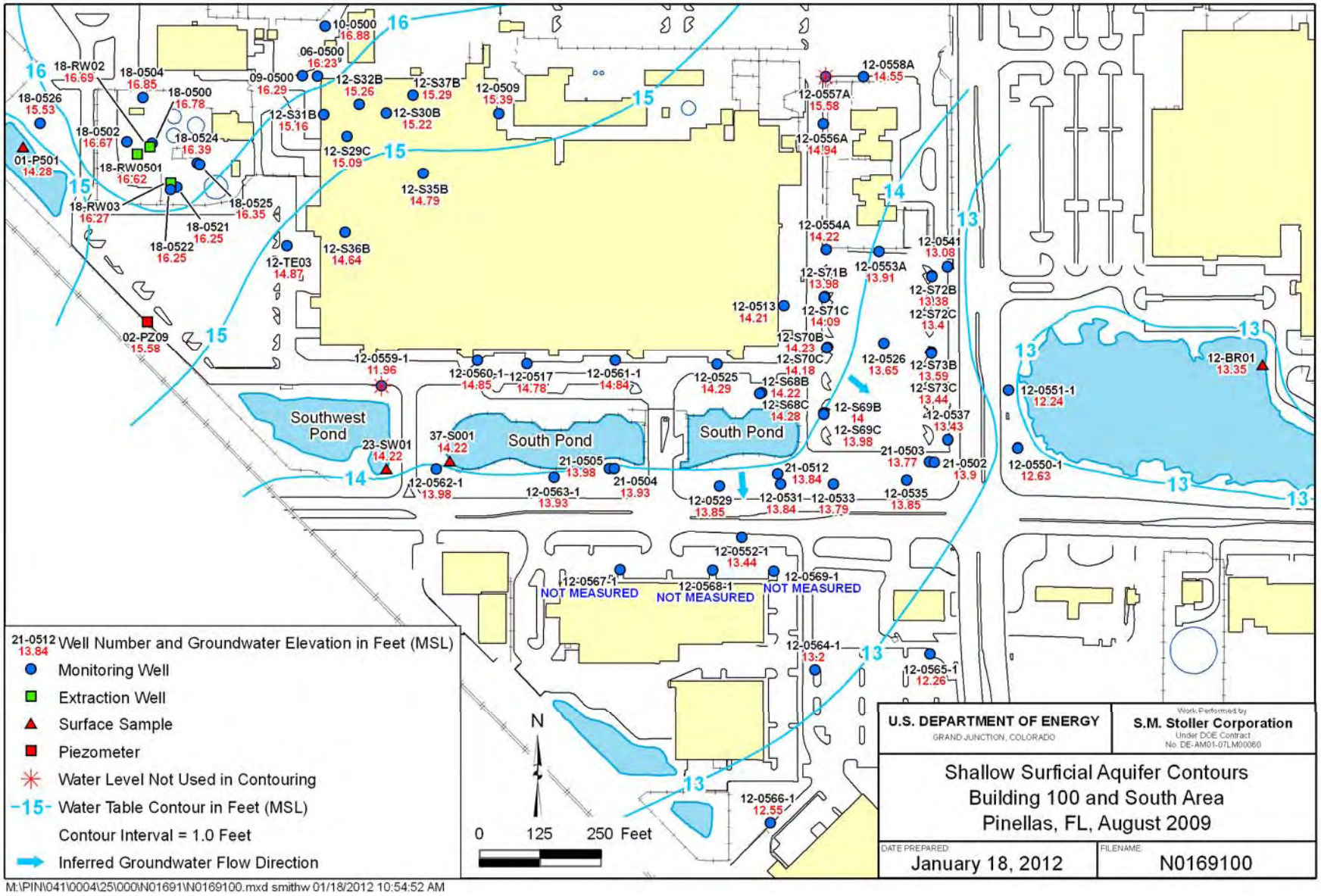

Figure 8. Shallow Surficial Aquifer Flow August 2009

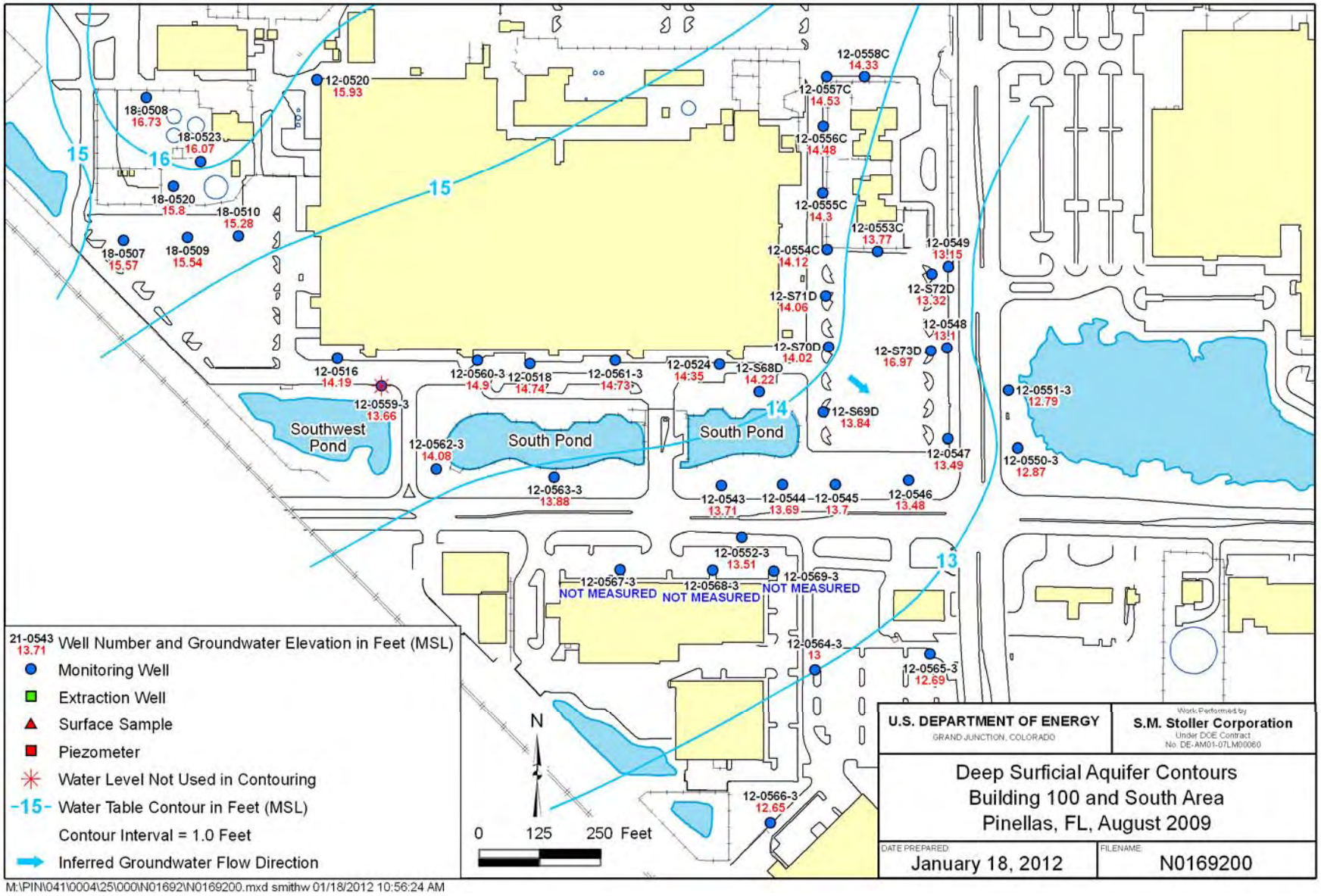

Figure 9. Deep Surficial Aquifer Flow August 2009

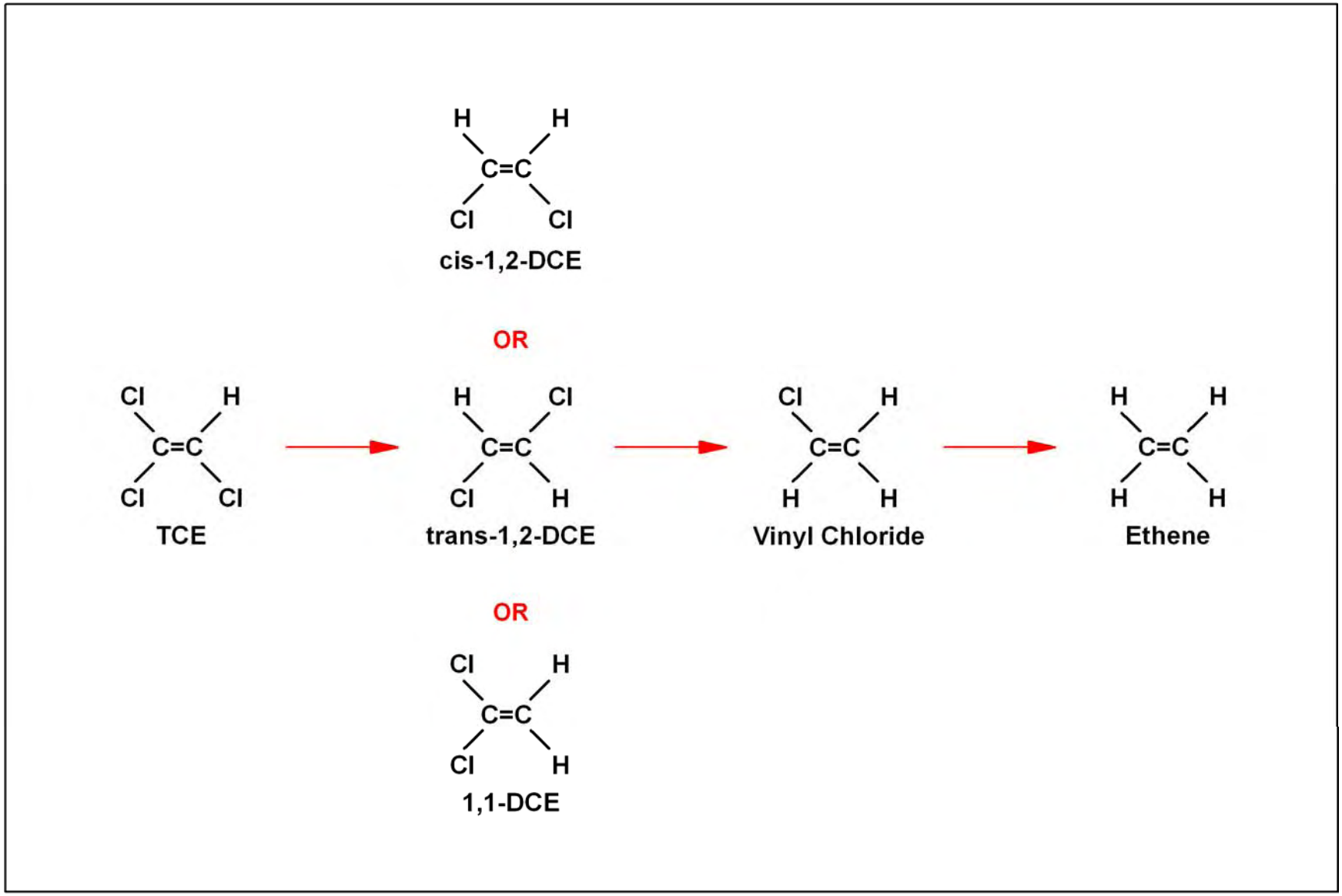

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Figure 10. TCE Biodegradation Pathway

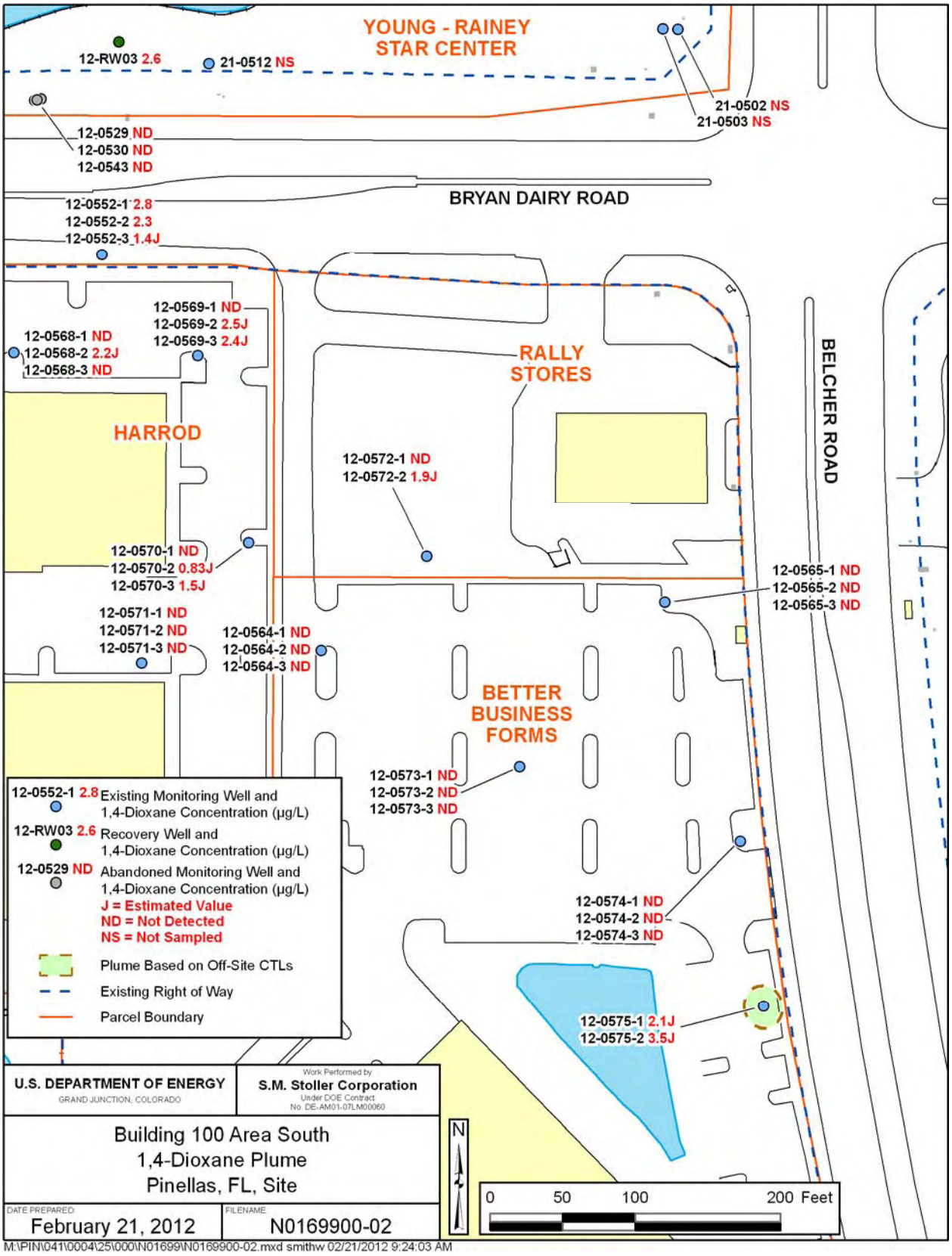

Figure 11. Building 100 Area South Plume—1,4-dioxane

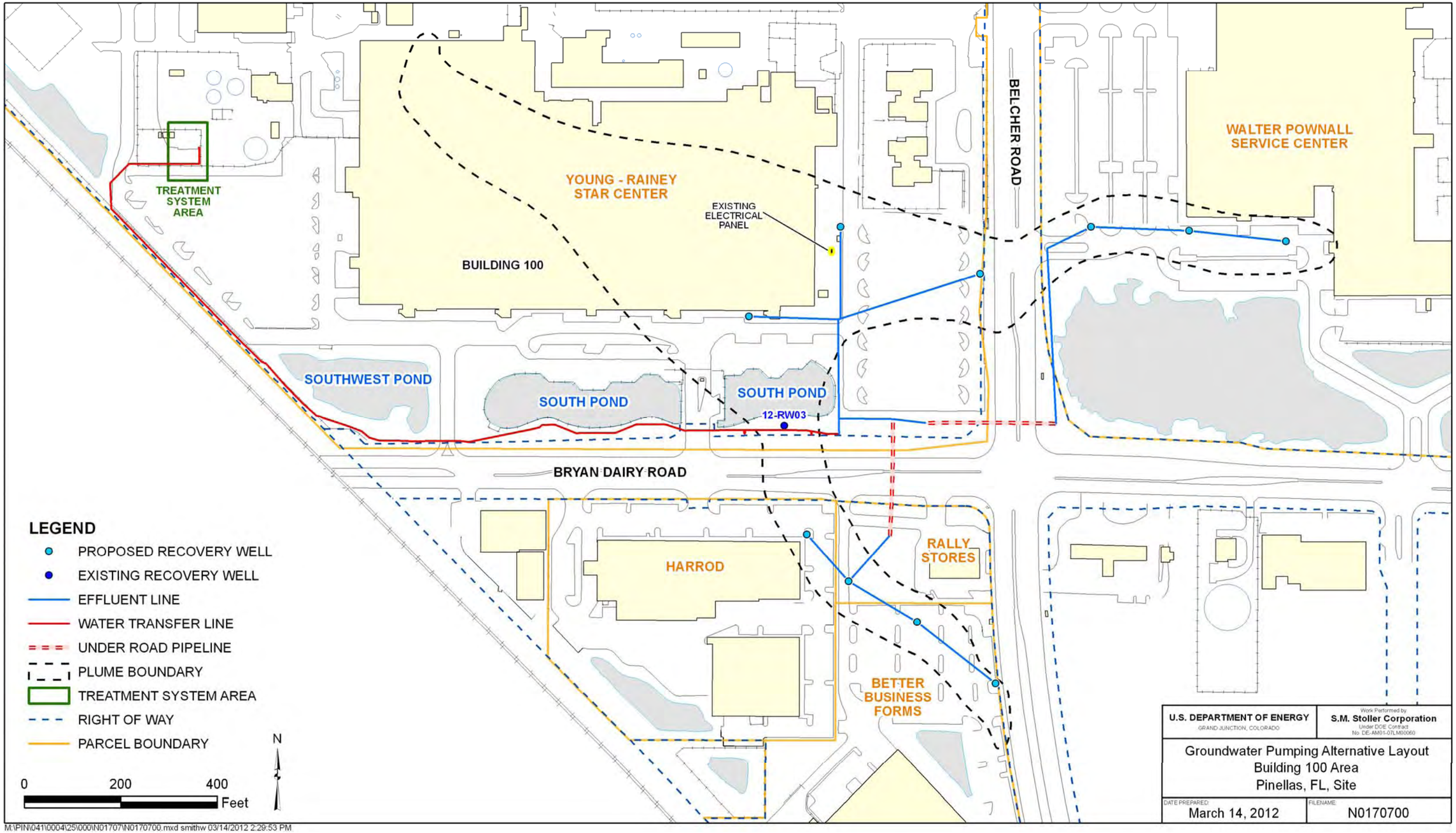

Figure 12. Groundwater Pumping Layout

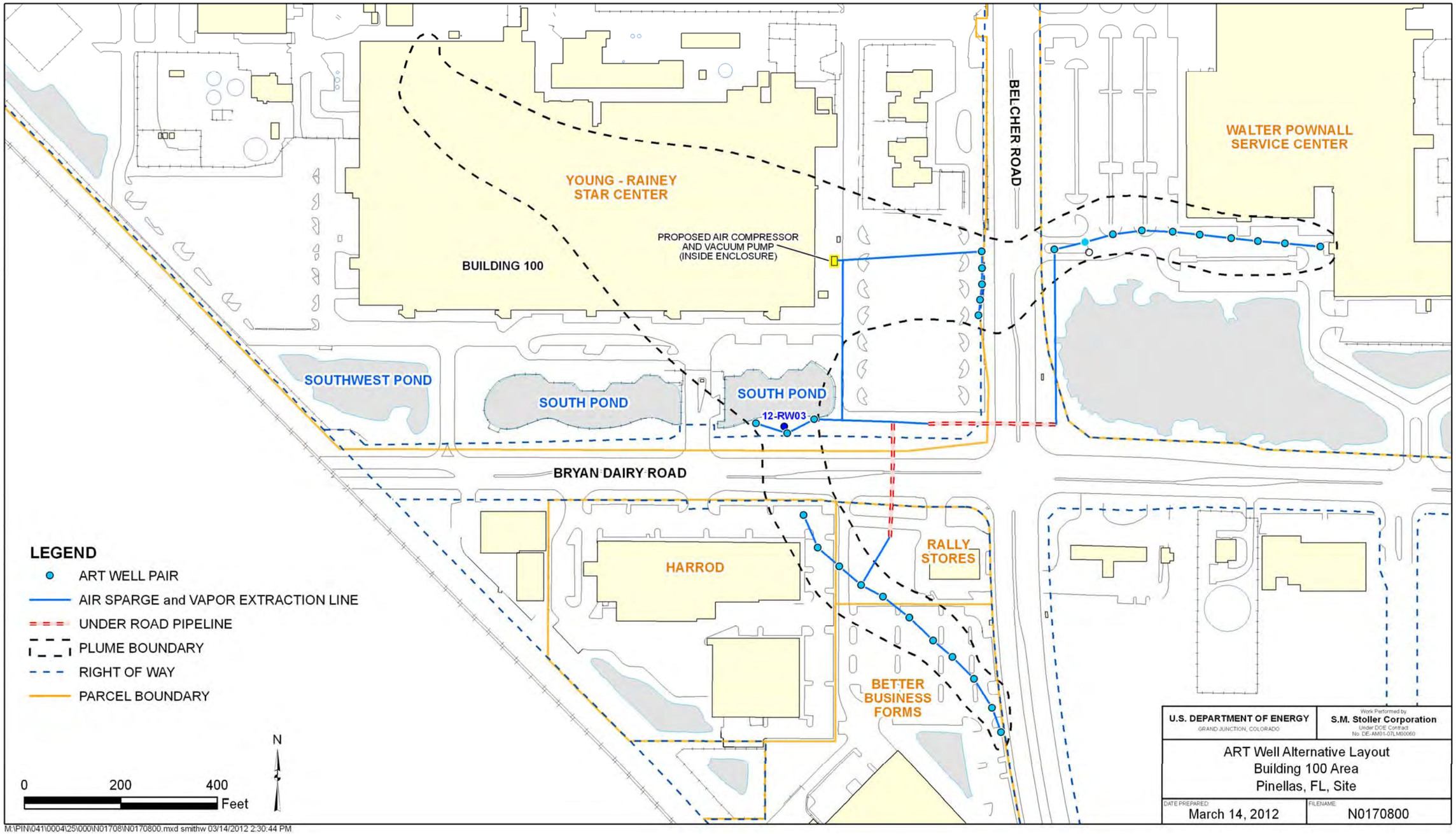

Figure 13. ART Well Layout

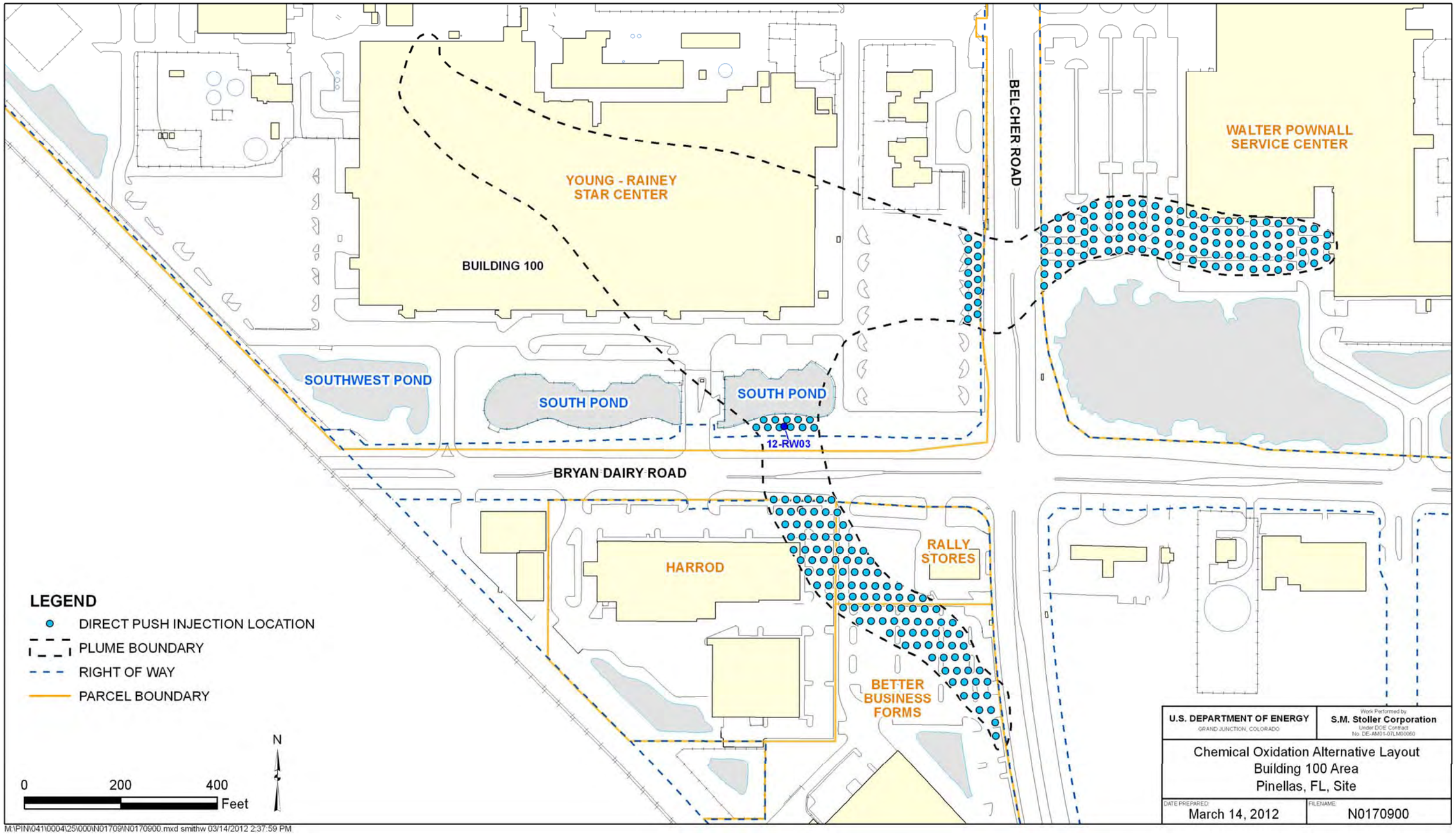

Figure 14. Chemical Oxidation Layout

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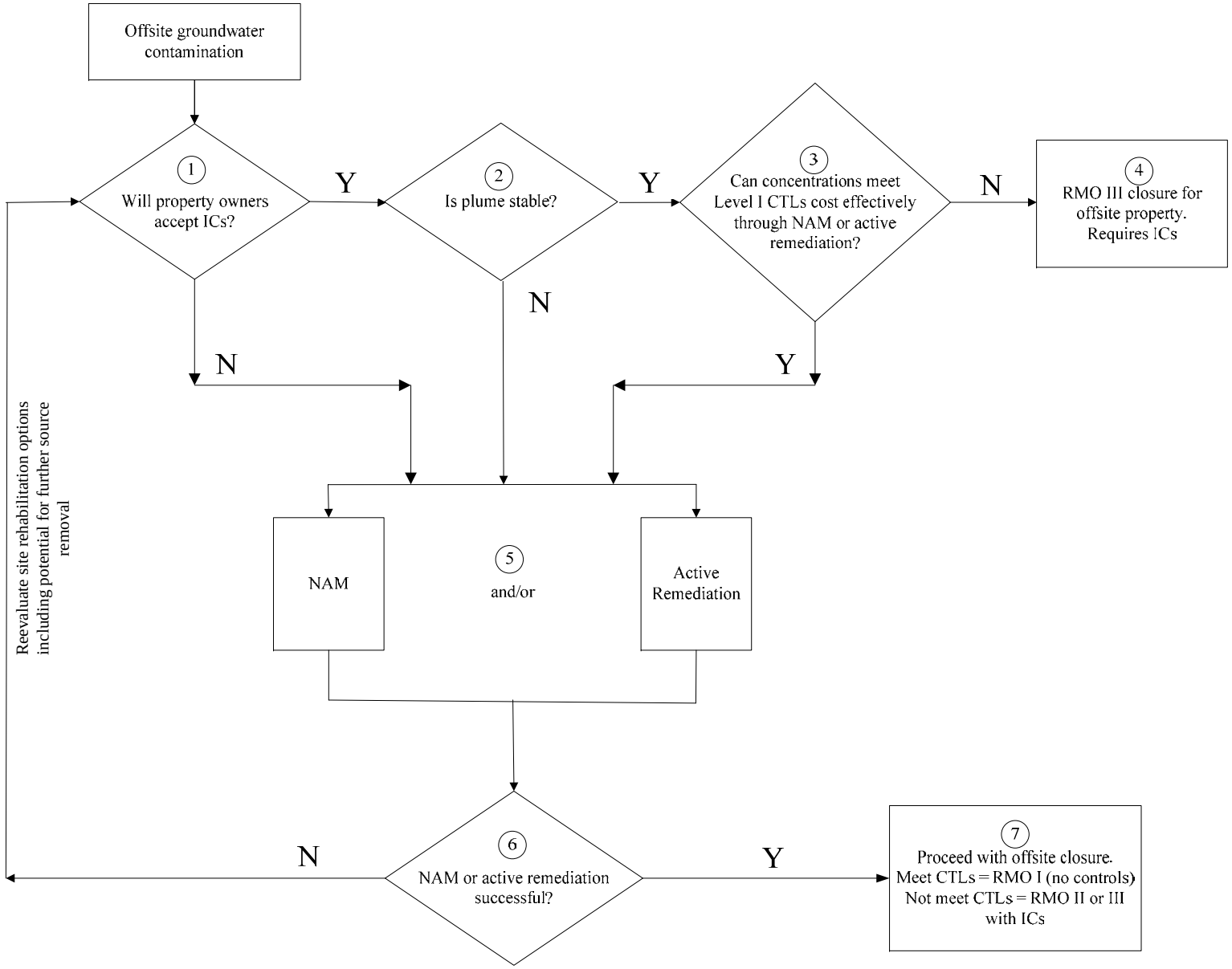

Figure 15. RBCA Decision Process

Table 1. COPCs, CTLs, and Maximum Concentrations Since 2007
Values in µg/L

	TCE	cDCE	tDCE	1,1-DCE	VC	1,4-dioxane
Onsite CTL	30	700	1,000	70	10	32
Offsite CTL	3	70	100	7	1	3.2
South Plume Maximum Concentrations						
South Edge Building 100	1,200	11,000	69	520	1,900	13
Southern Property Boundary (RW03)[a]	410	1,800	18	120	290	2.6
Northern Part of Harrod Property	0.8	1,600	7	98	350	3.5
East Plume Maximum Concentrations						
East Edge of Building 100	ND	110	30	2	940	440
Eastern Property Boundary	ND	53	15	4	260	370
WPSC Property	ND	36	3	5	91	160

[a] Concentrations measured in recovery well RW03 during initial operations in July 2009. There was some dilution caused by the recovery well, so actual concentrations likely are higher.
ND = not detected

Table 2. Description of All Commercially Available Remediation Technologies

Technology Type	Description
In Situ Biological Treatment	
Natural Attenuation	Natural attenuation is not a technology, but is a set of naturally occurring subsurface processes such as dilution, volatilization, biodegradation, adsorption, and chemical reactions resulting in reduction of contaminant concentrations. For the purpose of this study, natural attenuation is distinct from the NAM concept as defined in 62-780.690 F.A.C.
Enhanced Biodegradation	Increasing the concentration of electron acceptors, electron donors, nutrients, or microorganisms in groundwater to enhance the rate of direct or co-metabolic, aerobic or anaerobic, biodegradation of organic contaminants by microorganisms.
Phytoremediation	Process that uses plants to remove, transfer, stabilize, or destroy contamination in groundwater.
Biosparging	Injection of air into the subsurface to attain aerobic conditions that facilitates direct or co-metabolic aerobic biodegradation of contaminants. Sparging is a minor component of this process because air flow rates are much lower than with air sparging.
In Situ Physical/Chemical Treatment	
Air Sparging	Air is injected into the subsurface to remove contaminants through volatilization. Typically coupled with soil vapor extraction.
In-Well Air Stripping	Involves pumping of water from a contaminated zone into a well from an upper (or lower) screen zone, sparging the water with air to volatilize contaminants, then pumping the cleaned water back into the subsurface through an upper (or lower) screen zone, thus creating a circulating flow cell.
Surface Water Stripping	Contaminated groundwater is induced to flow into a surface water body where processes such as volatilization, photodegradation, and biodegradation remove the contamination.
Dual Phase Extraction (DPE)	Uses a high-vacuum system to remove contaminated groundwater and contaminant vapors from the subsurface.
ART In-Well System	This approach involves applying air stripping, air sparging, soil-vapor extraction, enhanced bioremediation, and groundwater recirculation. These technologies operate concurrently in a 4-inch-diameter or larger well that is screened above and below the water table.

Table 2 (continued). Description of All Commercially Available Remediation Technologies

Technology Type	Description
Bioslurping	Combines bioventing and vacuum-enhanced free-product recovery to remove light nonaqueous phase liquids from the surface of the water table. Stimulates aerobic bioremediation.
Barometric Pumping	A passive soil vapor extraction system that uses natural changes in barometric pressure to remove contaminant vapors from the subsurface.
Electrokinetics	Involves applying an electric potential across the contaminated zone using electrodes placed in the ground. Contaminants are mobilized and then removed via a separate process.
Fracturing	Air, liquid, or solid material (such as sand) is injected into the subsurface at high pressure to fracture the aquifer matrix.
Permeable Reactive Barrier Walls	Typically, an opening filled with reactive material is placed to intercept a contaminant plume. Degradation or removal of contaminants occurs as contaminated water passes through the wall. Reactive materials include iron metal, limestone, organic carbon, bone char phosphate, and microorganisms. Includes funnel and gate, continuous trench, or hydraulic fracture configurations. Can also be installed via injection of reactive materials, without excavation or trenching.
Chemical Oxidation	Injection of strong oxidizing agents degrades contaminants in place. Oxidants include permanganate, Fenton's reagent, and ozone.
Lasagna	Couples electrically driven transport (electro-osmosis) with layered treatment zones containing a reactive medium such as zero-valent iron.
Soil Flushing 1. Surfactant flushing 2. Co-solvent flushing	Surfactants or co-solvents are applied to the soil or injected into the groundwater to enhance solubility of NAPLs. The groundwater containing the solubilized contaminant is then extracted and treated.
Dewatering with hot air flushing/vapor extraction	Barrier wall is installed around treatment area, area is dewatered and then flushed with hot air to volatilize and remove contaminants. Vapors require surface treatment.
Electrical Heating 1. Six Phase Heating 2. Three Phase Heating 3. In Situ Thermal Desorption 4. Radio Frequency Heating	Electricity is used to resistively or conductively heat the subsurface, volatilizing or destroying contaminants. Vapors removed via vapor extraction system and treated at the surface.
Steam Injection May include electrical heating of cold spots or use of hydrous pyrolysis to degrade contaminants in situ.	Steam is forced into aquifer through injection wells to vaporize volatile contaminants. Vapors removed through vapor extraction system.
Containment	
Groundwater Pumping	Extraction of contaminated groundwater followed by treatment at the surface. Includes horizontal wells under Building 100.
Hydraulic Phytostabilization	The use of plants to control groundwater gradients for the purpose of stabilizing contaminant plumes.
Vertical Impermeable Barriers	Vertical barriers are defined as subsurface barriers made of an impermeable material designed to contain or divert groundwater flow, thereby preventing contaminant movement. Includes slurry wall, geosynthetic wall, deep soil mixing, and sheet pile.
Dual Drainline Techniques	Recovery lines are placed horizontally on top of an impermeable stratigraphic unit and DNAPL flows into the collection trenches and seeps into the recovery lines.
Removal	
Soil Removal Includes ex situ treatment options.	Excavate contaminated soil and treat on site or send to approved disposal facility.

Table 3. Groundwater Remediation Technology Screening

Technology Type	Effectiveness at Meeting CTLs	Implementability	Cost	Status[a]
Natural Attenuation	To date, natural attenuation has not resulted in a decrease in concentrations to CTLs, and it appears unlikely that it will do so in the future. Eliminated.	–	–	Eliminated.
Enhanced Biodegradation	Enhanced biodegradation is a good option for the chlorinated ethenes, but biodegradation of 1,4-dioxane has been demonstrated in laboratory experiments but not in situ. Eliminated.	–	–	Eliminated.
Phytoremediation	It is extremely unlikely that plant roots could extend to the depth needed to remediate the plumes (at least 35 ft bls). Eliminated.	–	–	Eliminated.
Biosparging	Biosparging was implemented at the 4.5 Acre Site in 1999. This technology did not decrease contaminant concentrations and resulted in spreading the plume. Eliminated.	–	–	Eliminated.
Air Sparging Includes soil vapor extraction.	The soil particle size causes injected air to channel, limiting contact to a small part of the aquifer. 1,4-dioxane is not volatile, and likely would not be removed by air sparging. Eliminated.	–	–	Eliminated.
In-Well Air Stripping	1,4-dioxane is not removed from water during ex situ air stripping treatment, so it would not be removed during in situ air stripping either. Eliminated.	–	–	Eliminated.
Surface Water Stripping	1,4-dioxane is not removed from water during ex situ air stripping treatment, so it would not be removed during surface water stripping either. Eliminated.	–	–	Eliminated.
Dual Phase Extraction	The groundwater pumping component of dual phase extraction could be effective for removal of 1,4-dioxane and the chlorinated ethenes. The vapor extraction component would aid removal of the chlorinated ethenes but would not be effective for 1,4-dioxane.	Dual phase extraction was implemented at the 4.5 Acre Site in 1997. It would be more difficult to implement this technology at the Building 100 Area and the offsite plumes, but it would be possible.	The vapor extraction component would not provide any advantage over groundwater pumping in terms of removal of 1,4-dioxane. But the initial cost and O&M costs for dual phase extraction would be higher than that for groundwater pumping. Eliminated in favor of groundwater pumping.	Eliminated.

Table 3 (continued). Groundwater Remediation Technology Screening

Technology Type	Effectiveness at Meeting CTLs	Implementability	Cost	Status[a]
ART In-Well System	This technology has been shown to be effective at decreasing high concentrations of chlorinated ethenes and 1,4-dioxane.	It should be possible to implement this technology.	The cost of this technology could be similar to that for groundwater pumping, so this technology will be retained for detailed evaluation.	Retained for detailed evaluation.
Bioslurping	The purpose of this technology is to remove floating free product from the surface of the water table. Not applicable for removal of contamination dissolved in groundwater. Eliminated.	–	–	Eliminated.
Barometric Pumping	1,4-dioxane is not volatile, so this technology would not be effective for this contaminant. Eliminated.	–	–	Eliminated.
Electrokinetics	1,4-dioxane and the chlorinated ethenes are non-polar organic molecules, and this technology only affects polar or ionic contaminants, so this technology would not be effective. Eliminated.	–	–	Eliminated.
Fracturing	Fracturing is a supplemental technology that would not aid in remediation of these contaminants. Eliminated.	–	–	Eliminated.
Permeable Reactive Barrier Walls	Could be effective for both the chlorinated ethenes and 1,4-dioxane if an oxidation approach is used.	Implementation of a trenched barrier wall may not be reasonable for the offsite properties because the reactive medium would need to be replaced fairly often, causing disruption. An injected barrier wall would be the best option.	Due to the slow groundwater velocity of a few feet per year, numerous barrier walls would need to be installed to treat the offsite plumes in any reasonable time frame. Numerous walls would be very costly. Eliminated.	Eliminated.
Chemical Oxidation	Chemical oxidation can treat both the chlorinated ethenes and 1,4-dioxane.	Using direct push to inject a chemical oxidant into the subsurface would be relatively east to implement.	Medium cost.	Retained for detailed evaluation.
Lasagna	1,4-dioxane and the chlorinated ethenes are non-polar organic molecules, and this technology only affects polar or ionic contaminants, so this technology would not be effective. Eliminated.	–	–	Eliminated.
Soil Flushing	This is a NAPL remediation technology, and it is very unlikely that it would decrease the relatively low contaminant concentrations to CTLs. Eliminated.	–	–	Eliminated.

Table 3 (continued). Groundwater Remediation Technology Screening

Technology Type	Effectiveness at Meeting CTLs	Implementability	Cost	Status[a]
Dewatering with Hot Air Flushing	1,4-dioxane is not volatile, so this technology would not be effective. Eliminated.	–	–	Eliminated.
Electrical Heating	Although this is a NAPL remediation technology, it could be effective at treating the contaminants to CTLs.	This technology requires significant infrastructure that most likely would not be possible to implement at the offsite properties.	Very high cost. Eliminated.	Eliminated.
Steam Injection	Although this is a NAPL remediation technology, it could be effective at treating the contaminants to CTLs.	This technology requires significant infrastructure that most likely would not be possible to implement at the offsite properties.	Very high cost. Eliminated.	Eliminated.
Groundwater Pumping	Could be effective at decreasing contaminant concentrations to CTLs.	Relatively easy to implement given that the under-road pipelines installed for a previous project are already in place to transfer water from the offsite properties onto the STAR Center for treatment.	Low cost.	Retained for detailed evaluation.
Hydraulic Phytostabilization	It is extremely unlikely that plant roots could extend to the depth needed to remediate the plumes (at least 35 ft bls). Eliminated.	–	–	Eliminated.
Vertical Impermeable Barriers	Would not be effective at decreasing contaminant concentrations to CTLs. Eliminated.	–	–	Eliminated.
Dual Drainline Techniques	This NAPL remediation technology would not result in a decrease in contaminant concentrations to CTLs. Eliminated.	–	–	Eliminated.
Soil Removal	Removing all the soil containing the contaminated groundwater would meet CTLs.	Removing all the soil containing the offsite plumes is not implementable due to the extreme disruption. Eliminated.	–	Eliminated.

[a] If a technology was eliminated by the first or second criterion, it was not evaluated using subsequent criteria.
– = Not evaluated

Table 4. Plume Control Technology Screening

Technology Type	Effectiveness at Controlling the Plume	Implementability	Cost	Status[a]
Natural Attenuation	Natural attenuation has not controlled the plumes to this point, and it appears unlikely that it will control the plumes in the future. Eliminated.	–	–	Eliminated.
Enhanced Biodegradation	Enhanced biodegradation is a good option for the chlorinated ethenes, but biodegradation of 1,4-dioxane has been demonstrated in laboratory experiments but not in situ. Eliminated.	–	–	Eliminated.
Phytoremediation	It is extremely unlikely that plant roots could extend to the depth needed to remediate the plumes (at least 35 ft bls). Eliminated.	–	–	Eliminated.
Biosparging	Biosparging was implemented at the 4.5 Acre Site in 1999. This technology did not decrease contaminant concentrations and resulted in spreading the plume. Eliminated.	–	–	Eliminated.
Air Sparging Includes soil vapor extraction.	1,4-dioxane is not volatile and likely would not be removed by air sparging. Eliminated.	–	–	Eliminated.
In-Well Air Stripping	1,4-dioxane is not volatile and likely would not be removed by air stripping. Eliminated.	–	–	Eliminated.
Surface Water Stripping	1,4-dioxane is not volatile and likely would not be removed by surface water stripping. Eliminated.	–	–	Eliminated.
Dual Phase Extraction	The groundwater pumping component of dual phase extraction could be effective for removal of 1,4-dioxane and the chlorinated ethenes. The vapor extraction component would aid removal of the chlorinated ethenes but would not be effective for 1,4-dioxane.	Dual phase extraction was implemented at the 4.5 Acre Site in 1997. It would be more difficult to implement this technology at the Building 100 Area, but it would be possible.	The vapor extraction component would not provide any advantage over groundwater pumping in terms of removal of 1,4-dioxane. But the initial cost and O&M costs for dual phase extraction would be higher than those for groundwater pumping. Eliminated in favor of groundwater pumping.	Eliminated.
ART In-Well System	This technology has been shown to be effective at decreasing high concentrations of chlorinated ethenes and 1,4-dioxane.	It should be possible to implement this technology.	The cost of this technology could be similar to that for groundwater pumping, so this technology will be retained for detailed evaluation.	Retained for detailed evaluation.

Table 4 (continued). Plume Control Technology Screening

Technology Type	Effectiveness at Controlling the Plume	Implementability	Cost	Status[a]
Bioslurping	The purpose of this technology is to remove floating free product from the surface of the water table. Not applicable for removal of contamination dissolved in groundwater. Eliminated.	–	–	Eliminated.
Barometric Pumping	1,4-dioxane is not volatile, so this technology would not be effective for this contaminant. Eliminated.	–	–	Eliminated.
Electrokinetics	1,4-dioxane and the chlorinated ethenes are non-polar organic molecules and this technology only affects polar or ionic contaminants, so this technology would not be effective. Eliminated.	–	–	Eliminated.
Fracturing	Fracturing is a supplemental technology that would not aid in remediation of these contaminants. Eliminated.	–	–	Eliminated.
Permeable Reactive Barrier Walls	Could be effective for both the chlorinated ethenes and 1,4-dioxane if an oxidation approach is used.	Implementation of a trenched barrier wall may not be reasonable for the offsite properties because the reactive medium would need to be replaced fairly often, causing disruption. An injected barrier wall would be the best option.	Due to the slow groundwater velocity of a few feet per year, numerous barrier walls would need to be installed to treat the offsite plumes in any reasonable time frame. Numerous walls would be very costly. Eliminated.	Eliminated.
Chemical Oxidation	Chemical oxidation can treat both the chlorinated ethenes and 1,4-dioxane.	Using direct push to inject a chemical oxidant into the subsurface would be relatively east to implement.	Medium cost.	Retained for detailed evaluation.
Lasagna	1,4-dioxane and the chlorinated ethenes are non-polar organic molecules and this technology only affects polar or ionic contaminants, so this technology would not be effective. Eliminated.	–	–	Eliminated.
Soil Flushing	This is a NAPL remediation technology, and it is very unlikely that it would decrease the relatively low contaminant concentrations to CTLs. Eliminated.	–	–	Eliminated.
Dewatering with Hot Air Flushing	1,4-dioxane is not volatile, so this technology would not be effective. Eliminated.	–	–	Eliminated.

Table 4 (continued). Plume Control Technology Screening

Technology Type	Effectiveness at Controlling the Plume	Implementability	Cost	Status[a]
Electrical Heating	Although this is a NAPL remediation technology, it could be effective at treating the contaminants to CTLs.	This technology requires significant infrastructure that most likely would not be possible to implement at the offsite properties.	Very high cost. Eliminated.	Eliminated.
Steam Injection	Although this is a NAPL remediation technology, it could be effective at treating the contaminants to CTLs.	This technology requires significant infrastructure that most likely would not be possible to implement at the offsite properties.	Very high cost. Eliminated.	Eliminated.
Groundwater Pumping	Could be effective at decreasing contaminant concentrations to CTLs.	Relatively easy to implement based on past experience. The water transfer line to the treatment area is in place from a previous project.	Low cost.	Retained for detailed evaluation.
Hydraulic Phytostabilization	It is extremely unlikely that plant roots could extend to the depth needed to remediate the plumes (at least 35 ft bls). Eliminated.	–	–	Eliminated.
Vertical Impermeable Barriers	Likely would be effect at controlling the plume.	Would be fairly difficult to implement given the large number of utilities in the area, but is possible.	An impermeable barrier would require groundwater pumping to eliminate bypass of water around the barrier, so the initial cost would be higher than that for groundwater pumping alone. Eliminated in favor of groundwater pumping.	Eliminated.
Dual Drainline Techniques	This NAPL remediation technology would not result in a decrease in contaminant concentrations to CTLs. Eliminated.	–	–	Eliminated.
Soil Removal	Soil removal is not an option for plume control.	–	–	Eliminated.

[a] If a technology was eliminated by the first or second criteria, it was not evaluated using subsequent criteria.
– = Not evaluated

Table 5. Summary of Detailed Evaluation of Alternatives

Criterion	NAM	ICs	Groundwater Pumping[a]	ART Well System[a]	Chemical Oxidation[a]
Long-term and short-term human health and environmental effects	The only potential contact with contaminated groundwater would be through routine sampling.	None—exposures to contaminated groundwater would be prevented with this remedy.	Minimal.	Minimal.	Some potential for worker exposure to oxidants if mishandled.
Implementability	Can use monitoring wells already in place after east plume delineation.	Requires landowner approval.	Easily implementable. Much of the infrastructure is already in place.	The required 6 ft stickup for each well would impede traffic.	Generally implementable, although property owner acceptance is unknown.
O&M requirements	Regular monitoring, reporting, and notification.	Periodic review to ensure ICs are not being violated; state responsible for auditing, enforcement.	Moderate O&M requirements.	Moderate O&M requirements.	No O&M.
Reliability	Reliable; regular notification required.	Reliable; ICs are enforceable by FDEP.	The groundwater pumping and treatment technologies are mature, reliable technologies.	Reliable. Combines three common, mature technologies.	Reliable. Uses common equipment for injection.
Feasibility	Feasibility of meeting CTLs is higher with plume control.	Feasible if property owners accept.	The existing recovery well has shown that contaminant concentrations can meet CTLs and that the plume can be controlled.	The ability of this system to meet the 1,4-dioxane CTL is unproven.	The ability of a chemical oxidant to meet CTLs is questionable due to preferential pathways and aquifer clogging.
Estimated time	Decades to achieve CTLs.	Several years for implementation.	Estimated 5 years to meet CTLs.	Estimated 10 years to meet CTLs, if possible.	Estimated 4 years to meet CTLs, if possible.
Cost	Monitoring costs only.	Unknown.	$1,268,000 for offsite remediation. $3,441,000 for plume control.	$4,952,000 for offsite remediation. $6,423,000 for plume control.	$4,359,000 for offsite remediation. $37,771,000 for plume control.

[a] The evaluation of the three active remediation alternatives is the same for both groundwater remediation and plume control, except for cost.

Table 6. Compatibility of Alternatives

Offsite Plume Alternatives	Onsite Alternatives	Compatibility
Natural Attenuation with Monitoring	Natural Attenuation with Monitoring	Yes
	Institutional controls	Yes
	Plume control	Yes, if needed
Institutional Controls	Natural Attenuation with Monitoring	Yes
	Institutional controls	Yes
	Plume control	Yes, if needed
Groundwater Remediation	Natural Attenuation with Monitoring	Not recommended
	Institutional controls	Not recommended
	Plume control	Yes

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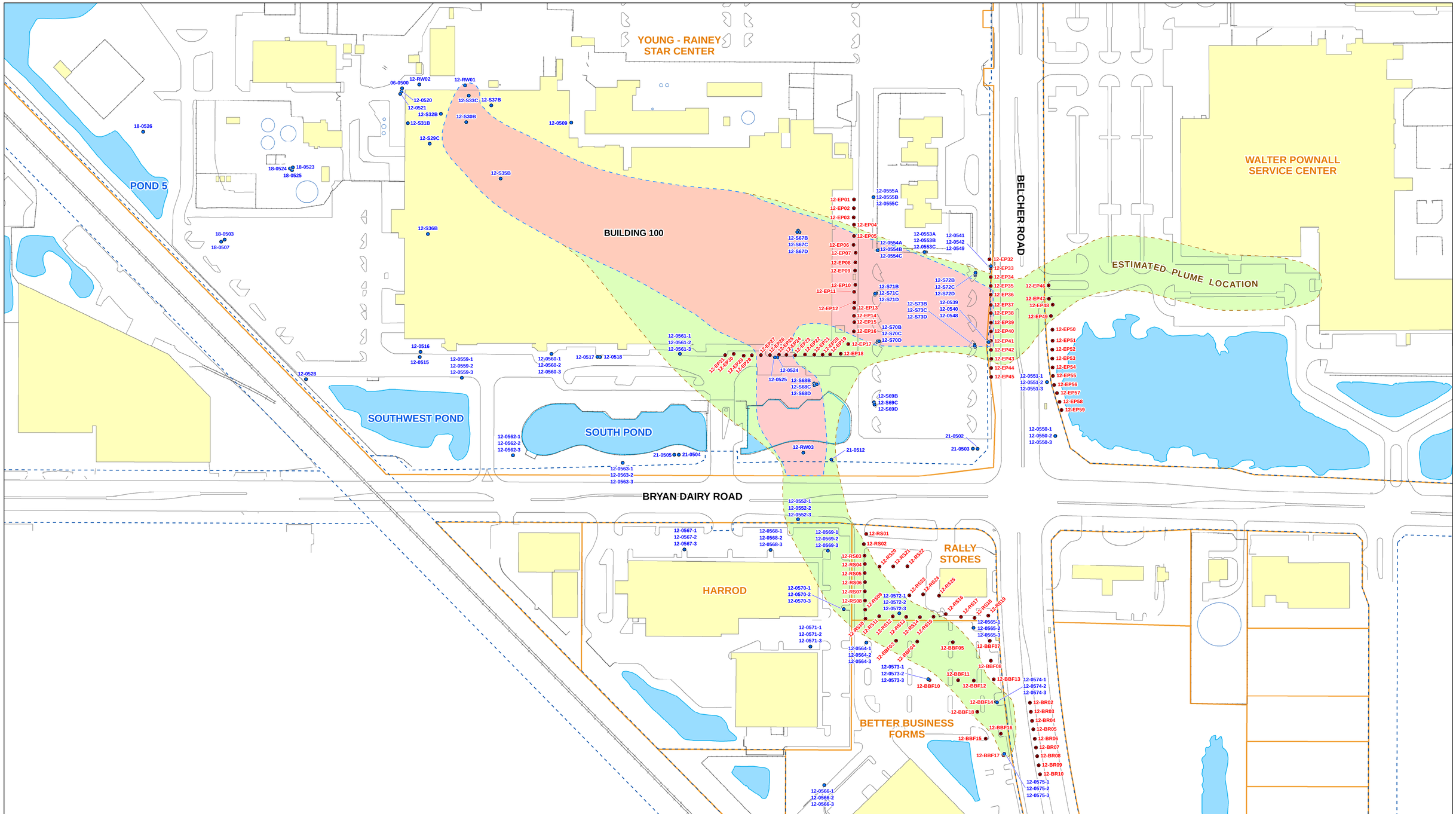

LEGEND

- Active Well
- Temporary Sampling Point
- Parcel Boundary
- Right of Way
- Approximate On-Site VC Plume
- Approximate VC Plume Based on Off-Site CTLs

N

0 100 200 Feet

U.S. DEPARTMENT OF ENERGY GRAND JUNCTION, COLORADO	Work Performed by **S.M. Stoller Corporation** Under DOE Contract No. DE-AM01-07LM00060

PLATE 1: Approximate Vinyl Chloride Plume Alternatives Analysis Base Map
Building 100 Area
Pinellas, FL, Site

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Appendix A

Potential Contaminant Source Areas

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Although this study did not address remediation of the contaminant source under Building 100, identification of the locations of contaminant sources is helpful in determining plume configuration, and this is discussed in the following text.

Industrial Drain Leaks consists of the liquid waste drain system that served Building 100. Four individual drainage systems were present within the building: health physics, chemical, sanitary, and storm water systems. These drain systems ran through the floor of the building and then laterally under the foundation to lift stations at various locations around the building, and eventually to the industrial wastewater neutralization facility located to the west of the building (Plate A1). By the mid-to-late 1970s, some of the chemical and health physics drain lines had deteriorated so that several wastewater leaks occurred under the building (DOE 1987). The drain lines were repaired when the leaks were discovered, but an undetermined amount of wastewater escaped to the soil. Information about the location of these leaks is very limited, but apparently they were beneath the northwest part of the building (Plate A1).

A second investigation to determine the existing conditions of the Building 100 waste drainage systems was conducted in 1989 (EMC 1989). All four drainage systems were investigated using in-line video observation. System routing was verified and the condition of underground and aboveground piping and ancillary equipment was determined. Employee interviews were also conducted. Following is a summary of this investigation.

- The health physics drain system was composed of iron piping and the chemical drain system was composed of both iron (older parts of the system) and PVC (newer parts of the system) piping. In general, the iron piping was subject to corrosion and the PVC piping was subject to installation flaws.
- Typical observations in the health physics system include decayed appearance, infiltration of groundwater, and possible absence of pipe wall.
- There is almost no information concerning exactly where the problems with the health physics drain system were located.
- The condition of the chemical drain system was generally good, but a few bad areas were identified. Broken fittings and blistered pipe were described as typical problems.

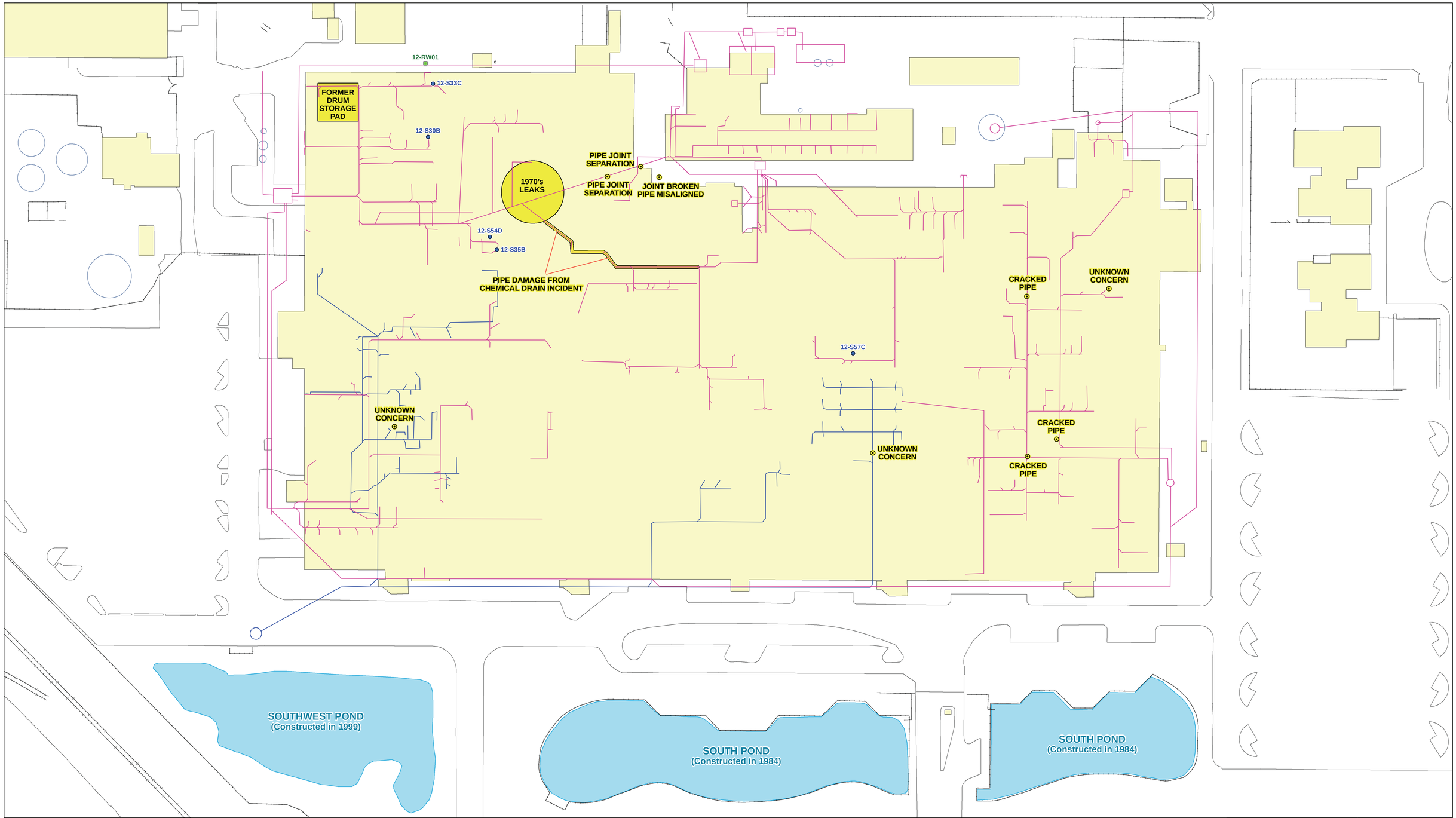
Following the 1989 drain investigation, the drain problems were repaired. Subsequently, the health physics and chemical drain systems were flushed, grouted, and abandoned in 1996, and some of the chemical drain systems were replaced by an above ground system that currently is in use.

The Old Drum Storage Site is the former location of a concrete storage pad, equipped with a drain and containment system, used to store hazardous waste. Employee interviews indicated that drums were inverted on and around the pad to drain any remaining material from the used drums. The pad was removed in October 1983. No environmental investigation or remediation was conducted in association with the pad removal, and the building was expanded to cover the former pad area in 1984.

The locations of known drain line problems and the drum storage pad are shown on Plate A1. Other than the information summarized on this map, there is no known information in the historical documentation to determine whether or not a specific problem area leaked wastewater into the subsurface, how much was leaked, or which contaminants were leaked.

However, it is clear from 20 years of groundwater characterization work that contaminants were released to the subsurface near the northwest corner of the building and probably at other locations beneath the building. It appears that at least some portion of the waste stream contained TCE and perhaps other solvents, and that the TCE formed a nonaqueous phase liquid (NAPL) in the subsurface. NAPLs have limited aqueous solubility and therefore act as a source of contamination as groundwater moves past the NAPL area and slowly dissolves the NAPL. Wells that contain contaminant concentrations exceeding one percent of the aqueous solubility of the particular contaminant are generally considered to be located near an area of NAPL. Six wells contain (or have contained) contaminant concentrations that exceed one percent of solubility, and these wells are also shown on Plate A1.

Some of the monitoring wells under the building show decreasing concentration trends, and it has been suggested that this could indicate that the contaminant source is being depleted. The most significant decreasing concentration trends are observed in wells near the northwest corner of the building; these decreases are most likely due to mass removal by the two recovery wells that operated there from 1997 to 2006. The other wells show minor decreasing concentration trends. While the source could be depleting somewhat, the unknown locations of the sources and the relatively sparse data density preclude a definitive determination of source depletion.



Potential Source Locations

- Point Source
- Line Source
- Area Source

Wells Near Source Areas

- Monitoring Well
- Extraction Well

Historical Drain Features

- Chemical Drain
- Health - Physics Drain

Existing Site Features

- Fence
- Road
- Railroad
- Tank
- Building
- Pond

N

0 50 100 Feet

U.S. DEPARTMENT OF ENERGY
GRAND JUNCTION, COLORADO

Work Performed by
S.M. Stoller Corporation
Under DOE Contract
No. DE-AM01-07LM00060

PLATE A1: Potential Source Areas
Building 100 Area
Pinellas, FL, Site

DATE PREPARED: February 22, 2012

FILENAME: N0169000

M:\PIN\041\000\425\000\N01690\N0169000.mxd smithw 02/22/2012 3:30:17 PM

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Appendix B

Plume Cross-Sections

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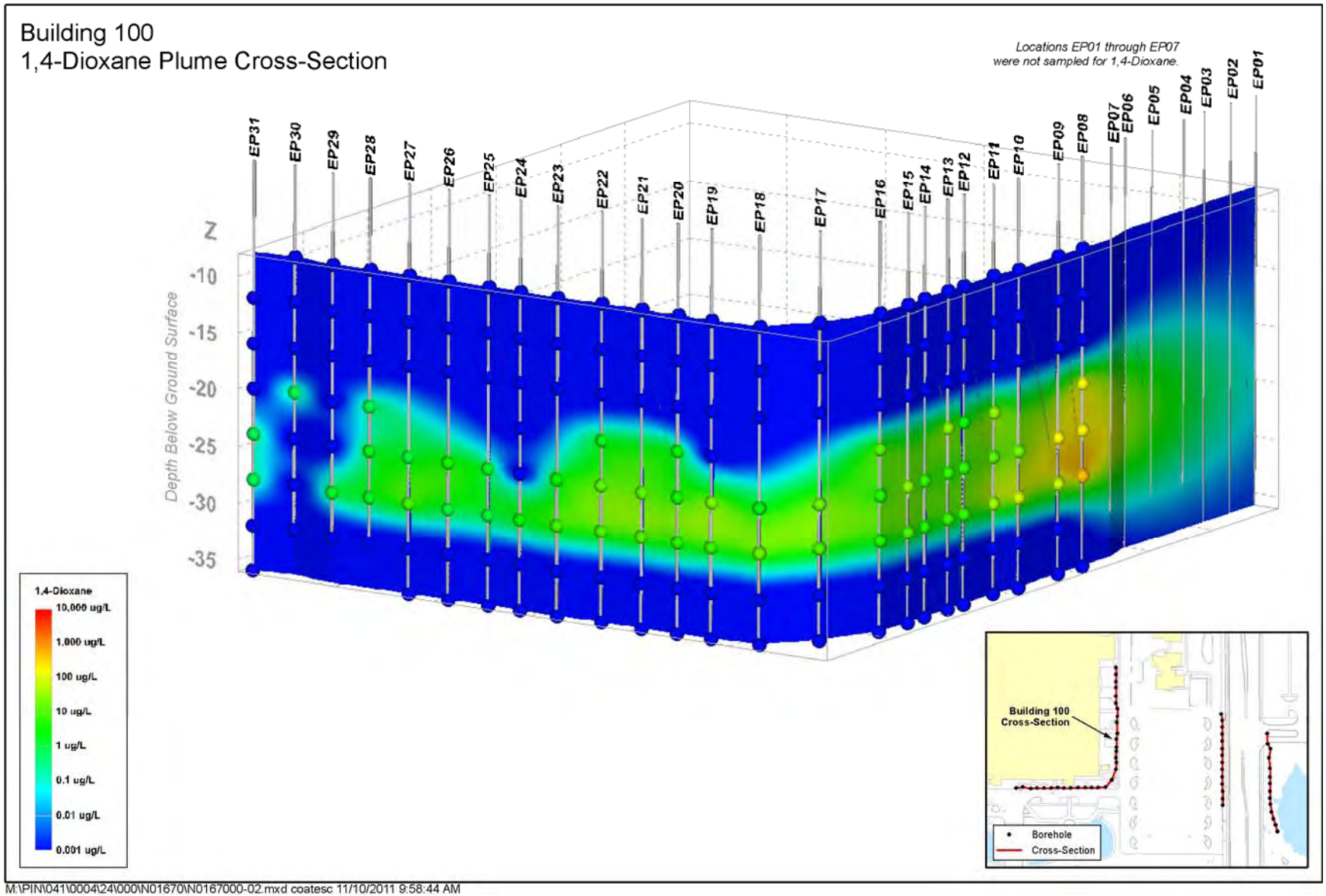

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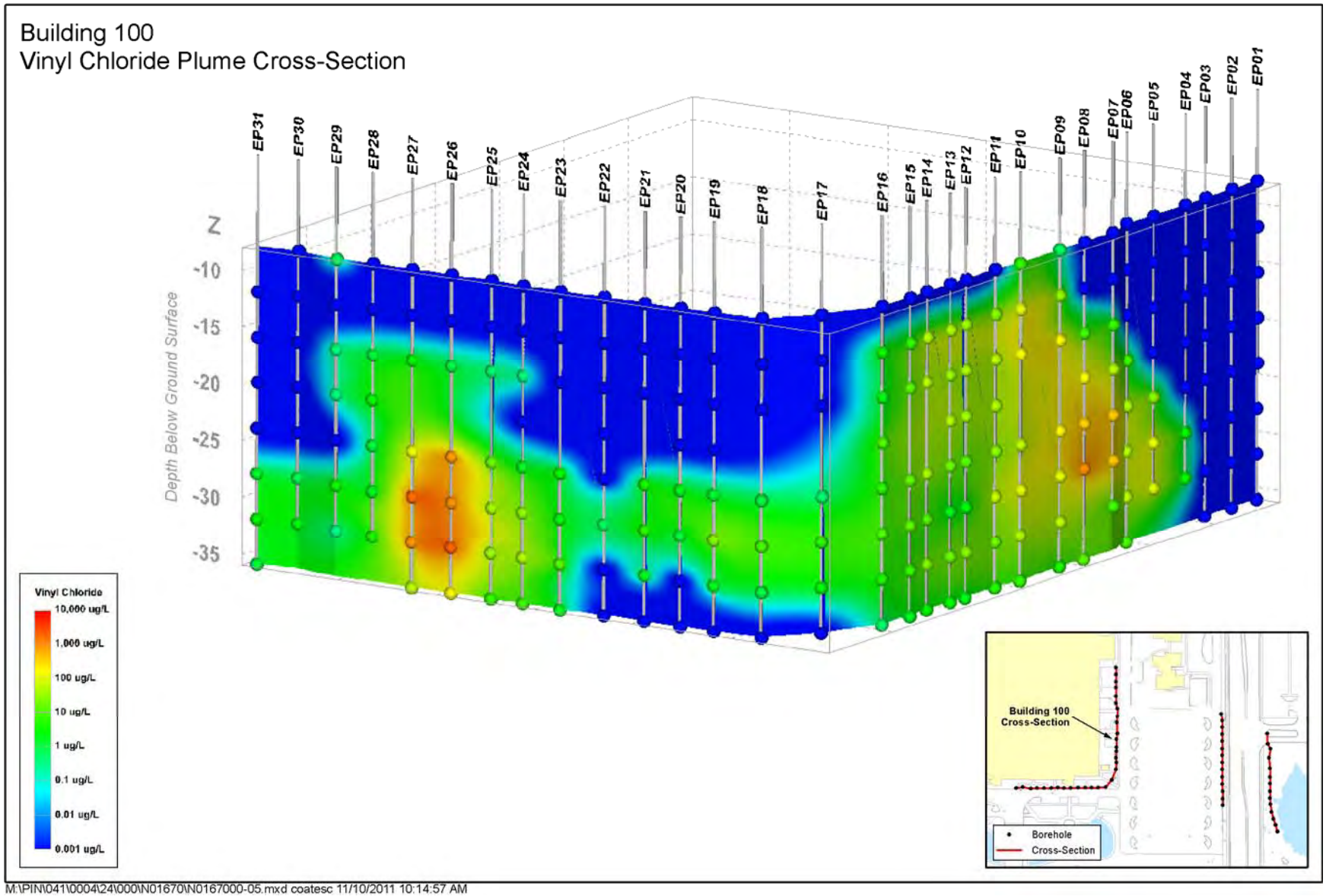

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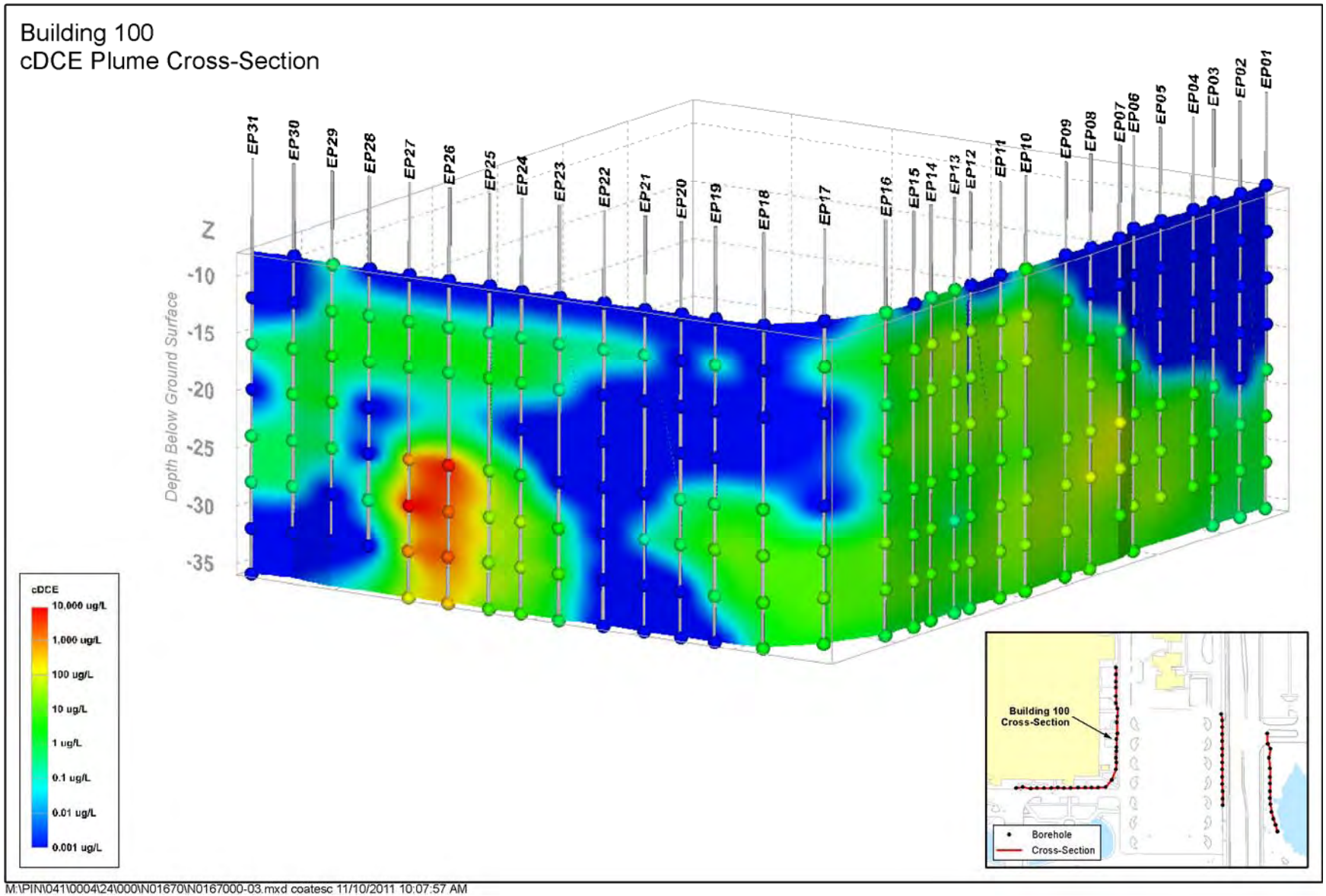

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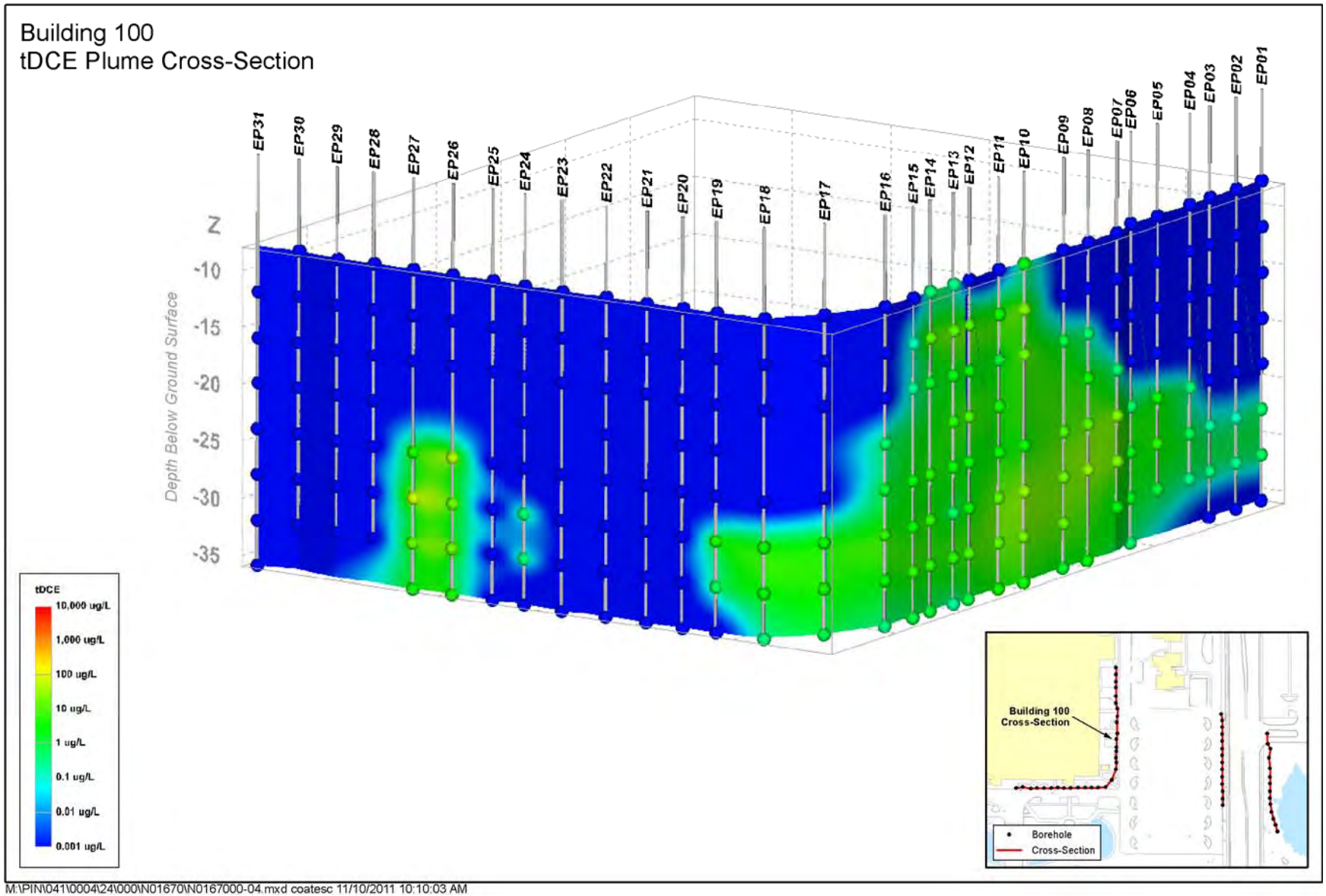

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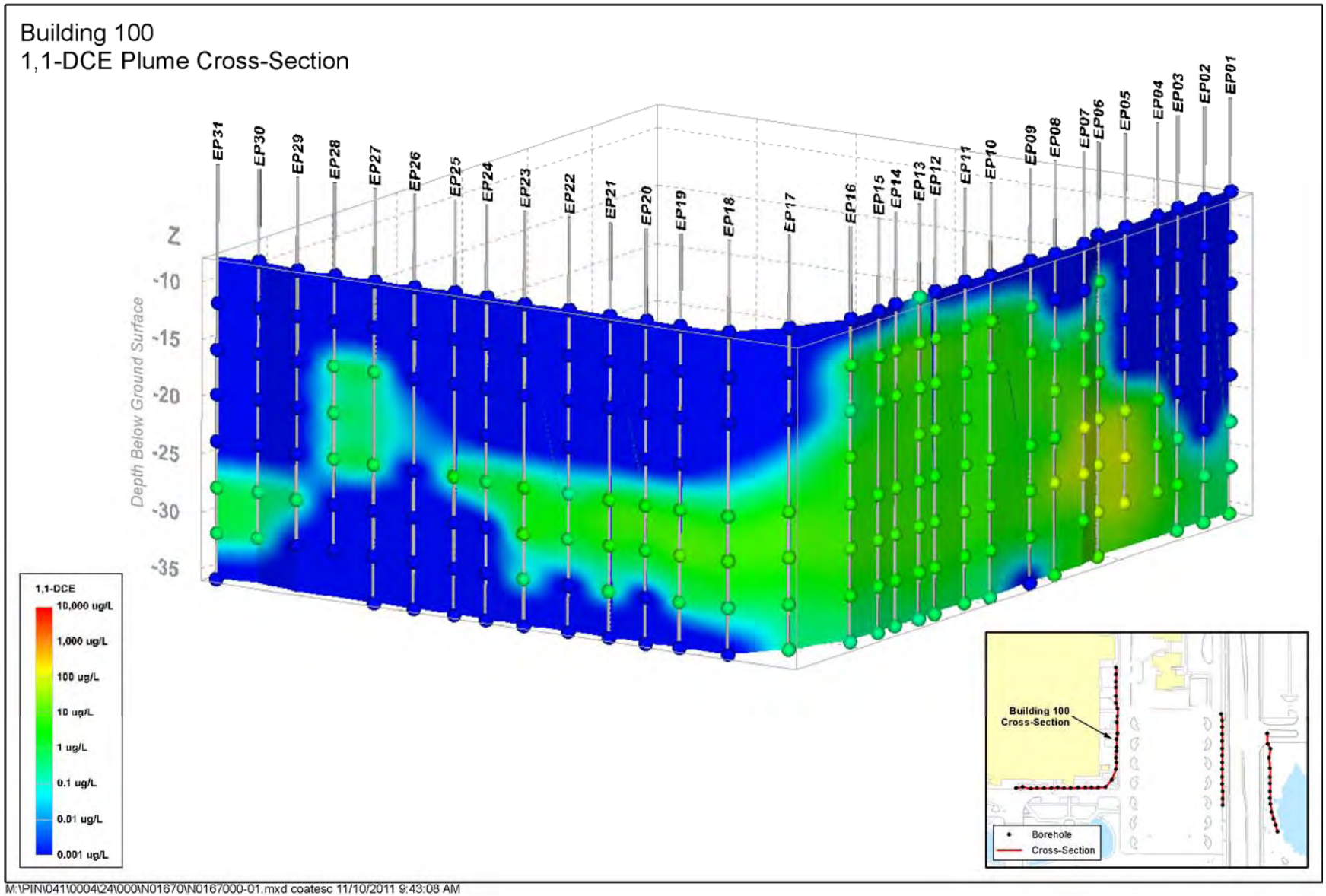

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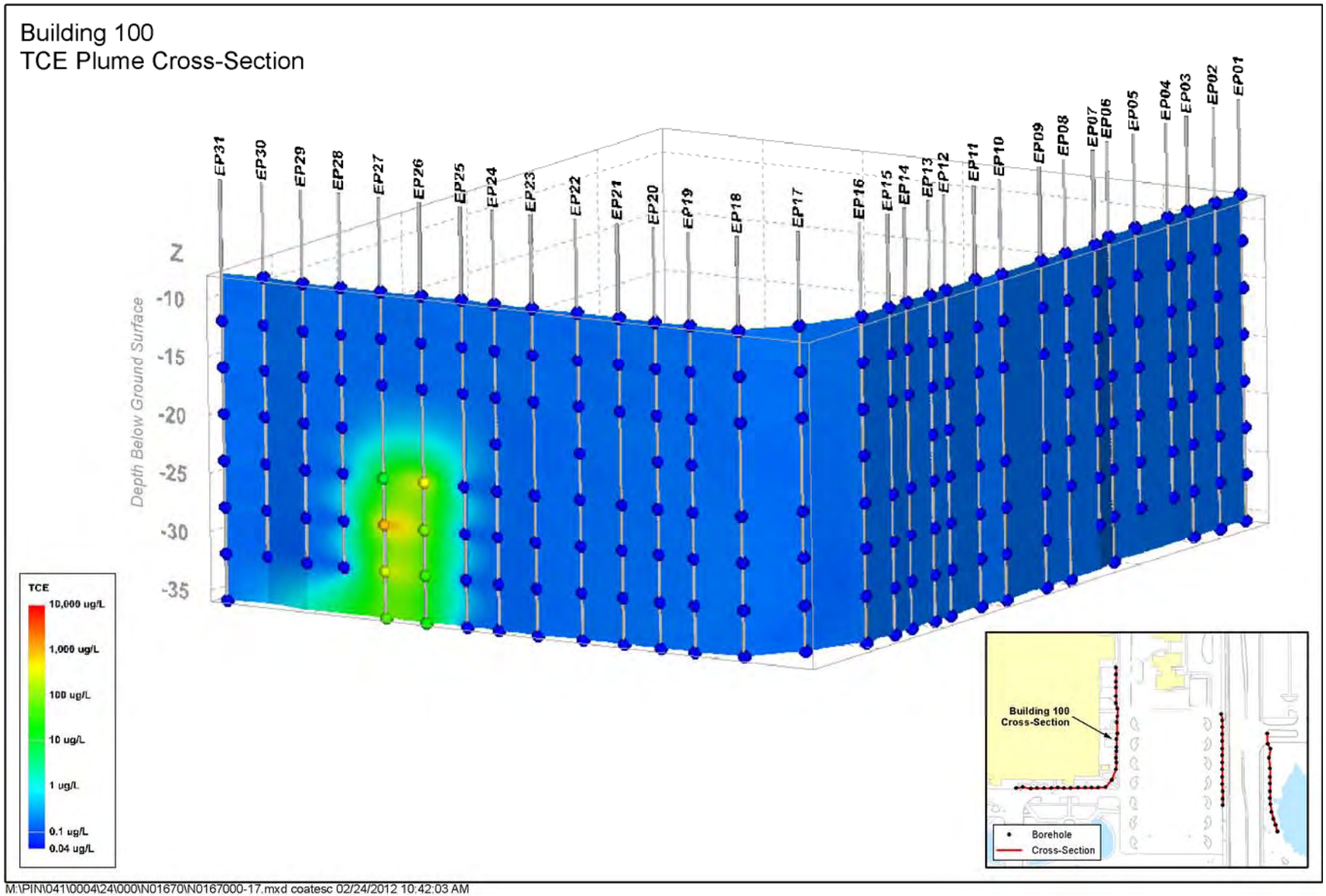

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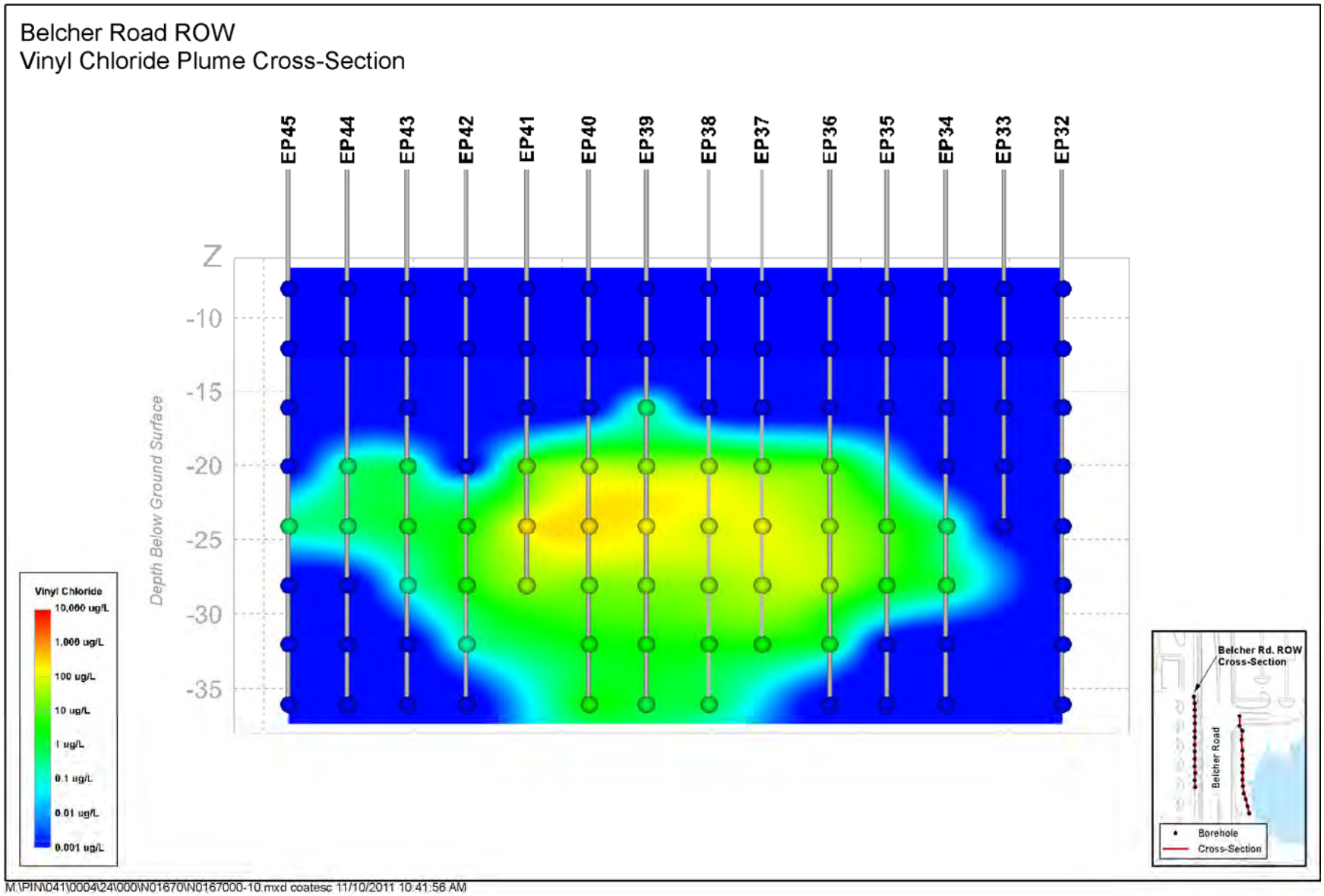
Belcher Road ROW
Vinyl Chloride Plume Cross-Section
EP45
EP44
EP43
EP42
EP41
EP40
EP39
EP38
EP37
EP36
EP35
EP34
EP33
EP32
Z
-10
-15
-20
-25
-30
-35
Depth Below Ground Surface
Vinyl Chloride
10,000 ug/L
1,000 ug/L
100 ug/L
10 ug/L
1 ug/L
0.1 ug/L
0.01 ug/L
0.001 ug/L
Belcher Rd. ROW Cross-Section
Belcher Road
Borehole
Cross-Section
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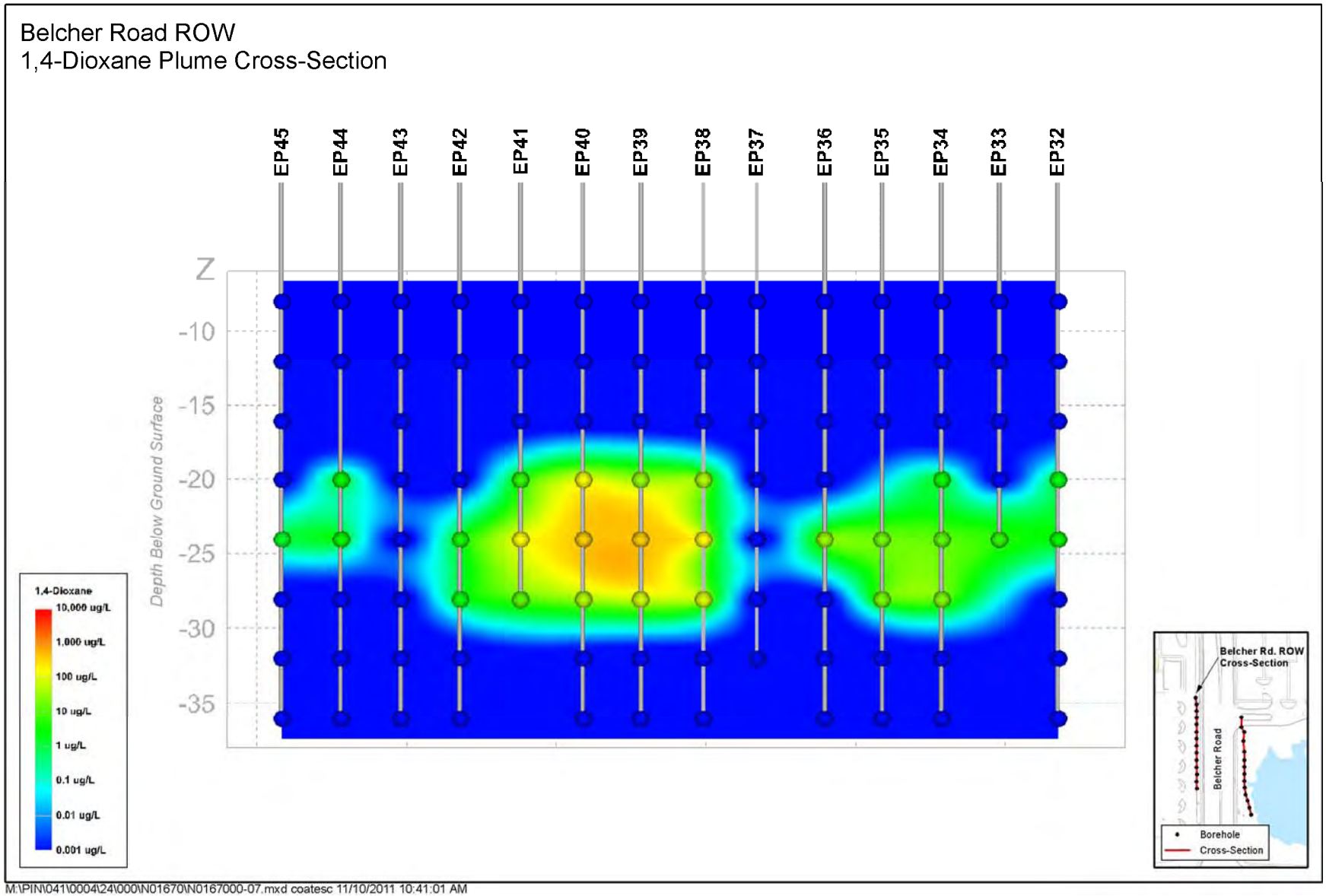

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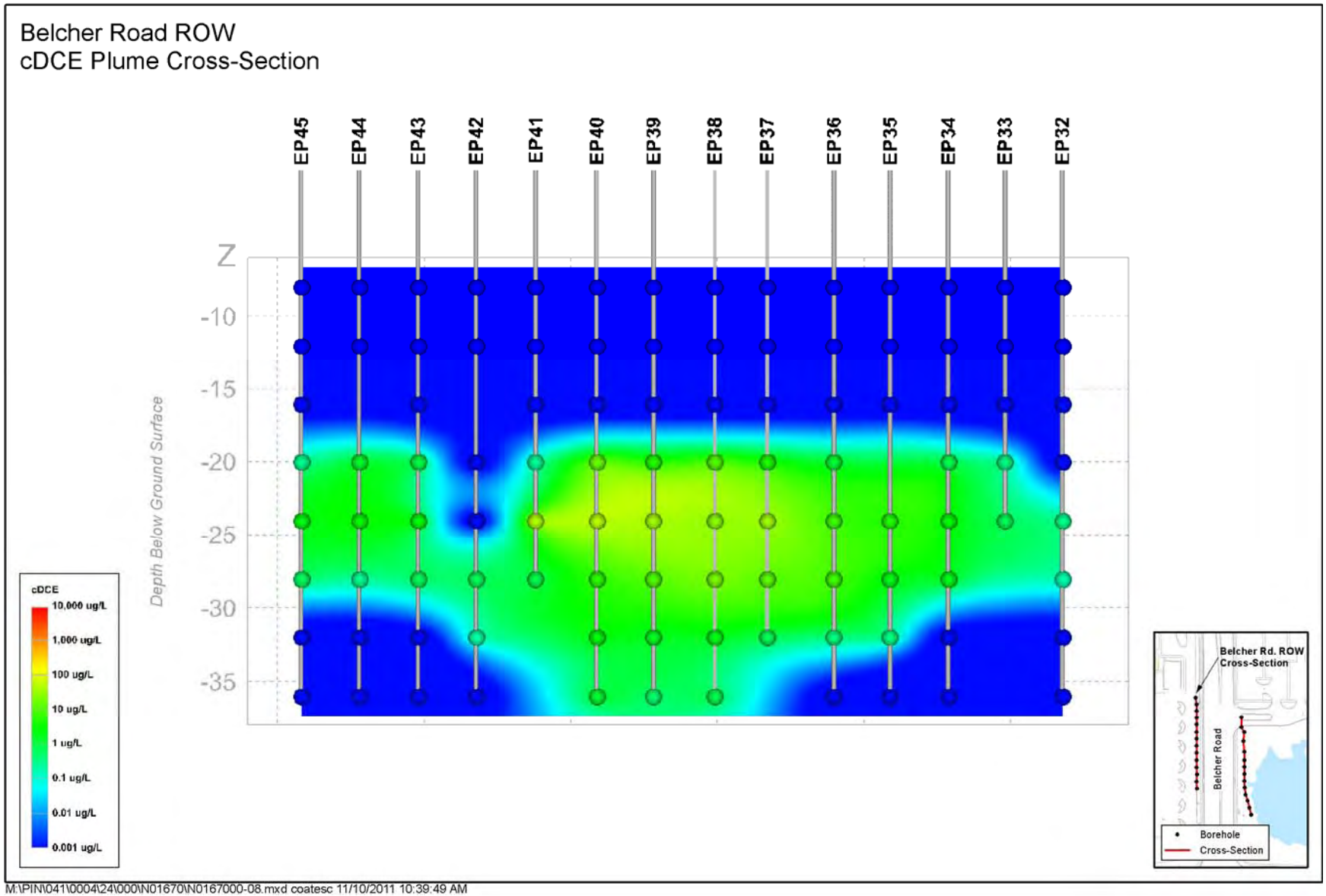

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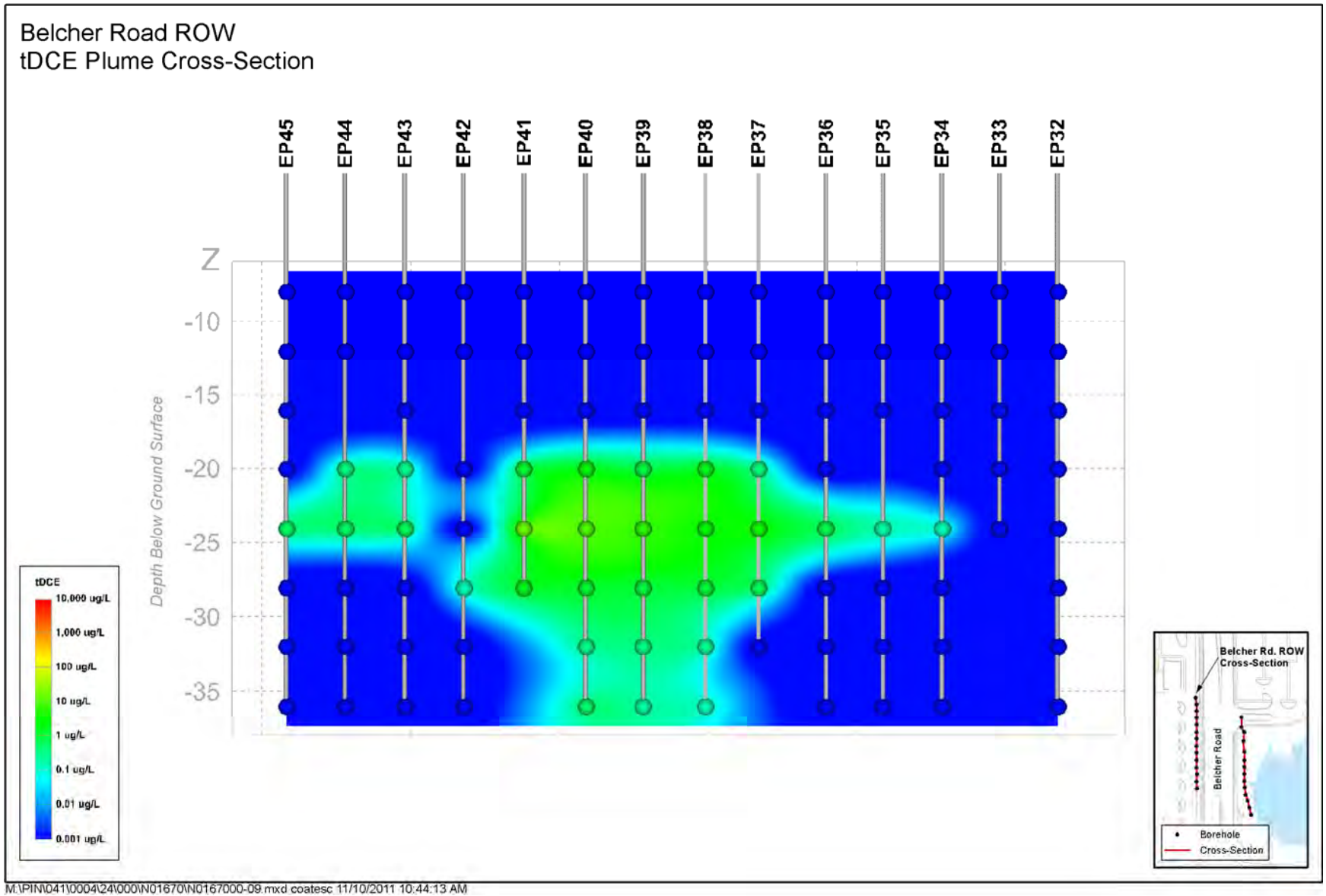

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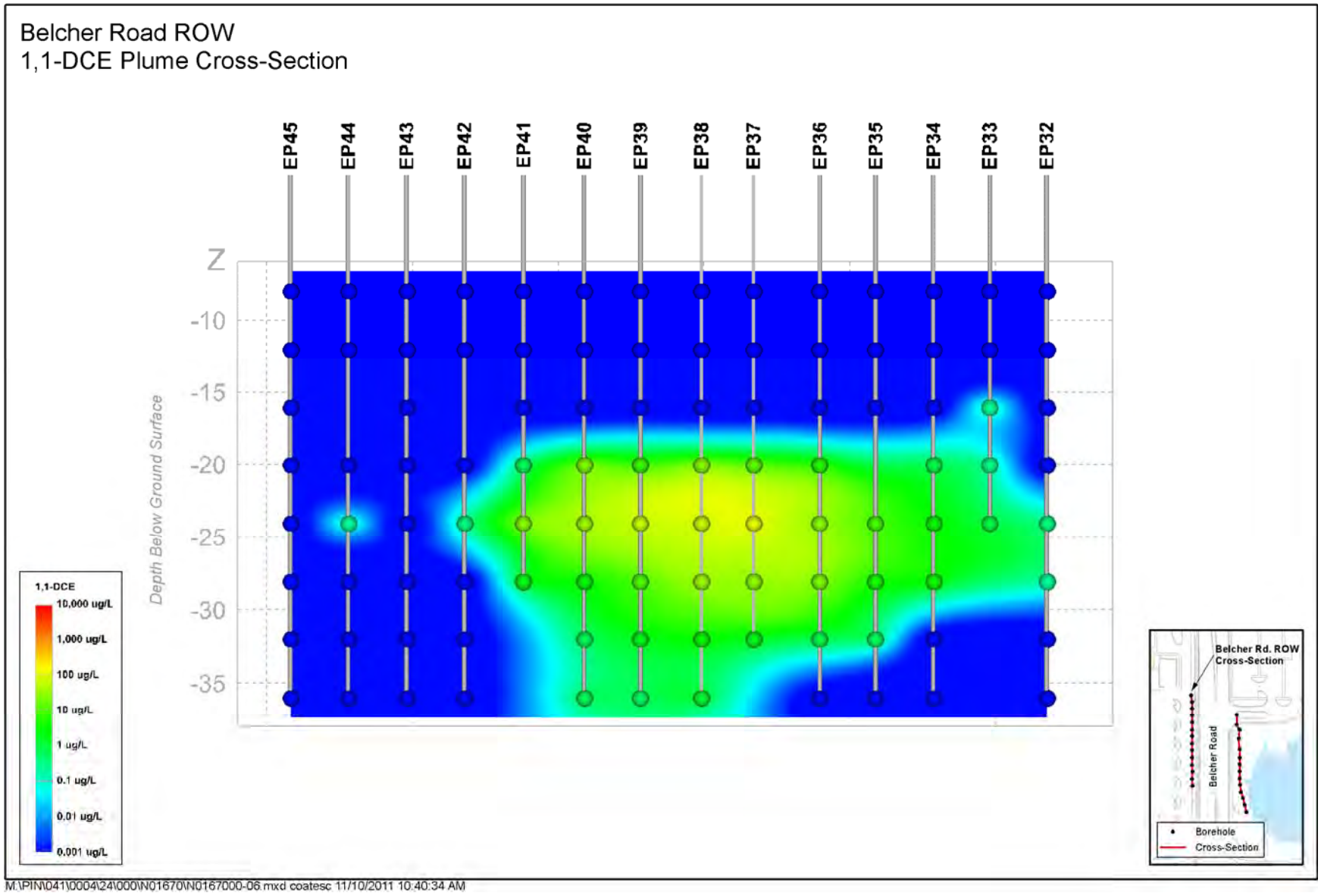
Belcher Road ROW
1,1-DCE Plume Cross-Section
EP45
EP44
EP43
EP42
EP41
EP40
EP39
EP38
EP37
EP36
EP35
EP34
EP33
EP32
Z
-10
-15
-20
-25
-30
-35
Depth Below Ground Surface
1,1-DCE
10,000 ug/L
1,000 ug/L
100 ug/L
10 ug/L
1 ug/L
0.1 ug/L
0.01 ug/L
0.001 ug/L
Belcher Rd. ROW Cross-Section
Belcher Road
Borehole
Cross-Section
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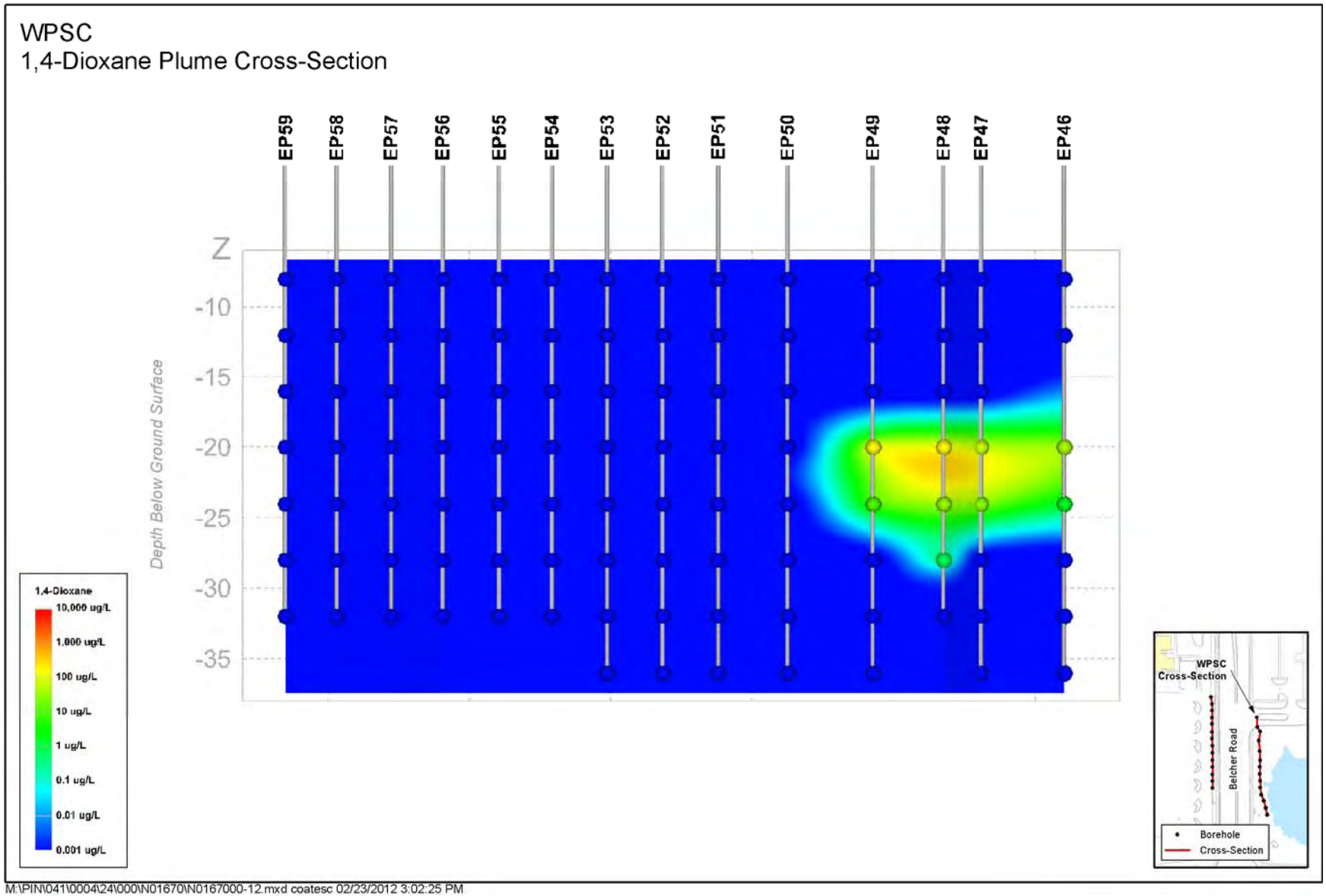

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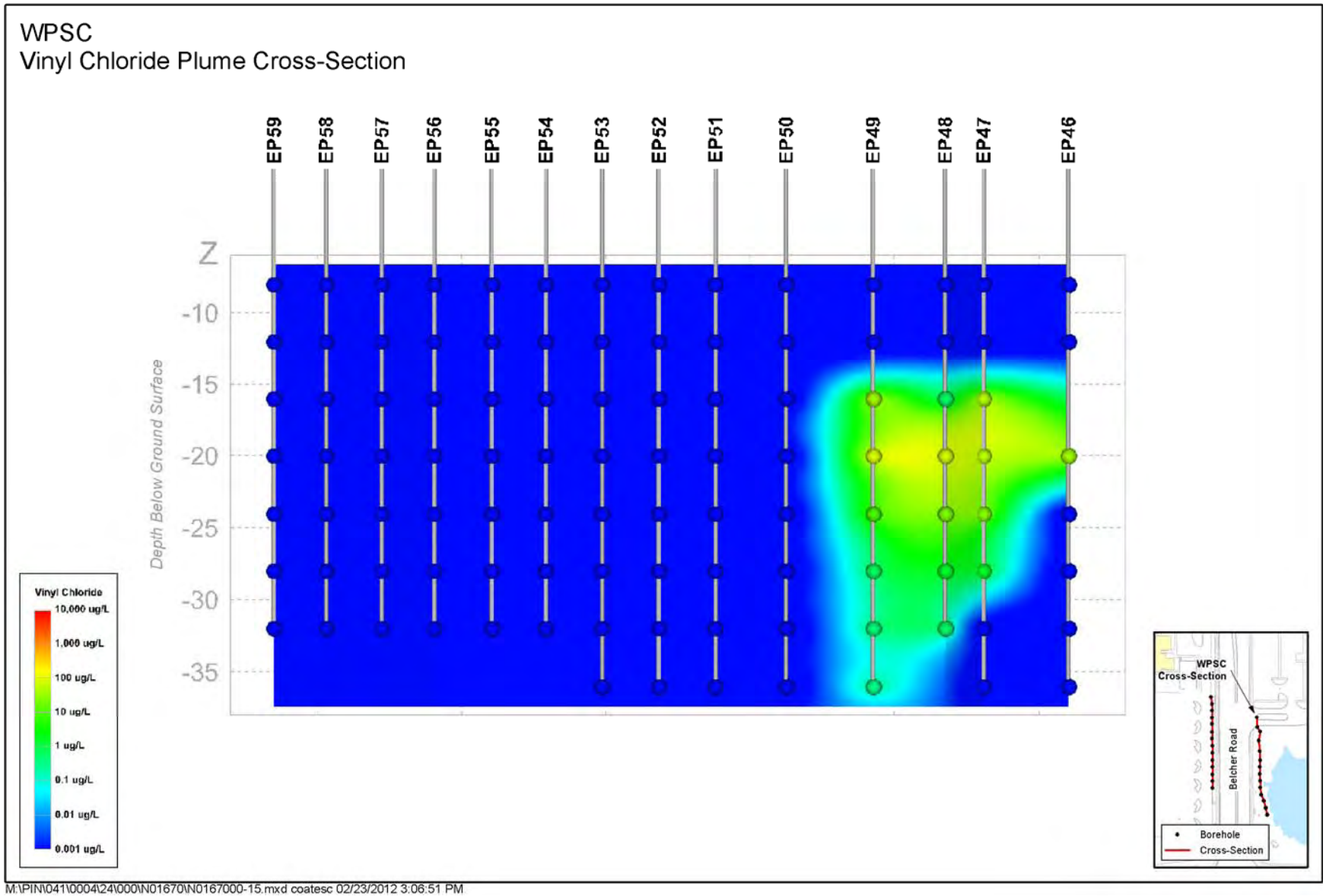

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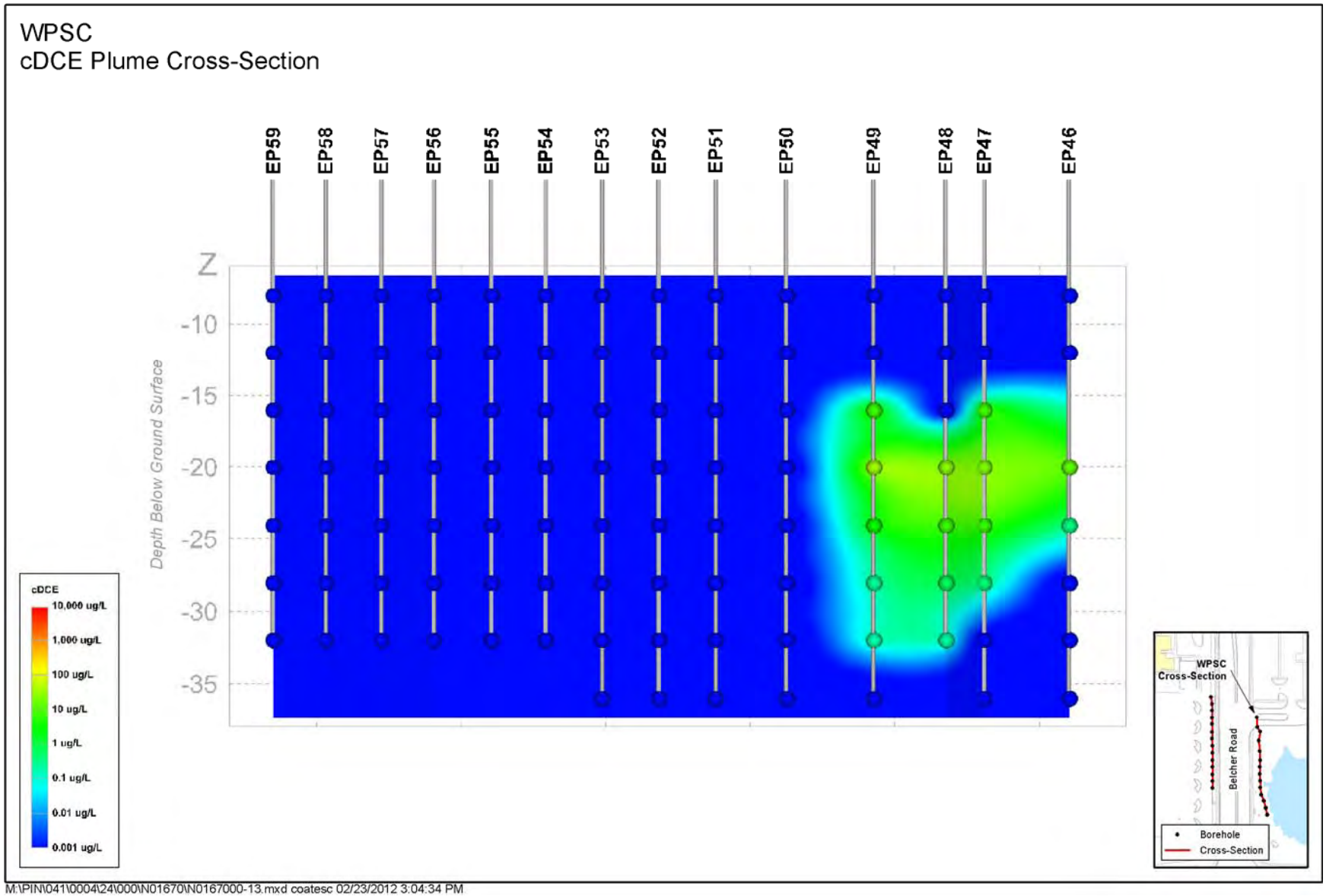

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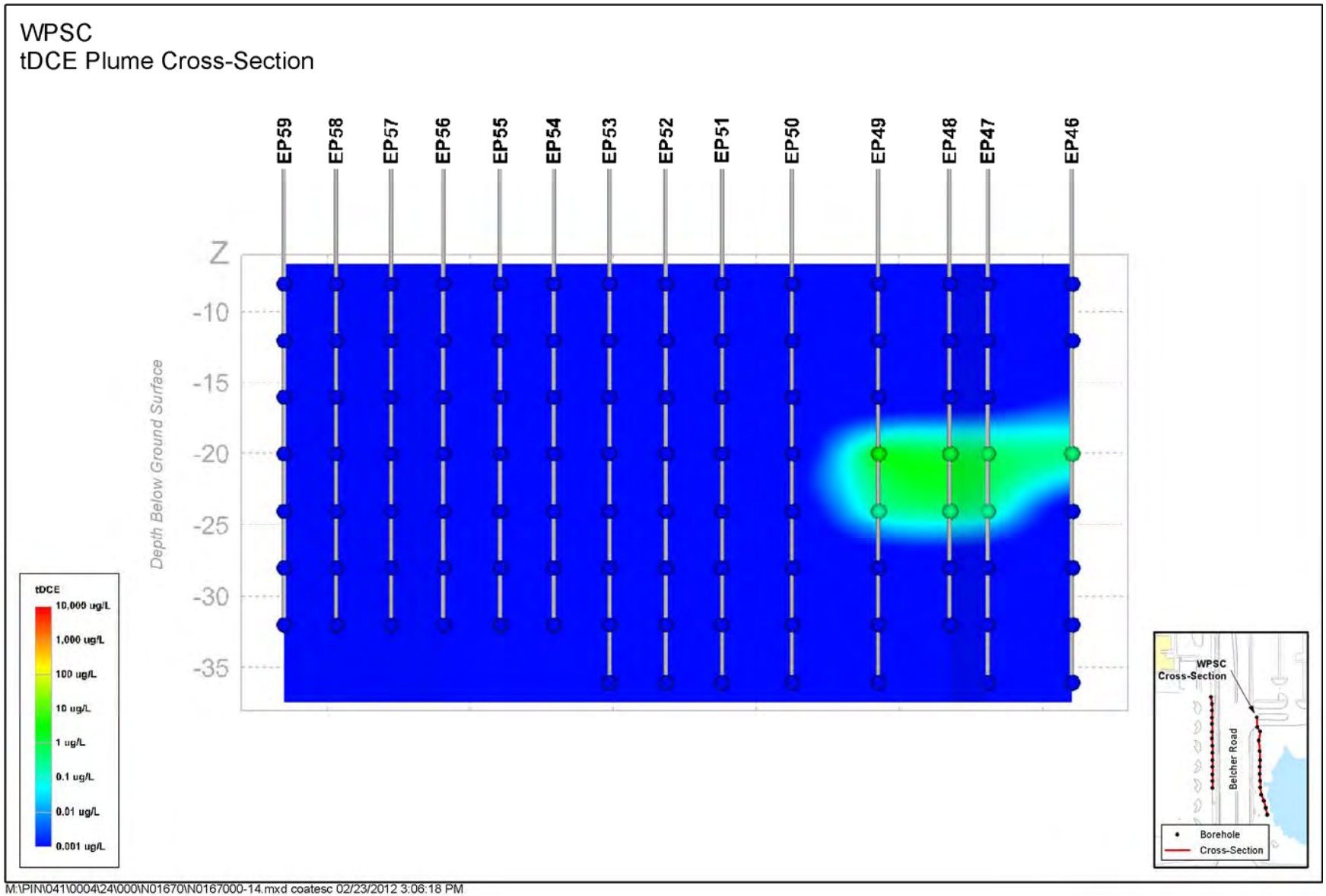

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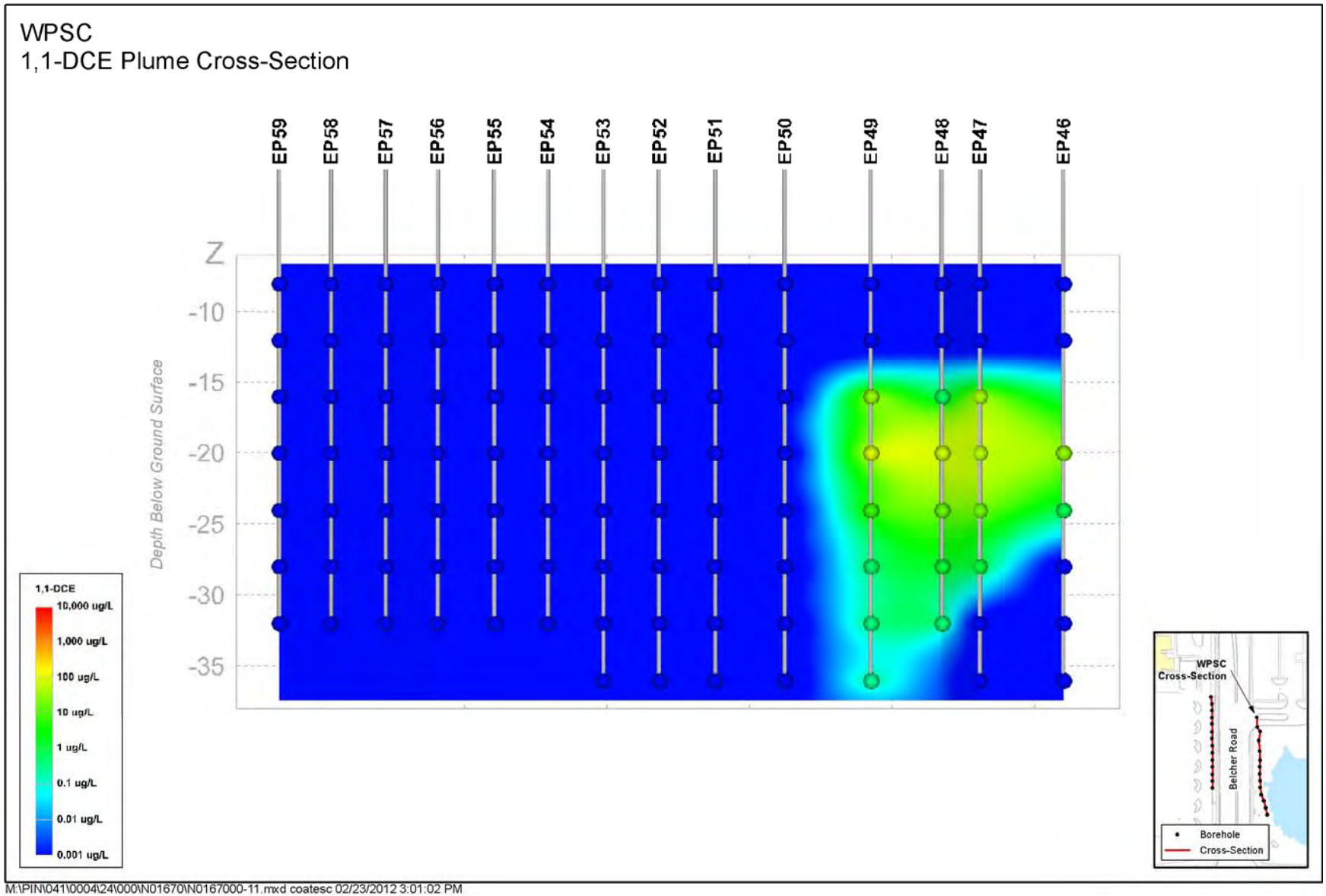

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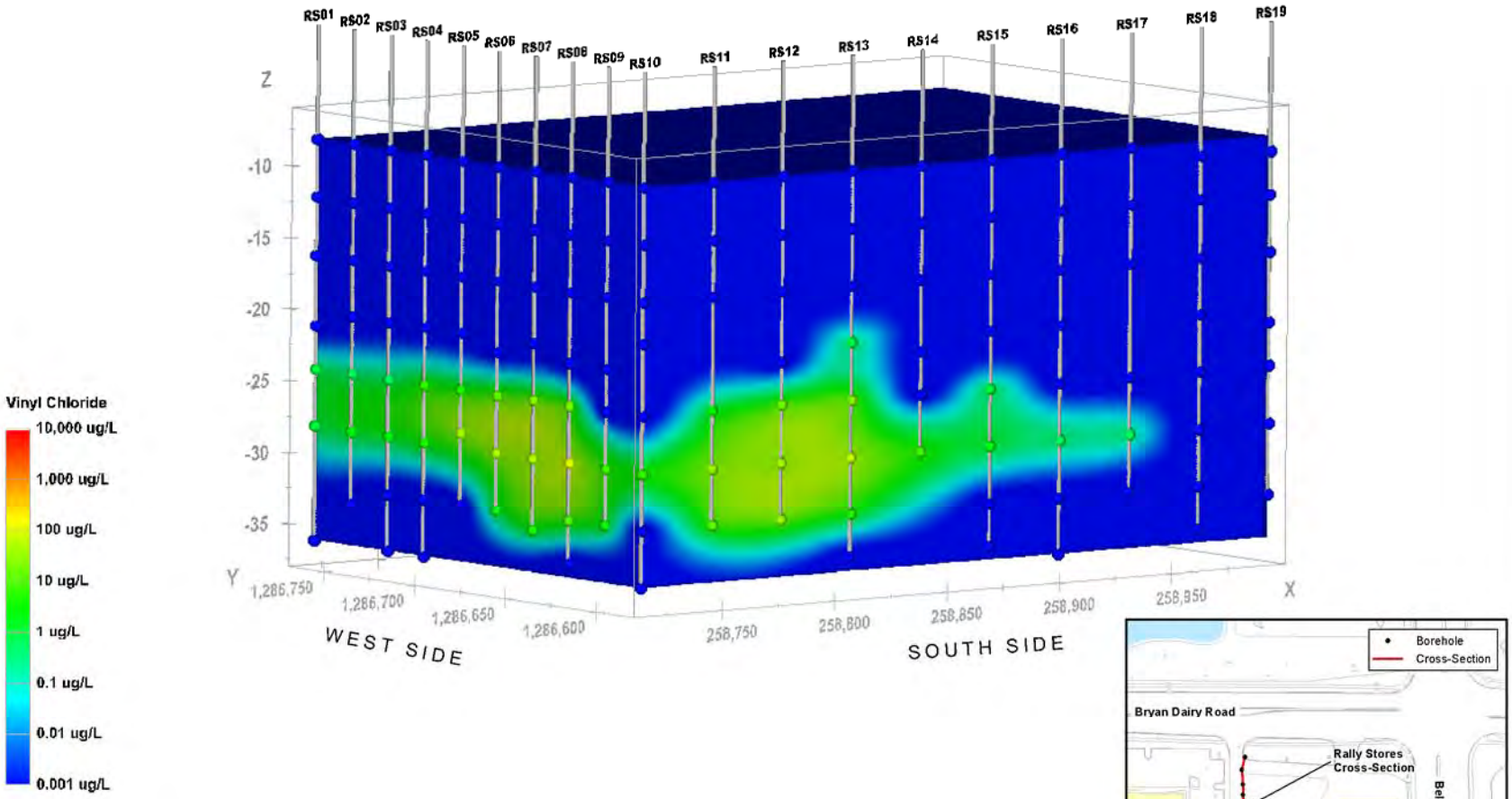
Rally Stores
Vinyl Chloride Plume Cross-Section



Note:
Z values are depth in feet below land surface.
X and Y values are state plane coordinates in feet. (State Plane Coordinate System Florida West Zone NAD27)

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Appendix C

Time-Concentration Plots

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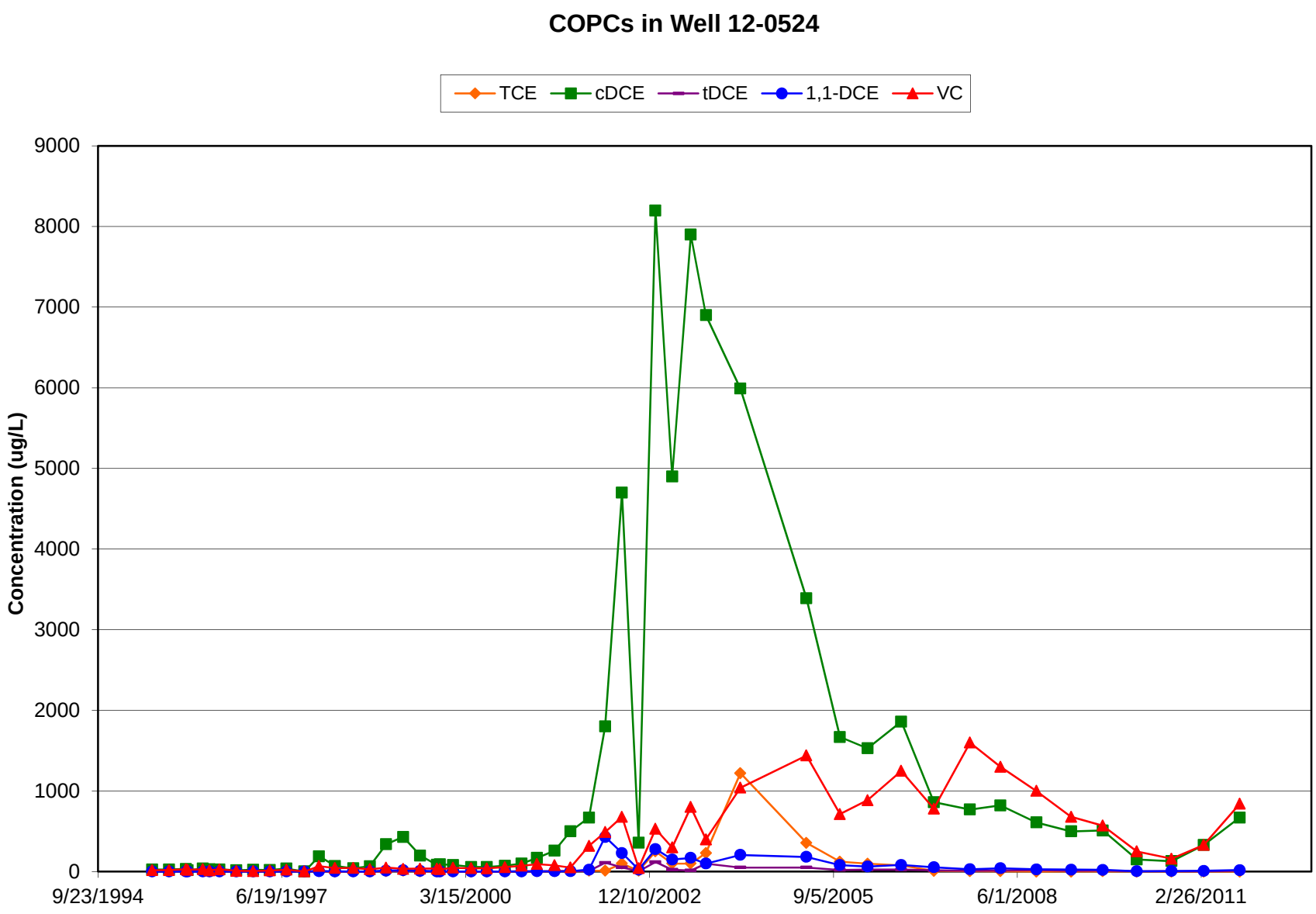
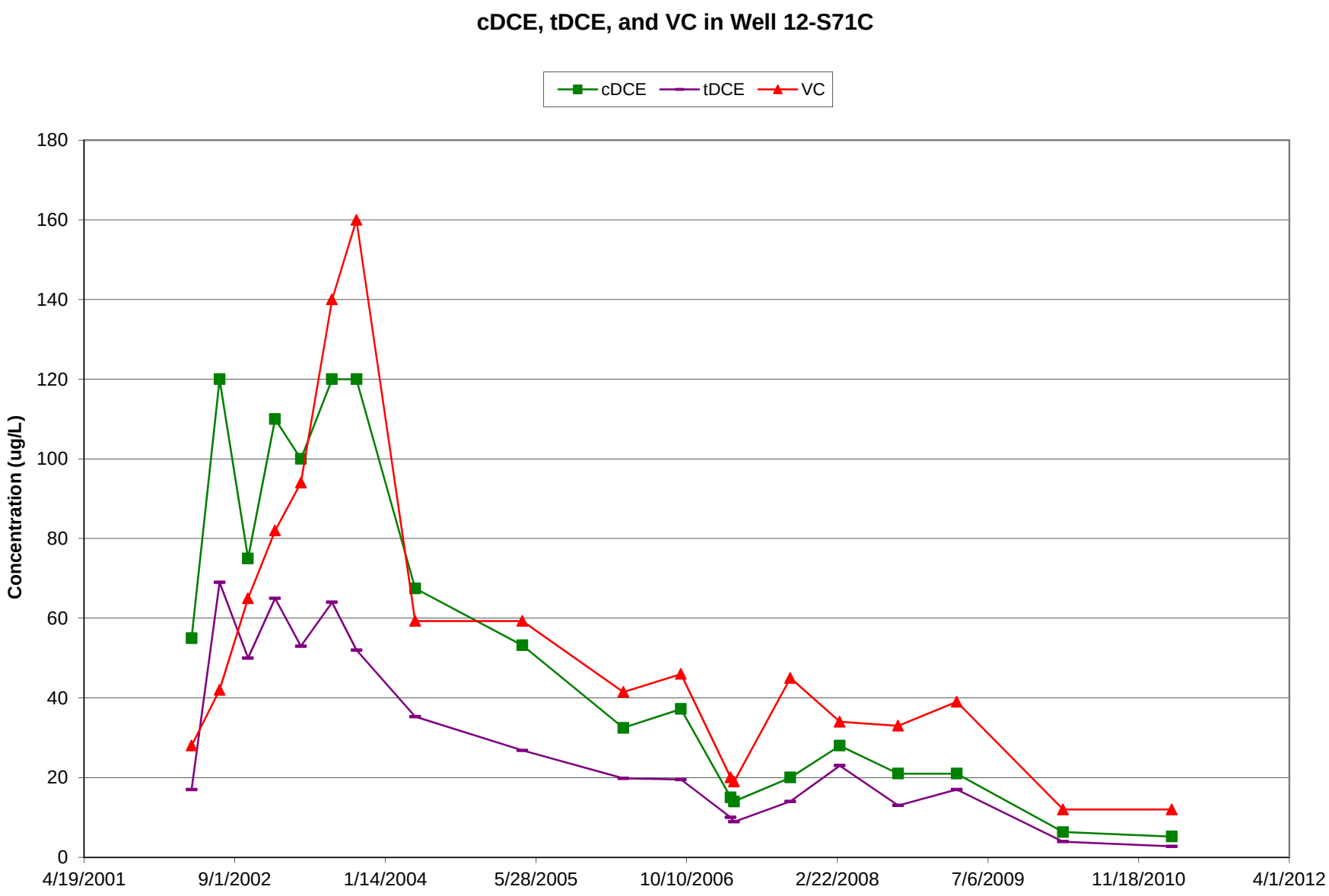
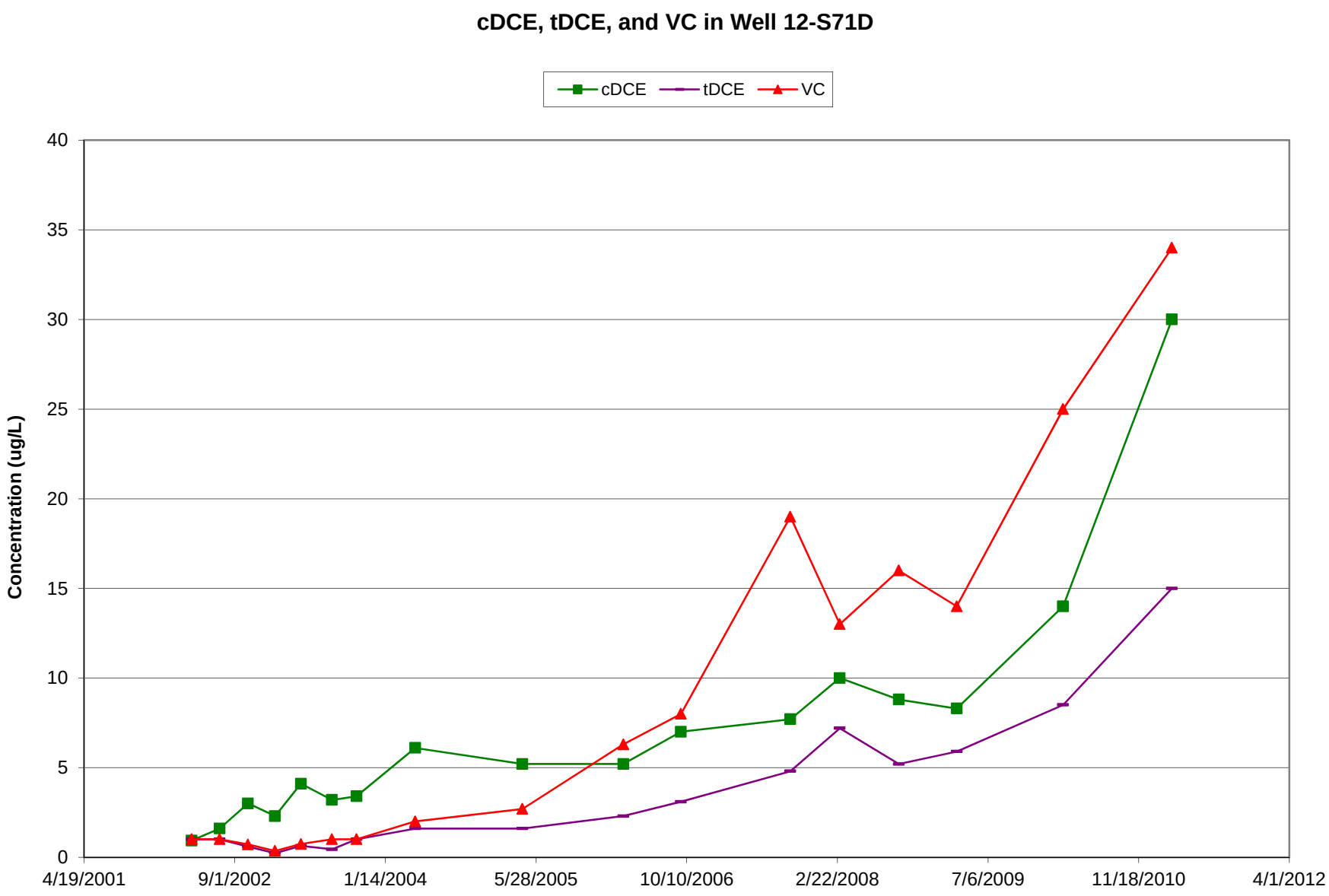
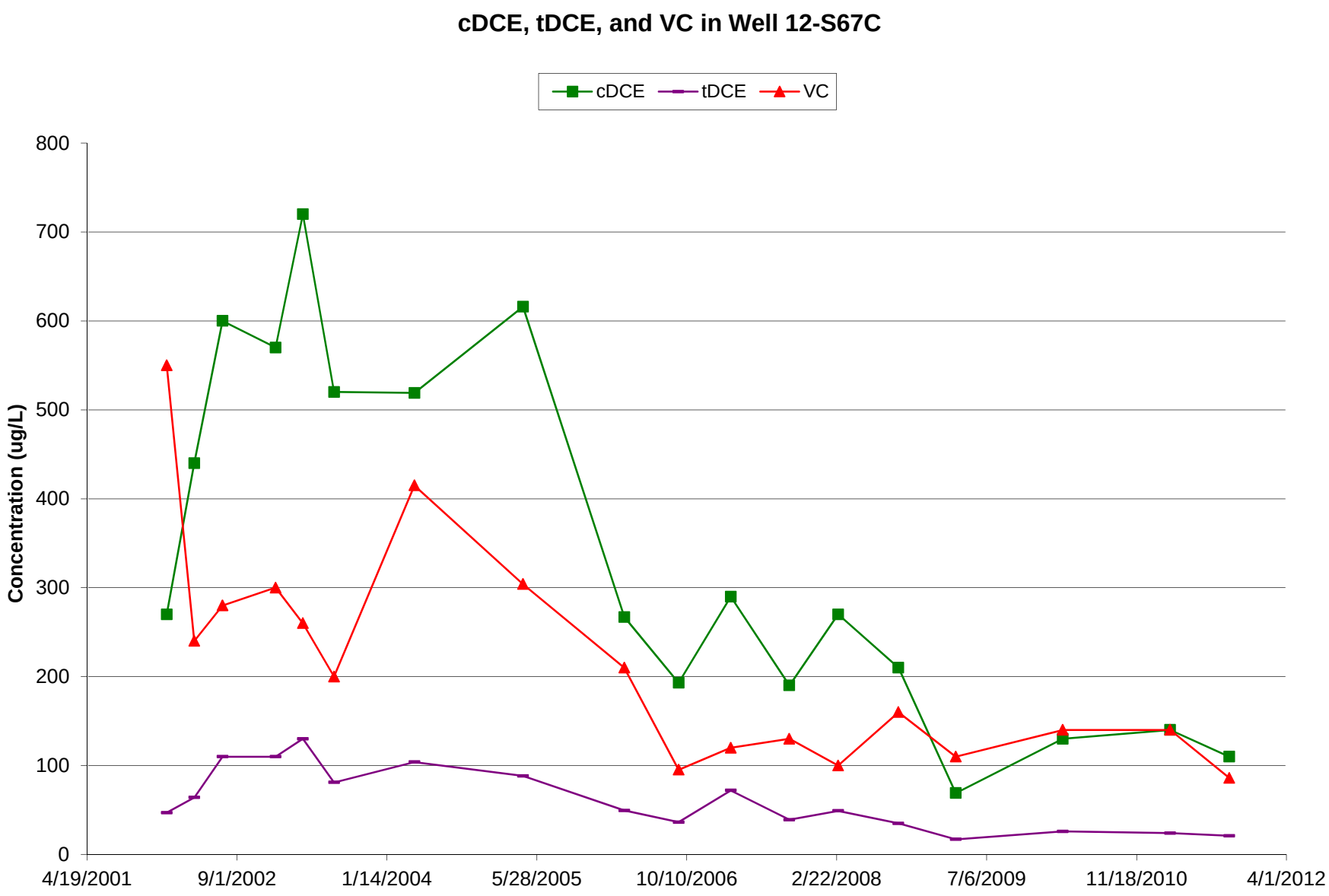

COPCs in Well 12-0524
TCE
cDCE
tDCE
1,1-DCE
VC
Concentration (ug/L)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
9/23/1994
6/19/1997
3/15/2000
12/10/2002
9/5/2005
6/1/2008
2/26/2011


cDCE, tDCE, and VC in Well 12-S71C
cDCE
tDCE
VC
Concentration (ug/L)
180
160
140
120
100
80
60
40
20
0
4/19/2001
9/1/2002
1/14/2004
5/28/2005
10/10/2006
2/22/2008
7/6/2009
11/18/2010
4/1/2012


cDCE, tDCE, and VC in Well 12-S71D
cDCE
tDCE
VC
Concentration (ug/L)
40
35
30
25
20
15
10
5
0
4/19/2001
9/1/2002
1/14/2004
5/28/2005
10/10/2006
2/22/2008
7/6/2009
11/18/2010
4/1/2012


cDCE, tDCE, and VC in Well 12-S67C
cDCE
tDCE
VC
Concentration (ug/L)
800
700
600
500
400
300
200
100
0
4/19/2001
9/1/2002
1/14/2004
5/28/2005
10/10/2006
2/22/2008
7/6/2009
11/18/2010
4/1/2012

Appendix D

Engineering Drawings for Groundwater Remediation and Plume Control Technologies

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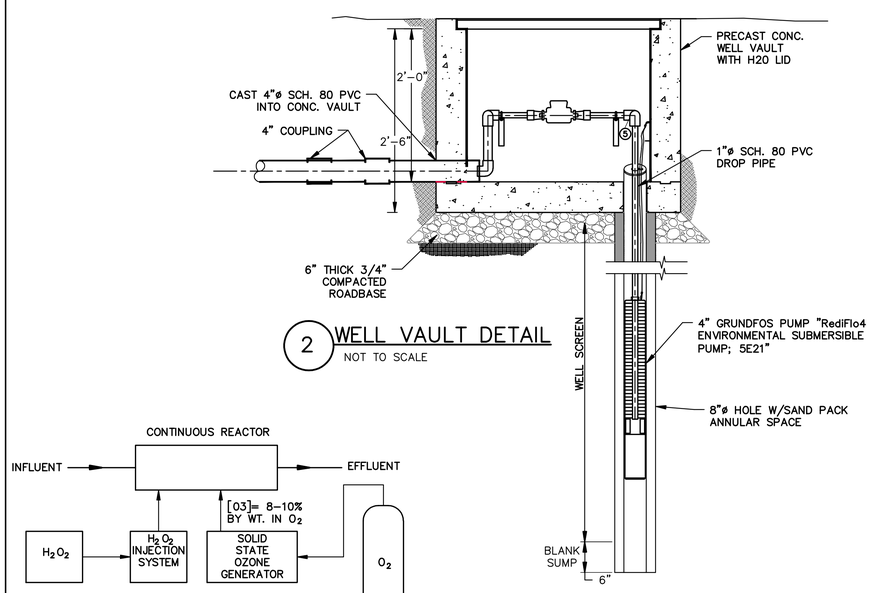
EXIST. DISCHARGE LINE
550
800
500
1500
1600
BUILDING 100
PROP. 1, 4-DIOXANE TREATMENT SYSTEM SEE DETAIL 1
EXIST. AIR STRIPPERS FOR VOC, TREATMENT
EXIST. F.O.B.
EXIST. DOUBLE CONTAINED BURIED DEWATERING TRANSMISSION LINE (55 gpm capacity)
EXIST. DOUBLE CONTAINED BURIED DEWATERING TRANSMISSION LINE (55 gpm capacity)
PROP. RECOVERY WELL AND CONCRETE VAULT (TYP.)
EXIST. ELECTRICAL PANEL
PROP. TRANSMISSION LINE
EXIST. GROUNDWATER TRANSMISSION LINE AND ELECTRICAL POWER/CONTROL LINE
PROP. TRANSMISSION LINE AND ELECTRICAL CONDUIT(S)
PROP. RECOVERY WELL AND CONCRETE VAULT (TYP.)
EXIST. DOUBLE CONTAINED BURIED DEWATERING TRANSMISSION LINE (55 gpm capacity)
PROP. HDPE EFF LINE AND ELECTRICAL CONDUIT(S)
BELCHER ROAD
WALTER DOWNFALL SERVICE CENTER
PROP. TRANSMISSION LINE AND ELECTRICAL CONDUIT(S)
PROP. RECOVERY WELL AND CONCRETE VAULT (TYP.)
EAST PLUME
(3 RECOVERY WELLS)
~POND~
SADDLE AND STUBS
PROP. ELECTRICAL IN CONDUIT (S)
PROP. TRANSMISSION LINE AND ELECTRICAL CONDUIT(S)
EXIST. 6" SDR9 HDPE UNDER STREET TRANSFER LINE WITH NEW TRANSMISSION AND ELECTRICAL CONDUIT(S)
~SOUTHWEST POND~
~SOUTH POND~
~SOUTH POND~
2" HDPE EFF LINE
EXIST. RW03 WELL
BRYAN DAIRY ROAD
HARROD
EXIST. 6" SDR9 HDPE UNDER STREET TRANSFER LINE WITH NEW TRANSMISSION AND ELECTRICAL CONDUIT(S)
RALLY STORES
SOUTH PLUME
(4 RECOVERY WELLS)
PROP. TRANSMISSION LINE AND ELECTRICAL CONDUIT(S)
PROP. RECOVERY WELL AND CONCRETE VAULT (TYP.)
BETTER BUSINESS FORMS



2 WELL VAULT DETAIL
NOT TO SCALE

1 HIPOX UNIT
NOT TO SCALE

N

PLAN

SCALE IN FEET
80 40 0 80 160 240

LEGEND

PROPERTY LINE
ROW LINES
PLUME OUTLINE

NOTE

EXISTING ROADS, ROW, AND UTILITY LINES REPRESENT PINELLAS COUNTY ROAD IMPROVEMENT TO BE COMPLETED IN 2012.

U.S. DEPARTMENT OF ENERGY GRAND JUNCTION, COLORADO	Work Performed by S.M. Stoller Corporation Under DOE Contract No. DE-AM01-07LM00060
PLATE D1: GROUNDWATER PUMP & TREAT	
DATE PREPARED: MARCH 12, 2012	FILENAME: N01678AB

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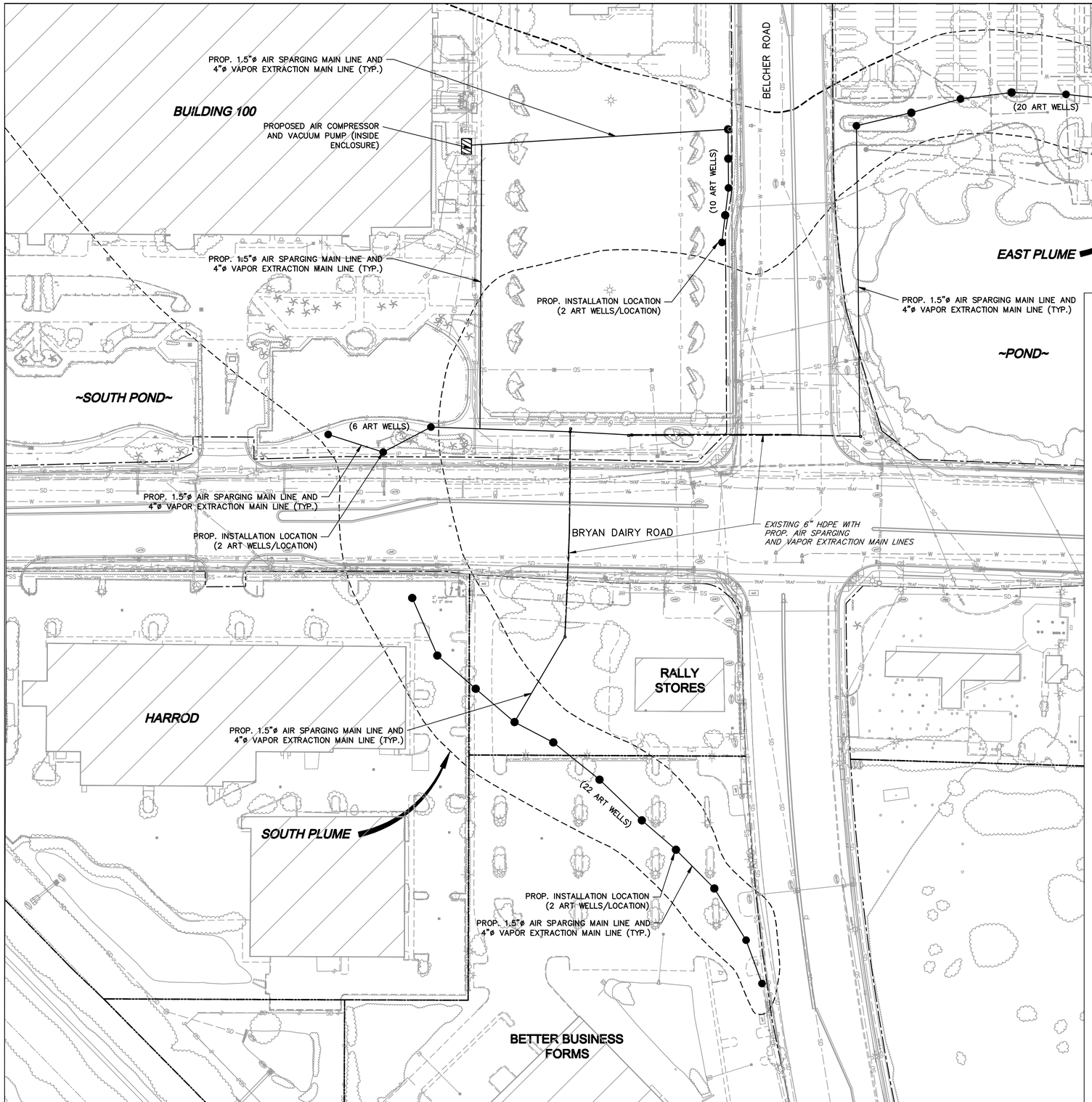

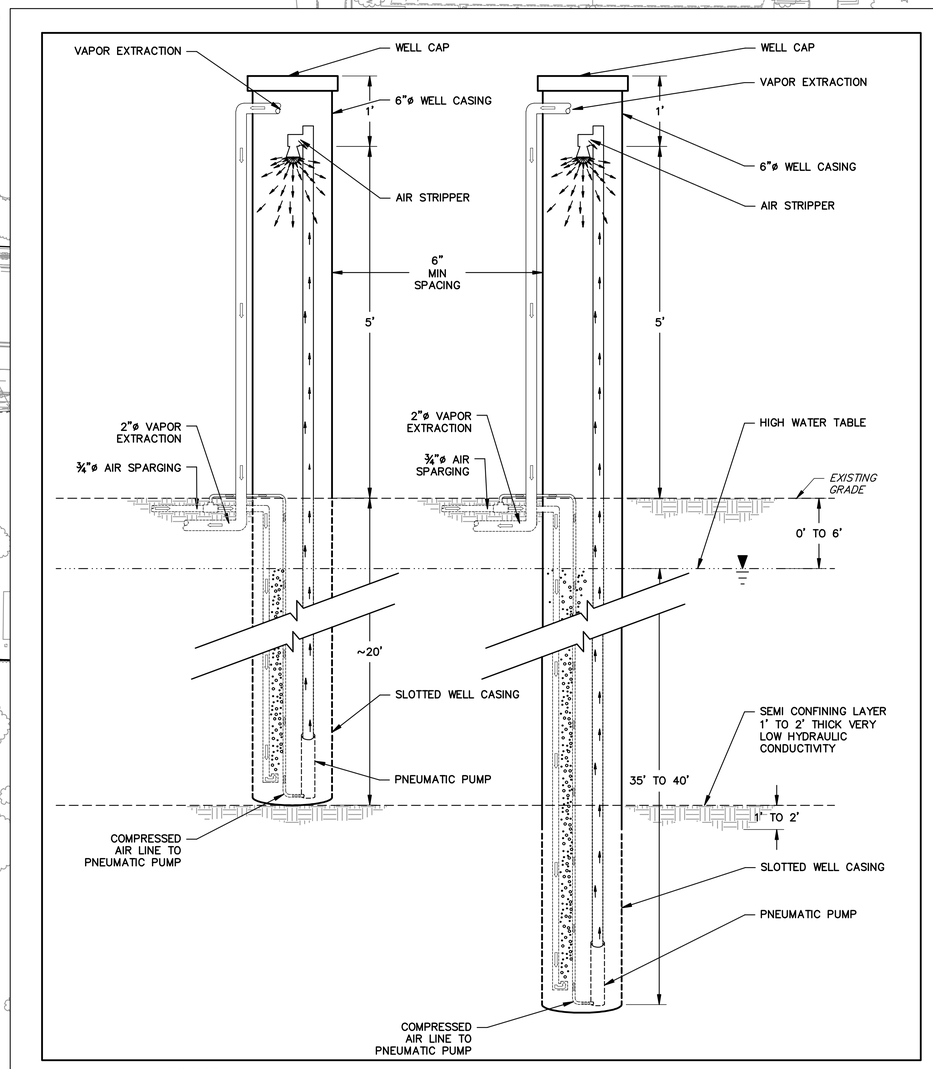

LEGEND

- PROPERTY LINE
- ROW LINES
- PLUME OUTLINE
- PROPOSED ART WELLS (2 UNITS)
- PROPOSED AIR COMPRESSOR AND VACUUM PUMP INSIDE ENCLOSURE
- PROPOSED AIR SPARGING AND VAPOR EXTRACTION LINES

N

PLAN

SCALE IN FEET

60 30 0 60 120 180

NOTE

EXISTING ROADS, ROW, AND UTILITY LINES REPRESENT PINELLAS COUNTY ROAD IMPROVEMENT TO BE COMPLETED IN 2012.

U.S. DEPARTMENT OF ENERGY GRAND JUNCTION, COLORADO	Work Performed by S.M. Stoller Corporation Under DOE Contract No. DE-AM01-07LM00060
PLATE D2: ART IN-WELL ART	
DATE PREPARED: MARCH 3, 2012	FILENAME: N01680AB

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BUILDING 100

BELCHER ROAD

(15 INJECTION POINTS)

WALTER POWNALL SERVICE CENTER

EAST PLUME
(118 INJECTION POINTS)

~POND~

~SOUTH POND~

(11 INJECTION POINTS)

EXIST. 6" SDR-9 HDPE

EXIST. 6" SDR-9 HDPE

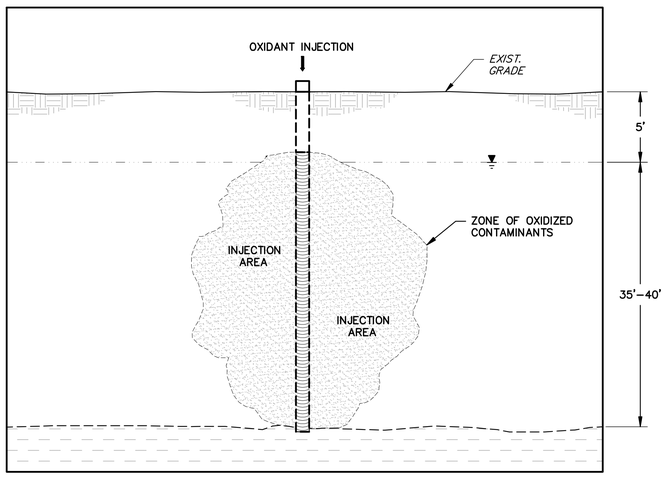
BRYAN DAIRY ROAD

RALLY STORES

HARROD

SOUTH PLUME
(112 INJECTION POINTS)

BETTER BUSINESS FORMS



OXIDANT-INJECTION

NOTES:

1. IN-SITU CHEMICAL OXIDATION USING DIRECT-PUSH INJECTION.
2. BOA SUBCONTRACTORS TO PERFORM DIRECT-PUSH INJECTION AT SPECIFIED TIME INTERVALS (ASSUME ONCE A YEAR.)

N

PLAN

SCALE IN FEET
60 30 0 60 120 180

LEGEND

- PROPERTY LINE
- ROW LINES
- PLUME OUTLINE
- DIRECT PUSH INJECTION WELLS

NOTE

EXIST. ROADS, ROW, AND UTILITY LINES REPRESENT PINELLAS COUNTY ROAD IMPROVEMENT TO BE COMPLETED IN 2012.

U.S. DEPARTMENT OF ENERGY GRAND JUNCTION, COLORADO	Work Performed by S.M. Stoller Corporation Under DOE Contract No. DE-AM01-07LM00060
PLATE D3: PERSULFATE INJECTION FOR CHEMOX	
DATE PREPARED: MARCH 3, 2012	FILENAME: N01679AB

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Appendix E

Cost Estimate Details and Assumptions

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1. Statement of Purpose

This estimate has been prepared as a tool to assist in determining the best possible course of action to take when deciding upon which of the three offsite plume remediation and onsite plume containment alternatives are most appropriate to achieve the overall project goals.

2. Project Cost Estimate Summary

2.1. Offsite Remediation

2.1.1. HiPOx Groundwater Pump and Treat: Total: $1,268,000

- East Plume $604,000
  - Treatment Duration: 5 years.
  - Overall project duration (including install and decommissioning and demolition [D&D]): 6 years.
- South Plume $664,000
  - Treatment Duration: 5 years.
  - Overall project duration (including install and D&D): 6 years.

2.1.2. ART Wells: Total: $4,952,000

- East Plume $2,270,000
  - Treatment Duration: 10 years.
  - Overall project duration (including demonstration test system, install, and D&D): 12 years.
- South Plume $2,682,000
  - Treatment Duration: 10 years.
  - Overall project duration (including demonstration test system, install, and D&D): 12 years.

2.1.3. Redox Chem-Ox Direct Push: Total: $4,359,000

- East Plume $2,201,000
  - Treatment Duration: 2 years.
  - Overall project duration (including pilot test, install, and D&D): 4 years.
- South Plume $2,158,000
  - Treatment Duration: 2 years.
  - Overall project duration (including pilot test, install, and D&D): 4 years.

2.2. Onsite Plume Containment

All onsite plume containment is assumed to be continuous for a period of 50 years with D&D taking place in life cycle year 50. Institutional controls (ICs) are assumed to be in place in perpetuity.

2.2.1. HiPOx Groundwater Pump and Treat: Total: $3,441,000

- Onsite Plume East Lobe $1,831,000
- Onsite Plume South Lobe $1,609,000

2.2.2. Art Wells: Total: $6,423,000

- Onsite Plume East Lobe $3,956,000
- Onsite Plume South Lobe $2,467,000

2.2.3. Redox Chem-Ox Direct Push: Total: $37,771,000

- Onsite Plume East Lobe $21,043,000
- Onsite Plume South Lobe $16,728,000

2.3. Institutional Controls

While ICs are a viable option for addressing the offsite plumes, determining the type of IC and an associated cost to implement them are relatively unknown factors at this point and therefore no costs associated with IC have been included at this time.

Table 2. Alternatives Analysis—Life Cycle Cost Estimate Summary

Life Cycle Cost Estimate

Summary Table ($ in K): Report Value: Present Dollars

Technology	Offsite East Plume Remediation		Offsite South Plume Remediation		Offsite Remediation Combined Subtotal	Onsite East Plume Control		Onsite South Plume Control		Onsite Control Combined Subtotal	Offsite & Onsite Combined Total
	Cost	Treatment Duration	Cost	Treatment Duration		Cost	Treatment Duration	Cost	Treatment Duration		
HiPOx Groundwater Pump & Treat	604	5 Years	664	5 Years	1,268	1,831	50 Years	1,609	50 Years	3,441	4,709
Art Wells	2,270	10 Years	2,682	10 Years	4,952	3,956	50 Years	2,467	50 Years	6,423	11,375
Redox Chem Ox - Direct Push	2,201	2 Years	2,158	2 Years	4,359	21,043	50 Years (6 wk intervals) (434 treatments)	16,728	50 Years (6 wk intervals) (434 treatments)	37,771	42,130

3. Estimate Assumptions

3.1. General Assumptions

1. This estimate is an order of magnitude type of construction cost estimate and was generated using information from the preliminary layout drawings, site inspection and input from site personnel. The general use of this type of estimate is for feasibility studies, development of project scope and program, selection from alternative designs, and long range budget forecasting. The accepted industry accuracy range of this type of estimate is –30% to +50%.
2. This estimate includes direct construction costs only. It does not include any costs associated with engineering design, construction support, project management, or S.M. Stoller Corporation G&A or fee.

3. This estimate has been prepared assuming an open, competitive bid process and has allowed for standard market rates for labor and equipment
4. Labor, material and equipment pricing was generated from RS Means with adjustment factors applied for the local market. RS Means Database: 2011—4th Quarter, Local Modification Index: St. Petersburg, FL.
5. Preliminary vendor budget pricing was obtained for the chemical oxidation, direct push (Redox Tech, LLC, Cary, NC); groundwater pump & treat including HiPOx (APT Water, Pleasant Hill, CA) and ART well technology (Specialty Systems Integrators, Inc., Plymouth, MN).
6. Included in the above pricing is an overall 26% general contingency. This contingency is based upon the level of design information available at the time of the estimate along with the complexity of the project as well as factors such as calendar appropriate construction timing. This is a "construction estimate" contingency applied only to construction costs to compensate and allow for the lack of any engineering design since the project is in the very early programmatic options analysis stage. As the engineering designs are developed and mature, additional project details become evident and the construction estimate contingency is intended to cover the costs for those details that are unknown at this time. This contingency is not intended to be an "owner's contingency." The inclusion of this type of contingency at this stage of project development is considered an industry accepted practice. The amount of the construction contingency will generally decrease as the engineering plans progress through the design process.
7. The above estimate includes state and local sales taxes and is based upon present dollars escalated to the assumed construction start of 2015. Escalation rate of 2.8% from the DOE Office of Cost Analysis Escalation Rate Table—Base Year 2011 was used in developing this estimate.

3.2. Alternate Specific Assumptions

3.2.1. HiPOx Groundwater Pump and Treat

3.2.1.1. Offsite—East and South Plumes

1. The assumption is made that no pilot study will be required for this alternative.
2. Installation of the HiPOx treatment system equipment is assumed to take place in year 1 and is assumed to be installed within the confines of the existing concrete containment pad where the air stripper is currently operating. The HiPOx equipment is assumed to be installed down flow of the air stripper.
3. Offsite plume remediation allows for three extraction wells in the east plume and four extraction wells in the south plume. The wells will include a concrete equipment vault with the vault and well head being installed flush with the ground surface.
4. A subsurface transmission pipeline will be installed between the offsite wells and routed to connect to the existing onsite transmission line already in place and servicing RW03.

5. The assumption is made that the existing sub-surface HDPE pipelines crossing under both Belcher and Bryan Dairy roads is available for and is of adequate size to serve as the road crossing point for system piping in this scenario.
6. Operations and maintenance is described in Section 7.4.1 of the main document.
7. D&D of system components is assumed to take place the year after treatment is complete. Included in D&D is the repair and reclamation of the disturbed asphalt and landscape areas.

3.2.1.2. Onsite—East and South Plume Lobes

1. Onsite plume containment assumes the use of the existing RW03 on the south side of the onsite plume and allows for the installation of one new extraction well on the east side of the onsite plume near the property line, one extraction well installed near the existing electrical panel located near the east side of Building 100, and one extraction well installed near the building just east of the entrance driveway.
2. A subsurface transmission pipeline will be installed between the onsite wells and routed to connect to the existing onsite transmission line already in place and servicing RW03.
3. Operations and maintenance is described in Section 7.4.1 of the main document.
4. D&D of system components is assumed to take place the year after treatment is complete. Included in D&D is the repair and reclamation of the disturbed asphalt and landscape areas.

3.2.2. ART Wells ART Wells

3.2.2.1. Offsite—East and South Plumes

1. Installation of the offsite ART well treatment system is assumed to take place after completion of a demonstration system and system test data analysis. The installation is assumed to take place in year 2 of the life-cycle timeline assuming a demonstration system is installed in year 1.
2. Offsite plume remediation allows for 10 ART wells in the east plume and 11 ART wells in the south plume.
3. A subsurface transmission pipeline will be installed between the offsite ART wells and routed and connect to a small system control shed located next to the east side of Building 100 near the existing exterior electrical rack.
4. Due to the level of the subsurface water table the ART well heads will rise approximately 6 feet above the ground surface and will be protected with concrete filled steel bollards.
5. The assumption is made that the existing sub-surface HDPE pipelines crossing under both Belcher and Bryan Dairy roads is

available for and is of adequate size to serve as the road crossing point for system piping in this scenario.

6. Operations and maintenance is described in Section 7.4.1 of the main document.
7. D&D of system components is assumed to take place the year after treatment is complete. Included in D&D is the repair and reclamation of the disturbed asphalt and landscape areas.

3.2.2.2. Onsite—East and South Plume Lobes

1. Installation of the onsite ART well treatment system is assumed to take place after completion of a demonstration system and data analysis. For estimating and alternative comparison purposes, the installation is assumed to take place in year 1 of the life-cycle timeline.
2. Offsite plume remediation allows for five ART wells in the east lobe of the onsite plume and three ART wells in the south lobe of the onsite plume.
3. A subsurface transmission pipeline will be installed between the onsite ART wells and routed and connected to a small system control shed located next to the east side of Building 100 near the existing exterior electrical rack.
4. Due to the level of the subsurface water table the ART well heads will rise approximately 6 feet above the ground surface and will be protected with concrete filled steel bollards.
5. Operations and maintenance is described in Section 7.4.1 of the main document.
6. D&D of system components is assumed to take place the year after treatment is complete. Included in D&D is the repair and reclamation of the disturbed asphalt and landscape areas.

3.2.3. Redox Chem-Ox Direct Push

3.2.3.1. Offsite—East and South Plume

1. System installation is expected to take place after completion of a pilot test and data analysis and therefore, is assumed to take place in year 2 of the life-cycle timeline.
2. Offsite plume remediation includes a total of 96 injection points at the East plume and 118 at the South plume and assumes a total of two injection applications approximately 18 months apart.
3. Temporary patching of the asphalt and landscape areas between injection applications has been allowed for.
4. Final patching of the asphalt surfaces after the second application assumes a 1 inch overlay of the asphalt areas and restoration of landscape areas disturbed during injection activities.

3.2.3.2. Onsite—East and South Plume Lobes

1. System installation is expected to take place after completion of a pilot test and data analysis. However, for estimating and alternative comparison purposes, the installation is assumed to take place in year 1 of the life cycle timeline.
2. Onsite plume containment includes a total of 26 injection points. 15 injection points will be located in the onsite plume's east lobe near the east property line and 11 injection points will be located in the onsite plume's south lobe near the south property line.
3. The assumption is made that injections to contain the onsite plume will be required every 6 weeks for the 50 year analysis period used in this cost estimate. To facilitate injection point location consistency and ease of application for the continued injections at the 6 week intervals the initial injection for onsite plume control will include the installation of screened well casings in each of the 26 injection point locations.
4. As a direct push injection process the assumption is made that operations and maintenance will not required for this treatment alternative.
5. Final patching of the asphalt and landscape areas upon completion of the injection applications has been allowed for.