ALABAMA DEPARTMENT OF TRANSPORTATION

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July 10, 2008

Mr. Steve Cobb
Alabama Department of Environmental Management
Governmental Hazardous Waste Branch
Land Division
1400 Coliseum Boulevard
Montgomery, AL 36110

Re: **Response to the ADEM Review Comments: Site-Wide Corrective Measures Evaluation**, dated April 25, 2008
Coliseum Boulevard Plume Site
Alabama Department of Transportation
Project Fund: 348-211-9273

Dear Mr. Cobb:

Included herein are ALDOT's responses to the ADEM Review Comments dated April 25, 2008 to the Site-Wide Corrective Measures Evaluation (CME) for the Coliseum Boulevard Plume project (CBP). The responses include references and citations to facilitate location of revisions in the CME Report or to reference information submitted in previous reports. Revisions to the CME Report are also attached. The revised text (Revised July 2008) should replace the October 2007 text. The table (Table 7-1), figures (3-6R, 2-12A1, and 2-16R), and the supplemental appendix (Appendix A1) should be inserted as appropriate.

The CME Report was submitted to ADEM on April 25, 2007, after completion of the primary investigation phase of the CBP project, to provide a comprehensive overview of site investigations, risk assessments, evaluation of applicable remedial technologies, and an overview of the Institutional, Remedial and Engineering Control programs for the CBP. ADEM provided comments to the CME Report on August 17, 2007 and August 31, 2007. On October 15, 2007, the ALDOT responded to the ADEM comments, and revised the CME to reflect the ADEM comments. ADEM provided additional comments on April 25, 2008, which are addressed in this letter and revisions to the CME.

This project is dynamic and complicated by the large geographic size and multiple uses of the land area (over 2200 individual parcels of residential and commercial real property) presently impacted or potentially impacted by the CBP. Thus, the ALDOT implemented a plan to complete site investigations and a thorough analysis of potentially applicable corrective measures while designing, implementing and substantially completing an Institutional Control Plan to protect public health by restricting access to or use of groundwater. Therefore, the CBP Project has been implemented in stages (See attached Figure 1), and we are currently in the process of finalizing some of the remedial plans and completing the design of certain components of additional remedial plans.

The CME Report was not intended to contain all the details for each of the potential corrective measure plans. Because of the complexity of the project, ADEM and the ALDOT agreed that the Corrective Measures Evaluation Report would be an overview of corrective measures that may be applicable for the CBP Project, and that each corrective measure recommended by the ALDOT and approved by ADEM would be included in an area-specific Corrective Measures Implementation Plan. Consistent with this plan, the details of the various remedial plans evaluated have been or will be contained in a set of area-specific implementation plans, to wit:

- Institutional Control Implementation Plan - submitted to ADEM in April 2008;
- Long Term Monitoring Plan – to be submitted in July 2008;
- Kilby Ditch and Low-Lying Area Corrective Measure Implementation Plan – to be submitted in August 2008,
- Southwest groundwater control Corrective Measure Implementation Plan - to be submitted in December 2008.
- Annual Institutional Control Effectiveness Monitoring Report–submission date to be determined.
- Long-term Monitoring Report to evaluate effectiveness of applied corrective measures and the predicted variance of TCE concentrations within the CBP over time–submission date to be determined.

All Plans and Reports will all be available for public review and comment following approval by the ADEM.

We hope revisions of the previously submitted CME Report and our response comments address the issues and concerns set out in ADEM's April 25, 2008 Comment letter. Throughout this project, ALDOT has designed and implemented our investigation and remediation plans to comply with ADEM requirements, and to manage the CBP in a manner that protects the health of persons who live, work or travel through the CBP area. We are available to discuss any issue of concern at any time so that we can avoid any unnecessary delays in remedial design and implementation.

Sincerely,

B.E. Cox, Jr., P.E.
Geotechnical Engineer

cc: Kristy Wright, ADEM
Ashley Cousins, ACESS
Floyd Gilliland, Nix Holtsford
Andy Eversull, Malcolm Pirnie

ALDOT Responses to ADEM Comments
CME Comment Letter Dated April 25, 2008

1. ***Figure 3-6.*** *The cone of depression from the pumping at the sand and gravel mines is not defined. Due to the size and extent of the CBP, additional delineation of groundwater flow in the southwestern area of the site is needed. Section 4.2.3.2 predicts that the plume will be captured by the sand and gravel mines between 2026 and 2036. However, there are no enclosed groundwater contours on Figure 3-6 indicating that the pumping will capture the TCE contamination. Continued pumping in this area or pumping from the proposed locations will draw contaminated groundwater originating from the Probe Hole 12 area underneath numerous residences. Please revise the document to address this issue.*

   ALDOT Response:

   The current pumping in the southwestern part of the CBP is controlling the movement of groundwater that contains dissolved TCE within the boundary of the Institutional Control Program through the year 2036. Figure 3-6 (right side of figure) has been revised to show the model simulated drawdown due to the pumping at the sand and gravel mines. The view of the revised Figure 3-6 is also shifted to the west to show groundwater contours around the sand and gravel mines rather than just the eastern side of the mines.

2. ***Section 5.6.3 and 5.7.*** *All potentially feasible remediation technologies should be evaluated against the nine Environmental Protection Agency (EPA) evaluation criteria in order to determine the appropriate course of action as stated in the August 17, 2006 comment letter. No technologies should be screened out until they have been evaluated and compared using the EPA criteria. In-situ chemical oxidation and enhanced biodegradation should be retained for evaluation and comparison using the nine EPA evaluation criteria because:*
   - *The amount of oxidant/amendments needed is relative to the size of the plume.*
   - *The number and spacing of injection points may present some implementation problems, but they do not cause either method to be ineffective.*
   - *Reapplication, maintenance, or other optimization will also be needed with other forms of remediation.*
   - *Subsurface heterogeneities are site specific conditions and will be present with any form of remediation.*
   - *There will be levels of disruption to the community with all forms of remedial action.*
   - *There will be inaccessible areas with all forms of remedial action.*

ALDOT Response:

Due to the size of the CBP, no one remedial technology would be effective site-wide, with the exception of Institutional Controls. Thus, several remedial technologies were grouped together to evaluate site-wide corrective measures to control plume migration and to decrease TCE concentrations at potential points of exposure.

A statement has been added in sections 5.6 and 5.7 that in-situ chemical oxidation and enhanced bioremediation will be reevaluated in the 5-year review to determine if the technology is feasible based on the site conditions.

3. ***Section 6.3.1.*** *The first paragraph states that the objective of the corrective measures at the Kilby Ditch is to minimize exposure to TCE and to treat surface water so that the discharge will not exceed the ADEM action level of 175 µg/L of TCE in the surface water. The ADEM action level of 175 µg/L for TCE in surface water will likely change to 17.5 µg/L in May 2008. All potential remedial measures should be evaluated using the 17.5 µg/L action level for TCE. The new lower action level may cause the selected and retained remedies to be less feasible than other remedial measures. Please revise the report to address the new proposed action level.*

ALDOT Response:

The CME was prepared prior to the regulatory change which will ultimately lower the discharge concentration from the wetland treatment system by an order of magnitude. Based on a meeting with ADEM Water Quality Branch personnel, this regulatory change will apply to the CBP in May 2011. We have evaluated the proposed wetland treatment system in light of the future action level and conclude that it is still the preferred alternative, because treatment within the system can be enhanced or modified to meet action levels. It should be noted that use of a wetland treatment system is a sustainable "green technology" and affords flexibility in augmentation of treatment mechanisms that will be used within the system. As part of the Long-Term Monitoring Program for the CBP, we will collect samples from the wetland treatment area bi-monthly for compliance with the ADEM action levels. If monitoring indicates that the action levels are not met, the system can be modified to include chemical, additional biological, or physical treatment. Where applicable within the CME, we have referenced that the action level will be 17.5 µg/L in May 2011. Details on the Wetland Treatment system will be provided in the Corrective Measures Implementation Plan (CMIP). References have been added in Sections 1, 5, 6, 7, and 9, that reflect ALDOT's knowledge of the regulatory change that will be accounted for in the final design and submitted in the CMIP.

4. ***Figure 2-16.*** *The plume should be vertically delineated. Because TCE is a DNAPL and the site geology is predominantly sand and gravel the highest concentrations of TCE and free product will be found along the lower confining layer. The clay layer underlying most of the site, referred to as "the first distinct clay," is a very thin layer; approximately 1-3 feet thick. It is possible that this clay layer is permeable or even discontinuous in some areas. A similar thin clay layer occurs on the Maxwell AFB site and has been proven to be discontinuous. Data from multilevel wells suggests that the greatest concentrations of TCE in the probehole 12/CMT 1 area are deeper than the screened intervals of the monitoring wells. It does not appear that any wells were completed at the lower confining layer in the area near CMT 1 and PH L6. Additionally, the Eutaw Aquifer is considered the source of recharge for the Gordo Aquifer in this region, despite the Gordo Aquifer being somewhat confined by the Gordo Clay. Please revise the report to address this issue.*

   ALDOT Response:

   A "Deep Zone" Assessment of PH12 Area was completed in 2003 and found that "Based on the thicknesses of the first distinct clay penetrated at the boreholes of the deep-zone monitoring wells, the first distinct clay immediately beneath the shallow zone of the PH12 area, should provide a barrier to vertical migration of TCE into the deep-zone within the PH12 area." Subsequent to this early investigation, numerous additional probeholes and wells were completed in the PH12 area and the findings did not conflict with the conclusion in the 2003 report. In addition to the extensive investigations to delineate the vertical and lateral extent of TCE in the PH12 area, an investigation specifically designed to investigate the potential for DNAPL was conducted in 2004 and 2005. As part of this DNAPL investigation, a membrane-interface-probe, with extensive sediment and groundwater verification sampling, was used to search for residual free-phase TCE (i.e.,DNAPL) throughout the Probehole 12 area. Numerous probeholes were driven to the first distinct clay, which was detected with a soil-conductivity probe that preceded the detector of the membrane-interface-probe. No free-phase TCE was detected in the samples or by the probe. An additional figure (Figure 2-12A) has been added to the CME to depict the vertical evaluation of TCE in the probehole 12/CMT 1 area and the report has been revised to state that vertical delineation has been completed in the probehole 12/CMT 1 area.

   Section 2.4.2.2 has been revised to clarify that the vertical distribution in the shallow zone has been completed and that TCE is absent in the deep zone. A revised Figure 2-16R is also included. A new figure 2-12A is also included that shows all deep zone monitoring points on a separate figure.

5. ***Section 6.5.2.*** *This section states that a simulation of the CBP groundwater contaminant fate and transport model was run for the following scenarios:*
   - *No sand and gravel mine dewatering at the southwestern sand and gravel mines for the thirty year evaluation period, which would represent a no action alternative at the southwestern area.*
   - *Hydraulic control in the southwestern area of the CBP via continued pumping at the southwestern sand and gravel mines or a separate groundwater extraction system.*

   Why was no simulation run presented for a groundwater extraction system located in the probe hole 12 area? Please provide this information.

   ALDOT Response:

   The Probehole 12 Area Status Report (ALDOT 2005) contained evaluation of numerous alternatives for the PH12 area. It was determined based on the current land use configuration (density of residential and commercial structures) and implementability limitations of the evaluated technologies, that hydraulic control in the PH12 Area would not affect TCE concentration at the distal ends of the CBP. While pumping groundwater may slightly reduce the mass of TCE, the overall treatment would not reduce TCE concentrations to 0.005 mg/L, and therefore, institutional controls were needed to restrict access to and use of groundwater. ALDOT will conduct a 5 year technology review and model update to determine if changes in site conditions (i.e. concentrations, land use, surface cover, etc) justify treatment in the PH12 Area. Details on the PH12 remedial alternatives evaluated are contained in the 2005 report. References to the findings in the 2005 PH12 Area Status Report have been added to sections 1.2 and 2.8.1.2.

6. ***Section 6.5.2.1.*** *This section states that the gradient in the southwestern area would decrease if dewatering stopped. This would slow migration of the plume to the southwest and allow the plume to migrate or spread further north and south along the western portion of the CBP. The report should state or compare the volume or acreage of contaminated groundwater and affected residences predicted by the simulation in the two scenarios.*

   ALDOT Response:

   As stated in Section 3.3.4 (page 3-14) of the CME, 121 additional residential properties would be affected if you compare the non-pumping scenario to the pumping scenario. This information has been added to 6.1 and 6.5.2.1.

7. ***Section 7-2****. This section of the report refers to Table 7-1. However, this table is not included in the report. Please revise the report to include this table.*

   ALDOT Response:

   Table 7-1 was inadvertently left out of the report. The table is included.

8. ***Sections 5.8 and 9.2.1.2.*** *Model simulations were run for the proposed PRBs, however, no simulation was run for the constructed wetlands. Section 5.8 and 9.2.1.2 do not discuss the construction of the constructed wetlands in enough detail for evaluation. ADEM has previously commented on this issue and ALDOT has stated that a design for the wetlands treatment will be included in the CMIP. However, this report should discuss this alternative in more detail, including the amount of the northeastern extent of the CBP that the wetland is expected to capture horizontally and vertically. Please revise the report accordingly.*

   ALDOT Response:

   As outlined in the revised CME Report Introduction, the details for the Wetland Treatment System will be included in the Kilby Ditch / Low-Lying Area Treatment; Corrective Measures Implementation Plan. Section 5.8 is only a general description of the technology and does not include site-specific details regarding design. As noted in Section 9.2.1.2, the design of the wetlands treatment system will be submitted in the CMIP. Additional investigations have been conducted to collect the data necessary for design. Model runs showing capture will be included in the CMIP.

   A Kilby Ditch / Low-lying Area Corrective Measures Implementation Plan (CMIP) with provisions for long-term sampling and data evaluations through 2036 is in preparation for submittal to the ADEM. The CMIP provides for continual evaluations of the effectiveness of the selected corrective measure so that the corrective measure can be, if necessary, modified or augmented to achieve the compliance requirement. The Kilby Ditch / LLA CMIP will be a stand-alone document so that any modification to the corrective measure can be appended to this CMIP. ALDOT has revised the CME to clarify the rationale for providing the detailed information in the standalone Kilby Ditch / LLA CMIP.

9. ***Section 7.2.*** *Each alternative should be assigned a numerical value that corresponds to the effectiveness of each alternative when compared to each of the nine EPA evaluation criteria. A scale is needed to determine the different degrees of effectiveness, such as the 1-10 scale. Please revise this report accordingly.*

ALDOT Response:

Table 7-1 was inadvertently left out of the October 2007 CME. The table is included and the numerical rating system has been incorporated into the table.

10. ***Tables 7-2, 7-3, and 7-4.*** *These tables do not provide cost estimates for maintaining hydraulic control of the CBP at the southwestern area. ALDOT should clearly address the southwestern area of the plume in this report. This information should be presented.*

ALDOT Response:

ALDOT will present the final plan for hydraulic control in the southwest in the Southwest Corrective Measures Implementation Plan. The Institutional Control Program includes those properties that are projected to be impacted within the next 30 years.

11. ***Figure 2-16.*** *Please clarify why the first distinct clay beneath the water table is represented by a dashed line between Brockway Drive and Ferndale Court.*

ALDOT Response:

The original interpretation shown on the cross-section in the CME originated from the 2002 Conceptual Geology Report. The cross-section has been updated with boring logs for sites CMT-5, PW-2, and PZ-7 which coincide scale-wise with the original line of cross section. The geological information from these borings was used to eliminate the inferred line that was on the Figure 2-16. A revised Figure 2-16R is included.

12. ***Figure 3-1.*** *All isoconcentration figures provided are of the maximum concentrations recorded to date. The report should include figures that show advancement of the plume on a sample interval of yearly basis. Please provide this evaluation.*

ALDOT Response:

Maximum TCE concentrations recorded to date have been used to present distribution of the plume because it provides the most conservative interpretation of TCE within the CBP. Providing annual TCE contours based on the historical data to show advancement of the plume would not be meaningful because data collected as part of the CBP investigations have been carried out in phases and the number and location of sample points have varied significantly during the investigation phase. Only within the past several years has the extent of the plume been delineated. As a consequence, historical TCE contour maps will more reflect resolution as a function of the number and location of sampling points at that time rather than the actual distribution of the TCE at that time. TCE movement over time is better evaluated in the Trend Analysis reports, where trends in TCE concentrations in permanent monitoring wells are evaluated over time.

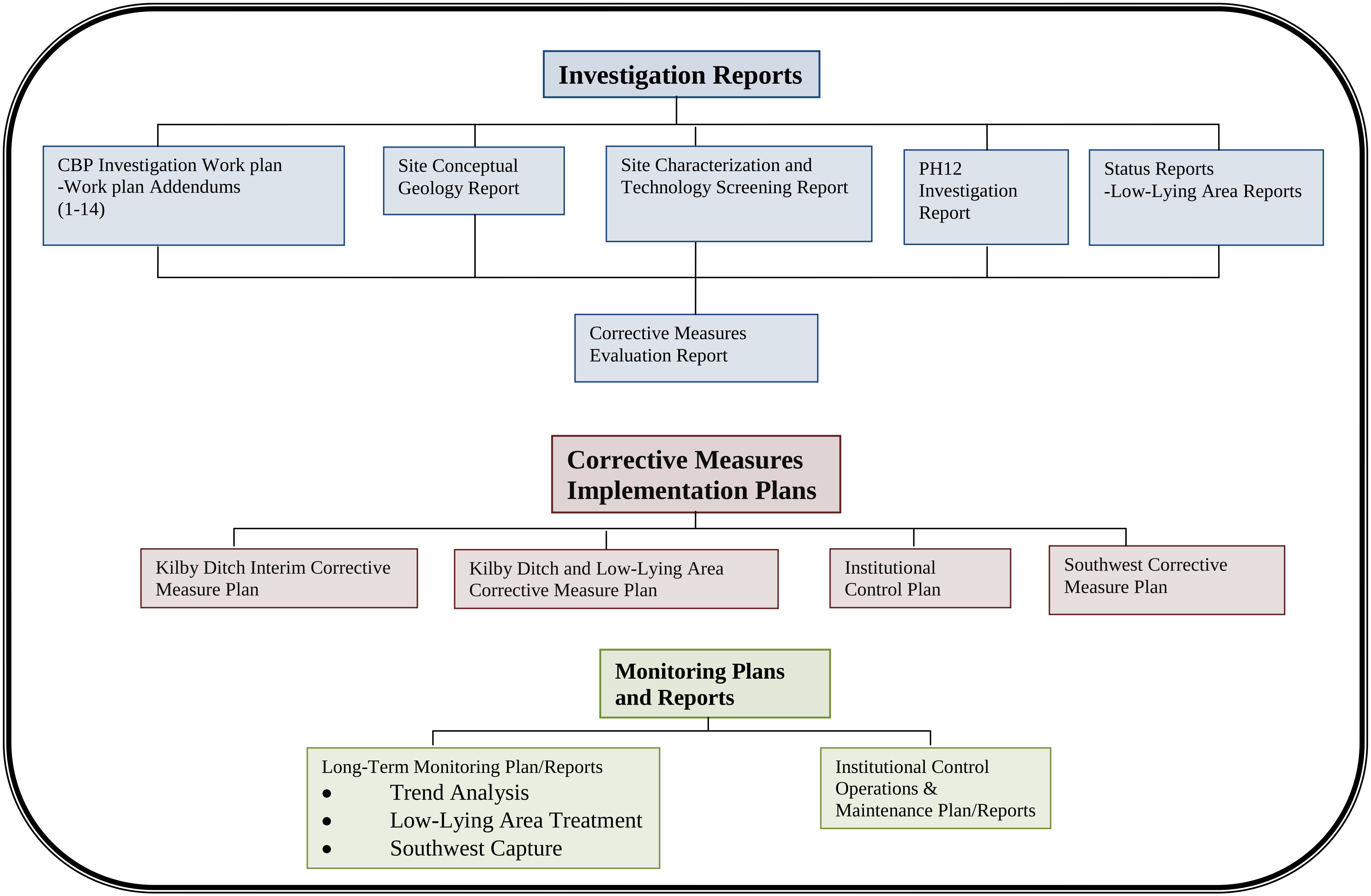
Once the Long Term Monitoring Plan is implemented, the Sentry Wells are in place, and a consistent and uniform number of points are monitored on an annual basis, annual TCE contour maps will be provided that will illustrate movement of the plume over time.

13. ***Figure 6-3****. Please revise the report to include a cost estimate and a detailed explanation of the vertical extraction wells, pipeline, and treatment facility for the system in this figure. ALDOT should consider installing a similar system in the probe hole 12 area. Please address.*

ALDOT Response:

Costs relative to the vertical southwest groundwater extraction wells have not been finalized as we are continuing to evaluate the best route and right-of-way requirements for the system. ALDOT previously completed (2005) an extensive evaluation of a variety of groundwater extraction well designs in the PH12 area along with costs estimates for the systems. Results of this analysis were included in the Probehole 12 Area Status Report in Support of Corrective Measures Development. Because these systems could not control the extent of the CBP and because they had very little effect on TCE concentrations outside of the PH12 area within the 30-year evaluation period they were not carried forward for further analysis.

Figure 1



Investigation Reports
CBP Investigation Work plan
-Work plan Addendums
(1-14)
Site Conceptual
Geology Report
Site Characterization and
Technology Screening Report
PH12
Investigation
Report
Status Reports
-Low-Lying Area Reports
Corrective Measures
Evaluation Report
Corrective Measures
Implementation Plans
Kilby Ditch Interim Corrective
Measure Plan
Kilby Ditch and Low-Lying Area
Corrective Measure Plan
Institutional
Control Plan
Southwest Corrective
Measure Plan
Monitoring Plans
and Reports
Long-Term Monitoring Plan/Reports
• Trend Analysis
• Low-Lying Area Treatment
• Southwest Capture
Institutional Control
Operations &
Maintenance Plan/Reports

FINAL

SITE-WIDE CORRECTIVE MEASURES EVALUATION

Coliseum Boulevard Plume Site
Montgomery, Alabama

Submitted By:

Alabama Department of Transportation
1409 Coliseum Boulevard
Montgomery, Alabama

Revised July 2008

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1.1 REPORT ORGANIZATION

This Corrective Measures Evaluation report is a summary of the environmental findings, assessments and evaluation of corrective measures alternatives for the Coliseum Boulevard Plume (CBP).

- Section 1 presents an overview and introduction of the Corrective Measures Evaluation
- Section 2 contains the site characterization based on previous investigations at the CBP.
- Section 3 contains a summary of the groundwater model.
- Section 4 presents the Preliminary Screening Level Evaluation to document site-specific risk.
- Section 5 provides the General Response Actions for the Site
- Section 6 provides the Corrective Measures Alternatives
- Section 7 is the Evaluation of Performance Standards for the Corrective Measures Alternatives
- Section 8 presents an overview of the Institutional Control Plan
- Section 9 includes the Summary and Recommendations

To supplement this report, the ALDOT will submit specific implementation plans to address future actions at the Site. These plans include the Institutional Control Plan, Kilby Ditch Plan and Wetland Treatment Plan, and the Southwest Plan. Additionally, ALDOT will provide a Long Term Monitoring Plan (LTM). These plans will comprise the Corrective Measures Implementation Plan (CMIP) for the CBP. Annually, ALDOT will prepare and submit a Long Term Monitoring Report and an Effectiveness Report for the Institutional Controls Program.

An overview of site investigation reports, corrective measure plans and proposed annual monitoring reports is presented on Figure 1-1A. A brief summary of these reports and plans is included in Appendix A1. This Corrective Measures Evaluation Report includes a summary of previous site investigations and evaluation of corrective measures for the CBP.

1.2 OVERVIEW

The Alabama Department of Transportation (ALDOT) has completed numerous investigations to document the nature and extent of chlorinated volatile organic compounds (VOCs) within the Coliseum Boulevard Plume (CBP) since 1999. These investigations have been conducted through a voluntary agreement with and oversight by the Alabama Department of Environmental Management (ADEM). ALDOT's investigations included evaluation of the site geology, groundwater, surface water, soil, soil vapor, and air within the CBP. Trichloroethene (TCE) is identified as the primary constituent of concern (COC). The CBP, shown on Figure 1-1, encompasses approximately 770 acres. These investigations have resulted in an enhanced understanding of the site and development of a site-wide model to predict future behavior of the plume.

Four major study areas have been established at the CBP:

- Kilby Ditch,
- Low-Lying Areas,
- Probehole 12 Area (PH12 Area), and;
- Southwestern Area (Figure 1-1).

The occurrences of TCE within the Kilby Ditch Area were investigated extensively during the very early parts of the CBP investigations because of potential exposure pathways from discharge of TCE-containing groundwater into two branches of the Kilby Ditch. ALDOT implemented an interim corrective measure (ICM) at the Ditch after conferring with ADEM and the Alabama Department of Public Health (ADPH). During the Kilby Ditch investigations, ADEM established an action level of 0.175 mg/L for TCE in the surface water within Kilby Ditch[1]. Quarterly surface water samples are collected from Kilby Ditch and the Low-lying Areas, which receive the discharge from Kilby Ditch.

The PH12 Area contains the greatest concentrations of TCE in the groundwater. A groundwater divide is present at the PH12 area, which limits the rate of movement of the groundwater from this area. A groundwater flow and transport model developed for the site has been used to evaluate future movement of TCE in the groundwater and to develop corrective measures. Investigations and findings of the PH12 Area were compiled in a “Site Characterization and Technology Screening Report” and a “Report in Support of Corrective Measures Development” (PH12 Area Status Report), which were submitted to the ADEM in June 2003 and September 2005, respectively.

The September 2005 report contained the substantive finding that the evaluation of corrective measures for the PH12 Area should be deferred and integrated into a comprehensive, Site-wide, corrective-measures

[1] In May 2011, the action level for TCE will change from the current level of 0.175 mg/l to 0.0175 mg/l in accordance with ADEM regulations. The evaluation of corrective measures was based on the current water quality standard, prior to the regulatory change; however, ALDOT will design treatment to comply with the lower water quality standards, where appropriate.

evaluation (CME). The Site-wide evaluation concluded that reducing the chlorinated VOC concentrations within the PH12 Area does not substantially affect the TCE concentrations in distal portions of the CBP, where potential exposure pathways are present.

The Probehole 12 Area Status Report (ALDOT 2005) presented evaluations of numerous remedial alternatives for the PH12 area. It was determined based on the current land use configuration (density of residential and commercial structures) and implementability limitations of the evaluated technologies, that hydraulic control in the PH12 Area would be the most effective technology to implement due to the density of structures at the land surface. However, hydraulic control would not affect TCE concentrations at the distal ends of the CBP. While pumping groundwater may slightly reduce the mass of TCE, the overall treatment would not reduce TCE concentrations to the regulatory goal of 0.005 mg/L, and therefore, institutional controls are needed. ALDOT will conduct a 5 year technology review and model update to determine if changes in site conditions justify treatment in the PH12 Area. Details on the PH12 remedial alternatives evaluated are contained in the 2005 report.

The most recent investigations have been focused in the Southwestern Area where there are two large sand and gravel mines. These mines are dewatered through the cumulative pumping of about 7,000 gallons of groundwater per minute. This pumping affects the southwestward migration of the dissolved TCE groundwater plume. The operator of the sand and gravel mines estimated that there are sufficient sand and gravel reserves to continue the mining operations and associated groundwater flow control for 30 years or more.

As discussed in Section 2 of this Report, groundwater samples have been collected from 124 groundwater monitoring wells. Pursuant to an agreement with ADEM, ALDOT currently conducts quarterly sampling of selected wells within, on the margins of, and outside of the CBP to monitor possible plume expansion, groundwater flow directions, and groundwater quality. Additionally, samples of surface water and sediment are collected quarterly in areas at the northeastern perimeter of the CBP (herein referred to as the Low-Lying Areas) where groundwater discharges to surface water.

Groundwater and surface water monitoring will be part of any corrective measures for the CBP. Data collected through the monitoring program will provide the ALDOT with the necessary information to evaluate and modify, if necessary, the corrective measures.

Early in the investigations, ALDOT undertook a program of affirmative community involvement and outreach activities to communicate two key facts:

1. Potable (drinking) water in the CBP is provided by the Montgomery Water Works & Sanitary Sewer Board and is not affected by the TCE in the groundwater at the CBP, and
2. The shallow groundwater under the impacted neighborhoods contains TCE and should not be utilized as a water supply source.

To provide this information to the public, ALDOT has conducted many public and community information meetings, held numerous media briefings and news conferences, and established and regularly meets with a Community Outreach Group (COG) made up of residents and business owners in the CBP area. Throughout this investigation and evaluation of corrective measures alternatives, major focus has been placed on the protection of public health and elimination, minimization, and management of potential exposure pathways.

1.3 PURPOSE

After submittal of the PH12 Area Status Report in September 2005, ALDOT conducted additional investigations to evaluate further the extent of TCE in the northern and southwestern areas of the CBP. Data from these investigations were used to finalize a site-wide groundwater flow and contaminant fate and transport model. This model was used to evaluate corrective measures alternatives for the CBP, with emphasis on the evaluation of those CBP areas where TCE-containing groundwater could discharge into surface water. The purpose of this CME is to present these evaluations and recommend a corrective measures approach for the CBP that is focused on the long-term protection of public health and management of potential exposure pathways.

1.4 CORRECTIVE MEASURES OBJECTIVES

The basis for evaluating Site-wide corrective measures for the CBP is restriction of potential exposure pathways to TCE at the CBP. As discussed in the PH12 Area Status Report (ALDOT 2005), potential exposure pathways have been investigated throughout the CBP through groundwater, surface water, soil, soil vapor, and air sampling.

Previous investigations at the CBP have revealed that pathways of exposure via air (soil-vapor intrusion) or soil are not present. A preliminary screening-level evaluation (PSLE) was performed for the CBP, in accordance with the Alabama Risk-based Corrective Action (ARBCA) Guidance Manual (ADEM, 2006). Groundwater in the CBP is currently not used. Institutional controls, including environmental covenants with restrictions on access to and use of groundwater, have been implemented to prevent future groundwater access or use in the CBP. Details of the institutional controls are included in the Institutional Control Plan (ALDOT 2008).

Currently, there are no COCs in surface water or sediment that require further risk evaluation pursuant to the ARBCA guidance. However, corrective measures are proposed because the most likely potential exposure pathway to chlorinated VOCs in the CBP is discharge of TCE-containing groundwater into accessible surface waters. Therefore, potential corrective measures focus on Kilby Ditch and the Low-lying Areas to the northeast, two areas of the CBP where chlorinated VOCs currently discharge to the surface water. Hydraulic control will be maintained in the southwest part of the CBP. Pursuant to the United States Environmental Protection Agency (USEPA) guidance for detailed analysis of alternatives (USEPA, 1988), the performance and estimated costs of corrective measures alternatives were evaluated over a 30-year performance period for the purposes of this CME. The proposed corrective measures for the CBP will include a combination of engineering controls, remedial measures, and institutional controls. This CME also presents an overview of the institutional controls that are being implemented, through environmental covenants and groundwater use restrictions, to prevent access to and use of the groundwater within the CBP. ALDOT's Institutional Control Program, as outlined in Section 8, began in 2005 and is currently being expanded to cover all properties within the CBP Institutional Control Boundary. A separate Institutional Control Plan has been submitted to the ADEM as part of the CMIP.
As an agency of the State of Alabama, ALDOT can meet the technical and financial requirements to implement, operate, maintain, and monitor the corrective measures that are recommended for the CBP.

This CME is based on a review of available technologies to address the CBP. As new or modified technologies are developed and their effectiveness demonstrated those technologies will be evaluated for applicability to the CBP. Any remedy selected for the site will include a maximum 5-year technology review to assess if new technologies or improved existing technologies are available that may be applicable to the CBP.

2.1 SITE DESCRIPTION

The CBP is within north Montgomery, Alabama and, based on a 1 part per billion (ppb) isoconcentration of TCE in the groundwater, encompasses about 770 acres. The western part of the 71-acre ALDOT Central Complex is within the CBP. Parts of the following four residential neighborhoods are within the CBP: Chisholm and Highland Gardens in the southwestern part, Eastern Meadows in the central part, and Vista View in the northeastern part. The Montgomery Zoo and Chisholm Elementary School are in the northwestern part of the Site.

Major topographical features in the area of the Site are the Alabama River to the west, Three-Mile Branch to the east, and Galbraith Mill Creek to the north. These natural features are important because of their effects on groundwater flow within the area that encompasses the CPB.

There are three principal stormwater ditches (Main Kilby, West Kilby, and the Montgomery Zoo Ditch) that convey surface-water runoff at the CBP. The Montgomery Zoo Ditch is located in the area of the Montgomery Zoo. Main Kilby Ditch is generally oriented north-south and extends from the North Boulevard (Figure 1-1). The intersection of Main Kilby Ditch with North Boulevard is about 500 feet east of Coliseum Boulevard. Main Kilby Ditch is an earthen open channel with the exception of a concrete-lined segment that extends from the ADEM building to about 20 feet north of the confluence of Main Kilby Ditch with the West Kilby Ditch. West Kilby Ditch is open and earthen west of Coliseum Parkway and is concrete lined from the east side of Coliseum Boulevard to its intersection with Main Kilby Ditch. An underground culvert conveys stormwater from Coliseum Parkway to the east side of Coliseum Boulevard. West Kilby Ditch is concrete lined from the east side of Coliseum Boulevard to its intersection with Main Kilby Ditch.

Surface water infiltrates into the soil in the earthen parts of the ditches and recharges groundwater. Periodically (based on seasonal variations of rainfall), groundwater discharges into the bottoms of Main and West Kilby Ditches. Trichloroethylene (TCE) has been detected in water samples collected from the segment of Main Kilby Ditch north of the confluence with the West Kilby and the segment of West Kilby Ditch that is east of Coliseum Boulevard. Barrier fences were erected around these segments of West Kilby Ditch and Main Kilby Ditch to minimize access. These fences prevent casual and unintentional entry into West Kilby Ditch where it is east of Coliseum Boulevard and into Main Kilby Ditch from its confluence with West Kilby Ditch to its intersection with North Boulevard.

2.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

2.2.1 REGIONAL GEOLOGY

Knowles, et al. (1963) described the geology and groundwater resources in Montgomery County. Their hydrogeologic descriptions were updated in the wellhead-protection plan for the City of Montgomery (CH2MHill, 1997). The hydrogeology at the nearby Gunter Air Force Station Annex (formerly Gunter Air Force Base) has been reported by Radian (1999). These reports and geologic logs for probeholes, piezometers, and monitoring wells were reviewed to develop the conceptual geology and hydrogeology of the CBP.

The ALDOT Complex, Vista View residential area, the Northeast Montgomery Industrial Park, and the Gunter Annex are within the Alluvial-Deltaic Plain District of the East Gulf Coastal Plain physiographic section (Sapp and Emplaincourt, 1975).

Northeastern Montgomery is underlain by Quaternary and Cretaceous sedimentary deposits (Figure 2-1). The Cretaceous sediments strike generally eastward and dip southward at about 30 to 40 feet per mile. Beneath these sedimentary deposits are pre-Cretaceous igneous and metamorphic rocks.

Quaternary alluvial and terrace deposits overlie the Cretaceous sediments throughout the northeastern sector of Montgomery except for the hilly areas of southern Chisholm, Capitol Heights, and Dalraida (Figure 2-1) where the Eutaw Formation crops out. The alluvial deposits crop out along the flood plains of the Alabama and Tallapoosa Rivers. Terrace deposits (alluvial deposits of an old flood plain) crop out from Chisholm through the ALDOT Complex and Vista View area, to the Gunter Annex area. The alluvial deposits typically are 40 to 85 feet thick and the terrace deposits typically are 40 to 55 feet thick. The alluvial and terrace deposits comprise lenses of gravel and pale-yellow-orange, medium- to coarse-grained, poorly sorted sands that commonly are interbedded with dark-reddish-brown sandy clay (Knowles et al. 1963).

The CBP is on a river terrace that is about 175 to 220 feet above mean sea level (AMSL).

Beneath the alluvial and terrace deposits is the Cretaceous Eutaw Formation, which crops out from the southern part of Chisholm through Capitol Heights and Dalraida (Figure 2-1). The Eutaw Formation comprises marine glauconitic sand that is interbedded with clay and sandy clay. Review of sample logs indicates that the Eutaw Formation is about 200 feet thick in eastern Montgomery. However, only the basal 50 to 60 feet of the Eutaw Formation underlies the Chisholm-Vista View-Gunter Annex area. The occurrence of only basal Eutaw Formation at the CBP agrees with the findings of CH2MHill (1997) in the wellhead-protection plan for the City of Montgomery. Radian (1999) reported that the Eutaw Formation pinches out on the Gunter Annex, which is southeast of the CBP.

Beneath the Eutaw Formation is the Gordo Formation. The Gordo Formation comprises a basal zone of non-marine sand and gravel that is overlain by alternating beds of sand and varicolored mottled clay from the western part of Alabama through Montgomery County. Review of drillers' logs, geologists' sample logs, and geophysical logs for wells and test wells indicates that this clay is 10 to 50 feet thick in the Montgomery area. This varicolored clay is about 60 to 100 feet below land surface (BLS) in the Chisholm-ALDOT Complex-Vista View-Gunter Annex area. The Gordo Formation is about 300 to 340 feet thick in northeastern Montgomery.

Beneath the Gordo Formation is the Coker Formation. The Coker Formation comprises a basal non-marine zone of deltaic sand, gravel, and clay. The basal zone is overlain by marine sand, clay, and thin beds of calcareous sandstone. Review of drillers' logs, geologists' sample logs, and geophysical logs indicates that the Coker Formation is 350 to 400 feet thick in northeastern Montgomery. Beneath the Coker Formation are pre-Cretaceous Rocks.

2.2.2 REGIONAL HYDROGEOLOGY

The Coker, Gordo, and Eutaw Formations are the major aquifers in the Montgomery area. These aquifers comprise sand and gravelly sand beds. Water in the Coker, Gordo, and Eutaw aquifers generally moves downdip from the recharge areas. These aquifers are confined downdip from their recharge areas. Downdip, the upper confining layer for the

Eutaw aquifer is the Mooreville Chalk. This upper confining Chalk is absent at the CBP. The upper confining layer for the Gordo aquifer is the varicolored mottled clay that marks the top of the Gordo Formation. The upper confining layer for the Coker aquifer is a bed of marine clay at the top of the Coker Formation. These confining layers occur consistently from western Alabama throughout Montgomery County.

2.3 GROUNDWATER USE

2.3.1 WELLS

2.3.1.1 Active Wells <u>(Within one mile)</u>

The Coker and Gordo Formations are sources of water supply for the Montgomery Water Works and Sanitary Sewer Board's (MWWSSB) "North Well" and "West Well" Fields. The easternmost wells of the West Well Field, the most distant of the two Fields, are about three miles southwest of the southwestern extent of the CBP. According to personnel of the MWWSSB, there are seven public-supply wells within the North Well Field. The nearest well, Well 11, is about 1.3 miles southwest of the CBP.

In 1992, the MWWSSB collected water samples from wells 9W and 9E, which are within the North Well Field. The samples, which were collected for the MWWSSB Wellhead Protection Program contained trace concentrations of tetrachloroethene. Tetrachloroethene, commonly referred to as "perc" is a dry-cleaning solvent. Tetrachloroethene has not been detected in any of the CBP groundwater monitoring wells. Thus, the tetrachloroethene did not migrate to the MWWSSB wells from the CBP. Upon discovery of the tetrachloroethene, the MWWSSB closed all of the wells in the North Well Field within the shallow alluvial aquifer. The remaining wells, which are in the deeper aquifer, have not been used but were retained as part of the emergency system. The MWWSSB has an aggressive testing program to ensure that the water in the deeper wells meet drinking-water standards. Wells 9W and 9E were abandoned in 1992 and 1997, respectively.

ALDOT reviewed files at ADEM, the Alabama Geological Survey, the Plumbing Gas and Mechanical Permit and Inspection Department of the City of Montgomery and completed personal interviews to identify active wells that are within one mile of the CBP. Information about the wells that were identified during these reviews and interviews is summarized below. .

Location: Resurrection Catholic Church
Address: 2815 Forbes Drive (about 100 yards north of the North Boulevard: about 2500 feet northwest of the northwest extent of the CBP).
Date Drilled: June 2003
Well Use: Irrigation
Depth: 193 feet

Location: Bonnie Crest Golf Course
Address: 1410 Federal Drive (about 4000 feet southeast of the south central extent of the CBP).
Date Drilled: June 2001
Well Use: Irrigation
Depth: 451 feet
Screened intervals: 90-100 feet; 170-290 feet; 310-330 feet; 350-390 feet

Location: J.B Crosby
Address: 3609 Lower Wetumpka Road (about 2500 feet northwest of the northwest extent of the CBP).
Date Drilled: August 2005
Well Use: Irrigation
Depth: 349 feet
Screened interval: 209-349 feet

Location: Circle J Roll Offs
Address: 4040 North Boulevard (about 2000 feet east of the northeastern extent of the CBP; east of Three Mile Branch)
Date Drilled: ?
Water Use: Water animals
Depth: Reportedly “shallow”

Location: Cooks Pest Control
Address: 1861 Congressman W.L. Dickinson Drive (about 2000 feet southeast of the eastern extent of the CBP)
Date Drilled: 2004
Well Use: Irrigation
Depth: 200 feet (probably taps Gordo Formation)

2.3.1.2 Inactive Wells (Within 1000 feet)

Three domestic wells were identified during early investigations and monitoring activities within the CBP. Two of the domestic wells are dug wells that are adjacent to Houser Street. The first dug well is about 3 feet in diameter. According to an interview with the well owner on June 6, 2002, the well was dug in 1952 or 1953 and is about 35 feet deep. The water from the well was used to water the grass until about 1962 when the pump and piping of the well were removed. On June 6, 2002, the well was found to have caved to about 20 feet BLS. The second domestic dug well could not be examined because the well was covered with a heavy concrete slab. The property owner reported that this second well was at least 70 years old but had not been used for years. The owner was not certain if the electrical supply to the well had been disconnected.

A third domestic well that was observed is about 400 feet southwest of the intersection of Lower Wetumpka Road with the CSX Railroad. This well has a 4-inch diameter casing and is about 28 feet deep. The owner reported that the well was used to water his garden and flowers. However, the well had not been used since 2000 because the pump was inoperable and parts were not available. On June 20, 2002, a sample of water was collected from the well and analyzed for volatile organic compounds (VOCs). The depth to water in the well was about 15 feet BLS. No VOCs were detected in the water sample (analytical detection limit of 0.001 mg/L [milligram per Liter]).

"Notification of Intent to Drill a Water Well and Certification of Completion" forms were reviewed at the Alabama Geological Survey (AGS) to identify wells that might be within the CBP; no domestic wells were identified.

Publications of the Alabama Geological Survey also were reviewed to identify wells. Five wells that might be within or near the CBP were found in a 1960 report of the Survey (Knowles et al, 1960). Based on review of Plate 1 in this 1960 report, the approximate locations of the five wells were transposed to a topographic map onto which had been plotted the extent of the CBP. Physical addresses were not identified in the AGS report; however, ALDOT has observed the areas where the wells were plotted in the report and these wells were not observed during the reconnaissance. Three of the five wells would have been within the CBP:

- One of the wells was at the former Kilby Prison (currently the Vista View Subdivision). This well, which has probably been destroyed, was 80 feet deep and tapped the Eutaw Formation.
- The second well was near the intersection of Lower Wetumpka Road and Rigby Street, which is at the southwestern most extent of the CBP. This well was reported as being a 27-foot deep dug well that tapped terrace deposits.
- The third well was near the intersection of Crouson and Broadway Streets, which is near the south edge of the southwest part of the CBP. This well was reported as being 60 feet deep, tapping the Eutaw Formation, and is not used.
- The remaining two of the five wells that were identified within the 1960 report were within about 1,000 feet of the south edge of the southwest part of the CBP.
    - The first of these wells was near the intersection of Rigby Street and Texas Street. This well was 100 feet deep and was used as a domestic/stock well and to supply a "fish-bait" farm.
    - Glenwood Nurseries was listed as owning the second well, which was near the intersection of Rigby Street and Fairground Road. The well was 355 feet deep, tapped the Gordo Formation, and was reported as not used.

The above five wells probably are either destroyed or not in use. The ALDOT completed a vehicular reconnaissance of parcels encompassing the probable locations of these historical wells. There was no visual evidence of the wells.

2.3.1.3 Abandoned Wells

A well to provide water to the elephant moat was constructed by the City of Montgomery Zoo in August 2004. The well was discovered during the review of the certification of completion forms that are routinely filed, as a regulatory requirement, with the ADEM and that are filed also with the Alabama Geological Survey. The well was screened within the shallow-zone aquifer and also within the upper part of the Gordo Formation. Use of the well, which yielded about 100 gallons per minute, began in August 2005. With the cooperation of the City of Montgomery, the ALDOT plugged and abandoned the well in March 2006. Monitoring wells were installed to investigate the groundwater near the former Montgomery Zoo well.

ALDOT also plugged and abandoned an irrigation well at the Bama Budweiser facility at 1700 Emory Folmar Boulevard, which is in the northeastern part of the CBP. The well was plugged because water samples collected on April 5 and 6 , 2007 contained 13 and 7 ug/L of TCE, respectively. ALDOT completed a camera survey and borehole geophysical logging of the well prior to the abandonment and determined that the TCE detections probably resulted from leakage along the casing of the well. ALDOT subsequently contructed shallow- (MW-158) and deep-zone (MW-358; see Plate 2-1 and Figure 2-12A) monitoring wells and a replacement irrigation well. Monitoring well MW-358 is screened from about 43 to 48 feet BLS predominantly in a sandy clay, which is below the first distinct clay, and the replacement irrigation well which is screened in the upper Gordo Formation.

2.3.1.4 Site-Wide Well Survey

As part of ALDOT's Institutional Control Program (ICP), each parcel within the CBP is being inspected to determine if a well is present or was historically present on the parcel. These inspections are being scheduled with property owners as they participate in the Institutional Control Program (see Section 8). A table with the results of the door-to-door well survey will be provided in the Institutional Control Plan, which will be submitted as part of the CBP Corrective Measures Implementation Plan (CMIP) The two dug wells and the drilled well that were identified during the early investigation above have been added to this table, with their parcel identifiers, so that arrangements can be made to abandon the wells as part of the ICP. The table will be updated as these inspections progress. Any other wells identified will be evaluated such that a plan to ensure no access to groundwater is implemented.

2.3.2 SAND AND GRAVEL OPERATIONS (BORROW PITS)

North Montgomery Materials and Asphalt Contractors operate sand and gravel mines on properties that encompass about 320 acres and 114 acres, respectively, southwest of the CBP. Both of the facilities have NPDES Permits to discharge process wastewater from their dewatering and washing operations. Discharged wash water, groundwater and storm water are pumped from pits in dredging and excavation areas into either settling basins or water-supply ponds to provide water for material washing. Combined, a total of about 7,000 gallons per minute of water are reportedly pumped for about 8 to 10 hours per day by these two mining operations. Much of this water is recirculated as part of the washing processes at the mines but their extraction of groundwater significantly influences the groundwater flow in the southwest CBP.

2.4 SYNOPSES OF INVESTIGATIONS

The lateral and vertical extents of TCE in the sediments and groundwater at the CBP have been delineated through a series of investigations. Reports of these investigations have been submitted previously to the ADEM. Two saturated “zones” have been investigated to determine the horizontal and vertical extents of TCE in the groundwater at the CBP. The “shallow zone” is the saturated zone from the water table to the first distinct clay beneath the water table. The “deep zone” is the saturated zone immediately beneath the first distinct clay.

A total of 124 groundwater monitoring wells and continuous multi-channel tubing (CMT) wells have been completed during the CBP investigation to evaluate groundwater quality. Groundwater hydrology has been assessed using five pump test wells along with four observation wells to monitor groundwater levels during the pump test. Monitoring wells were also used as observation wells during the groundwater pump test to evaluate the groundwater hydrology. Forty piezometers have been installed to measure groundwater elevations in addition to the monitoring wells.

The characteristics of these wells are compiled in Tables 2-1, 2-2 and 2-3. ALDOT has completed 117 monitoring wells within the shallow zone. The A-series wells comprise the wells completed during the initial phase of groundwater investigations. These wells, MW-1 through MW-9, were used to asses TCE in the groundwater in and around the ALDOT Central Complex.

Subsequent shallow-zone wells are classified as either 100 or 200 series monitoring wells based on their completions within the upper or other parts of the shallow water-bearing zone. The 100-series wells are generally in the upper part of the shallow zone; whereas, the 200-series wells are immediately above the first restrictive clay. Seven (7) monitoring wells, classified as 300 series wells, have been completed within the deep zone (between the first restrictive clay and the top of the Gordo formation). One additional well, 400 series, has been installed in the Gordo aquifer.

The following discussions outline the efforts to investigate the horizontal and vertical extents of TCE within the shallow saturated zone and to determine if there is TCE within the deep saturated zone within the CBP. Also discussed are descriptions of the wells that were constructed for long-term monitoring of the groundwater within the CBP.

2.4.1 SHALLOW ZONE

Direct-push technology (DPT) methods, including membrane interface probe (MIP) technology, were used to collect sediment and groundwater samples from over 200 probeholes to delineate the extent of the TCE within the shallow saturated zone. Samples were collected from continuous four (4) foot intervals in many of these probeholes to investigate potential zones where TCE might be present in the sediment. Samples were analyzed by using either a mobile laboratory at the project Site or expedited turn-around time at a fixed laboratory. The results of these analyses were used to develop a network of monitoring wells to monitor the shallow saturated zone throughout the CBP (see Plate 2-1).

2.4.1.1 Shallow-Zone Monitoring Wells/Piezometers

Investigation of the CBP began in October 1999 in response to the discovery of TCE in the groundwater beneath Alfa Insurance Company property that is north of the ALDOT Central Complex (Goodwyn, Mills, and Cawood, 1999). Goodwyn, Mills and Cawood constructed five monitoring wells during a Phase II Environmental Site Assessment. Subsequently, nine monitoring wells were constructed, by TTL, Inc., near the ALDOT Central Complex to provide groundwater samples for VOC analyses (particularly, TCE). These nine monitoring wells were screened from the water table to the first distinct clay beneath the water table (TTL, 1999a).

Since the discovery of the TCE on the Alfa property, 117 monitoring wells (see Tables 2-1 to 2-3), 40 piezometers, and 7 continuous multi-tubing (CMT) monitoring wells have been constructed at the CBP to investigate and to verify the extent of TCE within the shallow saturated zone. The locations of these wells and piezometers are shown on Plate

2-1. The screens of the cluster wells are 5 to 10 feet long and were constructed to monitor the upper, middle or lower parts of the shallow saturated zone. The CMT wells were constructed to refine information about the vertical distribution of VOCs within the PH12 Area.

2.4.1.2 Shallow-Zone Monitoring (100 and 200 Series Monitoring Wells)

Quarterly groundwater monitoring events have been conducted since April 2002. Groundwater samples are collected from the shallow-zone monitoring wells and the CMT wells and analyzed for VOCs. (See Section 2.8 for the distribution of TCE within the groundwater.)

VOCs, other than TCE, have been detected in the quarterly groundwater samples that have been collected at the CBP. These other VOCs are: carbon tetrachloride; cis-1,2-dichloroethene (cis-1,2-DCE); 1,1-dichloroethene (1,1-DCE); vinyl chloride, and chloroform. Plots of the concentrations of carbon tetrachloride; cis-1,2-DCE; 1,1-DCE, and chloroform that have been detected in water samples are shown in Figures 2-2, 2-3, 2-4, and 2-5, respectively. These figures depict the maximum concentrations within groundwater samples collected through 2007. The concentrations of vinyl chloride were not plotted because vinyl chloride has been detected only in the quarterly samples from four CMT monitoring wells. These CMT wells (CMT-1, -2, -3; and -4) are within the PH12 Area. Vinyl chloride was detected first in the July 2005 samples from well CMT-4. The first detections of vinyl chloride in samples from wells CMT-1 and CMT-2 occurred in the January 2006 samples. The first detection of vinyl chloride in samples from CMT-3 was in April 2006.

The maximum concentrations for these other VOCs were in groundwater samples from the PH12 Area. The occurrences of the maximum concentrations of these other VOCs coincided predominately with the occurrences of the maximum concentrations of TCE in groundwater samples. Occurrences of chloroform within the water samples probably reflect the effects of the infiltration of water that originated from a public supply, because chloroform is a byproduct of the disinfection process typically used in public water systems.

In addition to VOC analyses, groundwater samples have been analyzed for inorganic analytes: total alkalinity, chloride, nitrate, nitrite, sulfate, ferrous iron, total iron, methane, ethane, and ethene.

The distributions of these inorganic analytes in the groundwater samples from the CBP are depicted in Figures 2-6 (total alkalinity), Figure 2-7 (chloride), Figure 2-8 (nitrate), Figure 2-9 (sulfate), Figure 2-10 (total iron), Figure 2-11 (ferrous iron), and Figure 2-12 (methane). These figures depict the maximum concentrations within groundwater samples collected through July 2007. Review of these plots indicates that the groundwater at the CBP is typically low in alkalinity and chloride, sulfate, and nitrate concentrations. There were elevated concentrations of sulfate and elevated total alkalinity values in a few of the groundwater samples. These elevated values in the groundwater samples were concluded to be the residual effects of grout used during construction of the CMT wells.

Most of the groundwater samples contained less than 5 mg/L of nitrate (Figure 2-8). The higher concentrations of nitrate probably result from the fertilizing of lawns or leakage from sanitary sewers. Most of the iron in the water samples (Figures 2-10 and 2-11) was ferrous iron rather than ferric iron.

Review of Figure 2-12 indicates that there are two areas where the groundwater contains higher, relative to the rest of the Site, concentrations of methane: the PH12 Area and the northern part of Main Kilby Ditch. The higher concentrations of methane in samples of groundwater from within the PH12 Area probably result from leakage from the sanitary sewers prior to the relining of the sewers by the MWWSSB. The degradation of the TCE at the Site is probably not the source of the elevated methane concentrations because two groundwater samples, collected in 2003, from the PH12 Area did not contain the bacterial strain (*Dehalococcoides ethenogenes*) necessary to degrade the TCE. The higher concentrations of methane in water samples at the north part of Main Kilby Ditch probably are due to the marshy, anaerobic conditions that are common in that part of the Ditch and the downstream Low-Lying Areas.

Review of the occurrences of other VOCs in groundwater samples from the PH12 Area indicates that there has been limited natural degradation of TCE. The absence of the necessary bacterial strain, the predominance of ferrous iron, the occurrences of only limited amounts of compounds that are degradation products, and the aerobic characteristics of the shallow-zone aquifer indicate that substantial effort would be required to dehalogenate the TCE that is within the PH12 Area. The aquifer would have to be converted from aerobic to anaerobic conditions, the appropriate bacterial strain would likely have to be injected into the aquifer, and the inorganic chemistry would have to be augmented and maintained to support the bacteria.

2.4.2 DEEP-ZONE

The "deep zone" at the CBP refers to the saturated zone that is immediately between the first distinct clay beneath the water table and the top of the Gordo formation. Investigations to determine whether TCE had migrated to the deep zone began in May 2001 with the drilling, by the Rotasonic method, of an exploratory boring adjacent to ALDOT monitoring well MW-1. A borehole for a deep-zone monitoring well (MW-304) also was drilled in the east part of the ALDOT Central Complex (see Plate 2-1).

The Rotasonic method was used to drill eight exploratory borings to the top of the Gordo Formation. The locations of these borings (DZ1 through DZ8) are shown on Plate 2-1. The sites for these deep exploratory borings were placed outside the PH12 Area to avoid drilling within areas that contained elevated concentrations of TCE. Three of the borings were in the southwest part of the Site, two were in the east part of the Site, and two were in the north part of the Site. The eighth boring was on the Garrett Coliseum Property, which is south of the CBP.

Groundwater samples were collected from four of the deep-zone borings and analyzed for VOCs. TCE was not detected in the groundwater samples from these borings (TTL, 2002c)

2.4.2.1 Deep-Zone Monitoring Wells (300 Series Monitoring Wells)

Information obtained from deep-zone monitoring well MW-304 and the exploratory borings were reviewed and used to construct five additional deep-zone monitoring wells to monitor for TCE, if any, within the deep zone. Each of the deep-zone wells was terminated at the top of the Gordo Formation. Four (MW-339 through MW-342) of these five deep-zone monitoring wells were constructed adjacent to the PH12 Area. The fifth deep well (MW-311) is within the extreme southwest part of the CBP. The locations of the deep-zone monitoring wells are shown on Plate 2-1 and Figure 2-12A. Sediment samples from the borings for the four wells were collected in FLUTe sleeves. There was no evidence of staining or color changes on any of the FLUTe sleeves that would indicate TCE dense non-aqueous phase liquid (DNAPL) (TTL, 2002b).

As described in Section 2.3.1.3, the ALDOT plugged and abandoned a production well at the City of Montgomery Zoo. The production well had been screened in both the shallow saturated zone and the upper Gordo Formation. Two monitoring wells were constructed within 30 feet of the production-well site. One of the monitoring wells (MW-357) was constructed with the screened interval within the deep saturated zone (the saturated zone beneath the first distinct clay at the site but above the Gordo Formation). The second monitoring well (MW-457) was constructed within the upper Gordo Formation. The top and bottom of the screen of this second monitoring well correspond approximately to the depths of the top of the screen and the pump intake of the former production well. Both monitoring wells were constructed to determine whether the dual screening of the production well might have provided a conduit for the downward movement of water from the shallow-zone aquifer into the deep saturated zone and/or the upper Gordo Formation.

2.4.2.2 Deep-Zone Monitoring

During quarterly groundwater monitoring, groundwater samples are collected from monitoring wells screened within the deep zone and analyzed for VOCs. Groundwater samples collected from deep zone monitoring well MW-341 during the February 7, 2003 and January 16, 2006 sampling events contained 0.0012J and 0.0016J mg/l of TCE, respectively. "J" indicates an estimated concentration which is less than the lowest concentration of the instrument calibration curve but above the detection limit. TCE concentrations of 0.0191 mg/L and 0.003 mg/L were detected in groundwater samples from well MW-341 during the April 7, 2006 and July 14, 2006 sampling events, respectively. TCE was not detected above the laboratory method detection of 0.0010 mg/L in the groundwater sample from MW-341 during the most recent sampling event conducted on July 9, 2007. Monitoring well MW-341 is on East Park Avenue about 650 feet west of the intersection with Fairground Road.

Initially, TCE was not detected (detection limit of 0.001 mg/L) in groundwater samples collected on March 30, 2006 and April 20, 2006 from monitoring well MW-357, which is completed within the saturated zone immediately beneath the first distinct clay near the former well at the Montgomery Zoo. TCE subsequently was detected at 0.0041, 0.0020, and 0.001 mg/L in groundwater samples collected from MW-357 on July 26, 2006; October 19, 2006 and January 23, 2007, respectively. However, TCE was not detected in the April and July 2007 groundwater samples from MW-357.

TCE has not been detected in any of the six groundwater samples collected from monitoring well MW-457. MW-457 is completed within the upper Gordo Formation near the former well at the Montgomery Zoo. Upon approval by the ADEM, monitoring well MW-457 may be plugged and abandoned since TCE has not been detected in the well.

The absence of DNAPL within the shallow water-bearing zone within the PH12 Area (where there are the greatest concentrations of dissolved TCE) previously was determined through collections of numerous water samples from probeholes and monitoring wells and by investigations with a membrane-interface probe with associated extensive verification sediment and groundwater sampling. This sampling also provided for delineation of the vertical distribution of dissolved TCE within the PH12 Area. Review of the results of this investigation indicated that the first distinct clay is continuous and is a barrier to the vertical migration of the dissolved TCE.

Water samples collected and analyzed from exploratory borings (DZ5 through DZ8; see Plate 2-1 and Figure 2-12A) to the top of the Gordo Formation and from the deep-zone monitoring wells substantiated the conclusion that the dissolved TCE that is within the shallow water-bearing zone has not migrated into the deep zone. (Recall that the deep zone is the saturated zone immediately beneath the first distinct clay.) Semi-annual water samples will continue to be collected from the deep-zone monitoring wells and analyzed for TCE as part of the Long-Term Monitoring Plan for the CBP. Five of the deep-zone monitoring wells surround the PH12 Area where there are the greatest concentrations of dissolved TCE.

Deep-zone monitoring well MW-358, located at the Bama Bud facility and not near the PH12 Area, is also included in the monitoring program for the CBP. To date, well MW-358 has yielded insufficient water for analysis.

2.5 GEOLOGY OF THE COLISEUM BOULEVARD PLUME SITE

2.5.1 SITE-WIDE GEOLOGY

The following summary of the geology of the CBP was based on published and unpublished reports and review of the vertical and horizontal distributions of stratigraphic layers at the Site. Soil/sediment samples that were retrieved during the investigations to delineate the vertical and horizontal extents of the TCE and during construction of the shallow- and deep-zone monitoring wells were described by an on-Site geologist. These on-Site descriptions provided lithologic "controls" for interpreting the geology at the Site.

Probeholes have been driven to maximum depths of about 100 feet BLS (about 120 feet AMSL) and boreholes for monitoring wells have been drilled to a maximum depth of about 120 feet BLS (about 100 feet AMSL).

Sediments at the CBP were classified into the following three lithofacies: (1) a sandy clay (consisting of the surficial clay and first distinct clay), (2) a fine-to-coarse-grained sand with gravel, and (3) a graded sand (fine- to coarse-grained) that is glauconitic, silty and/or clayey (TTL, 2001b). The three lithofacies were classified into five hydrostratigraphic units to develop the groundwater flow and transport model for the CBP.

The CBP is on 20 to 45 feet of terrace and alluvial deposits of the Alabama River and Catoma Creek. The terrace deposits are of fluvial origin and comprise primarily sands with gravel, silt, and clay.
Four geologic cross-sections (Figures 2-13, 2-14, 2-15, and 2-16) were prepared by examining the lithologic descriptions of samples recovered from probeholes and boreholes at the Site. The locations of these cross-sections are shown on Plate 2-1. As shown on Figures 2-13 and 2-16 (cross-sections A-A' and D-D'), the majority of the CBP is capped by a 2-to 20-foot-thick sandy clay. Beneath the clay are 1 to 10 feet of fine- to coarse-grained sand that is underlain by a 5- to 20-foot-thick layer of sand and gravel. The gravels are well-rounded, quartz, and pebble- to cobble-sized and are typically 10 percent to 50 percent, by weight, within this layer of sand and gravel.

The alluvial and terrace deposits are underlain by 30 to 60 feet of the Eutaw Formation, which comprises fine- to coarse- grained glauconitic sands with interbedded clay. The glauconitic sands may be the contact between the terrace deposits and the lower Eutaw Formation. This contact may not be distinct because the Eutaw Formation could have been reworked by alluvial processes. The shallow-zone and deep-zone monitoring wells and CMT wells that have been constructed during investigations of the CBP have been completed within the alluvial and low-terrace deposits and/or underlying Eutaw Formation.

Beneath the glauconitic sand is clay that has been referred to in investigations of the CBP as "the first distinct clay beneath the water table". The first distinct clay separates the "shallow zone" (saturated zone above the first distinct clay) and the "deep zone" (saturated zone immediately beneath the first distinct clay). As shown on Figure 2-13 (cross-section A-A'), the first distinct clay ranges from about 40 to 60 feet BLS, is generally 1 to 3 feet thick, brownish-yellow and light-brownish-gray and/or light gray in color, and slightly sandy throughout most of the CBP. Most of the probeholes and boreholes for the shallow-zone monitoring wells were terminated at the first distinct clay. The depths to groundwater within the shallow saturated zone range from about 10 to about 35 feet BLS within the CBP.

The Eutaw Formation is underlain by the Gordo Formation. The top of the Gordo Formation at the Site is a reddish-brown and bluish-gray to greenish-gray mottled clay. The Gordo aquifer is confined by this mottled clay, which ranges in thickness from 10 to 50 feet throughout Montgomery County (Scott, written communication, 2001). The Gordo Formation is about 300 feet thick at the CBP (CH2MHill, 1997).

Gravels of the terrace and alluvial deposits have been the target of gravel-mining operations in areas southwest, northwest and northeast of the CBP. Sand and gravel mines that are southwest of the CBP have been excavated, as of October 2007, to a maximum depth of about 50 feet BLS. Review of Figure 2-13 indicates that the glauconitic sand thickens southwestward. There is, however, a distinct change in the stratigraphy southwest and southeast of Amanda Lane. There is a much greater thickness of gravelly sand and the stratigraphic sequence is interrupted by a 20-foot-thick greenish-gray, organic clay about 1200 feet southwest of piezometer PZ-19. The surficial sandy clay, the fine to coarse-grained sand, and the majority of the gravelly sand interval probably have been removed by the excavating at the sand and gravel mines.

2.5.2 GEOLOGY OF THE PH12 AREA

The PH12 Area is capped by about 7 to 15 feet of surficial sandy clay except for isolated areas where the upper few feet of this clay has been disturbed or has been removed and replaced with fill (Figure 2-14). The surficial sandy clay is underlain by about 5 to 10 feet of fine- to coarse-grained sand; this sand is underlain by 10 to 20 feet of fine- to coarse-grained sand and gravel. Beneath the sand and gravel is the fine to coarse-grained glauconitic sand. Within the PH12 Area, this glauconitic sand contains multiple 1/8 to 1/2-inch thick clay lenses.

In general, the average depth to the first distinct clay is 50 to 60 feet BLS within the PH12 Area. As shown on Figure 2-14 (cross-section B-B'), which extends north-south along the east part of the PH12 Area, the first distinct clay is the brownish-yellow and light-brownish-gray and/or light-gray sandy clay penetrated throughout the majority of the CBP. Review of stratigraphic information from boreholes and probeholes east and west of the PH12 Area indicates that there is a transition such that the first distinct clay is a thick, dark gray to greenish-gray clay with fine sand laminae within parts of the PH12 Area. This dark gray clay, which is depicted on Figure 2-15 (cross section C-C'), is as much as 25 feet thick at the ALDOT Materials and Testing Laboratory and is probably continuous beneath the PH12 Area.

Immediately beneath the dark-gray to greenish-gray clay within the PH12 Area is the deep saturated zone. This deep saturated zone consists of approximately 5 to 20 feet of silty fine- to medium-grained glauconitic sand and/or silt (Figure 2-15).

2.6 HYDROGEOLOGY OF THE COLISEUM BOULEVARD PLUME SITE

The Site geology is used in this subsection to develop the hydrogeology for groundwater modeling of the shallow saturated zone. The hydrogeologic characteristics of the PH12 Area were developed initially by reviewing existing reports and information that were collected as part of the investigations conducted within the CBP. Substantial knowledge about the hydrogeologic characteristics for the PH12 Area also was gained from compiling the groundwater elevations of wells and piezometers that are screened within the shallow saturated zone.

Review of the geology of the shallow saturated zone indicates that it is a distinctly heterogeneous zone. Because of this heterogeneity, slug and bail tests and laboratory permeability tests were used to characterize the hydrology of each partially saturated or saturated hydrostratigraphic unit. Five, three-day, aquifer tests were used to obtain composite hydrologic information for the shallow saturated zone. The information from the slug/bail and laboratory tests and from the aquifer tests were used as "starting" hydrologic characteristics from which to develop groundwater-flow and transport models by dividing the three lithofacies described in the Geology Section into five hydrostratigraphic units. Although not all of the five units are saturated, they are termed "hydrostratigraphic" because of their link to the groundwater model.

Slug/bail tests (*in situ* hydraulic-conductivity tests) have been conducted in 98 monitoring wells within the CBP and in 8 piezometers beyond the boundary of the CBP. The hydraulic conductivity was determined only from the bail test at the location when the static water level was within the screen of the monitoring well or piezometer. The hydraulic conductivity at a location was determined from both the bail and slug test when the water level was above the screen of the monitoring well or piezometer. The hydraulic conductivities were estimated by analyzing the data from the tests by the Bouwer and Rice Method (1976).

Two of the five aquifer tests were at Kilby Ditch. The results of these two aquifer tests were interpreted and used as baseline hydrogeologic information for a groundwater model that was used to evaluate interim corrective measures for the Kilby Ditch Area. The third and fourth aquifer tests were immediately adjacent to the PH12 Area and the fifth aquifer test was in the extreme southwestern part of the CBP. The results from these latter three aquifer tests were used as baseline hydrogeologic information for a groundwater model that was used to evaluate corrective measures for the entire CBP.

2.6.1 HYDROGEOLOGIC CHARACTERISTICS

The uppermost aquifer is within the sediments that overlay the first distinct clay beneath the water table. These sediments have been divided into five general hydrostratigraphic units based on their occurrence within the stratigraphic sequence and their general hydrologic characteristics. From the land surface to the first distinct clay, these hydrostratigraphic units are:

Layer 1 – Surficial Sandy Clay (unsaturated)
Layer 2 – Fine- to Coarse-Grained Sand (primarily unsaturated; vertical permeability ranged from 0.17 ft/day to 1.8 ft/day)
Layer 3 – Fine to Very Coarse Sand with Fine to Coarse Gravel (partially to fully saturated; average conductivity based on the slug/bail tests is 11 ft/day with a range of 0.4 ft/day to 103 ft/day)
Layer 4 – Fine- to Medium-Grained Glauconitic Sand (comprises the majority of the saturated thickness of the shallow saturated zone; hydraulic conductivity based on the slug/bail tests ranges of 0.4 ft/day to 34 ft/day with an average of 11 ft/day; subdivided into Layer 5 based on basal medium to coarse sand)
Layer 5 – Medium- to Coarse-Grained Glauconitic Sand (hydraulic conductivities based on the slug/bail tests ranged from 10 to 100 ft/day with an average of 34 ft/day).

The two aquifer tests immediately adjacent to the PH12 Area resulted in average transmissivities from the pumping and recovery data of 5,700 to 5,800 feet squared per day (ft^2/day) and storage coefficients of 0.02 to 0.04. The average transmissivity from the pumping and recovery data for the aquifer test in the southwestern part of the CBP was 1,600 ft^2/day. Storage coefficients ranged from 0.01 to 0.3. The average transmissivity from the pumping and recovery data for the two aquifer tests at Kilby Ditch were 800 and 100 ft^2/day. The respective storage coefficients for these latter two tests were 0.01 and 0.06.

2.7 GROUNDWATER FLOW

2.7.1 SITE-WIDE GROUNDWATER FLOW

Groundwater flow in the CBP is controlled largely by topography, surface-water features, and groundwater withdrawals. Groundwater at the CBP flows toward the Alabama River to the west, Three Mile Branch to the east, and Galbraith Mill Creek to the north (Figure 2-17). Based on the USGS Topographic Map, the stage of the Alabama River is 110 feet AMSL. To the east, the land surface at Three Mile Branch is approximately 180 feet AMSL and, to the north, the land surface is approximately 150 feet AMSL at Galbraith Mill Creek. Other notable features that affect groundwater flow are the Kilby Ditch network and the Montgomery Zoo pond.

The Kilby Ditch network drains a significant part of the stormwater at the CBP. In the PH12 Area, the base of West Kilby Ditch is generally above the top of the water table and is predominately dry between precipitation events. Perennial flow in West Kilby Ditch begins at the intersection of the Ditch with Coliseum Boulevard.

Prior to establishment of the Montgomery Zoo at its current location, the Zoo pond was a sand and gravel mine. This pond is now an alternating groundwater “source and sink” because surface water flows from the pond to the shallow saturated zone during and after significant precipitation events and groundwater flows into the pond during the intervening periods. The pond is predominantly a groundwater sink.

The sand and gravel mines that are southwest of the CBP significantly affect the groundwater flow at the CBP. As described earlier, significant quantities of groundwater are pumped from these pits as part of routine dewatering at the mines.

2.7.2 GROUNDWATER FLOW IN THE PH12 AREA

The PH12 Area is on a northwest-southeast groundwater divide (Figure 2-18). Groundwater to the east of the divide flows toward Kilby Ditch and Three Mile Branch. Groundwater to the west of the divide flows toward the Alabama River and the two active sand and gravel mines. The axis of the divide dips to the north toward the Montgomery Zoo Pond and Galbraith Mill Creek. The majority of the TCE within the PH12 Area is west of the divide (Figure 2-18). The gradient in the PH12 Area is relatively slight (0.001 ft/ft) but steepens largely to the southwest (toward the sand and gravel mines) where the gradient near the southwestern border of the CBP increases to approximately 0.01 ft/ft.

The depths to groundwater within the PH12 Area are greatest (that is, 30 feet) at the center of the PH12 Area. The depths to groundwater are approximately 24 feet at the northern and southern edges of the PH12 Area. The depths to groundwater decrease to less than 15 feet BLS to the north and east (toward the Montgomery Zoo pond and Kilby Ditch, respectively).

2.8 DISTRIBUTION OF TCE

2.8.1 GROUNDWATER

2.8.1.1 Site-Wide

Figure 2-18 shows the maximum concentrations of TCE, through July 2007, within the groundwater at the CBP. The plume of TCE encompasses about 770 acres, based on a 0.005 mg/L level. The plume of TCE is about 10,000 feet long and about 4,000 feet wide. The orientation of the plume, northeast-southwest, coincides with the general patterns of groundwater flow at the CBP.

The areas of greatest TCE concentrations are immediately west of Fairground Road (the PH12 Area); areas of the Eastern Meadows Subdivision; and the Kilby Ditch Area. The concentrations of TCE exceed 10 mg/L within the PH12 Area. The concentrations of TCE within the Eastern Meadows area range from about 1 to about 5 mg/L. The concentrations in the Kilby Ditch Area range from about 0.1 to about 1 mg/L.

TCE concentrations within hydrostratigraphic layers 1 through 5 are illustrated on Figures 2-19 through 2-23. The greatest concentrations of TCE have been in samples collected from groundwater within the glauconitic sands (hydrostratigraphic Layers 4 and 5) within the area immediately west of Fairground Road. With the exception of the area around Chisholm Street, TCE concentrations that exceed 10 mg/L are constrained to the fine-grained glauconitic sand (hydrostratigraphic Layer 4), which is the hydrostratigraphic unit with the lowest hydraulic conductivity. Near the intersection of Chisholm Street and Fairground Road, TCE concentrations that exceed 10 mg/L extend into the medium to coarse-grained glauconitic sand (hydrostratigraphic Layer 5). The first distinct clay is located beneath Layer 5.

2.8.1.2 PH12 Area

The PH12 Area is a north-south trending area of about 10 acres where the groundwater contains greater than 10 mg/L of TCE (Figure 2-18). The southern border of the Area is between Houser Street and Broadway Street, the northern border is between Gardendale Drive and Park Avenue, the eastern border is along Fairground Road, and the western border is about 600 feet west of Fairground Road.

DNAPL Investigation

The PH12 Area was investigated for TCE DNAPL with a combined MIP and soil-conductivity (SC) direct-push tool. The data from this intensive investigation for DNAPL were used to map the distribution of dissolved TCE within the PH12 Area. Eighty-one probeholes (Plate 2-2) were completed during this investigation.

Sediment samples were collected at 27 probehole sites and groundwater samples were collected at 19 of these 27 sites to verify the MIP results. The computerized algorithm NAPLANAL (Mariner et al. 1997) was used as an additional analytical tool to evaluate the sediment and groundwater data for the presence of TCE DNAPL.

Review of the results from the DNAPL investigation and previous investigations within the PH12 Area indicates that:

- There is no TCE DNAPL within the sampled parts of the PH12 Area.
- The majority of dissolved TCE within the PH12 Area is within a zone that is 30 to 60 feet below ground surface.
- The sediments within the 30- to 60-foot zone contain many clay lenses/stringers; the greater concentrations of dissolved TCE probably are proximate to the many clay lenses/stringers that are within the 30- to 60-foot zone.

Vertical TCE Distribution in PH12 Area

Distribution of TCE in the PH12 area is also described in Section 2.4 of the ***PH12 Area Status Report in Support of Corrective Measures Development*** (September 2005). The vertical distribution of TCE in groundwater is directly related to the hydraulic conductivity of the hydrostratigraphic layers, with the highest concentrations in the fine grained glauconitic sands (layer 4) and the lowest concentrations in the sand and gravel (layer 3). The lower advective flow rate in the finer grained units is responsible for this distribution. As described in Section 2.4.4 of the ***PH12 Status Report*** (2005), the field investigations conducted in September 2004 through April 2005 did not detect any evidence of DNAPL TCE in the PH12 area.

Dissolved TCE has not migrated beneath the first distinct clay in the PH12 area. As stated in Section 2.4.2.2 Deep-Zone Monitoring, five groundwater wells are located adjacent to and around the PH12 Area for the purpose of collecting water samples from the deep zone (beneath the first distinct clay). Results from these samples indicate that TCE has not migrated to the deep zone. Samples from the deep zone monitoring wells will continue to be collected and analyzed for VOCs as part of the long term monitoring program.

2.8.2 TCE IN SHALLOW SOILS/SEDIMENTS

To date, more than 700 soil/sediment samples have been collected from various depths throughout the CBP and analyzed for VOCs. The majority of the soil/sediment samples that contained TCE were immediately above the water table or within the saturated zone. Very few soil/sediment samples from the unsaturated zone have contained TCE. Section 3 and Appendix A present the detected volatile organic compounds in shallow soil/sediment samples for the Low-Lying Areas for the preliminary screening level evaluation (PSLE). The Low-Lying Areas are a potential point of exposure for the CBP.

Soil samples were collected from 18 probeholes adjacent to the West and Main Branches of Kilby ditch in March 2008 to determine if soil excavated during remediation construction activities could be managed on-site. None of the soil samples contained detectable TCE, or other VOCs.

2.8.3 TCE IN SOIL VAPOR / AMBIENT AIR

Four sets of vapor implants were constructed within the PH12 Area in March 2000. The implants were constructed to investigate the effectiveness of the surficial sandy clay as a barrier to vertical migration of vapors from chlorinated hydrocarbons, particularly TCE, in the shallow saturated zone. A shallow and a deep vapor implant were constructed at each site so that the concentrations, if any, of TCE within the unsaturated parts of the fine- to coarse-grained sand could be compared to the concentrations of TCE within the overlying surficial sandy clay. The surficial sandy clay in the PH12 Area was determined to be a barrier that inhibits the migration of vapors that might be emitted from elevated concentrations of TCE within the shallow groundwater in the PH12 Area.

Summa canisters were used to collect soil-vapor, crawlspace air, and ambient-air samples at 30 houses or structures in June and November, 2002 and February through March 2003. The majority of these sites were within the PH12 Area. The soil-vapor samples were collected from beneath the slab or foundation of the house. The crawl-space samples were collected from about midway between the floor and the ground. Breathing-zone samples were collected at the "porch" at each of two houses within the PH12 Area. The intakes for the breathing-zone samples were placed at the heights of the occupants breathing zones, based on on-sight observations. Background air samples also were collected during each sampling event. The background air samples were collected immediately north, east, south, and west of the probable extents of the dissolved TCE within the CBP.

Review of the results of the soil-vapor and ambient-air samples indicated that the surficial sandy clay that extends from the land surface to about 7 to 15 feet BLS within the PH12 Area inhibits the migration of VOCs through the shallow unsaturated zone. No ambient-air or soil-vapor sample has contained TCE at concentrations that exceeded the ADEM action level for TCE of 20 ppbv.

2.9 SURFACE-WATER MONITORING

2.9.1 KILBY DITCHES

Surface-water samples have been collected from West and Main Kilby Ditches since the discovery of TCE in the Ditches in March and May 2000. Surface-water samples are collected from West and Main Kilby Ditches at five locations and from one location east of the Montgomery Zoo (Figure 2-24). TCE, when detected, has been consistently less than the ADEM-specified action level for TCE in surface water of 0.175 mg/L[12.]

2.9.2 LOW-LYING AREAS

Since November 2001, samples of sediment and surface water have been collected from the Low-lying Areas within the CBP and analyzed for VOCs (Figure 2-25). The construction of paved and dirt roads, a railroad, and other human and natural activities have resulted in the impoundment of water in these Low-lying Areas.

[1] In May 2011, the action level for TCE will change from the current level of 0.175 mg/l to 0.0175 mg/l in accordance with ADEM regulations. The evaluation of corrective measures was based on the current water quality standard, prior to the regulatory change; however, ALDOT will design treatment to comply with the lower water quality standards, where appropriate.

[2] TCE has not been detected in samples of water from the Montgomery Zoo Ditch.

The largest of the Low-lying Areas (about 33 acres) adjoins the northern side of the CSX Railway (formerly the Western Railway of Alabama), which is about 600 feet north of North Boulevard. There are mixed hardwood trees, shrubs, and herbaceous vegetation throughout this largest of the Low-lying Areas. The known sources of water within this largest Area are: streams, stormwater runoff, and springs. The second Low-lying Area is between North Boulevard and CSX Railway and encompasses 12 acres. There is mostly herbaceous vegetation in the center of this second Area. The mixed hardwood trees that are within this second Area are mostly adjacent to the main drainageway that meanders northward and eastward through the Area before it empties into Three Mile Branch. Known sources of the water within this second Area are Kilby Ditch and the drainage way that empties the third Low-Lying Area.

The third Low-Lying Area, which is the smallest of the three Low-Lying Areas, is between North Boulevard and Russell Corporation. The vegetation within this third area, which encompasses about 2 acres, is mostly herbaceous although there are a few small trees adjacent to the drainageway before it drains beneath North Boulevard. This drainage then reemerges on the north side of North Boulevard where it empties into the second of the Low-Lying Areas. The sources of the surface water within this third, small Low-Lying Area are: part of the flow of Kilby Ditch (via a concrete flume that adjoins the immediate south side of North Boulevard), stormwater runoff, an outfall from Russell Corporation, and shallow groundwater.

Sediment and surface water samples have been collected in the third Low-Lying Area (Figure 2-25). The sediment samples have been collected from about 3 to 12 inches BLS. A majority of the samples collected in this area from 2001 through 2005 have been below the analytical method detection level of 3.0 ug/Kg. Sporadic detections of TCE have been less than the ecological screening level. No surface water samples collected in this area have been above the ADEM action level of 0.175 mg/L TCE.

3.1 OBJECTIVE

To facilitate the corrective measures technology evaluation presented in Section 6 of this report, the existing numerical Site-wide groundwater flow and contaminant fate and transport model developed for previous CBP investigations was updated and re-calibrated. The resultant numerical model was applied to the site-wide CBP for use in evaluating the effects of selected passive (no hydraulic control) and active (with hydraulic control) potential corrective measures on contaminant migration. The results of the contaminant fate and transport simulations for the potential corrective measures were compared to a baseline simulation showing fate and transport of the TCE plume without corrective measures to evaluate their effect on the CBP plume over a 30-year evaluation period.

The numerical model was based on the geologic and hydrogeologic information discussed in Section 2 and was updated with new information from Site investigations conducted between September 2003 and July 2007. The updates included revisions based on information on groundwater withdrawals from existing sand and gravel mines southwest of the CBP, projected expansion of the existing pits, and anticipated sand and gravel mines northwest of the CBP.

3.2 MODEL SUMMARY

The groundwater flow and contaminant fate and transport models summarized below were based on previous models created for the PH12 Area. The model was modified to incorporate new data regarding floodplain stratigraphy and reevaluation of model inputs and withdrawals, including recharge and dewatering sand and gravel mines as discussed below.

3.2.1 MODEL SELECTION

The USGS modular, three-dimensional finite-difference groundwater model MODFLOW (McDonald and Harbaugh, 1988) was used to simulate hydraulic heads in the model domain. The USGS particle-tracking post-processor MODPATH (Pollack, 1989) was used to track the groundwater flow paths within the model. The USEPA/USACE Modular Three-Dimensional Multi-species Transport Model MT3DMS was used to simulate movement of the TCE in the groundwater. The input and output files for these models were managed in Groundwater Modeling System (GMS), a pre- and post-processing software program developed by Brigham Young University for the United States

Department of Defense, and in ArcGIS, a geographic information system software package developed by ESRI.

3.2.2 MODEL DESIGN

3.2.2.1 Model Domain and Boundary Conditions

The model domain was based on regional hydrologic and hydrogeologic characteristics including groundwater flow, groundwater flow divides, aquifer recharge, surface drainage, and groundwater withdrawals.

Areas of the southwestern and southern boundaries of the model were assigned zero-flux (or no-flow) cells, which coincided with groundwater flow divide areas that represent the local watershed boundary as inferred from topographic data. No-flow cells were also assigned along the lateral boundaries parallel to assumed regional groundwater flow. General head cells were used to simulate the downgradient boundary of the model at the Alabama River. The specified head assigned to the cells representing the Alabama River approximated the average annual river stage (surface elevation). General head boundaries are specified head boundaries where the flux through the cell is controlled using a conductance value, which is based on the cell dimensions and hydraulic conductivity.

3.2.2.2 Model Grid and Layer Discretization

The model grid was oriented parallel to the regional groundwater flow direction toward the Alabama River. Grid cells in the vicinity of the CBP were refined to approximately 50 feet by 50 feet. Outside of this area, the grid cell size was increased incrementally by a factor of 1.5 to a maximum of 250 by 250 feet. The refined grid in the vicinity of the CBP provided more detailed model results in the area where corrective measures are being considered and was supported by the Site-specific geologic and water level data.

As described in Section 2, the water-bearing soils in the vicinity of the CBP represent sand and gravelly sand terrace deposits and fine to coarse-grained silty sands of the Eutaw Formation (the shallow zone). These deposits in the shallow aquifer above the first distinct clay were divided into five general hydrostratigraphic units (layers) based on their occurrence within the stratigraphic sequence and their general hydrologic characteristics: surficial sandy clay (Layer 1), fine- to coarse-grained silty sand (Layer 2), fine to coarse sand with fine to coarse gravel (Layer 3), fine- to medium-grained glauconitic Sand (Layer 4), and medium- to coarse-grained glauconitic sand (Layer 5). The uppermost hydrostratigraphic unit, the surficial sandy clay, is unsaturated throughout much of the model domain and within the CBP. Underlying the surficial sandy clay is the silty sand, which is also unsaturated over most of the CBP. The sand and gravel unit is the first hydrostratigraphic unit that is partially to fully saturated throughout the CBP. The model was vertically discretized into five layers from the ground surface to the first distinct clay, corresponding to the hydrostratigraphic units as described above:

- Model Layer 1 - surficial sandy clay unit.
- Model Layer 2 – upper sandy clay unit.
- Model Layer 3 – sand and gravel unit.
- Model Layer 4 – fine-grained silty glauconitic sand unit.
- Model Layer 5 – coarse-grained glauconitic sand unit.

The top of the clay that underlies the lower coarse-grained glauconitic sand unit (Layer 5) defines the base of the groundwater model. The layers were constructed in MODFLOW using all available boring data from the Site investigations.

As discussed in Section 2, stratigraphy outside of the terrace areas is representative of a floodplain sequence related to deposition from the Alabama River and Three Mile Branch. These floodplain areas were segregated laterally within the model domain into depositional zones based on assumed areas of related floodplain deposition:

- Western floodplain area based on flood plain deposition from the Alabama River.
- Low-lying Areas, north of Kilby Ditch, based on deposition from Kilby Ditch and Three Mile Branch
- Transitional area, north of the CBP between the western floodplain area and the Low-lying Areas.
- Sand and gravel mine areas, based on boring logs from borings within that area and the stratigraphic sequence observed in the sand and gravel mines.

The deposits in the floodplain areas above the first distinct clay were also divided into five general hydrostratigraphic units (layers) in each depositional zone, based on their occurrence within the stratigraphic sequence and their general hydrologic characteristics. At the edge of the terrace area, the hydrologic properties representing the terrace deposits assigned to each layer transitioned into the hydraulic properties for the floodplain deposits as illustrated on the Generalized Floodplain Figure in Appendix B.

3.2.2.3 Aquifer Parameters

Critical hydrologic inputs to the model consisted of hydraulic conductivity and porosity of each of the five stratigraphic layers, recharge from precipitation, recharge/discharge from surface water bodies (lakes/ponds, rivers/streams, and ditches), and groundwater withdrawals.

Hydraulic conductivities for Layers 1 and 2 were estimated based on the geologic characteristics of each layer. The hydraulic properties (transmissivity and storage) for Layers 3 through 5 were measured through 5 aquifer tests conducted throughout the CBP. Two aquifer tests were conducted near the Kilby Ditch, two in the PH12 area and one in the southwest near the borrow pits. Transmissivity at each test location was correlated to hydraulic conductivities measured at each of the observation wells and used to adjust the spatial hydraulic conductivity throughout the CBP. The initial spatial distribution of hydraulic conductivities for Layers 3 through 5 was based on the aquifer test adjusted slug tests conducted on monitoring wells throughout the CBP. The initial hydraulic conductivity values were adjusted during the model calibration process, as the results of the slug and bail tests and grain size analyses are approximate only and the results of the aquifer tests were based on wells screened across all of the saturated layers of the model. Thus, estimates of hydraulic conductivity and storativity from the pumping test analysis were not specific to the layers defined in the model.

Vertical hydraulic conductivity was based on an assumed ratio of horizontal to vertical hydraulic conductivity of 10 to 1 and adjusted during model calibration. In general, the ratios of horizontal to vertical hydraulic conductivity of the sandy clay layers were lower than those of the more uniform sand and gravel layers.

The porosity for each of the five layers was assigned a constant value of 30 percent (0.3 parameter value), which was estimated based on the porosity for sand (25-40 percent) and silt (35-50 percent) (Driscoll, 1995).

3.2.2.4 Surface Water

Surface water features, such as the ponds, ditches, creeks, and rivers, were modeled using either the MODFLOW river or drain package. The Alabama River, a regional groundwater discharge boundary, was represented as a general head boundary. The ponds and creeks were simulated using the MODFLOW river package, with the stage level and bottom elevations based on topographic information. This allowed water to be removed from the aquifer or released to the aquifer by the river cell based on adjacent head conditions. Lakebed elevation and lake stage data for the City of Montgomery Zoo Pond, located north-northwest of the PH12 Area within the CBP, were established from piezometers located adjacent to the pond (PZ-5, PZ-12, PZ-14, and PZ-17) and the Zoo Pond gage located near the shoreline to measure the lake stage. The streambed/lakebed conductance was initially set equal to the conductivity of the adjacent sediments and adjusted during the calibration process.

The MODFLOW drain package was used to simulate flow into ditches, including West Kilby Ditch, and small drainage channels north of the CBP. Drain cells only remove water from the aquifer if the head in adjacent cells is higher than the stage elevation assigned to the drain cell. As with the river package, the initial ditch conductance was set equal to the surrounding sediment and adjusted during model calibration. The base elevation and stage for the surface water bodies represented in the model were obtained from site surveys and USGS topographic maps.

3.2.2.5 Aquifer Recharge and Evapotranspiration

Areal recharge was varied spatially based on land cover, with higher recharge in areas with little impervious surfaces (open fields) and lower recharge in areas with significant development and/or storm water controls. Recharge to the aquifer was applied to the uppermost active layer of the model at an initial rate between 6 and 12 inches per year, and reduced by a factor of 0.3 to 1.0 depending on the land use, as determined from available land use mapping, aerial photography, and recent development in the area of the CBP. This recharge rate accounts for precipitation reaching the groundwater table after accounting for losses through surface water runoff and interception. The initial recharge rate and land use reduction factors were adjusted during model calibration.

As illustrated on the Existing Land Cover Type Figure in Appendix B, evapotranspiration (ET) was applied to the surface of the model domain based on land cover type. The extinction depth used to simulate ET in the model varied between six inches and four feet BLS based on land cover type. The maximum ET rate was calculated from the Thornthwaite Potential ET for the given land cover type and summed to an annual potential evapotranspiration amount.

3.2.2.6 Groundwater Withdrawals

The bottoms of the sand and gravel mines southwest of the Site are about 50 feet BLS, and the minimum water level in the bottom of the pits is approximately 14 feet BLS based on survey and LIDAR data. The dewatering pumps operated by Asphalt Contractors operate seven days a week for eight hours each night, with the pumps set at 4,000 GPM, for approximately 1.9 MGD. The Asphalt Contractors sand and gravel mine is pumped down to approximately 45-50 feet BLS to allow excavation of the source material. The total size of the Asphalt Contractors sand and gravel mine is about 120 acres with about 75 additional acres capable of being mined. The life of this pit is estimated to be approximately another 5 years.

North Montgomery Materials (NMM) uses the same type of pit operation and their sand and gravel mine is dewatered by pumping from the bottom of the pit at an estimated rate of approximately 3,000 gpm or approximately 1.4 MGD. NMM has estimated continued operations that require dewatering for approximately another 30 years, and will extend their mining operation to the north and east of the present excavation area.

Much of the water pumped from the pits is discharged to either settling basins or water supply ponds and recirculated for material washing. As a consequence, the majority of the 3.3 MGD total water pumped from the pits as part of the mining operations is not directly from groundwater.

In addition to the southwest sand and gravel mines, a new sand and gravel mine to the northwest is anticipated. This sand and gravel mine is expected to begin operation within the next 10 years and is expected to continue operations beyond 2036. For the purpose of this CME, it was assumed that the sandy floodplain deposits down to the top of the first distinct clay would be removed in the northwest pit and the pit area dewatered to that depth.

The MODFLOW drain package was used to simulate dewatering in the sand and gravel mines by setting drain elevations to match the sand and gravel mine maintained groundwater level detailed above. As with the river package, the initial drain conductance was set equal to the surrounding sediment and adjusted during model calibration.

3.2.3 Model Calibration

Model calibration included running steady-state and transient simulations and comparing the resulting simulated hydraulic heads to measured water levels. Steady state calibration of the model is shown on the Steady-State Calibration – Whisker Plots in Appendix B. In general, an iterative approach was used to calibrate the model by adjusting individual input parameters within the range of material-specific values. For each model run, the simulated heads were compared to the measured heads at each well location, and qualitative differences between simulated potentiometric contours and potentiometric contours interpolated from observed heads were reviewed. Additionally, the mean, absolute mean, and root-mean-squared errors were calculated for each model run. This iterative method was repeated until the calculated errors and disparity between simulated and observed heads were minimized. The potentiometric contours of simulated heads from the uppermost active layer in the steady-state calibrated model and the areal distribution of differences between modeled and measured heads, and the calibration error summary, are shown on the Steady-State Calibration – Whisker Plots in Appendix B.

The aquifer parameters used in the initial steady-state calibrated model were used for the transient calibration and then modified using the iterative method discussed above. A transient test of the model was conducted by simulating the 72-hour aquifer test performed at PW-3 in the Kilby Ditch Area of the CBP and PW-4 in the southwestern area of the CBP in August 2005. Specific storage and specific yield values were estimated from the aquifer test results. Drawdown measured in monitoring wells surrounding the test wells during the aquifer tests was compared to drawdown simulated in the transient pumping model, at observation points used in the model to approximate the observation wells. Resultant adjustments to aquifer parameters made during the transient calibration were incorporated into the steady-state model for confirmation.

3.2.4 TRANSIENT FLOW MODEL

Based on the results of the steady-state and transient groundwater flow calibration process, a transient flow model was developed to provide a groundwater flow solution for application to the contaminant fate and transport model. The transient model was used to simulate changes in sand and gravel mining in both the southwestern and northwestern areas of the model domain during the 30-year period simulated by the model as well as land use changes to reflect continued development within the CBP model area.

3.2.4.1 Simulation of Sand and Gravel Mining Scenarios

The transient groundwater flow model was assigned different stress periods to simulate changes in dewatering at the sand and gravel mines during the 30 year evaluation period:

- Current dewatering of the southwestern Asphalt Contractors and NMM sand and gravel mines from present until 2011 were maintained. Beginning in 2006 and extending through 2016, a gradually increasing stage was simulated in the existing sand and gravel mines to represent a shift in production to the immediately adjacent property to the north (sand and gravel mine expansion area as shown on Figure 1-1).
- Beginning in 2006 and extending through 2016, a gradually decreasing stage was simulated in the expansion area for the southwest sand and gravel mines. From 2016 through 2036, stage levels were maintained at the same level for the southwest pits.
- The anticipated northwestern sand and gravel mine areas were assumed to be inactive until 2016. Beginning 2016 and extending through 2026, a gradually decreasing stage was simulated to a maximum depth of approximately 130 feet AMSL, and maintained through the remainder of the model run.
- Dewatering of the existing southwestern sand and gravel mine areas until 2036, with dewatering in the southwestern extension area. The anticipated northwestern sand and gravel mine areas become active in 2016, and dewatering activities in the existing southwestern pits are diminishing.
- Cessation of dewatering activities in the southwestern sand and gravel mine area was simulated from 2006 through 2036 to assess plume dimensions in the event that sand and gravel mine dewatering is discontinued.

Elevations for the drain cells used to simulate dewatering in the sand and gravel mine areas were taken from survey information from the existing sand and gravel mines. The timing of the stress periods for the transient model corresponds to the currently anticipated operational plans for the sand and gravel mines. For the purposes of the simulation, the post-dewatering drain elevations were adjusted to return the southwestern sand and gravel mines to the groundwater level that corresponds to pre-mining groundwater levels along the western border of the sand and gravel mines. The pre-mining groundwater levels were estimated using the groundwater flow model with no active sand and gravel mine dewatering.

3.2.5 CONTAMINANT FATE AND TRANSPORT MODEL

The calibrated transient MODFLOW model summarized above was used in conjunction with MT3DMS to simulate the fate and transport of TCE in the groundwater during the varying groundwater withdrawal regimes created by changing dewatering operations in the sand and gravel mine areas over time.

The distribution of TCE was based on all samples collected from the CBP through October 2006 with initial concentrations applied to the model by sample depth into the respective model layer. Where multiple results were available within a single model cell (e.g., time series concentrations) or at a single point with a model layer (e.g., multiple vertically stratified samples from the same hydrostratigraphic unit), the maximum TCE measured for that cell was used in the model. By using the maximum concentration, under prediction of TCE concentrations in the groundwater is avoided. Dispersivity was based on the length of the 10 mg/L TCE isopleth, and set to a constant value for all model layers. Longitudinal dispersivity was set to a value of 30, transverse dispersivity to 3, and vertical dispersivity to 0.3.

While investigations within the CBP have not identified the presence of any TCE DNAPL, the potential presence of residual TCE associated with an immobile phase in the soils was incorporated in the model to be conservative for the purposes of modeling. A rate-limited sorption was used to model kinetic mass transfer between mobile and immobile zones in a dual-domain (dual porosity) mass transfer model with sorption. Transport through the mobile zone (through zones of high hydraulic conductivity) primarily occurs by advection whereas transport through zones of low hydraulic conductivity (immobile zone) primarily occurs by diffusion.

The model allows the use of mass and concentration to introduce constituents in the immobile phase. To better simulate the TCE plume, TCE in the immobile phase was introduced to represent residual TCE existing within the CBP. To conservatively predict the effect of residual TCE in the CBP, the dissolved phase TCE within the CBP was replicated as an immobile phase. A relatively high mobile phase porosity of 0.05 was used for all model layers, which will tend to conservatively predict residual TCE mass in the CBP. Overall, the conservative introduction of the immobile phase TCE in the model effectively increased TCE mass in the CBP by approximately 17 percent.

A diffusive mass transfer rate equivalent to the molecular diffusion coefficient of TCE was used in all layers of the model. Additionally, a soil sorption coefficient was used for the dissolved phase. Initially, a value equivalent to the soil/water partition coefficient for TCE was used for the soil sorption coefficient and then this value was adjusted to match observed changes of TCE concentration with time as a model calibration to the TCE movement in the CBP. Also, a bulk density of 1.55 g/m^3 was used from measurements obtained on undisturbed sediments collected from the CBP.

3.3 BASELINE SIMULATIONS

3.3.1 BASELINE (ASSUMING NO CORRECTIVE MEASURES)

The baseline fate and transport model simulated the movement of TCE in the groundwater with no corrective measures in the CBP. Only the effects of advective transport, diffusion, sorption, and dual domain transfer were considered (i.e., no biological degradation). Transport for the baseline scenario was simulated under transient conditions (advective transport changed over time) to evaluate the effect of dewatering from sand and gravel mines to the west. The following flow regimes were considered:

- Dewatering the sand and gravel mines to the southwest only, from 2006 through 2016
- Dewatering the sand and gravel mines to the southwest and the anticipated sand and gravel mines to the northwest from 2016 to 2036

Maximum depth for the sand and gravel mines was set to 114 feet AMSL based on surveyed elevations and LIDAR data for the bottom of the existing pits. The southwest sand and gravel mine pumping was initiated in the existing sand and gravel mine area beginning in simulation year 2006, expanding at a linear rate to the north in the southwest expansion area from 2006 through 2016. From 2016 through 2026, pumping was assumed to gradually cease in the existing sand and gravel mine area while the future expansion area for the southwest sand and gravel mines continued to operate through 2036. The proposed northwest sand and gravel mines were assumed to operate from 2016 through 2036.

In addition to the sand and gravel mine operations, development was assumed to continue to occur within the CBP. Existing, undeveloped properties, in particular the area around Kilby Ditch, were assumed to be developed in a manner consistent with their current zoning designation over the next 20 years. For instance, undeveloped properties zoned for residential use were assumed to build out at a similar density as adjacent like zoned residential properties. Recharge rates over the period of 2006 to 2026 were adjusted down for these areas to represent a greater impervious area and stormwater drainage.

3.3.2 BASELINE MODEL RESULTS

The dominant advective forces that currently influence movement of the plume are expected to remain relatively constant over the next 10 years. As a consequence, movement of TCE in the CBP continues to follow the current direction of flow over this period (2006 through 2016). That is, the southwest edge of the plume continues to migrate slowly toward the active sand and gravel mines located to the southwest. The northeast extension of the plume continues to migrate more slowly in the direction of the Low-lying Areas and Three Mile Branch. Based on extrapolating current conditions over the next 10 years (e.g., assuming no significant meteorological or land use changes), the leading edge of the TCE plume to the southwest is expected to reach the sand and gravel mines in less than 5 years (Figures 3-1 through Figure 3-3). TCE concentrations in groundwater in the Kilby Ditch Area are expected to gradually increase over the next 10 years, exceeding 1.0 mg/L in groundwater in the vicinity of West Kilby Ditch and exceeding 0.5 mg/L over an appreciable portion of Main Kilby Ditch. The 0.1 mg/L area continues to slowly expand, extending into the Low-lying Areas by 2036.

The PH12 Area itself continues to remain relatively stable, with only a slight decrease in concentration over the next 10 years. The PH12 area coincides with the groundwater divide, with flow from the PH12 Area to the northeast toward Three Mile Branch and toward the west-southwest toward the sand and gravel mines and the Alabama River. Rather than a “source area”, the PH12 Area represents an area where groundwater is moving very slowly and straddles the groundwater divide. Advective transport in this area is very low (less than 5 ft/yr to less than 10 ft/yr). TCE transport in this area is very low due to the corresponding low groundwater advection rates. Outside the groundwater divide area advective transport rates increase; therefore, TCE transport increases in these areas.

The relationship between the PH12 Area and groundwater flow rate is illustrated in Figure 3-4. A TCE Concentration (y-axis) to Groundwater Flow Rate (x-axis) chart is presented in the lower right corner of Figure 3-4. Within the entire PH12 Area, groundwater flow is less than 10-feet/year. With distance from the groundwater divide the flow rate increases to over 25-feet/year with the greatest increase to the southwest (Figure 3-4). This is also the area where significant increases in TCE concentrations at downgradient wells (MW-223 and MW-232) were observed. These observed trends are also consistent with the CBP model predicted changes in TCE concentration. Even though there are changes in TCE concentration within and adjacent to the PH12 Area, it is expected that the location of the groundwater divide will not shift significantly and, as a consequence, advection within the PH12 Area will remain correspondingly low.

Advection rates in the PH12 area range from less than 5 ft/yr near the center of PH12 to less than 10 ft/yr near the western perimeter of PH12. Sentry wells will be used to monitor for TCE concentrations in groundwater near the Institutional Control Boundary.

From 2026 through 2036 (Figure 3-4 and Figure 3-5), the southwest extension of the plume is entirely captured by dewatering at the southwest sand and gravel mines. The effects of dewatering at the mines were used to predict concentrations of TCE in the surface water. Due to the radial groundwater flow (from the west, south, north and east) into the pits caused by this pumping, TCE concentrations will remain less than the ADEM-specified action level of 0.175 mg/L.[1]

[1] In May 2011, the action level for TCE will change from the current level of 0.175 mg/l to 0.0175 mg/l in accordance with ADEM regulations. The evaluation of corrective measures was based on the current water quality standard, prior to the regulatory change; however, ALDOT will design treatment to comply with the lower water quality standards, where appropriate.

3.3.3 BASELINE SCENARIO WITHOUT ACTIVE DEWATERING IN THE SOUTHWESTERN SAND AND GRAVEL MINES (ASSUMING NO CORRECTIVE MEASURES)

The groundwater model was used to simulate groundwater flow direction and TCE movement by using a scenario whereby Asphalt Contractors and North Montgomery Materials would cease operations and discontinue pumping in 2006. This simulation assumed that the southwestern pit excavations would fill with water corresponding to the 2006 grade elevations. Although this scenario is unlikely, the results were used to evaluate the plume dimensions if dewatering in the southwest ceases at any time.

3.3.4 BASELINE WITHOUT ACTIVE SAND AND GRAVEL MINE DEWATERING MODEL RESULTS

The simulated groundwater model results with and without dewatering at the sand and gravel mines indicate no significant changes in groundwater VOC concentrations specifically for the PH12 Area, Kilby Ditch, Low-Lying Areas and areas east of the groundwater divide at PH12 Area. For both scenarios, the plume would continue to move to the west-southwest toward the southwest sand and gravel mines and to the northeast toward Three Mile Branch and the Low-Lying Areas. The primary effect would be the change in the rate of groundwater flow along the southwestern portion of the CBP. Under current dewatering activities, the groundwater gradient along the southwestern portion of the CBP is relatively steep, in contrast to the modeled non-dewatering scenario. The area of significant change in the groundwater gradient between these two scenarios is limited to the leading edge of the southwestern portion of the CBP. In general, continued dewatering in the sand and gravel operations will draw the southwestern CBP to a specific area, whereas, discontinuing the dewatering activities will allow a greater spread or expansion of the southwestern CBP to the north and south. In addition, continued dewatering activities reduces the time for the CBP to reach the sand and gravel operations; discontinuing the dewatering activities will slow down the rate of groundwater movement thereby increasing the time for the CBP to reach the area of the sand and gravel operations.

For example, under the current southwest sand and gravel mine dewatering scenario, the leading edge of the CBP to the southwest is expected to reach the sand and gravel mines in less than 5 years.

Under the non-dewatering sand and gravel mine scenario, the leading edge of the TCE plume to the southwest is expected to reach the current active sand and gravel pit between 2026 and 2036. Also, the non-dewatering sand and gravel mine scenario indicates that the spread or increased area of TCE concentrations of 0.001 mg/L is estimated to be 121 parcels (600 feet to the northwest and 800 feet to the southwest) by the year 2036 compared to the dewatering sand and gravel mine scenario for the same time period.

3.4 MODEL USES

The calibrated model was used to screen the potential corrective measures described in Section 6 of this report. The potential effectiveness of these corrective measures was compared to the baseline scenario.

For each remedial scenario, multiple configurations were initially evaluated to determine the most effective and feasible configuration. The remedial scenarios were then evaluated individually and in conjunction with each other to devise overall remedial alternatives that best meet the technical performance standards and evaluation criteria outlined in Section 7 of this report.

This section analyzes the potential for exposure of human and ecological receptors to TCE, TCE degradation products, and other detected constituents in the groundwater that underlies or migrates from the CBP. Consistent with ADEM (2006) and USEPA (1989) guidance, the analysis links the sources, locations, and types of environmental releases with population locations and activity patterns to evaluate whether there are pathways of exposure, and the potential for human and/or ecological health risks from such exposure, at the CBP.

4.1 SITE CONCEPTUAL EXPOSURE MODEL

The analysis is based on a site conceptual exposure model (SCEM) that outlines the working hypotheses regarding constituent fate and transport processes and the potential for exposure of human and ecological receptors to constituents detected in or originating from groundwater. The SCEM is presented in Figure 4-1 and considers:

- Constituent source areas
- Constituent release and transport mechanisms
- Environmental media (e.g., groundwater) that are currently impacted or may in the future be impacted by these constituents
- Possible exposure pathways
- Current and likely future site conditions and surrounding land use
- Potential human and ecological receptors
- Possible exposure routes

A complete exposure pathway generally comprises the following four elements (USEPA, 1989):

- A source and mechanism of constituent release
- Retention or transport media
- A potential contact point with an affected medium
- An exposure route (i.e., ingestion, dermal contact, inhalation) at the contact point

The exposure pathway is incomplete, and there is no potential for exposure or health risk, if any of the elements are or will be missing.

The following are potential exposure pathways at the CBP (see also Figure 4-1) that have been considered throughout the CBP investigations and this evaluation of Site-wide corrective measures:

- Air - volatile constituents in the shallow-zone groundwater may migrate to ambient and/or indoor air
- Groundwater - groundwater may be used for potable and/or non-potable purposes and contact with the relatively high water table could occur in some areas of the CBP
- Surface water - dissolved constituents may be transported in the shallow-zone groundwater and discharged to surface water and sediment
- Sediment –To date, detected VOCs in the sediment samples have been below the preliminary screening levels as determined through the ARBCA guidance manual.

Investigations of soil have indicated no exposure pathway because TCE was not detected in shallow soil samples collected to a depth of 15 feet below land surface.

Potential receptor populations for these exposure pathways within the CBP include:

- Current and future residents
- Current and future commercial workers
- Current and future construction/utility workers who may contact shallow groundwater during activities involving excavation.
- Current and future trespassers who may have occasional, casual contact with surface water and sediment or who may consume sport fish within or downgradient of the CBP.
- Ecological receptors including threatened/endangered species, wetlands, and sensitive habitats.

4.2 EVALUATION OF POTENTIAL EXPOSURE PATHWAYS

4.2.1 AIR PATHWAYS

Potential Pathways: Analysis of the air pathway is based on consideration of existing and projected VOC concentrations that could volatize from groundwater, migrate as vapors through unsaturated subsurface soil/sediment, and enter the ambient air or the indoor air of overlying buildings. The exposure concern is the potential for inhalation of those VOCs by residents and workers within the CBP. Vapor intrusion is a potential concern for buildings with basements and ordinary slab-on-grade constructions. There is generally less concern for buildings with crawl spaces because the crawl space interrupts the pathway between the subsurface and the building foundation and, depending on the construction, provides for dispersion of vapors into ambient air.

The potential for vapor migration into ambient air and/or vapor intrusion into indoor air was evaluated through extensive collection and analyses of samples of soil vapor, ambient air, breathing-zone air, and crawl space air at 30 representative residential properties throughout the CBP (ALDOT, 2003). Samples were collected during three events to evaluate seasonal variations: June 2002, November-December 2002, and February-April 2003. The conclusion from these investigations was that the surficial sandy clay present at most of the CBP inhibits the migration of VOCs from the shallow unsaturated zone to the land surface (ALDOT, 2003). No ambient air, breathing zone air, or crawl space air sample from any residential property, and no background ambient air sample from any location, contained TCE at a concentration that exceeded the 20 parts per billion by volume (ppbv) screening level set by ADEM.

Finding: The results of the 2002 and 2003 soil vapor and air studies indicated that there is no current exposure from vapor intrusion. Since the TCE release occurred in the mid-1960s to 1970s, and a current exposure pathway does not exist, it is believed that there will be no exposure pathway for residents or commercial workers in the future.

4.2.2 GROUNDWATER PATHWAYS

Potential Pathways: Analysis of the groundwater pathways is based on consideration of the potential for contact, by individuals of all ages, with dissolved constituents during either potable or non-potable use of the groundwater throughout the CBP. Potable use of the groundwater provides for the potential ingestion of dissolved constituents and the inhalation of and dermal contact with those constituents during routine household uses (e.g., bathing, cleaning). Non-potable use of the groundwater provides for the potential dermal contact with, inhalation of, or ingestion of dissolved constituents during use of the water for sanitary, process, irrigation, or other purposes.

There is also the potential for dermal and inhalation exposure whereby construction/utility workers excavate into the shallow-zone groundwater (e.g., east of Coliseum Boulevard and the Low-lying Areas). The water table in portions of this area is less than 6 feet BLS in these areas and TCE concentrations in groundwater are expected to gradually increase in the Kilby Ditch Area over the next 10 years and to slowly expand north to the Low-lying Areas in the next 30 years.

Finding: There is minimal potential for exposure to constituents in the groundwater due to potable and non-potable use of the groundwater because:

- The CBP Area is supplied with water by the Montgomery Water Works & Sanitary Sewer Board, which draws water from a surface water source and from a deeper aquifer that is distant from the CBP.
- There is currently no non-potable use of the groundwater within one mile of the CBP Area that would provide human contact.
- A comprehensive Institutional Control Program, described in Section 8, will be implemented to prevent future potable and non-potable use of the groundwater. The Program includes groundwater use restrictions (restrictive covenants) that will be maintained on all residential, commercial, and unimproved properties located within the 1 ug/L isoconcentration line for TCE projected to the year 2036, plus a 100-foot buffer based on the Site-wide groundwater model. There will be a restrictive covenant for each property that restricts the use of and access to the groundwater.
- An aggressive public notification process has been implemented through public meetings, media stories (newspaper and broadcast), direct mailings and door hangers, Community Outreach Group involvement, and availability of information through a Public Repository, web-site and 24-hour information line.

Finding: There is minimal potential for contact with shallow-zone groundwater within the CBP because:

- Buildings are constructed without basements
- Buried utilities are shallow and above the water table
- Rights-of-way limit or prevent unapproved intrusion into the subsurface.
- A comprehensive Institutional Control Program, described in Section 8, will be implemented. It will include routine notification of utilities, contractors, and well drillers that could excavate in areas of the CBP with a relatively high groundwater table.

4.2.3 SURFACE WATER AND SEDIMENT PATHWAYS

Potential Pathways: Analysis of the surface water and sediment pathways includes consideration of the potential for contact with the shallow-zone groundwater via its discharges to Kilby Ditch, the Low-lying

Areas downstream of Kilby Ditch, and eventually to the southwestern sand and gravel mines.

4.2.3.1 Kilby Ditch and Low-lying Areas

Kilby Ditch discharges into an unnamed perennial tributary to Three Mile Branch, which is north of North Boulevard. This stream flows to the north and east into the Low-Lying Areas and the stream channel becomes braided through portions of the Low-Lying Areas. .The streams, stormwater runoff, and groundwater discharge provide water to the Low-lying Areas, which are north of North Boulevard and the railroad tracks. Human and natural activities, including the construction of roads and railroad tracks, have impounded water in these Low-lying Areas.

Access to Kilby Ditch varies from its origin to the downstream Low-lying Areas. The part of West Kilby Ditch from the east side of Coliseum Boulevard to its intersection with the Main Kilby Ditch is concrete-lined and enclosed by a chain-link fence. South of the West Kilby and Main Kilby Ditch junction, the groundwater is not in contact with the ditch; thus, the ditch only contains water during storm events. North of the junction and towards North Boulevard, access remains limited by a chain-link fence, steep banks, and dense vegetation. The Low-lying Areas are not fenced; however, there is dense vegetation throughout the area. Currently, there are warning signs posted around Kilby Ditch and the Low-lying Areas.

A preliminary screening-level evaluation (PSLE) was performed, in accordance with the ARBCA Guidance Manual (ADEM, 2006), to evaluate the surface water and sediment pathways identified for Kilby Ditch and the Low-lying Areas. The PSLE was submitted to the ADEM in a letter that is dated January 3, 2007 and is attached in Appendix A. The following presents a summary of the evaluation of the surface water and sediment pathways and the findings presented in the PSLE.

Finding: The PSLE considered the potential for risk of non-carcinogenic health effects and increased cancer risk to adolescent trespassers from dermal contact with constituents in surface water and from incidental ingestion of and dermal contact with constituents in sediment during recreational activities. Incidental ingestion of constituents in surface water is not considered a potential exposure route since Kilby Ditch and the Low-lying Areas do not support swimming. Maximum constituent concentrations from the two most recent years worth of surface water and sediment data were compared to preliminary screening values (PSVs) that were derived using:

- The target hazard quotient (0.1) and target cancer risk (1 x 10^{-6}) specified for PSLEs in Table 2-1 of the ARBCA Guidance Manual.
- Standard USEPA and ADEM risk assessment methodology and equations of the same format as the risk-based target level equations presented in Appendix B of the ARBCA Guidance Manual.
- Default exposure factors for trespassers that are provided in Table 3-1 of the ARBCA Guidance Manual. However, as indicated in the January 3, 2007 letter (provided in Appendix A), a few exposure factors (e.g., an exposure frequency of 50 days/year) were selected based on professional judgment.
- Toxicity values specified in Table 3-4 of the ARBCA Guidance Manual.

Surface water data were collected from two monitoring points in West Kilby Ditch, three compliance points in Main Kilby Ditch, and 16 sampling locations in the Low-lying Areas. Sediment data were limited to samples collected at 16 locations in the Low-lying Areas. As shown in Tables 1 and 3, respectively, in the January 3, 2007 letter (provided in Appendix A), none of the maximum detected surface water or sediment concentrations were greater than the corresponding PSVs, indicating that, currently, human health risks from these exposure pathways are unlikely. However, under the baseline contaminant fate and transport model simulation presented in Section 3.3.2, TCE concentrations in groundwater in the Kilby Ditch Area are expected to gradually increase over the next 10 years, exceeding 1.0 mg/L in groundwater in the vicinity of West Kilby Ditch and exceeding 0.5 mg/L over an appreciable portion of Main Kilby Ditch. The 0.1 mg/L area will continue to slowly expand, extending into the Low-Lying Areas by 2036. These results indicate that the potential for human exposure to TCE in surface water, and the potential for health risks from such exposure would exist in the future.

Finding: The PSLE considered the potential for exposure of trespassers (e.g. adult sport fishermen) to constituents in surface water that may bioaccumulate in fish, since site characterization indicates there may be some fishing in standing water pools in the Low-lying Areas. Maximum detected concentrations from the two most recent years' worth of surface water data from the two monitoring points and three compliance points in Kilby Ditch and the 16 locations in the Low-lying Areas were compared to PSVs that are protective of fish consumption and were derived using the ADEM procedure for deriving criteria applicable to waters of the state (ADEM Admin. Code R.335-6-

10-.07). As shown in Table 1 in the January 3, 2007 letter (provided in Appendix A), none of the maximum detected surface water concentrations were greater than the corresponding water quality criterion, indicating that, currently, human health risks from fish consumption are unlikely.

Based on the results of the baseline simulation presented in Section 3.3.2 and noted above, the potential for human exposure to TCE in consumed fish, and the potential for health risks from such exposure would exist in the future. Thus, a corrective measure(s) is necessary to address this area.

Finding: The PSLE considered the potential for risk to ecological receptors from exposure to constituents in surface water and sediment of the unlined portions of Kilby Ditch and the Low-lying Areas. Maximum detected concentrations from the two most recent years' worth of surface water data from the three compliance points in Main Kilby Ditch and the 16 locations in the Low-lying Areas were compared to the USEPA Region 4 and USEPA Region 5 Ecological Screening Levels (ESLs), where applicable. Surface water data from the two monitoring points in West Kilby Ditch were not included, since that portion of the ditch is periodically maintained by removing accumulated sediment and pioneer plant species and is not conducive to the development of ecological habitat. Maximum detected concentrations from the two most recent years' worth of sediment data from the Low-lying Areas were compared to the USEPA Region 5 ESLs. As shown in Tables 2 and 3, respectively, in the January 3, 2007 letter (provided in Appendix B), none of the maximum detected surface water or sediment concentrations was greater than the corresponding ESLs, indicating that, currently, ecological risks are unlikely.

Based on the results of the baseline simulation presented in Section 3.3.2 and noted above, the potential for risks to ecological receptors in Kilby Ditch and the Low-lying Areas would exist in the future. Thus, a corrective measure(s) is necessary to address this area.

4.2.3.2 Southwest Sand and Gravel Mines

Currently, the CBP has not reached the active sand and gravel mines in the Southwestern Area. However, under the baseline simulation presented in Section 3.3.2, the leading edge of the TCE plume is predicted to reach the sand and gravel mines in less than 5 years and the southwestern part of the plume is predicted to be captured by the sand and gravel mines between 2026 and 2036. While there currently is no exposure pathway at the southwest sand and gravel mines, such a pathway could develop for receptors (e.g., commercial workers or trespassers) when the leading edge of the TCE plume reaches the sand and gravel mines. At that time, a potential human exposure pathway could include dermal contact with surface water dissolved constituents.

Finding: The effects of pumping required for sand and gravel mine dewatering were used to predict concentrations of TCE in the surface water. These concentrations are not predicted to exceed 0.005 mg/L, and since they are well below the PSV developed for trespasser exposure to TCE in surface water from dermal contact only, human health risks from this exposure pathway in the future are unlikely.

General response actions (GRAs) are those remedial actions that may satisfy the CM objectives of the study as discussed in Section 1. GRAs have been identified as technologies that may be appropriate for the CBP site. In this section, the GRAs are described and generally evaluated for the CBP Site. Based on the GRA evaluation presented herein, GRAs are retained or not retained for further consideration. Technology types include categories such as treatment or containment, whereas process options are specific processes within technology types (e.g., treatment - oxidation, or containment – treatment barrier).

This section develops a list of potential technology types and process options for treatment or containment of groundwater and surface water potentially affected by TCE. The retained technologies and process options are subsequently used to develop Corrective Measures Alternatives discussed in Section 6 of this report.

General response actions and identified technologies for the CBP Site are:

- **No Further Action**
- **Monitored Natural Attenuation**
- **Institutional Controls**
- **Hydraulic Control**
- **Permeable Reactive Barriers**
- ***In-situ* Chemical Oxidation**
- **Enhanced Bioremediation**
- **Constructed Wetlands**
- **Covering Portions of Kilby Ditch and Channel Stabilization**

A description of these corrective action technologies is provided below.

5.1 NO ACTION

The "no action" option, by definition, involves no further institutional controls or remedial action at the CBP Site, and, therefore, has no technological barriers. The no action option differs from Monitored Natural Attenuation (MNA – see below) in that the no-action option does not include groundwater monitoring for parameters to evaluate the effects of natural attenuation. However, groundwater elevations, flow direction(s) and TCE concentrations would be evaluated as part of the no action options to evaluate movement of the TCE plume over time. The no-action option is retained for further consideration as a comparison baseline.

5.2 MONITORED NATURAL ATTENUATION

MNA is a remedial approach where contaminants degrade without enhancement to concentrations acceptable to a regulatory agency. Natural attenuation processes such as biodegradation, hydrolysis, dispersion, dilution, sorption, and volatilization affect the fate and transport of organic contaminants in all hydrologic systems. The degree to which VOCs can biodegrade or otherwise attenuate under natural conditions can be evaluated by measuring the concentrations of several natural attenuation parameters and potential microbial energy sources and nutrients in the groundwater. Natural attenuation parameters include dissolved oxygen (DO), oxidation/reduction potential (ORP), chloride, nitrite, nitrate, sulfate, ferrous iron, alkalinity, dissolved sulfide, dissolved organic carbon, carbon dioxide, dissolved hydrogen, methane, ethane, and ethene.

A MNA sampling program could be initiated to evaluate the effectiveness of natural attenuation at reducing the concentrations of VOCs in the CBP Site groundwater. The CBP Site would be monitored by sampling groundwater for natural attenuation parameters to assess the progress of natural processes (i.e., dispersion, dilution, and chemical transformation).

A monitoring program would be designed to evaluate if incomplete degradation of TCE is occurring at the CBP Site during the degradation process. Byproducts such as cis-1,2-DCE and VC could be produced which would require additional efforts to either control their migration or to complete the biodegradation process to inert end products. The complete degradation of chlorinated VOCs, such as TCE to ethane under anaerobic conditions has been shown to occur where the microorganism *dehalococcoides ethanogenes* (DHE) is present. Groundwater sampling at the CBP Site has not shown the presence of this key organism. Recent samples, however, have shown an increase in cis-1, 2-DCE and VC in the CMT wells. Subsequent sampling of the CMT wells did indicate the presence of DHE.

The most important process for the natural biodegradation of chlorinated compounds such as TCE is reductive dechlorination. Under anaerobic conditions, reductive dechlorination results in the sequential removal of chlorine atoms from TCE to DCE, to VC (Morrison, 2000). Depending upon the geochemical conditions and the presence of any specific microorganisms responsible for degradation, the process may proceed to completely dechlorinated compounds or terminate after removal of only some of the chlorine atoms. Some partially dechlorinated compounds (i.e., DCE and VC) may be degraded under aerobic or iron-reducing conditions. Under the influence of biodegradation, cis-1,2-DCE is a more common intermediate than trans-1,2-DCE. The least prevalent of the three DCE isomers is 1,1-DCE. The reductive dechlorination process, in which the chlorinated compounds serve as electron acceptors, requires the presence of electron donors.

Reductive dechlorination has been demonstrated under nitrate- and iron-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of chlorinated compounds, occur under sulfate-reducing and methanogenic conditions. An energy source (i.e., an electron donor) is needed for microbial growth to occur under these conditions.

Because significant natural attenuation of the chlorinated VOCs in the groundwater is not occurring via biological processes, at a significant rate, as shown by the relative absence of degradation products, MNA, by itself, will not be considered further in the development of the corrective measures alternatives for the CBP Site. However, the abiotic (without biological action) physical processes of natural attenuation (i.e., dispersion, sorption, and dilution) will have beneficial effects on all alternatives considered for the CBP Site.

5.3 INSTITUTIONAL CONTROLS

"Institutional Controls", as defined by the USEPA, are administrative and/or legal controls that minimize the potential for human exposure to contamination by limiting land or resource use. Institutional controls may consist of legal and/or administrative restrictions on the use of a particular property or group of properties that protect the property users from exposure to environmental contaminants. Examples of these restrictions include prohibitions on the use of groundwater, establishment of areas where excavations are prohibited without prior notification, or restrictions on land use.

Institutional Controls are effective at limiting or preventing exposure to contaminants in groundwater or surface water at the CBP site. Therefore, Institutional Controls will be necessary as part of any remedial alternative proposed for the CBP Site.

5.4 HYDRAULIC CONTROL

Hydraulic control is used to intercept, capture, or control groundwater flow. Hydraulic control as a remedial technology involves the use of dewatering systems (i.e., wells, pumps, excavation dewatering) to affect the movement of ground water. A hydraulic-control system is capable of accomplishing a remedial objective of plume containment within a controlled boundary and minimizing exposure at the extraction point. The cost-effectiveness of a groundwater pumping system typically decreases as the concentration of the contaminant in the groundwater decreases. The installation of hydraulic control systems can be disruptive in developed or residential areas. Hydraulic control systems require frequent and long-term maintenance.

Hydraulic control via pumping may require treatment, disposal, and/or discharge of the extracted groundwater. Groundwater extracted from within the plume or that contains concentrations above accepted levels could be treated and then discharged to a surface water body or re-injected below the land surface to control groundwater flow. Re-injected groundwater can be modified to contain chemical oxidants and/or other amendments.

Hydraulic control and treatment systems have been shown to be minimally effective at reducing widespread groundwater contamination to default regulatory standards. Large areas of groundwater contamination can be controlled by using pumping wells to control groundwater flow and slow the spread of contamination.

Using hydraulic control to manage groundwater flow and control plume migration toward the southwest is an effective option in the Southwestern Area to control the TCE plume migration. Dewatering at the southwest sand and gravel mine is expected to continue during the 30-year evaluation period, which results in an existing and projected hydraulic control option for the Southwestern Area of the CBP. Hydraulic control in the Southwestern Area could be continued if, for any reason, sand and gravel mining ceases sooner than anticipated. Hydraulic control could be achieved through extraction wells in the southwest portion of the CBP Site to limit plume migration to the southwest. Therefore, hydraulic control to manage the plume migration of the CBP toward the southwest is retained as an alternative for the Southwestern Area.

Based on contaminant fate and transport simulations, the concentrations of TCE in surface water in the southwest sand and gravel mine are not expected to exceed 0.005 mg/L during the 30-year evaluation period. Therefore, *ex-situ* treatment of extracted water is not likely to be required. If groundwater wells are installed to continue hydraulic control in the southwest area, groundwater may need to be treated based on the proximity of the well(s) locations to the edge of the TCE plume. Descriptions of treatment options for extracted groundwater containing concentrations above accepted levels are provided in Sections 5.4.1 through 5.4.3.

5.4.1 ADVANCED OXIDATION PROCESSES

Advanced oxidation processes are similar to *in-situ* chemical oxidation in that oxidants are used to degrade contaminants to carbon dioxide, water, and simple organic and inorganic compounds. The process typically uses ozone, hydrogen peroxide, and ultraviolet light (UV) in some combination to form hydroxyl radicals. Hydroxyl radicals have the highest oxidation potential and readily breakdown contaminants such as TCE.

Advanced oxidation processes are available in many forms. The most widely used products are systems using hydrogen peroxide/UV, ozone/UV, and hydrogen peroxide/ozone. For evaluation purposes, the hydrogen peroxide/ozone system has been selected. This system is effective in treating VOCs and is not significantly affected by turbidity as are processes using UV due to the need to keep UV lamps clean. Ozone is readily mixed with groundwater in the controlled environment of the treatment piping.

5.4.2 AIR STRIPPING

Air stripping involves the mass transfer of VOCs from water to air. In the air stripping process, VOCs are partitioned from extracted groundwater by increasing the surface area of the water containing TCE exposed to air.

Aeration methods typically include packed towers, diffused aeration, tray aeration, and venturi aeration. For groundwater remediation, the most widely used process typically involves use of a packed tower or tray aeration. The typical packed tower air stripper includes a spray nozzle at the top of the tower to distribute water containing VOCs over the packing in the column, a fan to force air countercurrent to the water flow, and a sump at the bottom of the tower to collect treated water. Packed tower air strippers can be installed as either permanent structures on concrete pads or as temporary structures on a skid or trailer, mainly depending on the volume of water treated. Low-profile air strippers, or tray aerators, include a number of trays in a very small chamber to maximize air-water contact. These systems are easier to install and operate than other air strippers, but have a somewhat larger footprint. A venturi air stripper uses highly turbulent jets of water to shear and accelerate fluid films within an open bore. They typically generate a low off-gas volume, but also have higher operating costs due to higher energy demands. Air strippers commonly use vapor-phase activated carbon systems to capture VOCs in off-gases, especially in early stages of remediation when VOC concentrations are higher.

5.4.3 CARBON ADSORPTION

Liquid phase carbon adsorption typically involves pumping groundwater through one or more vessels in series containing activated carbon to which dissolved TCE adsorbs. When the concentration of contaminants in the effluent from the treatment vessel exceeds a certain level, the carbon is typically removed and regenerated off site or disposed. The most common reactor configuration for carbon adsorption systems involving groundwater is the fixed bed approach with two vessels in series. The fixed-bed configuration is the most widely used for adsorption from liquids. The duration of operation and maintenance (O&M) is dependent upon the contaminant type, concentration, mass treated, other organics or metals that occupy adsorption sites, and the clean-up requirements.

5.5 PERMEABLE REACTIVE BARRIERS

Permeable Reactive Barriers (PRBs) are vertical zones of materials that are installed to intercept groundwater flow. As groundwater flows through the permeable zone, interactions with the materials reduce the concentrations of groundwater contaminants. PRBs for groundwater that contains VOCs are commonly constructed with zero-valent iron.

Such PRBs can be constructed as a wall beneath the ground surface either by open trenching or with minimal disturbance to above-ground structures and property using trenchless injection technology. The PRB material is more permeable than the surrounding soil matrix so groundwater readily flows through the PRB and VOCs are treated as they flow through the iron. PRBs are proven to be effective for treating groundwater containing TCE and related compounds, which are reduced to non-toxic components.

PRBs are installed in or down gradient of a contaminant plume. The contaminants in the plume are broken down into nontoxic by-products or immobilized by precipitation or sorption after reacting with the media inside the PRB. PRB systems have been used successfully to treat chlorinated organic compounds at numerous full-scale applications. The design concept for the use of a PRB to degrade TCE in groundwater is relatively simple. A trench is excavated across the path of a migrating VOC plume and filled with the appropriate reactive material (such as a mixture of sand and iron particles), or the reactive material is injected into the ground using direct push technology or injection wells. As the groundwater containing TCE flows through the reactive material, a number of reactions occur that indirectly or directly lead to the reduction of the chlorinated solvents. One mechanism is the reaction of iron filings with oxygen and water, which produces hydroxyl radicals. The hydroxyl radicals in turn oxidize the contaminants.

The use of reactive iron to treat chlorinated VOCs has been well documented. This technology utilizes zero-valent iron particles, typically in granular (macro-scale) form, to completely degrade chlorinated VOCs via abiotic reductive dehalogenation. As the iron is oxidized, a chlorine atom is removed from the compound using electrons supplied by the oxidation of iron. During this process, the chloride in the compound is replaced by hydrogen, resulting in the complete transformation of chlorinated VOCs to non-toxic byproducts (ethene, ethane, and chloride ions). Since degradation rates using the process are several orders of magnitude greater than under natural conditions, any intermediate degradation byproducts formed during treatment (e.g., VC) are also reduced to non-toxic byproducts in the treatment zone. The use of reactive iron to treat chlorinated VOCs is covered under several patents, depending on the application method.

A PRB is a passive remedial technology that requires no pumping, although the rate of groundwater treatment could be accelerated by groundwater withdrawal or injection in the vicinity of the PRB. A groundwater monitoring system would be put in place to monitor the effectiveness of a PRB over the long term.

The hydraulic gradient within some areas of the CBP Site is relatively low. As such, groundwater would slowly flow through the PRB unless a hydraulic gradient is induced via groundwater withdrawal or injection. This may include targeted pumping and, potentially, recirculation of groundwater in the aquifer. Combining these two technologies capitalizes on the benefits of each, controlling a large volume of contaminated groundwater while treating the groundwater *in-situ*, reducing the effort and cost of O&M. It would also decrease the amount of time necessary compared to passive remediation.

PRB longevity is dependent on contaminant concentration, groundwater flow velocity, and the geochemical makeup of the groundwater. The oldest full-scale PRB was installed in February 1995 at a site in Sunnyvale, California. This PRB has successfully reduced the concentrations of TCE, DCE, VC, and Freon throughout its 12 years of operation (ETI, 2006). Since the age of the oldest PRB is only 12 years, bench scale studies using reactive iron columns (from both cores obtained from emplaced reactive walls and from virgin reactive iron) have been conducted to evaluate long-term PRB longevity. These tests have shown that, although the reactivity of the iron declines with long-term exposure to groundwater, conditions promoting the dehalogenation of chlorinated solvents are maintained over the long term. Based on these studies, the expected life of a typical reactive wall (where life is defined as the period over which the reactivity of the iron declines by a factor of two) is approximately 30 years (ESTCP, 2003). However, these studies also indicated that groundwater geochemistry, specifically the concentration and resulting flux of natural organic matter (NOM), total dissolved solids (TDS), and carbonate, along with the distribution of VOC concentrations, greatly influences the lifetime of the reactive iron and should be considered in the PRB design process (Klausen et al., 2003).

Minimal disturbance to above-ground structures and property can be achieved with trenchless technology. However, a limitation to PRBs installed via the trenchless technology is that it may be difficult to configure the depth of the PRB to the top of the first distinct clay. As discussed in Section 2, the top of the first distinct clay layer beneath the CBP Site that underlies the upper saturated zone (in which TCE-containing groundwater is present) is undulating. The depth of a PRB can vary along the length of the PRB. However, to minimize the potential of breaching the first distinct clay layer, a PRB installed in an area where the depth to the first distinct clay varies would likely be designed so as to not penetrate the clay layer. Therefore in some areas there could be zones below the PRB's base and above the first distinct clay where groundwater would not be fully treated by the PRB.

PRBs can also be installed through open trenching. Open-trench installation of PRBs is generally limited to shallower depths, approximately less than 30 feet BLS. Open-trench installations at shallow depths are likely to be more cost effective than trenchless technology.

PRBs are retained for evaluation as part of selected corrective measures alternatives for the site-wide management strategy.

5.6 *IN-SITU* CHEMICAL OXIDATION

In-situ chemical oxidation (ISCO) has been used since the early 1990s to treat environmental contaminants in groundwater, soil, and sediment. Many of these projects have focused on the treatment of chlorinated solvents and petroleum compounds, although several projects have also used the process to treat semi-volatile organic compounds such as pesticides and polycyclic aromatic hydrocarbons (USEPA, 1998). Many projects utilizing ISCO have focused on the treatment of chlorinated VOCs (i.e., TCE and PCE) and gasoline constituents (i.e., benzene, toluene, ethylbenzene, and xylene (BTEX) (Siegrist, 2001).

ISCO is defined as the delivery and distribution of oxidants and other amendments into the subsurface to transform contaminants into innocuous end products such as carbon dioxide, water, and inorganic compounds. A chemical oxidant is injected through wells screened in areas where a reduction in groundwater concentrations is desired. Injection locations can be either permanently installed wells or temporary injection points installed using direct-push methods. When oxidants come in contact with chlorinated compounds these compounds are broken down into non-toxic components. However, contact between the oxidant and contaminant is the most important technical aspect of this technology, as it can be difficult to accomplish.

Accordingly, this remedial approach generally includes several injections over time accompanied by groundwater monitoring. Thousands of injection wells may be required to treat the entire contaminant plume. Most of these injection wells may need to be installed on residential properties. Site limitations can potentially require an injection spacing interval (estimated at 20 feet), which, due to the proximity of residences and utilities in the area, is impractical. More than one application is generally needed, depending on the final contaminant concentration desired, therefore the overall costs are medium to high relative to other technologies. Since the reaction with the contaminant and the chemical oxidant generally occurs over a relatively short period, treatment can be more rapid than other *in-situ* technologies. The technology does not generate large volumes of waste material that must be disposed and/or treated.

ISCO generally provides the greatest benefit for localized source areas since it is capable of treating very high concentrations of contaminants by adding more oxidants. ISCO typically becomes prohibitively expensive for large areas requiring treatment to low concentration endpoints.

The most common oxidants utilized for ISCO are hydrogen peroxide with an iron salt (Fenton's reagent), potassium and sodium permanganate, and sodium persulfate. A general summary of each of these oxidants is presented below.

5.6.1 FENTON'S REAGENT (HYDROGEN PEROXIDE)

Hydrogen peroxide-based *in-situ* chemical oxidation is driven by the formation of a hydroxyl free radical in the presence of a metal catalyst. This reaction, known as the Haber-Weiss mechanism, was first utilized for the treatment of organic compounds in wastewater in the 1890s by H.J.H Fenton using an iron catalyst (Fenton's reagent). The hydroxyl free radical is a powerful oxidizer of organic compounds, thus many organic compounds in the subsurface that contact the chemical oxidant are readily degraded to innocuous compounds (e.g., water and carbon dioxide). Any residual hydrogen peroxide remaining after the reaction has been completed decomposes to water and oxygen. Soluble iron (ferrous iron), the transition metal catalyst, added to the subsurface during injection of the oxidant mixture is precipitated out of solution during conversion to ferric iron.

Typical hydrogen peroxide concentrations utilized for treatment with Fenton's reagent range from five to 50 percent by weight, however, concentrations less than 15 percent are utilized at a majority of sites. The hydrogen peroxide concentration used in the injection fluid is based on contaminant concentrations, subsurface characteristics, and treatment volume. Acids are also typically added to the injection solution to lower the pH of the contaminated zone if the natural pH is not low enough to promote the Fenton's reaction.

5.6.2 SODIUM AND POTASSIUM PERMANGANATE

Permanganate is an oxidizing agent with a unique affinity for oxidizing organic compounds with carbon-carbon double bonds (e.g., TCE and PCE), aldehyde groups or hydroxyl groups. There are two forms of permanganate that are used for ISCO, potassium permanganate ($KMnO_4$) and sodium permanganate ($NaMnO_4$). Potassium permanganate has been used in drinking water and wastewater treatment for several decades to oxidize raw water contaminants, typically for odor control. Potassium permanganate is available as a dry crystalline material, while sodium permanganate is a liquid. Permanganate turns bright purple when dissolved in water; this purple color acts as a built-in indicator for unreacted chemical. Reacted permanganate is black or brown, indicating the presence of a manganese dioxide (MnO_2) byproduct.

Sodium permanganate has a much higher solubility in water than potassium permanganate, allowing it to be used for ISCO at higher concentrations, compared to two to five percent for potassium permanganate. Since it is supplied in liquid form, the use of sodium permanganate commonly requires no on-site mixing. Sodium permanganate can also be used at sites where the potassium ion cannot be tolerated (i.e., sites where the potassium ions may interfere with background radiation monitoring).

5.6.3 SODIUM PERSULFATE

Sodium persulfate is a strong oxidant that derives its oxidizing potential through the persulfate anion ($S_2O_8^{2-}$). The persulfate anion is capable of oxidizing a wide range of contaminants, including chlorinated ethenes, BTEX, phenols, MTBE, and some PAHs. However, when catalyzed in the presence of heat (thermal catalyzation) or transition metals ions (i.e., ferrous iron), the persulfate ion is converted to the sulfate free radical (SO_4^{2-}•), which is second only to Fenton's reagent in oxidizing potential. Sodium persulfate is supplied in an aqueous solution at concentrations up to 50 percent by weight. The use of sodium persulfate for the treatment of chlorinated VOCs is a relatively new process in the marketplace.

Advantages of ISCO typically include:

- relatively short remediation times in areas where groundwater flow does not introduce additional contaminants with time (typically one to two years)
- limited long-term O&M costs in such settings; and
- the breakdown of VOCs without the generation of potentially more toxic degradation products (although not all VOC mass may break down).

Disadvantages of ISCO include:

- its application to areas with only the highest contaminant concentrations is typically most cost effective;
- the need to inject large volumes of oxidant (especially in areas where groundwater flow introduces additional contaminants over a long period of time from upgradient directions);
- potential disruption to area residents;
- the need for multiple injections;
- the difficulty of contacting oxidants with groundwater contaminants intended for destruction when injecting into low permeability formations;
- health and safety issues associated with the handling and injection of oxidants and reagents; and
- relatively high costs per volume treated.

In-situ chemical oxidation is not retained for evaluation as part of potential corrective measures alternatives for the site-wide management strategy for the following reasons:

- Excessive volume of oxidant needed to treat the groundwater in the CBP
- Number and spacing of injection points
- Necessity to reapply oxidants to ensure complete reaction
- Subsurface heterogeneities that require oxidant injections at multiple depths
- Disruption to the community; and,
- The large number of inaccessible areas
-

However, in-situ chemical oxidation will be reevaluated at the 5-year review to determine if this technology is appropriate based on site conditions.

5.7 ENHANCED BIOREMEDIATION

Naturally occurring microorganisms in the subsurface can break down (biodegrade) organic compounds in the soil and groundwater. The rate of this degradation depends on the species of microorganisms, environmental conditions, and the available nutrients. Biodegradation can be enhanced or augmented by injecting nutrients and/or microorganisms that specifically degrade TCE and/or its breakdown products. Anaerobic conditions are necessary for such microorganisms to flourish. However, the majority of the CBP has aerobic conditions.

Common injectable nutrients are molasses, lactase, Hydrogen Release Compound (HRC®), food-grade oil-based mixtures, and alcohols. The use of certain of these amendments for groundwater treatment is patented. Microorganisms (for example, KB-1® and other variants of *Dehalococcoides* organisms) are sometimes added with the nutrients if indigenous microorganisms are not present in sufficient quantities. *Dehalococcoides* are the only known microorganisms shown to convert chlorinated VOCs to non-toxic ethene.

Enhancement and augmentation by injecting nutrients and/or microorganisms presents many of the same challenges as *in-situ* chemical oxidation. Because natural biodegradation of TCE is not occurring and the aquifer is aerobic, creating and maintaining suitable conditions for growth of microbes typically requires multiple injections. Similar to ISCO, this remedial approach generally includes several injections over time at multiple locations accompanied by groundwater monitoring. As with ISCO, close spacing of injection points is necessary. The distribution of amendments in the saturated zone could be enhanced through the use of injection and extraction wells. Injections can be conducted through either permanent wells or temporary injection points installed using direct-push methods.

Enhanced biodegradation does not always result in a complete breakdown of chlorinated compounds. Breakdown products generated during biodegradation can include compounds that are more toxic and more mobile than the parent compound (e.g., vinyl chloride, a known human carcinogen). Therefore, additional measures would need to be implemented to ensure complete breakdown of TCE in the groundwater. Control of potential soil vapors may require the installation and operation of a soil vapor extraction system.

The general advantages of enhanced bioremediation typically include:

- Limited O&M costs; and,
- The use of non-toxic, non-hazardous materials.

The disadvantages of enhanced bioremediation typically include:

- Continued disruptions to residents during injections;
- Injecting relatively large volumes of nutrients and/or microbes;
- Continuous or repetitive injections of nutrients and/or microbes;
- Difficulty injecting into low permeability formations;
- Incomplete degradation of chlorinated VOCs and the production of toxic and mobile degradation compounds in groundwater or soil vapor;
- Potential need to inject microorganisms that can degrade chlorinated VOCs (i.e., *Dehalococcoides* organisms); and,
- Injecting nutrients/microbes in a tight pattern (e.g. 15-20 foot spacing) that disrupts property usage and neighborhood traffic.

Enhanced biodegradation is not retained for evaluation as part of potential corrective measures alternatives for the site-wide management strategy for the following reasons:

- Excessive volume of amendments needed to treat portions of the CBP;

- Number of injection points and duration of each injection event;

- Necessity to reapply nutrients to maintain anaerobic and growth stimulating conditions within the aquifer;
    - Enhanced bioremediation of TCE in groundwater requires anaerobic conditions. The CBP covers approximately 770 acres of the shallow (water table) aquifer system, which is naturally aerobic and is constantly being replenished with oxygen-rich recharge.
- Subsurface heterogeneities that require amendment injections at multiple depths;
- Disruption to the community; and
- Inaccessible areas.

However, in-situ biodegradation will be reevaluated at the 5-year review to determine if this technology is appropriate based on site conditions.

5.8 CONSTRUCTED WETLANDS/WETLAND TREATMENT SYSTEM

Because of their contaminant removal capabilities, natural wetlands have been used to treat water for at least 100 years in some locations. Studies have showed significant pollutant reduction in these systems (Kadlec and Knight, 1996; Barr Engineering, 2005 and 2006; Lorah et al, 1997; Smith, 2006; ITRC, 2003; Opperman, 2002).

Constructed wetlands improve water quality through numerous and often interrelated mechanisms, including:

- Adsorption and ion exchange on the surfaces of plants, substrate, sediment, and litter
- Aerobic and anaerobic breakdown processes
- Breakdown and transformation of pollutants by microorganisms and plants
- Chemical transformation
- Filtration and chemical precipitation through contact of the water with the substrate and litter
- Settling of suspended particulate matter

- Uptake and transformation of nutrients by microorganisms (bioremediation) and plants (phytoremediation)
- Volatilization

These mechanisms have been shown to reduce many families of contaminants, including: VOCs, TSS, hydrocarbons, nitrogenous compounds, phosphoric compounds, metals and pathogens (ITRC, 2003). The reducing conditions found in wetland sediments combined with the chemical breakdown and uptake abilities of plants are two major benefits of using wetlands to attenuate and reduce TCE concentrations.

Constructed wetlands can use various types of plants and abiotic processes to remove, transfer, stabilize, and/or destroy contaminants in the soil, surface water, and groundwater. For instance, wetland systems, if irrigated by surface water or upflowing groundwater, may remove organic substances, nutrients, and pathogens from the water. This removal is accomplished by diverse mechanisms: sedimentation, filtration, chemical precipitation and adsorption, microbial biofilm interactions, and uptake by vegetation. Both natural and constructed wetlands have been used for waste water treatment, water purification, and nutrient removal. The advantage of phytoremediation through the use of wetland systems is the presence of reducing conditions in wetland sediments as well as the realized effects of plants listed above. As discussed in Section 5.2, reductive dechlorination has been demonstrated under nitrate- and iron-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of chlorinated compounds, occur under sulfate-reducing and methanogenic conditions which can occur in wetlands.

Constructed wetlands can be designed as highly engineered systems or natural systems. The engineered systems typically include impermeable multi-cell wetlands with hydraulic features to evenly distribute flow and control the discharge. These systems require significant maintenance. A natural constructed wetland does not have an impermeable liner, which allows groundwater to enter the system. A natural constructed wetland considered for this project would be constructed in the appropriate landscape position to capture as much of the discharged groundwater as feasible. Sizing of the wetland would be based on water budgets and would account for direct precipitation, stormwater runoff, and evapotranspiration (water loss through plant respiration). Flow through the system would be controlled by earthen berms of varying heights and positioned to create a long flow path to impede hydraulic short-circuiting and increase retention time.

Geochemically, the greater concentrations of carbon and other potential terminal electron receptors (e.g., sulfur salts) at the groundwater/wetland interface increases the VOC removal capabilities of wetlands (Mitsch and Gosselink, 1993). Based on numerous studies on various families of contaminants, constructed wetlands can remove up to 90 percent of the VOCs from groundwater entering the system. Lorah and Olsen (1999) examined the natural attenuation of TCE and 1,1,2,2-tetrachloroethane (PCA) in a contaminant plume discharging from an aerobic aquifer through wetland sediments and showed that both contaminants were completely mineralized as a result of reductive dechlorination. TCE in groundwater has been observed to biodegrade in sediments from a site in Dallas, Texas (Bradley and Chapelle, 1997). Dechlorination of other VOCs has also been observed in a Jacksonville, Florida stream (Bradley and Chapelle, 1997).

A constructed wetlands system could include the use of plants suited to conditions at the CBP Site to degrade and/or remove the chlorinated VOCs. Vegetation may not need to be imported into the constructed wetland; native vegetation may be sufficient. Previously existing wetlands could be altered into constructed wetlands or enhanced to provide the desired treatment design.

To be effective, constructed wetlands must be properly designed, constructed, operated, and maintained. Once completed, a constructed wetland system requires regular monitoring to ensure proper operation. As with any remedial technology these systems may require enhancements or modifications in addition to routine management to maintain optimum performance.

Constructed wetlands are retained for evaluation as part of selected corrective measures alternatives for the site-wide management strategy.

5.9 PHYSICAL BARRIERS (COVERING KILBY DITCH AND CHANNEL STABILIZATION)

Physical barriers are used to prevent contact with contaminated, or potentially contaminated, media. Such barriers include engineered cap systems, covered or buried piping or channels, and security fencing. At the CBP Site, a physical barrier would be used to prevent contact with dissolved chlorinated VOCs that result from groundwater discharge into Kilby Ditch. This barrier would include the conversion of portions of Kilby Ditch from an open channel to a covered culvert system. This culvert system would be designed to accommodate the flows in the Kilby Ditch Area that result from both groundwater discharge and precipitation runoff.

In addition to the installation of a culvert system, modifications to the channel, including grading the channel sides and installing rip-rap could also be made. Sufficient rip-rap could be placed in the bottom of the channel to reduce direct access to the base surface water elevation. This would decrease the potential for direct contact with TCE in the surface water. The rip-rap installation would include installation of a geo-fabric to support the rip-rap. Vegetation would be planted over the geo-fabric to aid in erosion control on channel side slopes.

Physical barriers such as security fencing can be used to restrict access. Fencing is commonly coupled with warning notices and periodic inspection and repair to maximize the effectiveness of this physical barrier. The visual impact of fencing is commonly mitigated by landscape plantings adjacent to the fencing.

Physical barriers are retained for evaluation as part of selected corrective measures alternatives for the site-wide management strategy.

6.1 INTRODUCTION

In this section, corrective measures technologies retained in Section 5, are identified for each area of the CBP for which a potentially complete exposure pathway was identified (Kilby Ditch Area, Low-lying Areas, and Southwestern Area). As described in Section 1, the corrective measures objective is to restrict potential exposure pathways to TCE at the CBP and capture and treat, if necessary, surface water prior to discharge at the endpoints. Corrective measures alternatives were developed by combining technologies that were selected for each area of the CBP.

The results of the baseline simulation discussed in Section 3 predict that the southwestern part of the CBP will continue to move toward the active sand and gravel mining operation located to the southwest. The northeastern part of the plume will continue to slowly move to the north and northeast in the direction of the Low-lying Areas and Three Mile Branch. As a result, monitoring of the CBP expansion in these areas will be included as a component of any corrective measure alternative selected for the CBP. Based on the groundwater model, the spread or increased area of TCE concentrations of 0.001 mg/L is estimated to be 121 parcels (approximately 600 feet to the northeast and 800 feet to the southwest) by the year 2036 compared to the dewatering sand and gravel mine scenario for the same period. Dewatering at the sand and gravel mines will continue for an estimated 30 years and control the migration and spread of TCE. As discussed in Section 3, the effects of dewatering the sand and gravel mines were used to predict concentrations of TCE in the surface water that will discharge from the mines. These surface water concentrations are not predicted to exceed 0.005 mg/L.

6.2 PH12 AREA

In the September 2005 *Probehole 12 Area Status Report in Support of Corrective Measures Development*, ALDOT identified and evaluated potential corrective measures for the PH12 Area of the CBP. These measures included groundwater pumping with ex-situ treatment, PRBs, in-situ chemical oxidation, and enhanced bioremediation. Based on the September 2005 report, an exposure pathway does not exist in the PH12 Area and the corrective measures evaluated for the PH12 Area will not remove the need for or in any other way affect the proposed corrective measures in the distal areas of the plume where there are potential exposure pathways. During this Site-wide Corrective

Measures evaluation, the conclusions of the 2005 report were reaffirmed and, consequently, specific actions to reduce TCE concentrations in the PH12 Area are not included in the corrective measures alternatives proposed for the site-wide CBP. However, monitoring of the PH12 Area will continue as part of the Long Term Monitoring Program and, if site conditions change that could create a potential exposure pathway, an alternative corrective measure will be developed.

6.3 KILBY DITCH

6.3.1 OBJECTIVE

Groundwater containing dissolved TCE has migrated over time toward Kilby Ditch, where it eventually discharges to the surface water in this area. The significant distinction between the PH12 Area and Kilby Ditch Area is that no groundwater exposure pathways are present at the PH12 Area, whereas there are potentially complete surface water and sediment exposure pathways within Kilby Ditch (see Section 4). To minimize potential exposure, GRAs from Section 5 were evaluated for their ability to restrict access to surface water and sediment in Kilby Ditch and treat surface water containing TCE so that discharge will not exceed the ADEM action level of 0.175 mg/L of TCE in surface water.

Applicable fate and transport model simulations for the potential corrective measures technologies were compared against the baseline simulation (as discussed in Section 3) to evaluate corrective measures alternatives to reduce and/or control the exposure to TCE in the Kilby Ditch Area. The resultant corrective measures alternatives simulated for the Kilby Ditch Area are discussed in this Section. The results of contaminant fate and transport model simulations for a 30 year duration are illustrated on Figures 3-2 through 3-6.

6.3.2 POTENTIAL CORRECTIVE MEASURES TECHNOLOGIES

Potential corrective measures for the Kilby Ditch Area include:

- A PRB using zero-valent iron to degrade chlorinated VOCs through abiotic reductive dechlorination
- Covering portions of Kilby Ditch to minimize access to TCE in surface water
- Stabilizing the northern section of the Kilby Ditch channel
- Restrict access to surface water and sediment using security fencing

6.3.2.1 Permeable Reactive Barriers

PRBs were evaluated to determine their effectiveness in reducing TCE concentrations in groundwater upgradient of Kilby Ditch and thereby minimizing the potential for surface water TCE concentrations in the ditch to exceed the ADEM-specified action level of 0.175 mg/L of TCE in surface water. A PRB was simulated west of Kilby Ditch, in the right-of-way of Coliseum Boulevard (Figure 6-1), and on the open, vacant property south of West Kilby Ditch (Figure 6-2). The PRBs were simulated under passive groundwater flow conditions.

The lengths and locations of the PRBs in both scenarios were developed using the contaminant fate and transport model simulation developed in MT3DMS for the CBP (as discussed in Section 3). The PRBs were placed to intersect TCE concentrations of approximately 0.3 mg/L or greater within the part of the CBP that is migrating toward Kilby Ditch. A first-order reaction rate with a high reaction rate constant was used to simulate TCE decay as the TCE plume moved through the PRB.

Coliseum Boulevard Right of Way

An approximately 1500-foot long PRB was simulated along Coliseum Boulevard in the contaminant fate and transport model (Section 3) to evaluate the overall effectiveness of a PRB. The simulated PRB would extend northward along the east side of Coliseum Boulevard from the intersection of Coliseum Boulevard and Gardendale Drive (Figure 6-1). TCE concentrations east of the PRB would not be treated because of the eastward groundwater flow. However, the concentrations of TCE in groundwater west of the PRB, exceeding 1 mg/L, would be reduced prior to discharging to the Kilby Ditch Area (see Figures B-1 to B-4, Appendix B).

PRB South of West Kilby Ditch

An approximately 1000-foot long PRB was simulated along the southern edge of West Kilby ditch in the contaminant fate and transport model (Section 3). The PRB would extend along West Kilby Ditch for approximately 350 feet and then angle southerly toward Main Kilby Ditch for approximately 650 feet (Figure 6-2). Based on the results of the model simulations, this PRB would limit TCE concentrations in the groundwater that discharges to West and Main Kilby Ditches to less than 0.175 mg/L during the 30-year evaluation period (see Figures B-5 to B-8, Appendix B).

6.3.2.2 Covering West Kilby Ditch

As shown on Figure 1-1, West Kilby Ditch discharges to Main Kilby Ditch on the east side of Coliseum Boulevard. Based on the results of surface water monitoring in West Kilby Ditch, an interim corrective measure (ICM) was completed for West Kilby Ditch Area in 2003. The ICM included sealing manholes and pipe joints to prevent and/or minimize the inflow of shallow groundwater into the underground storm drains. These measures have reduced the TCE infiltration from the shallow groundwater table into the storm culvert that discharges into West Kilby Ditch. However, groundwater with higher TCE concentrations continues to flow toward the Ditch, thus a permanent corrective measure is needed to satisfy the corrective measures objective of limiting or preventing access to surface water contaminated with chlorinated VOCs over the 30-year evaluation period. The corrective measures evaluated for limiting or preventing direct contact with TCE in surface water at West Kilby Ditch include physically covering the ditch to remove the potential for the public to come into contact with TCE-containing water.

Shallow groundwater discharges into the Kilby Ditch. Although a chain-link fence currently encloses the Ditch an underground culvert system would also eliminate the potential for direct contact with the surface water. A hydrologic analysis of the contributing watersheds resulted in the determination that an underground stormwater culvert could replace the West Kilby Ditch.

6.3.2.3 Channel Stabilization of Main Kilby Ditch

Modifying and stabilizing the northern section of the Main Kilby Ditch channel is also evaluated as a means to minimize access to surface water in the Main Kilby Ditch channel. The channel modifications would begin at the north end of the existing concrete trapezoidal channel of the northern section of the Main Kilby Ditch and continue to North Boulevard. The channel modifications would include:

- Creating a uniform channel with a consistent bottom width and side slope.
- Lining the bottom and part of the side slopes with approximately 12 to 18 inches of rip-rap or equivalent.
- Grading the side slopes of the channel to an approximate slope ratio of 2 to 1.

- Reinforcing the upper banks of the channel with appropriate material for erosion control.

Sufficient rip-rap or equivalent material would be placed in the bottom of the channel to reduce direct access to the groundwater that discharges into the West Kilby Ditch.

A large scour hole is present immediately downstream of the concrete trapezoidal channel, and bank erosion is evident within the unlined channel. By reducing the side slopes and providing permanent turf reinforcement, the potential for bank erosion by high flow velocities can be reduced. Preventing erosion in this portion of the northern section of the Main Kilby Ditch would also result in less sedimentation downstream.

A geo-fabric would support the rip-rap. Vegetation would be planted over the permanent turf reinforcement to aid in erosion control. A hydraulic analysis would be performed to assess if these modifications would have a negative impact on the existing storm drainage hydraulics and surrounding area.

As discussed in Section 2.8.2, soil samples were collected adjacent to the West and Main Branches of the Kilby Ditch to determine if soil excavated for remediation construction could be used on other areas of the project. Analytical results did not indicate any detectable TCE or other VOCs, thus, ALDOT proposes to use soil excavated during construction of the remedy as construction fill on the project.

6.3.2.4 Access Restriction by Fencing

An alternative corrective measure for mitigating the potential surface water pathway within West and Main Kilby Ditches includes fencing to reduce the likelihood that the public could gain access to surface water that contains TCE. This alternative would include retaining the 8-foot-high perimeter chain link fence around West Kilby Ditch and the northern section of Main Kilby Ditch, and display of appropriate warning signs. Locked gates would be installed in the perimeter fencing to allow access for site monitoring. Inspection and maintenance of the fencing would be performed to ensure the integrity of the barrier.

6.4 LOW-LYING AREAS

6.4.1 OBJECTIVE

The Low-lying Areas are in the path of migration of the northeast portion of the CBP where groundwater discharges to surface water (Figures 1-1 and 2-25 in Sections 1 and 2, respectively). They also receive storm water discharge via the Kilby Ditch, which has a drainage area of approximately 1.2 square miles. The Site conditions within these areas would support many of the pollutant reduction processes discussed in Section 5.8 (Constructed Wetland/Wetland Treatment System). Strategic enhancement of existing wetlands in these areas to intercept discharging groundwater and surface water from the Kilby Ditch is a potential corrective measure because wetlands can remove significant amounts of pollutants from groundwater and surface water.

6.4.2 POTENTIAL CORRECTIVE MEASURES TECHNOLOGIES

Potential corrective measures technologies for the Low-lying Areas include:

- Constructed wetlands
- Access restriction by fencing

6.4.2.1 Constructed Wetlands

As discussed in Section 5, constructed wetlands can be designed as highly engineered systems or naturally constructed systems. The highly engineered systems typically include impermeable multi-cell wetlands with impermeable liners and hydraulic features to distribute flow and control the discharge. A naturally constructed wetland does not have an impermeable liner, which allows groundwater to enter the system.

The natural wetlands would be constructed to maximize capture of the discharged groundwater. Sizing of the wetland would be based on water budgets to account for direct precipitation, stormwater runoff, groundwater inflow, and evapotranspiration (water loss through plant respiration).

Factors Affecting Treatment Efficiency

The primary parameter influencing the removal efficiency of wetland treatment systems is the reaction rates for groundwater and surface water contaminants. This is affected by retention time, variability in hydraulic and contaminant load, ambient temperature, and plant vigor. Actual contaminant loads will depend in large part on the technology that is selected for the Kilby Ditch Area.

Siting Considerations

Siting considerations are similar to many other construction projects. Site conditions that are not ideal can often be managed; however, project costs typically increase to address these sub-optimal conditions to an acceptable tolerance. The Low-lying Areas are suitable for wetland creation or enhancement due to their topographic position and because of the presence of the railroad bed, which, is a preexisting berm that could be incorporated into the design. Discharge rates and water depths within the wetland could be controlled by additional earthen berms. Depending on the findings of a detailed topographic survey, the berms would be approximately two feet high. The berms would be positioned to create a long flow path to impede hydraulic short circuiting and to increase retention time. Additional steps required to assess the proposed Low-lying Areas for a constructed wetland would include the following:

- A site investigation that characterizes the presence of existing wetlands and confirms local depths to groundwater and soils.
- A water budget, consisting of stormwater runoff, groundwater inflow, precipitation and associated runoff, evapotranspiration, and flow through.
- A site topographic survey
- Preliminary design
- Final design

Other than construction of low berms, limited site work would be anticipated because the Low-lying Areas are relatively flat. The existing microtopography will provide varying water depths that will improve habitat and induce a variety of redox conditions. Flow from the system would discharge into Three Mile Branch, which will constitute the compliance monitoring point for the Kilby Ditch and Wetland Treatment system.

6.4.2.2 Access Restriction by Fencing

An additional corrective measure for mitigating the potential surface water pathway within the Low-lying Areas includes fencing to reduce the likelihood that the public could contact the TCE-containing water. This would include the installation of an 8-foot-high perimeter chain link fence around the Low-lying Areas and display of appropriate warning signage. Locked gates would be installed in the perimeter fencing to allow access for site monitoring. Inspection and maintenance of the fencing would be performed to ensure the integrity of the barrier.

6.5 SOUTHWESTERN AREA

6.5.1 OBJECTIVE

Potential corrective measures were evaluated for the Southwestern Area of the CBP to control plume migration, minimize potential impacts to surface waters in the southwestern sand and gravel mines, and to protect surface waters present to the west of the sand and gravel mines (including the Alabama River).

As discussed in Section 3, dewatering operations at the sand and gravel mines control the movement of the CBP to the southwest and limit the concentrations of TCE in the surface waters within the mine areas. Continuation of dewatering at the mines is expected for the next 30 years. The mining operations have estimated sufficient sand and gravel reserves in this Southwestern area for at least 30 additional years of mining.

6.5.2 POTENTIAL CORRECTIVE MEASURES TECHNOLOGIES

The potential corrective measure described above was simulated by using the site-wide groundwater and contaminant fate and transport models developed for the CBP and compared to the baseline simulation, as discussed in Section 3. Potential corrective measures for the Southwestern Area that were evaluated include:

- No sand and gravel mine dewatering at the southwestern sand and gravel mines for the 30-year evaluation period. This scenario would represent a “no-action” alternative in the Southwestern Area; and,
- Hydraulic control in the Southwestern Area of the CBP via continued dewatering at the southwestern sand and gravel mines or a separate groundwater extraction system.

6.5.2.1 Termination of Dewatering at Southwestern Sand and Gravel Mines

Currently, the dewatering of the southwest sand and gravel mines is drawing groundwater from the CBP toward the mines. Within the next five to ten years, groundwater from the CBP will be captured by the dewatering activities. The resultant mix of groundwater recovered and discharged as surface water will have a lower TCE concentration compared to groundwater recovered only from the CBP. Termination of dewatering would eliminate groundwater mixing and the CBP, located upgradient of the sand and gravel mine area, would discharge into the sand and gravel mine surface water. Based on the results of the baseline simulation (Section 3), termination of dewatering in the southwestern sand and gravel mines would most likely not result in surface water concentrations within the sand and gravel mine area greater than the ADEM-specified action level for TCE in surface water of 0.175 mg/L during the 30-year simulation[1].

The gradient in the Southwestern Area would decrease if dewatering ceased. This would slow plume migration to the southwest and allow the plume to migrate or spread further north and south along the western portion of the CBP. As noted in Section 3, this would result in 121 additional residential properties would be affected if you compare the non-pumping scenario to the pumping scenario.

6.5.2.2 Continued Groundwater Dewatering and Hydraulic Control

The baseline simulation described in Section 3 predicted that the southwestern area of the CBP will enter the properties in the sand and gravel mine area in less than five years at predicted TCE concentrations between 0.001 and 0.005 mg/L. As discussed in Section 3, simulated TCE concentrations in the groundwater in the southwestern sand and gravel mine areas are not predicted to exceed 0.01 mg/L during the 30-year simulation. As a result, continued hydraulic control within this area is predicted to control further migration of TCE toward the sand and gravel mine area and adjacent surface water bodies to the west of the sand and gravel mine area (including the Alabama River).

North Montgomery Materials anticipates that sand and gravel reserves are sufficient to continue mining for the next 30 years. The dewatering activities associated with the sand and gravel mine operations will continue to control movement of the CBP in the southwest area and will effect the CBP groundwater migration for the next 30 years. If dewatering at the mines is not continued, an interceptor well system consisting of approximately 8 vertical extraction wells can be installed in the Southwestern Area as shown in Figure 6-3. The interceptor well system will sustain the current migration of the CBP toward the southwest.

[1] In May 2011, the action level for TCE will change from the current level of 0.175 mg/l to 0.0175 mg/l in accordance with ADEM regulations. The evaluation of corrective measures was based on the current water quality standard, prior to the regulatory change; however, ALDOT will design treatment to comply with the lower water quality standards, where appropriate.

Extracted groundwater would be treated using an air stripping system, a carbon filtration system, or both. The treated water would be discharged to an un-named tributary of the Alabama River that is located northwest of the treatment system.

6.6 SITE-WIDE CORRECTIVE MEASURES ALTERNATIVES

Based on the evaluations discussed above, the following site-wide corrective measures alternatives have been developed for further evaluation. These alternatives are:

Alternative A:

- PRB at West Kilby Ditch;
- Retain security fencing along West and Main Kilby Ditches;
- Construction of perimeter security fencing in the Low-lying Areas;
- Continued groundwater pumping and hydraulic control in the Southwestern Area of the CBP;
- Groundwater and surface water monitoring; and,
- Implementation of institutional controls to restrict access to and prevent use of groundwater.

Alternative B:

- PRB along Coliseum Boulevard;
- Retain security fencing along West and Main Kilby Ditches;
- Construction of wetlands and perimeter security fencing in the Low-lying Areas;
- Continued groundwater pumping and hydraulic control in the Southwestern Area of the CBP;
- Groundwater and surface water monitoring; and,
- Implementation of institutional controls to restrict access to and prevent use of groundwater.

Alternative C:

- Covering of West Kilby Ditch and slope stabilization of the northern section of Main Kilby Ditch;
- Retain or reposition security fencing along Main Kilby Ditch;
- Construction of wetlands and perimeter security fencing in the Low-lying Areas;
- Continued groundwater pumping and hydraulic control in the Southwestern Area of the CBP;

- Groundwater and surface water monitoring; and,
- Implementation of institutional controls to restrict access to and prevent use of groundwater.

Based on the predicted migration of the CBP toward the southwest, north, and northeast, long-term monitoring of the CBP expansion will be included as a component of any corrective measure selected for the CBP. ALDOT will prepare a long-term groundwater monitoring program for the CBP for approval by ADEM. The groundwater monitoring plan will include installation of additional groundwater monitoring wells adjacent to the existing CBP to the north, northeast, and southwest of the plume, groundwater sampling and analysis on a modified schedule, and reporting of monitoring results. The need for additional corrective measures will be based on the monitoring results and evaluation of exposure pathways. Rationale for developing additional corrective measures is presented in Section 8.0 of this CME report.

7.1 SITE-WIDE CORRECTIVE MEASURES ALTERNATIVES

Based on the evaluations described in Section 6, the following site-wide corrective measures alternatives have been selected for further evaluation. These alternatives are:

Alternative A:

- PRB at West Kilby Ditch;
- Retain security fencing along West and Main Kilby Ditches;
- Construction of perimeter security fencing in the Low-lying Areas;
- Continued groundwater pumping and hydraulic control in the Southwestern Area of the CBP;
- Groundwater and surface water monitoring; and,
- Implementation of institutional controls to restrict access to and prevent use of groundwater.

Alternative B:

- PRB along Coliseum Boulevard;
- Retain security fencing along West and Main Kilby Ditches;
- Construction of wetlands and perimeter security fencing in the Low-lying Areas;
- Continued groundwater pumping and hydraulic control in the Southwestern Area of the CBP;
- Groundwater and surface water monitoring; and,
- Implementation of institutional controls to restrict access to and prevent use of groundwater.

Alternative C:

- Covering of West Kilby Ditch and slope stabilization of the northern section of Main Kilby Ditch;
- Retain or reposition security fencing along Main Kilby Ditch;
- Construction of wetlands and perimeter security fencing in the Low-lying Areas;
- Continued groundwater pumping and hydraulic control in the Southwestern Area of the CBP;
- Groundwater and surface water monitoring; and,
- Implementation of institutional controls to restrict access to and prevent use of groundwater.

7.2 EVALUATION CRITERIA

The USEPA has developed evaluation criteria by which proposed corrective measures alternatives should be judged. These evaluation criteria include:

1. Overall protection of human health and the environment
2. Reduction of toxicity, mobility, and volume
3. Compliance with ARARs
4. Short-term effectiveness
5. Long-term effectiveness and permanence
6. Implementability
7. Cost
8. Community acceptance
9. State acceptance

An evaluation of each of the proposed corrective measures alternatives is provided below and summarized in Table 7-1.

7.2.1 OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

The three alternatives will be protective of human health by limiting access to and use of groundwater that contains chlorinated VOCs and surface water containing TCE concentrations greater than the ADEM-specified action level of 0.175 mg/L[1]. For all three alternatives, institutional controls will prevent and/or significantly minimize the potential for complete exposure pathways to groundwater that contains chlorinated VOCs.

Under Alternatives B and C, constructed wetlands in the Low-lying Areas would reduce the concentrations of chlorinated VOCs in surface water that discharges at the compliance point in Three Mile Branch. In Alternative A, the PRB would reduce VOC concentrations in groundwater prior to discharging to Kilby Ditch. These alternatives would

[1] In May 2011, the action level for TCE will change from the current level of 0.175 mg/l to 0.0175 mg/l in accordance with ADEM regulations. The evaluation of corrective measures was based on the current water quality standard, prior to the regulatory change; however, ALDOT will design treatment to comply with the lower water quality standards, where appropriate.

limit access to chlorinated VOC-containing surface water, and specifically to surface water that contains TCE concentrations that could exceed the ADEM-specified action level for TCE in surface water of 0.175 mg/L.

Alternatives A and B would be less protective than Alternative C because access to surface water would be limited via maintenance of existing fencing only and not by a concrete or rip-rap barrier as in Alternative C. Under Alternatives B and C, VOC concentrations in surface water in Kilby Ditch would likely be greater than those under Alternative A. However, Alternatives A and C would be equally protective at limiting exposure to surface water that could potentially contain TCE concentrations greater than the ADEM-specified TCE surface water action level.

All three alternatives will include continued groundwater pumping and hydraulic control in the Southwestern Area of the CBP and will be equally protective of human health and the environment by limiting or preventing plume migration into areas outside of the Institutional Control Boundary. The overall protection of human health resulting from the implementation of the selected alternative will be confirmed through the development and implementation of a comprehensive plan to monitor groundwater and surface water.

7.2.2 REDUCTION IN TOXICITY, MOBILITY, AND VOLUME

In all three alternatives, lateral migration of VOC-containing groundwater in the southwestern area is primarily controlled via the continued groundwater pumping and hydraulic control. The constructed wetlands in Alternatives B and C would result in a reduction in the toxicity, mobility, and volume of the chlorinated VOCs in the Low-lying Areas. Under Alternatives A and B, the PRBs in the Kilby Ditch Area would reduce the toxicity, mobility and volume of the chlorinated VOCs through *in-situ* treatment, which would transform the chlorinated VOCs to innocuous byproducts through the process of reductive dechlorination. Therefore, because Alternative B treats a larger volume of the VOC-containing groundwater through the PRB and the constructed wetlands, it is marginally more effective than the other alternatives under this criterion.

7.2.3 COMPLIANCE WITH ARARS

As discussed in Section 5, the size of the CBP limits the availability of individual or combined corrective measures to achieve compliance with ARARs for groundwater within the CBP. The overall management strategy for the CBP includes preventing use of and exposure to groundwater that contains TCE at concentrations greater than 0.005 mg/l, which is the USEPA maximum contaminant level (MCL) and the ADEM-specified ARAR for groundwater in the CBP. Because each alternative includes a comprehensive institutional control and long-term monitoring strategy to prevent use of and exposure to groundwater in the CBP, all three alternatives will achieve groundwater ARARs at the Institutional Control Boundary.

Both Alternatives A and B include PRBs that would be effective at meeting the ADEM-specified, surface water action level of 0.175 mg/l within the Kilby Ditch Area. The groundwater/surface water treatment within the constructed wetland will reduce surface water concentrations below the surface water action level of 0.175 mg/L at the discharge point to Three Mile Branch. In the Southwestern Area, the action level of 0.175 mg/l for surface water would be met through continued pumping and mixing of groundwater outside of the CBP.

7.2.4 SHORT-TERM EFFECTIVENESS

Alternative C would be most effective in the short term because covering West Kilby Ditch and stabilizing the Main Kilby Ditch would reduce exposure to surface water in the Kilby Ditch. Although Alternative A would limit exposure to surface water with TCE concentrations potentially greater than the ADEM-specified action level for TCE in surface water, this alternative is considered relatively less effective than Alternative C in the short-term because it would be less restrictive of exposure to surface water in Kilby Ditch. Alternative B would be least effective in the short term because groundwater downgradient of the PRB, which contains TCE at concentrations greater than the ADEM-specified action level for TCE in surface water, would discharge to West Kilby Ditch and only maintenance of the existing fencing is included to limit access to the Kilby Ditch.

7.2.5 LONG-TERM EFFECTIVENESS AND PERMANENCE

Implementation of permanent institutional controls to restrict access to and use of groundwater would be effective over the long term for all three alternatives. Groundwater pumping and hydraulic control in the Southwestern Area of the CBP would continue throughout the 30-year evaluation period (via sand and gravel mine dewatering or a groundwater extraction system) and would be effective because VOC concentrations would be permanently managed such that TCE concentrations would remain less than the ADEM-specified action level for TCE in surface water.

Alternative C would be most effective over the long term because covering West Kilby Ditch and channel stabilization in and fencing around the northern section of Main Kilby Ditch would prevent contact with surface water in Kilby Ditch. The closest point of exposure to VOC-containing surface water would be the surface water at Three Mile Branch. The Wetland Treatment system will be within a fenced area and treatment within the wetlands will reduce the concentration of TCE in the surface water.

Alternative A would be slightly less effective in the long term than Alternative C because VOCs would not be completely removed from the groundwater by passage through the PRB. Potential contact with surface water in West Kilby Ditch could occur, but VOC concentrations would be lower than those under alternatives that do not include groundwater treatment.

In Alternative C other technologies would be used to limit potential exposure downstream of the covered West Kilby Ditch. Under Alternative C slope stabilization would be implemented along the entire northern section of Main Kilby Ditch. The plantings and rip-rap associated with the slope stabilization would limit the potential for exposure to surface water in the northern section of Main Kilby Ditch. The portion of the Ditch not covered would be enclosed with a security fence and vegetation, further reducing the likelihood of access to the water in the channel.

Alternative B would be least effective over the long term because maintenance of the existing fencing would be the only measure implemented to prevent exposure to surface water in the Kilby Ditch. Maintaining the existing fencing would be less effective than covering the ditch or implementing slope stabilization. The evaluation of long-term effectiveness of Alternatives A and B assumes that the PRBs would be effective for 20 to 30 years from the time of installation. Therefore, replacement of the PRB may be required based on the actual effective duration of this technology.

7.2.6 IMPLEMENTABILITY

All three alternatives can be implemented using readily-available and proven technologies. Alternatives A and C would be more easily implemented because they do not include the installation of a PRB along Coliseum Boulevard. Implementing Alternative B would cause traffic disruptions and require a high level of safety controls. Alternative C is moderately less difficult to implement because it involves more standard construction techniques than Alternatives A and B, which require specialty construction techniques. Alternative B would be the most difficult alternative to implement.

7.2.7 COST

Engineering estimates of capital expenditures and first-year O&M costs for the three alternatives were developed based on proposals and projected costs from technology vendors, RS Means 2005 information, and previous project experience (Tables 7-2 through 7-4). Administration, contingency and design costs were applied equally for each component of the alternatives. The shared components in the three alternatives include institutional controls and monitoring of surface water and groundwater.

Present net worth (PNW) estimates of the three alternatives range from approximately $11.4 million to $16.8 million. Alternative B would be the most expensive alternative, with a capital cost of approximately $12.2 million and a PNW of approximately $16.8 million. The PNW of Alternatives A and C would be approximately $14 million and $11.4 million, respectively.

7.2.8 COMMUNITY ACCEPTANCE

Alternative C would be more acceptable than Alternatives A and B because exposure to surface water in Kilby Ditch would be more effectively eliminated by covering Kilby Ditch. Alternative C should be aesthetically pleasing to the community. Alternative C would provide a long-term remedy, where Alternatives A and B would require replacement in 20 to 30 years. Replacement activities would be disruptive and less acceptable to the community

Under Alternative A, the PRB along Kilby Ditch would reduce chlorinated VOCs in groundwater prior to the groundwater discharging to Kilby Ditch. However, the ditch would not be covered and therefore less aesthetically pleasing.

Alternative B would be the least acceptable alternative, because of short-term disruption of vehicular and/or pedestrian traffic along public ROWs to allow for the installation of the PRB along Coliseum Boulevard.

This CME report along with the Corrective Measures Implementation Plan will be made available for public review and comment. This is consistent with ALDOT's ongoing community outreach efforts that have been established for this project.

7.2.9 STATE ACCEPTANCE

Alternative C should be more acceptable than Alternatives A and B because exposure to surface water containing chlorinated VOCs in Kilby Ditch would be eliminated. Although maintenance of the existing fencing is included in Alternatives A and B, these measures are less effective at limiting access to surface water in Kilby Ditch than covering or slope stabilization.

Under Alternative A, the PRB along Kilby Ditch would reduce the concentration of chlorinated VOCs in groundwater prior to it discharging into Kilby Ditch. However this alternative would not include the Wetland Treatment System in the Low-Lying Area to provide additional treatment.

Alternative B would be the least acceptable alternative, because it would be disruptive to the community and likely require replacement in 20-30 years.

ALDOT will continue to work with the ADEM and ADPH to evaluate the CBP and implement corrective measures that are protective of human health and the environment.

8.1 INSTITUTIONAL CONTROLS

8.1.1 PURPOSE

"Institutional Controls", as defined by the USEPA, are administrative and/or legal controls that minimize the potential for human exposure to contamination by limiting land or resource (i.e. groundwater) use. Institutional controls for the CBP include the immediate and long-term administrative, legal, and outreach controls and actions that ALDOT will implement. As an agency of the State of Alabama, ALDOT can meet the technical and financial requirements to implement, operate, maintain, and monitor the institutional controls.

The Institutional Control Plan (ICP) will document the institutional control programs that have been implemented at the Site, as well as, programs proposed for future monitoring and management of the CBP site. The ICP, along with the proposed engineering controls for the Northeast and Southwest portions of the CBP, will be presented in a Corrective Measures Implementation Plan (CMIP). An adaptive management process will be utilized to continually monitor and evaluate site conditions and treatment technologies that may result in revising or augmenting the CMIP.

8.1.2 JURISDICTIONAL BOUNDARIES

A groundwater numerical model was developed and used to simulate groundwater flow at the CBP Site. The model was calibrated to baseline data to verify that it simulates groundwater flow and the transport of the TCE that is dissolved within the groundwater in the CBP Site. The model was used to evaluate corrective measures for the Site and to predict the distribution of the dissolved TCE through the year 2036.

The current extent of the CBP Site is provided on Figure 8-1. The Institutional Control Boundary (ICB) includes all parcels that are predicted to be underlain with groundwater containing 0.001 mg/L TCE through the year 2036, plus a 100-foot buffer (See Figure 8-2)

<u>Legal Controls</u>

The following legal controls are proposed for each parcel in the Institutional Control Boundary:

- Restrictive covenants that run with the land and are enforceable in perpetuity to control access and/or use of groundwater;

- Affirmative access easements to allow entry to property (excluding structures) for continued investigation and remedial measures. Coordination with the property owner/occupant will be performed prior to property entry.

8.1.3 INSTITUTIONAL CONTROL PLAN COMPONENTS

An array of actions and controls have been developed and will be monitored and adjusted, as necessary, to restrict access to the groundwater and surface water in the ICB. Specific controls will include the following:

- Engineering controls as previously discussed to manage the groundwater within the CBP and capture and treat surface water prior to discharge from the ICB area.
- Institutional controls that will provide administrative and legal actions to restrict access to and use of groundwater. Institutional controls implemented at the Site include:
    - A court-ordered groundwater use restriction for residential properties within the CBP as shown on Figure 8-3 (Phase I Parcels).
    - Environmental covenants with groundwater use restrictions on all Phase II Parcels within the ICB (Figure 8-4). These covenants will be filed at the Montgomery County Probate office to provide legal notice to property owners that access to groundwater is restricted and the property owner must notify the ALDOT prior to any activity that could result in the potential access to the groundwater. The deed restriction runs with the land; therefore, all future property owners will be legally bound by the restriction.
    - The ICP will include proactive monitoring and compliance evaluations to document the effectiveness of the institutional controls. The Site will be monitored both on the ground and with aerial photography on a regular basis to identify potential landuse activities that could result in an exposure to groundwater or surface water. Property deeds will be reviewed both annually and following legally recorded property transactions to ensure that the groundwater use restriction is properly included with the deed recorded at Probate. A process to evaluate the effectiveness and modify the ICP, if

necessary, will be included to comply with ADEM's requirements for Institutional Controls.

- Public Outreach and Stakeholder participation are continuous activities incorporated in the ICP. The ICP will document all Stakeholders (e.g., the Alabama Department of Environmental Management, City of Montgomery, Montgomery Water Works and Sanitary Sewer Board, Montgomery County, etc.) that may have an interest in or be affected by the CBP. A plan to communicate and coordinate site activities and reporting on the status of the CBP will be included in the ICP.

8.2 CONTINGENCY MEASURES

As documented in this CME, the ALDOT has completed numerous investigations to assess the nature and extent of chlorinated volatile organic compounds (VOCs) within the CBP since 1999. ALDOT's investigations include groundwater, surface water, soil, sediment and air. Based on the conclusions of the investigations in the PH12 Area and the Site-wide CBP, two objectives were identified to prevent exposure to the VOCs within the CBP:

- Restrict access to and contact with groundwater within the CBP; and,

- Restrict contact with TCE-containing surface water within the CBP and treat the surface water as it is collected prior to final discharge, if necessary

As part of the effort to meet these objectives, ALDOT has developed and began implementation of an Institutional Control Program (ICP) to minimize potential human exposure to chlorinated VOCs (primarily TCE) within the groundwater and surface water at the CBP. As stated earlier, the ICP comprises legal, administrative, and outreach components that will allow the ICP to meet the above objectives. The ALDOT will evaluate the effectiveness of the Institutional Controls to document that they are meeting the above objectives. Engineering Controls will also be implemented to manage and control the movement of groundwater and collect and treat surface water containing TCE prior to discharge from the Institutional Control Boundary. Figure 8-5 depicts the parcels within the ICB that the ALDOT owns. Some of these parcels will be included in the Engineering Controls proposed for the Site.
Should the ICP or any element within the ICP be determined to be ineffective, ALDOT will develop and implement an alternative corrective

measure for area(s) within the ICB that do not meet the ICP objectives. The ICB incorporates all previously defined study areas (Kilby Ditch, Low-Lying Areas, PH12, and Southwest) for the CBP. The process that would be employed to develop and implement an Alternative Corrective Measure should the ICP fail to meet the required objectives is presented below.

8.2.1 ALTERNATIVE CORRECTIVE MEASURES DEVELOPMENT PROCESS

The basis for development and implementation of an alternative corrective measure for the CBP would be determined by three factors related to the effectiveness of the ICP:

1. Failure of the ICP to prevent access to and contact with groundwater or surface water within the CBP;
2. Model assumptions are determined to be inaccurate based on additional information or changes in surrounding land uses that influence migration of the TCE in groundwater or surface water; or,
3. Migration of TCE in groundwater is predicted to exceed the MCL beyond the ICB.

Any of these conditions would be documented in the ICP Annual Compliance Report and, if present, would initiate the corrective measure development process described below.

A Long Term Monitoring (LTM) plan will be included in the CMIP. This LTM plan will provide the documentation and rationale for Corrective Measures Monitoring (CM) and Sentry Well (SW) monitoring. Data will be evaluated as follows:

1. Has a significant deviation occurred at the sample location(s) relative to the Site-Wide groundwater model that could result in a potential failure at a point of exposure (POE),
2. If yes, the sample location(s) should be resampled to confirm the TCE concentration,
3. If the confirmation sample(s) indicate a potential failure at the POE, the ALDOT will perform an investigation to evaluate any Site-Wide or specific area change in conditions,
4. If a change in conditions has occurred, the ALDOT will implement the appropriate remedial response that is protective of the POE,
5. The Site-Wide model will be recalibrated to account for the remedial response, if appropriate.

8.2.2 ALTERNATIVE CORRECTIVE MEASURE REVIEW

A review of existing and new technologies will be performed to determine if advances in existing technologies or new remedial technologies may be applied to the appropriate area. Technologies to be reviewed are those that could modify or reduce the rate and direction of transport, reduce or modify the mass flux, or prevent a potential exposure via additional legal and administrative measures. If necessary, legal and administrative actions, in addition to groundwater use restrictions recorded on real property deeds within the CBP, would also be considered, if contact to the groundwater was deliberately sought within the ICB.

8.2.3 TECHNOLOGY SCREENING

Technologies identified during the technology review would be screened for their applicability as potential remedial alternatives. Selected technologies will be used as the basis of a corrective measures alternative.

8.2.4 CORRECTIVE MEASURE ALTERNATIVE DEVELOPMENT

Based on the results of the technology screening, corrective measure alternatives will be developed and screened based on the following criteria:

- Overall protection of human health and the environment
- Reduction of toxicity, mobility, and volume
- Compliance with ARARs
- Short-term effectiveness
- Long-term effectiveness and permanence
- Implementability
- Cost
- Community acceptance
- State acceptance

Based on the results of the corrective measure alternative evaluation, a corrective measure alternative will be selected for the appropriate area. The results of the evaluation and the selected remedy will be submitted to ADEM for review and comment.

8.2.5 Corrective Measure Design and Procurement

Based on the results of the Corrective Measures Development Process, ALDOT will design the selected corrective measure. The design of the corrective measure will be submitted to ADEM for review and comment. Procurement for the final design of the corrective measure will be obtained in accordance with ALDOT procedures.

8.2.6 Corrective Measure Implementation

Once procurement is completed and a contract awarded, ALDOT will implement the selected corrective measure for the appropriate area. Construction of the corrective measure may be conducted in phases to mitigate the potential effects on the community.

8.2.7 Monitoring and Corrective Measure Review Process

Once the corrective measure is in place it will be monitored to document its performance. ALDOT will perform an annual review of the corrective measure to assess if it is meeting the remedial objectives, and to evaluate its effect on site conditions in relation to the ICP program. If the evaluation demonstrates that the alternative corrective measure has affected site conditions such that the ICP program could again be effective without the alternative corrective measure in place, ALDOT may recommend to ADEM that the operation of the alternative corrective measure be suspended. Following any such suspension, conditions at the CBP will continue to be monitored in accordance with the long-term monitoring plan and the ICP.

8.3 Institutional Control Plan

The Institutional Control Plan will be submitted as a component of the Corrective Measures Implementation Plan. The final plan will include a detailed explanation of how the Institutional Controls will work on all properties, with or without restrictive covenants in place, within the ICB along with measures to assess the effectiveness of the Institutional Controls.

9.1 INTRODUCTION

This CME provides the background and reasoning that resulted in the development of three composite Alternatives for the long-term protection of public health and management of potential exposure pathways from chlorinated VOCs in groundwater and surface water within the CBP. Potential exposure pathways have been investigated throughout the CBP through several area-specific and general investigations that included groundwater, surface water, soil, soil vapor, and air sampling. Groundwater samples have been collected from as many as 149 monitoring wells and 7 multi-channel wells during these investigations. The most likely potential exposure pathways to chlorinated VOCs at the CBP are discharges of VOC-containing groundwater into Kilby Ditch and the Low-Lying Areas.

The performance and estimated costs of the three Alternatives were evaluated for a 30-year period as recommended by the USEPA guidance for detailed analysis of alternatives (USEPA, 1988). The Alternatives were evaluated primarily for their effectiveness in limiting exposure to surface waters where concentrations may exceed the ADEM-specified action level for surface water. Alternative measures that could have ancillary benefits, such as reducing the mobility or toxicity of the TCE-containing groundwater, also were considered as part of the Site-wide Area corrective measures strategy. Each alternative contains institutional controls to restrict access to and use of groundwater.

9.2 SELECTED SITE-WIDE CORRECTIVE MEASURES

Alternative C is recommended for the CBP because it will be the least difficult to implement, the most effective at minimizing potential exposure to chlorinated VOCs in surface water, and a more permanent solution than Alternative A or B. Alternative C also provides for a five-year technology review to evaluate new or modified technologies that could be implemented.

9.2.1 OVERVIEW OF REMEDY ELEMENTS

Alternative C comprises the following corrective measures:

- Covering of West Kilby Ditch and slope stabilization of the northern section of Main Kilby Ditch;
- Retain or reposition security fencing along Main Kilby Ditch;
- Construction of wetlands and perimeter security fencing in the Low-lying Areas;

- Continued groundwater pumping and hydraulic control in the Southwestern Area of the CBP;
- Groundwater and surface water monitoring; and,
- Implementation of institutional controls to restrict access to and prevent use of groundwater.

9.2.1.1 Covering of West Kilby Ditch and Slope Stabilization

West Kilby Ditch will be enclosed with a concrete storm culvert to restrict access.

The northern section of Main Kilby Ditch will be modified to create a uniform channel by sloping the sides, grading and stabilizing the channel bottom. These modifications will begin at the north end of the existing concrete trapezoidal channel of the northern section of Main Kilby Ditch and continue to North Boulevard. A hydraulic analysis will be performed to assess the effects of such modifications on the existing storm drainage.

Sufficient rip-rap or equivalent material will be placed in the bottom of the channel to reduce the likelihood of direct access to the groundwater that discharges into Kilby Ditch. Stabilization of the channel slopes will include a suitable erosion control material.

9.2.1.2 Constructed Wetlands/Wetland Treatment System

The wetlands in the Low-lying Areas will be enhanced and expanded to intercept and maximize capture and treatment of VOC-containing water. Discharge rates and water depths in the wetlands will be controlled by constructing earthen berms to impede hydraulic short circuiting and to increase retention time. Flow from the system will discharge into Three Mile Branch, which will be designated as the compliance point for monitoring the performance of the wetland treatment system[1]. The specific details of the wetland treatment system will be discussed in a component of the Corrective Measures Implementation Plan, to be submitted to ADEM. The design of the wetlands treatment system will be based on the following:

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[1] In May 2011, the action level for TCE will change from the current level of 0.175 mg/l to 0.0175 mg/l in accordance with ADEM regulations. The evaluation of corrective measures was based on the current water quality standard, prior to the regulatory change; however, ALDOT will design treatment to comply with the lower water quality standards, where appropriate.

- A site investigation that characterizes the presence of existing wetlands and evaluates local depths to groundwater and soil.

- A water budget comprising stormwater runoff, groundwater inflow, precipitation and associated runoff, evapotranspiration, and flow through.
- A site topographic survey

9.2.1.3 Fencing at Kilby Ditch and Low-Lying Areas

The existing fence around West Kilby Ditch will be removed because of its replacement with the underground storm culvert. An 8-foot-high perimeter chain link fence with appropriate signage will be maintained around the northern section of Main Kilby Ditch, An 8-foot-high perimeter chain link fence and appropriate warning signs will be installed and maintained around the wetland treatment system. Locked gates will be installed in the perimeter fencing to allow access for site maintenance and monitoring. The fence will be inspected regularly and maintained.

9.2.1.4 Monitoring Groundwater and Surface Water

The effectiveness of Alternative C will be confirmed through a comprehensive groundwater and surface water monitoring program. A Long Term Monitoring (LTM) plan will incorporate elements of the existing CBP monitoring program, sampling of groundwater from sentry wells to monitor the Institutional Control Boundary (ICB), and monitoring of the constructed wetland in the Low-lying areas. Monitoring frequency and reporting of findings will be consistent with ADEM-specified requirements. The specific details of the monitoring plan will be discussed in a component of the Corrective Measures Implementation Plan, to be submitted to ADEM.

9.2.1.5 Groundwater Pumping and Hydraulic Controls in the Southwestern Area

Hydraulic control of the southwestward migration of the CBP will be sustained through continued dewatering at the sand and gravel mines in the Southwestern Area or with an interceptor well system near the western edge of the CBP.

9.2.1.6 Institutional Controls

Institutional Controls were designed to restrict access to and use of groundwater. The specific details of the Institutional Controls Program will be discussed in a component of the CMIP, to be submitted to ADEM.

9.2.2 Operations and Maintenance of Recommended Alternative

A detailed Operations and Maintenance Plan (O&M Plan) will be developed that will provide details on site monitoring activities and schedules, the reporting requirements, and periodic review and annual re-certification of engineering and institutional controls. The O&M Plan will include an annual report to ADEM that will provide a summary of the results of monitoring, trend analyses of the data, a written certification that the institutional and engineering controls are in place and are effective, and recommendations for changes in the O&M plan, as applicable.

9.3 Conclusions

Alternative C will meet the primary corrective measures objective of restricting potential exposure pathways to TCE at the CBP in the groundwater and surface water. It will be protective of human health by limiting access to groundwater via Institutional Controls. Additionally, Alternative C will be effective because covering West Kilby Ditch and the proposed improvements to the northern section of Main Kilby Ditch will limit access to surface water in Kilby Ditch. Potential exposure to VOC-containing surface water in the constructed wetlands will be prevented by the installation and maintenance of fencing and other security controls. The wetlands treatment system will be designed to treat TCE concentrations in the surface water such that the discharge at the compliance point at Three Mile Branch will not exceed the ADEM action level. Migration of TCE in groundwater in the southwestern part of the CBP will be controlled through existing dewatering at the sand and gravel mines or through a separate groundwater pumping system.

As an agency of the State of Alabama, ALDOT can meet the technical and financial requirements to implement, operate, maintain, and monitor the corrective measures that are recommended for the CBP.

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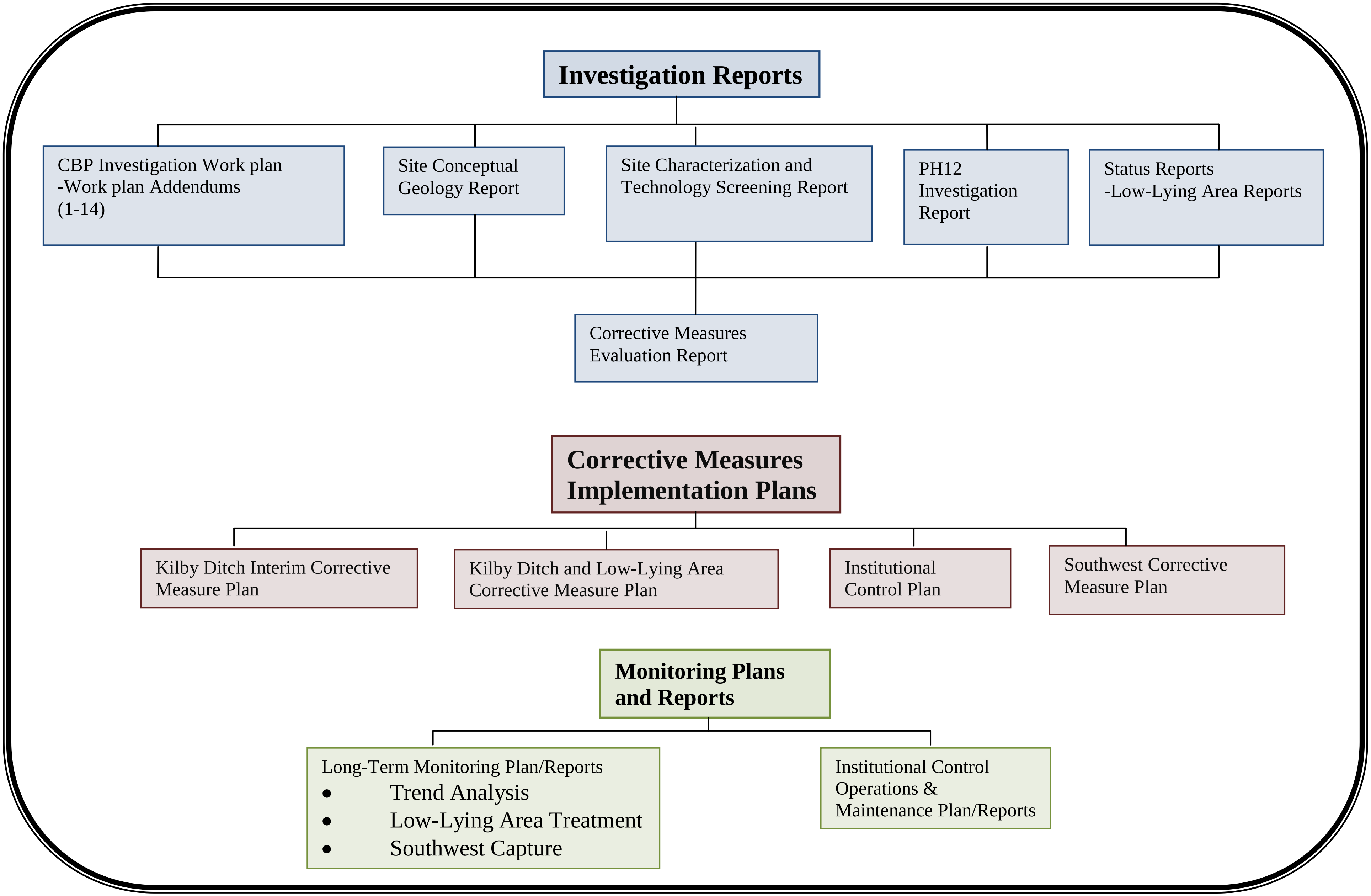
Figures

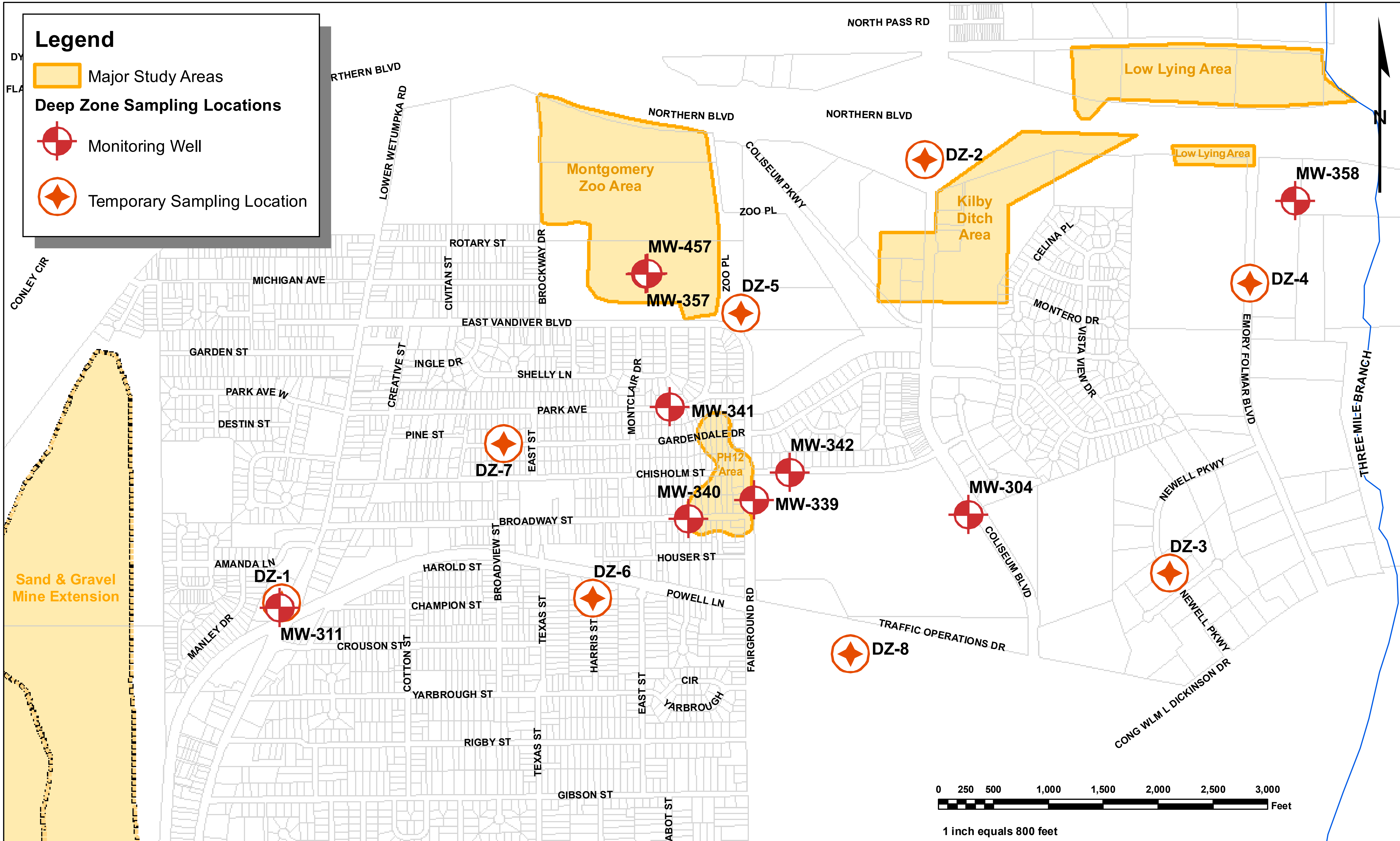
SITE-WIDE CORRECTIVE MEASURES EVALUATION

COLISEUM BOULEVARD PLUME SITE
MONTGOMERY, ALABAMA

DEPARTMENT OF TRANSPORTATION

Figure 1-1A


Investigation Reports
CBP Investigation Work plan
-Work plan Addendums
(1-14)
Site Conceptual Geology Report
Site Characterization and Technology Screening Report
PH12 Investigation Report
Status Reports
-Low-Lying Area Reports
Corrective Measures Evaluation Report
Corrective Measures Implementation Plans
Kilby Ditch Interim Corrective Measure Plan
Kilby Ditch and Low-Lying Area Corrective Measure Plan
Institutional Control Plan
Southwest Corrective Measure Plan
Monitoring Plans and Reports
Long-Term Monitoring Plan/Reports
• Trend Analysis
• Low-Lying Area Treatment
• Southwest Capture
Institutional Control Operations & Maintenance Plan/Reports

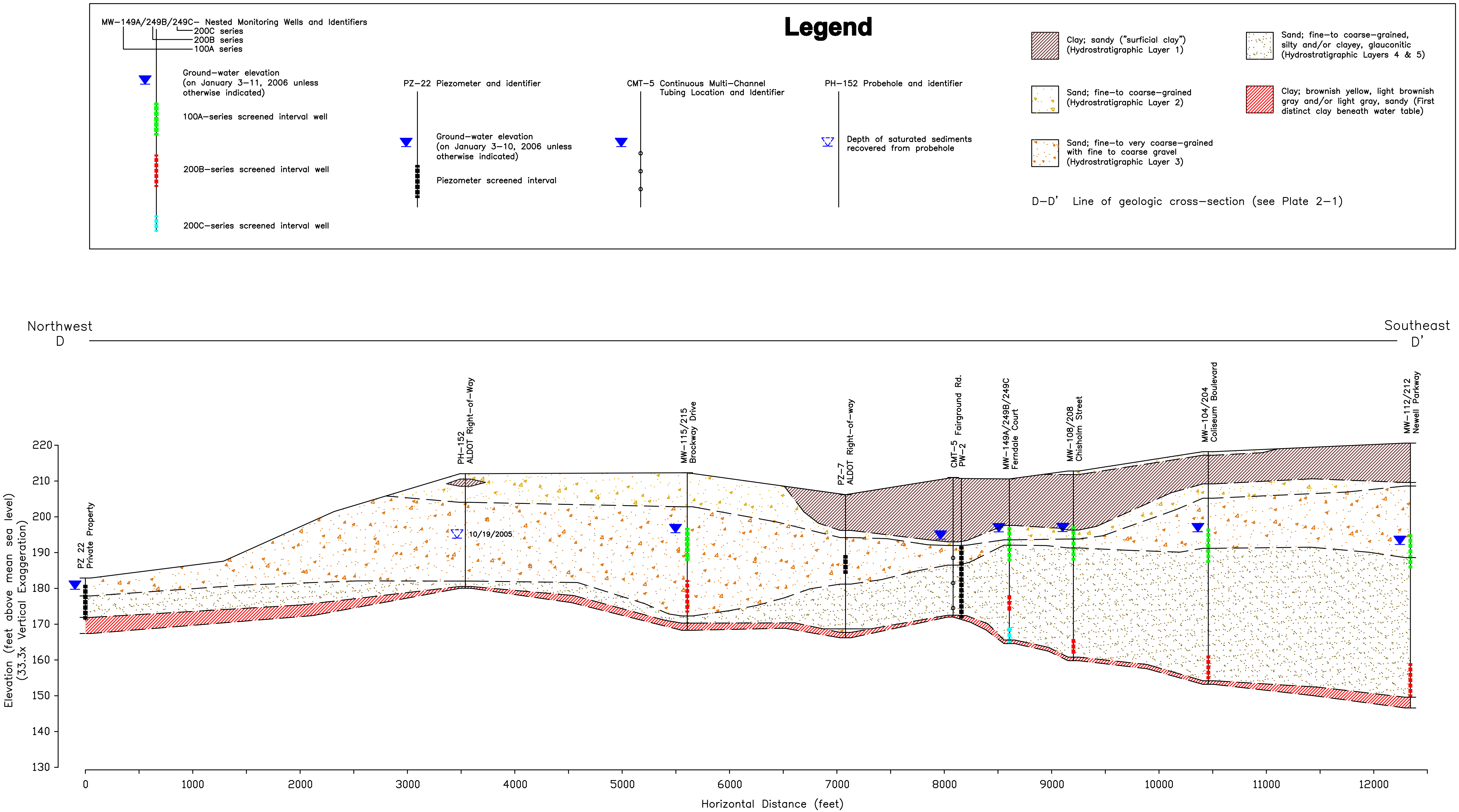


Alabama Department of Transportation
Coliseum Boulevard Project

DEEP ZONE SAMPLE LOCATIONS

FIGURE 2-12A

JUNE 2008

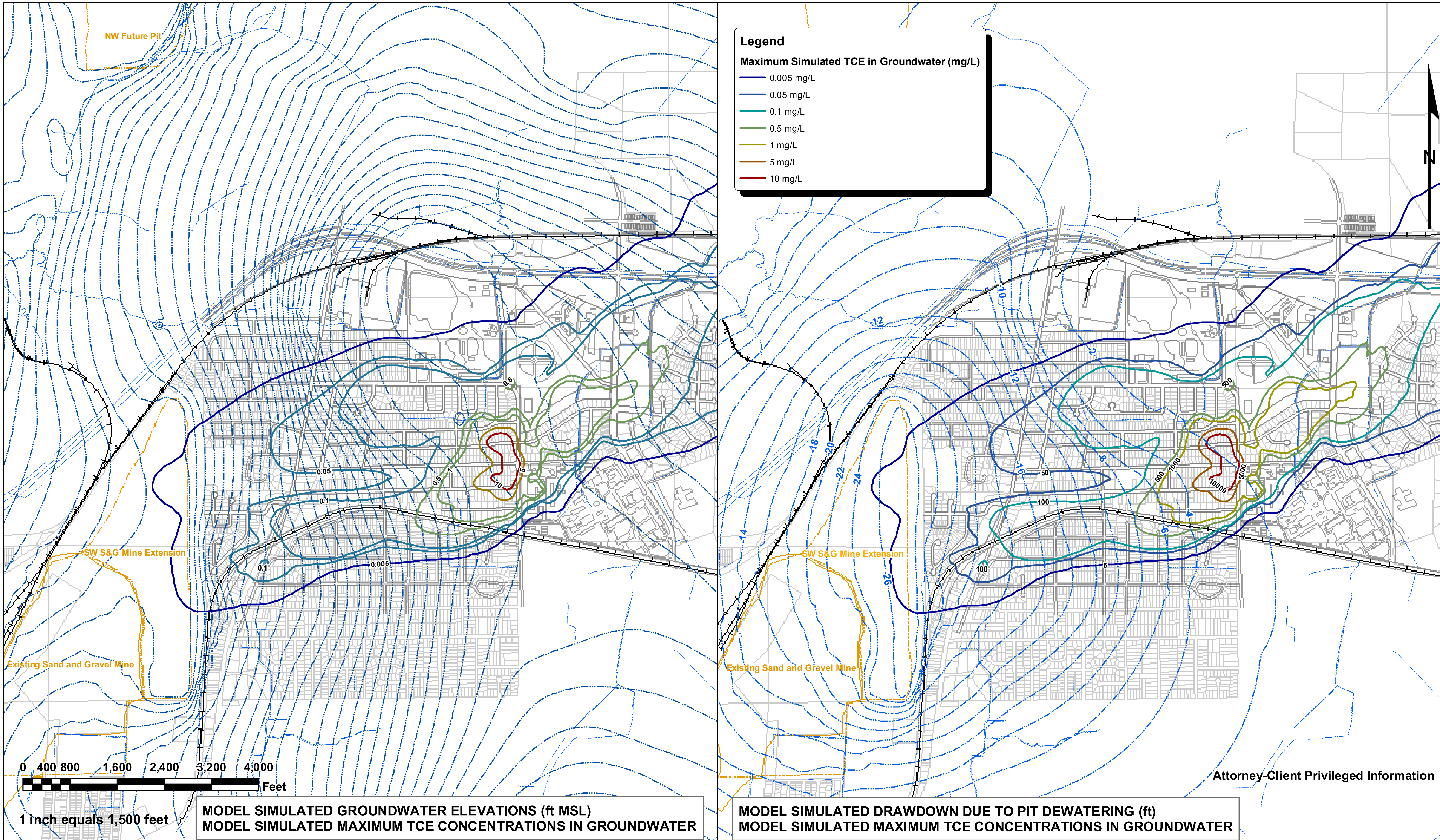


ALABAMA DEPARTMENT OF TRANSPORTATION
COLISEUM BOULEVARD PLUME

NORTHWEST-SOUTHEAST GEOLOGIC CROSS-SECTION D-D';
COLISEUM BOULEVARD PLUME; MONTGOMERY, ALABAMA.

JUNE 2006

FIGURE 2-16 R



DEPARTMENT OF TRANSPORTATION

Alabama Department of Transportation
Coliseum Boulevard Project

MODEL SIMULATED BASELINE CONDITIONS - YEAR 2036

FIGURE 3-6R

June 2008

SITE-WIDE CORRECTIVE MEASURES EVALUATION

COLISEUM BOULEVARD PLUME SITE
MONTGOMERY, ALABAMA

DEPARTMENT OF TRANSPORTATION

Table 7-1
Summary of Alternatives Evaluation
Site-wide CMS Report
ALDOT CBP – Montgomery, Alabama

ALTERNATIVE	CORRECTIVE MEASURES	OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT	LONG-TERM EFFECTIVENESS	REDUCTION OF TOXICITY, MOBILITY, AND VOLUME	SHORT-TERM EFFECTIVENESS	IMPLEMENTABILITY	COST	COMMUNITY ACCEPTANCE	STATE ACCEPTANCE	COMPLIANCE WITH ARARs	OVERALL EVALUATION
A	▪ Install PRB at West Kilby Ditch ▪ Retain fencing along West and Main Kilby Ditches ▪ Construct perimeter fencing in the Low-lying Areas ▪ Continue operation of Southwestern borrow pit dewatering operations ▪ Monitor groundwater and surface water ▪ Implement institutional controls to restrict access to and prevent use of groundwater	Protective via limiting access to groundwater and surface water Protective via fencing, and border vegetation to prevent and/or minimize complete dermal, inhalation, and/or ingestion pathways via surface water. Equally protective as Alternative C with respect to limiting access to surface water with TCE concentrations >0.175 mg/L action level set by ADEM. PRB would reduce VOC concentrations to <0.175 mg/L in baseflows to Kilby Ditch. Less protective than Alternative C with respect to limiting access to Kilby Ditch.	Slightly less effective than Alternative CVOC concentrations reduced but access to surface water not eliminated. Access limited by fencing only, which is less effective than covering ditch or implementing slope stabilization	PRB in reduces toxicity, mobility and volume of chlorinated VOCs in limited area near West Kilby Ditch.	Effective in short term because PRB reduces VOCs in groundwater before discharging to West Kilby Ditch.	Moderately more difficult than Alternative C because constructing PRB involves more specialized construction techniques than Alternative C.	▪ PNW of $11.4M ▪ Capital cost of approximat ely $6.9m	Anticipated less acceptable to community because Kilby Ditch is not covered, preventing access to surface water and resulting in less aesthetic value. Installation of PRB may be temporarily disruptive to community.	PRB would reduce VOC concentrations in surface water to less than 0.175 mg/L, but would not eliminate surface water exposure via West Kilby Ditch as does Alternative C. No constructed wetland to reduce surface water concentrations discharging to Three Mile Branch. Institutional controls would limit or prevent exposure to groundwater across the CBP.	PRB would reduce VOC concentrations to less than the 0.175 mg/L surface water ARAR in baseflows to Kilby Ditch. Institutional controls would limit or prevent exposure to groundwater exceeding the 0.005mg/l ARAR for TCE in groundwater at the CBP.	Slightly more difficult and costly than Alternative C, but not significantly more effective at meeting remedial objectives. Meets surface water ARARs for Kilby Ditch. Protective of human health for groundwater exceeding ARARs.
Numerical Rating		7	7	5	10	7	7	5	5	7	Average Rating – 6.7
B	▪ Install PRB along Coliseum Boulevard ▪ Retain fencing along West and Main Kilby Ditches ▪ Construct wetlands and modify stream for TCE treatment. Construct hydraulic barrier and perimeter fencing in the Low-lying Areas ▪ Continue operation of Southwestern borrow pit dewatering operations ▪ Monitor groundwater and surface water ▪ Implement institutional controls to restrict access to and prevent use of groundwater	Protective via limiting access to groundwater and surface water. Less protective than Alternative C because access to surface water not prevented. VOC concentrations in surface water in Kilby Ditch probably greater than the concentrations via Alternative A. Wetlands would reduce VOC concentrations in surface waters.	Least effective because groundwater east of Kilby Ditch and west of PRB not treated by PRB. Access limited by fencing only, which is less effective than covering ditch or implementing slope stabilization	Marginally the most effective because treats a larger volume of VOC-containing groundwater and treats surface water within the constructed wetlands. PRB in Kilby Ditch area reduces toxicity, mobility and volume of chlorinated VOCs. Effectiveness of constructed wetlands equal to Alternative C.	Least effective of the three alternatives because VOC-containing groundwater downgradient of the PRB would discharge to West Kilby Ditch and Main Kilby Ditch.	Most difficult to implement. Traffic disruptions and high levels of health and safety controls to construct PRB along Coliseum Boulevard. PRB requires more specialized construction techniques.	▪ PNW of $15.3M ▪ Capital Cost of approximat ely $10M	Least acceptable alternative because short-term disruption of vehicular and pedestrian traffic and would not eliminate surface water exposure via West Kilby Ditch as does Alternative C.	PRB would reduce VOC concentrations in surface water to less than 0.175 mg/L, but would not eliminate surface water exposure via West Kilby Ditch as does Alternative C. Includes constructed wetland to provide reduction of VOCs in surface water to meet discharge criteria of Three Mile Branch. Institutional controls would limit or prevent exposure to groundwater across the CBP.	PRB would reduce VOC concentrations to less than the 0.175 mg/L surface water ARAR in baseflows to Kilby Ditch. Institutional controls would limit or prevent exposure to groundwater exceeding the 0.005mg/l ARAR for TCE in groundwater at the CBP.	Most difficult and costly to implement, and least effective at meeting objectives. Meets surface water ARARs for Kilby Ditch. Protective of human health for groundwater exceeding ARARs.
Numerical Rating		5	5	10	5	5	5	5	7	7	Average Rating – 6.0
C	▪ Cover West Kilby Ditch and stabilize the slope along the northern section of Main Kilby Ditch ▪ Retain or reposition fencing along Main Kilby Ditch ▪ Construct wetlands and modify stream for TCE treatment. Construct hydraulic barrier and perimeter fencing in the Low-lying Areas ▪ Continue operation of Southwestern borrow pit dewatering operations ▪ Monitor groundwater and surface water ▪ Implement institutional controls to restrict access to and prevent use of groundwater	Protective via limiting access to groundwater and surface water. VOC concentrations in surface water in Kilby Ditch potentially greater than the concentrations via Alternative A. Wetlands would reduce VOC concentrations in surface waters. Most protective at significantly reducing access to VOC-containing surface water in West Kilby Ditch and northern section of Main Kilby Ditch.	Permanently eliminates access to surface water in West Kilby Ditch. Potential access in northern section of Main Kilby Ditch significantly reduced by slope stabilization with plants and rip rap.	Effectiveness of constructed wetlands equal to Alternative B.	Effective in short term because covering West Kilby Ditch & slope stabilization of Main Kilby Ditch significantly reduces access.	Easiest to implement of the three alternatives because covering West Kilby Ditch, implementing slope stabilization, and constructing wetlands uses standard construction techniques, versus PRBs, which require specialized construction techniques.	▪ PNW of $10M - this is $1.4M-$5.3M less than the two other alternative s. ▪ Capital cost of $4.5M, which is 30% less than capital cost for Alternative A.	Potentially most acceptable to public because West Kilby Ditch covered and potential access to surface water in Main Kilby Ditch reduced. Also may increase aesthetic value of area. Less disruptive to community and traffic than other alternatives.	Covering Kilby Ditch would limit or prevent exposure to surface water that may exceed 0.175 mg/L. Includes constructed wetland to provide reduction of VOCs in surface water to meet discharge criteria of Three Mile Branch. Institutional controls would limit or prevent exposure to groundwater across the CBP.	Covering Kilby Ditch would limit or prevent exposure to surface water exceeding the 0.175 mg/L surface water ARAR in baseflows to Kilby Ditch. Institutional controls would limit or prevent exposure to groundwater exceeding the 0.005mg/l ARAR for TCE in groundwater at the CBP.	Easiest to implement and effective at meeting objectives. Protective of human health for groundwater exceeding ARARs. Protective of human health for surface water in Kilby Ditch exceeding ARARs.
Numerical Rating		10	10	8	10	10	10	10	10	7	Average Rating – 9.4

Note: Numerical values range from 1 (least effective) to 10 (most effective)

APPENDIX A1

OVERVIEW OF ALDOT CBP REPORTS AND PLANS

SITE-WIDE CORRECTIVE MEASURES EVALUATION

COLISEUM BOULEVARD PLUME SITE
MONTGOMERY, ALABAMA

ALABAMA
DEPARTMENT OF TRANSPORTATION

Synopsis of: "Conceptual Geology and Hydrogeology Based on Investigations through March 2001; Coliseum Boulevard Plume Site; Montgomery, Alabama"; May 9, 2001

This report was the culmination of an investigation to determine the geology and extent of TCE in soils/sediments and shallow ground water within the CBP. The investigation was completed in phased tasks over 18 months and comprised continuous soil/sediment coring to determine geology; constructions of monitoring wells and piezometers; and analyses of soil/sediment, groundwater, surface water, and vapor samples. The report provided the initial site-conceptual model of the geology, shallow stratigraphy, groundwater/surface-water interactions, influences on the directions of groundwater flow, and analytical results of site investigations that had been completed, to date. The locations of probeholes, piezometers, vapor implants, and monitoring wells and the results of the analyses of ground-water samples for TCE/VOCs were provided on two Plates within the report.

The investigators established the hydrogeologic framework for the CBP and identified site-specific lithofacies by reviewing cross-sections developed from examinations of geologic logs, sieve analyses, and soil-conductivity logs. Hydraulically connected lithofacies were identified that control the movements of the shallow ground water and dissolved chlorinated solvents. Soils/sediments within the upper 80 feet at the CBP Site were "lumped" into three (3) lithofacies: (1) sandy clay; (2) fine- to coarse-grained sand that contains lenses of gravel and, (3) graded fine- to medium-grained sands with variable fractions of fines. The "fine- to coarse-grained sand with gravel lenses" was determined to be laterally continuous and to convey the majority of the ground-water flow within the shallow aquifer at the CBP.

Synopsis of: Coliseum Boulevard Plum Investigation Work Plan; Coliseum Boulevard Plume Site; Montgomery, Alabama; September 2000

The Work Plan provides the procedures, or roadmap, for assessment, investigation, feasibility study, and remedial design components that are required to ultimately implement the corrective measures for the CBP.

The Work Plan states that guidelines and methodologies of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) will be followed during the CBP evaluation. This includes completing a remedial investigation/feasibility RI/FS), remedial design (RD), and remedial action (RA). A brief description of the CERCLA components, as described in the Work Plan and submitted to the ADEM, are provided below:

- Remedial Investigation (e.g. CBP Investigation Reports): The RI gives the methods for data collecting which characterizes the site conditions, TCE's nature and extent, the amount of risk to human health and the environment, and treatability studies which evaluate remedial alternatives' cost and performance potential.

- Feasibility Study (e.g. Corrective Measure Evaluation Report): The FS provides the methods for the development, screening, and evaluation details of potential alternative remedial actions. The comprehensive feasibility study is required once the field investigation, collection of data, data analysis, and baseline risk assessment is completed. The feasibility study focuses on the development of temporary and final corrective measures for the CBP.

- Remedial Design (e.g. Corrective Measure Implementation Plans): The Remedial Design uses engineering criteria to describe the selected alternative. A drafted specification package is also included in the Remedial Design in order to implement the selected alternative.

Additionally, the Work Plan describes field and analytical methods that follow United States Environmental Protection Agency Region IV Standard Operating Procedure and Quality Assurance Manual and ADEM approved documents and methods.

Synopsis of: "Institutional Control Program, Coliseum Boulevard Plume, Montgomery, Alabama"; April 2008.

The Institutional Control Program (ICP) provides the details of institutional controls, which are a component of the CME report. Institutional controls are non-engineered instruments such as administrative and/or legal controls that minimize the potential for human exposure to contamination by limiting land or resource use. ADEM adopted this definition of institutional controls in ADEM Rule 335-15-1-.02(z)(2 and 3) for land-use controls to limit or control exposure to residual contamination on property.

The purpose of the ICP is to restrict access to TCE within the groundwater in the CBP. The ICP comprises legal, administrative, and outreach components. The legal component provides for agreements with owners of real property in the CBP for restrictive covenants. The covenants are executed with each owner of property at the time of execution and are filed in the probate records such that the covenants are legally enforceable in perpetuity with deed restrictions that prohibit unauthorized access to and use of groundwater and access easements for continued CBP investigations and monitoring. The administrative component of the ICP provides procedures for ongoing oversight, monitoring and enforcement of the deed restrictions. Through the outreach component, current and future stakeholders in the CBP will continue to receive information about institutional controls.

The ICP is being administered in two steps. First, Restrictive Covenants that contain groundwater access and use restrictions are being executed for parcels within an Institutional Control Boundary (ICB). These Covenants are being recorded and indexed in the land records of Montgomery County to provide notice of the restrictions to all interested parties. Second, administrative and outreach procedures are being implemented for ongoing oversight and enforcement of the restrictions.

Synopsis of: "Interim Corrective Measures Report, East Coliseum Ditch Area, Coliseum Boulevard Site, Montgomery, Alabama"; September 2001

The purpose of the Interim Corrective Measures Report (ICM) was to develop, screen, evaluate, and select interim corrective measures alternatives, which are protective of human health, to eliminate or reduce the potential exposure to TCE detected in Kilby Ditch.

The ICM for Kilby Ditch provided qualitative and quantitative Interim Corrective Measures Objectives (ICMOs), or clean-up objectives, which were established on the basis of the known nature and extent of detected constituents, the resources that were threatened at the time, and the potential for human and environmental exposure. The ICMO was to minimize the potential for contact with TCE in the West and Main Kilby Ditches. The ICMO would be achieved using one or more of the following corrective measures:

- Eliminate groundwater entering the West Kilby Ditch through the stormwater system.
- Reduce TCE concentrations in groundwater prior to entering the Ditches so that no TCE enters the West and Main Kilby Ditches through groundwater discharge.
- Eliminate the potential contact with surface water in the West and Main Kilby Ditches.

Eight (8) alternatives were developed and evaluated in an effort to represent a wide range of corrective actions in terms of both cost effectiveness and protection of human health and the level of difficulty in implementing the alternative. The alternatives evaluated included:

1. No Further Action with monitoring
2. Stormwater Pipe Repair and Existing Fence
3. Covering Ditch Area with Grating
4. Interceptor Trench with Treatment and Discharge
5. In-situ Chemical Oxidation
6. Reactive Wall
7. Reactive Interceptor Trench and Discharge
8. In-Channel Reactive Barrier

"Alternative 2" (Stormwater Pipe Repair and Existing Fence) was selected based on an evaluation of EPA and ADEM balancing criteria as the best alternative to meet ICMOs specific to Kilby Ditches. Specifically, Alternative 2 included the following components:

- Patch sealing of all leaking joints/cracks in the 84 by 54 inch reinforced concrete arch pipe located west of Coliseum Boulevard, the junction box adjacent to Coliseum Boulevard, the two 65 by 40 inch pipes under Coliseum Boulevard, and the 18-inch pipe located east of Coliseum Boulevard that runs from the cul-de-sac area north of West Kilby Ditch.
- Utilization of the existing fence to prevent potential human contact with the surface water within the West and Main Kilby Ditches.
- Enhanced monitoring of groundwater and surface water in this area to assess the effectiveness of the effort to reduce groundwater infiltration into the stormwater pipes.

Synopsis of: "PH12 Area Status Report in Support of Corrective Measures Development"; September 2005

Following submittal of the PH12 Area Site Characterization and Technology Screening Report (ALDOT, 2003) to ADEM, ALDOT proposed to conduct an additional investigation in the PH12 Area to assess the potential presence of dense non-aqueous phase liquid (DNAPL). The purpose of the *PH12 Area Status Report in Support of Corrective Measures Development* report was to present the results of the supplemental PH12 Area investigation (Including results of membrane interface probe and soil conductivity DNAPL screening), and numerical groundwater modeling performed in support of the effort to evaluate potential corrective measures for the PH12 Area. This report summarized:

- The groundwater modeling effort and results.
- The interrelation between TCE concentrations in the PH12 Area and the remainder of the CBP.
- Evaluations of several potential corrective measures, potential exposure pathways and receptors.
- Conclusions and recommendations in support of the preparation of a site-wide CBP CMS Report.

Evaluation of potential exposure pathways indicated that there were no exposure pathways within the PH12 Area because: 1) There are no surface water bodies within the PH12 Area; 2) groundwater within the CBP (including the PH12 Area) is not used for public or private water supplies; and, 3) the results of extensive soil vapor sampling in and around the PH12 Area indicated that VOC concentrations in soil vapor do not exceed the ADEM screening level of 20 parts per billion by volume (ppbv). The supplemental characterization of the PH12 Area:

- Indicated the absence of TCE DNAPL;
- Confirmed previous results of TCE concentrations in that area; and,
- Provided a more detailed assessment of the stratigraphy and hydrogeology of the PH12 Area in locations that were previously not accessible prior to 2005.

Results of modeling indicated that potential corrective measures in the PH12 Area could remove a significant amount of mass from the PH12 Area and lower TCE concentrations near the PH12 Area over a 30-year period. The following engineering controls and treatment technologies were evaluated during the technology screening evaluation:

- Groundwater pumping with ex-situ treatment.
- Fluid flushing with amended water.
- Chemical oxidation using hydrogen peroxide (Fenton's reagent), sodium and potassium permanganate, sodium persulfate, or ozone.
- Enhanced bioremediation using anaerobic, aerobic, and co-metabolic processes.
- Barrier walls, including slurry walls and sheet piling walls.
- Reactive iron injection using zero-valent iron particles to degrade chlorinated VOCs through abiotic reductive dehalogenation.
- Groundwater circulation wells (GCWs).
- Permeable Reactive Barrier (PRB) walls, based on trenching technology.

The corrective measures that focus on the PH12 Area would, during 30 years, not address TCE groundwater concentrations at the distal portions of the CBP or in areas where groundwater discharges to surface water, such as the Kilby Ditch Area. The report concluded that, as no exposure pathways exist in the PH12 Area, no interim corrective measures were needed to address the PH12 Area while a site-wide CMS was prepared. Because of the anticipated limited effect of potential PH12 Area corrective measures on distal portions of the CBP, it was deemed necessary to further evaluate the site-wide TCE plume and integrate the corrective measures for the CBP site with those of the PH12 Area. Therefore, ALDOT proposed to prepare a Corrective Measures Study (CMS) for the CBP that incorporated the PH12 Area into the CBP as a whole.

Synopsis of: "PH12 Area Site Characterization and Technology Screening Report"; June 2003

The purpose of the *PH12 Area Site Characterization and Technology Screening Report* was to summarize the PH12 investigations that were performed to characterize the nature and extent of TCE in the PH12 Area. The report also presented a preliminary screening of potential remedial technologies for the PH12 Area, with plans for a comprehensive corrective measures study (CMS) for the PH12 Area to be provided in a later report. The first part of the Report summarized results of site characterization activities, which included:

- Direct-push sampling of both soil and groundwater in the PH12 Area to assess the extent of TCE in the shallow saturated zone of PH12;
- Sampling and analysis of groundwater samples from existing and new shallow-zone monitoring wells in the PH12 Area; and,
- Sampling and analysis of groundwater samples from deep-zone monitoring wells in the PH12 Area.

In addition to a summary of sampling and analysis results in the PH12 Area, the report also provided a characterization of the PH12 Area, including discussions of site geology and hydrogeology. The Report also provided a brief synopsis of soil vapor and ambient air sampling results from work performed previously in the PH12 Area. The PH12 Area characterization results indicated that, while there is a significant area of relatively high concentrations of TCE in the shallow saturated zone groundwater within the PH12 Area, a DNAPL source was not identified during the extensive and various investigations. In addition, results from the deep saturated zone investigation concluded that TCE and other contaminants present in the shallow saturated zone had not migrated to the deep saturated zone.

The second part of the report summarized the results of the general CME for the PH12 Area. The report identified the following general response actions for the PH12 Area:

- **No Further Action**;
- **Monitoring**, including long-term monitoring and monitored natural attenuation;
- **Institutional Controls**, including access restrictions, groundwater use restrictions, and land use restrictions;

- **Engineering Controls/Containment Technologies**, including groundwater pumping and barrier wall technologies;
- ***In Situ* Treatment Technologies**, including chemical technologies (chemox, iron injection, and PRBs), physical technologies (fluid flushing and groundwater circulation wells), and biological technologies (anaerobic, co-metabolic, and aerobic enhanced bioremediation);
- ***Ex Situ* Treatment Technologies,** including chemical technologies (advanced oxidation processes), physical technologies (air stripping, liquid-phase carbon adsorption, and separation processes), and bioreactors; and
- **Groundwater Disposal Options**, including reinjection to the subsurface, discharge to publicly-owned treatment works, and discharge to surface water.

Each GRA was evaluated based on its potential effectiveness, implementability, and relative cost. The CME concluded that no further action, monitoring, groundwater pumping, treatment options (chemical oxidation, fluid flushing, advanced oxidation process, air stripping, liquid-phase activated carbon, and enhanced bioremediation), and groundwater disposal were viable technologies for the PH12 Area. The report concluded that these technologies would be assembled into corrective measures alternatives for discussion and further evaluation in a proposed comprehensive CMS for the PH12 Area.

Synopsis of: Status Reports; Coliseum Boulevard Plume Site; Montgomery, Alabama; July 1, 2008

The status reports consist of the on-going investigation and monitoring data collected at the Coliseum Boulevard Plume site in Montgomery, Alabama. The data is generated from the routine monitoring of groundwater monitoring (MW) wells, continuous multi-channel tubing (CMT) wells, sediment, and surface water. The quarterly and annual monitoring is completed in accordance with Modification to Addendum 13 – Ground Water Monitoring Plan (dated March 17, 2005).

For groundwater monitoring, samples are collected from a select number of wells for analysis of VOCs. Prior to sample collection, a bladder or peristaltic pump is used to purge the wells until field parameters (pH, conductivity, turbidity, temperature, and ORP) stabilize. EPA Method 8260 is used by the laboratory to analyze VOCs in groundwater samples. Groundwater is also sampled for inorganic parameters including total alkalinity, chloride, nitrate, sulfate, and total organic carbon. Wells are also gauged for groundwater elevation and total depths of wells.

Surface water samples are collected at the west and main branches of Kilby Ditch at five locations (these locations are compliance points CP-1, CP-2, CP-3, and monitoring points MP-1 and MP-2). Surface water samples are also collected from the Zoo Ditch at one location (ZD-1) and the Zoo Pond at location ZP-1. At each of the locations, the surface water samples are collected from water column in the middle of each ditch and from the pump intake location at the Zoo Pond.

At the Low-Lying Area, surface water and sediment samples are collected and included in the status reports. These samples are collected under the guidance of the Addendum 04 of the Comprehensive Work Plan. The sediment samples are collected using a hand auger at selective locations by EnCore samplers. For the determination of moisture content, a split sample is also taken that allows the analysis of VOCs on a dry weight basis. Sediment samples are collected immediately above the first hard silt, clay, or organic layer, which is located at a depth of less than one foot below land surface (BLS). The surface water samples are collected using a VOC glass vial (vial contains hydrochloric acid preservative) and carefully lowering the vial into the water as to not displace the preservative.