Section 10

Source Zone Remedial Evaluation

Updated March 2017

SOURCE ZONE REMEDIAL EVALUATION

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March 2013
Updated March 2017

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Contents

Tables

1. INTRODUCTION

Department of Energy (DOE) is scheduled to depart the Bannister Federal Complex (BFC) sometime in the near future. In light of the pending departure, DOE is interested in the potential impacts of source area remediation on the scope and duration of groundwater pump-and-treat operations. This **Source Zone Remediation Evaluation** was undertaken to evaluate various potential source zone remediation scenario outcomes and how those outcomes might reduce the duration of pump-and-treat operations if the BFC remains as is and if all the buildings are removed and the building footprints are replaced with grass. This evaluation continues the **Kansas City Plant Building Decommissioning and Interceptor System Evaluations** (A. D,. Laase Hydrologic Consulting, 2010A) that evaluated potential contamination migration patterns following various building decommissioning scenarios and developed well field configuration and pumping schedules to mitigate contaminant migration, and pumping schedules and number of interceptor wells required to halt contaminant migration for current and future BFC operations, respectively.

Just as important as what comprises this study, is what the study is not. This study does not evaluate or recommend specific remedial technologies, rather the evaluations are intended to provide insight into the source area remedial performance required to reduce the scope and duration of future BFC groundwater pump and treat operations. Given that remedial technology performance is site specific and is dependent on hydrogeology and the source area architecture (how DNAPL is distributed in the subsurface) vendors of the various remedial technologies will need to determine how their technology will likely perform at the BFC and whether their technology is capable of achieving the performance metric identified in this evaluation as necessary for successful source area remediation.

This evaluation focuses on how changes in source concentration and/or source duration resulting from remediation potentially influence the scope and duration of groundwater pump-and-treat operations at the BFC. Source concentration refers to the groundwater concentration within the source area. Source area groundwater concentrations are the ultimate arbitrator of source remediation because that is the metric that will determine when BFC pump-and-treat operations cease. Source duration refers to the length of time that the source will be active. In the absence of source area remediation, source duration (often referred to as ambient source duration) is the time required for the source mass to dissolve into passing groundwater such that resultant source area groundwater concentrations meet applicable standards. Source remediation removes source mass with the degree of removal being a function of the remedial technique and subsurface contaminant distribution. In other words, while source removal likely will remove the majority of the source mass, some source mass will remain. Source duration after source remediation is the time required for the remaining source mass to dissolve into passing groundwater such that resultant source area groundwater concentrations meet applicable standards.

Finally, this evaluation focuses on the effects source remediation at the Building 50, Department 26 and Former Plating Building (derived from the former Plating Building degreaser) and Northeast Area sources (Figure 1) will have on BFC temporal groundwater contaminant concentrations. It is recognized that there are other source areas that will have to be remediated for BFC pump-and-treat operations to cease.   The results from the **Source Zone Remediation Evaluation** are applicable to the other source areas and will elucidate the source area remediation performance metrics required to reduce the duration of BFC pump-and-treat operations.

2. METHODOLOGY

The **Source Zone Remediation Evaluation** was initiated by evaluating soil contaminant concentration data for Building 50, Department 26 and the Former Plating Building, and the Northeast Area to determine source area contaminant mass. The evaluation was performed by discretizing the existing Building 50, Department 26 and the Former Plating Building, and the Northeast Area source area contamination data into five foot vertical increments and contouring the trichloroethylene (TCE), dichloroethylene (DCE) and vinyl chloride (VC) soil concentrations within specific vertical intervals using *Surfer*™, a commercially available contouring program. It is recognized that free-phase TCE, a dense non-phase aqueous liquid (DNAPL) is the ultimate source material at the BFC. However, locating free-phase TCE is near impossible and thus TCE, DCE and VC soil concentrations were used to evaluate the mass of contamination present within the source areas. A routine within *Surfer*™ determined the mass of contamination present within each soil horizon.

After source area mass was determined, the time required for the source to completely dissolve into groundwater in the absence of remediation was calculated for Building 50, Department 26 and the Former Plating Building, and the Northeast Area source areas. The calculated durations serve as benchmarks to understand the magnitude of the problem and as a value to compare the potential benefits of undertaking source area remediation.

Next, the existing BFC MODFLOW2000 (Harbaugh et al, 2001) groundwater flow and RT3D (Clement, T. P. 1998) transport models were used to simulate various source area mass reduction outcomes for current conditions, where the BFC remains as is, and for future conditions where all the BFC buildings are removed. RT3D simulates the transport of TCE and daughter products DCE and VC in a single simulation based on assigned half-lives. The simulations used the extraction well field configurations and extraction rates presented in the **Kansas City Plant Building Decommissioning and Interceptor System Evaluations** report except as noted in Section 6. The transport simulations did not simulate actual source material dissolution, but rather expected changes in source area groundwater concentrations that result from source area dissolution and/or remediation. Simulation of actual source material dissolution is impossible given the current state of knowledge about the actual distribution and architecture of DNAPL in the BFC subsurface. Model-predicted, current and future condition temporal groundwater contaminant concentrations immediately downgradient of the three source areas were used to evaluate the potential benefits of source area remediation.

3. CONCEPTUAL MODEL OF DNAPL MIGRATION AT THE BANNISTER FEDERAL COMPLEX

The following Sections discuss conceptualized BFC subsurface DNAPL migration and potential limitations in characterizing DNAPL mass in the subsurface.

3.1 Conceptualized BFC DNAPL Migration and Fate

The hypothesized migration pathways of DNAPL from ground surface to the bottom of the alluvium are shown in Figure 2. The alluvium at the BFC is approximately 45-ft thick and includes and upper layer of clayey-silt and a basal gravel (1 to 8 feet thick) underlain by relatively impermeable bedrock. Spills at ground surface spread laterally following topography and those occurring as leaks from underground piping follow pipe chases. Vertical migration occurs when the spreading DNAPL encounters the more permeable vertical pathways within the upper clayey-silt. Given sufficient mass to overcome capillarity, the DNAPL migrates vertically until it reaches the basal gravel unit where, given sufficient volume, the DNAPL pools and spreads out laterally on the bedrock surface. Some lateral spreading can also occur along the top of less permeable horizontally trending layers during vertical migration.

The described DNAPL migration pattern isn't the final disposition of DNAPL distribution. As a result of capillarity and gravity, DNAPL in the more permeable vertical pathways snaps off and forms ganglia. In addition, as DNAPL migrates vertically, concentration gradients cause contamination to move horizontally away from the vertical pathway into the less permeable matrix creating a narrow cylindrical halo of source material around the pathway. The same diffusive phenomenon occurs within the basal gravel. DNAPL originally pooling on the bedrock surface diffuses into the surrounding basal gravel clay matrix.

3.2 Characterization Limitations

The above hypothesized distribution of source material at the BFC makes it difficult to characterize source mass. In the upper clayey-silt source mass is vertically trending. Soil sampling is accomplished using hollow-stem augers that collect continuous vertical cores of soil. Realistically there is minimal chance that the auger hole will be started over a vertical migration pathway or even if it did that the vertical migration pathway would remain perfectly vertical within the sampling borehole path. Thus, there is a high probability the higher concentration soil volumes within the upper clay-silt will be missed during characterization.

Source area characterization within the basal gravel is also problematic. Hollow-stem augers rely on a catching device (Figure 3) to keep the soil core from dropping out of the auger during retrieval. The soil catcher is hemispherical with "fingers" that open when the auger is moving downward and close to trap the soil core with upward auger movement (retrieval). Because of its hemispherical shape, a necessity to ensure soil core capture, the last few of inches of soil at the bottom of the core hole are typically not captured. Unfortunately, the "missed" horizon likely contains the highest source zone concentrations, assuming source material is present. In addition, encountering gravel pieces larger than the width of the coring device will not allow soil samples to be collected below the elevation where the gravel was encountered.

In summary, given the conceptualized complex subsurface DNAPL migration patterns and sampling limitations, the level of uncertainty in source mass characterization can be as high as an order of magnitude or more (EPA 2003). That being said, the inability to accurately assess source mass doesn't impact the ability to characterize source location which is a function of contamination occurrence and not absolute concentrations.

4. SOURCE AREA MASS EVALUATION

Soil VOC concentration data, provided by Honeywell FM&T, was evaluated to determine the mass of contamination present at Building 50, Department 26 and the Former Plating Building, and the Northeast Area source areas (Figure 1). The evaluation was initialed by dividing the soil data into five foot depth horizons and contouring the data using Surfer™ and then applying a Surfer™ algorithm that determines the mass present within the contour limits. To limit the extent of contoured soil contamination, control points having zero as values were placed at the edges of the source areas.

4.1 Building 50

Source mass evaluation predicts that a total of 66 pounds of TCE, DCE and VC are present in the subsurface at Building 50 (Table 1). Note that no soil samples were collected in the 20 to 25 feet below ground surface interval. TCE is the dominant Building 50 subsurface contaminant. In general the majority of mass is associated with a single bore hole (Figures 4 through 21). Note that soil contamination data was not collected consistently at all depth intervals, which may explain the variability in contaminant mass with depth.

4.2 Department 26 and the Former Plating Building

Source mass evaluation predicts that a total of 30,560 pounds of TCE, DCE and VC are present in the subsurface at Department 26 and the Former Plating Building (Table 2). The distribution of soil contamination (TCE, DCE and VC) as a function of depth at the Department 26 and Former Plating Building source area is shown in Figures 20 through 45. Note that 99% of the calculated mass is associated with TCE contamination in a single soil boring at depths of 40 to 45 feet below ground surface. The absence of significant soil contamination at other depths intervals in a source area having the highest BFC groundwater contamination concentrations (MW192 located at the source area has TCE concentrations approaching the saturation limit) demonstrates the difficulty in characterizing source mass. Clearly significant contaminant mass must be present for such high, persistent TCE groundwater concentrations to exists. However, high concentration soil contamination wasn't encountered, with exception of a single borehole at one depth, during characterization activities.

To put the uncertainty associated with source mass calculations in perspective compare the 30,560 pounds of VOCs predicted to be at the source area with a narrative describing past operations at the Plating Building Vapor Degreaser (the likely source of contamination noted in the Department 26 and Former Plating Building area). The Vapor Degreaser, when TCE was the solvent, was in operation between 1957 and 1976, a period of 19 years. An employee remembers adding a 55-gallon drum of TCE to the unit every week to replace what was lost through evaporation and leaks. If true, and no written records exist to verify the claim, approximately 988 55-gallon drums of TCE, weighing 661,960 pounds, were consumed by the Vapor Degreaser in 19 years. The pounds of TCE reportedly "consumed" are approximately 22 times that characterized as being present in the source area. While it is unlikely the entire 661,960 pounds of TCE was lost to the subsurface it is likely that the mass actually lost to the subsurface is greater than the characterized source area mass.

4.3 Northeast Area

At the Northeast Source Area, source mass evaluation predicts that a total of 27,608 pounds of TCE, DCE and VC are present in the subsurface (Table 3). The distribution of soil contamination (TCE, DCE and VC) as a function of depth at the Northeast Area source area is shown in Figures 48 through 74. DCE, a degradation product of TCE, is the dominant contaminant present at the source area. The majority of contamination (91%) is present at 15 feet to 30 feet below ground surface.

5. SOURCE AREA MASS EVALUATION

Paramount to determining the value of undertaking source remediation is an understanding of how long the contaminant source will last in the absence of source remediation. A source that will expire in a few decades is a different problem than one that will last for thousands of years. Simplistically, the DNAPL source will be active until it has completely dissolved into groundwater which is a function of how much DNAPL is present, how much groundwater flows through the source area and the dissolution rate of the DNAPL into groundwater (represented by the down gradient groundwater contaminant concentrations). The following sections evaluate expected ambient source duration at Building 50, Department 26 and the Former Plating Building and the Northeast Area.

5.1 Building 50

Source duration at Building 50 was calculated using the following equation (1):

$SD = S_m/(G_wF*\sum G_wC)$

Where:

SD = Source Duration, t

S_m = Source Mass, M

G_w F = Groundwater Flux, L^3/t

$\sum G_wC$ = Sum of representative TCE, DCE and VC groundwater concentrations downgradient of the source area, M/L^3

Table 4 lists the inputs for the above equation which assumes linear dissolution of source mass. Typical groundwater concentrations are based on the historic record from monitoring well GS01-501. The volume of groundwater flowing though the source area (groundwater flux) was extracted from the BFC calibrated groundwater flow model (A. D. Laase Hydrologic Consulting, 2010B). Calculations predict in the absence of remediation the Building 50 source area is expected to last another 35 years. However, recognize that based on source mass characterization uncertainty (Section 3.2) the source duration estimate could be off by an order of magnitude or more. Thus, the Building 50 source could be active between 35 years and 350 years.

It should be noted that the above calculation uses present day groundwater flow rates through the Building 50 source area. It is recognized that BFC groundwater flow rates and patterns will change in response to future BFC uses. For the purposes of this evaluation it was assumed that all the BFC buildings are removed and the building footprint replaced with grassy areas. However, the potential change in groundwater flow rates through the source area is expected to be significantly less than the uncertainty associated with source mass characterization. Thus, while it is recognized that groundwater flow volumes will change with building demolition, the calculated source mass duration is still likely to be reasonably representative.

5.2 Department 26 and the Former Plating Building

Coupling Equation 1 with the values listed in Table 5 yields an ambient source duration of 20 years for the Department 26 and Former Plating Building source area. Note that the source duration calculation includes both westward groundwater flow towards the tile drains and eastward groundwater flow towards the extraction wells. Typical groundwater concentrations are based on the historic record from monitoring well MW-192. Again, the volume of groundwater flowing though the source area (groundwater flux) was extracted from the BFC calibrated groundwater flow model (A. D. Laase Hydrologic Consulting, 2010B). Because of uncertainty in source mass characterization, the source duration estimate could be off by an order of magnitude or more. Recognizing this, the Department 26 and Plating Building source could be active between 20 and 200 years.

To confirm the 20 year estimate of potential ambient source duration, the Department 26 and Former Plating Building source duration was also evaluated based on dissolved contaminant mass within the Indian Creek plume and typical BFC extraction system groundwater pumping rates. In 2012 pumping from the BFC extraction wells totaled approximately 16 gallon/minute with approximately half of the pumping coming from Indian Creek Flow System extraction wells. In 2012 the BFC groundwater extraction system was operated solely as a containment system, that is just enough groundwater was pumped (8 gallons/minute) to halt downgradient Indian Creek plume migration. Simplistically groundwater flow volume into the Indian Creek plume now equals what is being pumped by the Indian Creek extraction wells.

The Indian Creek plume contains 118,247,413 gallons of contaminated groundwater and 1,494 pounds of dissolved volatile organic contamination (DOE 2012). Note that the Indian Creek Plume volume and mass are one-quarter that reported in the 2012 Annual Report. This is because the calculations did not include porosity, which was assumed to be 0.25. Dividing the Indian Creek plume volume by the cumulative annual Indian Creek extraction well pumping rate shows that approximately 28 years are required to capture the entire Indian Creek plume.

Based on plume mass and the time required to capture one plume volume, source duration at Department 26 and the Former Plating Building can be calculated using the following equation (2):

$$SD = S_m/(P_m/PC_t)$$

Where:

SD = Source Duration, t

S_m = Source Mass, M

P_m = Plume mass, M

PC_t = Time to capture one plume volume, t

Table 6 lists the inputs for the above equation which like before assumes linear dissolution of source mass. Calculations predict that 576 years are required for complete source area dissolution, which is more believable when compared to the previous estimate of 20 years. It is recognized that contamination within the Indian Creek Plume is derived from more than just the Department 26 and Former Plating Building Source Areas. It is also recognized that footing tile drains capture some of the Indian Creek Plume. However, excluding additional source masses and extraction volumes from the calculation, won't likely change the overall magnitude of the source duration estimate. Many hundreds of years will be required for the source to be dissolved under ambient conditions. As with previous calculations, based on source mass characterization uncertainty (Section 3.2) the source duration estimate could be off by an order of magnitude or more. Thus, the Department 26 and Plating Building source area could be active between 576 and 5,760 years.

5.3 Northeast Area

As with the two previous source areas, Northeast Area source duration was also evaluated using typical groundwater concentrations and model-predicted groundwater flow (Equation 1). Input values for the evaluation are listed in Table 7. The results predict Northeast Area ambient source duration of 766 years. Typical groundwater concentrations are based on the historic record from monitoring well MW-18. Again, the volume of groundwater flowing though the source area (groundwater flux) was extracted from the BFC calibrated groundwater flow model (A. D. Laase Hydrologic Consulting 2010B). Because of uncertainty in source mass characterization, the source duration estimate could be off by an order of magnitude or more. Recognizing this, the Northeast Area source could be active between 766 and 7,660 years.

While an ambient source duration of 766 years is believable, for comparison purposes, similar to the Department 26 and Former Plating Building source duration evaluation, Northeast Area source duration was also evaluated based on dissolved contaminant mass within the Blue River plume and typical BFC extraction system groundwater pumping rates (Equation 2). In 2012, pumping from the BFC extraction wells totaled approximately 16 gallon/minute with approximately half of the pumping coming from Blue River extraction wells. In 2012 the BFC groundwater extraction system was operated solely as a containment system, that is just enough groundwater was pumped (8 gallons/minute) to halt downgradient Blue River plume migration. Simplistically, as with the Indian Creek Flow System, groundwater flow volume into the Blue River plume now equals what is being pumped by the Blue River extraction wells.

The Blue River plume contains 46,813,231 gallons of contaminated groundwater and 692 pounds of dissolved volatile organic contamination (DOE 2012). Again note that the Blue River plume volume and mass are one-quarter that reported in the 2012 Annual Report. This is because the calculations did not include porosity, which was assumed to be 0.25. Dividing the Blue River plume volume by the cumulative annual Blue River extraction well pumping rate shows that approximately 11 years are required to capture the entire Blue River plume.

Based on plume mass and the time required to capture one plume volume, Northeast Area source duration can be calculated using Equation 2.

Table 8 lists the inputs for the above equation which like before assumes linear dissolution of source mass. Calculations predict that 439 years are required for complete source area dissolution, a number similar in magnitude to the previous prediction of 766 years. As with previous source duration calculations, based on source mass characterization uncertainty (Section 3.2) the source duration estimate could be off by an order of magnitude or more. Thus, the Northeast Area source area could be active between 439 and 4,390 years.

5.4 Biodegradation Evaluation

Subsurface biodegradation of contamination does occur in the subsurface at the BFC as evidenced by the presence of DCE and VC, both degradation products of TCE. An evaluation was undertaken to determine whether ambient biodegradation at the source areas could be a viable remediation strategy or part of the remediation strategy. That is, would a source area left alone degrade sufficiently fast such that active remediation is not warranted. Additionally, ambient biodegradation might be used to augment active remediation. Rather than completely reducing source area contaminant concentrations, the remediation effort could be halted at predetermined concentrations and biodegradation used to further reduce source concentrations to the target levels.

The biodegradation evaluation used the following equation (3):

Half-life = $(-\ln(2) \times t)/\ln(TCE(t)/TCE_0)$ [BIOSCREEN, EPA/600/R-96/087]

Where:

TCE_0 = moles TCE at release, time = 0

TCE(t) = moles TCE at time t (time since release or travel time between points)

ln(2) = 0.69

t = time since release

The evaluation assumes that the number of moles of TCE, DCE and VC present are equal to the initial molar mass of TCE.

Review of the biodegradation rates calculated for Building 50, Department 26 and the Former Plating Building and the Northeast Area revealed that the calculated source area rates are not supported by site data and as such the results were not reported. For example, biodegradation half-life evaluation suggested that 740 years is required for half of the TCE present at the Northeast Area source to degrade to DCE. Given that approximately 50 years have passed since releases occurred in the Northeast Area and 74% of the source mass present is DCE, a biodegradation product of TCE, the calculated biodegradation rates are clearly not representative. In the absence of representative biodegradation rates, biodegradation effects were not included in the estimates of source duration.

5.5 Summary of Source Duration Evaluation

Source duration calculations predict that as little as 20 years and as much as 766 years are required for BFC sources to dissolve completely in groundwater under ambient conditions. The calculations assume a linear dissolution rate. It is likely that the actual dissolution rate is not linear and dissolution rates will slow down after the most accessible contamination has been dissolved. In addition, as discussed in Section 3.2, it is likely that characterization under-estimates source mass by as much as an order of magnitude which could result in a corresponding increase in ambient source duration. Based on characterization uncertainty, and the likely non-linearity of source material dissolution, it is possible that complete dissolution of BFC source material under ambient conditions could take as much as 10,000 years.

6. SOURCE AREA REMEDIATION EVALUATION

The potential benefits of source remediation were evaluated with solute transport models where source area concentrations and/or source duration were systematically reduced and the predicted change in downgradient groundwater concentrations evaluated to access potential remedial effectiveness. The systematic reductions in source groundwater concentration and source duration are not intended to mimic specific remedial technologies, rather the simulation results are intended to provide insight into the source area remedial performance required to reduce the scope and duration of future BFC groundwater pump and treat operations. Note that the performance of the various remedial technologies is site specific and is dependent on hydrogeology and the source area architecture. Vendors of the various remedial technologies can best determine how their technology will likely perform at the BFC. In addition to simulating systematic reductions in source groundwater concentrations and durations, transport simulations were also performed where the source was allowed to dissolve under ambient flow conditions and when the source was instantaneously removed. These two simulations are considered end member scenarios against which the various source remediation scenarios can be compared against.

The evaluations were performed for current and expected future BFC operational conditions, including groundwater pump and treat operations. Figure 75 and 76 show extraction well locations and pumping rates for current and future conditions. Current conditions represent today's building and parking lot configuration and extraction well operations. Future conditions assume the BFC complex buildings will be removed and the building foot prints replaced with grass. Note that the extraction well configuration and pumping rates are different than what is presented in the **Kansas City Plant Building Decommissioning and Interceptor System Evaluations** (A. D. Laase Hydrologic Consulting 2010B). In working on this evaluation it was discovered that a mistake had been made in reporting the extraction well locations and pumping rates. The future conditions also assume that the current parking lot configuration will remain static. Truthfully there is no way of knowing the future disposition of the BFC. The implications of this are that it is impossible to predict with complete confidence the future groundwater flow regime and the "best" extraction well configuration to contain contamination. Reality is that the proposed future extraction well configuration will need to be revisited after the future of the BFC has been determined.

With respect to the contaminant transport simulations, the simulations that mimic decreases in source groundwater concentrations but no corresponding decrease in source duration represents removal of the more easily accessed subsurface contamination, that being located in the more permeable portions of the alluvium, and the retention of contamination diffused into the lower permeability portions of the aquifer. For example, a treatment technology may remove source material within the more permeable portion of the alluvium but leave source material located in the lower permeability portions of the alluvium untreated. The source material remaining in the low permeability portions of the alluvium after remediation will continue to contaminate groundwater via diffusion potentially for decades or centuries.

The simulation scenarios where dissolved contamination levels remain similar to current concentrations after remediation but for a shorter duration represent relatively homogenous but incomplete destruction of contamination. That situation is analogous to a source area of sufficient strength such that groundwater saturation is reached at the upgradient portion of the source area. Under that condition no additional contaminant mass is dissolved as saturated groundwater flows through the remaining source. With remediation, an analogous situation is mass is removed but the remaining mass is still sufficient to saturate groundwater such that downgradient groundwater concentrations are maintained, albeit for a shorter duration relative to doing nothing. Note that the volume of saturated groundwater and the volume of aquifer sampled by the well may represent different scales. The sample collected from the well more or less represents concentrations over the well screen while saturation may occur in a much smaller volume of water than the length of the well screen.

The final simulation scenario is where remediation reduces both the source mass, which results in a reduction in downgradient groundwater contaminant concentrations, and the source duration. Remediation under this scenario removes contaminant mass such that the remaining mass distribution yields lower dissolved contaminant concentrations and dissolves in a shorter duration of time due to a reduction in mass.

Lastly, the above simulation scenarios represent idealized scenarios. Dissolved contaminant concentrations are not expected to be constant throughout the dissolution process. More than likely concentrations will slowly decline with time and then drop relatively quickly once the majority of mass is dissolved.

All current and future scenarios assumed maximum source durations of 250 years. It is recognized the source duration evaluations predicted, that as a result of uncertainty, ambient source duration could be as much as 10,000 years (Section 5.4). However, preliminary evaluations showed that simulating contaminant transport for even 1,000 years would require approximately 80 days to complete. In recognition that multiple transport simulations are required for the evaluation the simulations were limited to 250 years. Conclusions resulting from the 250 year simulations are still applicable for instances where ambient source duration is greater than that time span. This is because under the idealistic conditions simulated, the source is assumed to instantaneously deplete at the end of the ambient source durations. Model-predicted temporal groundwater concentrations following source mass depletion will follow the same downward path and require the same amount of time to reach groundwater standard whether the source duration is 250 years or 1,000 years. Thus, in a relative sense, the relationship between remedial outcomes for the various scenarios is preserved regardless of ambient source duration.

6.1 Building 50

Transport simulations were performed where the Building 50 source area concentration and duration were systematically altered for both current and future conditions. Source area changes included complete source removal (100% reduction in source area concentration and duration), source area concentration reductions of 50%, 75% and 95% with no corresponding reduction in source area duration, source area reductions in durations of 50%, 75% and 95% with no corresponding reduction in source area concentrations, and no source remedial action (0% reduction in source area concentration and duration).

For evaluation and comparison purposes, model-predicted concentrations were extracted from the model at a location immediately downgradient of Building 50 (Figure 77). Model-predicted, temporal TCE, DCE and VC concentrations for all current and future condition remedial scenarios are shown in Figures 78 through 83. While the magnitude of the concentration predictions is different for TCE, DCE and VC, the three contaminants show similar trends for current and future conditions and as such only a single discussion will be presented regarding the predicted results.

No Source Remediation

As shown by the blue line starting at zero years, if no source remediation is undertaken Building 50 groundwater contaminant source area concentrations will remain constant (flat line) for 250 years for both current and future conditions. Note that the green line representing a reduction in source duration but not source concentration overlays the blue line for a portion of the 250 year ambient source duration. There is a brief period at the beginning of the future condition simulation simulations where concentrations decline in response to the groundwater flow regime changing from current to future conditions. However, concentrations quickly stabilize and remain constant for the duration of the future conditions simulation. At 250 years, after the source mass has completely dissolved into passing groundwater, source area groundwater concentrations decline precipitously and drop below standards (TCE – 5 µg/L, DCE – 70 µg/L and VC – 2 µg/L) within a few years after complete source dissolution (Table 9, Figures 78 through 83, blue line). It should be reiterated that the simulation assumes 250 year ambient source duration. The actual source duration could be shorter or longer, depending on the source mass present and the architecture of the contamination in the subsurface. Regardless of the actual source duration, in the absence of remediation, idealized dissolved concentrations are expected to remain constant over the duration of the source and then rapidly decrease once the source material has been exhausted.

The transport simulation does not include potential matrix diffusion effects which will result in tailing where low level concentrations persist for considerable time after the higher concentrations have dissipated. Tailing occurs when low level dissolved contamination, which remains in the lower permeability portions of the aquifer after the higher concentrations have dissipated; slowly diffuse into the more permeable portions of the aquifer. There is no way of determining beforehand to what degree tailing will occur other than to acknowledge that it is likely to occur. In addition, further complicating the degree that tailing will impact dissolved contamination cleanup times, tailing is a function of heterogeneity and as such is expected to be spatially variable at the BFC. While difficult to predict, tailing effects exist at the BFC, as evidenced by persistent low level groundwater contaminant concentrations adjacent to the Blue River decades after extraction wells halted Northeast Area plume migration. The end result is that the actual time to reach groundwater standards following source dissolution will likely be longer than the model-predicted time with the difference being impossible to predict.

Appendices 1 through 3 figures show Building 50 TCE, DCE and VC plume responses under current conditions if no source remediation is undertaken. As shown, plume concentrations remain constant for 250 years, the assumed ambient life of the source. Within 10 years following the 250 year source dissolution period (260 years total), assuming no tailing effects, the Building 50 plume disappears.

Appendices 4 through 6 figures show Building 50 TCE, DCE and VC plume responses under future conditions if no source remediation is undertaken. As shown, the Building 50 plume shifts trajectory to the east in response to removal of the BFC Buildings and tile drains. After an approximately 30 yearlong period over which the plume trajectory shifts, plume concentrations remain constant for the assumed ambient life (250 years total) of the source. As with the current conditions, the plume figures suggest, in the absence of tailing effects, for future conditions complete capture of the plume by the extraction wells and/or complete biodegradation will occur within 30 years following the 250 year source dissolution period (280 years total).

Complete Source Remediation

As shown by the orange line, starting at zero time, following complete source remediation, assumed to be instantaneous, source area groundwater concentrations drop rapidly. Within six years after complete Building 50 source remediation groundwater contaminant concentrations immediately downgradient of the site are predicted to fall below applicable standards(TCE – 5 µg/L, DCE – 70 µg/L and VC – 2 µg/L) for both current and future conditions years (Table 9, Figures 78 through 83, orange line). After complete source depletion, additional time will be required for the remaining plume to discharge to either the West Boiler House, under current conditions, or the line of extraction wells located upgradient of Indian Creek for future conditions. The transport simulations predict that complete dissipation of the plume will occur within a few years.

Appendices 7 through 9 figures show Building 50 TCE, DCE and VC plume responses assuming complete source remediation under current conditions. Within 10 years after complete source remediation, assuming no tailing effects, the Building 50 plume disappears.

Appendices 10 through 12 figures show Building 50 TCE, DCE and VC plume responses under future conditions if complete source remediation is undertaken. As with the current conditions, the plume figures suggest, in the absence of tailing effects, for future conditions complete capture of the plume by the extraction wells and/or complete biodegradation will require more than 40 years after undertaking complete source remediation.

Reduction in Source Concentration, No Reduction in Source Duration Remediation Scenarios

As shown by the red lines (solid and dashed) starting at zero time, following source remediation the Building 50 transport simulation results show that there is no benefit to undertaking source remediation for both current and future conditions if the remediation only reduces the source groundwater concentration but does not lessen the source duration (Table 9 – 50%. 75% and 95% source groundwater concentration reduction and 0% source duration reduction, Figures 78 through 83, red lines). As stated previously this situation is analogous to a scenario where remediation removes the “low hanging fruit” but does not reduce the mass of contamination present in the harder to reach, lower permeability portions of the aquifer. The remaining mass continues to contaminate groundwater, albeit at lower levels than that of the un-remediated source. As the simulation results show, under this scenario, source area groundwater concentrations drop rapidly (~5 years) to levels corresponding to 50%. 75% and 95% source groundwater concentration reductions. Upon reaching the reduced source groundwater concentrations the concentrations stabilize until the remaining source mass is completely dissolved. For these simulations, complete dissolution of the remaining source mass is assumed to take 250 years, the same duration required to dissolve the source under ambient conditions. At the end of 250 years, following dissolution of the remaining source mass concentrations decline rapidly and reach groundwater standards in the same approximate time as if no remediation was undertaken.

Appendices 13 through 21 figures show Building 50 TCE, DCE and VC plume responses for current conditions assuming the source remedial action results in between 50% and 95% reduction in source concentrations but no reduction in source duration. With reductions in source concentrations the Building 50 plume footprint becomes smaller and plume concentrations lessen. In fact, if the Building 50 source concentrations are reduced by 95% the TCE and DCE plumes disappears within 10 years after source remediation is undertaken. Complete plume disappearance is a function of the relatively low initial source concentrations. A 95% reduction in source concentrations allows biodegradation to keep the TCE and DCE plumes from migrating any significant distance away from the source. For 50% and 75% source concentration reduction scenarios, the plume figures suggest, in the absence of tailing effects, for current conditions complete plume disappearance will occur within 5 to 10 years (255 years to 260 years total) after the 250 year source dissolution period.

Appendices 22 through 30 figures shows Building 50 TCE, DCE and VC plume responses under future conditions assuming the source remedial action results in between 50% and 95% reduction in source concentrations but no reduction in source duration. As shown, the Building 50 plume geometry shifts trajectory to the east in response to removal of the BFC Buildings and tile drains. As before, for the no reduction in concentration simulations, approximately 30 years is required for the plume to come to equilibrium with the new groundwater flow regime. Different than under current conditions, reducing source concentrations by 95% for future conditions does not result in disappearance of the Building 50 TCE plume. This is because the future condition groundwater flow regime is different than the current condition groundwater flow regime. After the approximately 30 year period over which the plume trajectory shifts, the plume footprint becomes smaller and concentrations lessen in response to reductions in source area concentrations. The plume figures suggest, in the absence of tailing effects, for future conditions complete capture of the plume by the extraction wells and/or complete biodegradation will occur within 20 to 30 years (270 years to 280 years total) after the 250 year source dissolution period.

No Reduction in Source Concentration, Reduction in Source Duration Remediation Scenarios

As shown by the green lines (solid and dashed) starting at zero time, following source remediation the Building 50 transport simulation results show that for both current and future conditions, reducing source duration even if there is no reduction in source area concentrations has benefit providing the source duration is significantly reduced (Table 9, Figures 78 through 83, green lines). Reductions of 50% and 75% in source duration result in source area groundwater concentrations dropping below standards within 129 years and 67 years, respectively. For source area groundwater concentrations to drop below standards in twenty years or less requires a reduction in source duration of 95% or more.

Appendices 31 through 39 figures show Building 50 TCE, DCE and VC plume responses for current conditions assuming the source remedial action results in between 50% and 95% reduction in source duration but no reduction in source concentration. As the plume figures show, Building 50 plume concentrations remain constant over the time the source is active (ranging between 13 years and 125 years). In the absence of tailing effects, for current conditions, complete plume disappearance will occur within 23 years (95% source duration reduction) and 135 years (50% source duration reduction).

Appendices 40 through 48 figures show Building 50 TCE, DCE and VC plume responses for future conditions assuming the source remedial action results in between 50% and 95% reduction in source duration but no reduction in source concentration. As shown, the Building 50 plume geometry shifts trajectory to the east in response to removal of the BFC Buildings and tile drains. As before, for the no reduction in concentration simulations, approximately 30 years is required for the plume to come to equilibrium with the new groundwater flow regime. As the plume figures show, Building 50 plume concentrations remain constant over the time the source is active (ranging between 13 years and 125 years). The plume figures show, in the absence of tailing effects, for future conditions, complete plume disappearance will occur within 40 years (95% source duration reduction) and 140 years (50% source duration reduction).

Reduction in Source Concentration, Reduction in Source Duration Remediation Scenarios

As shown by the purple lines (solid and dashed) starting at zero time, following source remediation the Building 50 transport simulation results show that for both current and future conditions, remedial endeavors that reduce both the source area concentration and duration are effective in reducing the time to achieve groundwater standards (Table 9, Figures 78 through 83, purple lines). Reductions of 50% and 75% in source concentrations and duration result in source area groundwater concentrations dropping below standards within 129 years and 67 years, respectively. For source area groundwater concentrations to drop below standards in twenty years or less requires a reduction in both source concentration and duration of 95% or more.

Appendices 49 through 57 figures show Building 50 TCE, DCE and VC plume responses for current conditions assuming the source remedial action results in between 50% and 95% reduction in both source concentrations and durations. As with the source concentration reduction, no source duration reduction simulation, when the Building 50 source concentrations are reduced by 95% the TCE and DCE plumes disappears within 10 years after source remediation is undertaken. Complete plume disappearance is a function of the relatively low initial source concentrations. A 95% reduction in source concentrations allows biodegradation to keep the TCE and DCE plumes from migrating any significant distance away from the source. For 50% and 75% source concentration and duration reduction scenarios, the plume figures suggest, in the absence of tailing effects, for current conditions complete plume disappearance will occur within 10 years after the source dissolution period (63 years for the 75% reduction scenario and 125 years for the 50% reduction scenario, respectively).

Appendices 58 through 66 figures show Building 50 TCE, DCE and VC plume responses for future conditions assuming the source remedial action results in between 50% and 95% reduction in source duration but no reduction in source concentration. As shown, the Building 50 plume geometry shifts trajectory to the east in response to removal of the BFC Buildings and tile drains. As with previous future simulations approximately 30 years is required for the plume to come to equilibrium with the new groundwater flow regime. Different than under current conditions, reducing source concentration and duration by 95% for future conditions does not result in disappearance of the Building 50 TCE and DCE plumes. This is because the future condition groundwater flow regime is different than the current condition groundwater flow regime. For future conditions, between 43 and 130 years after the source dissolution period (ranging between 13 years and 125 years), the Building 50 plume disappears.

6.2 Department 26 and the Former Plating Building

As with Building 50, transport simulations were performed where Department 26 and the Former Plating Building source area concentration and duration were systematically altered for both current and future conditions. Source area changes included complete source removal (100% reduction in source area groundwater concentration and duration), source area groundwater concentration reductions of 50%, 75% and 95% with no corresponding reduction in source area duration, source area reductions in durations of 50%, 75% and 95% with no corresponding reduction in source area groundwater concentrations, and no source remedial action (0% reduction in source area groundwater concentration and duration).

No Source Remediation

Different that Building 50, for current conditions, model-predicted groundwater contaminant concentrations were extracted at two downgradient locations for evaluation (Figure 77). Because of the Main Manufacturing Building tile drains and extraction well pumping, groundwater at the Department 26 and Former Plating Building source area under current conditions flows both to the east and west. Under future conditions, as simulated, the Main Manufacturing Building and associated tile drains are removed and as a result groundwater no longer flows westward from the source area to the tile drains. Thus, model-predicted groundwater concentrations were not extracted from the westerly sampling location for future conditions.

As shown by the blue line starting at zero years, if no source remediation is undertaken, groundwater contaminant concentrations at Department 26 and the Former Plating Building for current conditions will remain constant (flat line) for 250 years. Note that the green line representing a reduction in source duration but not source concentration overlays the blue line for a portion of the 250 year ambient source duration. Following complete source dissolution at the end of 250 years, an additional 40 to 50 years will be required to reach groundwater standards (Table 9, Figures 84 through 92, blue line). Note that that the 50-year duration to reach groundwater standards (TCE – 5 µg/L, DCE – 70 µg/L and VC – 2 µg/L) is much longer than the five or less years required to reach groundwater standards at Building 50 following complete source dissolution. The longer times required to reach groundwater concentrations is a function of higher initial Department 26 and Former Plating Building groundwater contaminant concentrations. Achieving groundwater standards is not as simple as flushing one pore volume of groundwater through the source area following source dissolution (or remediation). At the BFC non-source material subsurface contamination is present as dissolved (groundwater) contamination and as contamination sorbed to the aquifer matrix. The ratio of sorbed to dissolved contamination is a function of the BFC alluvium material and is assumed spatially constant. As "dirty" groundwater migrating out of the source area is replaced by "clean" groundwater, to maintain the sorbed to dissolved contaminant ratio, some of the sorbed contamination dissolves into the "clean" groundwater and "re-contaminates" the water but at a lower concentration than before. The net effect of this phenomenon is it takes many pore volumes of "clean" groundwater flowing through what was previously the source area to reach standards, with the exact number being a function of the initial dissolved source area contaminant concentration.

Note that the above described retardation effect is different than the tailings effect described previously which is a function of concentration gradients caused by contamination being removed faster from higher permeability zones (preferential flow paths) than lower permeability zones. Contamination remaining in the lower permeability zones diffuses slowly into the preferential flow paths causing chronic low level concentration for a considerable time after the majority of contaminants are flushed out of the flow system.

Because the groundwater flow regime is different following building removal, as shown by the blue line trajectory after 250 years, less than 20 years is required to reach groundwater standards following complete source dissolution under future conditions as compared to 50 years under current conditions (Table 9, Figures 84 through 92, blue line). Note, as shown by changing concentrations early in the time period, a few years are required after building removal for contaminant concentrations and distributions to equilibrate to the new groundwater flow regime.

Appendices 1 through 3 figures show Department 26 and the Former Plating Building TCE, DCE and VC plume responses under current conditions if no source remediation is undertaken. As shown, plume concentrations remain constant for 250 years, the assumed ambient life of the source. After more than 70 years following the 250 year source dissolution period (320 years total), assuming no tailing effects, the Department 26 and Former Plating Building plume disappears. While the eastern portions of the plume disappear relatively rapidly (~10 years) following the 250 year source dissolution period, the Department 26 and the Former Plating Building TCE, DCE and VC plumes are very recalcitrant beneath the Main Manufacturing Building. This is because groundwater velocities are relatively slow beneath the building and the plume concentrations are initially relatively high. As discussed previously in this Section, partitioning of contamination between sorbed and dissolved phases increases the time for the plume to disappear, the higher the initial plume concentrations the more pronounced the retardation effect.

Appendices 4 through 6 figures show Department 26 and the Former Plating Building TCE, DCE and VC plume responses under future conditions if no source remediation is undertaken. As shown, the Department 26 and the Former Plating Building plume shifts trajectory to the east in response to removal of the BFC Buildings and tile drains. After an approximately 30 yearlong period over which the plume trajectory shifts, plume concentrations remain constant for the assumed ambient life (250 years total) of the source. As with the current conditions, the plume figures suggest, in the absence of tailing effects, for future conditions complete capture of the plume by the extraction wells and/or complete biodegradation will occur within 20 years following the 250 year source dissolution period (270 years total). Note that the time required for the plume to disappear is less that that required for current conditions. This is because overall, in the absence of the Main Manufacturing Building, groundwater velocities are higher at the location of the former building.

Complete Source Remediation

As shown by the orange line, starting at zero time, assuming complete source removal, approximately 50 and 20 years is needed to reach groundwater standards (TCE – 5 µg/L, DCE – 70 µg/L and VC – 2 µg/L) for current and future conditions, respectively (Table 9, Figures 84 through 92, orange line). The difference in the time to achieve standards is a function of changing groundwater flow regimes.

Appendices 7 through 9 figures show Department 26 and the Former Plating Building TCE, DCE and VC plume responses assuming complete source remediation under current conditions. As shown, more than 70 years following complete source removal, assuming no tailing effects, the Department 26 and Former Plating Building plume disappears. As before, the eastern portions of the plume disappear relatively rapidly (~10 years) following source remediation. However, again as before, the Department 26 and the Former Plating Building TCE, DCE and VC plumes are very recalcitrant beneath the Main Manufacturing Building. This is because groundwater velocities are relatively slow beneath the building and the plume concentrations are initially relatively high. As discussed previously in this Section, partitioning of contamination between sorbed and dissolved phases increases the time for the plume to disappear, the higher the initial plume concentrations the more pronounced the retardation effect. Approximately 70 years following complete source removal are required for the Department 26 and the Former Plating Building TCE, DCE and VC plumes to disappear following source remediation.

Appendices 10 through 12 figures shows Department 26 and the Former Plating Building TCE, DCE and VC plume responses under future conditions when complete source remediation is undertaken. The plume figures suggest, in the absence of tailing effects, for future conditions complete capture of the plume by the extraction wells and/or complete biodegradation will occur within 40 years of undertaking complete source remediation.

Reduction in Source Concentration, No Reduction in Source Duration Remediation Scenarios

As shown by the red lines (solid and dashed) starting at zero time, following source remediation the Department 26 and Former Plating Building transport simulation results show that there is no benefit to undertaking source remediation for both current and future conditions if the remediation only reduces the source groundwater concentration but does not lessen the source duration (Table 9 – 50%. 75% and

95% source groundwater concentration reduction and 0% source duration reduction, Figures 84 through 92, red lines). As stated previously, this situation is analogous to a scenario where remediation removes the “low hanging fruit” but does not reduce the mass of contamination present in the harder to reach, lower permeability portions of the aquifer. The remaining mass continues to contaminate groundwater, albeit at lower levels than that of the un-remediated source. As the simulation results show, under this scenario, source area groundwater concentrations drop rapidly (~5 years) to levels corresponding to 50%. 75% and 95% source groundwater concentration reductions. Upon reaching the reduced source groundwater concentrations the concentrations stabilize until the remaining source mass is completely dissolved. For these simulations, complete dissolution of the remaining source mass is assumed to take 250 years, the same duration required to dissolve the source under ambient conditions. At the end of 250 years, following complete dissolution of the remaining source mass concentrations decline rapidly and reach groundwater standards in the same approximate time as if no remediation was undertaken.

Appendices 13 through 21 figures show Department 26 and the Former Plating Building TCE, DCE and VC plume responses for current conditions assuming the source remedial action results in between 50% and 95% reduction in source concentrations but no reduction in source duration. With reductions in source concentrations the Department 26 and the Former Plating Building plume footprint becomes smaller and plume concentrations lessen. However, because of slow groundwater flow velocities beneath the Main Manufacturing Building, 90 years following complete source removal (320 years total) are required for the Department 26 and the Former Plating Building TCE, DCE and VC plumes to disappear following source remediation for the various source concentration reduction scenarios.

Appendices 22 through 30 figures shows Department 26 and the Former Plating Building TCE, DCE and VC plume responses under future conditions assuming the source remedial action results in between 50% and 95% reduction in source concentrations but no reduction in source duration. As shown, the Department 26 and the Former Plating Building plume shifts trajectory to the east in response to removal of the BFC Buildings and tile drains. As with previous future simulations approximately 30 years is required for the plume to come to equilibrium with the new groundwater flow regime. Simulation results show that complete plume disappearance will occur within 20 years following the 250 year source dissolution period.

No Reduction in Source Concentration, Reduction in Source Duration Remediation Scenarios

As shown by the green lines (solid and dashed) starting at zero time, following source remediation the Department 26 and Former Plating Building transport simulation results show that for both current and future conditions, reducing source duration even if there is no reduction in source area concentrations has benefit providing the source duration is significantly reduced (Table 9, Figures 84 through 92, green lines). Reductions of 50% and 75% in source duration result in source area groundwater concentrations dropping below standards within 168 years and 131 years, respectively. For source area groundwater concentrations to drop below standards in twenty years or less requires for future conditions a reduction in source duration of 95% or more.

Appendices 31 through 39 figures show Department 26 and the Former Plating Building TCE, DCE and VC plume responses for current conditions assuming the source remedial action results in between 50% and 95% reduction in source duration but no reduction in source concentration. As the plume figures show, Building 50 plume concentrations remain constant over the time the source is active (ranging between 13 years and 125 years). In the absence of tailing effects, for current conditions, complete plume disappearance will require between 83 years (95% source duration reduction) and 195 years (50% source duration reduction) following source dissolution.

Appendices 40 through 48 figures show Department 26 and the Former Plating Building TCE, DCE and VC plume responses for future conditions assuming the source remedial action results in between 50% and 95% reduction in source duration but no reduction in source concentration. As the plume figures show, Building 50 plume concentrations remain constant over the time the source is active (ranging between 13 years and 125 years). In the absence of tailing effects, for current conditions, complete plume disappearance will require between 43 years (95% source duration reduction) and 140 years (50% source duration reduction) following source dissolution.

Reduction in Source Concentration, Reduction in Source Duration Remediation Scenarios

As shown by the purple lines (solid and dashed) starting at zero time, following source remediation the Department 26 and Former Plating Building transport simulation results show that for both current and future conditions, remedial endeavors that reduce both the source area concentration and duration are effective in reducing the time to achieve groundwater standards (Table 9, Figures 84 through 92, purple lines). Reductions of 50% and 75% in source concentrations and duration result in source area groundwater concentrations dropping below standards within 167 years and 101 years for current conditions, respectively. Groundwater concentrations drop more rapidly under future conditions. Reductions of 50% and 75% in source concentrations and duration result in future condition source area groundwater concentrations dropping below standards within 131 years and 68 years, respectively. As with the previous scenario where source duration was reduced by 95%, approximately 50 and 20 years required to reach groundwater standards for current and future conditions, respectively.

Appendices 49 through 57 figures show Department 26 and the Former Plating Building TCE, DCE and VC plume responses for current conditions assuming the source remedial action results in between 50% and 95% reduction in both source concentrations and durations. As the plume figures show, Department 26 and the Former Plating Building plume concentrations reduce after source concentration reduction but eventually plateau at new equilibrium concentrations until source dissolution occurs. An exception is when both source concentrations and source duration are reduced by 95%. Essentially there isn't enough time for equilibrium conditions to be achieved before the source expires. For the 95% reduction in source concentrations and duration plume concentrations continue to drop after source remediation until the source is gone 90 years after undertaking remediation. The plume responses show that more than 133 and 205 years are required for the Department 26 and the Former Plating Building plume to disappear if remediation reduces source concentrations and duration by 75% and 50%, respectively.

Appendices 58 through 66 figures show Department 26 and the Former Plating Building TCE, DCE and VC plume responses for future conditions assuming the source remedial action results in between 50% and 95% reduction in source duration but no reduction in source concentration. As shown, the Building 50 plume geometry shifts trajectory to the east in response to removal of the BFC Buildings and tile drains. As the plume figures show, for the 50% and 75% source concentration and duration reduction scenarios, Department 26 and the Former Plating Building plume concentrations remain constant over the time the source is active (ranging between 63 years and 125 years). In the absence of tailing effects, for future conditions, complete plume disappearance will occur within 10 years (73 years total-75% source duration reduction) and 20 years (145 years total-50% source duration reduction) following plume dissolution. For the 95% source concentration and duration reduction scenario there isn't enough time for plume concentrations to stabilize before the source is exhausted (13 years after remediation is undertaken). The plume disappears within 20 years following a 95% reduction in source concentration and duration.

6.3 Northeast Area

Transport simulations were performed where the Northeast source area concentration and duration were systematically altered for both current and future conditions. Source area changes included complete source removal (100% reduction in source area concentration and duration), source area concentration reductions of 50%, 75% and 95% with no corresponding reduction in source area duration, source area reductions in durations of 50%, 75% and 95% with no corresponding reduction in source area concentrations, and no source remedial action (0% reduction in source area concentration and duration).

For evaluation and comparison purposes, model-predicted concentrations were extracted from the model at a location immediately downgradient of the Northeast Source Area (Figure 77). Model-predicted, temporal TCE, DCE and VC concentrations for the above source area scenarios for both current and future conditions are shown in Figures 93 through 98.

No Source Remediation

As shown by the blue line starting at zero years, if no source remediation is undertaken Northeast Area groundwater contaminant source area concentrations will remain constant (flat line) for 250 years for both current and future conditions. Note that the green line representing a reduction in source duration but not source concentration overlays the blue line for a portion of the 250 year ambient source duration. There is a brief period at the beginning of the future condition simulation simulations where concentrations decline in response to the groundwater flow regime changing from current to future conditions. However, concentrations quickly stabilize and remain constant for the duration of the future conditions simulation. At 250 years, after the source mass has completely dissolved into passing groundwater, source area groundwater concentrations decline precipitously and drop below standards (TCE – 5 µg/L, DCE – 70 µg/L and VC – 2 µg/L) within a few years after complete source dissolution (Table 9, Figures 93 through 98, blue line). It should be reiterated that the simulation assumes 250 year ambient source duration. The actual source duration could be shorter or longer, depending on the source mass present and the architecture of the contamination in the subsurface. Regardless of the actual source duration, in the absence of remediation idealize dissolved concentrations are expected to remain constant over the duration of the source and then rapidly decrease once the source material has been exhausted.

Appendices 1 through 3 figures show Northeast Area TCE, DCE and VC plume responses under current conditions if no source remediation is undertaken. As shown, plume concentrations remain constant for 250 years, the assumed ambient life of the source. Within approximately 10 years following the 250 year source dissolution period (260 years total), assuming no tailing effects, the Northeast Area plume disappears.

Appendices 4 through 6 figures show Northeast Area TCE, DCE and VC plume responses under future conditions if no source remediation is undertaken. As with the current conditions, the plume figures suggest, in the absence of tailing effects, for future conditions complete capture of the plume by the extraction wells and/or complete biodegradation will occur within 10 years following the 250 year source dissolution period (260 years total).

Complete Source Remediation

As shown by the orange line, starting at zero time, following complete source remediation, assumed to be instantaneous, source area groundwater concentrations drop rapidly. Within six years after complete Northeast Area source remediation groundwater contaminant concentrations immediately downgradient of the site are predicted to fall below applicable standards (TCE – 5 µg/L, DCE – 70 µg/L and VC – 2 µg/L) for both current and future conditions years (Table 9, Figures 93 through 98, orange line). After complete source depletion, additional time will be required for the remaining plume to discharge to the Northeast Area extraction wells.

Appendices 7 through 9 figures show Northeast Area TCE, DCE and VC plume responses assuming complete source remediation under current conditions. Within 20 years after complete source remediation, assuming no tailing effects, the Northeast Area plume disappears.

Appendices 10 through 12 figures show Northeast Area TCE, DCE and VC plume responses under future conditions if complete source remediation is undertaken. As with the current conditions, the plume figures suggest, in the absence of tailing effects, for future conditions the plume will disappear within 20 years of undertaking complete source remediation.

Reduction in Source Concentration, No Reduction in Source Duration Remediation Scenarios

As shown by the red lines (solid and dashed) starting at zero time, following source remediation the Northeast Area transport simulation results show that there is no benefit to undertaking source remediation for both current and future conditions if the remediation only reduces the source groundwater concentration but does not lessen the source duration (Table 9 – 50%. 75% and 95% source groundwater concentration reduction and 0% source duration reduction, Figures 93 through 98, red lines). As stated previously this situation is analogous to a scenario where remediation removes the “low hanging fruit” but does not reduce the mass of contamination present in the harder to reach, lower permeability portions of the aquifer. The remaining mass continues to contaminate groundwater, albeit at lower levels that of the un-remediated source. As the simulation results show, under this scenario, source area groundwater concentrations drop rapidly (~5 years) to levels corresponding to 50%. 75% and 95% source groundwater concentration reductions. Upon reaching the reduced source groundwater concentrations the concentrations stabilize until the remaining source mass is completely dissolved. For these simulations, complete dissolution of the remaining source mass is assumed to take 250 years, the same duration required to dissolve the source under ambient conditions. At the end of 250 years, following complete dissolution of the remaining source mass concentrations decline rapidly and reach groundwater standards in the same approximate time as if no remediation was undertaken.

Appendices 13 through 21 figures show Northeast Area TCE, DCE and VC plume responses for current conditions assuming the source remedial action results in between 50% and 95% reduction in source concentrations but no reduction in source duration. With 50% and 75% reductions in source concentrations the Northeast Area plume footprint becomes smaller and plume concentrations lessen over the 250 year stable source concentration period. For the 95% source concentration reduction scenario, prior to the end of the 250 year active source duration period, the plume foot print is significantly reduced due to biodegradation effects, so much so that the plume doesn’t extend to the two most downgradient extraction wells. Within 5 to 10 years after source dissolution (255 to 260 years total), for all the source concentration scenarios, the Northeast Area plume completely disappears.

Appendices 22 through 30 figures shows Northeast Area TCE, DCE and VC plume responses under future conditions when the source remedial action results in between 50% and 95% reduction in source concentrations but no reduction in source duration. With 50% and 75% reductions in source concentrations the Northeast Area plume footprint becomes smaller and plume concentrations lessen over the 250 year stable source concentration period. Different than current conditions, due to a different groundwater flow field for future conditions, the plume reaches the two most down gradient extraction wells for the 95% source concentration reduction scenario. Within 10 years after source dissolution (260 years total), for all the source concentration scenarios, the Northeast Area plume completely disappears.

No Reduction in Source Concentration, Reduction in Source Duration Remediation Scenarios

As shown by the green lines (solid and dashed) starting at zero time, following source remediation the Northeast Area transport simulation results show that for both current and future conditions, reducing source duration even if there is no reduction in source area concentrations has benefit providing the source duration is significantly reduced (Table 9, Figures 93 through 898, green lines). Reductions of 50% and 75% in source duration result in source area groundwater concentrations dropping below standards within 129 years and 67 years, respectively. For source area groundwater concentrations to drop below standards in twenty years or less requires a reduction in source duration of 95% or more.

Appendices 31 through 39 figures show Northeast Area TCE, DCE and VC plume responses for current conditions assuming the source remedial action results in between 50% and 95% reduction in source duration but no reduction in source concentration. As the plume figures show, Northeast Area plume concentrations remain constant over the time the source is active (ranging between 13 years and 125 years). In the absence of tailing effects, for current conditions, complete plume disappearance will occur within 23 years (95% source duration reduction) and 135 years (50% source duration reduction).

Appendices 40 through 48 figures show Northeast Area TCE, DCE and VC plume responses for future conditions assuming the source remedial action results in between 50% and 95% reduction in source duration but no reduction in source concentration. As the plume figures show, Northeast Area plume concentrations remain constant over the time the source is active (ranging between 13 years and 125 years). In the absence of tailing effects, for future conditions, complete plume disappearance will occur within 23 years (95% source duration reduction) and 135 years (50% source duration reduction).

Reduction in Source Concentration, Reduction in Source Duration Remediation Scenarios

As shown by the purple lines (solid and dashed) starting at zero time, following source remediation the Building 50 transport simulation results show that for both current and future conditions, remedial endeavors that reduce both the source area concentration and duration are effective in reducing the time to achieve groundwater standards (Table 9, Figures 93 through 98, purple lines). Reductions of 50% and 75% in source concentrations and duration result in source area groundwater concentrations dropping below standards within 129 years and 67 years, respectively. For source area groundwater concentrations to drop below standards in twenty years or less requires a reduction in both source concentration and duration of 95% or more.

Appendices 49 through 57 figures show Northeast Area TCE, DCE and VC plume responses for current conditions assuming the source remedial action results in between 50% and 95% reduction in both source concentrations and durations. For the 50%, 75% and 95% source concentration and duration reduction scenarios, the time from undertaking source remediation to plume disappearance is 135 years, 73 years and 23 years, respectively.

Appendices 58 through 66 figures show Northeast Area TCE, DCE and VC plume responses for future conditions assuming the source remedial action results in between 50% and 95% reduction in source duration but no reduction in source concentration. For the 50%, 75% and 95% source concentration and duration reduction scenarios, the time from undertaking source remediation to plume disappearance is 145 years, 83 years and 23 years, respectively.

6.4 Partial Source Remediation Evaluation without Extraction Well Operation

It is possible that even after source area remediation that sufficient source mass may remain diffused in the lower permeable portions of the alluvium and function as long-duration, low concentration sources of contamination. If diffuse mass remains, groundwater concentrations immediately downgradient of the sources may remain above groundwater standards for centuries. In recognition of the possibility of chronic low-level sources still existing after remediation, simulations were performed to determine what source groundwater concentrations could remain such that groundwater standards would not be exceeded adjacent to Indian Creek and the Blue River if extraction well pumping was discontinued. It should be noted that these simulations only evaluate the effects of partial remediation of the Building 50, Department 26 and the Former Plating Building and the Northeast Area sources. Potentially there are other sources at the BFC that may require continued operation of extraction wells for containment purposes such that turning off the extraction wells may be problematic.

Transport simulation results show that in the absence of extraction wells, Building 50 source area dissolved concentrations have to be reduced by 66% to prevent groundwater contamination above standards from discharging to Indian Creek. The Department 26 and Former Plating Building Source is much more problematic and requires that groundwater concentrations at the source need to be reduced by 99.9% to prevent groundwater contamination above standards from discharging to Indian Creek. The requirement to reduce source contamination by 99.9% is driven by the higher source concentrations at Department 26 and the Former Plating Building. Source concentrations need to be at low enough levels such that dispersion and biodegradation reduce concentrations along the plume flow path to groundwater standards prior to the plume reaching a surrounding surface water body. To prevent groundwater contamination emanating from the Northeast Area source to reach the Blue River above standards requires an 80% reduction in groundwater source contaminant concentrations.

7. CONCLUSIONS

The following are conclusions of the **Source Zone Remediation Evaluation**:

With respect to source mass characterization:

- Building 50 source mass calculations, based on available soil concentration, data predict a source mass of 66 pounds.
- Department 26 and Former Plating Building source mass calculations, based on available soil concentration, data predict a source mass of 30,560 pounds.
- Northeast Area source mass calculations, based on available soil concentration, data predict a source mass of 27,608 pounds.
- There is significant uncertainty associated with source mass characterization. It is likely that the source mass determined from available soil data underestimates source mass by as much as an order of magnitude.

Ambient source duration evaluation shows:

- BFC source areas could dissolve into groundwater under ambient flow conditions in as little as 20 years or in as much as 766 years.
- Because of uncertainty associated with determining source zone mass, calculated ambient source area dissolution times could be off by as much as an order of magnitude (maximum of 7,660 years).
- Based on source mass characterization uncertainty, and the likely non-linearity of source mass dissolution, it is possible that complete dissolution of BFC source material under ambient conditions could take as much as 10,000 years.

The source area remedial evaluation predicts:

- Remediation efforts that reduce the ambient source duration (the time required for source mass to completely dissolve under ambient conditions) by 95% or more are effective in reducing the duration of required groundwater pump-and-treat operations from hundreds or thousands of years to decades.
- Remediation efforts that only lower source area groundwater concentrations but not the duration of the source reach groundwater standards in the same time as if no source remediation had been undertaken. This scenario could occur if sufficient source mass remains in the lower permeable portions of the alluvium as diffused mass following remediation. If persistent low-level diffuse source mass remains following remediation, there will be no reduction in the duration of pump-and-treat system operation (hundreds or thousands of years)
- Under ambient current and future groundwater flow conditions (no extraction wells) groundwater source concentrations need to be reduced by 66%, 99.9% and 80% at the Building 50, Department 26 and Former Plating Building, and Northeast Area sources, respectively, to prevent groundwater with contaminant concentrations above standards from discharging to Indian Creek and the Blue River. Satisfying a 99.9% reduction in source area groundwater

contaminant concentrations could be problematic if enough diffuse mass remains at the source area following remediation to chronically contaminate BFC groundwater at levels above current standards.

- The transport simulations predict that when the source duration is reduced by 95% relative to the ambient source duration, for future conditions when buildings have been removed and replaced with grassy areas, complete dissipation of the BFC plumes will occur within 40 years after complete source removal. During that 40 year period, some or all of BFC extraction wells will need to be operated to contain groundwater contamination until concentrations drop below standards.
- However, the “best-case” 40 year extraction well operational period will possibly be longer due to matrix diffusion effects. Pumping removes groundwater contamination more quickly in the higher permeability portion of the alluvium relative to lower permeable portions. As a result, when groundwater standards have been met in the higher permeability portions of the alluvium groundwater contamination above standards will still be present in the low permeability portions of the alluvium. As a result of the concentration differences, contamination will diffuse from the lower permeability portions of the alluvium into the higher permeability portions of the alluvium. This phenomenon is known as “tailing” and results in chronic low level groundwater contaminant concentrations. Tailing exist at the BFC, as evidenced by persistent low level groundwater contaminant concentrations adjacent to the Blue River two decades after extraction wells halted Northeast Area plume migration to the river. Rather than a 40 year operational period as predicted by the transport simulations, the pump-and-treat system will likely need to be operated, based on the duration of BFC tailing observed to date, for 60 years or more to prevent groundwater with low-level contaminant concentrations from reaching Indian Creek and the Blue River.

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DOE 2012. Annual Report

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