MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY

INTEROFFICE COMMUNICATION

TO: Sybil Kolon, Project Manager, RRD, Jackson District

FROM: Rick Mandle, Groundwater Modeling Specialist, RRD, Lansing

DATE: July 13, 2007

SUBJECT: Review of 2007 Model of Evergreen System

The Groundwater Modeling Program has completed its review of the model (2007 Model) used to evaluate the hydraulic containment effectiveness of the Evergreen System extraction wells. The application of this model is described in a report (2007 Model Report) entitled, "Evergreen System Review, May 2007". The 2007 model is a slight revision of the model that was previously developed by Fishbeck, Thompson, Carr & Huber, Inc. (FTC&H) of Kalamazoo, Michigan in 2002 (2002 Model).

The purpose of the 2007 Model was to assess the impact that reductions in the pumping rates for wells LB-1 and LB-3 would have on the capture effectiveness of the Evergreen System extraction wells. The rationale for reducing pumping rates from these wells is based on the presumption that the existing pumping rates are excessive and that they are causing contaminated groundwater to migrate toward the Evergreen Subdivision or toward the Prohibition Zone (PZ) boundary from areas south of I-94 and Jackson Road where 1,4-Dioxane contamination has been detected in the E aquifer. On the basis of model simulations, FTC&H has determined that pumping rates in wells LB-1 and 3 could be reduced by almost 50 percent and still maintain hydraulic containment of the 1,4-Dioxane plume, although they've recommended an initial 25 percent reduction in pumping rates for these wells and field data collection to verify plume containment. In these simulations, the pumping rate for well AE-3, the replacement for well AE-1, was varied from 10 to 32 gallons per minute (gpm). No analysis was conducted in which the impact of changing the location of, or eliminating the pumping rate from, well AE-3 on the effectiveness of the hydraulic containment of the Evergreen System.

The review comments contained in this document focus on the usefulness and limitations of the 2007 Model in assessing the capture effectiveness of the Evergreen System wells and in determining optimal pumping rates for these wells.

Modification to Model

The model used for this latest review of the Evergreen System is a slight modification of the 2002 Model. FTC&H noted that the groundwater levels in the area had been steadily declining since 1994. They attributed this decline to pumping by the Pall Life Sciences (PLS) remediation wells. Rather than attempting to simulate the decline in hydraulic heads (groundwater level elevations) as a means of calibrating their model, the hydraulic head values used at the downgradient constant-head boundary were decreased approximately 2 to 5 feet from values used in the 2002 Model. The location of this boundary with respect to the Evergreen Subdivision is shown in Figure 1. Since the upgradient constant-head boundaries were not changed, changing the constant-head values at the downgradient boundary resulted in a very slight increase in the hydraulic gradient through the model. It was not apparent that any other model features or parameter values were changed from those used in the 2002 Model.

Model Calibration

Model simulated hydraulic heads were compared to groundwater level elevations measured in wells open to model layers 2 (Unit D aquifer) and 4 (Unit E aquifer) from the September 2006 sampling event. The model simulated heads and differences between the simulated heads and measured heads (residuals) are shown in Figures 2 and 3. Positive residual values indicate that the measured heads are higher than the model simulated heads. Negative residual values indicate that the measured heads are less than the model simulated heads. The results show that, with the exception of wells MW-17 (-0.95 feet) and MW-BE1d (-2.48 feet), the model-simulated heads are lower than the measured heads in the Unit D aquifer (layer 2). On the basis of the limited number of hydraulic head measurements used for comparison, it appears that the model-simulated heads are lower than the measured heads in the Unit E aquifer (layer 4). Since there were no simulations or measurement of groundwater level elevations that reflect pre-pumping conditions, it is not apparent whether the model is over-predicting drawdown caused by the Evergreen System pumping or there is a conceptualization problem with model framework, hydraulic properties, or the values used to represent the constant-head boundaries. No other model calibrations, such as simulating the decline in hydraulic heads since 1994, comparing to another set of measured hydraulic heads, or tracking contamination back to source areas to verify simulated groundwater flow directions or model conceptualization were attempted. On the basis of statistics that were calculated using these head residuals, FTC&H determined that the model was “calibrated”.

Evaluation of Capture Effectiveness Using Different Pumping Rates

The capture effectiveness of the Evergreen System had been evaluated by FTC&H through particle-tracking analysis using the previous model (2002 Model). This was described in their November 18, 2002 report. In that analysis, the simulations showed a complete containment of the known extent of contamination using a combined pumping rate of 202 gpm from the three Evergreen System extraction wells. The particle-tracking analyses using the 2007 Model show the simulated capture effectiveness assuming pumping rates of 90, 45, and 67 gpm from extraction well LB-1; 80, 40, and 60 gpm from well LB-3; and 32, 10, and 10 gpm for well AE-3. The particle-tracking analysis for pumping LB-1, LB-3, and AE-3 at pumping rates of 90, 80, and 32 gpm, respectively, are presented in Figure 4. The impact of reducing the pumping rates 25 percent in LB-1 and LB-3 (to 67 and 60 gpm, respectively) and AE-3 to 10 gpm are shown by the particle-tracking analysis in Figure 5. The lateral extent (north-south) of capture is smaller than that shown on Figure 4 for the higher system pumping rates. On the basis of these particle-tracking analyses, FTC&H concluded that using the lower pumping rates would be adequate to contain the contaminant plume as they have delineated it. In their report, FTC&H also show, through particle-tracking analysis, that a further reduction in pumping rates for LB-1 and LB-3 to 45 and 40 gpm, respectively, would effectively contain the majority of the mapped extent of the 1,4-Dioxane plume in the Unit D aquifer. In their estimation, reducing the pumping rates would also result in less drawdown and a lower potential of inducing contamination to migrate to the north, toward the Evergreen System or the PZ boundary.

Proposed System Modifications

On the basis of the particle-tracking analyses, PLS and FTC&H have proposed a modification to the pumping rates required by the Washtenaw County Court’s July 17, 2000, Opinion and Remediation Enforcement Order (REO). They have proposed an initial reduction in pumping rates in LB-1 and LB-3 by 25 percent to 67 and 60 gpm, respectively. PLS and FTC&H have proposed that field data be collected from unspecified wells that will demonstrate the capture effectiveness of the two wells at the reduced pumping rate.

No simulations in which the location of a replacement well for AE-3 were presented in this report.

DEQ Review Comments

With the exception of the changes to the downgradient constant-head boundary, the 2007 Model is the same as the 2002 Model. It is our opinion that the Department of Environmental Quality (DEQ) review comments for the 2002 Model have not been adequately addressed and are still applicable to the 2007 Model. Model simulations performed in 2002 showed that pumping approximately 200 gpm from the Evergreen System was effective in containing the Unit D aquifer contaminant plume. However, our review of the 2002 Model (dated February 18, 2004) identified three issues with respect to the collection of field data that needed resolving to properly characterize the problem and verify plume containment. Because of the lack of characterization data, the model had limited usefulness for evaluating the capture effectiveness of the Unit D aquifer plume by the Evergreen System. These three issues dealt with: 1) Delineation of the 1,4-Dioxane plume using industry-accepted practices (e.g., vertical aquifer sampling), 2) Proper monitoring of the performance of the extraction system to verify model simulations that show complete plume containment, and 3) Assess the potential for vertical migration of contaminants between the Unit D aquifer to the Unit E aquifer through the collection of appropriate field data. In as much as FTC&H continues to use this model for remedial action decision making, it is our opinion that the issues raised in 2004 are still applicable and are worth repeating. In addition, we discuss issues not raised in our last review that focus on the development and use of the model.

Our comments begin with model conceptualization, calibration, and sensitivity analysis.

Model Conceptualization

1. Hydrogeologic Framework

Geologic data collected during drilling activities in the last couple of years show that the intervening clay layer may be absent near the east end of the Evergreen Subdivision. In spite of these recent findings, no changes were made to the model layers from the 2002 Model. The subsurface geology is represented in both the 2002 and 2007 Models as four discrete model layers, the most important being model layers two (Unit D aquifer) and four (Unit E aquifer). In these models, the clay layer (model layer three) separating the Unit D and Unit E aquifer layers is continuous and has a relatively low hydraulic conductivity. FTC&H has stated that,

"*the model is a simplification of the complex hydrogeological characteristics of the Evergreen System and does not incorporate some of the recent interpretations outlined in this report. Nevertheless, this model can be used as a tool to reasonably simulate pumping conditions in the Evergreen System area.*

Whether the 2007 Model can be used to obtain reasonable simulations of the impact of different pumping scenarios is debatable. The possible impact that "recent interpretations" might have on the model simulations and the particle-tracking analyses should have been evaluated in a model sensitivity analysis, especially if they result in a fundamental change to the conceptual framework of the model and the model is being used to make changes to the remediation system. Currently, there is an intervening confining layer in the model (model layer three) that separates the Unit D aquifer from the underlying Unit E aquifer. In the model, this confining layer has a low vertical hydraulic conductivity and is assumed to be laterally extensive, restricting the degree of connection between shallower units (Unit D aquifer) and deeper units (Unit E aquifer). FTC&H has stated that it is difficult distinguishing between the Unit D and Unit E aquifers in the eastern end of the Evergreen Subdivision. If data are available that show a greater degree of connection than the model would suggest, the impact of this connection on the simulated extent of capture and plume migration directions must be accounted for in the assessment of the Evergreen System pumping rates. Without this connection, model simulations (water budget analysis) show that the Evergreen System obtains the majority of its water from model layers 1 and 2 (Unit D aquifer), with very little coming from the underlying Unit E aquifer. This results in an overestimation of drawdown and capture in the Unit D aquifer. If the two aquifers are better connected, it is our opinion that there will be less simulated drawdown and a smaller simulated capture extent in the Unit D aquifer than shown in the simulations provided by FTC&H.

2. Groundwater Flow Directions

The direction of groundwater flow in the Evergreen Subdivision is based on a limited number of monitoring wells, especially north of Dexter Road. FTC&H has placed a "no-flow" boundary to the north of the Evergreen Subdivision area and a constant-head boundary along the east side of the model (see Figure 1). The no-flow boundary prevents groundwater from moving to the north and forces all groundwater to flow parallel to this boundary from west to east toward the constant-head boundary. It has always been our contention that there is some component of regional groundwater flow to the north that has not been adequately investigated. Regional groundwater flow directions in the glacial drift were inferred from records of residential water wells that have been installed since 1990. The contours of equal hydraulic head and inferred regional groundwater flow directions (black arrows) are shown on Figure 6. Also shown on this figure are the approximate digitized extent of 1,4-Dioxane contamination, the Montgomery Street well, the Huron River, and monitoring wells MW-77 and MW-92. This information appears to show that the PLS site is located on a "hydraulic head high" and that groundwater appears to be moving away from the site to the west-northwest, north and east away from the site. These inferred flow directions are somewhat verified by the depicted migration of site-related contamination to the west-northwest (not shown), toward the north-northeast (Unit D plume), and east (Unit E plume and Montgomery Street well). This indicates that there may be some validity to the interpolated hydraulic-head surface and inferred groundwater flow directions using the residential water well records. The presumed impact of pumping from the Montgomery Street well is based on a very limited number of well records; however, these data show a pronounced steepening of the potentiometric surface in the vicinity of Maple Road that is generally consistent with data gathered by PLS in their investigation of the Unit E aquifer contamination.

North of Dexter Road, the inferred directions of groundwater flow (see Figure 6) suggests that there may be the possibility of some contaminant migration to the north. However, the verification of groundwater flow and contaminant migration directions north of Dexter Road is incomplete, primarily because so little good-quality data (obtained through vertical aquifer sampling) have been collected in this area. In the model, the placement of the no-flow boundary to the north prevents the model from simulating a northward groundwater flow direction. As a result, the simulated groundwater flow direction near Dexter Road is due east, rather than to the north. This is an artifact of the manner in which the model is constructed that has not been verified by the collection of field data. Additional good-quality data (groundwater levels or chemical analyses) are needed north of Dexter Road to verify whether the west-to-east simulated flow directions or the regional groundwater flow directions to the north that are shown in Figure 6 are correct.

3. Extent of Contamination

In our review of the 2002 Model, we made the following statement regarding the extent of contamination.

"In order to determine whether the simulated capture is effective, it is necessary to know the full horizontal and vertical extent of the problem requiring containment. The plume delineated in the August 21, 2002 report was based on a limited number of vertical aquifer sampling profiles. Much of the horizontal and vertical delineation depends on existing residential wells or monitoring wells drilled to specified depths without the benefit of vertical aquifer sampling. It is possible that the contaminant plume extends farther horizontally and vertically than has been delineated, …"

There has been much work completed to the east (downgradient) of the Evergreen System extraction wells delineating the extent of 1,4-Dioxane contamination in the Unit E aquifer or near the PZ boundary. However, the present delineation of the nature and extent of the contaminant plume in the vicinity, and upgradient, of the Evergreen System is still heavily dependent on the sampling of residential wells or from monitoring wells that were installed without the benefit of vertical aquifer sampling (VAS). Because of this, it is not certain that the nature (1,4-Dioxane concentrations) and extent (horizontal and vertical) of the 1,4-Dioxane plume upgradient and northwest of the Evergreen System has been determined. Appropriate pumping rates cannot be determined, nor can the evaluation of the reasons for increasing 1,4-Dioxane concentrations in wells in the Evergreen Subdivision be completed until the nature and extent of the contaminant plume requiring capture has been acceptably delineated.

4. Nearby Boundary Conditions

The placement of the no-flow boundary and the downgradient constant-head boundary relatively close to the Evergreen System, besides determining groundwater flow direction in the model, results in a distorted cone of depression that will distort the simulated capture extent. Figure 7 shows the simulated drawdown for model layer two (Unit D aquifer) assuming a pumping rate of 202 gpm from the Evergreen System wells. The combined impact that these boundaries, the inferred zone of low hydraulic conductivity to the south of LB-1 and LB-3, and the lack of connection between the Unit D and Unit E aquifers (model layer three was assumed to be continuous throughout this area) have had on the simulated extent of capture should have been assessed.

It is our opinion that the no-flow boundary is not correct, nor is it supported by any field data. The impact of placing the no-flow boundary in this area on simulated flow directions and capture extent must be verified and assessed. In addition, the current constant-head value assignments in this downgradient boundary may be impacted by the elimination of pumping from the Montgomery Street well. Any future model simulations will have to assess the appropriateness of this constant head boundary or its impact on simulation results.

<u>Model Calibration</u>

In this report FTC&H states:

"Some slight modifications to the model were made for this analysis and to further calibrate the existing MODFLOW model."

It has never been the opinion of the DEQ that the 2002 model was calibrated. The emphasis of our February 18, 2004 review of the 2002 model was on the collection of additional data for better plume characterization, determining the direction of groundwater flow, and improving the performance monitoring network to verify, or refute, the extent of capture simulated with the 2002 model. At the time, we felt that further data collection was needed and did not focus our review on the adequacy of model calibration. While the head residuals computed with this model are not "bad", we feel that there are so few measured heads in the vicinity of the Evergreen Subdivision, in both the Unit D and E aquifers, against which to compare simulated heads or flow directions that any measure of calibration that is based strictly on head residuals is not adequate. There needs to be a comparison with groundwater flow directions and flow rates to provide a better assessment of model calibration.

The changes in the head values used for the downgradient constant-head boundary conditions in the 2007 Model are not an exercise in model calibration, but rather an attempt to impose lower hydraulic heads and a slightly steeper hydraulic gradient on the model domain. If the goal was to develop a calibrated model, a better calibration exercise would have been to attempt to reproduce the decline in groundwater levels that have been observed since 1994 or 2002. Decreasing the head values at the downgradient constant-head boundary is an indication that pumping from downgradient locations has been responsible for the decline in heads, not PLS remediation pumping.

An additional calibration exercise, one that is very important for verifying particle-tracking analyses and groundwater flow rates, is the transient simulation of groundwater and contaminant migration directions from the contaminant source areas, provided these are known with some certainty. It does not appear that this calibration exercise was attempted with this model. Our attempt to replicate contaminant migration pathways from site source areas, using the 2007 Model, results in particle-tracking pathlines that follow a more southerly trajectory than the mapped extent of 1,4-Dioxane contamination. This would indicate that the simulated groundwater flow directions or the mapped extent of the 1,4-Dioxane contamination are not entirely correct. Errors in representing the complex hydrogeologic conditions at this site in this model are the reason. These errors will affect model predictions.

<u>Sensitivity Analysis</u>

The predicted capture simulations are presented in the 2007 Model Report as if they are absolute outcomes with no uncertainty or errors of approximation. Predicted simulations should always be presented as a range of possible outcomes, not as absolute certainties. As has been discussed, there was no attempt to demonstrate the impact of model parameter uncertainty, errors in approximating boundary conditions, the impact of shutting down the Montgomery Street well, or "recent interpretations" on the simulations showing capture extent. Each of these should be included in a sensitivity analysis showing their potential impact on the simulated extent of capture. Until a sensitivity analysis is conducted, we cannot assess whether the model simulations depict a reasonable response to the different proposed pumping rates.

<u>Analysis of Northward Migration of Contaminants as a Result of "Overpumping"</u>

FTC&H has stated that one of the reasons for reducing the pumping rate in the Evergreen System wells is that they believe that contamination in the deeper Unit E aquifer is being "pulled toward LB-1, LB-3, and AE-3 wells" and that this is the reason that detected 1,4-Dioxane concentrations are increasing in several monitoring wells in the Evergreen Subdivision. We feel that there is much that is unknown about the degree of hydraulic connection between the Unit D and Unit E aquifers, and that the model is still not calibrated with respect to flow between these two units or within either the Unit D or Unit E aquifers. However, if we assume, for the sake of discussion, that the model accurately depicts groundwater flow conditions in the Unit D and Unit E aquifers, it could be used to test the hypothesis that contamination found in the Unit E aquifer is migrating toward the Evergreen System extraction wells. Two different particle tracking analyses were performed. The first was a reverse particle tracking analysisin which particles are placed around Unit D aquifer monitoring wells; the second analysis was a forward particle tracking analysis in which particles were placed in the Unit E aquifer in close proximity to the Evergreen Subdivision and the Evergreen System extraction wells.

A reverse particle-tracking analysis was performed using the 2007 Model by placing particles around several monitoring wells at which the concentrations of 1,4-Dioxane have been increasing or are near the edge of the simulated capture extent. The objective is to assess the possible origin of the contaminants that have been detected in these Unit D aquifer monitoring wells. Figure 8 shows the reverse particle tracking analysis with the Evergreen System wells pumping at a combined rate of 202 gpm (LB-1 = 90 gpm, LB-3 = 80 gpm, and AE-3 = 32 gpm). Particles were released around wells MW-77, MW-92, MW-100, MW-101, MW-KD1, MW-BE1, 456 Clarendon, and 465 Dupont. These simulations, if accurate, show that contaminants and groundwater found in the wells at 465 Dupont, MW-77, MW-KD1 and MW-92 would have migrated entirely within the Unit D aquifer from the west-northwest, from an area that is north and west of the delineated extent of the Unit D 1,4-Dioxane contamination (north of the intersection of Wagner Road and M-14). The reverse particle tracking analysis also shows that the contaminants and groundwater found at MW-100, 456 Clarendon, MW-BE1, would have migrated entirely within the Unit D aquifer from an area southwest of I-94 and MW-101. This area is south of the delineated southern extent of the Unit D aquifer plume.

The simulated capture extent and delineated extent of Unit D 1,4-Dioxane contamination are also shown on Figure 8. Wells MW-77, MW-100, MW-KD1, MW-BE1, 456 Clarendon, and 465 Dupont are all located within the simulated extent of capture. Only wells MW-92 and MW-101 are found outside the simulated capture extent of the Evergreen System. It's important to point out that the particles representing contaminant and groundwater flow to these wells do not enter the Unit E aquifer at upgradient locations, indicating no upwelling of groundwater from this lower aquifer to the Unit D aquifer. The model simulations would indicate that all of this contaminated groundwater comes from the Unit D aquifer, some of it coming from areas where 1,4-Dioxane concentrations have not been detected in the Unit D aquifer or there has been no investigation of possible 1,4-Dioxane contamination.

The second particle-tracking analysis was performed by releasing particles within the Unit E model layer in relatively close proximity to the Evergreen System extraction wells. The purpose of this analysis was to assess whether the pumping from the Evergreen System has had an influence on groundwater flow directions in the Unit E aquifer. In this analysis, the pumping from the Maple Village System was turned off to maximize the influence of the Evergreen System pumping on simulated heads in the Unit E aquifer. The resulting particle tracks are shown on Figure 9. As shown, there is no influence on simulated heads, groundwater flow directions, or particle tracks in the Unit E aquifer. This simulation does not support the contention that pumping by the Evergreen System wells draws Unit E aquifer contamination toward the wells in the Evergreen Subdivision.

Particle-tracking analyses with the 2007 Model clearly show that the contamination detected at wells in the Evergreen Subdivision would have come from the west and would have migrated entirely within the Unit D aquifer and, in some cases, would have come from areas where no Unit D aquifer contamination has been detected (e.g., north of Dexter Road or southwest of I-94). There is no indication from these model simulations that contaminants migrate from the deeper Unit E aquifer toward the Evergreen System extraction or monitoring wells. If the model is correct, the extent of 1,4-Dioxane in the Unit D aquifer is more widespread than indicated in plume delineation maps that have been submitted to the DEQ. This is entirely possible since much of the investigation work in this area has not employed VAS. If the model in not correct and there is better hydraulic connection with the Unit E aquifer so that groundwater and contamination in the Unit E aquifer are drawn into the Unit D aquifer and toward the extraction wells, the simulated extent of capture cannot be accurate and the model cannot be used to assess capture effectiveness or adjust extraction well pumping rates.

Recommendations

Use of 2007 Model

Additional extensive calibration and incorporation of new data are needed to improve the reliability of this model. However, we are not asking for further modification or calibration of the model unless PLS chooses to do so. At this time, we feel that time and resources are better spent collecting additional field data to verify the performance of the Evergreen System.

Plume Delineation:

In order to determine whether the simulated capture is effective, it is first necessary to know the full horizontal and vertical extent of the problem requiring containment. PLS has recently agreed to install a monitoring well north of the MW-KD cluster. A VAS boring should be completed prior to the installation of this well. A monitoring well cluster should be installed depending on the encountered subsurface geology regardless of whether the VAS data indicate the presence of multiple zones of contamination or multiple aquifers. In addition to the single monitoring well that PLS has agreed to install north of the MW-KD cluster, additional VAS borings will be needed to fully define the extent of the contaminant plume north of Dexter Road and west of Rose Drive.

Determination of Groundwater Flow Direction

The direction of groundwater flow north of Dexter Road and west of Rose Drive is not known. It may be that groundwater and 1,4-Dioxane contamination are migrating to the north. This may be the reason for the increase in 1,4-Dioxane concentrations at 465 Dupont and MW-77. It is necessary to collect additional groundwater level measurements north of Dexter Road to determine whether groundwater moves to the north or to the east. The design of the Evergreen System, and the orientation of the simulated capture extent, is based on the presumption that the direction of groundwater movement is to the east. If the direction of groundwater flow is to the north-northeast, the simulated groundwater flow directions, and the orientation of the extent of capture are incorrect.

Performance Monitoring

Previous comments with respect to monitoring the effectiveness of hydraulic containment (performance monitoring) were:

"Proper performance monitoring of the Evergreen extraction system is required since DEQ does not rely on model simulations as proof of remedy effectiveness. "Proof of remedy effectiveness" means the collection of physical data beyond the effective extent of treatment of the remedy. For a hydraulic containment system, hydraulic-head measurements and groundwater sample analyses are required at points beyond the estimated extent of capture. Model simulations show that a pumping rate of approximately 200 gpm will contain the delineated contaminant plume. The composite capture zone for this pumping rate is shown in particle-tracking plots in Figures 4 and 5. Currently, there is one monitoring well cluster (MW-47S and D) located downgradient of the simulated extent of capture. It is necessary to monitor more than one monitoring well cluster to verify the containment of the delineated plume in the Evergreen Area."

It is necessary to have data upon which to make timely decisions regarding the effectiveness of the performance of the Evergreen System or whether to adjust system pumping rates. This requires that monitoring well clusters be placed immediately beyond the estimated capture extent of the Evergreen System, not far downgradient. PLS has proposed to monitor selected unidentified monitoring wells while pumping rates in wells LB-1 and LB-3 are decreased; however, there are no existing wells that can be used to measure hydraulic gradients that would show hydraulic containment. Most available wells are not screened on the basis of VAS investigations, are not part of a monitoring well cluster, or are located too far downgradient to make a timely decision regarding the effective or optimum operation of the Evergreen System.

PLS and FTC&H are referred to two documents published by the U.S. Environmental Protection Agency (EPA) that describe the required elements to monitor the effectiveness of a hydraulic containment system and for locating performance monitoring wells or piezometers. These publications are:

Cohen, S.M., Vincent, A.H., Mercer, J.W., Faust, C.R., and C.P. Spalding. 1994. Methods For Monitoring Pump-And Treat Performance. EPA/600/R-94/123, June 1994, 102 p.

GeoTrans. 2003. Capture Zone How-To Guide for Ground Water Pump and Treat Systems. Draft document prepared for the U.S. Environmental Protection Agency under Tetra Tech Contract No. 68-W-02-034, Subcontract No. G9015.0.037.03.01, and under Dynamac Contract No. 68-C-02-092, Subcontract No. 092580. 60 p.

In particular, the discussion of the location of hydraulic-head measurement piezometer pairs in section 2.2.1.3 and groundwater quality monitoring locations in section 2.2.6.2, both in Cohen and others (1994), and pages 31-43 in GeoTrans (2003) should be reviewed in developing a performance monitoring network and plan for the Evergreen System. In keeping with the concepts discussed in these publications, we have prepared a figure (Figure 10) that shows the simulated extent of capture, and a buffer zone within which performance monitoring data are needed. We recommend that four monitoring well/piezometer pairs and a deeper monitoring well at the MW-47 well cluster be installed specifically for the purpose of monitoring the performance of the Evergreen System. The exact locations will be based on site access and buried utilities.

Evergreen System Pumping Rates

The pumping rates for the Evergreen System wells should not be adjusted until additional data delineating the extent of upgradient contamination, groundwater flow directions, and performance of the Evergreen System at present pumping rates are collected and evaluated.

You may contact me to discuss the model simulations and performance monitoring to verify model simulations at mandler@michigan.gov or (517) 241-9001.

 July 13, 2007

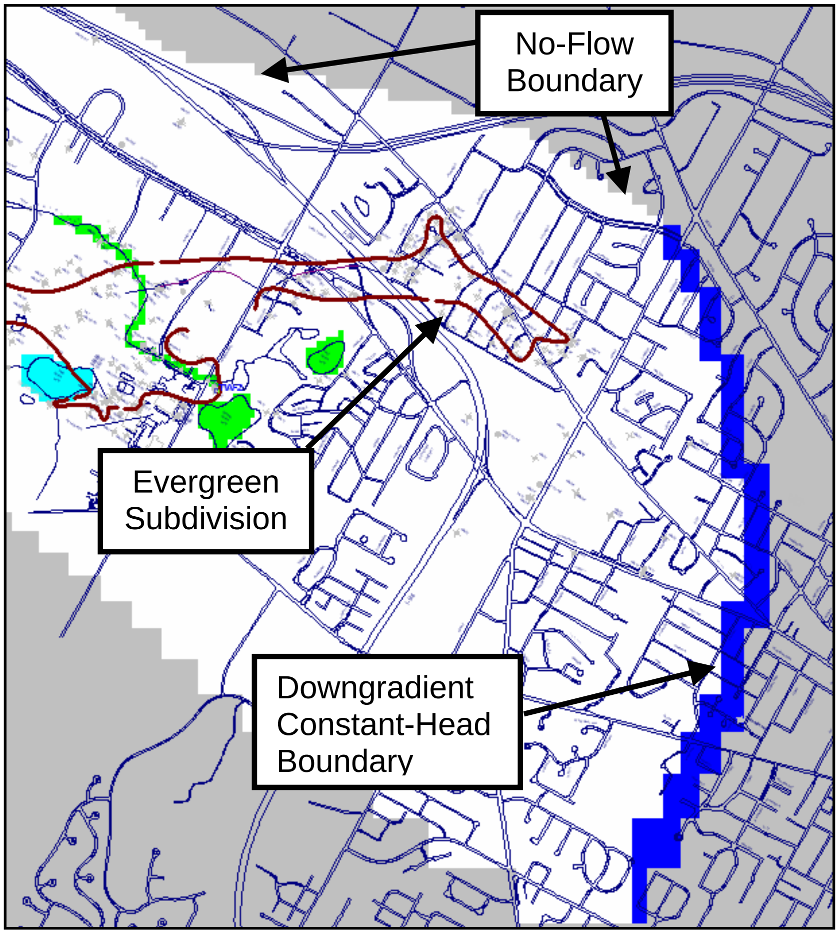

Figure 1 – Location of downgradient constant-head boundary.

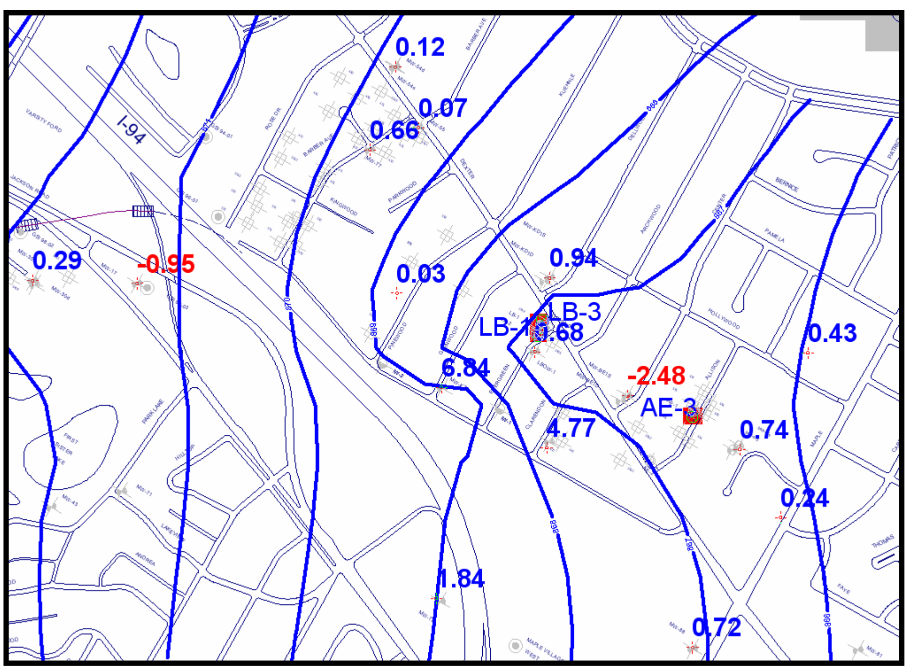

Figure 2 – Simulated calibration residuals for Model Layer 2.

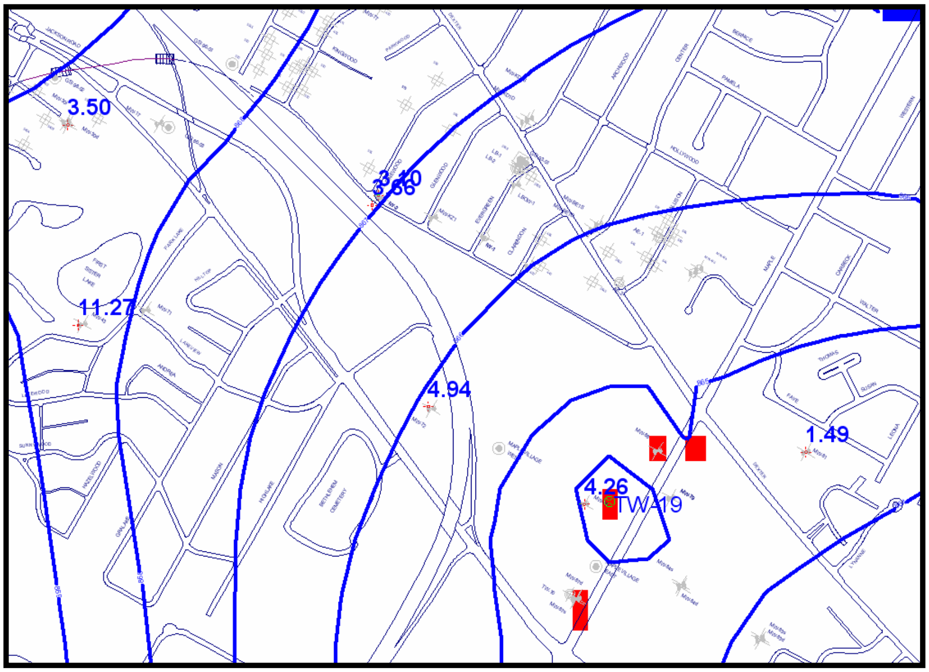

Figure 3 – Simulated calibration residuals for model layer 4.

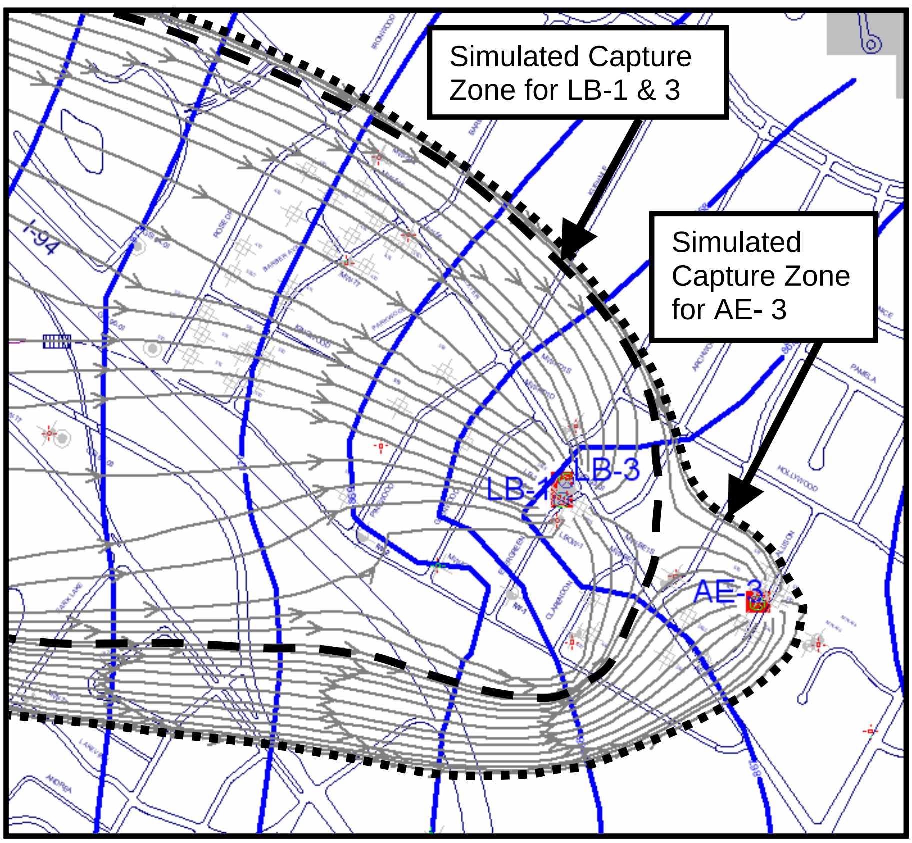

Figure 4 – Simulated heads and capture extent for Model Layer 2 (LB-1 = 90 gpm, LB-3 = 80 gpm, and AE-3 = 32 gpm).

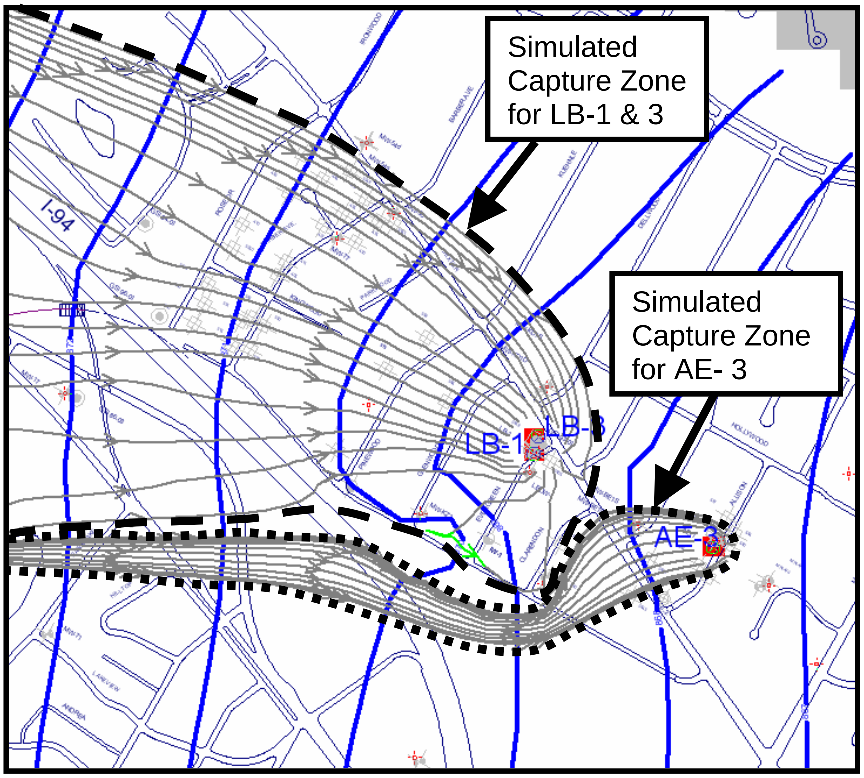

Figure 5 – Simulated heads and capture extent for Model Layer 2 (LB-1 = 67 gpm, LB-3 = 60 gpm, and AE-3 = 10 gpm).

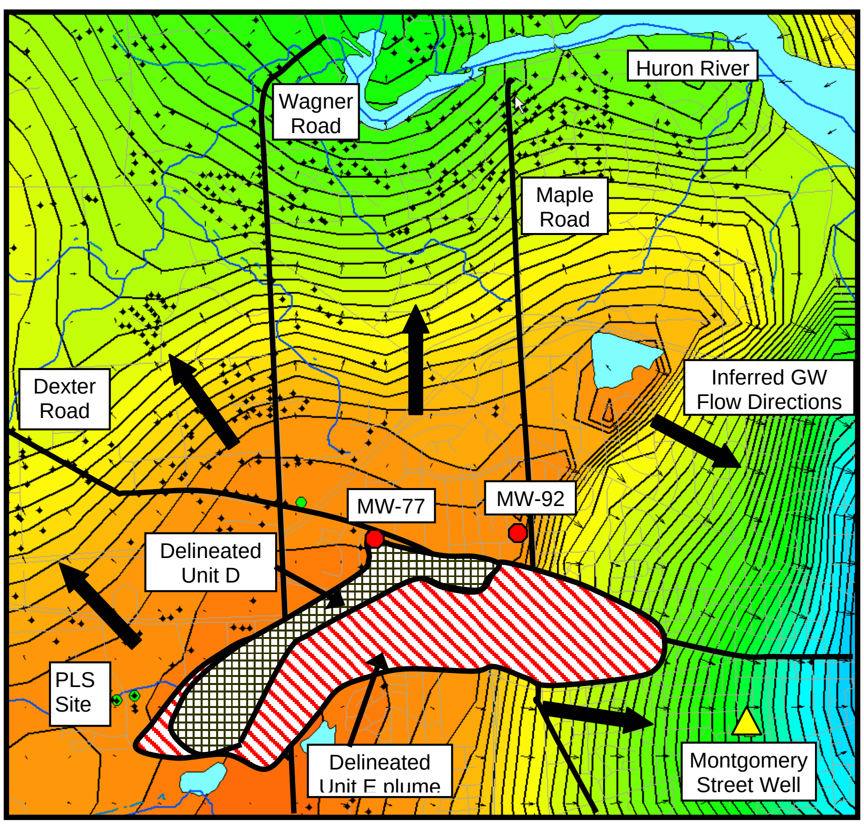

Figure 6 – Direction of Regional Groundwater Flow

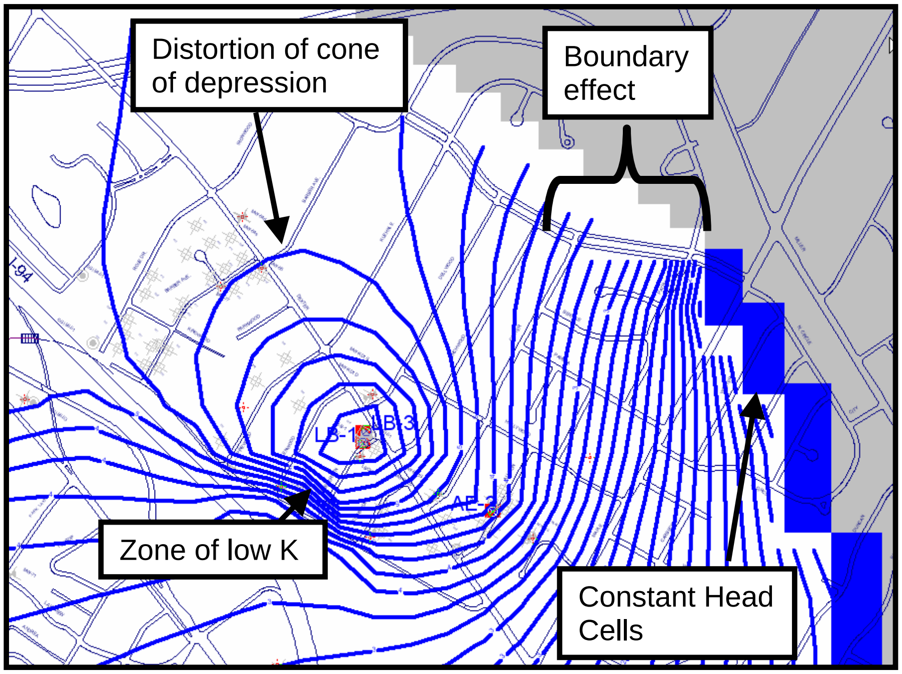

Figure 7 – Distortion of simulated cone of depression in Unit D aquifer (Model Layer 2).

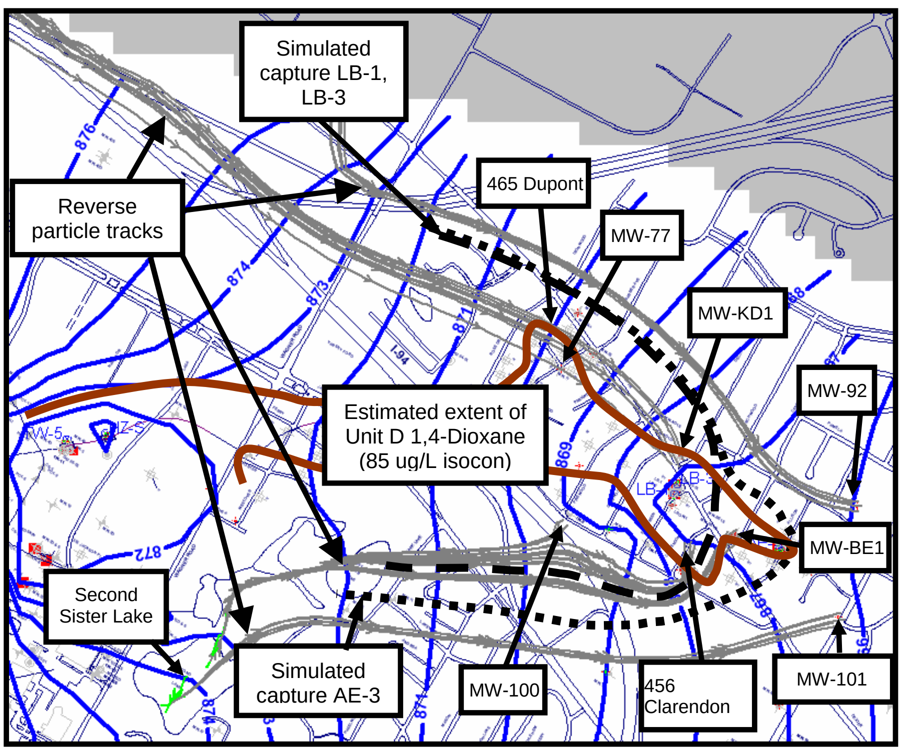

Figure 8 – Reverse Particle-Tracking in Model Layer 2, Evergreen System pumping 202 gpm.

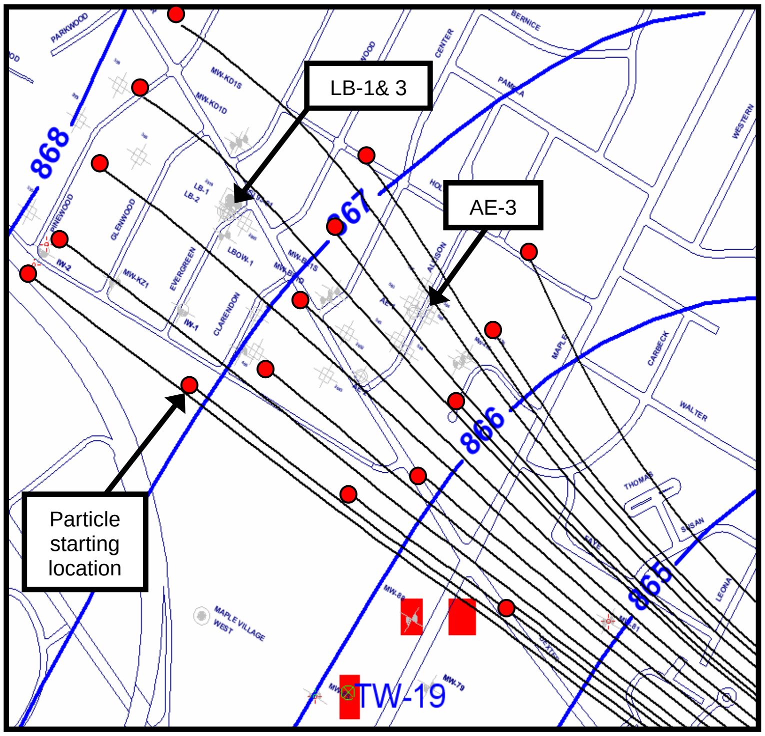

Figure 9 – Forward Particle-Tracking in Model Layer 4, Evergreen System pumping 202 gpm, and no pumping from Maple Village System.

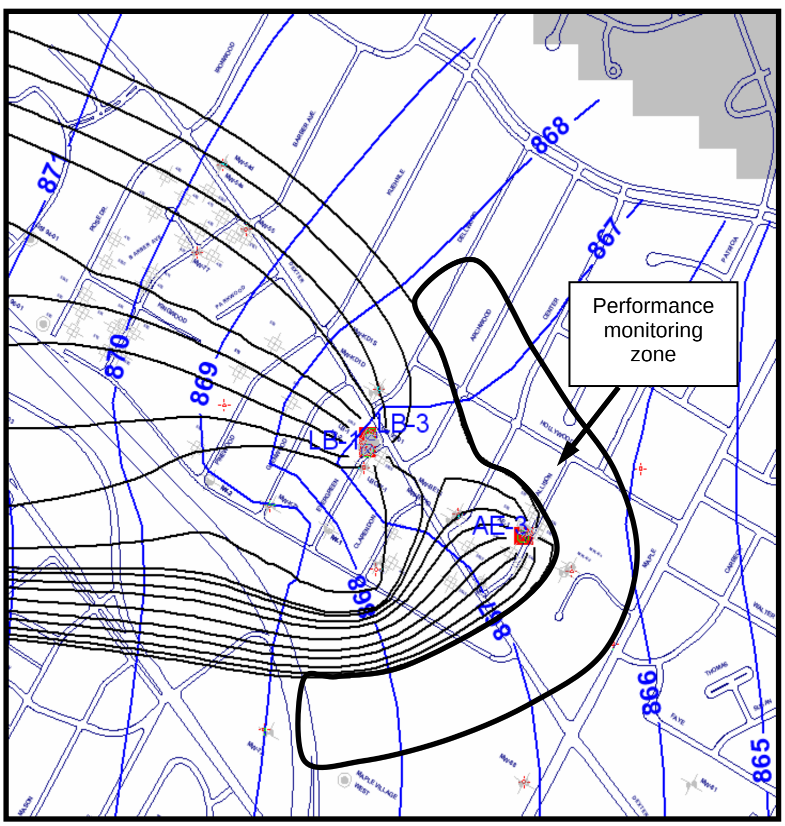

Figure 10 – Simulated heads and capture extent for Model Layer 2 (LB-1 = 67 gpm, LB-3 = 60 gpm, and AE-3 = 32 gpm).