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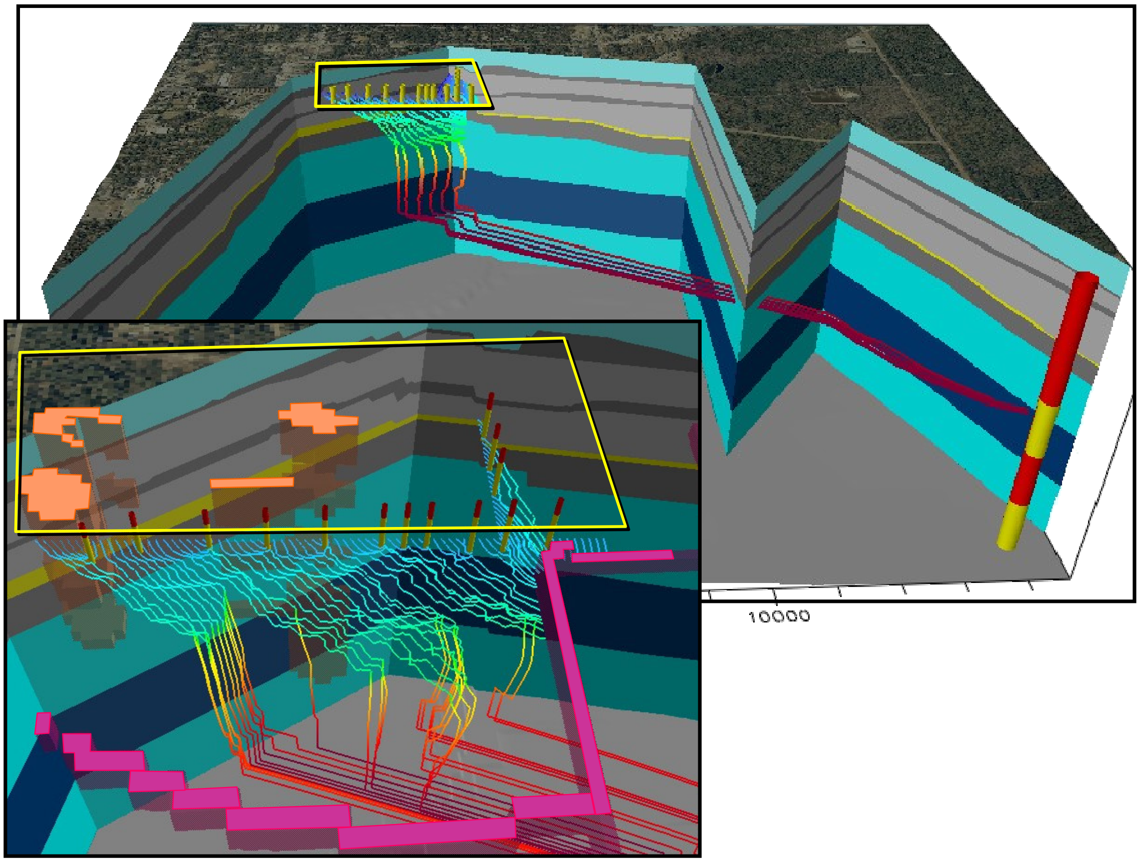
Cabot Carbon/Koppers Superfund Site Technical Memorandum Number 2



Evaluation of the Capture Effectiveness of the Ground Water Extraction System at the Koppers, Inc. Site, Gainesville, Florida

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1.0 Introduction

In June 2005, Waterloo Hydrogeologic, Inc. (WHI) and Princeton Groundwater, Inc. (PGI) produced a report evaluating a three-dimensional flow and transport model developed and calibrated (flow portion) by GeoTrans Inc. (GeoTrans Model) for the Cabot Carbon/Koppers Superfund Site (the Site) and the nearby Murphree Wellfield (Waterloo Hydrogeologic, Inc., 2005). The primary objective of the GeoTrans Model is to simulate the groundwater flow system and the fate and transport of dissolved contaminants at and beneath the Site in the Surficial Aquifer, the Hawthorn Group and the Upper Floridan Aquifer. GeoTrans used the model to predict the concentration distributions of naphthalene and arsenic and to assess their potential to travel to the Murphree Wellfield.

Emphasis in the first WHI/PGI report was initially placed on importing the model files into WHI's Visual MODFLOW and matching GeoTrans' results for flow, transport and travel times from the Surficial Aquifer through the Hawthorn Group, into the Ocala Upper Transmissive Zone (Ocala UTZ) and eventually to the Murphree Wellfield. After producing a matching base case model in Visual MODFLOW, the impacts of various parameters on flow, transport and travel times were evaluated. A major finding was the critical importance on travel times of the value chosen for the effective porosity in the Ocala UTZ. For example, the travel time from the site to the Murphree Wellfield is 5 years or less when an effective porosity of 1% is used compared to 59 years when GeoTrans' choice of 15% is used.

For a number of years, Gainesville Regional Utilities (GRU), as well as others, have questioned the effectiveness of the Surficial Aquifer extraction well system that has operated continuously at the Site since 1995. For example, in reviewing GeoTrans' July, 2004 draft modeling report, GRU asked GeoTrans the following: "Our primary interest is why the predicted groundwater levels indicate flow across the existing extraction system boundaries. It appears that the existing extraction system provides little hydraulic control of surficial groundwater moving across the site (p. 63, GeoTrans, 2004)." In an April, 2000 report, ThermoRETEC presented capture zones using the FLOWPATH II model, which showed complete capture of the Surficial Aquifer contaminated water, including contaminants migrating from all four known source areas (ThermoRETEC, 2000). The extraordinarily large size of the capture zones, which seemed improbable for 2-inch wells pumping most of the time between 2-3 gallons per minute (GPM), was noted by the GRU DNAPL consultant team in their review of reports related to the site. A request was immediately made to Beazer for the data used in generating these unusual capture zones (some as wide as 1500 feet). Beazer responded by saying that the FLOWPATH II model was no longer relevant as they were now using the more accurate three-dimensional fate and transport model developed by GeoTrans, and they provided a copy of a recent report written by RETEC that describes the change of models and the effectiveness of the extraction well system. The RETEC report (RETEC, 2005) states, "Results from the site model simulations indicate that the hydraulic containment system may not be 100-percent effective in capturing Surficial Aquifer groundwater flow from the site."

In this report we use a particle tracking analysis to examine the capture effectiveness of the Ground Water Extraction System (GWES) located in the Surficial Aquifer adjacent to the northern and eastern boundaries of the Koppers portion of the Site (Figure 1). The routes of the pathlines escaping the GWES were modeled. Pathlines represent the directions followed by groundwater flow and the travel times for the migration of water or a dissolved phase constituent. Contaminant concentrations were not modeled because there is insufficient concentration and associated parametric data such as dispersivities, distribution coefficients and degradation rates to achieve a satisfactorily calibrated transport model. Pathlines were modeled at this initial stage of our evaluation so as to compare to the pathline modeling performed by GeoTrans. Our analysis is based wholly on the calibrated flow model presented by GeoTrans, using the same model input parameters and boundary conditions as previously applied at the Site. Grid and layer modifications made to the GeoTrans model as described in this report helped us understand the predicted performance of the 2-inch extraction wells at a more refined scale than previously presented modeling results. The report will discuss the following items:

- Description of the grid and layer refinements made to the WHI Base Case Model to more accurately simulate the GWES, which consists of fourteen, fully-screened 2-inch wells pumping up to 4 GPM
- Description of the particle release simulations
- Observed pathline results from the simulations
- Summary and recommendations

2.0 The GeoTrans and WHI Base Case Models

The GeoTrans Draft Report entitled *Addendum 7: Groundwater Flow and Transport Model: Draft Report, Koppers Inc. Site, Gainesville, Florida*, dated October 5, 2004, gives a detailed description of the Site characterization and the original assumptions and parameters used in the GeoTrans Model (GeoTrans, 2004).

For evaluation purposes, WHI imported the original GeoTrans model files into the graphical user interface, Visual MODFLOW (Version 4.0). Within the Visual MODFLOW software package, the MODFLOW (McDonald and Harbaugh, 1988) code was used to simulate groundwater flow, and MODPATH (Pollock, 1994) was used to determine migration pathways from the Site to the Murphree Wellfield using particle tracking. The WHI and PGI report, entitled *Technical Memorandum: A Critique of the GeoTrans Flow and Transport Model, Koppers, Inc. site, Gainesville, Florida*, gives a detailed account of the importing process and modifications made to the GeoTrans Model to facilitate the evaluation of the Model (Waterloo Hydrogeologic, Inc., 2005).

The WHI Base Case Model area extends from approximately 2,000 feet south of the Cabot Carbon/Koppers Site to approximately 2 miles north, where it incorporates the southwestern corner of the Murphree Wellfield. The model consists of 92 rows by 72 columns by 12 explicit layers, for a total of 6624 grid cells in each numerical layer. In both the GeoTrans Model and WHI Base Case Model, the grid spacing varies from 60 by 60 feet at the Site to 500 by 500 feet near the external model boundaries (Figure 2a). The 12 numerical layers in the WHI Base Case Model represent the:

- Surficial Aquifer (Layer 1),
- Upper Hawthorn Clay (Layers 2 and 3),
- Upper Clayey Sand (Layers 4 and 5),
- Middle Hawthorn Clay (Layer 6),
- Lower Clayey Sand (Layer 7),
- Lower Sand (Layer 8),
- Lower Hawthorn Clay (Layer 9)
- Ocala Upper Transmissive Zone (UTZ) of the Upper Floridan Aquifer (Layer 10)
- Semi-Confining Unit (Layer 11)
- Ocala Lower Transmissive Zone (LTZ) of the Upper Floridan Aquifer (Layer 12)

There are several differences between the numerical layers in the original GeoTrans Model and the WHI Base Case Model. In the WHI Base Case Model, the Ocala Upper Transmissive Zone (Ocala UTZ) is represented as a single numerical layer approximately 100 feet thick. The 100-foot semi-confining unit (SCU) that separates the Ocala UTZ from the Ocala Lower Transmissive Zone (Ocala LTZ) exists as an explicit numerical layer in the WHI Model. The original GeoTrans Model represented the Ocala UTZ as a 200-ft numerical layer with the SCU as an implicit layer between the Ocala UTZ and LTZ. These differences are described in more detail in the WHI Report (Waterloo Hydrogeologic, Inc., 2005). Table 1 shows the parameters that were used in the WHI Base Case Model.

Table 1 Parameters in the WHI Base Case Model layers

Hydrogeologic Unit	Numerical Model Layers	K_x, K_y (ft/d)	K_z (ft/d)	Effective Porosity	Storage Coefficients
Surficial Aquifer	1	21	1.0	0.2	0.027 – 0.094
Upper Hawthorn Clay Unit	2,3	0.01	0.0018	0.15***	1.5e-6 – 1.0e-5
Upper Clayey Sand	4,5	0.3	0.05	0.15	7.5e-5 to 2.0e-4
Middle Hawthorn Clay Unit	6	0.01	0.00018	0.15***	5.0e-6 to 2.0e-5
Lower Clayey Sand	7	0.3	0.05	0.15	1.5e-5 to 7.0 e-4
Lower Sand	8	3	0.1	0.2	5.0e-4 to 1.5e-3
Lower Hawthorn Clay Unit	9	0.01	0.00012/ 0.0004**	0.15***	3.5e-5
Ocala UTZ	10	23/10*	0.0035	0.15***	8.5e-4 to 1.05e-3
Ocala SCU	11	1.0e-6	1	0.15***	1.0e-11
Ocala LTZ	12	175/75*	0.0035	0.15***	1.0e-3

* Hydraulic conductivity applied near the Murphree Wellfield Area
** Vertical hydraulic conductivity applied in the Western Zone of the Lower Hawthorn Clay Unit
***Effective porosity as used by GeoTrans, but expected to be much lower due to discrete flow pathways

3.0 Modifications to the WHI Base Case Model

In the GeoTrans Model, the Surficial Aquifer, from land surface to the contact with the Upper Hawthorn Clay, varies in thickness from approximately 20 to 50 feet, and is described as an unconsolidated, fine- to medium-grained sand, with thin layers of interbedded silt and clay deposits. For the purposes of evaluating the effectiveness of the well capture system, which consists of fourteen 2-inch diameter wells in the Surficial Aquifer at the Koppers Site, the principal modifications to the WHI Base Case Model consisted of increasing the grid discretization in the region of the Site, and dividing the Surficial Aquifer into several vertical numerical layers.

Table 2 gives a comparison of the original WHI Base Case Model with the revised models. In the original model, the grid spacing varies from 60 by 60 feet at the Site to 500 by 500 feet near the external model boundaries. In the revised models, the grid discretization remains 500 by 500 feet near the external model boundaries, but has been refined to 15 by 15 feet at the Koppers portion of the Site (Figure 2). The Surficial Aquifer, originally contained in one numerical layer in the base case, has been divided into four equal numerical layers in the first revised model. Over the full extent of the model, each layer in this scenario ranges between 5 and 12 ft (compared to the base case scenario of 20 to 50 ft). In the vicinity of the Site, the thickness for each layer ranges between 6 and 11 feet (giving a total Surficial Aquifer thickness of 24 to 44 feet). To examine the pathlines of groundwater flow near the contact between the Surficial Aquifer and the Hawthorn Group, Revised Model 2 was created by dividing the fourth numerical layer of Revised Model 1 into two equivalent layers that ranged between 2.5 and 6 ft in thickness. Two-dimensional and three-dimensional cross-sections of the WHI base case and revised models are shown in Figures 3a and 3b, respectively. Figure 3c shows the Surficial Aquifer layer thicknesses in plan view as distributed over the Site.

Table 2 Revisions to the WHI Base Case Model Grid Discretization

	WHI Base Case	**Revised Model 1**	**Revised Model 2**
Total Number of Rows and Columns	92 Rows by 72 Columns	260 Rows by 198 Columns	260 Rows by 198 Columns
Grid Sizes	Rows 1 to 20, 86 to 92 Columns 1 to 5, 47 to 72 From 500 x 500 ft to 90 x 90 ft Rows 21 to 85 Columns 6 to 46 60 x 60 ft	Rows 1 to 20, 245 to 260 Columns 1 to 15, 140 to 198 From 500 x 500 ft to 60 x 60 ft Rows 21 to 244 Columns 16 to 139 15 x 15 ft	
Number of Surficial Aquifer Model Layers	1	4	5
Numerical Model Layer Thickness Range	From 20 to 50 ft	Each Layer: From 5 to 12 ft	Layers 1 to 3: From 5 to 12 ft per layer Layers 4 to 5: From 2.5 to 6 ft per layer

Other Parameters and Modifications

The effective porosity for the Ocala UTZ used in the WHI Base Case Model was initially 15% for the purpose of matching the GeoTrans model. In the revised simulations, the WHI Revised Models 1 and 2 have been assigned an effective porosity of 1% for the Ocala UTZ. This is based on a literature review and detailed discussion of the effective porosities for flow in the Ocala karstic limestone by Stan Feenstra (Appendix C of WHI Report, 2005). This lower effective porosity is appropriate to account for the fact that most of the groundwater flow in the UTZ is expected to follow fracture and solution channel pathways rather than the limestone matrix. Where the WHI Base Case is discussed for comparison with the Revised Models, an effective porosity of 1% was also used for the Ocala UTZ to be consistent. The effective porosity of the Hawthorn clay units was not revised for this modeling work. The GRU DNAPL Team believes there is clear evidence that creosote migrated downward through the Hawthorn clay units along discrete flow pathways, such as “worm tubes”. Beneath the former North Lagoon, creosote has migrated downward at least 100 feet or at least 80% of the distance through the Hawthorn Group sediments in the 60 to 70 years since the lagoon began operation. Given that creosote has a viscosity 10 to 50 times higher than water, the travel time for groundwater along these discrete flow pathways in the Hawthorn sediments must be much less than the time taken for creosote to migrate downward. However, the natures and spatial distributions of these discrete flow pathways are not well understood in comparison with those present in the UTZ. As a consequence, at this time, lower and more appropriate values for effective porosity have not been applied to the Hawthorn clay units. Appropriate values for effective porosity of these clay units will be much less than 15%.

The ground water extraction wells at the Koppers Site were fully screened through the Surficial Aquifer in both the GeoTrans Model and the WHI Base Case Model, which are shown in yellow in Figure 3b. Preliminary simulations of the revised models where the Surficial Aquifer had been divided into several numerical layers resulted in a significant increase in the number of dry cells in the first numerical layer due to the water table dropping below the elevation of the bottom of the first numerical layer. Therefore, the extraction wells were re-screened to ensure that the total amount of water pumped remained consistent with the WHI Base Case Model (a standard procedure when using the USGS MODFLOW code), which used actual pumping rates reported for the site over the 10-year simulation period used by GeoTrans for the transient model calibration (January 1994 through July 2004). Specifically, in Revised Model 1, the extraction wells were screened through model layers 2, 3 and 4; in Revised Model 2, the extraction wells were screened through model layers 2 through 5.

4.0 Particle Tracking Simulations in the Surficial Aquifer

Particle tracking simulations were performed using the USGS' MODPATH, to evaluate the direction of groundwater flow through and beyond the Koppers Site. Because the groundwater flow solution in Revised Model 1 and Revised Model 2 resulted in dry cells for most of numerical model Layer 1 (indicating the water table elevation is lower than the elevation of the numerical layer and Layer 1 is simply in the unsaturated zone in these areas), particles were not released from the uppermost layer. The elevation of the predicted water table in the models with multiple layers to represent the Surficial Aquifer is similar to the elevation of the water table with a one-layer representation. Several hundred particles were released from the lower Surficial Aquifer layers at various locations within the Site borders, to determine the possible pathways that a conservative dissolved phase constituent might follow. Specifically, particles were released:

- Along an east-west line approximately 20 feet south of Wells EW-1, EW-2 and EW-3
- Along a north-south line located approximately 40 feet west of Wells EW-5 through EW-17 and extending slightly north of the Site
- Along a north-south line located close to the western boundary of the Koppers Site and extending approximately 900 ft south of the Site
- Along north-south lines located directly below and within the Former North and South Lagoons, the Former Drip Track and the Former Process Area.

Figure 4 shows the locations of the released particles for Revised Model 1 (Figure 4a) and Revised Model 2 (Figure 4b) as they were placed in the model grid. Table 3 gives the number of particles released from each region.

The GeoTrans simulation began in January, 1994, but the GWES did not begin operation until 1995. All but one of the extraction wells are turned on after 365 days into the simulation (see Appendix A). The final well, EW-16, began pumping after 1100 days (January, 1997). Consequently, particles were released after 500 days (May 1995), 1000 days (September 1996) and 2000 days (June 1999), to evaluate the performance of the wells when they were expected to exert the maximum influence on groundwater flow directions.

Table 3 Number of Particles Released in Revised Models 1 and 2

Region of Koppers Site where Particles were Released	Number of Particles Released	
	Revised Model 1 (Surficial Aquifer divided into 4 equivalent numerical layers; particles released from Layers 2, 3 and 4)	Revised Model 2 (Surficial Aquifer divided into 5 numerical layers; particles released from Layers 2, 3, 4 and 5)
Adjacent to East-West Extraction Wells	25	25
Adjacent to North-South Extraction Wells	75	75
Adjacent to Western Border of Koppers Site (extends south of Site)	70	0
Below Former North Lagoon	10	10
Below Former South Lagoon	15	15
Below Former Drip Track	10	10
Below Former Process Area	10	10
	215 per layer Total: 645	145 per layer Total: 580

5.0 Particle Track Results

Factors that influence the particle tracking analysis and the effectiveness of capture by the GWES are:

- The operational performance of the well field,
- The time that particles are released during the simulation,
- The depth at which the particles are released, and
- The distance from the GWES or drainage ditches/interceptor trench that particles are released.

At several discrete times during the simulation, many of extraction wells are pumping at reduced rates or not at all. Appendix A consists of a series of graphs showing the pumping rates for all of the extraction wells. For example, EW-2 has a pumping rate of 3.1 GPM at 365 days. However, there are significant variations in the pumping rates throughout the simulation, especially from July 2002 to March 2003 (days 3100 to 3400), where several times this well is not pumping. Since all of the wells have variable pumping rates, it is conceivable that particles approaching the wells at times of reduced pumping have a greater likelihood of bypassing the wells. The simulations used the same pumping schedule as the GeoTrans Model; no attempt was made to modify the schedule, such as to operate all the current wells at maximum capacity, to see the maximum capture effectiveness of the GWES.

Particles released from upper layers in the Surficial Aquifer are more likely to be captured by the extraction wells than those released from the lower Surficial Aquifer layers, which arrive at the contact between the Surficial Aquifer and the Hawthorn Group faster and then begin traveling laterally and in a more vertical direction towards the Ocala UTZ. *It is worth noting that the vertical distribution of creosote DNAPL in the Surficial Aquifer revealed during the 1995 coring operations by TRC (1999) indicates that most DNAPL is present in the lower ten feet of the Surficial Aquifer (which always corresponds to Model Layer 4, where applicable, Layer 5, and in places on the Site may include Model Layer 3).* Most of the particles released from the western region of the Site are never influenced by the extraction wells because they migrate into the Upper Hawthorn Clay at some distance from the wells and then travel laterally and vertically, eventually reaching the Murphree Wellfield.

5.1 Revised Model 1 (4-Layer Surficial Aquifer)

For Revised Model 1, the Surficial Aquifer was divided into four equal numerical layers of thickness 5 to 12 feet. Table 4 gives a summary of the particle destinations for Revised Model 1, based on the time (500, 1000 and 2000 days) and layer of release (2, 3 or 4). The pumping rates varied over the 10-year simulation period (January 1994 through July 2004) GeoTrans used for transient calibration, which explains the differences seen when one release time is compared to another. Comparing the fate of particles released in layers 2, 3 and 4, the closer a layer is to the Upper Hawthorn Clay layer, the higher the percentage of particles arriving at the Murphree Wellfield. For example, as many as 133 particles (out of 215) or 62% of the particles released from Layer 4 after 500 days eventually arrive at the Murphree Wellfield compared to 30% of the particles released in Layer 2 for the same release time. Layer 4 is the closest to the Upper Hawthorn Clay layer and the percentage of particles released in that layer arriving at the Murphree Wellfield is the highest for any release times and any layer. Layer 2 represents the upper part of the Surficial Aquifer and is therefore the furthest from the Upper Hawthorn Clay layer. The percentage of particles released in Layer 2 arriving at the Murphree Wellfield is the lowest for all release times compared to Layers 3 and 4. Conversely, the total percentage of particles released in Layer 2 and captured by the GWES and the Cabot drainage ditch/interceptor trench system is the highest for any release time and any layer.

Overall, the capture efficiency of the extraction well system was 36%, 38% and 47% for particles released at 500, 1,000, and 2,000 days, respectively. The Cabot Interceptor Trench captures less than 1% of the total number of particles released in Layer 2 at various locations and none for the other layers.

Table 4 Summary of Particle Destinations for Revised Model 1 Based on Time of Release

Particles Released from Layer	Number of Particles Released	Release Time	Destination of Particles		
			Number Captured by the Extraction Wells	Number Captured by the E-W Drainage Ditch/ Ground Water Interceptor Trench	Number Captured by the Murphree Wellfield
2 (Upper Surficial Aquifer)	215	500	96 (44%)	52 / 2 (24% / 1%)	65 (30%)
	215	1000	90 (42%)	53 / 0 (25% / 0%)	72 (33%)
	215	2000	118 (55%)	35 / 0 (16% / 0%)	62 (29%)
3 (Middle Surficial Aquifer)	215	500	86 (40%)	46 / 0 (21% / 0%)	83 (39%)
	215	1000	95 (44%)	39 / 0 (18% / 0%)	81 (38%)
	215	2000	106 (49%)	30 / 0 (14% / 0%)	79 (37%)
4 (Lower Surficial Aquifer)	215	500	52 (24%)	30 / 0 (14% / 0%)	133 (62%)
	215	1000	63 (29%)	26 / 0 (12% / 0%)	126 (59%)
	215	2000	79 (37%)	20 / 0 (9% / 0%)	116 (54%)

Figures 5 through 8 show the migration pathlines in three dimensions for particles released in all layers after 500 days, from various locations within the layers (using 3D Visual Explorer 4.0). Of the particles released adjacent to the east-west and north-south extraction wells, the majority that eventually reach the Murphree Wellfield were released at the southern end of the Koppers Site, especially south of the Former Drip Track area (shown in Figures 5a-c). Many particles also bypass the GWES and are intercepted by the drainage ditches. For particles released near the western border of the Koppers Site, those passing north of the Former North Lagoon are captured by the extraction wells. Particles released from Layer 2 near the southern end of the Site pass below the Former North and South Lagoon areas in the Surficial Aquifer before entering the Hawthorn Group (Figure 6a). Furthermore, many of the particles released from below the four source zone areas are not captured by the GWES and eventually reach the Murphree Wellfield (Figures 7 and 8), especially particles released in the Lower Surficial Aquifer where most of the DNAPL was located (TRC, 1999). Table 5 gives a detailed account of the final destinations for particles released after 500 days, based on the location of the release.

In summary, particles that escape the GWES and drainage ditches/interceptor trench and eventually reach the Murphree Wellfield include:

- 100% of the particles released from Model Layer 4 below the Former North and South Lagoons
- 70% of the particles released from Model Layer 4 and 50% of the particles released from Model Layers 2 and 3 below the Former Process Area
- 40% of the particles released from Model Layer 4 below the Former Drip Track

It is worth noting that less than 3% of the particles released in layer 2 adjacent to the North-South extraction wells were captured by the Cabot Interceptor Trench. None of the particles released at other locations and in different layers were captured by the Interceptor Trench.

Appendix B contains a series of figures showing particle tracking in plan view as the particles migrate through each model layer. For example, particles released adjacent to the east-west and north-south extraction wells are shown in Figure B-1. Figure B-1-i shows the particle migration through Layers 2 and 3, for particles that were released in Layer 2 after 500 days. The dark blue background represents the contact surface between Model Layers 3 and 4 of the Surficial Aquifer. For particles that have not arrived at either the extraction wells or the drainage ditches/interceptor trench, the termination points of the tracks represent the location where the particle moves into the next model layer. Figure B-1-ii appends the pathlines as they move through Layer 4 (the green background is the contact surface between the Surficial Aquifer and the Hawthorn Group), and Figure B-1-iii appends the pathlines as they pass below the Surficial Aquifer, into the Hawthorn Group and eventually arrive at the Murphree Wellfield. The violet background represents the contact between the Ocala UTZ and SCU. Figures B-2 and B-3 show the same migration pathlines for particles released in Layers 3 and 4, respectively.

Table 5 Itemized List of Particle Destinations for Revised Model 1 Based on Release Locations at 500 Days

Release Zone	Total Number of Particles Released from Each Layer	Final Destination of Particles	Itemization of Final Destination of Particles Based on the Release Location		
			Released from Layer 2	Released from Layer 3	Released from Layer 4
Adjacent to East-West Extraction Wells (20 ft south)	25	Extraction Wells	20 (80%)	19 (76%)	18 (72%)
		Drainage Ditch / Ground Water Interceptor Trench	5 / 0 (20% / 0%)	6 / 0 (24% / 0%)	7 / 0 (28% / 0%)
		Murphree Wellfield	0	0	0
Adjacent to North-South Extraction Wells (40 ft west)	75	Extraction Wells	24 (32%)	24 (32%)	25 (33%)
		Drainage Ditch / Ground Water Interceptor Trench	43 / 2 (57% / 3%)	36 / 0 (48% / 0%)	23 / 0 (31% / 0%)
		Murphree Wellfield	6 (8%)	15 (20%)	27 (36%)
Adjacent to Western Border of Koppers Site (extends 900 ft south of Site)	70	Extraction Wells	19 (27%)	10 (14%)	0
		Drainage Ditch / Ground Water Interceptor Trench	0	0	0
		Murphree Wellfield	51 (73%)	60 (86%)	70 (100%)
Below Former North Lagoon	10	Extraction Wells	10 (100%)	9 (90%)	0
		Drainage Ditch / Ground Water Interceptor Trench	0	0	0
		Murphree Wellfield	0	1 (10%)	10 (100%)
Below Former South Lagoon	15	Extraction Wells	12 (80%)	13 (87%)	0
		Drainage Ditch / Ground Water Interceptor Trench	0	0	0
		Murphree Wellfield	3 (20%)	2 (13%)	15 (100%)
Below Former Drip Track	10	Extraction Wells	6 (60%)	6 (60%)	6 (60%)
		Drainage Ditch / Ground Water Interceptor Trench	4 / 0 (40%)	4 / 0 (40%)	0
		Murphree Wellfield	0	0	4 (40%)
Below Former Process Area	10	Extraction Wells	5 (50%)	5 (50%)	3 (30%)
		Drainage Ditch / Ground Water Interceptor Trench	0	0	0
		Murphree Wellfield	5 (50%)	5 (50%)	7 (70%)

5.2 Revised Model 2 (5-Layer Surficial Aquifer)

For Revised Model 2, the Surficial Aquifer was divided into five layers; Layers 1, 2 and 3 were each 5 to 12 ft thick, while Layers 4 and 5 were each 2.5 to 6 ft thick. The particle migration pathlines appear very similar to the pathlines observed for the 4-Layer Surficial Aquifer Revised Model 1, so are not included as figures in this report. Table 6 gives the overall summary of destinations for the 145 particles released in each of Layers 2 through 5, based on the time of release. Note that for this scenario, the number and locations of released particles were not the same as for Revised Model 1. No particles were released from the western boundary of the Koppers Site, and slight variations in placement may occur when allocating particles to the various model layers. As shown in Figures 5 to 8, even a small difference in the lateral or vertical placement of particles can influence whether a single particle is captured or escapes, which explains differences between the results of the two Revised Models.

Overall, the capture efficiency of the extraction well system was 43%, 50% and 58% for particles released at 500, 1000, and 2000 days, respectively.

Table 6 Summary of Particle Destinations for Revised Model 2 Based on Time of Release

Particles Released from Layer	Number of Particles Released	Release Time	Destination of Particles		
			No. Arriving at Extraction Wells	No. Arriving at Drainage Ditch / Ground Water Interceptor Trench	No. Arriving at Murphree Wellfield
2 (Upper Surficial Aquifer)	145	500	78 (54%)	47 / 20 (32% / 14%)	0 (0%)
	145	1000	82 (57%)	40 / 23 (27% / 16%)	0 (%)
	145	2000	89 (61%)	35 / 21 (24% / 15%)	0 (%)
3 (Middle Surficial Aquifer)	145	500	77 (53%)	47 / 14 (32% / 10%)	7 (5%)
	145	1000	82 (56%)	39 / 13 (27% / 9%)	11 (8%)
	145	2000	94 (65%)	29 / 14 (20% / 10%)	8 (5%)
4 (Lower Surficial Aquifer)	145	500	55 (38%)	41 / 0 (28% / 0%)	49 (34%)
	145	1000	68 (47%)	31 / 0 (21% / 0%)	46 (32%)
	145	2000	81 (56%)	25 / 0 (17% / 0%)	39 (27%)
5 (Lower Surficial Aquifer)	145	500	41 (28%)	35 / 0 (24% / 0%)	69 (48%)
	145	1000	59 (41%)	24 / 0 (16% / 0%)	62 (43%)
	145	2000	74 (51%)	20 / 0 (14% / 0%)	51 (35%)

5.3 Comparison of Particle Destinations in Revised Models 1 and 2

Table 7 summarizes the destination of particles (as percentages) released in the Lower Surficial Aquifer below the source zones in Revised Model 1 (from Layer 4) and Revised Model 2 (from Layers 4 and 5). The model area and total thickness are the same for the two models. The percentages given for Revised Model 2 are the average of particle tracking results observed in Layers 4 and 5. Based on the simulation results, we note the following:

- Particles released below the North Lagoon are not captured by the GWES or drainage ditches in either of the revised models
- Differences in the number of particles captured by the GWES in Revised Model 1 and Revised Model 2 may be attributed to the release locations of the particles; in Revised Model 2, particles released in Layer 4 were released at a higher elevation than the particles released in Layer 4 of Revised Model 1
- 13% of the particles released below the South Lagoon in Layer 4 of Revised Model 2 were captured by the GWES
- 87% of the particles released from Layers 4 and 5 in Revised Model 2, which constitute the principal DNAPL zones beneath the Former North and South Lagoons and the Former Process Area, are predicted to reach the Murphree Wellfield
- 75% of particles are not captured by the GWES below the Former Process Area in Revised Model 2
- Increasing the number of layers at the base of the Surficial Aquifer has no effect on the destination of particles released below the Former Drip Track

Table 7 Comparison of Particle Destinations for 500-day Release: Layers 4 and 5 in Revised Models 1 and 2

Model	Location of Release	Particle Destination (%)		
		Extraction Wells	Drainage Ditch / Ground Water Interceptor Trench	Murphree Wellfield
Revised Model 1 (Released from Layer 4, Lower Surficial Aquifer)	North Lagoon	0	0	100
	South Lagoon	0	0	100
	Process Area	30	0	70
	Drip Track	60	0	40
Revised Model 2 (Released from Layers 4 and 5, Lower Surficial Aquifer)	North Lagoon	0	0	100
	South Lagoon	13	0	87
	Process Area	25	0	75
	Drip Track	60	0	40

5.4 Travel Times

Travel times were compiled for particles released in the Revised Model 1 and WHI Base Case Model. These results are presented in Appendix C and include the release locations, the minimum travel times for particles to reach the contact between the Hawthorn Group and the Ocala UTZ, the minimum travel time for particles to reach the Murphree Wellfield, and the time spent in the Ocala UTZ.

Depending on the particle release location in the Surficial Aquifer, travel times to reach the UTZ are between 51 years and 194 years for the Revised Model 1 and 75 to 124 years for the WHI Base Case Model. These long travel times reflect the use of a value of 15% for effective porosity of the Hawthorn clay units. As described in Section 3, the effective porosity of these units must be many times lower and as a result the travel times to the UTZ must be many times shorter than those predicted in this modeling.

These travel times are for a conservative, dissolved constituent flowing under Darcian conditions in a geologically homogeneous and isotropic aquifer. If non-Darcian conditions are present or if a constituent follows preferred pathways, such as those provided by worm-tubes or imbedded high hydraulic conductivity zones, faster travel times are probable. Figures C-1 to C-3 in Appendix C show the locations (the red star) in plan view of the particles at the point they permanently enter the Ocala UTZ (using the WHI Base Case Model), at positions approximately 1200 to 2500 ft north of the Cabot portion of the Site. Once particles released in the Surficial Aquifer enter permanently into the Ocala UTZ, the travel time from where they enter the UTZ to the Murphree Wellfield is between 2 and 3 years.

In the first WHI/PGI Report (Waterloo Hydrogeologic, Inc., 2005), it was shown that travel times to the Murphree Wellfield for particles released in the Ocala UTZ were 4.3 to 5.0 years. These particles were released *in the UTZ directly below the Koppers Site to simulate the fate of contaminants that had already reached the UTZ (*shown in Figure 4a in the WHI Report, 2005*).* However, in the current report, particles were released in the Surficial Aquifer and they migrate both laterally and vertically a significant distance in a northeastern direction from their point of release (approximately 1500 to 2500 feet due north of the Cabot Site) before permanently entering the Ocala UTZ. Particles were not released in the Ocala UTZ directly beneath the Cabot site because the site's proximity to the Kopper's site should result in essentially the same travel time range of 4.3 to 5.0 years. To see how long it would take to reach the Murphree Wellfield once the Hawthorn/Ocala UTZ contact was permanently reached, particles were released in the Ocala UTZ at these distant locations indicated by the green stars in Figure C-4. The travel times (given in Table C-2) from these locations (1500 to 2500 feet north of the northern boundary of the Cabot Site) to the Murphree Wellfield were between 2.6 and 3.1 years, which is consistent with travel times of 4.3 to 5.0 years for the longer path from the Kopper's Site to the Murphree Wellfield for a constituent already in the UTZ beneath the site.

6.0 Summary

The objective of this study was to evaluate the effectiveness of the Ground Water Extraction System (GWES) currently in operation at the Koppers site in Gainesville, Florida. To better quantify the effectiveness of the GWES, the original GeoTrans Model, which uses a single-layer for the Surficial Aquifer and 60 feet by 60 feet grid spacings in the vicinity of the wells, was modified. The grid spacing in the region of the Site was refined by a factor of four and the Surficial Aquifer was divided into four and five numerical layers for Revised Models 1 and 2, respectively. An effective porosity of 1% was applied in the Floridan Aquifer Upper Transmissive Zone (as opposed to 15% that was used in the original GeoTrans Model). Note that this change does not affect flow patterns in the Surficial Aquifer and Hawthorn Group. No other changes were made to the model.

Particle migration pathlines were generated below the elevation of the water table in the Surficial Aquifer layers of the model to assess the efficiency of groundwater capture by the extraction wells. These particle migration pathways simulate the movement of water or a dissolved phase constituent from the Site. The simulation began in January, 1994, one year before the GWES began operating. The particles were released at later times (500, 1000 and 2000 days) during the simulation to correspond to maximum extraction well pumping rates. Contaminant concentrations were not modeled because there is insufficient concentration and associated parametric data such as dispersivities, distribution coefficients and degradation rates to achieve a satisfactorily calibrated transport model.

Results of the particle tracking simulations show the GWES is not preventing the offsite migration of potentially contaminated groundwater. Overall, the GWES captured 36% to 58% of the particles released at the source areas on the Koppers Site. Specifically, a large percentage of particles are bypassing or not reaching the GWES or the Cabot drainage ditches/Ground Water Interceptor Trench, and could eventually reach the Murphree Wellfield. Many of the particles originally released at a significant distance from the GWES (such as the western border of the Koppers Site) arrived at the contact between the Surficial Aquifer and the Hawthorn Group before reaching the GWES, and therefore are not influenced at all by the current extraction system. Several of these particles passed below the Former North Lagoon and Former South Lagoon before reaching the base of the Surficial Aquifer and continuing into the Hawthorn Group. Recall that in 1995, TRC stated most of the DNAPL exists within the lower 10 feet of the Surficial Aquifer. The particles that passed below the Former North and South Lagoons traveled directly through this area, as shown in Appendix B. The percentage of particles released below the four known source areas after 500 days that are predicted to eventually reach the Murphree Wellfield are:

- 40% of particles released in the Lower Surficial Aquifer (Layer 4) below the Former Drip Track
- 70% of particles released in the Lower Surficial Aquifer (Layer 4) below the Former Process Area
- 100% of particles released in the Lower Surficial Aquifer (Layer 4) below the Former North and South Lagoons

In addition, to summarize the results for all particles released in Revised Model 1 after 500 days (with similar results for release times of 1000 and 2000 days):

- 30% of all particles released from the Upper Surficial Aquifer (Layer 2) are predicted to eventually reach the Murphree Wellfield
- 39% of all particles released from the Middle Surficial Aquifer (Layer 3) are predicted to eventually reach the Murphree Wellfield
- 62% of all particles released from Lower Surficial Aquifer (Layer 4,) are predicted to eventually reach the Murphree Wellfield

No attempt was made to quantify the capture efficiency of the extraction wells in terms of the gallons per day of water that escapes the GWES. Additionally, determining the optimal locations, numbers and pumping rates of extraction wells for the Site to achieve 100% capture was not part of this effort.

6.1 Recommendations

The modeling results predict that the Koppers GWES is likely allowing a significant volume of potentially contaminated water to escape the Site and migrate downward towards the Ocala UTZ. This water could eventually migrate to the Murphree Wellfield. Based on the data available at this time, there is no reliable way of predicting what the concentrations of these contaminants will be once they reach the Ocala UTZ and ultimately the Murphree Wellfield. To date, there have been little or no direct measurements of actual contaminant concentrations in the surficial and intermediate aquifers located downgradient of the GWES. Therefore, in cases where a water supply for over 170,000 people is potentially threatened, a prudent recommendation is to begin with quantifying the effectiveness of the GWES by performing direct measurements of potential contamination migrating past the GWES. The first step should be to determine the volume of water and contamination escaping the site, to better assess the threat to the wellfield from this migration pathway. Once the capture efficiency of the GWES is determined, a sufficient number of additional extraction wells should be installed to prevent future contaminant migration from the Surficial Aquifer of the Koppers site. As presented in this report and the first WHI/PGI Technical Memorandum report (Waterloo Hydrogeologic, 2005), additional controls in the Surficial Aquifer will not prevent the contamination that has already migrated into the Hawthorn Formation of the Site from reaching the Ocala UTZ and threatening the Murphree Wellfield.

Respectfully submitted,

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