GROUNDWATER FLOW MODEL DEVELOPMENT AND CALIBRATION INTERIM REPORT

KOPPERS INC. SITE
GAINESVILLE, FLORIDA

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EXECUTIVE SUMMARY

This interim report presents the development and calibration of the three-dimensional groundwater flow model at the Koppers, Inc. (KI) site in Gainesville, Florida (Site). This report is based on the Addendum 6: Work Plan, Groundwater Flow and Transport Modeling, Koppers Inc. Site, Gainesville, Florida which was submitted to EPA on April 22, 2004 (GeoTrans, 2004a). The modeling approach described in the work plan involves the use of two separate models: 1) A three-dimensional fate and transport model of the Surficial Aquifer, Hawthorn Group, and the Upper Floridan deposits (Site Model), and 2) An updated version of the existing Gainesville Regional Utility (GRU) Floridan Aquifer groundwater flow model (CH2M HILL, 1993) (Regional Model). This report will only discuss the development and calibration of the Site Model.

The primary objective of the Site Model is to evaluate groundwater flow and solute transport in the Surficial, Hawthorn Group, and Upper Floridan deposits at the Site. Ultimately, the combination of the Site Model and Regional Model will provide a comprehensive evaluation of fate and transport within the Surficial Aquifer, Hawthorn Group, and the Upper Floridan deposits and the potential for constituent transport from the Site to the Murphree Well Field.

The Site Model is an 11-layer model that encompasses an area of approximately 5-square miles around the Site. All major lithologic units within the Surficial Aquifer, Hawthorn Group, and the Upper Floridan deposits are incorporated into the model to represent groundwater flow and solute transport conditions at the Site. Recent Site characterization data are incorporated into the model to ensure that it accurately represents current understanding of Site conditions. The groundwater flow component of the Site Model is calibrated to monitoring well water-level data both on-site and off-site.

The groundwater model calibration involves adjusting select model hydrogeologic parameters until model water levels agree with observed values. Specifically for the Site, the objective of the model calibration was to develop a numerical model that accurately reproduced historical groundwater flow conditions, temporal potentiometric surface fluctuations, groundwater flow directions, and municipal well drawdowns. The model does an excellent job of reproducing the long-term and short-term temporal trend for monitoring wells completed in the surficial aquifer, the upper and lower Hawthorn, and the Ocala Limestone (uppermost hydrostratigraphic unit in the Upper Floridan Aquifer) at the site.

The large vertical hydraulic gradients across the Hawthorn Group deposits results in the groundwater flow model being extremely sensitive to the vertical permeability value of the upper, middle and lower clay units within this formation. Water-level elevations obtained from monitoring wells completed within the upper and lower Hawthorn Group deposits and the upper Floridan aquifer provide good calibration points with which to fine tune the site-wide average permeability of the three major clay units within this formation.

The Surficial Aquifer is sensitive to monthly precipitation recharge values and drain conductance values. Net recharge is applied to the model on a monthly basis. The monthly net recharge is calculated as a percentage of the total monthly precipitation. The magnitudes of water-level fluctuations for monitoring wells completed in the Surficial Aquifer are sensitive to the percentage of precipitation applied on a monthly basis. The modeled Surficial Aquifer water-level fluctuations are also sensitive to discharge rates to Springstead Creek, wetlands, drainage ditches and the horizontal drain on Cabot Carbon. The rate of discharge to these groundwater discharge points is controlled by the permeability of deposits surrounding these features. Within the model a conductance term is used to control the rate of discharge into these hydrologic features. The areal extent and magnitude of water-level fluctuation in wells adjacent to these features is controlled by the conductance term applied to these model drains. The historical water-level data for the Surficial Aquifer at both the KI and Cabot Carbon sites provide good calibration points for establishing conductance values for these discharge drains.

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1.0 INTRODUCTION

This report describes the development and calibration of a three-dimensional groundwater flow model for the KI wood-treating facility and surrounding area in Gainesville, Florida (Figure 1-1). This work was performed as described in Addendum 6: Work Plan, Groundwater Flow and Transport Modeling, Koppers Inc. Site, Gainesville, Florida (GeoTrans, 2004a).

1.1 BACKGROUND

The Site is within the City limits of Gainesville and is located on property that has been used as an active wood-treating facility for over 80 years. Adjacent properties include the former Cabot Carbon Superfund site to the east, private residences to the west, northwest, and north, and commercial facilities to the south along NW 23rd Avenue.

The approximately 80 years of wood-treating operations have resulted in creosote NAPLs infiltrating into shallow groundwater. Residual NAPLs are primarily restricted to four source areas of the Site: 1) Former north lagoon, 2) Former south lagoon, 3) Former cooling pond area, and 4) Former drip-track area. The primary dissolved-phase constituents of concern at the Site are polynuclear aromatic hydrocarbons (PAHs), of which naphthalene is the most mobile of the PAH constituents and the largest component by weight in creosote. Additionally, arsenic has been detected in select wells at the Site and is therefore an additional site constituent of interest.

Extensive investigation and characterization programs have been ongoing at the Site since the mid 1980s. These programs established that NAPLs and dissolved-phase Site constituents infiltrated into the Surficial Aquifer and the Hawthorn Group deposits beneath the Site. Four Upper Floridan Aquifer monitoring wells were installed at the Site in 2003 to investigate the potential of vertical migration of Site constituents into the upper Floridan Aquifer. Recently, nine Hawthorn Group wells and one Upper Floridan well were installed as part of the source delineation study (GeoTrans, 2004b) to delineate the vertical and horizontal extent NAPLs beneath potential historical source areas.

Beazer initiated a multi-faceted investigation, characterization and analysis program in 2003 to evaluate the potential for Site constituent migration into the Upper Floridan Aquifer. This modeling effort is one component of this on-going investigation and analysis.

2.0 HYDROGEOLOGIC CONCEPTUAL MODEL

The hydrogeologic conceptual model for the Site and surrounding areas was developed based on a comprehensive review of previous investigative reports and hydrogeologic data for the area. The major reports used to develop the conceptual flow model include the following:

1) *TRC report (September 1999) entitled* "Revised Supplemental Feasibility Study Volumes 1 and 2, Cabot Carbon/Koppers Superfund Site, Gainesville, Florida";

2) *TRC report (September 2002) entitled* "Field Investigation Activities Report: Cabot Carbon / Koppers Superfund Site, Gainesville, Florida*";*

3) *TRC report (August 2003) entitled* "Addendum Hawthorn Group Field Investigation Report: Cabot Carbon / Koppers Superfund Site, Gainesville, Florida";

4) *TRC report (November 2003) entitled* "Data Report, November Sampling Event, Investigation of the Hawthorn Group Formation: Cabot Carbon / Koppers Superfund Site, Gainesville, Florida";

5) *TRC report (June 2004) entitled* "Data Report, April Sampling Event, Investigation of the Hawthorn Group Formation: Cabot Carbon / Koppers Superfund Site, Gainesville, Florida";

6) *CH2M HILL report (March 1993) entitled, "Evaluation and Modeling of the Floridan Aquifer System in the Vicinity of the Murphree Well Field: Technical Memorandum No. 4"; and*

7) *GeoSys, Inc. report (April 2000) entitled, "Update of the Geology in the Murphree Well Field Area"*.

Additional sources of information used to develop the conceptual model included hydrogeologic and hydrologic databases containing aquifer characteristics, well logs, groundwater levels, aquifer and pumping-test results, groundwater municipal pumpage volumes/rates, and precipitation.

2.1 REGIONAL HYDROGEOLOGY

The Site is located in the Northern Highlands of Alachua County, where the Hawthorn Group confines the Floridan Aquifer. Four principal hydrostratigraphic units are present in this area: 1) Surficial Aquifer; 2) Hawthorn Group; 3) Upper Floridan Aquifer; and 4) Lower Floridan Aquifer.

Surficial Aquifer

The Surficial Aquifer consists of approximately 20- to 30-feet of Pliocene to Pleistocene marine terrace deposits (Figures 2-1 and 2-2). These deposits primarily consist of unconsolidated, fine- to medium-grained sand, with thin layers of interbedded silt and clay deposits. The Surficial Aquifer flow direction is controlled by land surface topography, and localized discharge points such as wetlands, creeks and drainage ditches. The Surficial Aquifer is not a major source of potable groundwater; however, locally some wells have been installed for domestic irrigation purposes.

Hawthorn Group

The Hawthorn Group underlies the Surficial Aquifer and consists of a thick sequence of low-permeability unconsolidated sedimentary deposits. These deposits are approximately 120 to 125 feet thick beneath the Site and separate the overlying Surficial Aquifer from the underlying Floridan Aquifer with low-permeability clay and silt deposits. The Hawthorn Group is not a major source of groundwater for this area. Hydraulic heads in the Hawthorn are controlled by interbedded low-permeability clay units. The horizontal groundwater flow component for this formation is only about a factor of two greater than the vertical flow component near the Site, when typically in interbedded sedimentary deposits similar to these the horizontal component is orders of magnitude greater. Hence, vertical groundwater flow is a significant flow component for this formation.

Upper Floridan Aquifer

The Upper Floridan Aquifer underlies the Hawthorn Group. The two primary formations that comprise the Upper Floridan aquifer are the Ocala Limestone and the Avon Park Limestone (Figure 2-3). The major water-producing zone in the Upper Floridan Aquifer is a 20- to 100-foot thick, high-permeability zone at the base of the Ocala Limestone and top of the Upper Avon Park Limestone (GeoSys, Inc., 2000). The majority of the groundwater produced in Alachua County is derived from this high permeability zone. A secondary water-producing zone in the Upper Floridan Aquifer is a 50- to 100-foot thick zone located near the top of the Ocala Limestone. The production capacity of this upper zone is highly variable over short distances, with the total volume of water produced from the upper zone being a small fraction of the lower more productive zone. The upper and lower production zones are separated by approximately 100 to 150 feet of dense, low-permeability carbonate deposits that produce minimal amounts of water. The regional direction of groundwater flow in the Upper Floridan Aquifer is to the west and northwest; however, large groundwater pumping centers such as the Murphree Well Field have locally changed flow directions.

Lower Floridan Aquifer

The Lower Floridan Aquifer is separated from the Upper Floridan Aquifer by approximately 200 feet of low-permeability carbonate deposits, in addition to numerous intra-aquifer low-permeability zones. The Lower Floridan Aquifer is effectively isolated from the Upper Floridan Aquifer, with limited potential for groundwater flow between them (Miller, 1997). No known water supply wells within Alachua County are completed in the Lower Floridan Aquifer (CH2M Hill, 1993).

2.2 KI SITE GROUNDWATER FLOW

Dominant groundwater flow paths at the Site consist of lateral flow in the Surficial Aquifer, vertical flow through the Hawthorn Group and lateral flow in the Upper Floridan Aquifer. The Surficial Aquifer's primary direction of groundwater flow is towards the northeast where it discharges to a series of drainage ditches and wetlands. Along the western KI property boundary, groundwater flow is more northerly where it discharges into Springstead Creek. A horizontal well was installed along the eastern Cabot Carbon site to collect and treat impacted groundwater at this site. This horizontal well is also a significant groundwater discharge point for this area and appears to impact groundwater flow directions along the eastern KI property boundary. A groundwater divide is projected to be present to the west of the Site as a result of Surficial Aquifer groundwater discharge to Hogtown Creek. The projected location of this divide is coincident with the western extent of the Site Model boundary. The average hydraulic gradient to the northeast across the Site in the Surficial Aquifer is approximately 0.005 ft/ft, and the average groundwater flow velocity is estimated to be approximately 150 ft/yr, based on an estimated effective porosity of 25 percent.

A Surficial Aquifer groundwater hydraulic-barrier system was constructed at the Site in 1995 to mitigate off-site migration of dissolved-phase site constituents in the Surficial Aquifer. The hydraulic barrier consists of 14 shallow extraction wells, with an average combined pumping rate of 29 gallons per minute (gpm). Because of these relatively low withdrawal rates and the hydrologic effects of the Cabot Carbon horizontal well, the northeasterly groundwater flow direction has not changed significantly since the implementation of the barrier system.

Groundwater flow in the Hawthorn Group is primarily controlled by three low-permeability clay units, which for the purpose of this discussion are designated as the upper, middle and lower clay units. The lateral continuity and variable thickness of the Hawthorn Group clay deposits were established by performing a detailed electrical resistivity (ER) survey over the Site Model domain. Results of the ER survey indicate that the upper two clay units are continuous across the Site Model domain, with the possible exception of where the upper clay has been eroded by Springstead Creek. The ER survey was unable to ascertain the lateral continuity and thickness of the lower clay unit because the depth to this unit exceeded the ER equipment depth limitation; however, borehole logs at the Site indicate that the lower clay unit is approximately 35 feet thick and laterally continuous. The upper clay unit ranges from approximately 2 to 6 feet in thickness and the middle clay unit is about 10 feet thick (Figures 2-1 and 2-2). Detailed geologic logs of these clay units from the recent installation of Hawthorn Group and Floridan wells indicate that the clay units actually consist of 1 to 2 feet thick clay deposits interbedded with 1 to 2 inch thick deposits of clay, silt, and occasional sand and gravelly sand stringers. The upper clay unit appears to be more permeable and contains less clay deposits than the middle and lower clay units. Separating the three major clay units are 40- to 60-foot thick deposits of clayey sand, sand, and occasional carbonate units. Similar to the clay units, these deposits contain thin interbedded clays, silts and gravelly-sand deposits. These more permeable intervening deposits have been locally designated as the upper and lower Hawthorn. Monitoring wells completed in the upper and lower Hawthorn deposits at the Site typically yield water at less than a few tenths of a gpm.

Groundwater flow within the Hawthorn Group deposits is primarily vertical through clay layers with a horizontal flow component in the upper and lower Hawthorn deposits. The permeability of the three clay units decreases with increasing depth as evidenced by the hydraulic gradient across the units. The hydraulic-head difference across the upper clay unit is approximately 2 feet, whereas the hydraulic-head difference across the middle clay unit is approximately 30 feet and the hydraulic-head difference across the lower clay unit is greater than 70 feet. The difference in the thickness of these clay units accounts for some of the increase in hydraulic-head loss; however, increasing thickness alone does not fully account for the head loss. The magnitude of the hydraulic-head difference is also a reflection of increasing amounts of lower-permeability clay and silt deposits in the middle and lower clay units. The vertical conductance (hydraulic conductivity divided by thickness of the unit) of the upper clay unit is considerably higher than the middle and lower clay units given that the hydraulic-head difference is a factor of 15 less than the middle clay unit and a factor of 35 less than the lower clay unit. In general, groundwater and constituent transport times increase with decreasing vertical conductance values, hence the groundwater travel times in the lower clay unit should be the highest of the three clay units.

The large vertical hydraulic gradient across the Hawthorn Group deposits makes a determination of lateral groundwater flow directions difficult for the upper and lower Hawthorn because relatively small differences in the monitoring well screen elevations corresponds to significant changes in the measured groundwater elevation for the well. Hence, differences in monitoring well screen elevations can have significant impacts on the interpreted groundwater flow direction. Therefore, potentiometric surface maps constructed for the upper and lower Hawthorn deposits have to account for differences in monitoring well screen elevations. The lateral direction of groundwater flow within the upper and lower Hawthorn deposits appear to be northeasterly to northerly.

The Upper Floridan Aquifer contains two primary transmissive zones, which are separated by lower permeability deposits (Figure 2-3). The highest transmissive zone is located at the contact of the Ocala Limestone and the Avon Park Limestone, at a depth of approximately 200 feet below the base of the Hawthorn Group deposits (approximately

350 feet below land surface). As discussed earlier, this is the primary source of groundwater for municipal production wells completed into the Upper Floridan Aquifer. The second and less transmissive zone is located at the top of the Upper Floridan Aquifer just below the contact of the Hawthorn Group and Ocala Limestone at a depth of about 150 feet below land surface. Groundwater production from this zone is a small fraction of the water produced from the deeper zone and is estimated to account for 10 to 20 percent of total production at the Murphree Well Field (GeoSys, Inc., 2000).

Four wells at the Site all are completed in this upper zone of the Upper Floridan Aquifer and no wells are completed into the lower more transmissive zone. The Site is located within the groundwater cone of depression for the Murphree Well Field, which is located approximately 2.5 miles northeast of the Site. Therefore, groundwater flow in the Upper Floridan Aquifer beneath the Site is toward the Murphree Well Field.

Aquifer tests performed in the four Upper Floridan monitoring wells at the Site resulted a geometric mean hydraulic-conductivity value of about 1.6 ft/day. No aquifer tests have been performed in the lower transmissive zone beneath the Site, but permeabilities are estimated to be equivalent to those measured at the Murphree Well Field, which is approximately one order of magnitude greater than the upper zone. The horizontal hydraulic gradient in the Ocala Limestone beneath the Site is approximately 0.0003 ft/ft and increases with decreasing distances from the wellfield. Groundwater flow velocities are estimated to be less than 40 ft/yr in the upper transmissive zone and more than 250 ft/yr in the lower transmissive zone.

Alachua County collects biannual groundwater samples and water levels from wells completed in the Upper Floridan Aquifer. As a result of this monitoring program, historical potentiometric surface maps of the Upper Floridan Aquifer are available as early as the1960s. Figure 2-4 shows the potentiometric surface map of the Upper Floridan Aquifer for September 2001. The potentiometric surface indicates groundwater flow in the Upper Floridan Aquifer is from the east toward the west and northwest. The area of influence of the pumping from the Murphree Well Field can be seen in the central portion of the County.

2.3 GROUNDWATER RECHARGE

The primary source of groundwater recharge for the Surficial Aquifer in the area of the Site is from infiltration of precipitation. The Alachua County area receives an average of 50.3 inches of precipitation per year. Motz (2003) estimated the net recharge (infiltration less evapotranspiration) to the surficial aquifer for 1995 in north-central Florida to be approximately 5.9 in/yr (equivalent to 12% of annual precipitation). The majority of the groundwater recharge occurs during the winter and spring months when long-duration storm events allow for significant infiltration of precipitation. During summer and fall months, less precipitation is available for recharging the shallow aquifers, and a greater percentage of the precipitation is consumed by evapotranspiration. Therefore, model recharge rates must account for temporal changes in both the precipitation rate and the percentage of recharge reaching the groundwater system during wetter and drier months.

Recharge to the Hawthorn Group and Upper Floridan Aquifer in the vicinity of the Site primarily results from leakance from the overlying Surficial Aquifer. South and southwest of the model area where the Upper Floridan Aquifer is unconfined, the aquifer is recharged directly from precipitation. Infiltration to the Upper Floridan Aquifer is restricted by groundwater flux through the Hawthorn Group deposits.

2.4 GROUNDWATER WITHDRAWALS

Alachua County has eight municipal groundwater-supply systems serving the cities of Alachua, Archer, Hawthorne, High Springs, Gainesville (Murphree), Micanopy, Newberry, and Waldo. In addition, Alachua County has14 non-municipal, community groundwater-supply systems (ACEPD, 1996). The only community water system within the Site Model domain is the Murphree Well Field located approximately 2.5 miles northeast of the Site (Figure 2-5). Pumping at the Murphree Well Field originated in 1968. The Kelly Well Field, located south of University Ave between Main St and S.H. 331, provided municipal water for the City of Gainesville from 1913 to 1968. The Murphree Well Field consists of 15 wells, which are completed in both the Ocala Limestone and upper portion of the Avon Park Limestone Formations. Approximately 25.3 million gallons per day (MGD) of groundwater were pumped from the Murphree Well Field in 2003. The full rated Murphree Well Field capacity is 57 MGD (GeoSys, 1997). The more than 35 years of groundwater withdrawals at this wellfield has resulted in the development of a laterally extensive drawdown cone within the Upper Floridan Aquifer. This drawdown cone extends beneath approximately 50 percent of Alachua County resulting in localized groundwater flow towards this well field. The Site is located within the groundwater capture zone of the Murphree Well Field.

2.3 SURFACE WATER HYDROLOGY

The primary surface water features in the model area are Springstead Creek located approximately 1,000 ft north of the Site and a large wetlands located about 1,000 feet to the northeast of the Site (Figure 1-1). The base of Springstead Creek is about 25 feet below the surrounding land surface. Water is present year-round in Springstead Creek. Surface water in Springstead Creek flows west and discharges into Hogtown Creek at their confluence about 0.9 miles northwest of the Site. Springstead Creek appears to be a groundwater discharge location for the Surficial Aquifer and the possibly the upper Hawthorn Group.

Two groundwater/surface water drainage ditches feed Springstead Creek. One ditch transects the Site and the other flows north of the Cabot Carbon site. The Main Street ditch, which parallels Main Street, flows into the ditch that runs north of the Cabot Carbon site. The ditch that transects the Site is a groundwater discharge point during high water-table conditions; however, this ditch primarily serves as a storm water diversion for areas to the south of the Site. The series of ditches to the north of the Cabot Carbon site appear to act as groundwater drains during most of the year.

3.0 GROUNDWATER FLOW MODEL

A three-dimensional groundwater flow model was developed for the Site area to help evaluate and quantify groundwater flow and constituent transport rates. Of particular concern is the rate of vertical transport of site constituents through the Hawthorn Group deposits and the lateral flow towards the Murphree Well Field within the Upper Floridan Aquifer. This interim report will present the results of the Site Model development, flow model calibration, and preliminary sensitivity analysis.

3.1 CONCEPTUAL FLOW MODEL

Development of a conceptual groundwater flow model for the region is the first step in the design of a numerical model. The conceptual model establishes the framework for the development of the numerical model by defining the principal hydrostratigraphic units and hydrologic features that affect regional and site-specific groundwater flow.

The principal hydrostratigraphic units in the vicinity of the Site are shown in Figures 2-1 and 2-2. The more permeable sandy deposits of the Surficial Aquifer control the lateral distribution of Site constituents. The Hawthorn Group deposits separate the overlying Surficial Aquifer from the underlying Upper Floridan Aquifer. Three principal low-permeability clay units in the Hawthorn Group control the vertical flux of groundwater and the transport rate of Site constituents to the Floridan Aquifer.

Groundwater flow for the Surficial Aquifer is controlled by a variety of groundwater discharge points in the vicinity of the Site. These discharge points include the series of drainage ditches to the north of the Site, Springstead Creek to the north, wetlands to the northeast and the groundwater collection drain along the eastern property boundary of the Cabot Carbon site. Temporal water-level fluctuations in the Surficial Aquifer are primarily caused by seasonal fluctuations in recharge. Similarly, lateral groundwater flow directions within the upper Hawthorn may also be influenced by the same hydrologic features controlling flow in the Surficial Aquifer. Groundwater flow in the Upper Floridan Aquifer is primarily controlled by groundwater withdrawals at the Murphree Well Field. Accurate simulation of groundwater flow conditions at the Site necessitates accurate representation of discharge/aquifer interactions, municipal well field withdrawal, and temporal variations in groundwater recharge.

The principal groundwater flow direction for the Surficial and Upper Floridan Aquifers is laterally towards the northeast, whereas the vertical component is more significant in the Hawthorn Group. A secondary, northeasterly groundwater flow component is also present in the upper and lower Hawthorn; however, accurate determination of average flow directions in the lower Hawthorn is difficult to establish due to the high hydraulic gradient through this formation.

3.2 NUMERICAL FLOW CODE

MODFLOWT (GeoTrans, 1997), an extension of the U. S. Geological Survey (USGS) MODFLOW code, was used to simulate the groundwater flow system. Geographical Information System (GIS) tools were used to expedite model development, design and analysis. The GIS tools allowed for graphical development of model data sets, efficient model calibration, and the ability to automatically superimpose model results on site base maps and data. This section discusses the approach to develop the groundwater model, the numerical model codes, model construction, and the model calibration.

3.3 FLOW MODEL DEVELOPMENT

Hydrogeologic data and site features were electronically transferred into a relational GIS system to graphically design the requisite model data sets. Once the GIS model design is finalized, the model data sets are automatically created and exported for direct use in the model simulations. The use of coupled relational GIS/model software allows for efficient model development and data set quality assurance/quality control (QA/QC).

The coupled GIS software and model are utilized throughout the model development and calibration process. The results of each model simulation are automatically converted to GIS compatible files to allow graphical overlay of model results on site features, such as base maps, aerial photos, contoured surfaces, and well data. The graphical display of model results accelerates the identification of potential model problem areas and expedites the calibration process.

The numerical groundwater flow model developed for the Site is an 11-layer model that incorporates major lithologies in the Surficial Aquifer and the Hawthorn Group deposits, and provides the detail required to simulate vertical transport from the Site to the Upper Floridan Aquifer (Figures 2-1 and 2-2). The Surficial Aquifer is represented in the model by one layer, since the Surficial Aquifer is fairly homogeneous and uniform at the Site. The Hawthorn Group deposits are represented by eight model layers to more accurately incorporate vertical heterogeneity of the three clay units and intervening deposits. The Hawthorn Group locally contains six major hydrostratigraphic units; however, the upper two hydrostratigraphic units in the Hawthorn Group were represented with two model layers each to increase the numerical accuracy of the model for simulating flow and transport through these units. The use of multiple layers within a hydrostratigraphic unit allows for a more accurate representation of the advancing plume front and will minimize numerical dispersion (spreading) of the plume. In addition to improving the numerical accuracy of the model, subdividing the upper hydrostratigraphic units will allow greater flexibility in evaluating remedial alternatives. The Upper Floridan Aquifer is represented by two model layers to accurately represent the two primary transmissive zones. The semi-confining unit separating the Ocala Limestone and Ocala / Avon Park Contact was implicitly represented in the model by a lower vertical conductance (i.e., permeability) between these two water producing units. The thickness of these layers was based on well logs and flow logging at the Murphree Well Field (GeoSys, 2000), the Kelly well field (GeoLogic, 1990), and the Kanapaha wastewater treatment plant (CH2M HILL, 1987).

The spatial variability and heterogeneity of the hydrostratigraphic units were incorporated into the model data sets. Individual model layers varied in thickness from about 3 feet (Upper Hawthorn Group clay unit) to greater than 150 feet (Ocala Limestone). Model layers were established based on contoured elevations of the tops and bottoms of the formations obtained from the ER survey and published reports. In addition, individual hydrostratigraphic units within formations were extrapolated and discretized to provide further refinement of the flow system. The ER surveys define and extrapolate Site geology to off-site locations to provide information on the continuity and lateral extent of Surficial and Hawthorn Group deposits over the model domain.

The Site Model grid extends from approximately 2,000 feet south of the Site to approximately 2 miles north, where it incorporates the southwestern corner of the Murphree Well Field (Figure 3-1). The approximately 5-square mile model area was chosen to incorporate major hydrologic stresses in the area and to help ensure that the external model boundary conditions do not artificially predicted modeling results. The proposed model grid is aligned north/south for consistency with the alignment of the regional model. In addition, the model grid was extended to the northeast to incorporate pumpage from the Murphree Well Field to ensure that this major hydrologic stress is accurately represented in the Site Model.

The model finite-difference grid consists of 92 rows by 72 columns by 11 layers, for a total of 72,864 cells. The grid spacing is smallest at the Site and gradually increases with increasing distance from the Site. The smallest grid size is 60 by 60 feet at the Site and the largest grid cell size is 500 by 500 feet near the external model boundaries (Figure 3-2). The Site contains approximately 2,800 of the 6,624 grid cells to ensure accurate representation of the Site hydrogeologic features and constituent data. The grid spacing on the Cabot Carbon site is 100 by 100 feet to provide sufficient detail of flow conditions at this adjoining site.

One critical aspect in the development of a groundwater flow model is defining the external model boundary. Two common problems encountered in the construction of groundwater models are: 1) Setting external boundaries too close to the area of interest, and 2) Artificially constraining the system with specified-head boundary conditions around the model area. It is important that external model boundaries are set far enough from the area of interest such that they do not artificially impact model simulation results. Similarly, it is important to establish technically defensible boundary conditions that are representative of the regional and local hydrogeologic systems.

External model boundary conditions are specified in a model to establish a baseline regional groundwater flow across the model area. Model layers 1, 10 and 11 contain a combination of no-flow and specified-head boundaries. The external boundaries for model layers 2 through 9 are all no-flow boundaries. Model layers 2-9 represent both low- and intermediate-permeability deposits of the Hawthorn Group. Lateral flow within these layers is assumed to be an insignificant component of the water budget for the modeled units. The external model boundary conditions for model layers 10 and 11 are shown in Figure 3-1. A no-flow boundary was established on the northern and eastern sides of the model and time-variant specified-head boundary conditions were established on the southern and northwestern corner of the model. The specified-head boundary conditions for the southern and northwestern model boundaries approximately parallels the potentiometric surface elevation contours of the drawdown cone from the Murphree Well Field. The no-flow boundary conditions on the eastern and northern sides of the model are perpendicular to the potentiometric surface contours; hence groundwater flow is parallel to these boundaries. External model boundaries for model layer 1 consist of specified-head boundary conditions in the southwestern and northeastern corners of the model and no-flow conditions for the other sides. The average northeastern groundwater flow direction for the Surficial Aquifer is based on water-level measurements at the KI and Cabot Carbon sites. Based on this average flow direction, specified-head boundary conditions are required in the southwestern and northeastern corners of the model in order to reproduce the northeastern flow direction. The remaining external boundaries were set to no-flow boundaries so that the model was not overly constrained by specified-head boundary conditions during the model calibration.

Internal model boundary conditions for the wetlands, creeks and surface drainage ditches were specified as drains. The Drain Package is similar to the River Package, with the exception that a drain node only allows flow out of the model. Unlike the River Package, when the water table drops below the drain node, it does not allow water to flow back into the aquifer. The wetlands to the northeast and Springstead Creek to the north were also simulated with the Drain Package to account for shallow groundwater discharge to these features. Recharge was applied to the uppermost model layer as a percentage of monthly precipitation. Additional recharge was applied to the surface drainage ditch through the central area of the Site to simulate increased infiltrations resulting from storm water runoff through this area.

3.3.1 MODEL PARAMETER VALUES

Hydrogeologic parameter values for each of the hydrostratigraphic units were obtained from a literature review of previous investigations in the area (CH2M HILL, 1993; Motz, 2003; ACEPD, 1996) and from aquifer tests, and laboratory permeameter tests conducted at the Site (TRC, 1999; TRC, 2002). In general, hydrogeologic parameter values specified in the model were uniform within each of the model layers. The final calibrated model parameter values are presented in Table 3-1.

Table 3-1. Model calibrated parameter values.

Hydrogeologic Units	**Model Layer**	**Hydraulic Conductivity (ft/d)**		**Storage Coefficient (S)**
		K_x, K_y	**K_z**	
Surficial Aquifer	1	21	1.0	0.025-0.065
Upper Hawthorn Clay	2, 3	0.01	0.01	1.5e-6 to 1.0e-5
Upper Clayey Sand	4, 5	0.3	0.05	7.5e-5 to 2.0 e-4
Middle Hawthorn Clay	6	0.01	0.00017	5e-6 to 2e-5
Lower Clayey Sand	7	0.3	0.05	1.5e-4 to 7.0 e-4
Lower Sand	8	3	0.1	5.0e-4 to 1.5e-3
Lower Hawthorn Clay	9	0.01	0.00012	3.5e-5
Lower Hawthorn Clay (Western Zone)	9	0.01	0.00034	3.5e-5
Ocala Limestone	10	23	1.25	8.5e-4 to 1.05e-3
Ocala/Avon Park Contact	11	175	NA	1.0e-3
Ocala Limestone (Murphree Well Field Area)	10	10	1.25	8.5e-4 to 1.05e-3
Ocala/Avon Park Contact (Murphree Well Field Area)	11	60	NA	1.0e-3

Hydraulic Conductivity

Pumping tests were conducted in four wells in the Surficial Aquifer at the Site. Surficial Aquifer horizontal hydraulic-conductivity values ranged from 16 to 29 ft/day (TRC, 1999). Laboratory permeameter tests in the upper and middle Hawthorn clay have geometric means of 0.00014 and 0.00012 ft/day, respectively. The model hydraulic-conductivity value for the upper clay unit was increased approximately an order of magnitude to account for the higher permeability interbedded slits and sand deposits. The lower Hawthorn clay was divided into two zones based on an apparent higher vertical permeability of this unit for the western part of the Site. The western zone was assigned a higher vertical hydraulic-conductivity value in order to match water levels in wells HG-2D and HG-5D, which tend to be approximately 4 feet lower than water levels in wells on the eastern side of the Site. Hydraulic-conductivity values resulting from aquifer tests conducted within the Upper Floridan Aquifer in Site monitoring wells have a geometric mean of 1.6 ft/day (TRC, 2002). The calibrated model permeability for the uppermost transmissive zone in the Upper Floridan Aquifer was approximately 20 times larger than the value measured at the Site. The low hydraulic gradient in the Upper Floridan Aquifer beneath the Site (less than 0.5 ft hydraulic head change across Site) indicated that the average hydraulic conductivity value for this hydrostratigraphic unit was larger than the value measured in the aquifer tests. The hydraulic conductivity of the lower more transmissive zone in the Upper Floridan Aquifer was based on aquifer tests conducted at the Murphree Well Field. The hydraulic-conductivity value was based on transmissivity values resulting from the tests and average thickness of about 100 feet for the transmissive zone. The horizontal transmissivity of the Upper Floridan Aquifer, layers 10 and 11 were reduced in the vicinity of the Murphree Well Field to correspond with values used in the GRU regional model and to more accurately represent increased drawdowns in this area. The hydraulic-conductivity values specified the Murphree Well Field area were approximately a factor of three less than those used in other areas of the model.

In general, vertical hydraulic-conductivity values for the model layers were assumed to be a factor of 10 to 100 less than the horizontal values, except for the lower portion of the Ocala Limestone where the semi-confining unit is implicitly defined as 0.0035 ft/d. The vertical permeability for the semi-confining unit in the Ocala Limestone was based on professional judgment of a reasonable value for this unit.

Aquifer Storage

The aquifer storage-coefficient values provided in Table 3-1 represent the range of values for each of the hydrostratigraphic units in the model. The storage coefficient is calculated by multiplying the aquifer's specific storage by its saturated thickness. The specific-storage value for each of the hydrostratigraphic units was uniform across the model area; however, variations in the aquifer saturated thickness cause the storage coefficient to vary. The storage-coefficient value for the Hawthorn Group deposits ranged from 0.000005 to 0.0015 and the storage-coefficient value for the Upper Floridan Aquifer varied from 0.00105 to 0.00085. In areas where the units were unconfined, a storage coefficient of 0.1 was used in place of the confined storage coefficient.

Formation Thicknesses and Elevations

Figures 3-3 and 3-4 show surface elevation contours for the top of the upper Hawthorn clay and the middle Hawthorn clay. These elevations are based on the lithologic database of borings and well logs from the Site and the ER Survey conducted by GeoHazards. The detailed on-site contours and ER survey data points were extrapolated to the boundaries of the model domain. Notice that the top of the upper Hawthorn clay increases in depth toward the northeast. The top of the middle Hawthorn clay shows a similar pattern with it dipping to the northeast. Figures 3-5 and 3-6 show the thickness of the upper and middle Hawthorn clay units. The upper clay thins toward the north/northwest near Springstead Creek and may be truncated by the creek. The thickness of the upper clay varies from 3 to 20 feet. The middle clay unit is thicker than than upper clay unit and ranges from 5 to 40 feet. The lower clay unit thickness ranged from 32 to 38 feet. An average uniform thickness of 35 feet was used for the model. All formations in the model domain show this same trend of dipping toward the northeast.

Drain Parameters

The drain package in MODFLOWT was used to simulate the hydrologic effects of Springstead Creek, drainage ditches, and wetlands. The drain package requires the following information: 1) Drain area occupying individual model cells; 2) Drain elevation; and 3) Hydraulic conductance of drain sediments (Vertical hydraulic conductivity divided by drain sediment thickness). Estimates of the drain area occupying a cell and drain elevations were made based on an electronic topographic map of the area. The hydraulic conductance of drain sediment was calculated by assuming a uniform and constant sediment thickness of 5 feet and sediment vertical hydraulic-conductivity values range from 0.5 to 1.0 ft/day. The final drain conductance values were adjusted by calibrating to water-level fluctuation observed in monitoring wells adjacent to the drains. The drains were assumed to be present in the uppermost model layer and did not extend into underlying layers.

Recharge

The amount of recharge that ultimately reaches the water table is directly correlated to the amount of precipitation occurring in a month. In general, the greater the amount of precipitation in a month, the higher the percentage of recharge reaching the water table. Model recharge values were varied based on the amount of precipitation occurring in a particular month (Figure 3-7). If the area received less than 6.0 inches of precipitation in a month, recharge was set to 12 percent of the monthly precipitation total; if the area received between 6.0 to 8.0 inches of precipitation in a month, recharge was set to 14 percent of the monthly total precipitation; and if the area received more than 8.0 inches of precipitation in a month, recharge was set to 16 percent of the monthly total precipitation. The ditch that transects the Site was delineated as an area of higher recharge because of increased storm-water runoff in this ditch during precipitation events. In addition, temporal water-level fluctuations in monitoring wells adjacent to this ditch support higher recharge in this area. Recharge along this ditch was set to twice the recharge rate applied to the rest of the model domain. The percent of precipitation applied as recharge in the model was established by calibrating the model to observed short-term groundwater fluctuations, while maintaining a total annual recharge of 13.6 percent of annual precipitation.

Municipal Groundwater Withdrawals

GRU provided GeoTrans with total monthly groundwater withdrawal amount for the Murphree Well Field production wells. Groundwater withdrawals were obtained from January 1994 through April 2004 for this well field.

The well package in MODFLOWT was used to simulate pumpage from the Murphree Well Field. The layout symmetry of the well field allowed for the corresponding drawdown cone to be subdivided into quarter sections, with only one quarter of the section simulated by the model. This is a common modeling technique that takes advantage of drawdown cone symmetry and the no-flow model boundary conditions to simulate well pumpage. Rather than applying the entire pumping rate for the wellfield, only approximately one quarter of the monthly pumping rate is applied at the northeastern corner of the model. In order to more accurately represent pumping rates for the wellfield, the GRU Regional Model in conjunction with the ZONEBUDGET program were used to calculate the percentage of the pumpage that should be applied to northeastern corner of the model. The modeling results indicated that 18.8 percent of the total well field pumpage should be applied in this area. Therefore, 18.8 percent of the total withdrawals for this well field were incorporated into the model for this well field.

Wells completed in the Murphree Well Field are producing water from both the upper and lower transmissive zones in the Upper Floridan Aquifer. Flow logging measurements at the Murphree Well Field (GeoSys, 2000), well logs at the Kelly Well Field (GeoLogic, 1990) and Kanapaha wastewater treatment plant (CH2M Hill, 1987) established that approximately 10 to 25 percent of the total flow was originating from the upper transmissive zone and the remainder was being produced from the lower transmissive zone. Based on these estimates, the model assumed that 15 percent of the produced water was originating from the upper transmissive zone and 85 percent was originating from the lower, which were applied to model layers 10 and 11, respectively.

3.3.2 MODEL CALIBRATION

Model calibration consists of adjusting select model hydrogeologic parameters until model outputs (such as water levels) agree with observed values. Specifically for the Site, the objective of the model calibration was to develop a numerical model that accurately reproduced historical groundwater flow conditions, temporal potentiometric surface fluctuations, groundwater flow directions and municipal well drawdowns for the Site and surrounding areas.

Model calibration is typically performed in two calibration steps: 1) A steady-state calibration and 2) A transient calibration. A steady-state calibration is performed by adjusting model parameters and boundary conditions to match the regional potentiometric surface and groundwater flow conditions. The primary objective of this calibration step is to get the model within the “ball park” of regional groundwater conditions. Ideally, the steady-state calibration is performed for an early period in time when hydrologic stresses are not significantly impacting groundwater flow conditions. Results from the steady-state calibration are typically only used to provide initial starting heads for the transient simulation. During the transient calibration, the model parameter values are “fined tuned” to match temporal potentiometric surface fluctuations resulting from changes in recharge, surface-water stage, drain withdrawals and groundwater pumpage. The transient calibration is the most critical of the two calibration steps and is the best measure of the accuracy of the model.

A steady-state calibration to pre-municipal well field pumping conditions for Alachua County was not possible. Therefore, an approximate steady-state calibration was performed by using average pumping rates for 1994 and average recharge rates for the past 100 years.

The potentiometric surface elevations from the steady-state model were used as initial starting conditions for the transient model calibration. The transient model calibration was performed for the period January 1994 through April 2004. A total of 124 monthly stress periods were incorporated into the model to approximate short-term temporal fluctuations in recharge and pumping rates. Figure 3-8 shows the location of wells used in the transient model calibration and Figure 3-9 shows the model generated potentiometric surface contours for the Surficial Aquifer for April 2004. The potentiometric surface map for the upper Hawthorn shows the effects of the drainage ditches and Cabot Carbon groundwater collection system on water levels in this hydrostratigraphic unit (Figure 3-10); however, the hydrologic effects of these systems do not extend into the Upper Floridan Aquifer (Figure 3-11). Figure 3-12 shows the model predicted potentiometric surface for the Ocala Limestone (uppermost hydrostratigraphic unit in the Upper Floridan Aquifer). Figures 3-13 to 3-19 show the transient model calibrated water-level elevations versus the measured water-level elevations for select wells across the Site. The model does an excellent job of reproducing the long-term temporal trend for monitoring wells completed in the surficial aquifer, Hawthorn Group, and the Upper Floridan Aquifer at the Site. The model accurately reproduces the short-term temporal water-level fluctuations. These short-term temporal fluctuations are a direct result of local changes in recharge, drain discharges, and pumping rates.

3.3.3 MODEL SENSITIVITY

The model calibration process provides information on the sensitivity of the model results to variations in model parameter values. These sensitivities provide insight into key hydrogeologic parameters that affect flow and transport at the Site. The results of the sensitivity evaluation demonstrated that hydrologic stresses in the Surficial Aquifer have essentially no impact on water-levels fluctuations in the lower Hawthorn and Upper Floridan Aquifer and moderate impacts on the upper Hawthorn. In addition, the upper and lower transmissive zones of the Upper Floridan Aquifer are fairly insensitive to water-level fluctuations in the upper and lower Hawthorn, because the middle and lower clay units act as effective hydrologic barriers mitigating the effects of water-level changes in the Hawthorn Group deposits. The Upper Floridan Aquifer is most sensitive to changes in groundwater pumpage at the Murphree Well Field and the distribution of pumpage between the upper and lower transmissve zones.

The Surficial Aquifer is sensitive to monthly recharge values and drain conductance values. The simulated water-level fluctuations for monitoring wells completed in the Surficial Aquifer are sensitive to model recharge rates. Similarly, Surficial Aquifer water-level fluctuations are sensitive to the drain conductance values for Springstead Creek, the series of ditches to the northeast of the Site, and the horizontal drain on the Cabot Carbon site. The rate of discharge to these groundwater discharge points is controlled by the permeability of deposits surrounding these features. Within the model a conductance term is used to control the rate of discharge into these hydrologic features. The areal extent and magnitude of water-level fluctuation in wells adjacent to these features is controlled by the conductance term applied to these model drains. The historical water-level data for the Surficial Aquifer at both the KI and Cabot Carbon sites provide good calibration points for establishing conductance values for these drains.

The large vertical hydraulic gradients across the Hawthorn Group deposits result in the simulated hydraulic head being extremely sensitive to the vertical permeability value of the upper, middle and lower clay units within this formation. The vertical permeability of the upper clay unit is the primary control on water-level elevations in the upper Hawthorn and the vertical permeability of the middle clay unit controls water level elevations in the lower Hawthorn. Water levels in the lower Hawthorn are less sensitive to order-of-magnitude changes in the vertical permeability of the lower clay unit; however, the lithologic logs of this unit indicate that the vertical permeability is fairly low, such that reasonable variations of this permeability have minimal impacts on water levels. Water-level elevations obtained from monitoring wells completed within the upper and lower Hawthorn Group deposits and the upper Floridan aquifer provide good calibration points with which to determine the site-wide average permeability of the three clay units.

4.0 REFERENCES

ACEPD, 1996, A Comprehensive Contaminant Source and Well Inventory near Wellfiled Areas of Alachua County, September 1995 through December 1995, prepared for State of Florida Department of Environmental Protection, March 1996.

CH2M Hill, 1987, Geophysical Logging and Hydraulic Test of Recharge and Monitor Wells, Lake Kanapaha Wastewater Treatment Plant, prepared for Gainesville Regional Utilities, August 1987.

CH2M Hill, 1993, Evaluation and Modeling of the Floridan Aquifer System in the Vicinity of the Murphree Well Field: Technical Memorandum No. 4, March 1993.

GeoLogic Information Systems, 1988, Analysis of the Hawthorn-Ocala Contact in the Murphree Well Field Area: A Report to Gainesville Regional Utilities, December, 1988.

GeoLogic Information Systems, 1990, Summary of Geophysical Data and Analysis of the Hydrogeologic Setting of the Kelly Well Field, prepared for Gainesville Regional Utilities, April, 1990.

GeoSys, Inc., 1997, Murphree Well Field Travel Time Modeling and Model Comparisons, May 1997.

GeoSys, Inc., 2000, Update of the Geology in the Murphree Well Field Area, April 2000.

GeoTrans, Inc., 1997, A Modular Three-Dimensional Groundwater Flow and Transport Model, MODFLOWT, 1997.

GeoTrans, Inc., 2004a, Addendum 6: Work Plan, Groundwater Flow and Transport Modeling, Koppers Inc. Site, Gainesville, Florida, April 2004.

GeoTrans, 2004b, Fifth Addendum to the Work Plan for Additional Investigation of Hawthorn Group Formation, DNAPL Source Evaluation for the Koppers Inc. Property, Cabot Carbon/Koppers Superfund Site, Gainesville, Florida, February 9, 2004.

Harbaugh, A.W., 1990, A Computer Program for Calculating Subregional Water Budgets Using Results from the U.S. Geological Survey Modular Three-dimensional Finite-difference groundwater flow model, U. S. Geological Survey Open-File Report 90-392.

Miller J.A., 1997, Hydrogeology of Florida, in, The Geology of Florida, A. F. Randazzo and D. S. Jones (Eds.), University Press of Florida, 69-88.

Motz L.H., and A. Gogan, 2003, North-Central Florida Active Water-Table Regional Groundwater Flow Model (Draft Interim Report), Prepared for St. Johns River Water Management District, November 2003.

TRC, 1999, Revised Supplemental Feasibility Study Volumes 1 and 2, Cabot Carbon/Koppers Superfund Site, Gainesville, Florida, September 1999.

TRC, 2002, Field Investigation Activities Report: Cabot Carbon / Koppers Superfund Site, Gainesville, Florida, September 2002.

TRC, 2003a, Addendum Hawthorn Group Field Investigation Report: Cabot Carbon / Koppers Superfund Site, Gainesville, Florida, August 2003.

TRC, 2003b, Data Report, November Sampling Event, Investigation of the Hawthorn Group Formation: Cabot Carbon / Koppers Superfund Site, Gainesville, Florida, November 2003.

TRC, 2004, Data Report, April Sampling Event, Investigation of the Hawthorn Group Formation: Cabot Carbon / Koppers Superfund Site, Gainesville, Florida, June 2004.