Overview of work completed and preliminary findings of groundwater modeling task - Woodlawn Landfill

For your review in preparation for our 12:30 meeting tomorrow.

Sincerely,

Jeff Smith

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MEMORANDUM

TO: Debra Rossi, Remedial Project Manager
FR: Scott Potter (Geraghty & Miller, Millersville, MD)
Date: 11 November 1996

CC: Mindi Snuparski (USEPA), Sesh Lal and Grant Anderson (U.S. Army COE), James Gravette (MDE), Timothy Bent, CPG (Bridgestone/Firstone) Suthan Suthersan and Jeff Smith (Geraghty & Miller, Inc.)

RE: Overview of the work completed and the preliminary findings of the groundwater modeling task for the Woodlawn Landfill Site

The following sections provide a brief overview of the work that has been performed to date associated with the modeling task at the Woodlawn Landfill. This memorandum is not intended to be a documentation of the work completed, rather a summary of the significant tasks and findings. The memorandum has been organized based upon the standard approach to develop a groundwater model and material to be presented to USEPA, the U.S. Army Corps of Engineers (COE), and the Maryland Department of the Environment (MDE) on Wednesday, November 13, 1996.

PURPOSE OF THE MODEL

The current groundwater model was developed to evaluate remedial scenarios at the Woodlawn Landfill Site. A simple two-dimensional one-layer model was developed for the site for the RI (1992). Significant new information collected since the RI indicated that the assumptions underlying the model needed to be refined and that there would be a benefit to performing additional groundwater flow and transport modeling.

CONCEPTUAL MODEL

The hydrogeology of the Piedmont Province including Maryland is summarized by LeGrand (1954; 1967; 1988) and Heath (1984). Several reports provide a summary of the regional hydrogeological conditions in Cecil county. These include the work of Otton, et al. (1988) which describe the geology and groundwater conditions throughout Cecil County. The landmark paper by LeGrand (1988) represents the general conceptual model for the groundwater system of the Piedmont. The fundamental components and concepts described by this paper are directly applicable to hydrogeologic setting of the Woodlawn Landfill Site.

The Woodlawn Landfill Site is located in the Piedmont Physiographical Province of Cecil County, Maryland. The Piedmont Province is bounded on the west by the Appalachians and on the east by the Coastal Plain. The eastern boundary of the province is marked by the Fall Line. The topography of the Piedmont is characterized by low rounded hills and gentle slopes with long northeast-southwest trending ridges (Powell and Abe, 1985). The topography is
controlled by both lithology and structure. Hills and ridges are underlain by rocks resistant to weathering; whereas, valleys form in areas of less resistant rocks. Fractured rock weathered more readily than massive rock; therefore, valleys often form in zones of fractured, faulted rock. Surface-water drainage is either dendritic or lineament (fractures, bedding planes, geologic contacts, and foliations) controlled.

The geology underlying the Piedmont Physiographic Province consists primarily of Precambrian to late Paleozoic-age igneous, and metamorphic, and Triassic-age sedimentary rocks. Igneous intrusions, volcanic rocks, and some limestone are also interspersed throughout the Piedmont. The metamorphic rocks consist of gneiss, schist, phyllite, marble, slate, and quartzite; igneous intrusions are comprised of granite and diabase. The sedimentary rocks occur in north-northeast to south-southwest trending graben-faulted basins and unconformably overlay the metamorphic and igneous rocks. The sedimentary rocks consist of sandstone, siltstone, shale, and coal which are intruded with diabase dikes and sills (Goodwin, et al., 1986).

One major characteristic of the Piedmont region is a relatively continuous layer of regolith. Regolith, the layer of weathered material overlying bedrock, is comprised of soil and saprolite, or alluvium. Saprolite is the decomposed, weathered rock zone between the soil and bedrock; alluvium is sediment deposited by streams. The regolith transcends across geologic units (LeGrand, 1988). Thickness varies from approximately 10 feet (ft) to 100 ft. The regolith thickness, like topography, is related to resistance to weathering, lithology, and structural fabric of the underlying bedrock. The saprolite tends to thicken over fractured rock and thin over massive bedrock (LeGrand, 1988). For example, granite is more massive than gneiss which is prone to fracturing due to foliation. In contrast to gneiss, fractures in the granite are less frequent and exhibit much less areal continuity.

The saprolite and regolith are very important to the groundwater flow systems of the Piedmont. These unconsolidated materials possess about 10 to 100 times greater the storage capacity than the bedrock. Small domestic supplies of groundwater can be obtained from the saprolite. However, the small saturated thickness of these shallow wells results in well failure during times of drought. Water elevations naturally decline below the bottom of the wellbore. A common practice is to drill domestic wells into the low yielding and low porosity bedrock to provide borehole storage in the ground and insurance against water levels dropping below the bottom of the well during drought. This permits sufficient time for water level recovery in the well between each pumping cycle. The saprolite and regolith act as a reservoir, storing the water that is captured by the well. The bedrock wells derive their water locally from vertical movement out of the storage reservoir (saprolite) through the weathered and shallow fractured bedrock into the borehole.

The regional geology is based upon the study conducted by the Maryland Geological Survey (Otton et al., 1988). The site is underlain by Precambrian-age granitic gneiss, metagraywacke, and metadiorite. The local investigation of hydrogeologic conditions conducted by the Maryland Geological Survey indicates that groundwater conditions in the Cecil County Piedmont are consistent with the general conceptual model that has been
developed by Harry LeGrand (1988). The site investigations that have been conducted during the RI (1993) and by HLA (1996) show that site conditions are also consistent with the general conceptual model.

MAJOR ASSUMPTIONS/LIMITATIONS OF THE IT MODEL

The groundwater model developed by IT is not appropriate to evaluate potential remedial scenarios for the following reasons:

- The model was developed as a single layer model that simulates two-dimensional horizontal flow only. This one layer approach lumps the saturated saprolite with the upper portion (fractured) of the bedrock aquifer.

- Boundary conditions and characteristics do not correspond to natural system boundaries (the preferred boundary for simulation purposes) but rather fall at arbitrary locations that have no apparent relevance to the actual flow system.

- IT’s model calibration was insufficient because 1) the model only simulated a single layer system with no vertical flow component, 2) there was no documentation of simulated groundwater flow directions compared to observed groundwater flow directions, and 3) the results of statistical analyses of water-level residuals (a standard measure of error in the model) is approximately 50 percent to 75 percent higher than is expected using typical standard evaluation procedures.

Other assumptions, interpretations, or model output that appear to be inadequate are:

- Justification for the distribution of horizontal hydraulic conductivity used in the model.
- Justification for the porosity value used and how a single value was considered representative of the saprolite and both fractured and competent bedrock zones.
- The overall predicted water budget does not appear reasonable and is difficult to evaluate given the chosen boundary conditions used in the model.
- The model grid size used for solute transport simulations - from both a source term and numerical dispersion perspective is too coarse.
- The simulated continued source loading predicted for 70 years does not fit with the observed historical data.
- The assumption of no degradation or breakdown of contaminants in the groundwater system does not fit with the observed historical data.

Some of these concerns have arisen due to new data and information that has become available since the IT modeling effort was performed. Others, however, are raised because of either an oversimplification of the actual groundwater flow system, selection of a technical model approach (representation of the system), or the quality of the model calibration.

The ability to conduct solute transport modeling at and in the vicinity of the site is of great value. This is only true, however, if the results can be relied upon with confidence. Because...
the foundation of all transport simulations is the groundwater flow model, the transport simulations and results presented in the IT report do not accurately represent the observed conditions in 1996 and cannot reliably predict the potential migration of contaminants within the groundwater system. To increase the level of confidence in simulated model results, significant modifications were required. To achieve the level of confidence needed, Geraghty & Miller developed the three-dimensional model presented in the following sections.

GROUNDWATER FLOW MODEL DEVELOPED BY GERAGHTY & MILLER

Framework:

The model has two layers, 131 columns, and 129 rows. The areal mesh spacing is graded from 250 ft on the edge of the model to 25 ft at the site. The first layer of the model represents the saprolite overburden, and the highly weathered bedrock in places where the saprolite is thin or the water table is in the bedrock.

The computer codes used to evaluate groundwater conditions are:

MODFLOW for groundwater flow (McDonald and Harbaugh, 1988)
MODPATH for particle tracking analysis (Pollock, 1989)
MT3D for solute transport (Zheng, 1996)

The groundwater flow model is calibrated to steady-state conditions; water-levels conducted in March 1996 are used as calibration targets (44). A least squares statistical calibration was performed. Hydraulic conductivity, recharge, and boundary conditions, were varied during the calibration process. The residual sum of squares of the final calibration is 124.66, and the residual mean is 0.074. The attached figures show the extent of the model domain, boundary conditions in the vicinity of the site, simulated water levels in layers one and two, distribution of hydraulic conductivity in layers one and two, and the recharge zonation.

GROUNDWATER TRANSPORT MODEL DEVELOPED BY GERAGHTY & MILLER

The MT3D computer code developed for the U.S. Environmental Protection Agency (Zheng 1996) was selected for solute transport modeling. MT3D is a publicly available computer program that features extensive documentation and verification. The code is fully three-dimensional, simulates transport in confined and unconfined flow systems, and can account for hydrodynamic dispersion, adsorption (retardation), and decay in solute transport calculations. MT3D was chosen for this modeling application because it was designed to be used in conjunction with MODFLOW (McDonald and Harbaugh, 1988), which was used in the groundwater modeling task of this investigation. MT3D uses the results from MODFLOW to compute the groundwater flow and velocity terms used in transport calculations.
The MT3D solute transport model uses the same finite-difference grid structure and boundary conditions developed for the groundwater flow model. Additional model parameters unique to the transport model are described below.

The simulation of solute migration requires specification of various transport parameters that control the rate, movement, mixing, adsorption, and degradation of a contaminant in the subsurface. Advection defines the process of contaminant migration due to the movement of groundwater. Dispersion accounts for the mixing of the contaminant in the groundwater due to tortuous flow paths in the aquifer medium. Adsorption refers to the partitioning of a contaminant between the liquid and solid phases of the aquifer. Degradation within the context of this application is a result of biochemical activity and/or chemical activity and/or volatilization within the aquifer.

Adsorption of a constituent between the liquid and solid phases of the aquifer is accounted for in MT3D using the distribution coefficient ($K_d$). The distribution coefficient is a function of the organic carbon content in the aquifer and the constituent distribution coefficient normalized to particulate organic carbon ($K_{oc}$). The log $K_{oc}$ value for vinyl chloride is 0.39 (Howard 1996). The organic carbon content was assumed to be 1% in all calculations. Based upon a total porosity of 30%, the retardation factor for vinyl chloride was computed to be 1.1.

Degradation is considered to be a significant degradation mechanism at the Woodlawn Landfill Site. Estimated degradation rates were made based upon changes in total dissolved mass between 1990 and 1996. Contaminant degradation is described by the equation:

$$C = C_0 e^{-\lambda t}$$

where:

$$\lambda = \frac{\ln(2)}{t_{1/2}}$$

In the above equations, $C$ is the concentration at time $t$, $C_0$ is the initial concentration, and $t_{1/2}$ is the half-life of the contaminant.

**Transport model scenarios conducted**

Five solute transport scenarios were simulated to calibrate the solute transport model. The objective of the solute transport calibration is to predict the observed distribution of vinyl chloride in 1996 using the observed distribution of vinyl chloride in 1990 as the initial conditions. A goal of the fate and transport model is to use the most basic and simplistic assumptions that result in the best representation of the observed vinyl chloride distribution in groundwater. Beginning with the most simplistic assumptions, the model calibration systematically evaluated each of the transport mechanisms that affect the migration of vinyl chloride in groundwater. In order to simulate and best represent the vinyl chloride distribution observed in groundwater in 1996, the following five solute transport scenarios were simulated:
1. Advection, dispersion, and natural dilution
2. Advection, dispersion, and natural dilution, with retardation (adsorption)
3. Advection, dispersion, and natural dilution, with retardation (adsorption), and degradation
4. Advection, dispersion, and natural dilution, with retardation (adsorption), degradation, and continuing source
5. Advection, dispersion, and natural dilution, with retardation (adsorption), and calibrated degradation and calibrated continuing source

The results from the iterative fate and transport calibration process indicate that the observed vinyl chloride distribution in 1996 cannot be simulated by the model without incorporating a natural degradation term and continuing source term. Based on the fate and transport simulations that were conducted, scenario 5 produced results that best represent vinyl chloride distributions observed at the site in 1996. The calibrated transport parameters are as follows:

<table>
<thead>
<tr>
<th>Constituent Half-Life</th>
<th>2 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispersivity</td>
<td>12.5 feet</td>
</tr>
<tr>
<td>Retardation</td>
<td>1.1</td>
</tr>
<tr>
<td>Constituent Source</td>
<td>1990 - 1996 (0.65 kg/yr average)</td>
</tr>
<tr>
<td></td>
<td>1996 - 2001 (0.11 kg/yr average)</td>
</tr>
<tr>
<td></td>
<td>2001 - 2006 (0.0188 kg/yr average)</td>
</tr>
<tr>
<td></td>
<td>2006 - 2011 (0.00319 kg/yr average)</td>
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</tbody>
</table>

(The source decays at a half-life rate of 2.0 years)

Transport scenarios were conducted to evaluate the long term impacts of the Woodlawn Landfill on nearby private domestic wells. Four scenarios were evaluated: (1) no domestic water use and a continuous residual source at the landfill; (2) no domestic water use and a decaying residual source at the landfill; (3) domestic water use and a decaying residual source at the landfill; (4) domestic water use, 70% return flow through on-site residential septic systems, and a decaying residual source at the landfill.
REFERENCES


Finite Difference Grid with Boundary Conditions in the Vicinity of the Woodlawn Landfill

BRIDGESTONE/FIRESTONE
Woodlawn Landfill, Cecil County, Maryland
Hydraulic Conductivity Zonation for Model Layer 1

GERAGHTY & MILLER, INC.
Environmental Services
A Heidemill Company

Bridgestone/Firestone
Woodlawn Landfill, Cecil County, Maryland

0.5 ft/day
2.8 ft/day
5.0 ft/day
7.6 ft/day
0.06 ft/day

LEGEND
- LINE
- APPROXIMATE LOCATION OF THE MODEL SIMULATION CELLS
- RECLINE
- HYDRAULIC CONDUCTIVITY ZONATION

Scale

NOV-12-1996 17:53
912157526879
P.15
Hydraulic Conductivity Zonation for Model Layer 2

Woodlawn Landfill, Cecil County, Maryland
Precipitation Recharge Zonation

GERAGHTY & MILLER, INC.
Environmental Services
A Heldemij Company

BRIDGESTONE/FIRESTONE
Woodlawn Landfill, Cecil County, Maryland

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912157526879
96%
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7.9 in/yr

62.6 in/yr

11.8 in/yr

LEGEND

Sensitivity analysis?
Simulated Water Levels and Residuals for Model Layer 1

BRIDGESTONE/FIRESTONE
Woodtown Landfill, Cecil County, Maryland

GERAGHTY & MILLER, INC.
Environmental Services
A Heidemij Company

Figure

NOV-12-1996 17:51 812157526879 96% P.13
Simulated Water Levels and Residuals for Model Layer 2

BRIDGESTONE/FIRESTONE
Woodlawn Landfill, Cecil County, Maryland