



1099 Miller Drive, Altamonte Springs, FL 32701

December 31, 2013

F. Thomas Lubozynski, P.E.  
Waste & Air Resource Programs Administrator  
Florida Department of Environmental Protection, Central District  
3319 Maguire Boulevard, Suite 232  
Orlando, Florida 32803-3767

Subject: Benzene Impact Investigative Study Memorandum  
JED Solid Waste Management Facility  
Osceola County, Florida  
Operating Permit No. SO49-0199726-022

Dear Mr. Lubozynski:

Omni Waste of Osceola County, LLC (Omni) is submitting the attached Memorandum prepared by Geosyntec Consultants documenting benzene investigative studies completed for our JED Solid Waste Management Facility. The investigative studies were proposed by Omni in the submittal "Water Quality and Methane Gas Migration" dated August 6, 2013 and approved by your Department on August 28, 2013. Geosyntec Consultants further evaluated the possible source of detected levels of benzene in the JED facility leachate, likelihood of benzene diffusion through the primary and secondary base liner system, and use of aerated or non-aerated leachate for recirculation.

If you have any questions or require additional information, please contact me at (904) 673-0446 or [mkaiser@wsji.us](mailto:mkaiser@wsji.us) at your earliest convenience.

Sincerely,

A handwritten signature in black ink that reads "Mike Kaiser".

Region Engineer  
Progressive Waste Solutions of FL, Inc.

Attachment

## Memorandum

Date: 27 December 2013

To: Michael Kaiser, Progressive Waste Solutions, Inc.

Copies to: Kwasi Badu-Tweneboah, Ph.D., P.E., Victor Damasceno, Ph.D., P.E.  
Geosyntec Consultants

From: Herwig Goldemund, Ph.D., Matt Wissler, P.G., Ramil Mijares, Ph.D.  
Geosyntec Consultants

Subject: Groundwater Contamination and Landfill Gas Migration  
Investigation and Assessment – Benzene  
J.E.D. Solid Waste Management Facility  
Omni Waste of Osceola County, LLC  
Geosyntec Project No.: FL2258

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In August 2013, Omni Waste of Osceola County, LLC (Omni), a Progressive Waste Solutions Company (PWS), contracted Geosyntec Consultants Inc. (Geosyntec) to assess potential volatile organic compound (VOC) groundwater contamination associated with landfill gas (LFG) migration at the J.E.D. Solid Waste Management facility (JED facility), a Class I landfill located in Osceola County, Florida. Specifically, Omni requested assessment of potential groundwater impacts in relationship to benzene detected in water quality, leachate and landfill gas sampling events, and use of contaminated soils for daily and intermediate cover at the JED facility. This technical memorandum has been prepared by Geosyntec and is divided into the following four tasks:

- Task 1. Evaluation of Leachate Chemistry;
- Task 2. Groundwater and Leachate Evaluation;
- Task 3. Aerated versus Non-aerated Leachate Evaluation; and
- Task 4. Landfill Gas and Groundwater Contamination Evaluation.

This technical memorandum has been prepared by Herwig Goldemund, Ph.D., Matt Wissler, P.G., and Ramil Mijares, Ph.D., and reviewed by Zahirul Islam, Ph.D., P.E., Beth Gross, Ph.D.,

P.E., Victor M. Damasceno, Ph.D., P.E., and Kwasi Badu-Tweneboah, Ph.D., P.E., all of Geosyntec.

## **EVALUATION OF LEACHATE CHEMISTRY**

Omni provided Geosyntec with leachate characterization data from the JED facility and two other larger municipal solid waste (MSW) landfills also owned and operated by PWS, including the Seneca Meadows Landfill in New York and the Lachenai Landfill in Terrebonne, Canada.

Additionally, Geosyntec summarized leachate characterization data from six more landfills in Florida using publically available data, and four landfills from Alabama, Florida, and Tennessee, which are only identified by state to protect data confidentiality. The leachate and groundwater characterization data are summarized in Table 1. Only BTEX (benzene, toluene, ethylbenzene, and xylenes) data are included in Table 1 since this analysis focuses on the potential impacts of these constituents on groundwater at the JED facility.

As shown in Table 1, the concentration of BTEX compounds in leachate from the JED facility are generally consistent with concentrations found at similar sites across Florida and the Southeast. However, concentrations of toluene appear to be somewhat higher than found in MSW leachate characterization data from other facilities previously discussed herein. Note that toluene has only been found at trace concentrations in groundwater, at levels well below the groundwater cleanup target level (GCTL) of 40 micrograms per milliliter ( $\mu\text{g/L}$ ) under Chapter 62-777 Florida Administrative Code (F.A.C.). Since toluene is detected in leachate, it can be used as a groundwater tracer and would be expected to be found at much higher concentrations in groundwater in the event of a leachate leak from the disposal areas; however, comparison between leachate and groundwater concentrations are not indicative of leachate as a source of groundwater impacts.

Based on the information presented herein, benzene is the only VOC detected in groundwater at the JED facility and is in excess of its GCTL (benzene has a GCTL of 1  $\mu\text{g/L}$ ). Benzene concentrations in leachate from the JED landfill are generally low (i.e.,  $<10 \mu\text{g/L}$ ) and at about the same level as found in groundwater. Even if there were a small leachate leak at the facility, concentrations of benzene would be diluted with meteoric groundwater and would be expected to be at least an order of magnitude below leachate concentrations. Therefore, benzene concentrations found in leachate are not indicative of leachate as a source of groundwater impacts with benzene. Nonetheless, the potential leakage of leachate and benzene diffusion through the landfill liner as a source of benzene in the groundwater are evaluated under the tasks presented later herein.

## GROUNDWATER AND LEACHATE EVALUATION

This section presents the results of contaminant transport modeling to evaluate whether the detected elevated levels of benzene in shallow groundwater monitoring wells at the JED facility are potentially due to the leakage of leachate and diffusion of benzene through the landfill liner system. Geosyntec considered the following two contaminant transport mechanisms through the landfill liner system in this evaluation: (i) advective flow (i.e., leakage) of leachate through potential defects in the liner system; and (ii) diffusive flux of contaminants through liner system.

Leachate constituents of concern that migrate through the landfill liner system may be transported downward through the underlying soil to shallow groundwater and then transported laterally in groundwater to the receptor point (i.e., groundwater monitoring well). The advective leachate flux and the diffusive flux are assumed to mix with the groundwater within the footprint of the landfill liner system. The resulting constituent concentrations are calculated using a simple “end-member” mixing approach that preserves the conservation of mass. Afterwards, horizontal transport of the constituents from beneath the landfill footprint to the receptor point is evaluated using a closed-form Domenico solution [Domenico and Schwartz, 1990] to the one-dimensional partial differential equation describing solute reduction due to dispersion.

### Advective Flow of Leachate through the Liner System

#### *Method of Analysis*

Advective flow of leachate (i.e., leachate flux) through the landfill liner system was evaluated using the Giroud equation [Giroud, 1997] which provides an analytical means of calculating the rate of leachate migration through composite liners. The leakage rate through a possible defect in the geomembrane component of a composite liner can be calculated as follows [Giroud, 1997]:

$$Q = 0.976 \cdot C_{qo} \cdot \left[ 1 + 0.1 \cdot \left( \frac{h}{t_{UM}} \right)^{0.95} \right] \cdot d^{0.2} \cdot h^{0.9} \cdot k_{UM}^{0.74} \quad (1)$$

where:

Q = rate of leakage through the composite liner due to defects in the geomembrane (m<sup>3</sup>/s);

h = hydraulic head on top of the geomembrane (m);

t<sub>UM</sub> = thickness of the low-permeability medium underlying the geomembrane (m);

d = diameter of the geomembrane defect (m);

k<sub>UM</sub> = hydraulic conductivity of the low-permeability medium underlying the geomembrane (m/s); and

$C_{qo}$  = dimensionless coefficient that characterizes the quality of contact between the geomembrane and the underlying medium.

For Equation. 1 to be valid, the hydraulic conductivity of the underlying medium,  $k_{UM}$ , should be less than or equal to  $k_G$ , where  $k_G$  is defined as follows [Giroud et al., 1994; Giroud, 1997]:

$$k_G = \left\{ \frac{0.3891 d^{1.8}}{C_{qo} \left( 1 + 0.1 \left( \frac{h}{t_{UM}} \right)^{0.95} \right) h^{0.4}} \right\}^{1/0.74} \quad (2)$$

where

$k_G$  = maximum or upper bound hydraulic conductivity (m/s);

$h$  = hydraulic head on top of the geomembrane (m);

$d$  = diameter of the geomembrane defect (m);

$t_{UM}$  = thickness of the low-permeability medium underlying the geomembrane (m); and

$C_{qo}$  = dimensionless coefficient that characterizes the quality of contact between the geomembrane and the underlying medium.

### ***Landfill Details***

The current Florida Department of Environmental Protection (FDEP) Solid Waste Operation Permit No. SO49-0199726-022 for the JED facility authorizes the development of Phases 1 through 4 of the JED facility. Phase 1 consists of four cells, Cells 1 through 4, and has a footprint of approximately 53 acres. Phase 2 consists of three cells, Cells 5 through 7, and has a footprint of approximately 36 acres. Phase 3 consists of three cells, Cells 8 through 10, and has a footprint of approximately 37 acres. Phase 4 consists of three cells, Cells 11 through 13, and has a footprint of approximately 47 acres. The combined footprint of Phases 1 through 4 is approximately 173 acres. To date, Cells 1 through 8 have been constructed at the JED facility, Cell 9 is currently under construction, and Cells 1 through 4 have been partially closed. Waste is primarily being deposited in Cell 8 (first cell in Phase 3 of the JED facility) at this time.

The liner system for Cells 1 through 5 had a double composite liner system, consisting of (from top to bottom): (i) a primary composite liner, which serves as a barrier layer and as a component of the leachate collection system (LCS); and (ii) a secondary composite liner, which functions as an additional barrier layer and part of the leak detection system (LDS). Both primary and secondary composite liners were constructed using the following components (from top to bottom): (i) a geocomposite drainage layer, (ii) a 60-mil HDPE textured geomembrane; and (iii)

a low-permeability geosynthetic clay liner (GCL), which consists of a thin layer of bentonite clay sandwiched between two layers of geotextile. Additionally, the sump area for Cells 1 through 5 was underlain by a 2-ft thick low permeability compacted clay layer.

The liner system for Cells 6 through 8 had a double liner system similar to the liner system for Cells 1 through 5 except that GCL was not used under the entire footprint of the primary liner system, only under the sump area. For the purpose of this analysis, the leachate flux through the landfill liner system is conservatively calculated as the leakage rate through the secondary liner.

### ***Input Parameters***

The following assumptions were made for the leakage rate analysis. Justifications for many of these assumptions are given by the USEPA [1987a; 1987b] and Giroud and Bonaparte [1989a].

### ***Construction Quality***

Leakage rates through composite liners are a function of many parameters, including hydraulic head, size of the considered geomembrane defect, geomembrane thickness, hydraulic conductivity of the medium underlying the geomembrane, and quality of contact between the geomembrane and the underlying medium. As indicated by the USEPA [1987a] and Giroud and Bonaparte [1989b], the latter parameter plays an essential role. The quality of contact between the geomembrane and the underlying medium can be defined as follows [Bonaparte et al., 1989; Giroud et al., 1989]:

- The *good contact condition* corresponds to a geomembrane installed, with as few wrinkles as possible, on top of a low-permeability soil layer that has been adequately compacted and has a smooth surface. In the case of *good contact*, the dimensionless coefficient that characterizes the quality of contact between the geomembrane and the underlying medium ( $C_{q0}$ ) is 0.21.
- The *poor contact condition* corresponds to a geomembrane that has been installed with a certain number of wrinkles, and/or placed on a low-permeability soil that has not been well compacted and does not appear smooth. In the case of *poor contact*, the dimensionless coefficient  $C_{q0}$  is 1.15.

### ***Size and Frequency of Geomembrane Defects***

The average size and frequency of defects considered in the analysis were assumed as follows:

- *Defect Size.* USEPA [1987a] and Giroud and Bonaparte [1989a] present case-study data which provide information on the size of defects that may occur in geomembranes at properly designed and constructed facilities, with good CQA. Using these data, a defect size of  $3.1 \text{ mm}^2$  ( $0.005 \text{ in}^2$ ) has been selected to calculate leakage rates for liner performance evaluation. The corresponding diameter for this assumed circular defect area is 2 mm. For

the purpose of this analysis wherein leakage through the secondary liner is being evaluated, a larger and thus more conservative value (i.e., 1 cm<sup>2</sup>) of defect size was also considered.

- *Defect Frequency.* Based on forensic analyses of the frequency of defects in geomembrane liners [Giroud and Fluet, 1986], a frequency of 1 defect per acre (4,000 m<sup>2</sup>) can be practically assumed for liner leakage rate analyses.

#### Head of Liquid on the Composite Liner

The leachate head used to evaluate the leakage through the secondary liner was chosen to be equal to the thickness of the geocomposite drainage layer (i.e., 0.5 cm). This value represents the most conservative case for evaluation of the performance of the secondary liner since it implies that the leak occurs at the same location in both primary and secondary liners which is not usually the case.

#### **Results**

A spreadsheet summarizing the leakage rate calculations for the secondary liner are provided in **Attachment A**. The leakage rate for the secondary liner assuming a 2-mm diameter defect size resulted in a lower bound value of  $3.01 \times 10^{-4}$  gal/acre/day corresponding to the good contact condition, and an upper bound value of  $1.65 \times 10^{-3}$  gal/acre/day corresponding to the poor contact condition. The leakage rate for the secondary liner assuming a 1 cm<sup>2</sup> defect size resulted in a lower bound value of  $4.25 \times 10^{-4}$  gal/acre/day corresponding to the good contact condition, and an upper bound value of  $2.33 \times 10^{-3}$  gal/acre/day corresponding to the poor contact condition.

From the results presented above, the most conservative value of  $2.33 \times 10^{-3}$  gal/acre/day was considered as the base case for contaminant transport modeling. This is equivalent to a leakage rate of  $3.13 \times 10^{-5}$  in/yr. Based on the 2010 potentiometric surface map (i.e., taken on 24 September 2010) for the site, groundwater divide exists within the middle of the landfill where wastes were already placed (Figure 1). Hence, groundwater flows either to the east or to the west of the groundwater divide. The groundwater divide also splits the landfill into two areas. To be conservative, the bigger area (i.e., to the west of the groundwater divide) was considered in this analysis as the landfill footprint. This translates to a leachate flux equal to approximately 6.432 ft<sup>3</sup>/yr within the landfill footprint.

#### **Diffusive Flux through the Liner System**

##### ***Method of Analysis***

Steady-state diffusive mass flux of VOCs emanating from the bottom of a composite liner was calculated using the Fick's first law as expressed by Foose et al. [2002] but extended to two soil layers (i.e., a GCL and underlying soil):

$$J_D = D_{eq} \left( \frac{\Delta C}{t_{gm} + t_{gcl} + t_s} \right) \quad (3)$$

where:

$D_{eq}$  = “equivalent” steady-state diffusion coefficient for the composite liner;

$\Delta C$  = difference in concentration between the solute source at the top of the geomembrane and the concentration at the soil immediately above the groundwater table;

$t_{gm}$  = geomembrane thickness;

$t_{gcl}$  = GCL thickness; and

$t_s$  = soil thickness above the groundwater table.

Accordingly, the equivalent steady-state diffusion coefficient for a VOC through a composite liner and the underlying soil is calculated as:

$$D_{eq} = \left( \frac{t_{gm} + t_{gcl} + t_s}{\frac{t_{gm}}{D_{gm} K_{d, gm}} + \frac{t_{gcl}}{D_{gcl}^* n_{gcl}} + \frac{t_s}{D_s^* n_s}} \right) \quad (4)$$

where

$D_{gm}$  = diffusion coefficient of the geomembrane;

$K_{d, gm}$  = partition coefficient of VOC on geomembrane;

$D_{gcl}^*$  = effective diffusion coefficient of the GCL;

$n_{gcl}$  = GCL porosity;

$D_s^*$  = effective diffusion coefficient of soil; and

$n_s$  = soil porosity.

For the purpose of this analysis, the diffusion through the secondary composite liner at the JED facility was calculated. This is a conservative case since the geomembrane component of the primary liner could also contribute to the reduction in the diffusive flux. The solute source concentration at the top of the geomembrane component of the secondary composite liner is assumed to be equal to 20 µg/L (i.e., the maximum benzene concentration measured from the leachate samples at the JED facility) while the concentration at the soil immediately above the groundwater table is assumed to be equal to 0 µg/L.

The thickness of the geomembrane is assumed equal to 0.060 in. (i.e., a 60-mil thick HDPE geomembrane). The GCL thickness is assumed equal to 0.25 in. and Foose et al. [2002] indicated GCL porosity equal to 0.70. Using benzene as the contaminant, Islam and Rowe



[2009] estimated a diffusion coefficient of benzene through geomembrane equal to  $1.9 \times 10^{-13}$  m<sup>2</sup>/s and a partition coefficient of benzene on geomembrane equal to 50. Furthermore, Rowe et al. [2005] indicated that diffusion coefficient for benzene through a GCL ranges from  $3.7 \times 10^{-10}$  m<sup>2</sup>/s to  $4.0 \times 10^{-10}$  m<sup>2</sup>/s. A conservative value of  $4.0 \times 10^{-10}$  m<sup>2</sup>/s was used in this analysis for diffusion coefficient of benzene through GCL.

The effective diffusion coefficient of contaminants diffusing through soil can be expressed as [Shackelford and Daniel, 1991]:

$$D_s^* = D_0 \tau_a \quad (5)$$

where:

$D_0$  = free-solution diffusion coefficient; and

$\tau_a$  = soil tortuosity factor.

The soil beneath the landfill liner system is predominantly sand [Geosyntec, 2011]. For sand, the tortuosity factor ranges from 0.025 to 0.29 [Shackelford and Daniel, 1991]. A conservative value of 0.29 was used in this analysis. Furthermore, Rowe et al. [2005] indicated that diffusion coefficient in free solution for benzene is equal to  $1.2 \times 10^{-9}$  m<sup>2</sup>/s. Hence,  $D_s^* = 3.4 \times 10^{-10}$  m<sup>2</sup>/s.

Based on the as-built drawings of the landfill liner system and the 2010 potentiometric surface map presented in Figure 1, the thickness of the unsaturated soil below the landfill liner system was calculated to be approximately between 1.5 and 26.5 ft (with an average thickness of approximately 10 ft) except in the sump areas wherein the bottom is within the groundwater table. Geosyntec [2011] noted that the porosity of this soil is equal to 0.25. For the purpose of this analysis, the landfill footprint was divided into three zones: (i) Zone 1, for the sump areas (i.e., approximately 1,000 ft<sup>2</sup> within the landfill footprint wherein  $t_s = 0$  ft); (ii) Zone 2, for areas within the landfill footprint with soil thickness ranging from 1.5 to 6.5 ft (i.e., approximately 587,000 ft<sup>2</sup> wherein  $t_s = 1.5$  ft); and (iii) Zone 3 for areas within the landfill footprint with soil thickness ranging from 6.5 to 26.5 ft (i.e., approximately 1,880,000 ft<sup>2</sup> wherein  $t_s = 6.5$  ft). This is a very conservative approach since the minimum thickness was considered for each zone. Hence, for each zone, the equivalent steady-state diffusion coefficient was calculated using Eqn. (4) and the resulting steady-state diffusive mass flux was calculated using Eqn. (3). This results to a total diffusive mass flux of benzene within the landfill footprint of approximately 11,079 mg/yr.

#### ***Mixing of Contaminant with Groundwater below the Landfill Footprint***

A mass balance process was applied to contaminant migrating through the landfill liner system (via advection and diffusion) to groundwater. When the contaminant mixes with groundwater, the resulting concentration is:

$$C_0 = \frac{C_L Q_L + J_{Dtotal} + C_{UG} Q_{UG}}{Q_L + Q_{Dtotal} + Q_{UG}} \quad (6)$$

where

- $C_0$  = constituent concentration after mixing;
- $C_L$  = concentration of constituent in leachate;
- $Q_L$  = advective leachate flux;
- $J_{Dtotal}$  = total diffusive mass flux;
- $Q_{Dtotal}$  = equivalent diffusive volumetric flux (i.e., mass flux divided by density);
- $C_{UG}$  = concentration of constituent in upgradient groundwater = 0; and
- $Q_{UG}$  = groundwater flux.

As calculated earlier, the annual volume of leachate that can enter the groundwater beneath the landfill footprint via advection is 6.432 ft<sup>3</sup> (i.e.,  $Q_L = 6.432$  ft<sup>3</sup>/yr). This leachate is assumed to have a benzene concentration of  $C_L = 20$  µg/L (i.e., the maximum benzene concentration measured from the leachate samples at the JED facility).

Using the total diffusive mass flux of benzene,  $J_{Dtotal} = 11,079$  mg/yr and benzene density of 0.8765 g/cm<sup>3</sup> [Islam and Rowe, 2009], the equivalent diffusive volumetric flux ( $Q_{Dtotal}$ ) was calculated to be 0.00045 ft<sup>3</sup>/yr.

The groundwater flux ( $Q_{UG}$ ) in Eqn. (6) is calculated as the product of the source width, source depth, and groundwater flow velocity. The source width is the length of a line that represents the widest path of groundwater flow beneath the landfill liner system. Based on the 2010 potentiometric surface map for the site, depending on the direction of groundwater flow (Figure 1), the source width varies. A representative source width of 3,000 ft was used for the mixing and transport analyses presented herein.

The depth of mixing (i.e., the source depth beneath the landfill) was calculated as [USEPA, 1996]:

$$d = (0.0112L^2)^{0.5} + d_a \left[ 1 - \exp \frac{-LI}{vd_a} \right] \quad (7)$$

where

- $d$  = mixing zone depth;
- $L$  = source length parallel to groundwater flow;
- $d_a$  = aquifer thickness;  $I$  = leachate percolation rate; and
- $v$  = groundwater flow velocity (Darcy velocity).

If the calculated mixing zone depth is greater than the aquifer thickness, then the aquifer thickness is used as the mixing depth.

The representative source length was selected to be 800 ft from the potentiometric surface map presented in Figure 1. The representative thickness of the water-bearing zone was selected to be 50 ft based on hydrogeologic data presented by Geosyntec [2011]. The representative horizontal groundwater flow velocity (Darcy velocity) for the upper aquifer was calculated to be 3.4 ft/yr based on hydrogeologic data presented by Geosyntec [2011].

Using Eqn. (7) with  $L = 800$  ft,  $d_a = 50$  ft,  $I = 3.13 \times 10^{-5}$  in./yr as calculated earlier, and  $v = 3.4$  ft/yr, the calculated depth of mixing beneath the landfill was 50 ft.

Considering a source width of 3,000 ft, source depth of 50 ft, and groundwater flow velocity of 3.4 ft/yr, the calculated flux of groundwater entering the source area within the footprint of the landfill liner system was 506,437 ft<sup>3</sup>/yr.

Using Eqn. (6), the concentration of benzene after mixing was calculated be 0.77 µg/L. This is equivalent to a dilution attenuation factor, DAF (i.e.,  $C_L/C_0$ ) of 26.

#### ***Domenico Analysis***

The form of the Domenico solution selected for this evaluation [Domenico and Schwartz, 1990] is used under several state Risk Based Corrective Action (RBCA) programs to estimate constituent concentrations at the point of compliance (i.e., receptor point for this project):

$$DAF = \left[ \exp \left[ \frac{x}{2\alpha_x} \cdot \left( 1 - \sqrt{1 + \frac{4\lambda\alpha_x R}{v_s}} \right) \right] \cdot \operatorname{erf} \left( \frac{S_w}{4\sqrt{\alpha_y x}} \right) \cdot \operatorname{erf} \left( \frac{S_d}{2\sqrt{\alpha_z x}} \right) \right]^{-1} \quad (8)$$

where

DAF = dilution attenuation factor;

x = distance from source plane;

$\alpha_x$  = longitudinal dispersivity;

$\alpha_y$  = transverse dispersivity in the y-dimension;

$\alpha_z$  = transverse dispersivity in the z-dimension;

$\lambda$  = first-order degradation constant;

R = retardation factor;

$v_s$  = groundwater linear velocity (seepage velocity);

$S_w$  = source width; and

$S_d$  = source plane depth in the z-dimension.

If source spreading is limited by water-bearing zone depth,  $H$ , the “x” term in the vertical dispersion component of the equation should be replaced with the approximately horizontal distance over which vertical spreading can occur:  $(H - S_d)^2 / \alpha_z$ . The results of this calculation provide a site-specific DAF that can be applied to a conservative constituent at a known source concentration. This approach was used to estimate the concentrations of the constituents of concern (e.g., benzene) in groundwater prior to migration beyond the receptor point.

It should be noted that the only attenuation mechanism contained in Eqn. (8) that is used in this analysis is dispersion. Retardation ( $R$ ) and the “decay” term ( $\lambda$ ) are not considered in this analysis. This represents an extremely conservative approach to calculating concentrations at the point of compliance (i.e., receptor point), since both of these processes can result in significant decreases in constituent concentration. Likewise, chemical and biological reactions occur in virtually all groundwater environments, resulting in lower actual concentrations at the point of compliance (i.e., receptor point) than are estimated here.

The modeling approach is also very conservative in the way in which the source concentration is handled. The approach assumes that the source of the constituent of interest is a plane of finite dimension, oriented perpendicular to the direction of flow. This plane provides a steady-state infinite source. Rarely are constituent sources infinite and steady state and this is especially true at landfills (e.g., see measured leachate collection rates for open and closed landfills presented by Bonaparte et al. [2002]).

A spreadsheet was used to solve the Domenico equation and is provided in **Attachment B**. The following sections describe the input parameters used in Eqn. (8) and analysis results.

### ***Input Parameters***

The initial source concentration is 20  $\mu\text{g/L}$  (i.e., the maximum benzene concentration measured from landfill leachate). The maximum contaminant level (MCL) for benzene for Secondary Drinking Water Standards (SDWSs) as outlined in Chapter 62-550, F.A.C. is 1  $\mu\text{g/L}$ . The source concentration was then reduced as described in the preceding section to account for mixing of leachate and groundwater within the 50-ft thickness of the water-bearing zone beneath the landfill liner prior to transport from the edge of the source zone to the receptor point.

The distance from the source plane was calculated as the minimum downgradient distance along the groundwater flow path from the limit of the landfill liner system to the receptor point. Using the 2010 potentiometric surface map developed by Geosyntec [2011] for the site (Figure 1), the shortest downgradient distance to a receptor point is approximately 30 ft.

The longitudinal dispersivity was calculated as  $0.1 \times \text{distance to the receptor}$ , the transverse dispersivity in the y-direction was calculated as  $0.0330 \times \text{distance to the receptor}$  (i.e., one-third of the longitudinal dispersivity), and the transverse dispersivity in the z-direction was calculated as  $0.005 \times \text{distance to the receptor}$  (i.e., one-twentieth of the longitudinal dispersivity) [Connor et al., 1996].

## **Results**

Groundwater flow and transport were evaluated for the sump area (Zone 1), areas within the landfill footprint with soil thickness ranging from 1.5 to 6.5 ft (Zone 2), and for areas within the landfill footprint with soil thickness ranging from 6.5 to 26.5 ft (Zone 3). Diffusive flux through the liner system results are summarized in **Attachment B**. Note that diffusion results for the individual zones were negligible; therefore, the total diffusive mass flux (i.e., Zone 1 + Zone 2 + Zone 3) was used. The calculated overall DAF for contaminant migrating through the landfill liner system and traveling through groundwater to the receptor point was 26. This translates to a benzene concentration at the receptor point equal to approximately 0.77 µg/L, which is less than its corresponding MCL. This is also significantly less than the maximum benzene concentration (i.e., 11.5 µg/L) measured from the groundwater monitoring wells.

## **AERATED VERSUS NON-AERATED LEACHATE**

Omni provided Geosyntec with aerated and non-aerated leachate characterization data for five sampling events from the leachate holding ponds at the JED facility. These data are summarized in Table 2 and include sampling events implemented in November/December 2009, May 2010, June 2011, November 2012, and December 2013.

Leachate samples collected from six leachate sumps in November 2009 were reportedly used as baseline data for comparison with the 7-day and 14-day aerated leachate data collected in December 2009 (aeration system start-up monitoring). Omni indicated in an e-mail to Geosyntec that the May 2010 VOC samples for aerated and non-aerated leachate were likely switched in the field or the laboratory since the aerated results exhibited BTEX detections while the non-aerated results exhibited non-detect results. This potential switch makes sense given that aeration promotes both volatilization and biological treatment of VOCs and other compounds amenable to volatilization and biological degradation.

As shown in Table 2 aeration substantially decreases the concentrations of BTEX compounds in leachate with the exception of the anomalous results from May 2010. This observation would be expected for VOCs being treated in an open pond using aeration. Omni reported that the JED facility currently only recirculates aerated leachate. Given that aeration promotes BTEX treatment, recirculation of treated leachate is not believed to increase BTEX concentrations in leachate collected from the various sumps that have received recirculated leachate. This is

consistent with the generally low concentrations of BTEX found in leachate, as previously discussed under Task 1.

## LANDFILL GAS AND GROUNDWATER CONTAMINATION

Omni provided Geosyntec with groundwater quality data from the shallow “A” zone wells dating between the baseline groundwater monitoring event in January 2004 and the most recent semi-annual sampling event completed May 2013. These data are summarized in Table 3 and in Figure 2.

Additionally, Omni provided Geosyntec with headspace analytical results for VOCs from several landfill gas probes outside of the waste footprint including GP-10, GP-11, GP-14, GP-15, GP-18, GP-19, GP-20, GP-21, GP-22, TGP-1 and TGP-3. The locations of the landfill gas probes are provided in Figure 3 (HDR, 2012). These data are summarized in Table 4 and include sampling events completed in June and December 2008 and December 2009. Note that the evaluation presented herein is limited to benzene because it is the only VOC detected in groundwater potentially associated with LFG exceeding FDEP GCTLs.

Benzene is detected in groundwater at all monitoring wells adjacent to Cells 1 through 6 with the exception of MW-2A and MW-7A. The detections of benzene do not indicate a steadily increase trend which is to be expected if an ongoing leachate release is occurring. Rather, the detections rise and fall sporadically which may indicate a source from landfill gas. The partitioning equilibrium of VOCs between landfill gas to shallow groundwater occurs within the gas/water interface where landfill gas is present. The “A” zone monitoring wells are screened across the historical range of the water table and are located in areas where landfill gas has been observed and documented previously at the JED facility.

The partitioning equilibrium behavior of VOCs between LFG and groundwater is defined by Henry’s Law:

$$C_w = \frac{C_g}{H} \quad (9)$$

where:

$C_w$  = the equilibrium water concentration (ppb);

$H$  = Henry’s Constant for benzene; and

$C_g$  = the landfill gas concentration (ppbv).

The concentration of VOCs from the LFG gas characterization data for samples collected from the JED facility and the resulting predicted groundwater concentrations are summarized in Table 4. TGP-1 and TGP-3 are located near groundwater wells which were sampled for VOCs just

prior to the LFG sampling event. The comparison of the equilibrium calculations and the results from the groundwater sampling at the monitoring wells are summarized below.

- TGP-1 –The headspace sampling results from December 2009 and resulting calculated benzene concentration of 0.4 µg/L using Henry’s Law indicates a close correlation with the groundwater result from MW-1A of 0.56 µg/L measured in November 2009. TGP-1 is located approximately 50 feet to the north and side gradient of MW-1A.
- TGP-3 – The headspace sampling results from December 2009 and resulting calculated benzene concentration of 0.34 µg/L using Henry’s Law indicates a poor correlation with the groundwater result from MW-11A of 2.9 µg/L measured in November 2009. TGP-3 is located approximately 60 feet to the south and side gradient of MW-11A. The poor correlation could be attributed to a preferential migration pathway for LFG not documented by the landfill gas probe.

Studies correlating the levels of VOCs in leachate and resulting concentrations in LFG have been performed [Tchobanoglous et al., 1993; Reinhart et al., 1994; Christensen et al., 1996; and Carel, 2004]. A summary of the range of benzene detections in LFG and calculated benzene concentrations in groundwater is provided in Table 5. As indicated in Table 5, the JED facility is within the range of typically observed benzene in LFG.

## SUMMARY

This technical memorandum presents four tasks associated with LFG migration and potential groundwater contamination at the JED facility. Comparison between leachate characterization data from the JED landfill and other landfills across Florida and the Southeast of the United States shows that the concentration of BTEX compounds in leachate from the JED landfill are generally consistent with concentrations found at similar sites. However, concentrations of toluene appear to be somewhat higher than found in “typical” MSW leachate across the Southeast.

Additionally, contaminant transport modeling were performed to evaluate whether the detected levels of benzene in shallow groundwater monitoring wells at the JED facility are potentially due to the leakage of leachate and diffusion of benzene through the landfill liner system. The modeling results indicate that the calculated maximum possible concentration of benzene at the groundwater monitoring wells (0.77 µg/L) due to advection and diffusion through the liner system is significantly less than the maximum concentration of benzene (11.5 µg/L) detected at the groundwater monitoring wells at the JED facility. It therefore appears that the elevated concentration of benzene detected at the groundwater monitoring wells could not solely be attributed to a source (by diffusion and advection) through the landfill liner system.



Comparison between non-aerated and aerated leachate data was also performed and shows that aeration substantially decreases the concentrations of BTEX compounds in leachate, as expected for VOCs being treated in an open pond using aeration. Given that aeration promotes BTEX treatment, recirculation of treated leachate is not believed to increase BTEX concentrations in leachate collected from the various sumps that have received recirculated leachate.

The results of the advective flow and diffusive flux modeling documented earlier in this report suggest leachate migration is not the source of the benzene observed in groundwater. As a result, the elevated concentrations of benzene detected in groundwater monitoring wells at the JED facility are more likely due to LFG migration rather than leachate migration due to the presence of LFG documented at landfill gas probes which result in the equilibrium partitioning between LFG and groundwater.

## REFERENCES

- Bonaparte, R., Giroud, J.P., and Gross, B.A. (1989). "Rates of Leakage through Landfill Liners", Conference Proceedings, Geosynthetics '89, Vol. 1, San Diego, CA, February 1989, pp. 18-29.
- Bonaparte, R., Daniel, D.E., and Koerner, R.M. (2002). "Assessment and Recommendations for Optimal Performance of Waste Containment Systems," U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Carel, (2004). "Evaluation of the Source of Volatile Organic Compounds in Groundwater Monitoring Wells W-23 and W-27 at the Jefferson Davis Landfill."
- Christensen, T.H., R. Cossu, and R. Stegmann (1996). "Landfilling of Waste: Biogas." E&FN Spon.
- Connor, J.A., Newell, C.J., and Malander, M.W. (1996). "Parameter Estimation Guidelines for Risk-Based Corrective Action (RBCA) Modeling," NGWA Petroleum Hydrocarbons Conference, Houston, TX, November.
- Domenico, P.A. and Schwartz, F.W. (1990). "Physical and Chemical Hydrogeology," John Wiley and Sons, New York. pp.372-381.
- Foose, G.J., Benson, C.H., and Edil, T.B. (2002). "Comparison of Solute Transport in Three Composite Liners", ASCE Journal of Geotechnical and Geoenvironmental Engineering, Vol. 128, No. 5, pp. 1-13.



- Geosyntec (2011). "Hydrogeological Investigation Report Addendum and Conceptual Water Quality Monitoring Plan; J.E.D. Solid Waste Management Facility", Prepared for Waste Services, Inc., February.
- Giroud, J.P. (1997). "Equations for Calculating the Rate of Liquid Migration Through Composite Liners Due to Geomembrane Defects", *Geosynthetics International*, Vol. 4, Nos. 3-4, pp. 335-348.
- Giroud, J.P., and Bonaparte, R. (1989a). "Leakage Through Liners Constructed with Geomembranes, Part I: Geomembrane Liners", *Geotextiles and Geomembranes*, Vol. 8, No. 1, pp. 27-67.
- Giroud, J.P., and Bonaparte, R. (1989b). "Leakage Through Liners Constructed with Geomembranes, Part II: Composite Liners", *Geotextiles and Geomembranes*, Vol. 8, No. 2, pp. 71-111.
- Giroud, J.P., and Fluet, J.E. Jr. (1986). "Quality Assurance of Geosynthetic Lining Systems", *Geotextiles and Geomembranes*, Vol. 3, No. 4, pp. 249-287.
- Giroud, J.P., Badu-Tweneboah, K., and Soderman, K.L. (1994). "Evaluation of Landfill Liners", *Proceedings, 5th International Conference on Geotextiles, Geomembranes, and Related Products*, Singapore, pp. 981-986.
- HDR (2012). "Installation and Initial Operation Report – Soil Vapor Extraction Pilot Test Study, JED Solid Waste Management Facility", Prepared for Waste Services, Inc., October.
- Islam, M.Z. and Rowe, R.K. (2009). "Permeation of BTEX through Unaged and Aged HDPE Geomembranes", *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 135, No. 8, pp. 1130-1140.
- Reinhart, D.R., C.D. Cooper, N.E. Ruiz (1994). "Estimation of Landfill Gas Emissions at the Orange County Landfill, Orlando." Civil and Environmental Engineering Department, University of Central Florida.
- Rowe, R.K., Mukunoki, T., and Islam, M.Z. (2005). "BTEX Diffusion and Sorption for a Geosynthetic Clay Liner at Two Temperatures", *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 131, No. 10, pp. 1211-1221.
- Shackelford, C.D., and Daniel, D.E. (1991). "Diffusion in Saturated Soil; I: Background", *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 117, No. 3, pp. 467-484.

Tchobanoglous, G., H. Theisen and S. Vigil, 1993. Integrated Solid Waste Management Engineering Principles and Management Issues, McGraw-Hill, 978 pp.

USEPA (1987a). "Background Document: Proposed Liner and Leak Detection Rule", EPA/530-SW-87-015, Prepared by GeoServices Inc., May 1987, 526 p.

USEPA (1987b). "Background Document: Bottom Liner Performance in Double-Lined Landfills and Surface Impoundments", EPA/530-SW-87-013, Prepared by GeoServices Inc., April 1987, 301 p.

USEPA (1996). "Soil Screening Guidance: Technical Background Document," EPA/540/R95/128, Office of Solid Waste and Emergency Response, Washington, D.C., May.

\* \* \* \* \*

## **TABLES**

**Table 1. Leachate and Groundwater Characterization Data Summary**

Facility	Sample Type	Data Values	Benzene	Toluene	Ethyl benzene	m,p-Xylenes	o-Xylene	Xylenes
			µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
JED Class I (MSW) Landfill	Leachate	Min	2	< 0.38	< 0.83	< 3.1	1.9 I	NR
		Max	20	930	48	58	26	NR
	LFG (ppmv)	Min	0.0016	0.016	0.0037	0.01	0.0039	NR
		Max	2.2	17	7.5	11	3.2	NR
	Groundwater	Min	< 0.066	< 0.5	< 0.21	NR	NR	0.14 I
		Max	11.5	3.7	2.2	NR	NR	2.95
Indian River County Landfill Class I (MSW) Landfill	Leachate	Min	1.7	6.2	5.5	8.2	5.1	1.7
		Max	2.3	27	32	26	15	68
Putnam Central Class I (MSW) Landfill	Leachate	Min	< 0.5	< 0.5	< 0.5	NR	NR	1.7
		Max	< 25	< 25	40.1	NR	NR	86.7
Cedar Trail Class I (MSW) Landfill, Bartow, Florida	Leachate	Min	1.79	0.269 J	0.495 J	NR	NR	2.46
		Max	3.6	3	6.1	NR	NR	13.6
Springhill Regional Class I (MSW) Landfill - North, Campbellton, Florida	Leachate	Min	NR	2.2	9.9	NR	NR	29
		Max	NR	17	12	NR	NR	78
Medley Class I (MSW) Landfill, Medley, Florida	Leachate	Min	NR	< 1		NR	NR	NR
		Max	NR	< 50		NR	NR	NR
Berman Road Class I (MSW) Landfill, Okeechobee, Florida	Leachate	Min	5.7	21	14	NR	NR	25
		Max	6.5	25	16	NR	NR	33
	Groundwater	Min	1.8	< 0.17	< 0.16	NR	NR	< 0.19
		Max	3.8	< 1	< 1	NR	NR	< 1
Seneca Meadows MSW Landfill, New York	Leachate	Min	0.38	NR	NR	4.9	3.2	NR
		Max	47	NR	NR	310	53	NR
Lachenai Landfill, Canada	Leachate	Min	< 0.2	< 0.1	< 0.1	NR	NR	8.7
		Max	36	670	260	NR	NR	6200
Florida Site	Leachate	Avg	1.6	9	NR	NR	NR	~ 30
Alabama Site I	Leachate	Avg	5.2	5.4	NR	NR	NR	~ 20
Alabama Site II	Leachate	Avg	3	5	NR	NR	NR	~ 45
Tennessee Site	Leachate	Avg	4.7	40	NR	NR	NR	~ 87

Notes: 1) NR = data not reported

**Table 2. Aerated versus Non-aerated Leachate Characterization Data**

Date	Sample Type	Data Values	Benzene	Toluene	Ethyl benzene	m,p-Xylenes	o-Xylene
			µg/L	µg/L	µg/L	µg/L	µg/L
November 2009 Results	Non-aerated Leachate	Min	5.6	13	30	34	18
		Max	11	350	48	58	26
	Aerated Leachate (7-day analysis)	Actual (i.e., 1 data only)	ND	ND	ND	ND	ND
	Aerated Leachate (14-day analysis)	Actual (i.e., 1 data only)	ND	ND	ND	ND	ND
May 2010 Results*	Non-aerated Leachate	Actual (i.e., 1 data only)	ND	ND	ND	ND	ND
	Aerated Leachate	Actual (i.e., 1 data only)	8.6 I	12	27	35	19
June 2011 Results	Non-aerated Leachate	Actual (i.e., 1 data only)	10.5	61	26	47	27.5
	Aerated Leachate	Actual (i.e., 1 data only)	ND	ND	ND	ND	ND
November 2012 Results	Non-aerated Leachate	Actual (i.e., 1 data only)	11	460	28	25	13
	Aerated Leachate	Actual (i.e., 1 data only)	ND	5.7 I	2.2 I	3.2 I	2.0 I
December 2013 Results	Non-aerated Leachate	Actual (i.e., 1 data only)	5.0	11	5.4	5.8 I	3.7 I
	Aerated Leachate	Actual (i.e., 1 data only)	ND	ND	ND	ND	ND

Notes: 1) \* = PWSFI indicated that samples may have been switched in the field/lab  
2) ND = not detected above method detection limit  
3) I = constituent detected between method detection limit and minimum reporting limit

Table 3. Benzene Concentrations in Groundwater

Well ID	PH 1 Baseline	1st Event	2nd Event	3rd Event	4th Event	5th Event	6th Event	7th Event	8th Event	9th Event	10th Event	11th Event	12th Event	13th Event	14th Event	15th Event	16th Event	17th Event	18th Event
	Jan-04	Jul-04	Jan-05	Jul-05	Feb-06	Jul-06	Feb-07	Jul-07	May-08	Nov-08	May-09	Nov-09	May-10	Nov-10	May-11	Nov-11	May-12	Nov-12	May-13
	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)
MW-1A	0.3	0.3	0.3	0.5	0.1	0.1	0.1	0.1	0.2	0.5	0.5	0.6	5.6	6.1	7.8	11.1	3.4	2.3	5.1
MW-2A	0.3	0.3	0.3	0.5	0.1	0.1	0.1	0.1	0.2	0.5	0.5	0.5	0.1	0.2	0.2	0.2	NA	0.3	0.2
MW-3A	0.3	0.3	0.3	0.5	0.1	0.1	0.1	0.1	0.2	0.9	0.5	0.8	1.2	6.7	0.2	4.5	NA	7.7	8.8
MW-4A	0.3	0.3	0.3	0.5	0.1	0.1	0.1	0.1	0.2	0.5	0.5	0.5	0.1	0.2	0.2	1.1	NA	3.8	4.0
MW-5A	0.3	0.3	0.3	0.5	0.1	0.1	0.1	0.1	0.3	0.8	0.7	0.5	0.3	0.2	0.2	0.2	NA	1.3	2.0
MW-6A	0.3	0.3	0.3	0.5	0.1	0.1	0.1	0.1	NA	NA	0.5	0.6	0.4	0.9	0.4	0.8	NA	1.3	3.1
MW-7A	0.3	0.3	0.3	0.5	0.1	0.1	0.1	NA	0.2	0.5	0.5	0.5	0.1	0.2	0.2	0.2	NA	0.2	0.2
MW-8A	0.3	0.3	0.3	0.5	0.1	0.1	0.1	0.3	0.2	0.5	0.5	1.3	1.6	1.3	1.0	5.0	1.6	6.0	2.2
MW-9A	0.3	0.3	0.3	0.5	0.1	0.1	3.9	1.4	2.8	7.7	2.5	9.6	11.0	11.5	9.4	10.3	5.2	1.4	2.3
MW-10A	0.3	0.3	0.3	0.5	0.1	0.1	0.1	0.1	0.4	1.3	1.0	2.9	3.3	2.7	0.8	0.9	0.2	6.5	4.7
MW-11A	0.3	0.3	0.3	0.5	0.1	0.1	0.1	0.7	3.3	1.8	0.6	2.9	8.0	5.7	0.7	3.0	3.8	8.6	8.1
MW-12A	0.3	0.3	0.3	0.5	0.1	0.1	0.1	0.1	0.2	0.5	0.5	0.5	2.0	2.2	2.7	3.5	2.8	4.7	3.8
MW-13A	0.3	0.3	0.3	0.5	0.1	0.1	0.1	0.1	0.2	0.5	0.7	0.9	1.2	1.3	1.3	1.1	2.0	2.1	3.4
MW-14A	0.3	0.3	0.3	0.5	0.1	0.1	0.1	MW-14A and MW-15A were abandoned in July 2007 prior to Phase 2 development											
MW-15A	0.3	0.3	0.3	0.5	0.1	0.1	0.1												
MW-16A	MW-16A through MW-23A were constructed as part of the Phases 2 and 3 development in September 2007							0.1	0.2	0.5	0.5	0.5	0.1	0.2	0.2	0.2	0.2	0.2	0.2
MW-17A								0.1	0.2	0.5	NA	NA	NA	NA	NA	NA	NA	NA	0.2
MW-18A								0.1	0.2	0.5	NA	NA	NA	NA	NA	NA	NA	NA	0.2
MW-19A								0.1	0.2	0.5	0.5	0.5	0.3	0.5	1.1	0.2	0.2	0.2	0.2
MW-20A								0.1	0.2	0.5	NA	NA	NA	NA	NA	NA	NA	0.2	0.2
MW-21A								0.1	0.2	0.5	NA	NA	NA	NA	NA	NA	NA	0.2	0.2
MW-22A								0.1	0.2	0.5	NA	NA	NA	NA	NA	NA	NA	0.2	0.2
MW-23A								0.1	0.2	0.5	0.5	0.5	0.1	0.4	0.6	0.4	0.2	0.3	0.4

**Table 4. Landfill Gas VOC Analytical Results from Gas Collection System and Landfill Gas Probes at the JED Facility.**

Data Collection Point	Date	Benzene Concentration in LFG (ppmv)	Predicted Benzene Concentration in GW (µg/L)	Corresponding Benzene Concentration in GW at Monitoring Well (November 2009) (µg/L)	Notes
TGP-1	12/15/2009	0.028	0.40	0.56	TGP-1 is located approximately 50 feet north and side gradient of MW-1A
TGP-3	12/15/2009	0.024	0.34	2.9	TGP-3 is located approximately 60 feet south and side gradient of MW-11A
GP-10	12/15/2008	0.0037	0.05		
GP-11	12/15/2009	0.018	0.26		
GP-14	12/15/2008	0.0026	0.04		
GP-15	12/15/2008	0.002	0.03		
GP-18	6/6/2008	0.010 U	NA		
	12/15/2008	0.0017	0.02		
	12/15/2009	0.012	0.17		
GP-19	12/15/2008	0.0021	0.03		
GP-20	12/15/2008	0.0023	0.03		
GP-21	6/6/2008	0.010 U	NA		
	12/15/2008	0.0016	0.02		
	12/15/2009	0.0056	0.08		
GP-22	12/15/2008	0.0017	0.02		
Flare	12/15/2009	2.2	31.4		

Notes: 1) <sup>A</sup> = Calculated benzene concentration determined by using Henry's Constant of 0.07 ppmv×µg/L

**Table 5. Summary of Benzene Detections in LFG and Calculated Benzene Concentrations in Groundwater.**

Geographic Location	Data Collection Point	Number of Samples	Range of Benzene Concentration in Gas (ppmv)	Range of Calculated Benzene Concentration in Groundwater (µg/L) <sup>A</sup>	Range of Observed Benzene Concentration in Groundwater (µg/L)	Source
California	Gas Recovery System Samples	10	0.52 - 3.6	7.4 - 51	NA	Christensen et al., 1996
	Single Point Headspace Samples	44	ND - 39	ND - 560		
Texas	Single Point Headspace Samples	6	0.16 - 0.64	2.3 - 9.14	NA	Carel, 2004
California	Gas Recovery System Samples	66	2.1 (mean) - 39 (maximum)	30 - 557	NA	Tchobanoglous et al., 1993
Florida	Gas Recovery System Samples	NA	ND - 0.47	ND - 6.7	NA	Reinhart et al., 1994
Florida	Gas Recovery System Samples	1	2.2	31.4	ND - 11.5	JED Landfill Reports
	Single Point Headspace Samples	15	ND - 0.028	ND - 0.4		

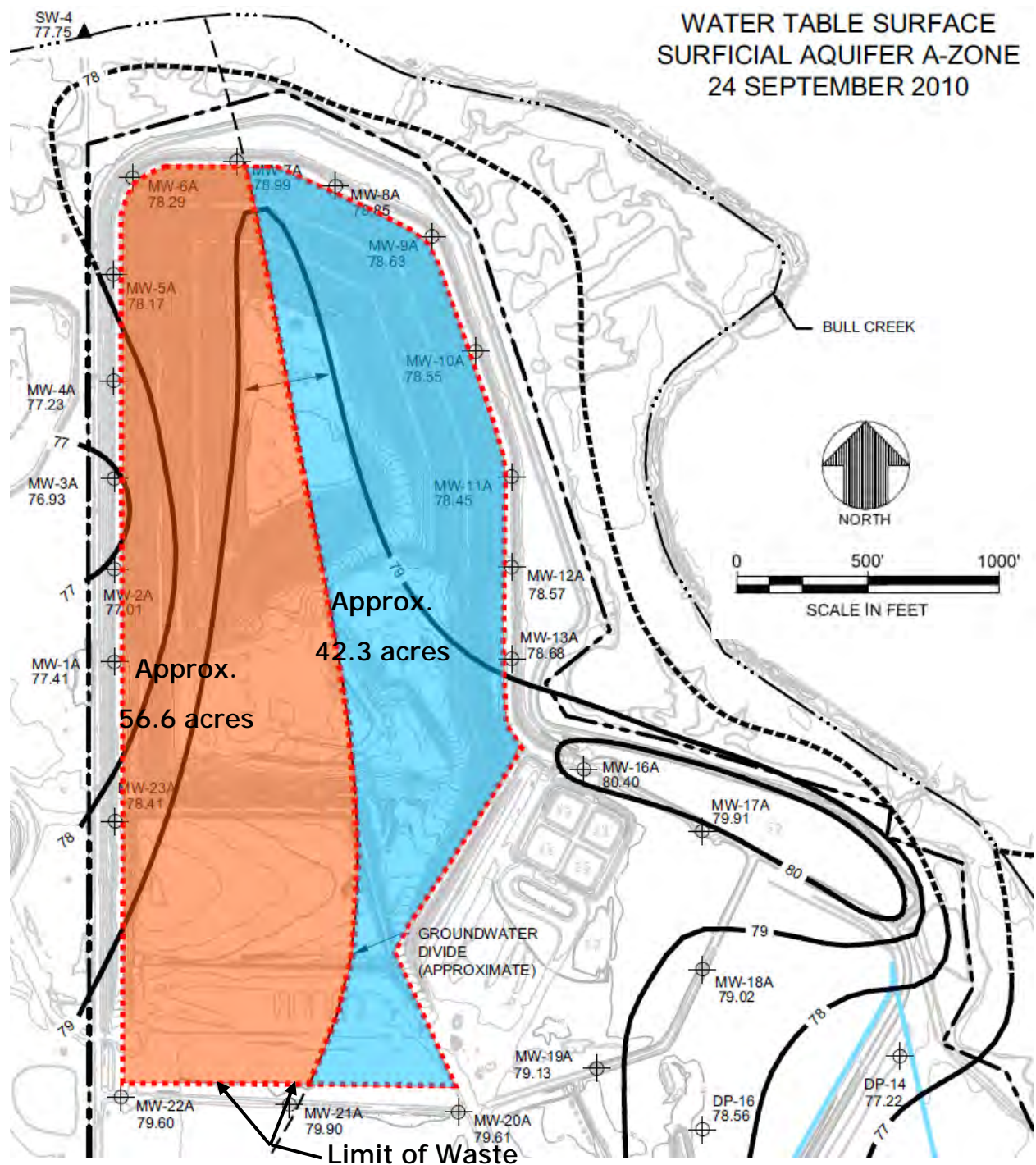
Notes: 1) NA = data not available

2) ND = constituent not detected above minimum reporting level

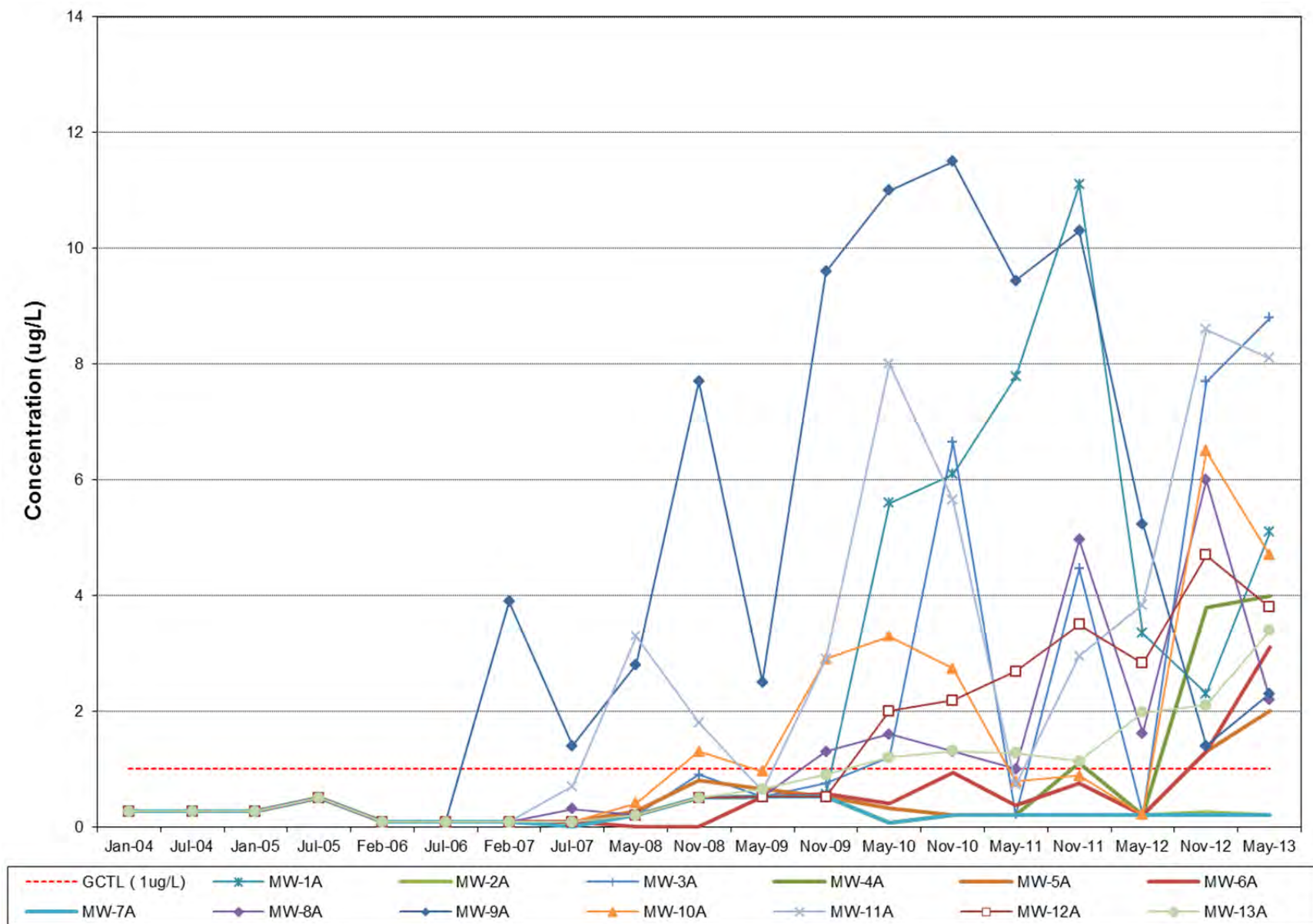
3) <sup>A</sup> = Calculated benzene concentration determined by using Henry's Constant of 0.07 ppmv\*ug/L



## **FIGURES**



**Figure 1. September 2010 Potentiometric Surface Map for JED Solid Waste Management Facility (adapted from Geosyntec [2011]).**



**Figure 2. Benzene Concentration in Groundwater.**

## **ATTACHMENT A**

**Liner System Leakage Calculations**  
**J.E.D. Solid Waste Management Facility**  
**St. Cloud, Florida**

<sup>(1)</sup> Leakage rate through geocomposite liner [Giroud, 1997]: 
$$Q = 0.976 C_{q0} \left[ 1 + 0.1 \left( \frac{h}{t_{UM}} \right)^{0.95} \right] d^{0.2} h^{0.9} k_{UM}^{0.74}$$

Size of Defect <sup>(2)</sup>	defect diameter (m)	Hydraulic Conductivity of Underlying Medium (k <sub>UM</sub> , m/s) <sup>(3)</sup>	t <sub>UM</sub> , Thickness of Underlying Medium (m)	Defect Area (m <sup>2</sup> )	h, Leachate Head above Defect (m) <sup>(4)</sup>	Limiting Hydraulic Conductivity (m/s) <sup>(5)</sup>	Lower Bound Leakage Rate (gal/acre/day) <sup>(6)</sup>	Upper Bound Leakage Rate (gal/acre/day) <sup>(6)</sup>
<b>Leakage Rate Calculations for Secondary Composite Liner</b>								
d = 2 mm	0.002	5.00E-11	0.005	3.14E-06	0.005	9.70E-07	3.01E-04	1.65E-03
1 cm <sup>2</sup>	0.0112838	5.00E-11	0.005	1.00E-04	0.005	6.53E-05	4.25E-04	2.33E-03

**NOTES:**

(1) Giroud, J.P., "Equations for Calculating the Rate of Liquid Migration Through Composite Liners Due to Geomembrane Defects", *Geosynthetics International*, Vol. 4, Nos. 3-4, 1997, pp. 335-348.

(2) Using data from USEPA [1987a] and Giroud and Bonaparte [1989a] at properly designed and constructed facilities, with good CQA, a defect size of 3.1 mm<sup>2</sup> (0.005 in<sup>2</sup>) has been selected. The corresponding diameter for this assumed circular defect area is 2 mm. In addition, for a more conservative estimate of leakage, a defect size of 1 cm<sup>2</sup> is also considered.

Based on forensic analyses of the frequency of defects in geomembrane liners [Giroud and Fluet, 1986], a frequency of 1 defect per acre can be practically assumed for liner leakage rate analyses.

(3) The hydraulic conductivity of a GCL used in a landfill liner application is typically between 5×10<sup>-12</sup> and 5×10<sup>-11</sup> m/s.

(4) Leachate head on the geomembrane/GCL liner corresponds to the thickness of the geocomposite directly above the liner (i.e., 0.5 cm).

(5) For equation in Note (1) to be valid, the hydraulic conductivity of the underlying medium (see Note 3) shall be less than or equal to this value.

(6) Lower and upper bound leakage rates refer to good and poor contact conditions, where C<sub>q0</sub> = 0.21 and 1.15, respectively.

## **ATTACHMENT B**

Contaminant Transport Modeling  
J.E.D. Solid Waste Management Facility  
St. Cloud, Florida

Source Concentration	Advective Leachate Rate	Zone 1 Landfill Footprint	Zone 2 Landfill Footprint	Zone 3 Landfill Footprint	Total Landfill Footprint Considered	Total Advective Leachate Flux	Zone 1 Diffusive Mass Flux	Zone 2 Diffusive Mass Flux	Zone 3 Diffusive Mass Flux	Total Diffusive Mass Flux
(µg/L)	(in/yr)	(ft²)	(ft²)	(ft²)	(ft²)	(ft³/yr)	(mg/yr)	(mg/yr)	(mg/yr)	(mg/yr)
BENZENE										
20.0	3.128E-05	1,000	586,888	1,879,750	2,467,638	6.432	320	6,120	4,640	11,080

Mixing Zone Depth, d	GW Flow Velocity	GW Flux	Calculated DAF for Mixing Beneath Liner System	Calculated Concentration Upon Mixing	Calculated Overall Dilution Attenuation Factor, DAF	Calculated Concentration in GW at Receptor Point	Groundwater MCL	Exceedance?
(ft)	(ft/yr)	(ft³/yr)	(--)	(µg/L)	(--)	(µg/L)	(µg/L)	(YES/NO)
BENZENE								
50	3.4	506,437	26	0.77	26	0.77	1.0	NO