SECTION 2.7

GROUNDWATER IMPACT EVALUATION

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2.7 GROUNDWATER IMPACT EVALUATION

Introduction

The Groundwater Impact Evaluation (GIE) has been performed to demonstrate that the site specific setting (geology and hydrogeology) and the proposed landfill design (which was developed with the geology and hydrogeology in mind) are protective of the public health, safety, and welfare. In other terms, the site geology and hydrogeology and design have been conjoined to each other and the GIE evaluates how the landfill functions in this setting.

This GIE has been prepared in general accordance with 35 Ill. Admin. Code Section 811.317 and 812.316.

The design and hydrogeologic setting of the proposed Veolia E. S. Zion Landfill Site 2 East Expansion (Site 2 East Expansion) has been evaluated using the data generated during the recent and previous hydrogeologic investigations, the proposed landfill design, and computer generated model. The site geology and hydrogeology are documented in Section 2.2 of this application.

The proposed landfill has been designed with extensive environmental safeguards, including a composite liner system consisting of a 60-mil HDPE geomembrane liner and a 5-foot recompacted cohesive soil liner (1 x 10^{-7} cm/sec), a leachate collection and removal system, and a composite final cover. The design of the proposed landfill is discussed in greater detail in Section 2.3 of this application. The site specific data obtained from the hydrogeologic investigation and the proposed design were incorporated into the computer model. When site specific data were not available, conservative estimates or assumptions (representing more stringent or safe environmental conditions) of model input parameters were used. The main conservative estimates or assumptions used in the model are as follows:

1. A constant concentration was used throughout the 124 year modeling period. The concentration of each constituent in leachate can be assumed to be constant or a specific mass can be assumed to be present. Assuming a specific mass results in a decreasing source concentration over time, which would most accurately represent the fact that leachate concentrations in landfills with leachate collection and removal systems will gradually decrease over time. However, a constant concentration was assumed as it results in conservative model results.

2. The landfill will have an inward gradient throughout the 124 year GIE modeling period, with groundwater flowing into the landfill in the unlikely event that a puncture of the liner was to occur. Conservatively, the groundwater model assumed that the landfill will have an outward gradient with 1 foot of leachate head acting on the liner. A 1 foot leachate head was used in the calculation of the landfill vertical seepage rate, resulting in higher predicted concentrations.

3. Poor liner contact was assumed in the calculation of the landfill vertical seepage rate, resulting in a higher seepage rate. A more conservative model is created by using a higher seepage rate through the liner. Section 2.5 discusses the Construction Quality Assurance Program, which details specifications for liner installation. Good contact between the 60-mil HDPE liner and recompacted soil liner is expected at the site, making the poor liner contact assumption conservative.

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4. Adsorption was conservatively not applied to the groundwater model. Adsorption can play a significant role in retarding the migration of numerous constituents in groundwater. Not using adsorption in the model results in a higher predicted concentration.

5. Additionally, degradation was conservatively not used in the groundwater model. Degradation can play a significant role in reducing the migration of numerous constituents in groundwater. Not using degradation in the model results in a higher predicted concentration.

The results of the computer model (including the conservative estimates and assumptions mentioned above) demonstrate that development of the proposed landfill is protective of the public health, safety, and welfare.

Summary of Findings

The findings of this GIE indicate that the proposed design of the Site 2 East Expansion, incorporated into the site specific geology and hydrogeology, will be safe and protect the public health, safety, and welfare. The results of the GIE demonstrate that the proposed landfill will not adversely impact the groundwater quality at or beyond the edge of the zone of attenuation (ZOA) within 100 years of closure of the landfill.

Proposed Landfill Evaluation

The potential impact from the proposed landfill was evaluated by first developing a conceptual model of the site stratigraphy and hydrogeologic conditions, and then assigning physical characteristics and engineering properties to the principal material types to be included as model input parameters for the conceptual model. The model was then used to evaluate the site hydrogeologic conditions after development of the landfill and site closure. The model considered the properties and physical conditions most likely to represent expected site conditions. Conservative assumptions were used in the modeling. The results of the model were evaluated at the base of the Wadsworth Formation prior to reaching the Shallow Drift Aquifer (uppermost aquifer) and the ZOA.

The findings of the model evaluation are as follows:

1. None of the constituents analyzed as part of the model will have an impact on the groundwater quality of the Shallow Drift Aquifer (Uppermost Aquifer) under the IEPA modeling criteria;

2. The representative maximum predicted groundwater concentrations represent the results of the models when taking into account the proposed landfill design, site hydrogeologic conditions, and conservative modeling assumptions; and

3. The proposed landfill is located and designed so as to protect the public health, safety, and welfare.

Groundwater Impact Evaluation Approach

This GIE was performed following the approach outlined below:

1. A conceptual site hydrogeologic model was developed and the pertinent landfill design details were identified;

2. Applicable Groundwater Quality Standard (AGQS) values were obtained from the June 5, 2009 Permit Modification No. 72 (No. 1995-343-LFM) for Site 2. The AGQS values have been used to evaluate the results of the GIE. Leachate concentrations were also obtained from Site 2. The AGQS values and leachate concentrations from Site 2 are representative of conditions that would be expected for the proposed expansion;

3. A modeling program (POLLUTE) which adequately simulates the varying hydrogeologic conditions at the site for both advective and chemical transport was selected;

4. The potential for advective and chemical transport at the site was modeled. Site and chemical specific data were used whenever possible. When site or chemical specific data were not available, data from published technical literature, which were conservative yet applicable to the site conditions, were used;

5. The groundwater model was used to generate groundwater concentration prediction factors at different distances and times;

6. Predicted concentration versus time and distance graphs were generated;

7. Sensitivity analyses were performed to evaluate contaminant transport model results to variations in model input parameters; and

8. The model predicted groundwater concentrations were compared to the lowest reported AGQS value for each constituent in order to evaluate the results of the GIE.

Landfill Design Considerations

Landfill design features must be considered prior to developing the conceptual model and establishing model input values. The landfill design features considered in the GIE include the final cover design, efficiency of the leachate collection system, and liner design.

As discussed earlier, the landfill will have an inward gradient throughout the 124 year GIE modeling period, with groundwater flowing into the landfill in the unlikely event that a puncture of the liner was to occur. Conservatively, the groundwater model assumed that the landfill will have an outward gradient with 1 foot of leachate head acting on the liner. A 1 foot leachate head was used in the calculation of the landfill vertical seepage rate, resulting in higher predicted concentrations.

Leachate Quality Characterization and Groundwater Quality Standards

Leachate Quality Characterization

Leachate characteristics established for existing Site 2 are expected to be similar for the proposed Site 2 East Expansion. The leachate quality data established for Site 2 was used in the model predictions. A summary of the leachate data for the existing landfill is included on Table 2.7-2 of this Section.

Groundwater Quality Standards

Applicable Groundwater Quality Standard (AGQS) values were obtained from the June 5, 2009 Permit Modification No. 72 (No. 1995-343-LFM) for Site 2. The AGQS values have been used to evaluate the results of the GIE. The AGQS values are provided in the model prediction table (Table 2.7-2).

Groundwater Impact Evaluation Model

After reviewing the hydrogeologic setting and proposed design of the Site 2 East Expansion, it was determined that contaminant transport would be modeled vertically through the liner system to the base of the Wadsworth Formation prior to reaching the Shallow Drift Aquifer (uppermost aquifer). A one dimensional POLLUTE model assessing the liner system and Wadsworth Formation as possible migration pathways was created for the proposed landfill (Figure 2.7-1).

The model input will be discussed in greater detail in the Model Input section later in this report. The Model Input section will also provide a more detailed discussion of how site specific design was incorporated into the computer model selected for use for this GIE.

Sensitivity analyses were performed on the model to identify the effect of changes on the model input parameters on the model predicted representative maximum Groundwater Concentration Prediction Factor (GCPF). Further explanation and the results of these sensitivity analyses are located in the Sensitivity Analysis section of this report.

Conversion of Conceptual Model to Mathematical Model

The potential transport mechanisms that may occur at the subject site for the various layers include advection, mechanical dispersion, and diffusion. For intact material, these transport mechanisms are represented by the following one dimensional flow equation (Rowe and Booker, 1990):

$$n\frac{\partial c}{\partial t} = nD\frac{\partial^2 c}{\partial z^2} - V_a\frac{\partial c}{\partial z} - \rho K\frac{\partial c}{\partial t} - \lambda c \qquad \text{(Equation 1)}$$

where:

c = concentration of contaminant at depth z at time t
n = porosity of soil at depth z
ρ = dry density of soil at depth z
K = distribution coefficient at depth z
D = Coefficient of hydrodynamic dispersion at depth z
V_a = nv = Darcy Velocity
v = groundwater (seepage) velocity at depth z
λ = constituent degradation constant

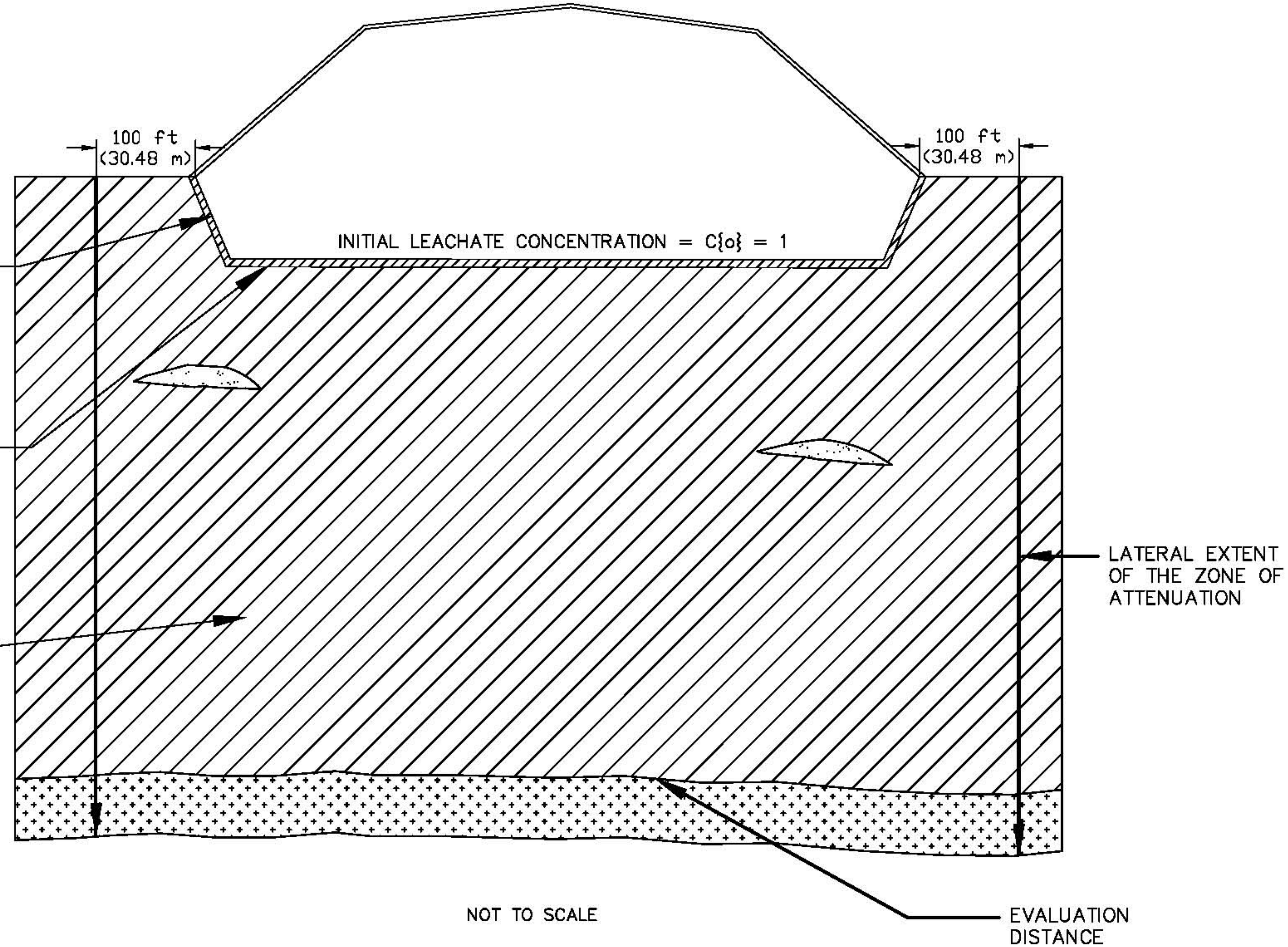
The solution of the Equation 1 yields both the temporal and the spatial distribution of predicted concentrations due to the leachate migration rate. The above equation incorporates the various transport mechanisms discussed with the conceptual model.

Rowe and Booker (1987) proposed a semi-analytical solution to the above mentioned groundwater flow equation governing advective and chemical transport (Laplacean and Talbot

HDPE GEOMEMBRANE – LAYER 1
TOTAL THICKNESS – 0.0015 m
D_v – 3.0×10^{-5} m^2/yr
POROSITY – 1
DISTRIBUTION COEFF. – 0
DEGRADATION – 0
DENSITY – 940 kg/m^3
V_v – 3.08×10^{-4} m/yr

RECOMPACTED COHESIVE SOIL LINER – LAYER 2
TOTAL THICKNESS – 1.524 m
D_v – 0.019 m^2/yr
POROSITY – 0.25
DISTRIBUTION COEFF. – 0
DEGRADATION – 0
DENSITY – 2,032.7 kg/m^3
V_v – 3.08×10^{-4} m/yr

WADSWORTH FORMATION – LAYER 3
TOTAL THICKNESS – 9.88 m
D_v – 0.019 m^2/yr
POROSITY – 0.25
DISTRIBUTION COEFF. – 0
DEGRADATION – 0
DENSITY – 2,032.7 kg/m^3
V_v – 3.08×10^{-4} m/yr



LEGEND

- RECOMPACTED COHESIVE SOIL LINER
- WADSWORTH FORMATION
- INTRA – TILL SEDIMENTS
- SHALLOW DRIFT AQUIFER

REV. NO.	DATE	DESCRIPTION

VEOLIA ENVIRONMENTAL SERVICES

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VEOLIA E.S. ZION LANDFILL SITE 2 EAST EXPANSION
ZION, ILLINOIS

FIGURE 2.7-1
GROUNDWATER IMPACT EVALUATION
CONCEPTUAL MODEL

DRAWN BY:	APD	APPROVED BY:	DJD	PROJ. NO.:	122150	DATE:	JULY 2009

T:\AutoCAD\Projects\122150\dwg\Geology\FIGURE 2.7-1.dwg 6/25/2009 3:02:34 PM CDT inversion schemes). These mathematical procedures require the subsurface to be modeled in separate layers. Each layer can have different physical properties. The theory behind the above equation and its solution technique can be found in Rowe and Booker (1987), and Rowe and Booker (1985, 1986, 1987, 1988).

Transport phenomena in the subsurface model layers is simulated using the groundwater transport model POLLUTE (Rowe et. al., 1990). POLLUTE was developed based on the semi-analytical solution to Equation 1. This program assumes that transport phenomena is governed by Equation 1.

The data input for POLLUTE is setup in such a way that it acquires all the input parameters, performs calculations for individual transport processes, and then uses the semi-analytical solution for the above mentioned transport equation to yield predicted concentrations at specified times and distances.

The conceptual model indicates that the HDPE, recompacted soil liner, and Wadsworth Formation are relatively uniform. Due to the relative uniform variables, a one dimensional model such as POLLUTE can accurately predict potential transport. The use of representative site specific parameters and incorporating landfill design and post-development conditions in modeling more closely simulates actual conditions in the field with respect to the groundwater flow. Therefore, a formal groundwater flow calibration process is not required. Additional discussion about the model suitability can be found in the Model Reliability section.

Calculating Predicted Groundwater Concentrations

An initial leachate concentration value of one (1) was used in the model. This value is not meant to represent a specific concentration for a specific constituent. The value represents a unit concentration of any constituent in the leachate. The results from the model can be used to predict the concentration in the groundwater for any leachate constituent by multiplying the model result for any given distance and time by the established initial leachate concentration. This concept is expressed as the following formula:

$$PGC_{tx} = GCPF_{tx} * C_o \qquad \text{(Equation 2)}$$

where:

PGC_{tx} = Predicted Groundwater Concentration at t years and x meters from the edge of waste;

$GCPF_{tx}$ = Groundwater Concentration Prediction Factor at t years and x meters. The model result, expressed as a fraction, is used to predict the concentration of any particular constituent in the groundwater; and

C_o = Established Leachate concentration of the constituent of concern.

Interpretation of POLLUTE Model Results

In order to evaluate the design and hydrogeologic setting of the Site 2 East Expansion, the leachate concentrations and the appropriate minimum AGQS values developed for Site 2 were used in conjunction with the groundwater concentration prediction factor obtained from the GIE model. A discussion of the results of the POLLUTE model is provided later in this section.

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GIE Model Input

The following information documents the assumptions and values used for the model. The model represents the anticipated site conditions for the design and hydrogeologic setting of the proposed Site 2 East Expansion. The assumptions and values are based on the actual design and CQA plan proposed in this application and the information obtained from the hydrogeologic investigation (Section 2.2). When site specific values were not available, appropriate and conservative values from literature or values recommended by the IEPA were used.

Model Input

POLLUTE requires values for the input parameters identified in Table 2.7-1. The sources of the assigned parameter values for this GIE are described as follows. To the extent possible, site or chemical specific values were used. As previously mentioned, when site or chemical specific parameters were not available, appropriate values were obtained from published literature or by values recommended by the IEPA. In general, the input parameter values assigned for use in this GIE were intentionally biased when site-specific values were not available, to result in a higher predicted groundwater concentration at the evaluation distance to conform to IEPA conservative approaches. An example of a "conservative" value is using an adsorption coefficient, K_d, equal to zero for constituents that would readily be adsorbed to the liner material.

All model input must have consistent units. Each of the model input parameters are discussed briefly in the following paragraphs. Documentation for model input parameters is included within Appendix P.

Model Length

As discussed earlier, three (3) layers will be modeled at the site: a 60-mil HDPE geomembrane liner, a 5-foot recompacted cohesive soil liner (1.0 x 10^{-7} cm/sec), and approximately 32.4 feet (9.88 m) of the Wadsworth Formation (extending from the base of liner system to the base of the Wadsworth Formation). Because the model predicts contaminant transport out of the liner system and vertically to the base of the Wadsworth Formation, the model length is the sum of the liner thickness and the distance to the base of the Wadsworth Formation. The HDPE is 0.0015 m thick and the recompacted clay liner is 1.524 m thick, resulting in a total liner system thickness of 1.5255 m. The total model length is 11.4055 m. Although the model has been set up assuming an infinite bottom boundary, the model was evaluated at the base of the Wadsworth Formation (11.4055 m).

Initial Leachate Concentration

The initial leachate concentration input used was one (1). This value is unitless because it represents unit leachate concentration of any given constituent. Therefore, the model results represent a fraction of the initial leachate concentration for any particular constituent.

Number of Layers

As discussed above, three layers will be modeled at the site: a 60-mil HDPE geomembrane liner, a 5-foot recompacted cohesive soil liner (1.0 x 10^{-7} cm/sec), and approximately 32.4 feet (9.88 m) of the Wadsworth Formation (Figure 2.7-1). POLLUTE also allows a layer to be subdivided so that the predicted concentration distribution within a layer can be evaluated.

TABLE 2.7-1 POLLUTE MODEL INPUT PARAMETER VALUES SITE 2 EAST EXPANSION			
Parameter	**Value**	**Notes**	**Data**
Model Length (L)(m)	11.4055	Total Length of Model including the HDPE, Recompacted Cohesive Soil Liner, and Thickness of Clay Below the Recompacted Cohesive Soil Liner	1,2
Initial Leachate Concentration (Co)	1	Unit Leachate Concentration	2
Number of Layers	3	Total Number of Modeled Layers	1,2
Modeling Period (years)	124	24 Years Active Life Plus 100 Years Past Closure.	2,3
TALBOT PARAMETERS			
TAU	7	Talbot Parameters for the Numerical Inversion of the Laplace Transform	2
Sigma	0		2
RNU	2		2
N	20		2
LAYER 1 - 60-mil HDPE Geomembrane Liner			
Sublayers	1	Model Parameter	2
Thickness (b) (m)	0.0015	Design Specification	1,2
Porosity (n)	1	Assume all flow through pinholes	1,2
Adsorption Coefficient (K) (Kg/m^3)	0.0	No Adsorption Modeled	2,3
Degradation (λ)	0.0	No Degradation Modeled	2,3
Density (ρ) (Kg/m^3)	940	HDPE Manufacturer's Specification	1,2
Vertical Darcy Velocity (m/yr)	3.08×10^{-4}	Assuming Outward Gradient	1,2
Coeff. of Hydrodynamic Dispersion (D) (m^2/yr)	3.0×10^{-5}	$D = D^*$ (Due to the low seepage rate, movement will be dominated by diffusion)	1,2

TABLE 2.7-1 (CONTINUED) POLLUTE MODEL INPUT PARAMETER VALUES SITE 2 EAST EXPANSION			
Parameter	**Value**	**Notes**	**Data**
LAYER 2 - Recompacted Cohesive Soil Liner			
Sublayers	5	Model Parameter	2
Thickness (b) (m)	1.524	Design Specification	1,2
Porosity (n)	0.25	Average Porosity from Laboratory Results for the Wadsworth Formation	1,2
Adsorption Coefficient (K) (Kg/m^3)	0.0	No Adsorption Modeled	2,3
Degradation (λ)	0.0	No Degradation Modeled	2,3
Density (ρ) (Kg/m^3)	2,032.7	Value Obtained from Laboratory Results for the Wadsworth Formation	1,2
Vertical Darcy Velocity (m/yr)	3.08×10^{-4}	Assuming Outward Gradient	1,2
Coeff. of Hydrodynamic Dispersion (D) (m^2/yr)	0.019	$D = D^*$ (Due to the low seepage rate, movement will be dominated by diffusion)	1,2
LAYER 3 - Wadsworth Formation			
Sublayers	32	Model Parameter	2
Thickness (b) (m)	9.88	Model Specification	1,2
Porosity (n)	0.25	Average Porosity from Laboratory Results for the Wadsworth Formation	1,2
Adsorption Coefficient (K) (Kg/m^3)	0.0	No Adsorption Modeled	2,3
Degradation (λ)	0.0	No Degradation Modeled	2,3
Density (ρ) (Kg/m^3)	2,032.7	Value Obtained from Laboratory Results for the Wadsworth Formation	1,2
Vertical Darcy Velocity (m/yr)	3.08×10^{-4}	Assuming Outward Gradient	1,2
Coeff. of Hydrodynamic Dispersion (D) (m^2/yr)	0.019	$D = D^*$ (Due to the low seepage rate, movement will be dominated by diffusion)	1,2

Explanation of Data:

1. Value is based on actual anticipated site conditions
2. Value is required model input parameter
3. Value is conservative value which will result in higher predicted concentrations than the actual anticipated site conditions

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The HDPE geomembrane liner, recompacted cohesive soil liner, and Wadsworth Formation were divided into 1, 5, and 32 sublayers, respectively.

Modeling Period

The modeling period is the expected life of the landfill plus 100 years after closure. The expected life of the landfill has been conservatively estimated to be approximately 24 years, resulting in a modeling period of 124 years.

Talbot Parameters

POLLUTE uses a Laplace transform to find the solution to the advection-dispersion equation. The numerical inversion of the Laplace transform depends on the Talbot parameters. The model provides default values for the Talbot parameters or they can be selected by the user. The default Talbot parameters were used in this groundwater model.

Boundary Conditions

POLLUTE requires the specification of an upper and lower boundary condition. The top boundary condition typically represents the landfill as a potential source. When modeling the landfill as a surface boundary, the concentration of each constituent in leachate can be assumed to be constant or a specific mass can be assumed to be present. Assuming a specific mass results in a decreasing source concentration over time, which would most accurately represent the fact that leachate concentrations in landfills with leachate collection and removal systems will gradually decrease over time. However, a constant concentration was assumed as it results in conservative model results.

The lower boundary condition was specified as an infinite bottom layer. This boundary condition assumes that horizontal flow can continue to any distance, which allows for realistic analysis of conditions at the base of the Wadsworth Formation.

Advective (Darcy) Velocity

POLLUTE requires the input of a Darcy velocity, which is calculated across the complete length of the groundwater model. Table 2.7-1 lists the Darcy velocity value for the model. The Darcy velocity was set equal to the calculated outward seepage rate of 3.08×10^{-4} m/yr. The seepage rate was calculated using an equation derived by Giroud and Bonaparte (1989). This equation and value (3.08×10^{-4} m/yr) have been accepted by the Illinois Environmental Protection Agency.

Hydrodynamic Dispersion Coefficient

POLLUTE requires the input of a hydrodynamic dispersion coefficient for each layer. The hydrodynamic dispersion coefficient is calculated by the following equation:

$$D = D^* + av \qquad \text{(Equation 3)}$$

where,

D	=	the hydrodynamic dispersion coefficient (m^2/yr),
a	=	the dispersivity (m),
v	=	the groundwater seepage velocity (m/yr),
D*	=	the effective diffusion coefficient (m^2/yr).

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Tables 2.7-1 lists the model input dispersion coefficient values. The dominant transport mechanism for the HDPE and recompacted cohesive soil liner, and Wadsworth Formation is diffusion due to the low outward seepage rate (3.08 x 10^{-4} m/yr). The diffusion rate in the clay liner and Wadsworth Formation will be greater than the conservative seepage rate out of the landfill. An effective diffusion coefficient (permeation rate) of 3.0 x 10^{-5} m^2/yr (Rowe, Quigley, Brachman, and Booker, 2004) was used for the 60-mil HDPE geomembrane liner. An input of 0.019 m^2/yr (Rowe, Quigley, Brachman, and Booker, 2004) was used to represent the effective diffusion coefficient in the 5-foot recompacted cohesive soil liner and Wadsworth Formation. Documentation of the Hydrodynamic Dispersion Coefficients is provided in Appendix P.

Porosity and Dry Density Input

Table 2.7-1 lists the porosity and dry density values for the model layers. The porosity of the 60-mil HDPE geomembrane liner was assumed to be 1 with all flow occurring through the pinholes in the liner. The density of the HDPE liner was obtained from manufacturer's specifications.

The porosity value for the recompacted cohesive soil liner and Wadsworth Formation (0.25) was obtained from laboratory data for the Wadsworth Formation, which has been provided in Section 2.2 of this Application, and has been included in Appendix P. The clay from the Wadsworth Formation will be used for construction of the recompacted cohesive soil liner. Density values for the recompacted cohesive soil liner and Wadsworth Formation were also obtained from site specific laboratory data.

Adsorption Coefficient

The adsorption coefficient (K_d) is used to simulate retardation of constituents in the subsurface. The adsorption coefficient is specific to each particular compound and the geologic material.

Although adsorption can play a significant role in retarding the migration of numerous constituents in groundwater, it is conservatively assumed that the adsorption coefficients are zero.

Degradation

Degradation is used to simulate degradation of constituents in the subsurface. Degradation is specific to each particular compound.

Although degradation can play a significant role in reducing the migration of numerous constituents in groundwater, it is conservatively assumed that degradation is not present.

Model Evaluation Distance

The model evaluation distance is not a model input parameter. However, this distance is needed in order to evaluate the results of the GIE since the model only provides results for specified distances. The model was evaluated at the base of the Wadsworth Formation, a distance of 11.4055 m.

Model Results

The GIE was completed to evaluate the anticipated site conditions based upon the hydrogeology and the proposed designs, the CQA plan, the operations, and the post-closure care of the facility. The results of the GIE, as discussed below, demonstrate that the landfill will not have an adverse impact on groundwater quality at the ZOA for 100 years after closure of the landfill.

Anticipated Site Conditions Phase

The model output for the Site 2 East Expansion is included in Appendix P. The model predicted representative maximum GCPF for the entire 124 year simulation period at the edge of the zone of attenuation is 1.35×10^{-7}.

As discussed earlier, the model predicted groundwater concentration for each of the constituents can simply be obtained by multiplying the maximum GCPF and the initial leachate concentration corresponding to the respective constituent.

The leachate quality data established at Site 2 was used in conjunction with the groundwater concentration prediction factors to compare the predicted groundwater concentrations at the base of the Wadsworth Formation to the AGQS values in Table 2.7-2. As indicated in Table 2.7-2, the model predicted groundwater concentrations at the base of the Wadsworth Formation (prior to the ZOA) do not exceed the AGQS for each respective constituent at the proposed Site 2 East Expansion.

Thus, the proposed landfill design and site hydrogeologic characteristics are such that there will be no adverse impact on groundwater quality in the Shallow Drift Aquifer (Uppermost Aquifer). Expected concentrations in the groundwater will actually be lower than those predicted in the GIE because of the overly conservative nature of the model.

Concentration versus time and depth plots for the baseline model are presented in Appendix P.

Sensitivity Analysis

As discussed in the Model Input section, many of the model input parameters were site specific. The baseline model used representative values from these site specific parameters. As discussed in the Model Results section and shown in Tables 2.7-2, model predicted GCPF values and thus groundwater concentrations were noted at the base of the Wadsworth Formation prior to the zone of attenuation. Accordingly, the sensitivity analysis focused on the effect of changes in baseline model input parameters on the model predicted representative maximum GCPF at the base of the Wadsworth Formation. The sensitivity analyses are provided in Appendix P. Justification for the variation used in the sensitivity analyses is discussed as follows. A table at the front of the sensitivity analyses summarizes the sensitivity analyses performed on the baseline POLLUTE model.

Coefficient of Hydrodynamic Dispersion

The coefficient of hydrodynamic dispersion of the HDPE (3.0×10^{-6} m²/yr) was increased and decreased by 25%. This value has been derived from laboratory testing. Therefore, a 25% change is considered conservative and will result in a satisfactory sensitivity evaluation of this parameter. In the 5-foot recompacted clay liner and the Wadsworth Formation, the baseline value used for the coefficient of hydrodynamic dispersion was 0.019 m^2/yr, which was

TABLE 2.7-2
Comparison of Model Predicted Results for the Shallow Drift Aquifer
Veolia E.S. Zion Landfill Site 2 East Expansion

Parameter	Units	Landfill[1] Leachate Data	AGQS	Model Predicted Groundwater Concentration at the Zone of Attenuation	Does the Model Predict an Exceedence of the AGQSs for the Existing Landfill?
Indicator Parameters					
Ammonia-Nitrogen	mg/L	377.89	0.60	5.10E-05	NO
Chloride	mg/L	1,346.85	12.0	1.82E-04	NO
Cyanide	mg/L	3.4	10.0	4.59E-07	NO
Fluoride	mg/L	35	1.86	4.73E-06	NO
Nitrate-Nitrogen	mg/L	1.31	0.50	1.77E-07	NO
Oil (Hexane Soluble)	mg/L	3.100	14.0	4.19E-04	NO
Phenols	mg/L	1.229	0.01	1.66E-07	NO
Sulfate	mg/L	206.634	9.7	2.79E-05	NO
Total Metals					
Aluminum	mg/L	8.85	173.0784	1.19E-06	NO
Antimony	mg/L	0.02	0.006	2.70E-09	NO
Arsenic	mg/L	0.0418	0.0062	5.64E-09	NO
Barium	mg/L	0.673	0.248	9.09E-08	NO
Beryllium	mg/L	0.024	0.004	3.24E-09	NO
Boron	mg/L	5.052	0.574	6.82E-07	NO
Cadmium	mg/L	0.15	0.01	2.03E-08	NO
Calcium	mg/L	462.345	300.0	6.24E-05	NO
Chromium	mg/L	0.0605	0.27	8.17E-09	NO
Cobalt	mg/L	0.27	0.1	3.65E-08	NO
Copper	mg/L	0.048	0.04	6.48E-09	NO
Iron	mg/L	159.857	0.992	2.16E-05	NO
Lead	mg/L	0.36	0.02	4.86E-08	NO
Magnesium	mg/L	333.187	140.0	4.50E-05	NO
Manganese	mg/L	3.752	0.063	5.07E-07	NO
Mercury	mg/L	0.00037	0.0002	5.00E-11	NO
Nickel	mg/L	0.331	0.119	4.47E-08	NO
Phosphorous	mg/L	1.483	1.59	2.00E-07	NO
Potassium	mg/L	272.1	11.0	3.67E-05	NO
Selenium	mg/L	0.0824	0.005	1.11E-08	NO
Silver	mg/L	0.0059	0.05	7.97E-10	NO
Sodium	mg/L	998.673	110.0	1.35E-04	NO
Thallium	mg/L	0.0079	0.0092	1.07E-09	NO
Vanadium	mg/L	0.093	0.075	1.26E-08	NO
Zinc	mg/L	4.894	0.032	6.61E-07	NO

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TABLE 2.7-2 (Continued)
Comparison of Model Predicted Results for the Shallow Drift Aquifer
Veolia E.S. Zion Landfill Site 2 East Expansion

Parameter	Units	Landfill[1] Leachate Data	AGQS	Model Predicted Groundwater Concentration at the Zone of Attenuation	Does the Model Predict an Exceedence of the AGQSs for the Existing Landfill?
Volatile Organic Compounds					
Acetone	ug/L	11,040	100.0	1.49E-03	NO
Acrolein	ug/L	< 25	25.0	3.38E-06	NO
Acrylonitrile	ug/L	< 70	200.0	9.45E-06	NO
Benzene	ug/L	11	5.0	1.49E-06	NO
Beta-BHC	ug/L	< 0.05	0.1	6.75E-09	NO
Bromobenzene	ug/L	< 5	5.0	6.75E-07	NO
Bromochloromethane (Chlorobromomethane)	ug/L	< 5	1.0	6.75E-07	NO
Bromodichloromethane	ug/L	< 5	5.0	6.75E-07	NO
Bromoform (Tribromomethane)	ug/L	< 5	10.0	6.75E-07	NO
Bromomethane (Methyl Bromide)	ug/L	< 10	10.0	1.35E-06	NO
2-Butanone (Methyl Ethyl Ketone)	ug/L	8,734	10.0	1.18E-03	NO
n-Butylbenzene	ug/L	< 5	5.0	6.75E-07	NO
sec-Butylbenzene	ug/L	< 5	5.0	6.75E-07	NO
tert-Butylbenzene	ug/L	< 5	5.0	6.75E-07	NO
Carbon Disulfide	ug/L	< 5	5.0	6.75E-07	NO
Carbon Tetrachloride	ug/L	< 1	5.0	1.35E-07	NO
Chlorobenzene	ug/L	< 1	5.0	1.35E-07	NO
Chloroethane (Ethyl Chloride)	ug/L	25	10.0	3.38E-06	NO
2-Chloroethyl Vinyl Ether	ug/L	23.6	8.8	3.19E-06	NO
Chloroform (Trichloromethane)	ug/L	8.4	5.0	1.13E-06	NO
Chloromethane (Methyl Chloride)	ug/L	< 10	10.0	1.35E-06	NO
o-Chlorotoluene	ug/L	< 5	1.0	6.75E-07	NO
p-Chlorotoluene	ug/L	< 5	5.0	6.75E-07	NO
Chlorodibromomethane (Dibromochloromethane)	ug/L	< 5	5.0	6.75E-07	NO
Dibromomethane (Methylene Bromide)	ug/L	< 10	10.0	1.35E-06	NO
1,2-Dibromo-3-Chloropropane (DBCP)	ug/L	< 5	25.0	6.75E-07	NO
cis-1,2-Dichloroethylene	ug/L	82	5.0	1.11E-05	NO
trans-1,2-Dichloroethylene	ug/L	< 5	1.0	6.75E-07	NO
1,2-Dichloroethane	ug/L	< 1	5.0	1.35E-07	NO
1,2-Dichloropropane (Propylene Dichloride)	ug/L	< 5	5.0	6.75E-07	NO
Dichlorodifluoromethane	ug/L	24	5.0	3.24E-06	NO
1,1-Dichloroethane	ug/L	24	5.0	3.24E-06	NO
1,1-Dichloroethylene	ug/L	< 1	5.0	1.35E-07	NO
1,1-Dichloropropene	ug/L	< 5	5.0	6.75E-07	NO
1,3-Dichloropropane	ug/L	< 5	5.0	6.75E-07	NO

TABLE 2.7-2 (Continued)
Comparison of Model Predicted Results for the Shallow Drift Aquifer
Veolia E.S. Zion Landfill Site 2 East Expansion

Parameter	Units	Landfill[1] Leachate Data	AGQS	Model Predicted Groundwater Concentration at the Zone of Attenuation	Does the Model Predict an Exceedence of the AGQSs for the Existing Landfill?
trans-1,4-Dichloro-2-Butene	ug/L	< 5	5.0	6.75E-07	NO
2,2-Dichloropropane	ug/L	< 15	15.0	2.03E-06	NO
Dichloromethane (Methylene Chloride)	ug/L	1,800	5.0	2.43E-04	NO
Ethanol	ug/L	130,000	1000.0	1.76E-02	NO
Ethylbenzene	ug/L	60	5.0	8.10E-06	NO
Ethylene Dibromide (EDB)(1,2-Dibromoethane)	ug/L	< 5	0.05	6.75E-07	NO
2-Hexanone (Methyl Butyl Ketone)	ug/L	994	50.0	1.34E-04	NO
Iodomethane (Methyl Iodide)	ug/L	< 10	10.0	1.35E-06	NO
Isopropylbenzene	ug/L	< 5	5.0	6.75E-07	NO
p-Isopropyltoluene	ug/L	5.1	5.0	6.89E-07	NO
4-Methyl-2-Pentanone (Methyl Isobutyl Ketone)	ug/L	847	50.0	1.14E-04	NO
n-Butyl alcohol (1-Butanol)	ug/L	18,000	5000.0	2.43E-03	NO
n-Propanol	ug/L	36,000	1000.0	4.86E-03	NO
2-Propanol	ug/L	23,000	1000.0	3.11E-03	NO
n-Propylbenzene	ug/L	< 5	5.0	6.75E-07	NO
Styrene	ug/L	17	10.0	2.30E-06	NO
1,1,1,2-Tetrachloroethane	ug/L	< 5	5.0	6.75E-07	NO
1,1,2,2-Tetrachloroethane	ug/L	< 5	10.0	6.75E-07	NO
Tetrachloroethylene (Perchloroethylene)	ug/L	380	5.0	5.13E-05	NO
Tetrahydrofuran	ug/L	1,435	20.0	1.94E-04	NO
Toluene	ug/L	206	5.0	2.78E-05	NO
1,2,3-Trichlorobenzene	ug/L	< 5	5.0	6.75E-07	NO
1,2,3-Trichloropropane	ug/L	< 15	15.0	2.03E-06	NO
1,2,4-Trichlorobenzene	ug/L	< 10	10.0	1.35E-06	NO
1,2,4-Trimethylbenzene	ug/L	15	5.0	2.03E-06	NO
1,3,5-Trimethylbenzene	ug/L	< 5	5.0	6.75E-07	NO
1,1,1-Trichloroethane (Methylchloroform)	ug/L	20	5.0	2.70E-06	NO
1,1,2-Trichloroethane	ug/L	< 5	5.0	6.75E-07	NO
Trichloroethylene (Trichloroethene)	ug/L	32	5.0	4.32E-06	NO
Trichlorofluoromethane	ug/L	12	5.0	1.62E-06	NO
Vinyl Chloride	ug/L	10	2.0	1.35E-06	NO
Vinyl Acetate	ug/L	< 10	10.0	1.35E-06	NO
Xylenes (total)	ug/L	140	10.0	1.89E-05	NO
m-Xylene	ug/L	56	10.0	7.56E-06	NO
o-Xylene	ug/L	42	10.0	5.67E-06	NO
p-Xylene	ug/L	56	10.0	7.56E-06	NO

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TABLE 2.7-2 (Continued)
Comparison of Model Predicted Results for the Shallow Drift Aquifer
Veolia E.S. Zion Landfill Site 2 East Expansion

Parameter	Units	Landfill[1] Leachate Data	AGQS	Model Predicted Groundwater Concentration at the Zone of Attenuation	Does the Model Predict an Exceedence of the AGQSs for the Existing Landfill?
p-Cresol (4-methylphenol)	ug/L	6,600	10.0	8.91E-04	NO
o-Dichlorobenzene (1,2-Dichlorobenzene)	ug/L	< 10	10.0	1.35E-06	NO
m-Dichlorobenzene (1,3-Dichlorobenzene)	ug/L	< 5	5.0	6.75E-07	NO
p-Dichlorobenzene (1,4-Dichlorobenzene)	ug/L	12	5.0	1.62E-06	NO
Diethyl Phthalate	ug/L	28	10.0	3.78E-06	NO
Dimethyl Phthalate	ug/L	< 10	10.0	1.35E-06	NO
Di-n-butyl Phthalate	ug/L	< 10	10.0	1.35E-06	NO
Hexachlorobutadiene	ug/L	< 10	10.0	1.35E-06	NO
Hexachlorocyclopentadiene	ug/L	< 54	50.0	7.29E-06	NO
Isophorone	ug/L	< 50	10.0	6.75E-06	NO
Naphthalene	ug/L	21	5.0	2.84E-06	NO
Pentachlorophenol	ug/L	< 50	1.0	6.75E-06	NO
Pesticides Method 8270B					
Alachlor	ug/L	0.090	2.0	1.22E-08	NO
Atrazine	ug/L	< 3	3.0	4.05E-07	NO
Parathion	ug/L	< 10	10.0	1.35E-06	NO
Pesticides Method 8318					
Aldicarb	ug/L	< 3	3.0	4.05E-07	NO
Carbofuran	ug/L	< 8	40.0	1.08E-06	NO
Chlordane	ug/L	< 0.5	2.0	6.75E-08	NO
Herbicides					
2,4-D	ug/L	13	10.0	1.76E-06	NO
2,4,5-TP (Silvex)	ug/L	< 1	2.0	1.35E-07	NO
Dalapon	ug/L	< 20	20.0	2.70E-06	NO
Dinoseb	ug/L	< 1	1.0	1.35E-07	NO
Picloram	ug/L	< 50	50.0	6.75E-06	NO
Simazine	ug/L	< 1	2.0	1.35E-07	NO
Pesticides Method 8081					
Aldrin	ug/L	< 1	1.0	1.35E-07	NO
PCBs	ug/L	1.3	0.5	1.76E-07	NO
Lindane (gamma-BHC)	ug/L	0.057	0.2	7.70E-09	NO
DDT	ug/L	< 10	10.0	1.35E-06	NO
Dieldrin	ug/L	< 10	10.0	1.35E-06	NO

TABLE 2.7-2 (Continued)
Comparison of Model Predicted Results for the Shallow Drift Aquifer
Veolia E.S. Zion Landfill Site 2 East Expansion

Parameter	Units	Landfill[1] Leachate Data	AGQS	Model Predicted Groundwater Concentration at the Zone of Attenuation	Does the Model Predict an Exceedence of the AGQSs for the Existing Landfill?
Endothall	ug/L	< 40	50.0	5.40E-06	NO
Endrin	ug/L	< 0.1	0.2	1.35E-08	NO
Heptachlor	ug/L	< 0.05	0.4	6.75E-09	NO
Heptachlor epoxide	ug/L	< 0.05	0.2	6.75E-09	NO
Methoxychlor	ug/L	< 0.5	40.0	6.75E-08	NO
Toxaphene	ug/L	< 1	3.0	1.35E-07	NO

Notes:
1) Leachate data was collected at the existing Site 2 Landfill from 4th Quarter 1998 through 1st Quarter 2009.
2) AGQS values were obtained from the existing Site 2 Landfill.
3) ug/L = micrograms per Liter (parts per billion)
4) mg/L = milligrams per Liter (parts per million)

obtained from published literature (Rowe, Quigley, Brachman, and Booker, 2004) as provided in Appendix P. This value is conservative because it is the diffusion coefficient for chloride through clay, which is considered to have a high ability to diffuse relative to other leachate constituents, and is not easily retarded by clay. As the baseline value is set at the maximum of the diffusive range, it was determined that a 25% change would be considered conservative and will result in a satisfactory sensitivity evaluation of this parameter.

Porosity

The porosity of the 5-foot recompacted clay liner and the Wadsworth Formation that was used for the baseline model (0.25) is the site specific average of the porosity from laboratory data for the Wadsworth Formation, which was provided in the Hydrogeologic Investigation (Section 2.2). The clay from the Wadsworth Formation will be used for construction of the recompacted cohesive soil liner. Due to the availability of site specific data, it was possible to obtain a range of values (0.21 to 0.29) from the samples tested. As such, sensitivity analyses were run using both the maximum and minimum porosity expressed in the laboratory results for the Wadsworth Formation. As a result, it was determined that a maximum and minimum change of porosities for the 5-foot recompacted clay liner and the Wadsworth Formation would result in a satisfactory sensitivity evaluation of this parameter.

It should be noted that the porosity of the HDPE was not changed because it is at the maximum recommended value suggested by the POLLUTE User's Guide (Rowe, Booker, and Fraser, 1994). This value is documented in Appendix P.

Layer Thickness

The average thickness of the Wadsworth Formation was calculated to be approximately 32.4 feet (9.88 m) between the base of the liner system and the base of the Wadsworth Formation prior to the Shallow Drift Aquifer (Uppermost Aquifer). The minimum and maximum thickness of the Wadsworth Formation between the base of the liner system and the base of the Wadsworth Formation will be 18.1 feet (5.52 m) and 43.9 feet (13.38 m), respectively. It was determined that sensitivity runs that used the minimum and maximum thickness of the Wadsworth Formation would result in a satisfactory sensitivity evaluation of this parameter.

The thickness of the 5-foot recompacted clay liner and HDPE will not vary. These layers will be installed / constructed and will be inspected in accordance with the CQA plan.

Darcy Velocity

For the baseline model, the vertical Darcy velocity was conservatively calculated with 1 foot of leachate head and poor liner conditions. This value is already overly conservative, but was increased by one order of magnitude for the sensitivity analysis. As a result, it was determined that a Darcy velocity increased by one order of magnitude would result in a satisfactory sensitivity evaluation of this parameter.

As discussed in the Model Results section, the model predicted representative maximum GCPF for the uppermost aquifer corresponds to the time period of 124 years. All the sensitivity analysis runs were carried out corresponding to a time period of 124 years.

The 'Summary of Results - Sensitivity Analysis' table in Appendix P includes all of the sensitivity analyses runs.

Sensitivity analysis of the above mentioned parameters resulted in satisfactory results for all of the sensitivity runs.

Model Reliability

The computer based transport model used in the present GIE is based on rigorous and sound analytical solutions to the advective and chemical transport equations. The equations were specifically derived for the purpose of modeling physical and chemical transport from subsurface waste impoundments. Numerous publications, comprehensive documentation and extensive use of this solution approach indicates the versatility of the model for groundwater impact assessment purposes (Rowe, 1987; Rowe and Booker, 1987; Rowe, 1988; Rowe and Booker, 1989; Rowe and Booker, 1985; Talbot, 1979). Results obtained using this solution approach are comparable to those obtained using other solution approaches to the transport equation (Rowe and Booker, 1990). The inherent soundness of the model gives rise to modeling the physical situation more closely to the actual conditions. This is evident from the results of the model run.

The assumption that advective and chemical transport is governed by a one dimensional advection - dispersion equation within the porous medium readily applies for the present problem as discussed under the transport processes section. The assumption that the individual layer parameters do not vary with the lateral position is reasonable for the model layers under consideration.

Conservativeness of Baseline Model

Site specific data were used for input parameters in the baseline model when possible. When site specific data were not available, appropriate input data was determined based on the extensive knowledge of the site and documented with research literature. These parameters, if they had a high degree of uncertainty, were conservatively estimated. Parameters in this model which had a high degree of uncertainty were conservatively estimated based upon research literature.

GIE Conclusions

This GIE was performed in order to evaluate the proposed Site 2 East Expansion design and site hydrogeologic conditions. The GIE transport model created to evaluate contaminant transport below the proposed Site 2 East Expansion yields groundwater concentration prediction factors, resulting in predicted groundwater concentrations at the base of the Wadsworth Formation (prior to ZOA) that are less than the permitted AGQS values.

The results of this GIE demonstrate that the design features of the proposed facility are effective in protecting groundwater quality in the Shallow Drift Aquifer (Uppermost Aquifer) at the proposed Site 2 East Expansion and that the site hydrogeologic conditions are favorable for the development of a landfill.

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