A-7

Gas Management System Design for SCA Final Cover System

Beech and Bonaparte
engineering p.c.

an affiliate of Geosyntec Consultants

CALCULATION PACKAGE COVER SHEET

Client: Honeywell **Project:** Onondaga Lake SCA Final Cover Design **Project/Proposal #:** GD5497

TITLE OF COMPUTATIONS **GAS MANAGEMENT SYSTEM DESIGN FOR SCA FINAL COVER SYSTEM**

COMPUTATIONS BY:	Signature		09/11/15
	Printed Name and Title	Ray Wu Senior Staff Engineer	DATE
ASSUMPTIONS AND PROCEDURES CHECKED BY:	Signature		09/11/15
	Printed Name and Title	Sowmya Bulusu, P.E. Senior Engineer	DATE
COMPUTATIONS CHECKED BY:	Signature		09/11/15
	Printed Name and Title	Sowmya Bulusu, P.E. Senior Engineer	DATE
COMPUTATIONS BACKCHECKED BY:	Signature		09/11/15
	Printed Name and Title	Ray Wu Senior Staff Engineer	DATE
APPROVED BY:	Signature		05/04/16
	Printed Name and Title	Jay Beech, Ph.D., P.E. Senior Principal	DATE

STATE OF NEW YORK · JOHN F. BEECH · No. 066337 · LICENSED PROFESSIONAL ENGINEER

APPROVAL NOTES:

REVISIONS (Number and initial all revisions)

NO.	SHEET	DATE	BY	CHECKED BY	APPROVAL

Written by:	**Ray Wu**	Date:	**09/11/2015**	Reviewed by:	**Sowmya Bulusu / Jay Beech**	Date:	**09/11/2015**
Client:	**Honeywell**	Project:	**Onondaga Lake SCA Final Cover Design**	Project/ Proposal No.:	**GD5497**	Task No.:	**03**

GAS MANAGEMENT SYSTEM DESIGN FOR SCA FINAL COVER SYSTEM

PURPOSE

The purpose of the analysis presented herein is to: (i) estimate a reasonable range of gas generation rates within the Sediment Consolidation Area (SCA), including in the Debris Management Area (DMA); (ii) evaluate the potential effects of the generated gas on the SCA final cover system; and (iii) if necessary, design a gas management system for the SCA final cover system.

DESIGN CRITERIA

The potential for gas generation from the SCA is evaluated and compared to the calculated maximum allowable gas pressure to achieve an acceptable factor of safety (FS) for final cover veneer stability. As necessary based on the results, a gas control system is designed to maintain gas pressures beneath the geomembrane component of the SCA final cover system at or below acceptable levels.

METHODOLOGY

The procedures presented in this package are used to:

- Estimate a gas generation rate that can be expected within the SCA;
- Perform a simple gas flow balance model to aid in estimating the effect of the generated gas on the final cover system; and
- If required, design a gas management system for the SCA final cover system.

The calculation procedures used consist of the following steps:

- Evaluate the estimated volume of decomposable content in the SCA;
- Estimate annual rate of gas generation within the SCA;
- Use a simple gas flow balance model to aid in evaluating the effect of the generated gas on the final cover system;
- Evaluate the potential effects of gas pressure buildup on the final cover system; and

- Design the layout of a gas management system (if needed), to reduce gas pressure buildup under the geomembrane cover.

Decomposable Content

The dredge material from the lake bottom placed in the SCA is expected to contain only small quantities of organic or decomposable material, mainly consisting of vegetation. Decomposable content of the dredge material is estimated based on testing of the organic content of the material in the lake subsurface and volume of dredge material placed in the SCA, as discussed in the design parameters section of this document. It is noted that the spent carbon bags being disposed of in the SCA do not consist of significant decomposable content, and therefore are not expected to contribute to gas generation.

The DMA is located in the southwestern portion of the SCA and occupies an approximate footprint of 2.3 acres. It is understood that material placed in the DMA includes wood debris, screened debris (decomposable and inert) from dredged material from the lake bottom, wooden piles, and other mixed construction related and vegetative waste. Therefore, the DMA waste is expected to contain higher amounts of decomposable material in comparison to the dredged material in other areas of the SCA.

Gas Generation

Gas (referred to as Landfill Gas or LFG), will be generated within the SCA due to biodegradation of decomposable material. LFG typically consists mainly of methane and carbon dioxide, along with oxygen, nitrogen, and other trace gases. LFG generation is estimated using the United States Environmental Protection Agency (US EPA) Landfill Gas Emissions Model (LandGEM). LandGEM is a Microsoft Excel based model used to estimate quantities of total landfill gas, methane, carbon dioxide, non-methane organic compounds, and individual air pollutants from decomposable waste [USEPA, 2005]. The model equation used in LandGEM is:

$$Q = \sum_{i=1}^{n} \sum_{j=0.1}^{1} \propto kL_0 \left[\frac{M_i}{10}\right] e^{-kt_{ij}} \qquad (1)$$

where:

Q	=	annual gas generation rate in the year of the calculation;
i	=	1 year time increment;
n	=	(year of the calculation) - (initial year of waste acceptance);

j	=	0.1 year time increment;
α	=	inverse fraction of methane in LFG (typically LFG is assumed 50% methane, therefore $\alpha = 2$);
k	=	methane generation rate constant;
L_0	=	potential methane generation capacity;
M_i	=	mass of waste accepted in the i^{th} year; and
t_{ij}	=	age of the j^{th} section of waste mass M_i accepted in the i^{th} year (decimal years, e.g., 3.2 years).

The total gas generation rate is typically calculated as the sum of gas generated for each type of decomposable material. Values for potential methane generation capacity (L_0) and methane generation rate constant (k) are obtained for each type of decomposable content based on a literature review.

Gas Flow Balance Model

A simple flow balance model is used to evaluate the effects of gas generation on the final cover (i.e., uplift and veneer stability). Generally, generated gas is collected, emitted, oxidized, or stored. A simple gas flow balance model can be described by the following:

- Total Gas Generated (Equation 1)
- Emission to Atmosphere = Gas Generated Prior to Completion of Final Cover
- Diffusion to Atmosphere = Gas Diffused After Completion of Final Cover
- Gas Stored = Gas Generated – Gas Emitted – Gas Collected – Gas Diffused
- Air-Filled Void Space = (Total Volume)(porosity)(1-saturation)
- $$\text{SCA Pressure} = (\text{Initial Pressure})\left(\frac{\text{Cumulative Storage+Air Filled Void Space}}{\text{Air Filled Void Space}}\right) \qquad (2)$$

SCA Pressure Evaluation

Two sources of pressure are anticipated on the SCA final cover:

- Uplift pressure due to gas generation in the SCA (SCA Pressure calculated in Equation 2) if no designated ventilation pathway (active or passive) is available; and
- Downward pressure from the atmosphere and weight of the layers of the SCA final cover above the geomembrane layer.

The gas stored in the SCA is expected to have no detrimental effects on the final cover system if: (i) the internal gas uplift pressure is less than the downward pressure (that includes atmospheric pressure and vertical stress due to the weight of the final cover system); and (ii) the gas uplift pressure does not reduce the FS for final cover veneer stability below 1.5.

The gas flow balance model and SCA pressure evaluation to determine the need for a gas management system is conservatively performed for the dredge material (with lower decomposable content) placed in the SCA. If, based on the evaluation for the SCA a gas management system is required to maintain veneer stability in the SCA, it will be required in the more critical (material with higher decomposable content) DMA as well, and a gas management system will be designed for both SCA and DMA as discussed below.

Gas Management System Design

If the calculated SCA gas pressure is larger than the estimated maximum allowable gas pressure for veneer stability of the final cover, a gas management system will be necessary to relieve the gas pressure buildup under the cover system and maintain veneer stability of the final cover.

Surficial passive gas management systems are typically designed to control and vent gas that may build up under the impermeable layer of the final cover. The gas management systems usually consist of permeable gas venting strips (soils or geosynthetics) under the impermeable final cover layer, which direct gas to vent pipes to be released to the atmosphere.

The spacing of the geosynthetic (geocomposite) gas venting strips and vents are calculated such that the gas pressure buildup under the geomembrane cover is maintained below the maximum allowable pressure for final cover veneer stability. The below equation is used to calculate the distance between the venting strips, as presented by Thiel [1998]:

$$D = \sqrt{\frac{8u_{g-allow}\Psi_g}{\Phi_g \gamma_g}} \quad (3)$$

where:

D	=	distance between venting strips (ft);
$u_{g\text{-allow}}$	=	maximum allowable gas pressure (psf);
Ψ_g	=	gas transmissivity of geocomposite venting layer (ft^2/s);
Φ_g	=	gas flux from underneath the SCA final cover area (ft^3/ft^{2}s); and
γ_g	=	unit weight of the gas (lb/ft^3).

Because there are very limited technical data on gas transmissivity properties of geocomposite material, this parameter is calculated based on the water (hydraulic) transmissivity of the specified geocomposite and properties of the gas and water, using the below equation:

$$\Psi_g = \Psi_w \frac{\mu_w \gamma_g}{\mu_g \gamma_w} \quad (4)$$

where:

Ψ_w	=	hydraulic transmissivity (ft^2/s);
μ_w	=	dynamic viscosity of water (lb$_f$ s/ft^2);
μ_g	=	dynamic viscosity of gas (lb$_f$ s/ft^2); and
γ_w	=	unit weight of water (lb/ft^3).

The width of each strip is calculated to maintain laminar conditions for flow of gas within the geocomposite. Assuming the geocomposite gas venting strips are performing similarly to gas pipes, the Reynolds number (calculated using Equation 5 below) should be less than 2,000.

$$R_e = \frac{\gamma_g V_g l}{\mu_g} \quad (5)$$

where:

R_e	=	Reynolds number (unitless);
V_g	=	velocity of gas flow (ft/s); and
l	=	thickness of geocomposite (ft).

DESIGN PARAMETERS

Engineering data are obtained from site-specific information and engineering tests. Data inputs for each of the parameters identified in the calculation procedure are provided in the following subsections.

Decomposable Content

Information on the volume of dredge material placed in the SCA in 2012, 2013, and 2014 was provided by the Parsons Operations Team. Dredging in Onondaga Lake and sediment transport to the SCA was completed in 2014. The assumed volumes of dredge material placed in the SCA from 2012 to 2014 are presented in the below table.

Year	Volume of dredge material, cy
2012	238,900
2013	910,600
2014	911,800
Total	2,061,300

Based on test data for the subsurface material in the lake bottom provided by Parsons summarized in the package titled *Summary of Subsurface Stratigraphy and Material Properties* prepared by Geosyntec Consultants in December 2009 (as part of the Onondaga Lake In-Lake Waste Deposit (ILWD) Stability project), the organic (decomposable) content of the material ranged between approximately 3 percent and 10 percent, with an average of 5.1 percent (by weight). For design of the SCA gas venting system, the decomposable content is conservatively assumed to be the average plus one standard deviation value of the data, i.e., 8.5 percent (by weight).

The volume of material placed in the DMA is estimated as 37,000 cy based on the SCA liner system grades and existing ground survey information as of December 2014. Based on discussions with Parsons on the type of material placed in the DMA, it is assumed that the DMA material consists of larger quantities of fairly decomposable material compared to the SCA dredge material. Detailed waste composition information for the DMA is not available. Therefore, it is conservatively assumed that up to 80 percent of the volume of material placed in the DMA is a mix of typical vegetative waste (i.e., equal quantities of wood/branches, leaves, and grass). Typical unit weights of 50 pcf, 70 pcf, and 80 pcf are assumed for wood/branches, leaves, and grass, respectively.

Gas Generation

Due to lack of information on the actual types and gas generation characteristics of the decomposable material placed in the SCA, these materials are conservatively assumed to have gas generation properties similar to that of grass. Therefore the methane generation rate constant, k, is assumed to be 0.20 year^{-1} [De la Cruz and Barlaz, 2010] and potential methane generation capacity, L_0, is assumed to be 4,357 ft^3/tons (equivalent to 136 m^3/Mg) [Eleazer et al., 1997].

For the DMA, the decomposable waste is assumed to consist of a mix of vegetative waste (i.e., wood/branches, leaves, and grass) with a methane generation rate constant, k, and potential methane generation capacity, L_0, as presented in the below table.

Parameter	Wood/Branches	Leaves	Grass	Reference
k, yr^{-1}	0.01	0.11	0.20	De la Cruz and Barlaz, [2010]
L_0, ft^3/tons (m^3/Mg)	2,018 (63)	993 (31)	4,357 (136)	Eleazer et al., [1997]

Gas Flow Balance Model

For this calculation, the following assumptions are considered:

- Gas Emitted before SCA final cover system construction = Total generated gas before SCA final cover system construction
- Gas Emitted after SCA final cover system construction = 0 (no gas emitted through the final cover)
- Gas Collected after SCA final cover system construction = 0 (assuming no active/passive gas system)
- Gas Oxidized = 0 (Oxidation of the methane portion of LFG is not considered because this can only occur after methane has entered oxygenated soils, i.e., soils above the geomembrane cover)
- Gas Diffused after SCA final cover construction = 0 (no gas diffused through the final cover)

Based on the above assumptions, the simplified LFG balance model after SCA final cover system construction is:

$$\text{Gas Stored} = \text{Gas Generated}$$

Construction of the final cover system started in 2015 with placement of the leveling layer material. For the purpose of the calculations presented in this package, it is conservatively assumed that the placement of the leveling layer material significantly reduces surface emissions of the gas generated, and all the generated gas in 2015 is stored in the SCA.

The initial pressure in the SCA is assumed to be equal to the atmospheric pressure of one (1) atm. The following table summarizes the additional data used to estimate the air-filled void space of material in the SCA and the SCA gas pressure.

Parameter	Value	Notes
Volume of material placed in the SCA	2,061,300 yd^3	*Based on actual 2012-2014 dredge volumes.*
Saturation	0.80	*The dredge material is pumped as a slurry into the SCA and allowed to dewater within the geotextile tubes. It is noted that a higher value for saturation results in less space available for gas storage (i.e., more conservative), therefore a value of 80 percent (i.e., 0.80) has been modeled for these analyses.*
Porosity	0.65	*Based on data obtained from consolidation testing from the In-Lake Waste Deposit (ILWD) prior to dredging, the porosity of the dredged SOLW ranged from 0.60 to 0.70. For purposes of this calculation package, a value of 0.65 has been assumed.*

SCA Pressure Evaluation

The weight of the final cover is calculated using a typical unit weight of 120 pcf for the 18-inch thick protective soil layer and 6-inch thick vegetative soil layer.

The gas pressure that will result in the final cover system veneer stability FS to be 1.5 is calculated to be 223.9 psf (equivalent to 43.0 inches of water column or 0.11 atm), as presented in the *Maximum Allowable Gas Pressure for Final Cover System Veneer Stability* calculation package.

Gas Management System

For designing the gas management system, it is assumed that geocomposite material specified for use in the SCA final cover system stormwater management on the side slopes will be used for the gas venting strips. As described in the Technical Specifications Section 02735, the proposed geocomposite is 250-mil thick with a minimum measured hydraulic transmissivity of 5.0 x 10^{-4} m^2/s (equivalent to 5.38 x 10^{-3} ft^2/s) [Technical Specifications, Section 02735]. After the use of reduction factors to account for creep (1.2), delayed intrusion (1.1), degradation (1.2), particulate clogging (1.2), and chemical clogging (1.2), and a general safety factor of 2.5, the design hydraulic (water) conductivity, Ψ_w, is calculated to be 8.77 x 10^{-5} m^2/s (9.44 x 10^{-4} ft^2/s).

Dynamic viscosity of water, μ_w, is 2.12 x 10^{-5} $lb_f\ s/ft^2$, and unit weight of water, γ_w, is 62.4 lb/ft^3. Dynamic viscosity and unit weight for the gas is calculated as a weighted average of these properties for methane and carbon dioxide, which are the main constituents of LFG. A typical composition of 50 percent methane and 50 percent carbon dioxide in LFG is assumed for these calculations. The properties for methane and carbon dioxide can be summarized as below:

$\mu_{methane}$ = 2.31 x 10^{-7} $lb_f\ s/ft^2$ and $\gamma_{methane}$ = 0.042 lb/ft^3

$\mu_{carbon\text{-}dioxide}$ = 3.15 x 10^{-7} $lb_f\ s/ft^2$ and $\gamma_{carbon\text{-}dioxide}$ = 0.114 lb/ft^3

COMPUTATIONS AND RESULTS

Calculations and results for each section of the methodology are presented below.

Decomposable Content

Tonnage of decomposable content is calculated using an average unit weight of 86 pcf for dredged material (as described in the calculation package titled "Slope Stability Analyses for SCA Final Cover Design"), with 8.5 percent decomposable content (by weight) in the overall dredge material placed in the SCA (as discussed previously).

Year 2012:

$$238{,}900\ (yd^3) \times 86 \left(\frac{lb}{ft^3}\right) \times 27 \left(\frac{ft^3}{yd^3}\right) \div 2000\ \left(\frac{lb}{tons}\right) \times 0.085 = 23{,}576\ (tons)$$

Year 2013:

$$910{,}600\ (yd^3) \times 86 \left(\frac{lb}{ft^3}\right) \times 27 \left(\frac{ft^3}{yd^3}\right) \div 2000\ \left(\frac{lb}{tons}\right) \times 0.085 = 89{,}863\ (tons)$$

Year 2014:

$$911{,}800\ (yd^3) \times 86 \left(\frac{lb}{ft^3}\right) \times 27 \left(\frac{ft^3}{yd^3}\right) \div 2000\ \left(\frac{lb}{tons}\right) \times 0.085 = 89{,}981\ (tons)$$

As discussed earlier, the decomposable content of the material placed in the DMA is assumed to be 80 percent (by volume), and consist of equal quantities of wood/branches, leaves, and grass. The tonnages for the decomposable material placed in the DMA are calculated based on the approximate volume of the material in the DMA and assumed unit weight for each type of material, as presented in the below table. All the material in the DMA is conservatively assumed to have been placed in 2014.

Material	Volume, cy	Unit Weight, pcf	Tonnage, tons
Wood/Branches	9,866	50	6,660
Leaves	9,866	70	9,324
Grass	9,866	80	10,656
Total	29,600	---	26,640

Gas Generation

The calculated gas generation for the first 50 years after placement of material in the SCA and DMA are presented in Tables 1 and 2, respectively (LandGEM output).

Gas Flow Balance Model

Calculations of the air-filled void space and the SCA Pressure are presented below.

Air-filled Void Space (V_i):

The pressure in the SCA is initially assumed to be equal to one (1) atm. The change in pressure can be calculated using the ideal gas law based on the amount of gas stored in the SCA, as follows:

$$PV = nRT$$

where:

P = pressure (atm);

V = volume (liter, L);

n = number of moles (dimensionless);

R = 0.082 (L atm/mole ºK); and

T = temperature (ºK).

$$\frac{P_1 V_1}{P_2 V_2} = \frac{n_1 R T_1}{n_2 R T_2}$$

Assume for the SCA, $T_1 = T_2$ and $V_1 = V_2$, thus:

$$P_2 = \frac{P_1 n_2}{n_1}$$

Volume of one mole of any gas at standard temperature (STP; T = 0 ºC) is 22.4 L, thus the volume of one mole of gas at 20 ºC is:

$$\frac{V_1}{V_2} = \frac{T_1}{T_2} \therefore \frac{22.4}{V_2} = \frac{273.15}{293.15}$$

$$V_2 = 24.04\ \left({}^{l}/_{mole}\right) \div 28.32\ \left({}^{l}/_{ft^3}\right) = 0.85\ \left({}^{ft^3}/_{mole}\right)$$

$$n_1 = \frac{V_i}{0.8489} \text{ and } n_2 = \frac{V_i + \Delta V}{0.8489}$$

$$P_2 = P_1 \left[\frac{\left(\frac{V_i + \Delta V}{0.85}\right)}{\left(\frac{V_i}{0.85}\right)} \right] = \frac{P_1 (V_i + \Delta V)}{V_i}$$

where all volumes are at STP; therefore, the air-filled void ratio (V_i) can be calculated using the volume (V_R), porosity, and saturation of material placed in the SCA:

$$V_i = (V_R)(porosity)(1 - saturation) \qquad (6)$$

$$Volume\ of\ material\ disposed\ in\ SCA,\ V_R = 2{,}061{,}300\ yd^3 \times 27 = 55{,}655{,}100\ ft^3$$

$$\begin{aligned} Air\ Filled\ Void\ Space\ (V_i) &= V_R\ (porosity)(1 - saturation) \\ &= 55{,}655{,}100 \times 0.65 \times (1 - 0.80) \\ &= 7{,}235{,}163\ ft^3 \end{aligned}$$

SCA Pressure:

The gas pressure in the SCA in 2015 (upon placement of the leveling layer) is as follows:

$$Stored\ Gas = Generated$$

$$= 286{,}758{,}422\ ft^3 \text{ (peak gas generation rate from Table 1)}$$

$$SCA\ Pressure\ =\ (Initial\ Pressure)\left(\frac{Stored\ Gas + Air\ Filled\ Void\ Space}{Air\ Filled\ Void\ Space}\right)$$

$$= 1.0 \times \left(\frac{286{,}758{,}422 + 7{,}235{,}163}{7{,}235{,}163}\right) = 40.63\ atm$$

SCA pressure for the first 50 years of the SCA's lifetime (assuming no gas management system installed) is presented in Table 3.

SCA Pressure Evaluation

The downward pressure on the final cover system includes the vertical stress at the base of the final cover system and atmospheric pressure (1.0 atm). The vertical stress at the base of the final cover soils above the geomembrane is calculated below.

Layer	Thickness (in)	Unit Weight (pcf)	Vertical Stress (psf)
Protective Soil	18	120	180
Vegetative Soil	6	120	60
		Total	240

The vertical stress of 240 psf from the final cover is equivalent to a pressure of 0.114 atm, resulting in a total downward pressure at the base of the SCA final cover equal to 1.114 atm (atmospheric pressure of 1.0 atm + vertical stress of 0.114 atm). Table 3 presents the calculated gas balance and anticipated pressure in the SCA over time.

Comparison between the calculated SCA gas pressures (assuming no gas management system is installed on the SCA) presented in Table 3 and the downward pressure at the base of the final cover system indicates that there will be a significant uplift force underneath the final cover geomembrane immediately after SCA final cover construction. Therefore, a gas management system is required to provide a ventilation pathway and relieve the pressure in the SCA and reduce risk of detrimental impact to the final cover system veneer stability.

As previously discussed, the gas pressure that will result in the final cover system veneer stability FS to be 1.5 is calculated to be 223.9 psf. The gas management system is designed to reduce uplift force underneath the final cover geomembrane to below the maximum allowable value, as discussed below.

Gas Management System

For designing the layout of the venting system, the gas transmissivity of the geocomposite (Ψ_g) is calculated from the hydraulic transmissivity of the geocomposite (Ψ_w) and the dynamic viscosity and unit weight properties of the gas (μ_g and γ_g, respectively), as presented below.

$$\mu_g = weighted\ average\ \mu_{methane}\ and\ \mu_{carbon\ dioxide}$$
$$= (0.50 \times 2.31 \times 10^{-7}) + (0.50 \times 3.15 \times 10^{-7})$$
$$= 2.73 \times 10^{-7}\ lb_f.s/ft^2 (equivalent\ to\ 8.78 \times 10^{-6}\ lb/s.ft)$$

$$\gamma_g = weighted\ average\ \gamma_{methane}\ and\ \gamma_{carbon\ dioxide}$$
$$= (0.50 \times 0.042) + (0.50 \times 0.114)$$
$$= 0.078\ lb/ft^3$$

Therefore:

$$\Psi_g = \Psi_w \frac{\mu_w \gamma_g}{\mu_g \gamma_w} = 9.44 \times 10^{-4} \times \frac{(2.12 \times 10^{-5}) \times (0.078)}{(2.73 \times 10^{-7}) \times (62.4)} = 9.14 \times 10^{-5}\ ft^2/s$$

Gas flux for the SCA ($\Phi_{g,SCA}$) is conservatively calculated based on gas generation in 2015 (upon placement of the leveling layer; presented in Table 1 with peak gas generation rate of 286,758,422 ft^3/year) and for an approximate footprint of 45 acres (equivalent to 1,960,200 ft^2) of the SCA.

$$\Phi_{g,SCA} = 286{,}758{,}422\ (ft^3/yr) \div 31{,}536{,}000 (s/yr) \div 1{,}960{,}200 (ft^2)$$
$$= 4.64 \times 10^{-6}\ (ft^3/ft^2 s)$$

Consequently, the spacing required between the geocomposite gas venting strips can be calculated as below:

$$D_{SCA} = \sqrt{\frac{8 u_{g-allow} \Psi_g}{\Phi_{g,SCA} \gamma_g}} = \sqrt{\frac{8 \times (223.9) \times (9.14 \times 10^{-5})}{(4.64 \times 10^{-6}) \times (0.078)}} = 674\ ft$$

Written by:	Ray Wu	Date:	09/11/2015	Reviewed by:	Sowmya Bulusu / Jay Beech	Date:	09/11/2015
Client:	Honeywell	Project:	Onondaga Lake SCA Final Cover Design	Project/ Proposal No.:	GD5497	Task No.:	03

Considering a FS of 1.5 on the calculated spacing for the geocomposite gas venting strips, the recommended maximum spacing ($D_{max,SCA}$) of the geocomposite gas venting strips is 449 ft in any direction since the generated gas can migrate in any direction within the SCA.

Gas flux for the DMA ($\Phi_{g,DMA}$) is similarly estimated as 6.11 x 10^{-6} ft^3/ft^2s, conservatively calculated based on gas generation in 2015 (upon placement of the leveling layer; presented in Table 2 with peak gas generation rate of 19,314,385 ft^3/year) and for an approximate DMA footprint of 2.3 acres. Consequently, the spacing required between the geocomposite gas venting strips in the DMA can be calculated as below:

$$D_{DMA} = \sqrt{\frac{8u_{g-allow}\Psi_g}{\Phi_{g,DMA}\gamma_g}} = \sqrt{\frac{8 \times (223.9) \times (9.14 \times 10^{-5})}{(6.11 \times 10^{-6}) \times (0.078)}} = 586\ ft$$

Considering a FS of 1.5 on the calculated spacing for the geocomposite gas venting strips, the recommended maximum spacing ($D_{max,DMA}$) of the geocomposite gas venting strips is 390 ft in any direction since the generated gas can migrate in any direction within the DMA.

The layout of the geocomposite gas venting strips and vents are placed in a grid that keeps the spacing of the strips under the maximum allowable spacing calculated in the footprint of the SCA, as shown in Drawing No. C-018 of the SCA Final Cover Contract Drawings. Four diagonally aligned geocomposite gas venting strips in the SCA and one geocomposite gas venting strip with a gas vent pipe in the DMA are conservatively added to reduce the risk of impact of gas pressure buildup on the SCA final cover top deck.

A gas vent pipe shall be provided at each geocomposite gas venting strip intersection, to vent to the atmosphere the gas that is conveyed through the strips. A total of 17 vents are proposed in the design for the SCA final cover footprint (including the DMA). The geocomposite gas venting strips will be 250-mil thick (equivalent 0.021 ft) and designed to be 4.5-ft wide. The geocomposite gas venting strips will be installed on top of the leveling layer, underneath the final cover geomembrane, as shown in the detail presented on the drawing.

To check the gas flow conditions in the geocomposite gas venting strips on the SCA, the gas flow rate per unit length (linear foot) of the strip, Q_{SCA}, is calculated based on the velocity of gas flow in the geocomposite, $V_{g,SCA}$, and cross-section dimensions of the geocomposite, as presented below.

$$Q_{SCA} = \Phi_{g,SCA} \times (coverage\ area) = 4.64 \times 10^{-6} \times \left(\frac{449 \times 1}{2}\right)$$
$$= 1.04 \times 10^{-3}\ \frac{ft^3}{s} per\ foot\ length\ of\ geocomposite$$

$$V_{g,SCA} = \frac{Q_{SCA}}{A} = \frac{1.04 \times 10^{-3}}{4.5 \times 0.02} = 0.01\ ft/s$$

The Reynolds number for flow of gas in the geocomposite gas venting strips on the SCA is calculated as shown below.

$$R_{e,SCA} = \frac{\gamma_g V_{g,SCA} l}{\mu_g} = \frac{0.078 \times 0.01 \times 0.02}{8.78 \times 10^{-6}} = 2.0\ (\ll 2{,}000)$$

Similarly, gas flow conditions in the geocomposite gas venting strip on the DMA are also calculated based on the gas flow rate per unit length of the strip, Q_{DMA}, and velocity of gas flow in the geocomposite, $V_{g,\ DMA}$, as presented below.

$$Q_{DMA} = \Phi_{g,DMA} \times (coverage\ area) = 6.11 \times 10^{-6} \times \left(\frac{390 \times 1}{2}\right)$$
$$= 1.19 \times 10^{-3}\ \frac{ft^3}{s} per\ foot\ length\ of\ geocomposite$$

$$V_{g,DMA} = \frac{Q_{DMA}}{A} = \frac{1.19 \times 10^{-3}}{4.5 \times 0.02} = 0.01\ ft/s$$

The Reynolds number for flow of gas in the geocomposite gas venting strip on the DMA is calculated as shown below, which is significantly less than 2,000, and laminar flow conditions will be maintained in the geocomposite strip on the DMA.

$$R_{e,DMA} = \frac{\gamma_g V_{g,DMA} l}{\mu_g} = \frac{0.078 \times 0.01 \times 0.02}{8.78 \times 10^{-6}} = 2.3\ (\ll 2{,}000)$$

SUMMARY AND CONCLUSIONS

The purpose of this calculation package is to: (i) estimate a reasonable range of gas generation rates within the SCA; (ii) evaluate the potential effects of the generated gas on the SCA final cover system; and (iii) if necessary, design a gas venting system for the SCA final cover system.

The decomposable material placed in the SCA is estimated to consist of over 200,000 tons of vegetative waste from dredging activities. The maximum annual quantity of gas generation in the SCA is estimated at approximately 290 million cubic feet (approximately 550 cfm) in 2015 (i.e., the year after dredging is completed). Although the DMA is part of the SCA footprint, the material placed in the DMA is assumed to consist of higher composition of decomposable materials, estimated to be about 27,000 tons and have potential to generate approximately 20 million cubic feet of gas in 2015 (i.e., the year after dredging is completed).

The gas flow balance model shows that, due to the presence of decomposable material, without a gas management system, gas generation in the SCA will cause a significant uplift force under the final cover. Therefore, a surficial passive gas management system consisting of a network of geocomposite gas venting strips and vent pipes is designed to relieve gas pressure buildup under the geomembrane cover and reduce risk of detrimental impact to the final cover system veneer stability.

The designed gas management system for the SCA final cover consists of (i) 250-mil thick and 4.5-ft wide geocomposite gas venting strips calculated to be spaced at a maximum distance of 449 ft for the SCA and 390 ft for the DMA, installed over the leveling layer and underneath the final cover geomembrane; and (ii) gas vent pipes at the intersection of the geocomposite gas venting strips to vent the gas flowing through the venting strips. This gas management system is designed assuming that the decomposable material was placed relatively uniformly in the entire SCA, and is not concentrated in specific areas, except at the DMA, where the design consists of an additional geocomposite gas venting strip and vent.

Written by:	Ray Wu	Date:	09/11/2015	Reviewed by:	Sowmya Bulusu / Jay Beech	Date:	09/11/2015
Client:	Honeywell	Project:	Onondaga Lake SCA Final Cover Design	Project/ Proposal No.:	GD5497	Task No.:	03

REFERENCES

De la Cruz, F.B., M.A. Barlaz. (2010). "Estimation of Waste Component-Specific Landfill Decay Rates using Laboratory-Scale Decomposition Data," *Environmental Science & Technology*, 44. 4722-4728.

Eleazer, W.E., W.S. Odle, Y.S. Wang, M.A. Barlaz. (1997). "Biodegradability of Municipal Solid Waste Components in Laboratory-Scale Landfills," *Environmental Science & Technology*, 31, 911-917.

Thiel, R.S. (1998). "Design Methodology for a Gas Pressure Relief Layer Below a Geomembrane Landfill Cover to Improve Slope Stability," *Geosynthetics International*, 5, 589-617.

United States Environmental Protection Agency (USEPA). (2005). "Landfill Gas Emissions Model (LandGEM) Version 3.02 User's Guide," EPA-600/R-05/047.

TABLES

Written by: **Ray Wu** Date: **09/11/2015** Reviewed by: **Sowmya Bulusu / Jay Beech** Date: **09/11/2015**

Client: **Honeywell** Project: **Onondaga Lake SCA Final Cover Design** Project/ Proposal No.: **GD5497** Task No.: **03**

Table 1. Gas Generation in the SCA – LandGEM Output

Year	Organic Waste in-place (tons)	Gas Generation ft^3/year
2012	0	0
2013	23,576	37,693,407
2014	113,438	174,534,088
2015	203,419	286,758,422
2016	203,419	234,777,939
2017	203,419	192,219,918
2018	203,419	157,376,359
2019	203,419	128,848,865
2020	203,419	105,492,528
2021	203,419	86,369,977
2022	203,419	70,713,756
2023	203,419	57,895,527
2024	203,419	47,400,848
2025	203,419	38,808,532
2026	203,419	31,773,739
2027	203,419	26,014,137
2028	203,419	21,298,574
2029	203,419	17,437,798
2030	203,419	14,276,861
2031	203,419	11,688,905
2032	203,419	9,570,066
2033	203,419	7,835,308
2034	203,419	6,415,007
2035	203,419	5,252,164
2036	203,419	4,300,108
2037	203,419	3,520,631
2038	203,419	2,882,449
2039	203,419	2,359,949
2040	203,419	1,932,163
2041	203,419	1,581,921
2042	203,419	1,295,168
2043	203,419	1,060,394
2044	203,419	868,177
2045	203,419	710,803
2046	203,419	581,956
2047	203,419	476,466
2048	203,419	390,097
2049	203,419	319,384
2050	203,419	261,490
2051	203,419	214,090
2052	203,419	175,282
2053	203,419	143,509
2054	203,419	117,495
2055	203,419	96,197
2056	203,419	78,759
2057	203,419	64,483
2058	203,419	52,794
2059	203,419	43,224
2060	203,419	35,389
2061	203,419	28,974

Written by: **Ray Wu** Date: **09/11/2015** Reviewed by: **Sowmya Bulusu / Jay Beech** Date: **09/11/2015**

Client: **Honeywell** Project: **Onondaga Lake SCA Final Cover Design** Project/ Proposal No.: **GD5497** Task No.: **03**

Table 2. Gas Generation in the DMA – LandGEM Output

Year	Waste in-place (tons)	Gas Generation ft^3/year
2014	26,640	0
2015	26,640	19,314,385
2016	26,640	16,006,803
2017	26,640	13,282,398
2018	26,640	11,037,179
2019	26,640	9,185,820
2020	26,640	7,658,299
2021	26,640	6,397,136
2022	26,640	5,355,141
2023	26,640	4,493,561
2024	26,640	3,780,563
2025	26,640	3,189,990
2026	26,640	2,700,345
2027	26,640	2,293,951
2028	26,640	1,956,270
2029	26,640	1,675,341
2030	26,640	1,441,318
2031	26,640	1,246,092
2032	26,640	1,082,982
2033	26,640	946,480
2034	26,640	832,045
2035	26,640	735,927
2036	26,640	655,030
2037	26,640	586,796
2038	26,640	529,109
2039	26,640	480,217
2040	26,640	438,668
2041	26,640	403,261
2042	26,640	372,997
2043	26,640	347,047
2044	26,640	324,720
2045	26,640	305,442
2046	26,640	288,734
2047	26,640	274,198
2048	26,640	261,498
2049	26,640	250,356
2050	26,640	240,536
2051	26,640	231,843
2052	26,640	224,111
2053	26,640	217,201
2054	26,640	210,994
2055	26,640	205,393
2056	26,640	200,313
2057	26,640	195,682
2058	26,640	191,441
2059	26,640	187,537
2060	26,640	183,927
2061	26,640	180,573
2062	26,640	177,443
2063	26,640	174,510

Written by: **Ray Wu** Date: **09/11/2015** Reviewed by: **Sowmya Bulusu / Jay Beech** Date: **09/11/2015**

Client: **Honeywell** Project: **Onondaga Lake SCA Final Cover Design** Project/ Proposal No.: **GD5497** Task No.: **03**

Table 3. Gas Flow Balance and SCA Pressure

Year	Total Generated LFG (ft^3/yr)	Total Emitted LFG (ft^3/yr)	Total Diffused LFG (ft^3/yr)	Total Stored LFG (ft^3/yr)	Cumulative Stored LFG (ft^3)	Gas Pressure (atm)
2012	0	0	0	0	0	1.00
2013	37,693,407	37,693,407	0	0	0	1.00
2014	174,534,088	174,534,088	0	0	0	1.00
2015	286,758,422	0	0	286,758,422	286,758,422	40.63
2016	234,777,939	0	0	234,777,939	521,536,360	73.08
2017	192,219,918	0	0	192,219,918	713,756,279	99.65
2018	157,376,359	0	0	157,376,359	871,132,637	121.40
2019	128,848,865	0	0	128,848,865	999,981,502	139.21
2020	105,492,528	0	0	105,492,528	1,105,474,030	153.79
2021	86,369,977	0	0	86,369,977	1,191,844,007	165.73
2022	70,713,756	0	0	70,713,756	1,262,557,763	175.50
2023	57,895,527	0	0	57,895,527	1,320,453,290	183.50
2024	47,400,848	0	0	47,400,848	1,367,854,138	190.06
2025	38,808,532	0	0	38,808,532	1,406,662,670	195.42
2026	31,773,739	0	0	31,773,739	1,438,436,409	199.81
2027	26,014,137	0	0	26,014,137	1,464,450,546	203.41
2028	21,298,574	0	0	21,298,574	1,485,749,120	206.35
2029	17,437,798	0	0	17,437,798	1,503,186,918	208.76
2030	14,276,861	0	0	14,276,861	1,517,463,779	210.73
2031	11,688,905	0	0	11,688,905	1,529,152,684	212.35
2032	9,570,066	0	0	9,570,066	1,538,722,751	213.67
2033	7,835,308	0	0	7,835,308	1,546,558,058	214.76
2034	6,415,007	0	0	6,415,007	1,552,973,065	215.64
2035	5,252,164	0	0	5,252,164	1,558,225,229	216.37
2036	4,300,108	0	0	4,300,108	1,562,525,337	216.96
2037	3,520,631	0	0	3,520,631	1,566,045,968	217.45
2038	2,882,449	0	0	2,882,449	1,568,928,416	217.85
2039	2,359,949	0	0	2,359,949	1,571,288,365	218.17
2040	1,932,163	0	0	1,932,163	1,573,220,528	218.44
2041	1,581,921	0	0	1,581,921	1,574,802,450	218.66
2042	1,295,168	0	0	1,295,168	1,576,097,617	218.84
2043	1,060,394	0	0	1,060,394	1,577,158,011	218.99
2044	868,177	0	0	868,177	1,578,026,188	219.11
2045	710,803	0	0	710,803	1,578,736,991	219.20
2046	581,956	0	0	581,956	1,579,318,947	219.28
2047	476,466	0	0	476,466	1,579,795,413	219.35
2048	390,097	0	0	390,097	1,580,185,510	219.40
2049	319,384	0	0	319,384	1,580,504,894	219.45
2050	261,490	0	0	261,490	1,580,766,384	219.48
2051	214,090	0	0	214,090	1,580,980,474	219.51
2052	175,282	0	0	175,282	1,581,155,756	219.54
2053	143,509	0	0	143,509	1,581,299,264	219.56
2054	117,495	0	0	117,495	1,581,416,759	219.57
2055	96,197	0	0	96,197	1,581,512,956	219.59
2056	78,759	0	0	78,759	1,581,591,715	219.60
2057	64,483	0	0	64,483	1,581,656,198	219.61
2058	52,794	0	0	52,794	1,581,708,992	219.61
2059	43,224	0	0	43,224	1,581,752,216	219.62
2060	35,389	0	0	35,389	1,581,787,604	219.63
2061	28,974	0	0	28,974	1,581,816,578	219.63

Note: Total LFG values do not include gas generation in the DMA.