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Memo

To: Thomas Plante, P.E., Project Manager
From: Jeffrey S. Hansen, P.H.
CC: file
Date: April 24, 2009
Re: Hempstead, New York – MGP Site, Groundwater Recharge Assessment

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In accordance with your request, an assessment was performed to evaluate the maximum head that could potentially develop on top of soils that are to be solidified at the former Hempstead Manufactured Gas Plant Site in Hempstead, New York. The results of this assessment will be used as part of the remedial design to determine whether subsurface drains are needed to control the head to minimize the potential for seepage into basements of buildings in the vicinity of the stabilization area.

The rainfall condition used for this assessment was a 100-year 24-hour storm event (i.e., design storm event). The analytical approach that was used to perform the assessment included the following components:

- Identifying the 24-hour 100-year rainfall (P) for the Site;
- Estimating the portion of the rainfall that would runoff (R) from the site using the United States Department of Agriculture Soil Conservation Service (SCS) Method;
- Estimating the amount of infiltration (I) that would occur from the storm event (P-R); and
- Estimating the head rise using several different analytical models (refer to attached calculations).

As indicated in the attached calculations, the 24-hour, 100 year rainfall for the Hempstead, New York area is approximately 8-inches[i]. Based upon rainfall/runoff relationships developed by the SCS, the runoff produced by such a storm would conservatively generate approximately 3.5 inches of runoff leaving approximately 4.5 inches of infiltration, assuming no losses from evaporation(see attached calculations). Observations at other sites indicate that it is reasonable to assume that this infiltration would occur over a 2 to 3 day time period[ii, iii].

Several analytical models were used to assess the increase in head that would likely occur above the solidified soils in response to this infiltration. These analytical models ranged from a simple calculation that relates the increase in hydraulic head to the quantity of recharge infiltrating the soil and the specific yield of the soil to more complex analytical solutions for evaluating groundwater mounds in response to artificial recharge (Hantush, 1967) and drawdown from large diameter pumping wells (Cooper/Papadopoulos 1967). Each of these models and their assumptions are discussed below.

HEAD AS A FUNCTION OF RECHARGE AMOUNT AND SPECIFIC YIELD

The simplest analytical model used to estimate the maximum head that could theoretically result from infiltration generated from the design storm event is represented by the following equation:

$$\Delta h = R/Sy$$

Where: Δh = maximum rise in head due to a given amount of recharge (L);
R = Amount of recharge or infiltration (L); and
Sy = Specific yield of the soil receiving the infiltration.

The equation presented above was used to establish the boundary condition for maximum head and assumes the following:

- Soils receiving the recharge are homogenous and isotropic, which is reasonable for the sandy soils that will be placed over the solidified soils;
- The recharge will be uniformly distributed over the recharge area, which is reasonable given that the final grade will be relatively flat and that it is assumed that the cover soils will be unpaved;
- All recharge instantaneously infiltrates the soils, which is conservative;
- Rainfall from the entire design storm event infiltrates the soils (i.e., no runoff), which is very conservative; and
- There is no lateral drainage of recharge from the soils to dissipate head, which is also conservative.

Given a 24-hour 100-year rainfall of 8 inches (i.e., 0.667 feet) and a specific yield of 0.2[iv] (Walton, 1992), the maximum theoretical incremental increase in head that could occur assuming all rainfall infiltrated the soils would be 3.33 feet. It should be noted that simulations previously performed by URS using the Hydrologic Evaluation of Landfill Performance (HELP) Model indicates that the average head on top of the solidified soils resulting from seasonal precipitation will be 0.75 feet. On this basis, the maximum total head (boundary condition) would be 4.08 feet (i.e., 3.33 + 0.75 feet). Given that over half of the precipitation is expected to runoff (as noted above) and additional precipitation will transpire and/or evaporate, the actual increase in head is expected to be much lower than this value.

Based upon the estimate of site recharge presented above (i.e., 4.5 inches [0.375 feet] of infiltration), this model predicts an increase in hydraulic head of 1.88 feet with the head on top of the solidified soils estimated to be 2.63 feet (i.e., 1.88 feet + 0.75 feet).

HANTUSH SOLUTION

To provide an independent validation of this estimate, additional calculations of head rise were performed using analytical models developed by Hantush (1967)[v] and Cooper-Papadopoulos (1967)[vi]

The equation predicting the transient rise of the water table beneath a rectangular recharge area is given by a solution by Hantush (1967).

$$h^2 - h_0^2 = Z(x, y, t) = \frac{\upsilon w}{K}\int_0^t \left[erf\left(\frac{l/2+x}{\sqrt{4\upsilon t}}\right) + erf\left(\frac{l/2-x}{\sqrt{4\upsilon t}}\right)\right]\left[erf\left(\frac{a/2+y}{\sqrt{4\upsilon t}}\right) + erf\left(\frac{a/2-y}{\sqrt{4\upsilon t}}\right)\right]$$

and

$$\upsilon = K\bar{b} / S_y$$

$$\bar{b} = 0.5[h_i(0) + h(t_1)]$$

where

- a is dimension of the recharge area in y direction [L]
- h is the head beneath the mound [L]
- h_0 is the static head prior to recharge (i.e., initial saturated thickness of aquifer) [L]
- K is the hydraulic conductivity of the aquifer [L/T]
- l is dimension of the recharge area in x direction [L]
- S_y is the specific yield of the aquifer [dimensionless]
- t is time [T]
- t_1 is time used in successive approximation [T]
- w is the recharge rate [L/T]
- x is coordinate of the observation point [L]
- y is coordinate of the observation point [L]

The transient rise of the water table beneath a circular recharge area using a solution by Hantush (1967).

$$h^2 - h_0^2 = Z(r, t) = \frac{2V}{\pi K}\int_0^\infty (1 - e^{-q\beta^2}) J_1(\beta) J_0(\rho\beta)\frac{d\beta}{\beta^2}$$

and

$$V = w\pi R^2$$

$$q = \upsilon t / R^2$$

$$\rho = r / R$$

$$\upsilon = K\bar{b} / S_y$$

$$\bar{b} = 0.5[h_i(0) + h(t_1)]$$

where

- *r* is radial distance from the center of the recharge area [L]; and
- *R* is the radius of the circular recharge area [L]

Both equations assume the following:

- The aquifer is homogenous and isotropic;
- Recharge is uniformly applied over the recharge area;
- The starting saturated thickness of the aquifer beneath the recharge area is uniform in thickness;
- The aquifer immediately beneath the recharge area is continuous and not affected by geologic or hydraulic boundary conditions; and
- The mound will continue to rise until the groundwater gradient increases to a magnitude that the groundwater flow rate away from the mound is equal to the recharge rate.

These assumptions are considered reasonable for the site for the following reasons:

- The eight feet of cover soil overlying the stabilized soils can be engineered to be homogenous and relatively isotropic;
- Given the minimal topographic grade and ability to maintain a minimal post cover grade, and since it is assumed that the cover will not be paved, it is reasonable to assume uniform recharge;
- Previous simulations performed by URS using the HELP Model indicate an average head above the stabilized soils of 0.75 feet;
- There are no streams or geologic boundaries known to exist near the site; and
- An understanding of basic hydraulics and conservation of mass indicates that discharge is proportional to head (i.e., discharge increases as the hydraulic gradient

increases) and that a balance will be achieved between recharge entering a groundwater system and groundwater leaving the system.

Calculations were performed using the modeling software AQTESOLV (circular recharge area) and HANTAXIS (rectangular recharge area) based upon the following:

Parameter	**Rationale**
Width (a) and Length (l) of Recharge Area – Rectangular Recharge Area	Based upon planimeter measurements, determined the area of the soils to be solidified. The length of the recharge area (558 feet) is based upon the longest dimension of the stabilization area and the width (302 feet) was determined by dividing the area by this length.
Hydraulic Conductivity (K)	Specified hydraulic conductivity for the soils placed over the stabilized soils will be a minimum of 28 feet per day (1 * 10^{-2} centimeters per second)
Static head (h_0)	Based upon previous simulations by the HELP Model, the average head at any given time on the stabilized soils was predicted to be 0.75 feet.
Specific Yield (Sy)	Specific yield for a sandy gravelly fill similar to what is proposed for the Site based upon values in the hydrogeologic literature ranges from 0.2 to 0.35.
Recharge Rate (w)	As noted earlier, infiltration was estimated to be 4.5 inches based upon the relationship of rainfall and runoff developed by the SCS. This infiltration was conservatively assumed to be applied over a two day period on a per square foot basis (0.19 feet per day per square foot of recharge area).
Time of Application (t)	Conservatively assumed to be 2 days.
Radius of Recharge Area (R)	Determined as the radius of a circle having an area that is equal to the area of stabilized soils measured using a planimeter (i.e., 232 feet).

Calculations performed using the Hantush equation for a rectangular and circular recharge area indicate maximum heads (including the 0.75 foot starting head) to be 2.65 feet and 2.62 feet, respectively (see attached calculations).

COOPER-PAPADOPOULOS SOLUTION

The Cooper-Papadopoulos equation was developed for predicting drawdown in a large-diameter pumping well. This equation can also be used to predict the rise in the groundwater in response to recharge by treating the pumping well as an injection well. The equation is instantaneously is applied to the groundwater surface.

The Cooper-Papodopoulos Equation is mathematically expressed as follows:

$$s = Q/4\pi T * F(\mu,\beta)$$

Where:

$$\mu = r_w^2 S/4Tt \quad \text{and} \quad \beta = r_w^2 S/r_c^2$$

Q = Recharge Rate (L^3/T);
T = Transmissivity (L^2/T) Product of horizontal hydraulic conductivity and saturated thickness. Assume b = 0.75 feet and K= 28 feet per day = 21 feet^2/day;
$F(\mu,\beta)$ = Well Function. From Kruseman, G.P., and N.A. DeRidder, 1983. *Analysis and Evaluation of Pumping;*
r_w = well radius (L);
S = Storage Coefficient or Specific Yield;
r_c = casing radius (L);
t = Recharge period (T); and
s = maximum head after recharge period t, (L).

Except as noted above, the parameters used in this equation were the same as those used for the Hantush equation. Results of this analysis indicate that if the 4.5 inches of recharge (infiltration) derived from the 24-hour 100-year rainfall event is applied over a two day period, the resulting head, including the 0.75 foot static groundwater head would be 2.7 feet.

SUMMARY

For comparison, results of the analysis are tabulated below.

Analytical Method	Starting Head (feet)	Incremental Increase in Head (feet)	Maximum Head (feet)
Recharge vs. Sy	0.75	1.88	2.63
Hantush Rectangular Recharge Area	0.75	1.90	2.65
Hantush Circular Recharge Area	0.75	1.87	2.62

Analytical Method	Starting Head (feet)	Incremental Increase in Head (feet)	Maximum Head (feet)
Cooper-Papodopoulos	0.75	1.95	2.70

As shown in this tabulation, the maximum theoretical head that is likely to occur at the Hempstead MGP Site is less than 3 feet. Based upon the current understanding of the proposed design, there are several buildings with basements in the vicinity of the stabilized soils. The buildings are located several feet from the edge of the proposed stabilized soils and are separated from the stabilized soils by native soils having a permeability that is approximately 5 times higher than the permeability of the cover soil. Moreover, the water table in the native soils is located more than 28 feet below ground surface. These higher permeability soils are anticipated to function as a vertical drain and will reduce the heads near the edge of the stabilized soils. On this basis and given that most basements are typically approximately six feet below grade, it is unlikely that infiltration from a 24-hour 100 year storm event would cause groundwater heads to rise to the level where groundwater would seep into basements of buildings adjacent to the stabilization area.

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i National Oceanic and Atmospheric Administration. *Technical Paper No 40 (TP 40) Rainfall Frequency Atlas of the Eastern United States for Duration from 30 minutes to 24 hours and Return Periods from 1 to 100 years - maps of ME and NH only.* National Weather Service.

ii Dunne, T. and L. B. Leopold, 1978, Water in Environmental Planning. W.H. Freeman and Company, San Francisco, California.

iii United States Geological Survey, 1988. *Hydrogeology, Water Quality, and Effects of Increased Municipal Pumpage of the Saco River Valley Glacial Aquifer: Bartlett, New Hampshire to Fryeburg, Maine.* Water Resources Investigation Report 88-4179.

iv Walton, W.C., 1991. *Principles of Groundwater Engineering.* Lewis Publishers, Boca Raton, Fl.

v Hantush, M.S., 1967. *Growth and decay of groundwater mounds in response to uniform percolation,* Water Resources Research, vol. 3, no. 1, pp. 227-234.

vi Papadopulos, I.S. and H.H. Cooper, 1967. *Drawdown in a well of large diameter,* Water Resources Research, vol. 3, no. 1, pp. 241-244.

Analysis by: JSH
Checked by: WAN

Calculations of Maximum Head
from 24 hour 100 year Storm Event
Hempstead MGP Site
Hempstead, NY

Project: Hempstead, New York

Subject: Maximum head buildup in response to 100 year 24 hour storm event

Problem:

Estimate the maximum hydraulic head that may develop in the groundwater system underlying the Hempstead Site in response to a 100-year 24-hour rainfall event after impacted soil has been solidified and covered with 8 feet of sandy soil. The 100-year 24-hour rainfall for Long Island, New York is approximately 8 inches.

Assumptions

1. The impacted soil will be solidified to a hydraulic conductivity of 1×10^{-6} centimeters per second (cm/sec) or less and will behave a barrier to vertical movement of groundwater.

2. Solidified soil will be covered with approximately 8 feet of soil having a minimum horizontal hydraulic conductivity of 28 feet per day (ft/day) or 1×10^{-2} cm/sec.

3. The surface of the cover will be graded with a shallow (assume 1 percent) slope and will as a worst case (from the standpoint of infiltration) be unpaved with no stormwater collection system.

4. The soils adjacent to the solidified soil have a geometric mean horizontal hydraulic conductivity of 159 ft/day or 5.6×10^{-2} cm/sec. This value was calculated using data from the shallow wells in Table 3-5 *Hydraulic Conductivity Results*, Pre-Design Investigation Report.

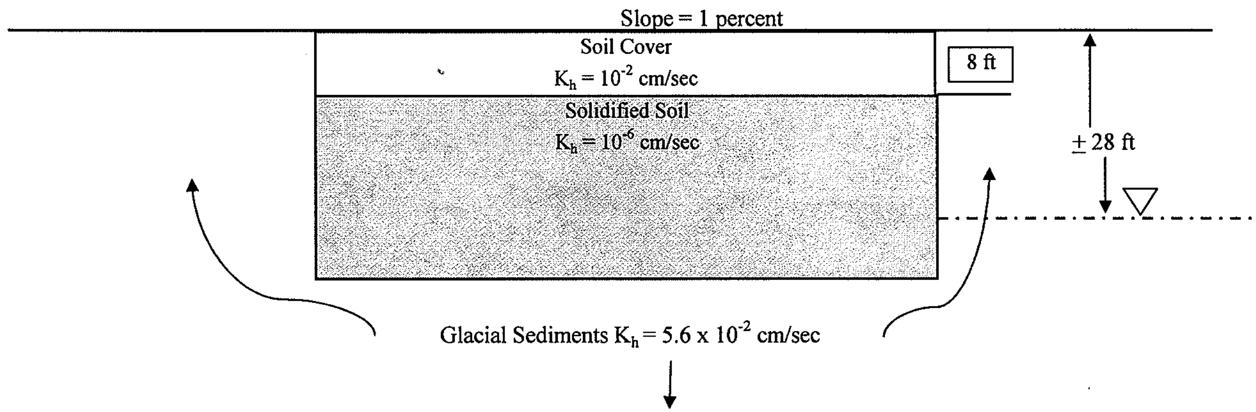
5. Static depth to water is approximately 28 feet below ground surface (bgs).

6. Distance from center of area of solidified soil to edge. Maximum distance is 130 feet (short axis) to 300 feet (long axis) in the largest area.

7. Assume no runon from adjacent areas during or after storm event.

8. Assume no subdrainage.

Calculations of Maximum Head
from 24 hour 100 year Storm Event
Hempstead MGP Site
Hempstead, NY



Other Relevant Information

The largest area to be solidified encompasses approximately 168,675 square feet based upon planimeter measurements from Figure 3-1 *Pre-Design Investigation Source Material Delineation Site Layout.*

From Hydrologic Evaluation of Landfill Performance Model Simulations, assume on average, there is 9 inches (0.75 feet) of water head on the solidified soils. See previous work by URS.

Analytical Approach

1. Calculate the amount of precipitation falling on the site during a 100-year 24-hour rainfall event.

2. Calculate the amount of runoff generated as a result of the 100-year 24-hour rainfall.

3. Calculate the difference in precipitation and runoff to obtain the amount of recharge entering the system.
   Assume infiltration takes place over 2 to 3 days and normalize to a daily recharge rate. This assumption is considered reasonable based upon a review of precipitation records and a groundwater hydrograph for a well screened in outwash sands exhibiting a similar permeability as the Site (United States Geological Survey, 1988. *Hydrogeology, Water Quality, and Effects of Increased Municipal Pumpage of the Saco River River Valley Glacial Aquifer: Bartlett, New Hampshire to Fryeburg, Maine* . Water Resources Investigation Report 88-4179. Well OW-7C) and is also consistent with drainage rates for sandy soils after prolonged periods of wetting (e.g., during a 24-hour 100-year storm event) as indicated by Dunne and Leopold (1978) in Water in Environmental Planning, W.H. Freeman and Company, San Francisco, CA.

4. Estimate maxium rise in water table if all precipitation enters system for worst case scenario.

5. Use Hantush (1967) (solved with the program Hantau and Hantaxis) to calculate a maximum mound height for the recharge calculated in step 3. Use the Cooper-Papadopoulos Equation (1967) and treat the area as a large diameter well with an injection rate that is equivalent to the recharge rate adjusted to a daily rate as an approximation check.

Calculation of Volume of Precipitation Falling on Area

Volume = Area * Precipitation

Area (ft^2)	Precipitation		Volume	
	inches	feet	ft^3	gallons
168675	8	0.67	112450	841126

Calculation of Runoff

Use the U.S. Soil Conservation Service Method to estimate runoff volume. For curve number, assume hydrologic soil group A defined as "soils with high infiltration capacity and low runoff potential, even when thoroughly wetted. Chiefly sands and gravels, deep and well drained." This is reasonable since infiltration will be on the higher end. Also assume average antecedent moisture conditions. From Table 10-8 (attached), the runoff curve number for a gravel road (parking lot) is 76. Using Figure 10-8, the volume of runoff generated from a total rainfall of 8 inches is estimated to be approximately 6 inches. For antecedent moisture condition I (dryer soils), the runoff curve number from Table 10-7 is approximately 58, so the amount of runoff from a total rainfall of 8 inches is estimated to be approximately 3.5 inches under these conditions.

Calculation of Infiltration

Infiltration = Precipitation - Runoff

Precipitation (inches)	Runoff (inches)	Infiltration		
		(inches)	(ft^3)	(gallons)
8	6	2	28112.5	210281.5
8	3.5	4.5	63253.1	473133.4

Infiltration ($ft/day/ft^2$)	Based upon infiltration duration of 2 days
0.08	Antecedent Condition II (average soil moisture)
0.19	Antecedent Condition I (dry soils)

Estimate of Maximum Rise in Groundwater - No Loss from Horizonal Groundwater Flow

Maximum head rise due to infiltration can be approximated using the following equation:

$$R/Sy = \Delta h$$

Where: R = Total recharge (length);

Sy = Specific yield (dimensionless); and
Δh = Change in head (maximum) (length).

For gravelly sands, Sy = 0.2 to 0.35 - Walton, W.C., 1991. *Principles of Groundwater Engineering*. Lewis Publishers, Boca Raton, Fl.

Therefore, for the estimated infiltration (i.e., recharge) presented above, the maximum theoretical rise of groundwater above the solidified soil would range from:

R (inches)	Sy (dimensionless)	Δh (inches)	Δh (feet)	Total h (feet)	
2	0.2	10	0.83	1.58	These heads include 0.75 foot initial heads
2	0.35	5.71	0.48	1.23	from HELP Model - See earlier work by URS.
4.5	0.2	22.50	1.88	2.63	
4.5	0.35	12.86	1.07	1.82	
8	0.2	40.00	3.33	4.08	Worst case - Assumes all precipitation infiltrated soil.
8	0.35	22.86	1.90	2.65	

From Hantush (1967) Model, maximum mound rise estimated to be less than 3 feet including an estimated 0.75 foot intitial head from the HELP Model. (Refer to previous analysis performed by URS).

Assumed the following:
1. Recharge of 0.19 feet per square foot over a two day duration and 0.37 feet per square foot in a one day duration (both equivalent to 4.5 inches total infiltration).
2. As a worst reasonable case, assumed specific yield of sandy cover soil was 0.2.
3. Horizontal hydraulic conductivity was assumed to be 28 feet per day.
4. Assumed application area of 302 feet by 558 feet based upon equivalent area of solidified soils where recharge will occur.

Range in head predicted excluding the 0.75 feet of initial head is 1.85 to 1.90 feet (see attached model simulation reports). Higher specific yield will result in smaller rises in the groundwater head. Note that for a circular recharge area having an equivalent radius of 232 feet as the rectangular area, a 1.87 foot head rise is predicted.

Check results asuming a circular recharge area using an equivalent surface area and corresponding radius.

Area = 168675 square feet
r = sqaure root(Area/pi) = 232 feet

Use Cooper-Papadopoulos Solution for a Large Diameter Well

$s = Q/4\pi T * F(\mu,\beta)$

Calculations of Maximum Head from 24 hour 100 year Storm Event Hempstead MGP Site Hempstead, NY

$\mu = r_w^2 S/4Tt$ and $\beta = r_w^2 S/r_c^2$

Where:

Q = Recharge Rate (L^3/T);

T = Transmissivity (L^2/T) — Product of horizontal hydraulic conductivity and saturated thickness. Assume b = 0.75 feet and K= 28 feet per day = 21 feet^2/day

$F(\mu,\beta)$ = Well Function — From Kruseman, G.P., and N.A. DeRidder, 1983. *Analysis and Evaluation of Pumping Pumping Test Data* . International Institute for Land Reclamation and Improvement. The Netherlands.

r_w = well radius (L)
S = Storage Coefficient or Specific Yield
r_c = casing radius (L)
t = Recharge period (T)
s = maximum head after recharge period t, (L)

1/μ	μ	r_w (feet)	S (dimensionless)	T (ft2/day)	t (days)	β	r_c (feet)	F(μ.β)
1.5637E-02	6.3950E+01	232	0.2	21	2	0.2	232	0.01
8.9355E-03	1.1191E+02	232	0.35	21	2	0.35	232	0.01
3.9093E-02	2.5580E+01	232	0.2	21	5	0.2	232	0.01
2.2339E-02	4.4765E+01	232	0.35	21	5	0.35	232	0.01

s (feet)	Q (ft3/day)	T (ft2/day)	Head with 0.75 foot initial head foot initial head	
2.40	63253	21	3.15	Q = 4.5 inches/12 inches/ft *168674 square feet/1 day
1.20	31627	21	1.95	Q = 4.5 inches/12 inches/ft *168674 square feet/2 days
0.80	21084	21	1.55	Q = 4.5 inches/12 inches/ft *168674 square feet/3 days
0.48	12651	21	1.23	Q = 4.5 inches/12 inches/ft *168674 square feet/5 days

If the 0.75 foot of initial head predicted by the HELP Model is added to Cooper-Papadopoulos prediction of maximum head, the ranges are similar to the predictions of maximum head predicted by Hantush.

Conclusion: Under reasonable infiltration scenario, the maximum head produced from a 100 year 24 hour storm event is conservatively estimated to be less than 3 feet.