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GSI White Paper #33

"Underdrain Design for Geomembrane Lined Surface Impoundments to Avoid Whales/Hippos from Occurring"

by

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Background

Pond liners (aka, geomembranes) date back to the 1930’s (thermoset types) and 1940’s (thermoplastic types). They have been, and continue to be, used as liners to contain all types of liquids among which are the following:

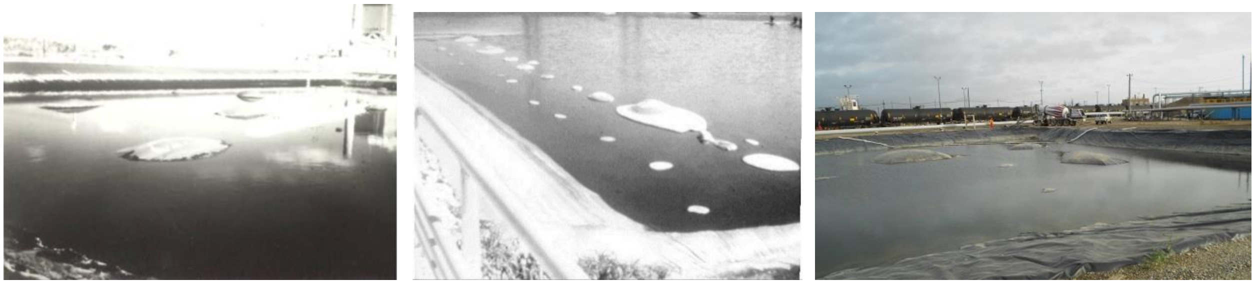
- potable water
- architectural ponds
- aquaculture ponds
- industrial water
- process waste liquids
- agriculture waste liquids
- sewage sludge
- industrial sludge
- slurried wastes
- hazardous liquids

For perspective on the size of the market, the U.S. EPA estimates that there are 206,000 hazardous liquid ponds in the U.S. One can only wonder just how large is the entire worldwide market for surface impoundments of all types???

Clearly there is more to pond design than digging a hole, throwing some plastic in it, and getting as long of a manufacturer’s warranty as possible. GSI gives a very popular 90-minute webinar on surface impoundment design covering the following consecutive items:

- Background and overview
- Geometric considerations
- Typical cross sections
- Geomembrane benefit/cost selection
- Geomembrane thickness design
- Subgrade and cover soil stability designs
- Runout and anchor trench design
- Leakage regulations and nondestructive evaluation
- Summary and recommendations

Focusing on the third item, one of the major design considerations in selecting a site-specific cross-section is the possibility of rising gases from the now-covered soil subgrade meeting the underside of the geomembrane, mobilizing pressure, and indiscriminately forming bubbles. Alternatively, liquid leakage through the geomembrane can exacerbate the situation and has caused the same type of bubbles in its own right. Called “whales” or “hippos” they grow beyond the surface of the liquid and can become quite numerous; see the photographs of Figure 1.



(undisclosed case in litigation) (photo compl. IFAI) (photo coml. GSI & Inova)

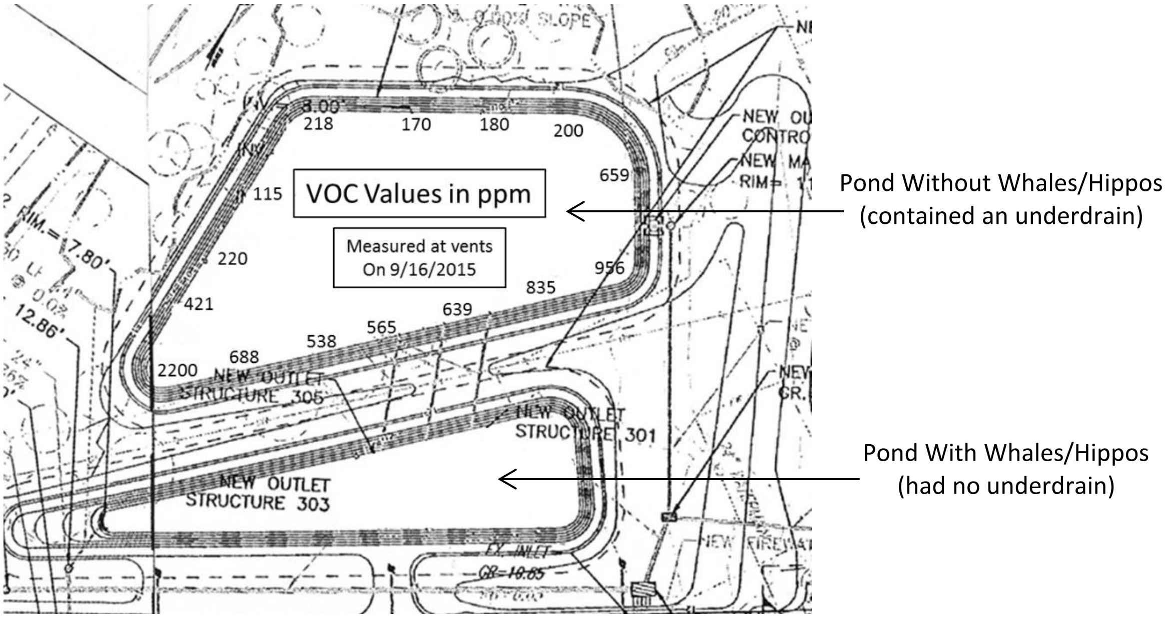
Figure 1. Examples of whales/hippos at surface impoundments.

So as to eliminate such occurrences from initiating in the first place, the inclusion of a drainage layer within the design cross-section is of paramount importance. *In this regard, a drainage layer beneath the geomembrane should always be a requirement and furthermore it must be continuous throughout the base*. If the situation is gas oriented the drainage layer must continue up the side slopes and be properly vented along the runout around the perimeter of the site. If it is leakage oriented the liquid must be directed to a drainage pipe system at the toe of the slope and then to a removal sump or well. Various geosynthetic drainage options are needle punched nonwoven geotextiles, geonet composites, geospacer composites, or even a perforated pipe network within geotextiles or soil. Two designs will be provided in this communication (gas and liquid)… *but, what causes the upward distortion of the geomembrane to begin with???*

Causes of Whales/Hippos

Based on our case histories and discussions with colleagues, it appears that the following causes have been discerned:

1. Degrading organic matter in the subgrade beneath the geomembrane is certainly a possible cause. This is likely aggravated by the increased temperature in the subgrade due to the very presence of the surface impoundment. How much organic matter is present and what temperatures occur is site-specific and should be part of the overall subgrade exploration process.
2. Rising hydrocarbons from contaminated sites are also site-specific and are heightened due to elevated subgrade temperature. In the plan view shown below in Figure 2, the lower pond had a geomembrane directly on the soil subgrade and resulted in numerous whales/hippos. The subsequently constructed upper pond had a heavy geotextile beneath the geomembrane and the vents were monitored for VOC-values (they were as high as 2200 ppm) as shown. This upper pond had no whales/hippos.



VOC Values in ppm

Measured at vents On 9/16/2015

Pond Without Whales/Hippos (contained an underdrain)

Pond With Whales/Hippos (had no underdrain)

Figure 2. Ponds constructed with underdrain (upper) and without underdrain (lower).

3. A rising water table, particularly in coastal areas, has caused whales/hippos to occur. This situation has been evaluated during legal action and was adjudicated against the designer for not having an underdrain system beneath the geomembrane.
4. For surface impoundments located on compressible silt and clay soils, the compression behavior over time will cause expulsion of the air in the voids and then possibly water under excess pore water pressure. Both situations can be analytically modeled insofar as release time and quantity.
5. Geomembrane leakage whereby liquid contained in the pond escapes through imperfections to the underside of the geomembrane is a generally accepted cause*. This has created whales/hippos (since hydrostatic pressures above and below the geomembrane are gradually equilibrated) and eventually bring the geomembrane to the surface of the pond. Higher than this elevation would require gas pressure which certainly could accompany the process.
6. It might also be mentioned that comments on changes in barometric pressure have been suggested as a cause of whales/hippos but this is unknown to have occurred by the authors.

The following table summarizes these six situations identifying if the cause is gas or liquids since underdrain design must focus on two different removal configurations.

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*For additional information see Ian Peggs' paper in Land and Water Magazine, Vol. 50, No. 4, 2006 titled "Geomembrane Liners in Wastewater Treatment Ponds: Whales and Their Prevention" - Related information is on www.geosynthetica.net.

Table 1 - Causes and removal considerations of geomembrane gas and liquid whales/hippos

Cause	Release Agent	Base Contour	Removal Method
1. organic degradation	subgrade gas	upward	top-of-slope vents
2. degrading VOC's	subgrade gas	upward	top-of-slope vents
3. rising water table	(a) subgrade gas (b) subgrade liquid	upward downward	top-of-slope vents outlet pipes or sumps
4. compressible subgrades	(a) subgrade gas (b) subgrade liquid	upward downward	top-of-slope vents outlet pipes or sumps
5. geomembrane leakage	contained liquid	downward	outlet pipes or sumps
6. barometric pressure (?)	subgrade gas	upward	top-of-slope vents

Underdrain Design for **Gas Uplift**

Whatever the liner cross-section of the proposed surface impoundment a drainage system beneath the lowest geomembrane should be required. Figures 3a and 3b show two cross-sections that are not appropriate because there is no underdrain beneath the geomembrane. There are also four acceptable cross-sections with underdrains (dashed lines) shown in Figures 3c through 3f. For gas uplift, as indicated in the above table, a heavy needle punched nonwoven geotextile will generally suffice. It requires an upward oriented base gradient leading to surface vents. This design will be presented next. For leaking liquid uplift, however, the subgrade base contour must be downward oriented to a perforated pipe collector system at the toe of the slope and then to a removal sump or well within or beyond the embankment. A second design will be offered in this regard. These two base contour alternatives are obviously critical to the design as are the quantities of gas and/or liquid to be removed.

Typical Cross Sections
(bottom-to-top)

(a) subsoil/GM (not recommended)
(b) subsoil/GM/cover soil (not recommended)
(c) subsoil/GT/GM
(d) subsoil/GT/GM/GT/cover soil
(e) subsoil/GT/GM/GN/GM
(f) subsoil/GT/GM/GN/GM/cover soil

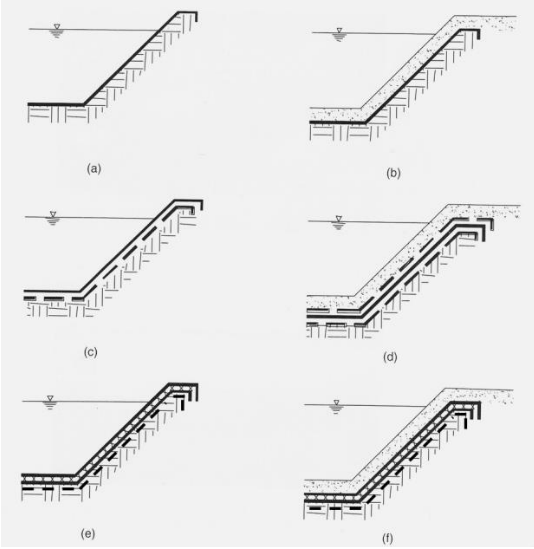

Figure 3. Various surface impoundment liner systems for gas removal wherein “a” and “b” are not acceptable since no underdrain system is provided as it is in “c”, “d”, “e” and “f”.

In the cross-sections illustrated gas is assumed to be the mobilizing action, and as such, it is necessary to provide an upward slope to the base. This is particularly important throughout the base of the surface impoundment. For release of gases there can be no high spots along a uniform upward gradient slope where gases can accumulate and form localized uplifting of the geomembrane. This upward slope is automatically achieved on the side slopes where the gas is eventually released to the atmosphere from vents around the perimeter of the site.

Numeric Example for **Gas Uplift**

Consider a 7 m deep geomembrane-lined pond that will create a barrier to rising gases from the biodegradation of the organic silt layer, as shown in Figure 4. The width of the impoundment is 400 m, with an upward grade rising from the center as shown. An estimate of gas generation is 0.10 m^3/day-m^2 at a pressure of 7.0 kPa. Assume that the density of moist air is 0.0118 kN/m^3. The proposed underliner to be used is a 550 g/m^2 needle-punched nonwoven geotextile. What is the factor of safety of this geotextile's transmissivity for this set of conditions?

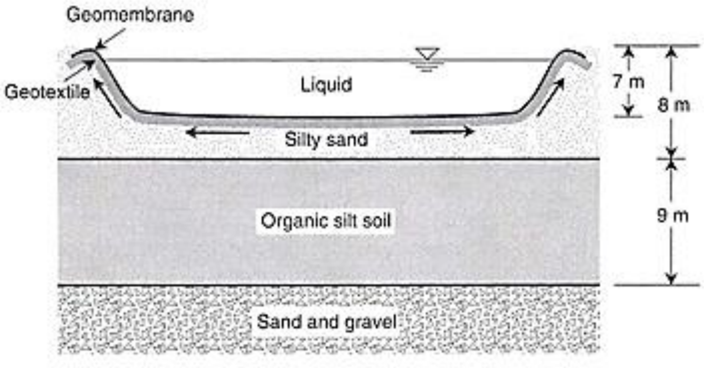

Figure 4. Cross-section sketch for example problem.

Solution

(a) The gas flow rate is

$$q = 0.10\left(\frac{400}{2}\times 1\right)$$
$$q = 20\ \text{m}^3/\text{day, at the higher elevation}$$
$$= \frac{20}{(24)(60)}$$
$$= 13.9\times 10^{-3}\, m^3/\text{min}$$

(b) The air gradient, assuming a uniform distribution of 7.0 kPa at the center to zero at the edge, is

$$i = \frac{\Delta P/\gamma_{air}}{L/2}$$
$$= \frac{7.0/0.0118}{200/2}$$
$$i = 5.9$$

(c) Although this problem is probably not one of laminar-flow conditions, we use Darcy's formula since it is a conservative approach and air-flow transmissivity data are available.

$$\begin{aligned} q &= kiA \\ &= ki(t \times W) \\ kt &= \theta_{reqd} = \frac{q}{i \times W} \\ \theta_{reqd} &= \frac{13.9 \times 10^{-3}}{(5.9)(1.0)} \\ &= 2.36 \times 10^{-3}\,\mathrm{m}^3/\mathrm{min}-\mathrm{m} \end{aligned}$$

(d) The actual transmissivity of the geotextile of the type proposed is given below. Here we obtain a θ_{allow} of 0.19 m^3/min-m at a normal stress of 7 (9.81) ≅ 70 kPa and an air pressure of 7 kPa.

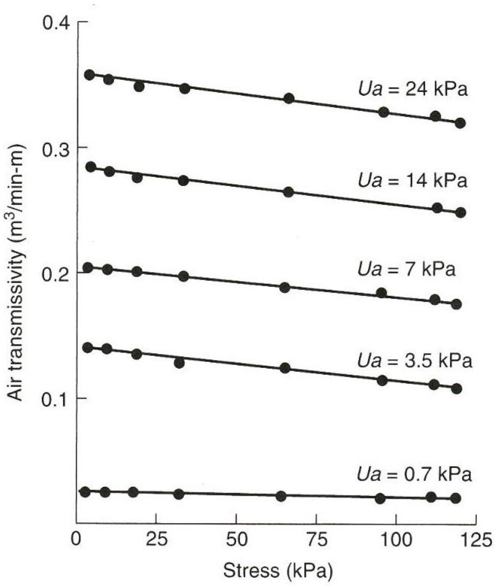

Figure 5. Radial air transmissivity data on a 550 g/m^2 nonwoven needle-punched geotextile. Koerner, R. M., Bove, J. A. and Martin, J. P., "Water and Air Transmissivity of Geotextiles," *J. Geotextiles and Geomembranes*, Vol. 1, 1984, pp. 57-73.

(e) The actual factor of safety is then calculated as follows:

$$\begin{aligned} FS &= \frac{\theta_{allow}}{\theta_{reqd}} \\ &= \frac{0.19}{0.00236} \\ FS &= 80;\ \text{which is more than adequate} \end{aligned}$$

Underdrain Design for **Leakage Liquid Uplift**

Conversely to the gas uplift situation just presented, leakage liquid uplift due to geomembrane holes or penetrations as in case #5 mentioned previously, the situation must be handled differently. Initially, the estimated leakage quantity must be assumed. As shown on the GSI White Paper #15 (www.geosynthetic-institute.org/papers/paper15.pdf) this value can range for various surface impoundments from 130 to 68,000 l/ha/day (13 to 6800 gal/acre-day)! This wide range is no misprint and only indicates how difficult it is for an engineer to arrive at a reasonable design. We will use the Interagency Wastewater Committee of the Great Lakes/Upper Mississippi Board of State and Provincial Public Health and Environmental Managers recommendation of 5000 l/ha/day (500 gal/acre-day). Next, the type of drainage layer will likely require a geonet or geospacer drainage composite due to such a large liquid flow requirement. The design then follows conventional leak detection for double lined landfill facilities in that *the grade is sloped downward toward pipe collectors* leading to removal sumps or wells.

Numeric Example for **Leakage Liquid Uplift**

Consider the same 7 m deep geomembrane pond as shown in the previous sketch but now has liquid leakage through the geomembrane of 5000 l/ha-day. The width is again 400 m with a 3% slope *downward from the center of the impoundment to the toe of the side slope(s)*. What is the FS-value for a 6.3 mm thick biplanar geonet drainage composite using the following allowable flow rate obtained from ASTM D4716 transmissivity testing?

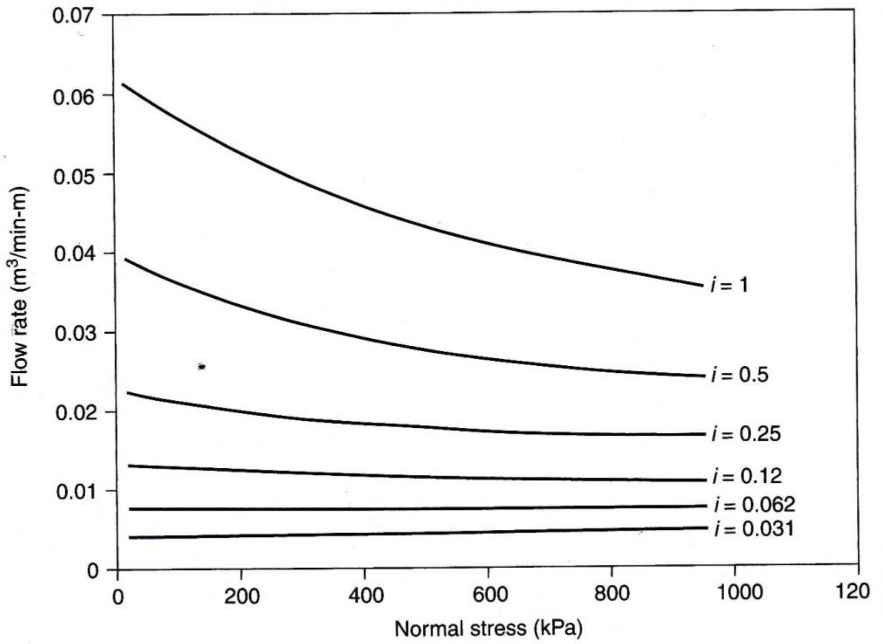

Figure 6. In-Plane liquid flow rate of a 6.3 mm thick biplanar geocomposite beneath a geomembrane and on a soil subgrade. (ref., Designing With Geosynthetics, 6th Edition, R. M. Koerner.)

(a) The allowable flow rate is as follows:

Normal stress $= 7 \times 9.81$

$= 69$ kN/m^2 = 69 kPa

q_{allow} (from graph) = 0.004 m^3/min

= 5.76 m^3-day

(b) q_{reqd} (given value) = 5000 l/ha-day

= 0.5 l/m^2-day

= 0.5 (0.001 m^3)/m^2-day

= 0.0005 m^3/m^2-day (× 200 m)

= 0.1 m^3/m-day

(c) Thus: $FS = \frac{q_{allow}}{q_{reqd}} = \frac{5.76}{0.1} = 58;$ which is more than adequate

Summary

Clearly, whales/hippos in surface impoundments are (i) unsightly, (ii) can cause thinning and/or possible failure of the geomembrane, and (iii) are certainly an embarrassment to all parties involved… mainly the designer! [Available insofar as remediation is concerned is a White Paper (#30) titled "In-Situ Repairs of Geomembrane Bubbles, Whales and Hypos"; see www.geosynthetic-institute.org/whitepapers.htm.] Unfortunately, if whales/hippos are eliminated in one location, adjacent areas are likely to follow. *Certainly, it is far better to design and install an underdrain system as a common compliment to all geomembranes used as surface impoundment liners.* The design process of such underdrains is the purpose of this particular White Paper.

Upon reviewing the possible causes of the whales/hippos which initiate the site-specific phenomenon, a major decision must be made if the cause is subsurface gas generation or geomembrane leakage caused by holes, penetrations, etc. This discussion can only be reached on the basis of a site-specific subgrade exploration program, i.e., soil borings and water observation wells, and an assessment of the geomembrane installation process. In this latter regard, certified installers (CQC), certified inspectors (CQA), and electrical leak location surveys (ELLS) are highly recommended for a leak free liner system.

In the case of rising subsurface gases, the solution tends toward a heavy needle-punched nonwoven geotextile. A numeric example was provided. If the case is one of geomembrane leakage, the solution tends toward a geonet or geospacer drainage composite. A numeric example was also provided. However, a conundrum is posed in that the rising gas scenario requires upward gradient of the base of the facility leading to vents, whereas the leaking liquid scenario requires a negative gradient of the base of the facility leading to pipes and sumps or wells. This is obvious since gas flows upward while liquids flow downward. If in doubt as to the possible cause it is probably best to crown the base for liquid flow and any gas that is generated will hopefully work its way through the liquid under pressure. The phenomenon is called *permselectivity*. This decision is obviously an important, and site-specific situation. In either case with the geotextile or geocomposite, one gets puncture protection and a clean working surface for geomembrane installation as bonuses!