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Hydrologic Performance of Synthetic Turf Cover Systems and Their Equivalency to Prescriptive Cover Systems

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ABSTRACT

Synthetic turf cover systems have gained popularity as a viable final cover system alternative to traditional soil-geosynthetic cover systems for various reasons (e.g., less material required, quicker installation, and less maintenance). Federal and state regulations commonly require that the design engineers demonstrate alternative cover systems perform equivalently with the prescribed traditional cover system. This paper presents a comparison between the calculated hydrologic performance of traditional and synthetic turf cover systems for two state regulations; one for municipal solid waste (MSW) landfills and one for hazardous waste landfills. The results of these analyses showed that synthetic turf cover systems have larger annual runoff and drainage collection with similar or smaller annual infiltration through the geomembrane when compared to the traditional cover systems. Therefore, the synthetic turf cover systems perform similar to or better than the prescribed traditional cover systems in terms of infiltration.

INTRODUCTION

Synthetic turf cover systems are a relatively new geosynthetic product that typically consist of the following layers (from bottom to top) [WatershedGeo, 2018]: (i) a structured linear-low density polyethylene (LLDPE) or high density polyethylene (HDPE) geomembrane, which includes studs on the top to act as a drainage layer and spikes on the bottom to increase the interface shear strength of the system; (ii) an engineered turf protective layer, consisting of HDPE grass blades attached to woven geotextiles; and (iii) a thin layer (12.5-mm. thick minimum) of specified infill, which is usually clean sand primarily used for ballasting and protecting the engineered turf and the structured geomembrane. Figure 1 shows a typical detail for a synthetic turf cover system.

Because synthetic turf cover systems typically require less material, are generally quicker to install, and are expected to require less maintenance after installation [WatershedGeo, 2018], they have gained popularity as a viable alternative to the traditional soil-geosynthetic cover system. Federal and state regulations commonly require that the design engineers demonstrate alternative cover systems perform equivalently in terms of infiltration compared to the prescribed traditional cover system. This paper presents a comparison between the calculated hydrologic performance of prescribed traditional cover systems and alternative synthetic turf cover systems to evaluate the hydrologic equivalency of the synthetic turf cover systems for two case studies.

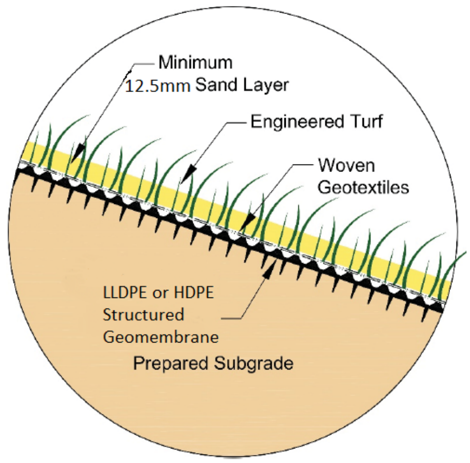

Figure 1. Typical synthetic turf cover system detail [WatershedGeo, 2018]

CASE STUDIES

The case studies examined in this paper represent two state regulations for MSW and hazardous waste landfills with varying slope angles and lengths.

Case Study 1: Indiana MSW Landfill. The first case study examines the Indiana state regulations for MSW landfills. A generic site in Indianapolis, Indiana was considered for this case study. As per Section 22-6(b)(8) of the 329 IAC 10 regulations [Indiana General Assembly, 2004], the slopes of the final cover system must not be less than 4 percent nor greater than 33 percent. Therefore, a 33-percent slope with a 18.3-m slope length and a 4-percent slope with 30.5-m slope length, were considered. Figure 2 shows a comparison between the prescribed traditional soil-geosynthetic cover system and the alternative synthetic turf cover systems for Case Study 1.

As per Section 22-6(b) of the 329 IAC 10 regulations [Indiana General Assembly, 2004], the final cover system for new or existing MSW landfills that have a composite bottom liner and a leachate collection system must consist of the following layers (from bottom to top): (i) a 0.3-m thick methane gas venting layer with a hydraulic conductivity of 1×10^{-3} cm/sec or more; (ii) a 0.6-m thick soil barrier layer with a hydraulic conductivity of 1×10^{-6} cm/sec or less; (iii) a 1.5-mm thick HDPE geomembrane; (iv) a 0.3-m thick drainage layer with a hydraulic conductivity of 1×10^{-3} cm/sec or more; (v) a 0.45-m thick protective layer consisting of earthen material; and (vi) a 0.15-m thick vegetative layer consisting of earthen material that is capable of sustaining vegetation.

For this case study, two alternative synthetic turf cover systems were considered: (i) a synthetic turf cover system that replaces all layers above the soil barrier layer; and (ii) a synthetic turf cover system that replaces all layers above the methane gas venting layer. For both alternatives, the synthetic turf cover system was modeled with the following layers (from bottom to top): (i) a 1.5-mm thick HDPE textured geomembrane; (ii) a 3.3-mm thick studded drainage layer that is part of the HDPE geomembrane; and (iii) 25-mm thick sand infill and engineered turf.

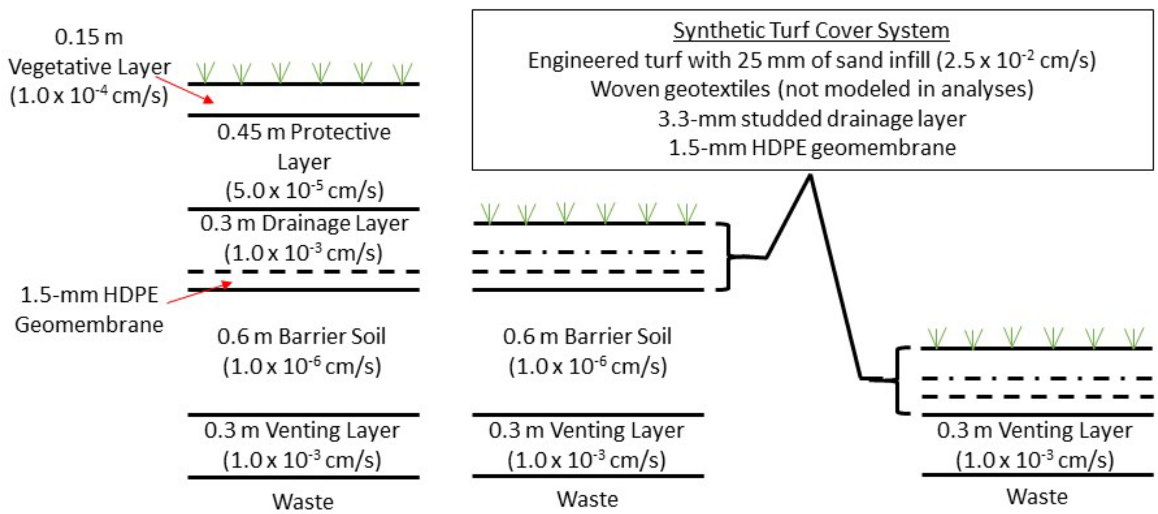

Figure 2. Prescriptive soil-geosynthetic cover system (left) and alternative synthetic turf cover systems with (center) and without (right) a barrier soil for Case Study 1

Case Study 2: Texas Hazardous Waste Landfill. The second case study examines the Texas state and federal regulations for hazardous waste landfills. A generic site in Houston, Texas was considered for this case study. The Texas Commission on Environmental Quality (TCEQ) in Section 335.174(a) of the Texas Administrative Code [TCEQ, 1996] and the U.S. Environmental Protection Agency (USEPA) in Section 264.310(a) of Subpart N of Title 40 [USEPA, 2017] provide design-based requirements for the design of final cover systems of industrial solid waste and municipal hazardous waste landfills. Details for final cover systems that satisfy these design-based requirements are provided by the USEPA [1989]. Maximum and minimum slopes of 33 percent and 3 percent with slope lengths of 19.8 m and 30.5 to 152.4 m, respectively, were considered for Case Study 2. Figure 3 shows a comparison between the prescribed traditional soil-geosynthetic cover system and the alternative synthetic turf cover systems considered for Case Study 2.

As per USEPA [1989], the prescribed traditional soil-geosynthetic cover system for Case Study 2 was modeled with the following layers (from bottom to top): (i) a 0.6-m thick compacted clay liner with a hydraulic conductivity of 1×10^{-7} cm/sec or less; (ii) a 1.5-mm thick HDPE geomembrane; (iii) a 7.6-mm thick geocomposite drainage layer, equivalent in hydraulic conductivity to a 0.3-m thick granular drainage layer with a hydraulic conductivity of 1×10^{-2} cm/sec or more; (iv) a 0.45-m thick protective layer consisting of earthen material; and (vi) a 0.15-m thick vegetative layer consisting of earthen material that is capable of sustaining vegetation. An intermediate/daily cover layer with a thickness of 0.15 m was also modeled below the compacted clay liner.

For this case study, two alternatives were considered for the synthetic turf cover system: (i) the synthetic turf cover system that replaces all layers above the compacted clay liner; and (ii) the synthetic turf cover system that replaces all layers above the compacted clay liner and replaces the compacted clay liner with a 7.6-mm thick geosynthetic clay liner. For both alternatives, the synthetic turf cover system was modeled with the following layers (from bottom to top): (i) a 1.5-mm thick HDPE textured geomembrane; (ii) a 3.3-mm thick studded drainage layer that is part of the HDPE geomembrane; and (iii) 12.5-mm thick sand infill and engineered turf.

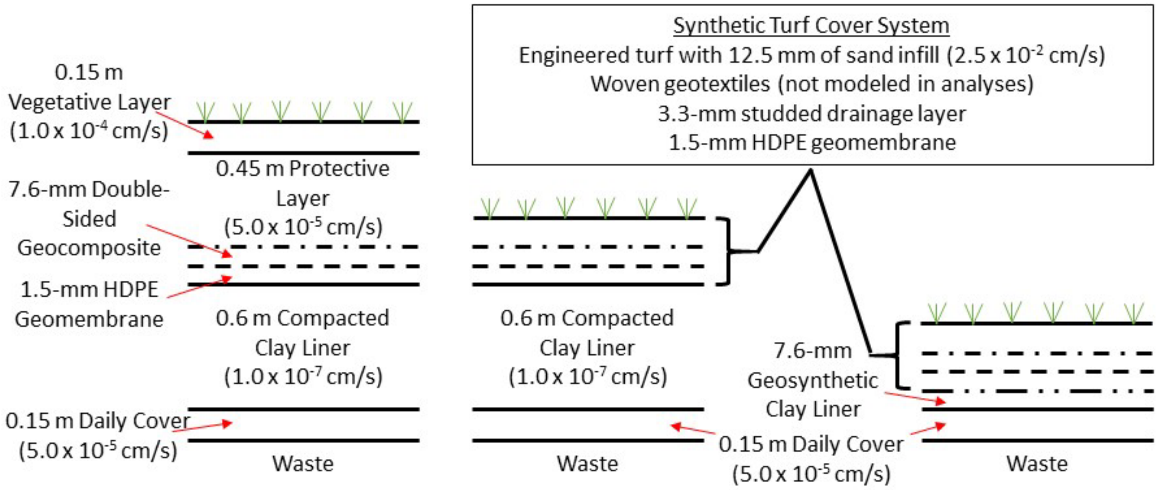

Figure 3. Prescriptive soil-geosynthetic cover system (left) and alternative synthetic turf cover systems with a compacted clay liner (center) and geosynthetic clay liner (right) for Case Study 2

ANALYSIS METHODOLOGY

The calculations for the hydrologic evaluation of the cover systems presented in this paper were modeled using the Hydrologic Evaluation of Landfill Performance (HELP) software, Version 3.07, developed for the USEPA [Schroeder et al., 1994a and 1994b]. The HELP program is a quasi-two-dimensional hydrologic model of water movement across, into, through, and out of a landfill's cover and/or liner systems. The program accepts climate, soil, and design data, and uses a solution technique that accounts for the effects of surface storage, runoff, infiltration, percolation, evaporation, soil moisture storage, and lateral drainage.

Climatic Data. The evaporative zone depth is defined as the maximum depth from which water may be removed by evapotranspiration. This depth affects the storage of water near the surface and directly impacts the computations for evapotranspiration and runoff [Schroeder et al., 1994a and 1994b]. For vegetated surfaces, the evaporative zone depth should be equal to the expected average depth of root penetration. For the traditional cover systems, the evaporative zone depths were selected as approximately 0.5 and 0.6 m for Case Studies 1 and 2 respectively, using the HELP default values. The evaporative zone depth for the alternative synthetic turf cover systems were selected as the combined thickness of the sand infill, engineered turf, and studded drainage layers (i.e., 28.3 and 15.8 mm for Case Studies 1 and 2, respectively).

Synthetic precipitation data for a 100-year modeling period were generated using the synthetic weather generator in HELP and site specific precipitation data from the National Oceanic and Atmospheric Administration (NOAA) precipitation frequency data server. Synthetic daily temperature, solar radiation, and relative humidity data were also generated for a 100-year modeling period for the closest default locations available in the HELP program.

Cover System Properties. Table 1 shows the properties used for the cover system components for Case Studies 1 and 2. The default properties available in the HELP database were used for porosity, field capacity, and wilting point. As noted in Table 1, the hydraulic conductivities of the cover system components correspond to either prescribed limits, typical values, or manufacturer-specified values. Case Study 2 considers long-term site conditions and thus, the hydraulic conductivities of the drainage layers are expected to decrease due to degradation, clogging, and/or creep of the drainage layers. Therefore, the hydraulic conductivities in Case Study 2 have been reduced by a factor of 2.4 to account for some creep, delayed intrusion, particulate clogging, and biological clogging and a factor of safety of 1.5. The reduction factor of 2.4 was developed from available technical literature [Giroud et al., 2000] and is typical for cover systems. Although a reduction factor could also be used for the granular drainage layer in Case Study 1, it was not considered for the analyses presented in this paper.

The geomembrane components of the prescribed and alternative cover systems were modeled to contain one hole per 0.004 km^2 and have good installation quality. For the calculations, each hole was modeled with an area of 1 cm^2 as recommended by Giroud and Bonaparte [1989]. A 100 percent runoff from precipitation on the cover systems was allowed in the HELP models; however, it should be controlled to prevent excessive erosion of the final cover system.

Table 1. Cover system properties used in HELP models

Component	Case Study (1)	Layer Thickness	Total Porosity (2)	Field Capacity (2)	Wilting Point (2)	Saturated Hydraulic Conductivity (cm/sec)	HELP Material Texture # (2)	HELP Layer Type
Vegetative Cover Layer	1, 2	0.15 m	0.471	0.342	0.210	1.0×10^{-4} (3)	12	Vertical Percolation
Protective Soil Layer	1, 2	0.45 m	0.471	0.342	0.210	5.0×10^{-5} (3)	12	Vertical Percolation
Granular Drainage Layer (4)	1	0.3 m	0.457	0.083	0.033	1.0×10^{-3} (5)	3	Drainage Layer
Double-Sided Geocomposite Drainage Layer	2	7.6 mm	0.850	0.010	0.005	11.84 (4.93) (6)(7)	20	Drainage Layer
HDPE Geomembrane	1, 2	1.5 mm	-	-	-	2.0×10^{-13} (7)	35	Geomembrane
Engineered Turf (8)	1	25 mm	0.437	0.062	0.024	2.5×10^{-2}	2	Vertical Percolation
	2	12.5 mm						
Woven Geotextile (8)	1, 2	-	-	-	-	-	-	Not Modeled
Studded Drainage Layer for Textured HDPE Geomembrane (8)	1, 2	3.3 mm	0.850	0.010	0.005	75.76 (31.57) (6)	20	Drainage Layer
Textured HDPE Geomembrane (with spike down) (8)	1, 2	1.5 mm	-	-	-	2.0×10^{-13} (7)	35	Geomembrane
Soil Barrier Layer (9)	1	0.6 m	0.427	0.418	0.367	1.0×10^{-6} (5)	16	Barrier Soil
Methane Gas Venting Layer (4)	1	0.3 m	0.457	0.083	0.033	1.0×10^{-3} (5)	3	Vertical Percolation
Compacted Clay Liner	2	0.6 m	0.427	0.418	0.367	1.0×10^{-7} (5)	16	Barrier Soil
Geosynthetic Clay Liner	2	7.6 mm	0.750	0.747	0.400	5.0×10^{-9} (7)	17	Barrier Soil
Daily/Intermediate Cover (9)	2	0.15 m	0.427	0.418	0.367	5.0×10^{-5} (3)	16	Vertical Percolation

Notes:
(1) Case study identifies for which case study or studies the cover system component was used.
(2) Values shown for total porosity, field capacity, and wilting point correspond to the default values for the selected HELP material texture number.
(3) Hydraulic conductivity values selected based on typical values.
(4) Drainage and methane gas venting layers are modeled with properties typical of filter sands.
(5) Hydraulic conductivity values selected based on minimum design requirements.
(6) Hydraulic conductivity values within the parentheses represent the long-term hydraulic conductivities with a reduction factor of 2.4 applied.
(7) Hydraulic conductivity values selected based on typical values from manufacturers.
(8) Properties for synthetic turf cover system layers were selected based on manufacturers design guidelines [WatershedGeo, 2018].
(9) Soil barrier layer and daily/intermediate cover are modeled with properties typical of compacted clays.

Output Data. The HELP program calculated and output the average annual rates for surface runoff, stormwater collected through the drainage layer, and infiltration through the geomembrane and the average hydraulic head over the geomembrane during the peak daily rainfall event. The average annual rates were calculated for a modeled area of 0.004 km^2 while the average hydraulic head over the geomembrane was calculated for the specified drainage lengths. All calculations considered a 100-yr modeling period. The values calculated for these parameters in the alternative synthetic turf cover systems were compared to the calculated values for the prescribed traditional cover systems and used to evaluate the equivalency of the alternative synthetic turf cover systems.

ANALYSIS RESULTS

Case Study 1. Table 2 presents the calculated average annual rates for runoff, drainage collected, and infiltration and the average hydraulic head over the geomembrane for the traditional and alternative cover systems examined in Case Study 1.

The calculated average annual rates for runoff and drainage collected for both alternative synthetic turf cover systems are approximately 3,000 L/day and 5,600 L/day for the modeled area, respectively, which are larger than the calculated rates for the traditional soil-geosynthetic cover system (i.e., approximately 2,200 L/day and 1,600 L/day for the modeled area, respectively). The alternative synthetic turf cover systems have much less material above the drainage layer (0.03 m) and a higher hydraulic conductivity for the drainage layer (approximately 76 cm/sec) than the traditional cover system (0.6 m and 1.0×10^{-3} cm/sec) and thus, store less water, have a shorter path to the drainage layer, and are able to more quickly convey water collected on the drainage layer. The average annual infiltration rates calculated for both alternative synthetic turf cover systems in this case study are less than the rates calculated for the traditional soil-geosynthetic cover system for both slopes modeled. This observation can predominantly be attributed to the significantly larger calculated hydraulic head over the geomembrane for the traditional soil-geosynthetic cover system (i.e., approximately 18 to 91 cm) compared to the calculated values for the alternative synthetic turf cover systems (i.e., less than 0.1 cm). The use of a barrier soil layer beneath the synthetic turf cover system does not affect the calculated average annual rates for runoff and drainage collected, as expected, but does reduce the calculated average annual infiltration rates by approximately two orders of magnitude.

Table 2. Results for Case Study 1 (reported values are for the modeled area of 0.004 km^2)

Final Cover Alternative	Slope (%)	Slope Length (m)	Barrier Soil Layer	Average Annual Runoff Rate (L/day)	Average Annual Rate of Drainage Collected (L/day)	Average Annual Infiltration Rate through Cover (cm/day)	Average Hydraulic Head over Geomembrane (cm)
Soil-Geosynthetic	33.0	18.3	Yes	2,277	1,623	4.5E-06	18.39
	4.0	30.5	Yes	2,183	1,682	5.3E-05	91.29
Synthetic Turf	33.0	18.3	Yes	2,997	5,634	1.9E-09	0.01
			No	2,997	5,634	1.9E-07	0.02
	4.0	30.5	Yes	3,006	5,568	1.3E-08	0.03
			No	3,006	5,567	2.0E-06	0.03

Case Study 2. The calculated average annual rates for runoff, drainage collected, and infiltration and the average hydraulic head over the geomembrane for the traditional and alternative cover systems examined in Case Study 2 are presented in Table 3.

Like Case Study 1, the alternative synthetic turf cover systems have larger calculated average annual rates for runoff (approximately 2,700 to 2,900 L/day for the modeled area) and drainage collected (approximately 7,600 to 7,800 L/day for the modeled area) than the rates calculated for the soil-geosynthetic cover system (approximately 1,500 to 2,100 L/day and approximately 1,600 to 2,000 L/day for the modeled area, respectively). However, for slope angles of 33 and 3 percent with slope lengths of 19.8 and 30.5 m, respectively, the calculated average annual infiltration rates for the alternative synthetic turf and traditional soil-geosynthetic cover systems are approximately equal. If the slope length for the slope with an angle of 3 percent is increased to 152.4 m, the calculated average annual infiltration rate for the traditional soil-geosynthetic cover system increases by approximately an order of magnitude while the calculated rates for the alternative synthetic turf cover systems do not significantly change. This increase in the calculated average annual infiltration rate for the traditional cover system with the increase in the slope length is likely the result of the drainage layer being unable to convey the water in the cover system for the longer drainage path, as evident by the much larger calculated average hydraulic head (increase from 0.23 cm to 39.46 cm). The use of a geosynthetic clay liner with the alternative synthetic turf cover system in place of the compacted clay liner does not affect the calculated average annual rates for runoff and drainage collected, as expected, but does slightly reduce the calculated average annual infiltration rates because of the lower hydraulic conductivity for the geosynthetic clay liner.

Table 3. Results for Case Study 2 (reported values are for the modeled area of 0.004 km^2)

Final Cover Alternative	Slope (%)	Slope Length (m)	Barrier Soil Layer	Average Annual Runoff Rate (L/day)	Average Annual Rate of Drainage Collected (L/day)	Average Annual Infiltration Rate through Cover (cm/day)	Average Hydraulic Head over Geomembrane (cm)
Soil-Geosynthetic	33.0	19.8	Compacted Clay	2,052	1,585	1.9E-09	0.04
	3.0	30.5	Compacted Clay	1,770	1,785	9.6E-09	0.23
		152.4	Compacted Clay	1,467	2,037	9.4E-08	39.46
Synthetic Turf	33.0	19.8	Compacted Clay	2,708	7,760	1.9E-09	0.01
			GCL	2,708	7,760	1.9E-09	0.01
	3.0	30.5	Compacted Clay	2,736	7,715	7.7E-09	0.08
			GCL	2,736	7,715	3.8E-09	0.08
		152.4	Compacted Clay	2,940	7,599	1.9E-08	1.30
			GCL	2,940	7,599	5.8E-09	1.30

SUMMARY AND CONCLUSIONS

The calculated hydrologic performance of synthetic turf cover systems and traditional soil-geosynthetic cover systems were compared for two case studies that considered different state regulations, landfill types, and slope angles and lengths. Average annual rates for surface runoff, stormwater collected through the drainage layer, and infiltration through the geomembrane and the average hydraulic head over the geomembrane during the peak daily rainfall event were calculated and output by the HELP computer program. The hydrologic equivalency of alternative synthetic turf cover systems to the prescribed traditional soil-geosynthetic cover systems was evaluated by comparing the output data from HELP for the cover systems.

For the two case studies presented in this paper, the alternative synthetic turf cover systems had greater calculated average annual runoff and drainage collection compared to the prescribed traditional cover system because they have a thinner layer for infiltration into the drainage layer and a drainage layer with a higher hydraulic conductivity. The average annual rates of infiltration calculated for the alternative synthetic turf cover systems were approximately equal to or less than the rates calculated for the corresponding prescribed traditional cover systems as a result of the lower calculated average hydraulic heads over the geomembrane components in the alternative synthetic turf cover systems. For Case Study 1, where a granular drainage layer is prescribed for the traditional soil-geosynthetic cover system, or Case Study 2, with the longer drainage slope length, the calculated average hydraulic heads over the geomembrane component in the alternative synthetic turf cover systems are much lower. Based on the results of analyses presented in this paper, the synthetic turf cover systems are considered equivalent compared to the prescribed traditional cover systems in terms of infiltration.

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