ALTERNATIVES TO SECONDARY CONTAINMENT LINING

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ABSTRACT

Federal regulations for the performance of secondary containment system for Aboveground Storage Tanks (AST) at bulk storage facilities states in 40 CFR §112.7(e)(2)(ii), that, "*all bulk storage tank installations should be constructed so that a secondary means of containment is provided for the entire contents of the largest tank plus sufficient freeboard to allow for precipitation. Diked areas should be sufficiently impervious to contain spilled oil.*" State requirements for the performance of secondary containment range from no specific requirements to specified numerical values for design (e.g., hydraulic conductivity, time to control and clean). While it is often assumed that building or retrofitting a secondary containment requires installation of synthetic liners, engineering alternatives exist that may provide equivalent or better protection of the environment.

This paper presents a methodology for selecting the optimum engineering alternative to retrofit secondary containments at bulk storage facilities. In the context of this paper, optimum engineering alternative is defined as the cost-effective engineering alternative that provides the required level of protection of the environment and meets operational constraints. The methodology is based on statistical analyses of failure and releases, risk analysis, and performance analysis.

The methodology is applied to an existing tank farm located inland and above the groundwater table. It is shown that, for this tank farm, optimum protection of the environment can be achieved with the installation of double bottoms, proper overfill

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prevention, and a perimeter catchment system around the tanks rather than through the installation of synthetic liners.

INTRODUCTION

The United States (US) Environmental Protection Agency (EPA) estimated in 1996 that approximately 502,000 facilities have Aboveground Storage Tanks (AST) and store significant quantities of oil in bulk. A typical facility consists of one or more AST. At most of these facilities, the AST are within a secondary containment area.

Historically, secondary containment areas have been built to provide horizontal confinement of the hypothetical spill. The design was governed by fire codes rather than environmental concerns. Consequently, the quality of the secondary containment system varies greatly and range from dikes built out of locally available soil to concrete walls [Figure 1]. The secondary containment area must contain the volume of the largest tank plus reasonable precipitation.

However, in recent years, concern has been the downward migration of product spilled in the secondary containment areas to groundwater and the lack of liners in the secondary containment areas. The USEPA (USEPA, 1996) estimates that approximately 84 percent of the AST facilities do not have impervious liners in the secondary containments.

Considering that a review of discharge data reported by the USEPA (USEPA 1996) indicated that 30 percent of reported oil discharges are to secondary containment areas, there has been an increase in regulatory pressure for requiring the installation of impervious liners in secondary containment areas.

Releases from ASTs may be classified into four broad categories:

- Shell Releases;
- Bottom Releases;
- Overfill; and
- Equipment/Appurtenances Leaks.

Shell releases may occur as a result of structural failure of the shell. A distinction is made between rapid shell release due to total rupture of the shell and slow shell release due to a small defect or a minor failure (cracked fitting). Rapid shell releases due to catastrophic failure of the shell are rare. One of the best known cases is the rupture of the newly repaired diesel tank at the Ashland Oil Terminal in Floreffe Allegheny County, Pennsylvania. On 2 January 1988, the tank ruptured sending releasing almost 3.9 million gallons of diesel fuel [http://www.dep.state.pa.us/dep/pa_env-her/ashland.htm, 2002].

Bottom releases occur through pinhole at the bottom of the tank and are mostly related to corrosion of the bottom plates. Cutter (1999) reports that a leak at a rate of 1 drop/sec will result in a total volume of 34 gallons (128.7 l) or roughly 0.8 barrels in one month.

Overfill occurs when the volume of the product received exceeds the capacity of the tank. The oil is typically released through the roof vent. Overfill are most often related to operator errors.

Equipment/appurtenance releases typically involve a defect or a failure such as cracking or a gasket failure.

The American Petroleum Institute (API) conducted an extensive review of the different types of releases and proposed a series of detection and prevention measures (API, 1997). Because of the risk of environmental impacts from releases at ASTs, regulatory changes have occurred pushing for retrofitting secondary containments.

REGULATORY OVERVIEW

The Oil Pollution Act (OPA) was passed in 1990 and amends §311 of the Clean Water Act (CWA) to increase federal response authority and private response capability and liability. CWA §311 requires the preparation of plan to respond to worst-case discharge of oil and set forth the requirements for these plans. These requirements are detailed in a proposed revision to the Oil Pollution Prevention regulation published as Part 112 of Title 40 of the Code of Federal Regulations (40 CFR 112). In particular, §112.7 details the requirements for a Spill Prevention Control and Countermeasure Plans (SPCC plan). Paragraph §112.7(e)(2)(ii) addresses the issue of secondary containment areas at bulk storage facilities and repairs that "*Diked areas shall be sufficiently impervious to contain spilled oil*." The terminology *sufficiently impervious* is not defined in the regulations.

Other agencies that provide insight in the design of secondary containments are the National Fire Protection Association NFPA Code 30 (NFPA, 1993 and the EPA Liner Study, USEPA (1996). The fire code provides recommendation for height and spacing of the berms. The fire code further specifies that the dikes or berms should be liquid tight. The EPA Liner study does not make any recommendation for permeability of the liners and further specifies that the requirement should be part of a voluntary program at state level.

At the state level, a review of all state regulations indicated a wide range of requirements. Example of requirements include:

- No Liner Required: CA, IL, MA
- Sufficiently Impermeable: AK and LA
- Impervious: KS and WI
- Liquid Tight: AL and 32 Other States that follow the NFPA 30 Fire Code
- No Breakthrough Within 72 Hours: VA
- Specific Values of Hydraulic Conductivity: MD: 1×10^{-4} cm/sec, PA: 1×10^{-6} cm/sec, ID: 1×10^{-7} cm/sec

RETROFITTING OPTIONS

There are two major groups of options for retrofitting an AST facility to minimize the risk of contamination of the environment by releases. The first group includes the installation of liners in the secondary containment areas or enhancing the soil in place. The second group includes the installation of environmental controls or the use of preventative measures or enhancement of the tanks. Table 1 below lists different options for each of the two groups.

TABLE 1: RETROFITTING OPTIONS

LINER OPTIONS		ENVIRONMENTAL/CONTROL OPTIONS	
Surficial Liners	**Enhanced Existing Soil Liner**	**Environmental Controls**	**Prevention and Enhancement**
Geomembrane	Biological Clogging	Slurry Walls	Double Bottoms in Tanks
Geosynthetic Clay Liner	Chemical Clogging	GW Control	Leak Detection Systems
Compacted Clay	Soil Cement		Preventative Measures
Concrete	Chemical Grouting		Backflow Prevention
Asphalt	Soil Bentonite		Overfill Prevention
Spray-On Liners			Operational and Procedural Controls

SELECTION METHODOLOGY

The selection methodology is a two-step process. The first step is to select the optimum liner. The second step is to select between a liner option and an environmental or enhancement option. To select, design, and implement the cost effective, technically sound and environmentally effective liner solution, a list of selection criteria was developed. The list includes criteria related to site conditions, engineering design, construction, operator issues, and cost. These criteria are listed in Table 2.

TABLE 2: SELECTION CRITERIA FOR LINER OPTIONS

Site Conditions	Engineering Design	Construction	Operator Issues	Cost
Existing Conditions	Product Compatibility	Constructability	Operation & Maintenance	Capital
Geometry	Desiccation Resistance	Availability of Materials	Operational Flexibility	Maintenance
Penetrations	Freeze-Thaw Resistance	Weather	Storm Water Management	Clean-up
Regulatory Acceptance	Temperature Extremes		Clean-up	Remediation
	Wind Resistance		Subsurface Remediation	
	Ultraviolet Resistance		Trafficability	
	Fire Resistance		Vegetation Control	

The methodology for selecting the optimum liner option is based on a ranking of the options. Each option is graded with respect to each of the selection criterion using a qualitative grade scale. The qualitative grade scale developed to rank the liner options is shown in Table 3.

TABLE 3: GRADING SCALE

GRADE	DEFINITION
A	Satisfactory Performance With Minimal Extra Effort
B	Satisfactory Performance if Specific Design Elements are Implemented
C	Significant Extra Effort May Be Required To Achieve Satisfactory Performance
D	Satisfactory Performance May Not Be Feasible
F	Satisfactory Performance Will Not Be Feasible

A matrix is developed summarizing site information, comments about the applicability of each criterion to each liner option, and the qualitative grade assigned to each liner option. The matrix developed for the example examined in this paper is shown in Table 4. The grades are tallied up and a ranking of the options is then established based on the total grade of each option. The top three options are then examined further to ensure that they will meet the intent of the design and meet the Owner's preferences if any.

The second step in the methodology is to compare the top-ranked liner option to a solution from the Environmental/Control group of options. This comparison is based on a risk analysis of the consequences of a spill. The risk analysis is based on an estimate of the volume of product that would be released on an annual basis to the environment under different scenarios and assuming a catastrophic failure.

To compare a liner in the secondary containment areas to a retrofitting of the tanks, the following two scenarios are examined:

- Scenario 1: Liner in the facility and single bottoms in the tanks.
- Scenario 2: No liner in the facility and double bottom in the tanks.

Under scenario 1, the volume of petroleum product, V_1 that will be released to the environment when a liner is installed in the open area and the single bottoms are left unchanged is given as:

V_1 = (Leakage Rate through Bottom) x (Area of Bottom) x (Time)

Note that it is assumed in these scenarios the bottoms have defects and/or pinholes and that the liner installed in the secondary containment does not. This latter assumption is conservative as depths in liners installed in tank farms have been observed. Defects in liners come from puncture, incomplete seams, or gaps at boots installed around pipe penetrations (Figure 2). Studies by Giroud and Bonaparte (1989) have shown that geomembrane liners installed with strict construction quality assurance could be considered to have one to two defects per acre with a diameter of 2 mm. Using electric detection surveys Laine (1991) has shown that liners installed with strict construction quality assurance could have five or more defects per acre with diameter less than 0.5 mm. In tank farms where numerous boots are installed around pipe penetrations, support, and others appurtenances it is expected that even with a very strict construction quality assurance the number of defects will exceeds the numbers listed previously. The importance of these defects is very important as they lower the effectiveness of the liner to function as an impervious barrier. The role of such defect in lowering the effectiveness of liner was further demonstrated by King et al. (1997). King et al. (1997) showed that a geomembrane with a defect rate of about 2 in^2/acre provided the same level of protection in the case of a catastrophic spill as a soil with a hydraulic conductivity of 10^{-5} cm/s.

Under scenario 2, the volume of petroleum product, V_2 that will be released to the environment when double bottoms are installed in each AST and the open area within the secondary containment area is left unchanged is given as:

V_2 = (Leakage Rate through Double Bottom) x
(Area of Double Bottom) x (Time) + (Volume of Product Infiltrated in Soil
Following A Hypothetical Catastrophic Failure)

The better scenario is the scenario that will minimize the volume of petroleum product release to the environment over the economic life of the tank farm.

Define a performance ratio to compare the two options:

$PR = V_1 / V_2$

Because PR is a function of time and of the volume of product infiltrated in the soil, it will depend upon the site characteristics such as the hydraulic conductivity of the soil, and will range from values less than one to values greater than 1. PR equals to 1 indicates that the two options are comparable. A PR greater than 1 indicates that the release to the environment is greater under Scenario 1 and, therefore, that Scenario 2 is a better scenario and installing double bottoms at the facility is a better option for protection of the environment than installing a liner in the facility while leaving the tank bottom untouched. The use of PR allows the owner to measure the level of risk he is willing to assume when considering retrofitting options.

EXAMPLE

The methodology discussed above is applied to a tank farm located inland in the Pacific Northwest. The tank farm includes 7 tanks storing refined petroleum product. The following information is available about the terminal:

TABLE 5: INFORMATION ABOUT SITE

Secondary Containment Areas: Total Area: 140,000ft^2 Open Area: 83,000ft^2 Area of Tank Bottom: 57,000ft^2 Height of Dikes: 5ft	**Largest Tank:** Diameter: 120 ft Safe Fill Height: 46ft Volume: ≅ 93,000 bbls
Soil: Homogenous Sand Deposit $k = 10^{-5}$ m/sec Thickness > 100ft Groundwater Depth: 50ft	**Tank Bottoms:** Average pinhole diameter d = 1 mm (0.04 in.) Average number of pinholes: 1/acre of bottom

Table 4 shows the ranking of the liner options for the facility. The ranking shows that a geomembrane is the preferred liner option. The second step is to compare installation of a geomembrane at the facility versus retrofitting the tanks by installing double bottoms with leak detection systems, a system of overfill protection at the terminal, and a spill recovery system. The spill recovery system consists of a pump with a pumping capacity of 2,500 gpm that can be activated in no less than 6 hours after a catastrophic spill has occurred.

The performance ratio PR discussed above is evaluated in the following. The volume of petroleum product, V_1 that will be released to the environment on an annual basis when geomembranes are installed in the open area and the single bottoms are left unchanged is given as:

V_1 = (Leakage Rate through Single Bottom) x (Area of Single Bottom) x (Time)

Using the Giroud et al. method (Giroud et al., 1997), the leakage rate is evaluated as a function of product height. Figure 3 shows flow in gallon/day as function of product height ranging from 0 to 50 ft. Under the product fill height of 46 ft in the tank, the leakage rate is 167 gallons per day (gpd) per acre.

V1= (167 gpd/acre)*(57,000ft^2/43.560 ft^2/acre*(365 days/year)/(42 gallons/bbl)
V1= 1899 bbls/year

The volume of petroleum product, V_2 that will be released to the environment on an annual basis when double bottoms are installed in each AST and the open area within the secondary containment area is left unchanged is given as:

V_2 = (Leakage Rate through Double Bottom) x
(Area of Double Bottom) x (Time) + (Volume of Product Infiltrated in Soil)
following the catastrophic spill.

For a double bottom tank, we assume that there is about 0.5 in of product that may have gone undetected by the leak detection system on top of the original old bottom. Therefore we assumed that there is 0.5 in. of head driving the flow out of the double bottom system. Under this assumption the flow is about 2.88 gpd/acre (Figure 2).

The volume of product infiltrated in the ground is estimated using the numerical model XSLIM (eXpanded Soil Liner Infiltration Model) (Myers et al, 2001) developed to assess the effectiveness of soil liners in controlling hypothetical catastrophic spills in secondary containment areas. XSLIM simulates penetration of petroleum product into the soil liner and the underlying vadose zone. In addition, XSLIM takes into account the response time from the operators, the pumping rate, and the decreasing ponding height of petroleum product as it is recovered from the secondary containment area. The calculated depth of infiltration of product in the ground is 0.54ft. Consequently the volume of product infiltrated in the ground is equal to the depth times the area times the porosity of the soil:

V_2 = (2.88) * (57000/43560)*(365 days/year)/(42 gallons/bbl)+
(0.54ft)*(83,000ft^2)/(5.6ft^3/bbl)*(0.35)
V2=2801bbls + 32.8 bbls/year

To compare the two retrofitting option the performance ratio defined as:

PR= V_1 / V_2

is evaluated as a function of time and plotted in Figure 4. Figure 4 shows that the performance ratio is one at 1.5 years. This indicates that unless the return period of a catastrophic failure of the largest tank containing 93,000 bbls is less than 1.5 years then installing double bottoms in the seven tanks at the tank farms provide better protection of the environment. The performance ratio was calculated assuming a defect size of 0.5mm and is reported in Figure 4. Figure 4 indicates that the PR is equals 1 after 6 years. Unless a catastrophic spill occurs every 6 years, a better protection of the environment is obtained retrofitting the tank bottoms rather than placing a liner at the facility and leaving the tank bottom untouched.

CONCLUSION

This paper presented a methodology to select the optimum engineering alternative at bulk storage facilities. The methodology provides tools to select the optimum liner option and tools to compare the liner option to alternative approach to secondary containment lining. The methodology was applied to an example and it was shown that for the site-specific conditions of the facility the optimum engineering alternative to protect the environment is to install double bottom in the tanks with an overfill protection system.

The opinions expressed in this paper are those of the authors and one should not assume endorsement by the US EPA.

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TABLE 4: RANKING OF LINER OPTIONS FOR SITE EXAMPLE

		Geomembrane		Geosynthetic Clay Liner		Spray-On Liners		Compacted Clay		Concrete		Asphalt	
		Plastic sheeting (geomembrane) is placed on ground. Sections are welded at edges to make a contiguous fluid barrier. Geomembrane is covered with a 1-ft thick protective soil layer		A geosynthetic clay liner (GCL) consists of either two geotextiles sandwiching a layer of bentonite or a geomembrane with a layer of encapsulated bentonite. It is installed like a rug and seaming is achieved by overlapping and placing powdered bentonite between the two materials along the seam. GCL is covered with a layer of soil for protection.		Liquid polymer is sprayed onto a nonwoven geotextile that is placed on a prepared soil surface. Result is a geomembrane-like barrier. Types commonly used today include polyurea and polyurethane.		Fine-grained soil is moisture conditioned and compacted to produce a low-permeability barrier. Material is typically compacted in 6-in. lifts, with total compacted thickness on the order of 2 ft.		Reinforced concrete slab is constructed to form a moisture barrier.		Two layers of asphalt sandwiching a resin-soaked nonwoven geotextile fabric; fabric is the primary permeability barrier.	
CRITERIA	**GENERAL DESCRIPTION**	**COMMENTS**	**GRADE**	**COMMENTS**	**GRADE**	**COMMENTS**	**GRADE**	**COMMENTS**	**GRADE**	**COMMENTS**	**GRADE**	**COMMENTS**	**GRADE**
Site Conditions													
Existing Conditions	Silty sand with some boulders, water table is approximately 50 and deep	boulders will need to be removed or covered. regrading is needed to make tanks the highest points within the diked areas	B	Boulders will need to be removed or covered, especially if a geomembrane-type GCL is used. Regrading is needed to make tanks the highest points within the diked areas	B	Boulders will need to be removed or covered. Regrading is needed to make tanks the highest points within the diked areas	B	Regrading is needed to make tanks the highest points within the diked areas	B	Regrading is needed to lower the diked areas; some subgrade preparation may also be required	C	Regrading is needed to lower the diked areas; some subgrade preparation may also be required	C
Geometry	Site is flat with available open space for construction operations and staging	Plenty of open space for construction at site, intermediate dikes may be removed to facilitate construction	A	Plenty of open space for construction at site, intermediate dikes may be removed to facilitate construction	A	Plenty of open space for construction at site, intermediate dikes may be removed to facilitate construction	A	Plenty of open space for construction at site, intermediate dikes may be removed to facilitate construction	A	Plenty of open space for construction at site; intermediate dikes may be removed to facilitate construction	A	Plenty of open space for construction at site; intermediate dikes may be removed to facilitate construction	A
Penetrations	Penetrations to be sealed include tank bottom chine, 3-ft deep concrete pipe foundations, and cathodic protection boxes; generally less than 10 penetrations per tank	Boots and seals required for pipeline foundations, pumps and at tank edge	B	Requires proper construction with bentonite seals at pipeline foundations and around tank edge	B	Excellent method for sealing penetrations around pipeline foundations and around tank base	A	Requires proper construction with bentonite seals	B	Boots or gaskets will be required around pipeline foundations and around tank base	B	Boots or gaskets will be required around pipeline foundations and around tank base	B
Regulatory Acceptance	Federal and State requirements	Very likely (proven technology)	A	Very likely (proven technology)	A	Very likely (proven technology)	A	Very likely (proven technology)	A	Very likely (familiarity)	A	Likely (effective, but novel approach)	B

TABLE 4: RANKING OF LINER OPTIONS FOR SITE EXAMPLE (continued)

		Geomembrane		Geosynthetic Clay Liner		Spray-On Liners		Compacted Clay		Concrete		Asphalt	
Engineering Design													
Product Compatibility	Tanks contain common petroleum hydrocarbon products	Limited reduction in strength properties after exposure to hydrocarbons for most geomembrane types. Reduced strength estimates can be used for design (I.e. puncture resistance, weld strength, etc.).	B	Not significantly impacted by exposure to hydrocarbons if hydrated	B	Not of concern with polyurea; of minor concern with polyurethane	B	If soil is dry when exposed to hydrocarbons, permeability will be high; soil should remain hydrated	C	Not of concern	A	Released product will partially deteriorate the asphalt	D
Dessication Resistance	Average annual precipitation is 17 in.; driest months are July, August and September (average monthly precipitation is less than 1 inch)	Not of concern	A	Dessication will increase permeability to an unacceptable level; GCL must remain hydrated; irrigation may be required in summer months	C	Not of concern	A	dessication will increase permeabilty in higher-plasticity materials; irrigation may be required in summer months	C	Not of concern	A	Volatile fraction in asphalt will evaporate with time; may induce some cracking	C
Freeze Thaw Resistance	Five months out of the year (November-March) have average high and low temperatures that are above and below freezing	Not of concern	A	GCL recovers from freeze-thaw cycles	B	Not of concern	A	May induce microcracking and reduce surficial permeability	C	Freeze-thaw may worsen existing cracking	C	Freeze-thaw may worsen existing cracking	C
Temperature Extremes	Difference between average annual high and low temperature is 61 degrees; difference between all-time high and all-time low is 133 degrees	Tempurature variations may induce stress concentrations and geomembrane rupture at welds and the geomembrane may become brittle at low temperatures, but the cover soil will reduce the effect	B	Not of concern	A	Some polyurethanes may become brittle at low temperatures	B	Not of concern	A	Temperature extremes may induce cracking	C	Temperature extremes may induce cracking	C
Wind Resistance	Windiest months are March and April (average wind speed = 13 mph)	Not of concern	A	Not of concern	A	Requires anchoring at dikes; ballast in open areas may also be required	B	Not of concern	A	Not of concern	A	Not of concren	A
Ultraviolet	Sunniest months are	Not of concern	A	Not of concern	A	Limited Concern	B	Not of concern	A	Not of conern	A	Not of concren	A

TABLE 4: RANKING OF LINER OPTIONS FOR SITE EXAMPLE (continued)

		Geomembrane		**Geosynthetic Clay Liner**		**Spray-On Liners**		**Compacted Clay**		**Concrete**		**Asphalt**	
Resistance	July and August, with 80% average possiblility of sunshine and 16 clear days per month												
Fire Resistance	Potential for spill and subsequent fire is considered low; smoking is not allowed at either terminal	Not of concern	A	Not of concern	A	Generally flammable, but flame-retardant polyurethanes are available	B	Not of concern	A	Not of conern	A	Not of concren	A
Operator Issues													
Construction	NO ISSUES												
Operations and Maintenance	Maintenance will include periodic inspection and repair of liners at facility	Repair requires trained specialists; difficult to inspect with soil cover	C	Easily repaired; but needs to remain covered and hydrated	C	Repair requires training of personnel, but repair kits can be used	B	Will need to prevent plant growth	B	Requires periodic inspection and sealing of cracks	B	Requires periodic inspection and sealing of cracks/patching	B
Operational Flexibility	Typical operations includes painting, snow removal, tank inspection and cleaning, and tank vac truck operation	Vehicular access restriction is reduced by the cover soil, but there will still be size limits for vehicles	B	Vehicular access restriction is lessened by burying the GCL, although there will still be size limits for vehicles	B	Access to tanks will be restricted unless the liner is protected with a layer of cover soil	B	Will restrict vehicular access if wet unless covered with granular protective layer	B	Not of concern	A	Not of concern	A
Stormwater Management	Average precipitation is 17 in./yr; wettest month is December (2.3 in/month); wettest month on record was 5.7 in.; sheen on water will require treatment	Good flow along geomembrane surface; need to minimize ponding near tank; sheen on water may result from impacted soil	B	Flow is slower than geomembrane; need to minimize ponding near tank; sheen on water may result from impacted soil	C	Excellent flow; need to minimize ponding near tank	A	Flow is slower than geosynthetic options; Sheen on water may result from impacted cover soil	C	Excellent flow; need to minimize ponding near tank	A	Excellent flow; need to minimize ponding near tank; sheen may result from asphalt	C
Clean-Up	Spills may occur due to overfills; unzipping spill is considered highly unlikely	Geomembrane may be damaged during cleanup operations; cover soil will need to be removed	C	Impacted GCL can be removed and replaced with new GCL after a spill; cover soil will need to be removed; subsequent repair is easier than buried geomembrane cover	B	May be damaged during cleanup	B	Requires soil removal	C	Not of concern	A	Accidental release of product (e.g. overfill) will partially deteriorate the asphalt	C
Subsurface Remediation	BTEX, MtBE, and others were not detected above threshold cleanup levels at either site in	Requires significant effort to remove for access to underlying soil and repair afterwards	C	Requires significant effort to remove for access to underlying soil; subsequent repair is easier than	B	Easy to remove for access to underlying soil	B	Underlying soil is accessible with minor excavation	B	Significant effort required to remove the concrete for access to underlying soil	C	Significant effort required to repair after removal	C

TABLE 4: RANKING OF LINER OPTIONS FOR SITE EXAMPLE (continued)

		Geomembrane		Geosynthetic Clay Liner		Spray-On Liners		Compacted Clay		Concrete		Asphalt	
	recent monitoring reports; remediation is not considered necessary at this time			buried geomembrane cover									
Trafficability	Vehicles require access to and around the perimeter of the tanks	Trafficable if cushioned and covered	B	Trafficable if cushioned and covered	B	Will restrict vehicular access to tanks; trafficable if cushioned and covered	C	Trafficable under dry conditions	B	Not of concern	A	Not of concern	A
Vegetation Control	Containment areas are periodically sprayed for weeds, although some weeds were found during the site inspection	Vegetation control will reduce the potential for root penetration	B	Essential	C	Not of concern	A	Essential for proper performance	C	Not of concern if cracks are sealed	B	Not of concern if cracks are sealed	B
Costs						**Economic and Political Criteria**							
Capital cost per square foot (not including engineering and CQA)	Preliminary costs to be used for comparison purposes only and not for bid preparation; these costs will need to be refined prior to bid preparation	Moderate to high -- $2.80 - 4.30 (includes geotextile cushion, boots, sealing around tank, and 1 ft protective cover soil)	C	Moderate -- $2.60 - 3.40 (includes geotextile cushion and 1-ft protective cover soil)	C	High -- $4.00 - 7.00 (range for flexible and rigid type polyurethanes)	D	Low to moderate -- $1.70 - 4.00 (for 2-ft thick layer; increase cost for hauling distances greater than 20 miles; total cost includes grading of existing surface, hauling, spreading and compaction)	C	High -- $5.00 - 6.60 (for 6 to 8-in. reinforced slab)	D	High -- $4.50 - 5.40 (includes 6 in. to 1 ft base, and 4 in. total asphalt thickness)	C
Maintenance	Maintenance may include devegetation, period inspections and repairs at each terminal	Low (should prevent plant growth)	B	Moderate (GCL must remain hydrated)	C	Low (repair kits are available)	B	Low (must prevent plant growth)	B	Low (periodic inspection and crack sealing)	B	Low (periodic inspection and crack sealing)	B
Clean-Up	Spills may occur due to overfills; unzipping spill is considered highly unlikely	High (removal of cover soil and possible repair of geomembrane)	D	High (removal of cover soil and replacement of GCL)	D	Low (some repair may be required)	B	High (due to soil removal)	D	Low	B	High (repair of paving fabric system)	D
Remediation	BTEX, MtBE, and others were not detected above threshold cleanup levels at either site in recent monitoring reports	High (due to removal of soil and geomembrane and repair of geomembrane)	D	Moderate (due to removal of cover soil and repair of GCL)	C	Moderate (removal and repair of cover required	C	Low	B	High (removal of concrete required)	D	High (replacement of paving fabric system)	D
Overall Performance		Excellent	**A**	Excellent	**A**	Excellent	**A**	Excellent	**A**	Excellent	**A**	Excellent	**A**

TABLE 4: RANKING OF LINER OPTIONS FOR SITE EXAMPLE (continued)

		Geomembrane		Geosynthetic Clay Liner		Spray-On Liners		Compacted Clay		Concrete		Asphalt	
Overall Reliability		Good	**B**	Average	**C**	Good	**B**	Average	**C**	Average	**C**	Average	**C**
Critical Performance and Reliability Issues		Proper construction and CQA are important to achieve acceptable performance; potentially high cleanup costs		GCL must be initially confined and hydrated remain confined and hydrated to perform properly; potentially high cleanup costs		Susceptibility to damage (although not as susceptible as a geomembrane) and cost		Susceptible to dessication cracking; potentially high cleanup costs; high soil procurement costs may prohibit this option		High construction costs, potential for cracking, and potentially high cleanup effort		Spill will chemically attack the asphalt; there is a significant potential for cracking and a potentially high cleanup effort associated with this option	
COMMENTS		This is an effective, reliable liner that can be constructed at a moderate cost and impose less hindrance to operations than the exposed geomembrane		This is an effective liner, but it must remain confined and hydrated to perform properly		This liner is durable, reliable, and excellent for odd geometries, but somewhat expensive		This is an effective liner, but may dessicate if not hydrated; procurement costs could be high		This liner is expensive and susceptible to cracking, but effective and durable		This liner is effective, but susceptible to chemical attack during a spill	
RANK		**1**		**2**		**3**		**5**		**6**		**7**	

FIGURE 1: TYPICAL SECONDARY CONTAINMENTS

FIGURE 2: DEFECTS IN GEOMEMBRANES

FIGURE 3: LEAKAGE RATE THROUGH DEFECT IN TANK BOTTOM

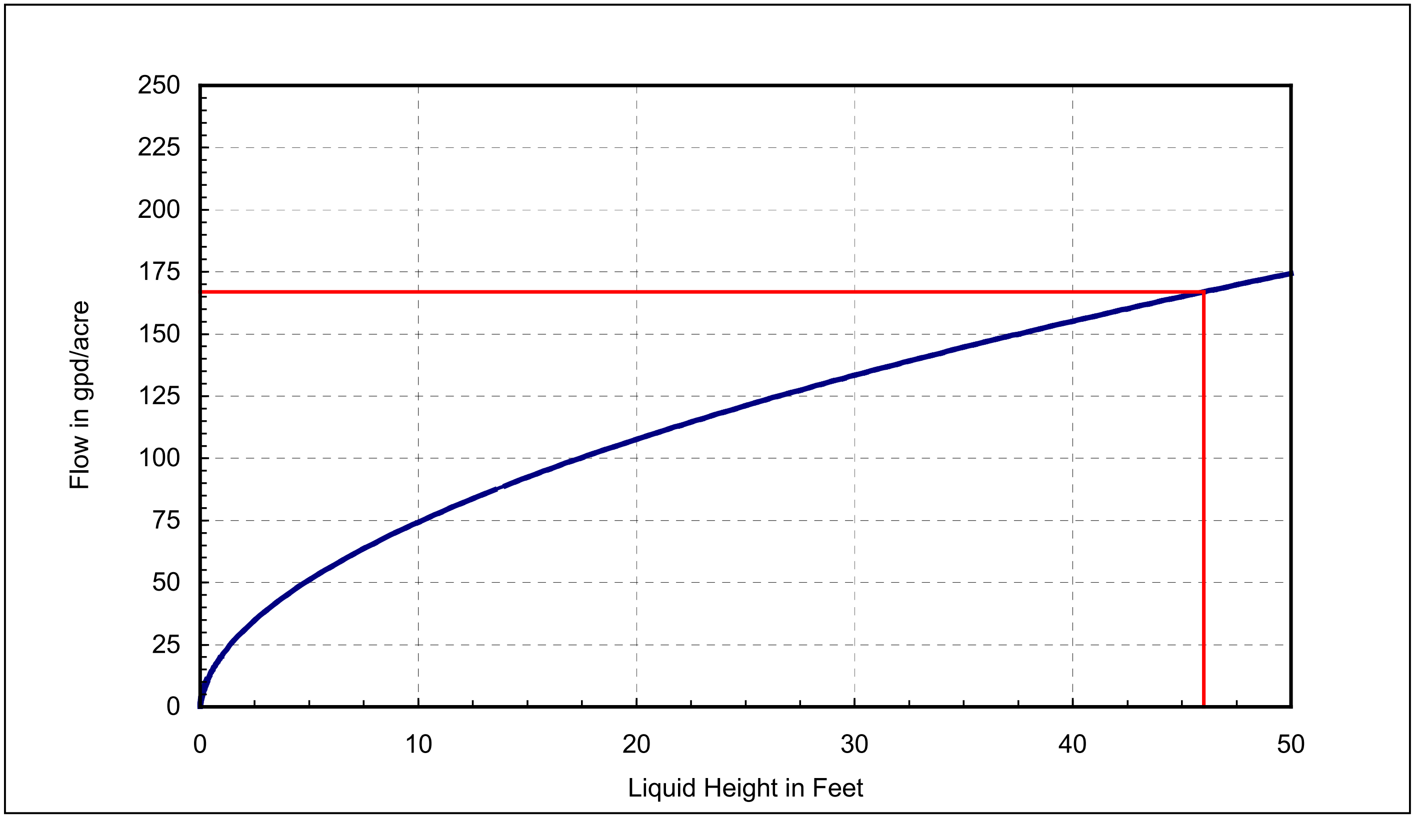

FIGURE 4: PERFORMANCE RATIO