A STUDY OF THE MERITS AND EFFECTIVENESS OF ALTERNATE LINER SYSTEMS AT ILLINOIS LANDFILLS

A RESEARCH PAPER
Submitted in Fulfillment of House Resolution 715
State of Illinois 92nd General Assembly
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by
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AN ABSTRACT OF THE RESEARCH PAPER OF

THE ILLINOIS ENVIRONMENTAL PROTECTION AGENCY, for House Resolution 715 of the State of Illinois 92nd General Assembly.

TITLE: A Study of the Merits and Effectiveness of Alternate Liner Systems at Illinois Landfills

The 92nd General Assembly directed the Illinois Environmental Protection Agency to study the merits and effectiveness of multiple liner systems at Illinois landfills and provide a recommendation on the advisability of requiring multiple liner systems at all future municipal solid waste landfills. This report analyzes current liner designs, evaluates the design's effectiveness and relative cost, and evaluates other alternate multiple liner designs including their cost and effectiveness. This report evaluates the current minimum liner design standard in Illinois for municipal solid waste landfills of a single liner system. Analysis of the single liner system's effectiveness for protection of human health and the environment is presented with an evaluation of the double-composite liner design for municipal solid waste landfills. This report includes a summary of regulatory requirements from other states for comparison. Finally an evaluation of the relative cost of liner designs is provided.

An evaluation of the effectiveness of the liner design standards of the existing Illinois regulations is not as straightforward as it would appear. The liner design for municipal solid waste landfills relies on the collection and removal of liquids from the landfill to

effectively protect human health and the environment. The Illinois regulations specify minimum design standards and also require an evaluation of the design in the specific geologic and hydrogeologic setting. The evaluation of the specific design can result in additional requirements beyond the minimum design standard including, but not limited to, a double-composite liner system.

Modifying the Illinois regulations to change the minimum liner design requirement from a single liner to a double-composite liner is not recommended at this time. Given the compromises that arise due to the complicated construction of double-composite lined municipal solid waste landfills, there is a much better chance of successfully completing construction of the liner if the design is kept simple. Also the additional cost of a double-composite liner is substantial without corresponding protection, except where shown to be necessary for the specific geologic and hydrogeologic setting. The current minimum technical requirements contained in the Illinois regulations are protective of human health and the environment.

A draft copy of this report was forwarded to Dr. David E. Daniel, P.E., Dean, College of Engineering at the University of Illinois for his review and comment. Dr. Daniel is a published expert on landfill design, specifically liners. In his review Dr. Daniel stated that "(t)o the best of my knowledge, there has been no documented instance of groundwater contamination anywhere in the U.S. as a result of leakage through single-composite liner systems, such as required in Illinois… In my view, the key issue to protect groundwater from landfills is not how many liners are used, but assurance that the liners are properly constructed, and construction verified through a very thorough construction quality assurance program… I agree with the report's conclusion that modifying Illinois regulations to require double liners is not recommended at this time."

AKNOWLEDGEMENTS

I would like to thank Vasantha Gudiwada who spent her summer as a Governor's Environmental Corps intern researching this paper. Also, from within the Illinois Environmental Protection Agency many people spent a great deal of time reviewing, offering comments and assisting in the contract development for this paper. I would like to express my sincere appreciation to those people, particularly, Chris Liebman, Gwenyth Thompson, Vanessa Keehner, Neelu Reddy, John Sherrill, Richard Amoako, Michael Nechvatal and William Child.

I wish to thank Earthtech for researching and completing the attached summary and cost estimates within a short time frame. In particular, I would like to thank Andy Querio, Shaoyan Gao, Ed Doyle and Terri Blackmar.

Finally I would like to thank Dr. David Daniel for taking time to review this paper under such a limited time frame.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ATTACHMENTS

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Introduction

According to the U. S. Environmental Protection Agency Office of Solid Waste (1989), the United States produces enough solid waste each year to fill ten 145,000-mile long dumpsters. The question of how to best manage these wastes has been a problem for decades. There are hundreds of different materials and products of varying weight and material composition. Primary methods developed to manage waste include incinerators, landfills and recycling facilities.

Landfills are sites that permanently store waste in a manner that minimizes the release of contaminants into the environment. The environmental containment systems for municipal solid waste landfills include a system beneath the waste and a cover system constructed over the waste. The system beneath the waste generally consists of a combination of a drainage layer overlaying low-permeability barriers or liners. The functions of liners and the drainage layer are complementary and work together to prevent the uncontrolled discharge of contaminants to the environment.

The drainage layer or leachate collection and removal system is an integral part of the environmental protection system of any liner. Leachate is the contaminated liquid in a landfill that passes through or has been in direct contact with solid waste. The leachate collection system is placed directly below the waste for the purpose of collecting the liquid above the liner. If this contaminated liquid is not removed from the landfill it creates a hydraulic head or downward force on the liner that drives the liquid out of the landfill. The leachate collection system collects and conveys leachate within the landfill to controlled collection points or sumps to limit the buildup of leachate or hydraulic head on the liner. The leachate collection system consists of a granular layer with perforated pipes to convey the leachate to the leachate removal system. The leachate removal system may contain networks of sumps, pumps, flow meters, and other flow conveyance and monitoring components for the purpose of removing the leachate on top of the liner.

The purpose of the liner is to impede leachate and gas migration out of a municipal solid waste landfill and improve the collection capability of the overlying drainage layer. Liners installed beneath modern municipal solid waste landfills generally consists of a recompacted earth liner, a single-composite liner or double-composite liner. The recompacted earth liner, as shown on Figure 1 as base liner system #1, consists exclusively of clay soil that is recompacted to a certain specification to limit movement of leachate through the material. The single-composite liner system, as shown on Figure 1 as base liner system #2, consists of a layer of recompacted clay soil beneath a geomembrane which is a man-made plastic material of a specified thickness. Both of these types of liner systems are directly overlain with a leachate collection system. The double-composite liner system, as shown on Figure 1 as base liner system #3, consists of a primary liner overlaying a secondary liner with a leak detection layer between the two liners. Both the primary and secondary liners have two low permeable components. The leak detection layer is a layer between the two liners. The purpose of the leak detection layer is monitor the performance of the upper liner and allow appropriate action to be taken when leachate is found in this layer. This liner system has a leachate collection system directly above the primary liner.

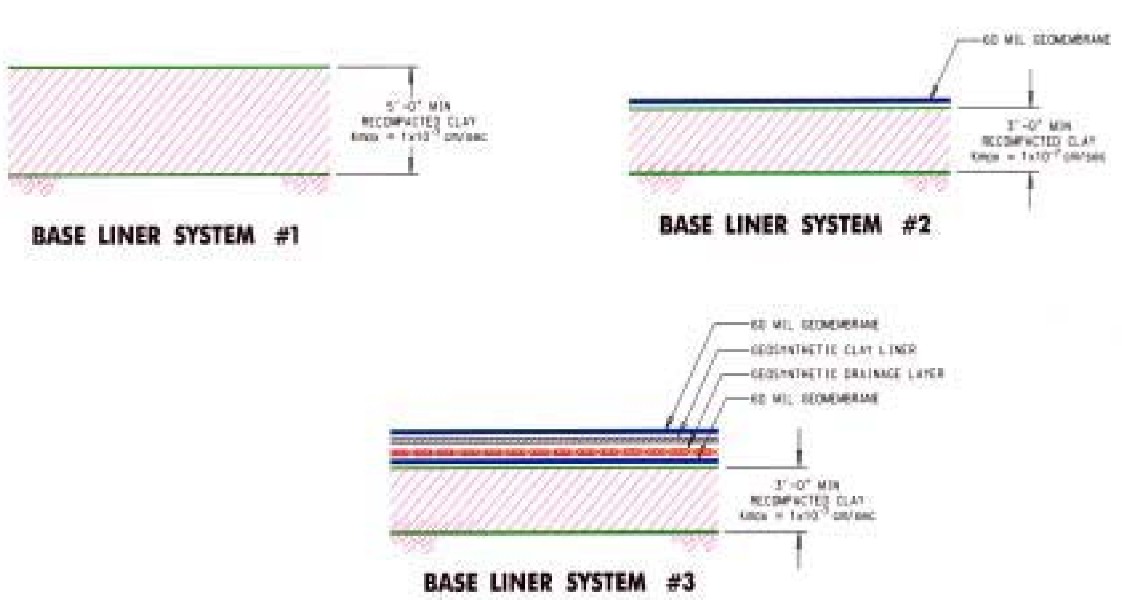

Figure 1: Base Liner Systems

Current Regulations

The current regulations in Illinois require that all municipal solid waste landfills be equipped with leachate collection and liner designed as an integrated system. The minimum design requirements for a liner in Illinois include two options. The first allows a recompacted earth liner with a minimum thickness no less than 5 feet and a specified compaction as shown on Figure 1 as base liner system #1. The second is a single-composite liner consisting of a geomembrane immediately overlaying a recompacted earth liner of a minimum of 3 feet in thickness as shown on Figure 1 as base liner system #2. For the composite liner the minimum thickness of the geomembrane is no less than 60 mils. One mil is one-thousandth of an inch. The earthen component of both of these liners must be recompacted to achieve a minimum hydraulic conductivity of $1x10^{-7}$ centimeters per second.

In addition to the minimum design requirements for the liner there are many other regulations that are an integral part of the environmental containment system. The construction of the liner must be carried out in accordance with the construction quality assurance procedures so as to reduce void spaces and allow the liner to support the loadings imposed by the waste disposal operation without settling that causes or contributes to the failure of the leachate collection and liner system. The liner must operate in conjunction with a leachate collection and removal system to achieve the performance required to protect human health and the environment. The leachate collection system must be designed to avoid loss of leachate through openings in the liner. The regulations further require the removal of gas from the municipal solid waste landfill when it is produced in sufficient quantity to produce an outward force.

Groundwater Impact Assessment

The regulations in Illinois further require that a groundwater impact assessment ("GIA") be performed for all municipal solid waste landfills. This assessment is used to determine if the minimum technical design standards are sufficient to protect human health and the environment under the exact geologic and hydrogeologic conditions of the site. The minimum technical design is assessed for the impact on groundwater using a contaminant transport model that requires the actual geologic and hydrogeologic conditions be characterized. The contaminant transport model is a mathematical model that must demonstrate that the minimum design can protect groundwater such that the concentration of any chemical constituent will not exceed the natural background concentration at the compliance point, which is located 100 feet from the waste boundary within 100 years of closure of the facility. If this cannot be demonstrated, the design must be increased to a level that will ensure that that the concentration of any chemical constituent will not exceed the background value at the compliance point.

The demonstration by the GIA is a performance standard that must be met in addition to the minimum design standard. The modeling results are used to show that the minimum liner design standards will provide the necessary amount of protection at the municipal solid waste landfill or additional protection must be added. Model results can never be utilized to waive the minimum design standards. The modeling results are be used to confirm, not derive, the acceptability of the design parameters. (Scientific/Technical Section of the Illinois Pollution Control Board ("Board"), 1990) This means that a municipal solid waste landfill liner must, at a minimum, meet one of the two specified design standards and may need to be enhanced based on the results of the GIA.

According to the background report in support of the current regulations by the Scientific/Technical Section of the Board, 1987, if the GIA demonstrates that, under the site-specific conditions, the minimum design standards are inadequate to prevent contamination of the groundwater at the point of compliance then additional protection must be provided. Additional protection specifically considered by the regulations includes a double-composite liner. Also considered is the use of special construction techniques to decrease the hydraulic conductivity, or admixtures to improve the characteristics of the liner. This allows the designer the flexibility, in approaching the prevention of groundwater contamination, to evaluate all alternatives. These alternatives include evaluating another, more suitable site, changing the final configuration of the unit to promote more runoff and less infiltration, prohibiting the disposal of certain wastes containing the offensive contaminants, or any combination of these in addition to other practices that ensure protection of human health and the environment.

Comparison of State Regulations

Earthtech (2002) presented, in the attached report, the liner requirements from thirty-five states for comparison to the current minimum liner design requirements found in Illinois regulations. The majority of the states presented require a single liner as the minimum design requirement. All of the states in the U.S. Environmental Protection Agency's Midwest Region, known as Region V, are presented. These states are Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin, which due to the similarities in climate, geology and demographics are appropriate for regulatory comparison. Of these states, only Michigan has the double-composite liner design for a minimum design requirement. However, this is required only under certain specified conditions and a single liner can be allowed. This is similar to Illinois' requirement to increase the design where necessary. The difference for Illinois regulations is use of the GIA to define the specific conditions where this is necessary compared to Michigan where the specific conditions are laid out in the regulation.

The other states bordering Illinois are also presented in the attached Earthtech (2002) report. These states include Kentucky, Tennessee, Missouri, and Iowa. Of these states, only Kentucky has the double-composite liner design for a minimum design requirement. However, a less stringent design can be allowed under site-specific conditions. In fact, only one double-composite liner has been required in Kentucky to date.

Of the other states presented in the attached Earthtech (2002) report, Delaware, Florida, Oregon, and New Jersey require a double-composite liner under certain specified conditions. This is similar to Michigan's standard as discussed above. Pennsylvania requires a double liner system, however, only one of the liners is required to be a composite liner.

Of the 35 states in the attached Earthtech (2002) report, only four states require a double-composite liner as the minimum design requirement. The four states are Kentucky, as discussed above, Connecticut, New York, and Massachusetts. Connecticut requires a double-composite liner however a less stringent design can be allowed on a case-by-case basis. New York requires a double-composite liner, without an allowance for any less stringent design. Massachusetts requires a double-composite liner for facilities built after December 20, 2000 until new regulations are adopted.

Evaluation of Liners

According to the Scientific/Technical Section of the Board (1987) in support of the adoption of the current regulations for municipal solid waste landfills, additional protection must be provided for municipal solid waste landfills if the minimum design and performance standards are inadequate to prevent the contamination of the groundwater outside the zone of attenuation. Double-composite liners are one design option available when the minimum design standard is shown to be inadequate in evaluating the GIA.

According to a study by the Wisconsin Department of Natural Resources (1997), where states have allowed or required double-composite liner designs, it is usually because of a perceived or actual lack of native clay in large regions of the state and lack of experience with the properties of clay as a barrier layer. In Illinois the use of the GIA allows the flexibility to tailor the design to the specific geologic setting.

According to the Wisconsin Department of Natural Resources in their 1997 study, double-composite lined landfills are enormously difficult to successfully construct. The design of double-composite lined landfills usually requires a reduced thickness of the soil components of the liner, compared to single liner. Only a few double-composite lined municipal solid waste landfills have been built in Wisconsin, and their construction has been shown to be complex, difficult to coordinate, and easily subject to interruptions by weather. It is common for construction of double-composite lined landfills to extend late into cold weather or to extend over two construction seasons, resulting in several months of exposure of the liner components to weather. All of these factors lead to doubt that double-composite lined landfills can be built to the same standard and performance as single lined landfills as reported by the Wisconsin Department of Natural Resources in the 1997 study for the proposed Crandon Mine.

Based on Wisconsin's experience with clay liner design and evaluation of performance monitoring data from numerous facilities, it was concluded that properly designed and constructed clay liners along with an efficient leachate collection system can provide a high level of groundwater protection at solid waste disposal facilities as reported in the 1997 Wisconsin study. Lee and Jones-Lee (1994) found that the leachate collection and removal system is the key component of the municipal solid waste landfill containment system to prevent groundwater pollution. If properly constructed and maintained, such a system can prevent leachate from entering the groundwater associated with the municipal solid waste landfill. The performance of the municipal solid waste landfill depends more on the functioning of the leachate collection and removal system rather than on the number of liners used, according to Lee and Jones-Lee (1994).

The key protection of groundwater quality in a double-composite lined landfill, where the lower composite liner's function is primarily that of a leak detection system for the upper composite liner, is the ability to take appropriate action when leachate is found in the leak detection layer between the two composite liners according to Lee and Jones-Lee. According to Bonaparte and Gross (1990), the leakage detection layers in double-composite liner systems frequently exhibit flows that may be due to leakage through the top liner or due to other sources such as construction water, consolidation water, and infiltration water. Thus, the double-composite liners provide ambiguous data, which makes it difficult for monitoring the performance of the municipal solid waste landfills. However, when leachate is found in the leak detection layer, it is assumed that the upper composite liner has failed. If the upper liner does fail, then the efficiency of the double-composite liner is reduced to that of the single-composite liner.

According to Daniel et al (1999), limiting the size of the active disposal area and using effective measures to minimize rainfall infiltration into the waste and to divert surface-water runoff away from the waste will significantly decrease leachate generation rates compared to the rates observed under less controlled conditions. Well designed and constructed cover systems can be very effective in minimizing infiltration of rainfall into the waste, thus reducing leachate generation rates to near-zero values (Daniel et al, 1999). Many waste containment system problems were evaluated, but increasing the number of liners for the municipal solid waste landfills was not recommended. It was discovered that most of the problems occurred due to construction and operation defects. A 1998 survey of 43 states has shown that for municipal solid waste landfills 72% require single liner systems, and 14% have single-composite and double-composite liner system options. (Daniel et al, 1999)

Cost Considerations

The attached Earthtech (2002) report included cost estimates for the different types of liners evaluated in this report. The costs were based on an average cost for construction and materials in Illinois. Also, numerous assumptions had to be made since this was an average cost for the state. There will be areas of the state where certain materials or labor costs will be higher or lower. The purpose of the costs presented is strictly for comparison in this report and is not meant to be authoritative on this subject.

For an average 100 acre municipal solid waste landfill in Illinois a recompacted earth liner will cost approximately $9,420,100 to build, including the associated cost of the GIA. The single-composite liner will cost approximately $7,988,300 to build, including the associated cost of the GIA. The average cost for a double-composite liner is $14,342,400. For comparison purposes, it was assumed that a GIA would not need to be performed if a double-composite liner is required. Under these assumptions, the double-composite liner will cost approximated 34% more than the recompacted earth liner. However the double-composite liner will cost approximated 44% more than the single-composite liner.

Conclusion

The current design requirements for municipal solid waste landfills contained in the Illinois regulations are protective of human health and the environment. The minimum liner design standard currently in the Illinois regulations requires a single liner.

However, the regulations in Illinois are unique in the requirement to evaluate the minimum design standard for liners in the specific geologic setting under the exact operating conditions using a mathematical model to determine if additional protection is needed. Additional controls must be included in the design for protection of groundwater when the model demonstrates that a groundwater standard will be violated without the additional controls. These additional controls include a double-composite liner when necessary to protect groundwater. Also unique to Illinois regulations is applying the existing chemical concentrations in uncontaminated background groundwater as the standard to confirm the acceptability of the liner design at municipal solid waste landfills.

States that require double-composite liners for the minimum design may not have sufficient natural geologic material to protect groundwater without the additional liner requirement. Also, most States that have a requirement for double-composite liners allow a less stringent design when approved by the regulating agency. In Illinois, the liner and additional design requirements are tailored to the site-specific geologic conditions through the use of the GIA as a performance standard.

Controls, other than liners, are often a more effective method of minimizing contamination. Research concludes that the leachate collection and removal system is an integral part of the environmental protection system and may be more important than additional liners in the protection of groundwater. The leachate collection and removal system removes the liquid above the liner, which decreases the driving head or downward force on the liner. Liquid cannot move without applying a force. The same is true of the gas causing an outward pressure, which is the second force that can move contaminants out of the municipal solid waste landfill containment system. The current regulations also require for gas to be removed before it can cause an outward force.

The current regulations in Illinois including the GIA with periodic reevaluation, monitoring schedule, assessment, and corrective action requirements have proven effective to protect groundwater. Double-composite liners are more costly without corresponding protection. If the upper liner fails, the efficiency of the double-composite liner is reduced to that of the single-composite liner. Given the compromises that arise due to the complicated construction of double-composite lined municipal solid waste landfills, there is a much better chance of successfully completing construction of the liner and leachate collection system if the design is kept simple. There is no advantage to the use of a double-composite lined municipal solid waste landfill design if it leads to poorer liner construction.

Modifying the Illinois regulations to change the minimum liner design requirement from a single liner to a double-composite liner is not recommended at this time, given the compromises that arise due to the complicated construction of double-composite lined municipal solid waste landfills and that the additional cost of a double-composite liner is substantial without corresponding protection. The current minimum technical requirements contained in the Illinois regulations allow the flexibility to require a double-composite liner in an area where it is necessary for such a requirement to protect human health and the environment.

References

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ATTACHMENT 1

December 3, 2002

Ms. Joyce L. Munie, P.E.
Manager, Permit Section
Bureau of Land, IEPA
PO Box 19276
Springfield, IL 62794-9276

RE: Cost Estimates for Various Base Liner Systems and GIA

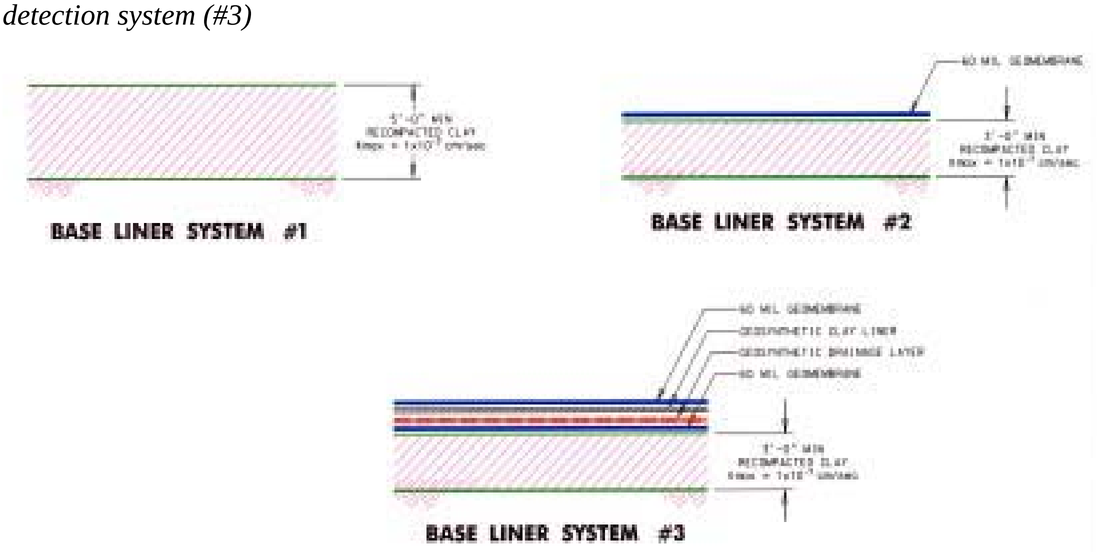
Dear Ms. Munie:

In follow-up to the second task outlined in the Scope of Work concerning assisting IEPA with a study on landfill liner requirements, this letter presents cost estimates for various base liner systems and groundwater impact assessment.

Cost Estimate for Various Base Liner Systems

Approximate construction costs have been estimated for the following base liners:

- *5-ft recompacted soil liner (Fig #1 below)*
- *Single composite liner system with 3-ft of recompacted clay and a geomembrane (#2)*
- *Double composite liner system with two composite liners separated by a secondary leak detection system (#3)*



The approximate costs for the three options are:

Liner Cross Section	Per Acre Cost	Total Cost for 100-acre Landfill
5-foot Recompacted Soil Liner	***$89,701***	***$8,970,100***

Single Composite Liner System	***$75,383***	***$7,538,300***
Double Composite Liner System	***$143,424***	***$14,342,400***

Assumptions used are summarized below:

- The various base liner system cross-sections evaluated are illustrated in the figures shown above. The soil liner and geomembrane materials meet 35 IAC 811 regulations.
- The geomembrane is HDPE.
- The low permeability soil component of the double composite liner system's primary liner is anticipated to be a GCL; use of a GCL as opposed to a compacted clay layer in this position is recognized as state of the practice.
- Refer to the attached Table 1 for details and further assumptions used in developing the cost estimates.
- Data from the R.S. Means construction cost estimating books and typical construction costs for landfills in the Midwest based on recent project experience were reviewed and utilized to develop the cost estimates.
- The costs include only the material and installation costs related to the base liner materials themselves.
- Costs for items such as cell excavation, leachate collection systems, underdrain systems, surveying, and CQA are not included.
- Cost for clay is assumed at $6 per cubic yard for purchase and delivery to the site. This is based on recent project experience. This value will vary based on the specific situation.
- Prices may vary based on the actual size of the landfill area and the quantity of materials purchased.
- Regional differences that may affect pricing have not been factored in, such as labor and soil purchase costs.
- Although a 100-acre landfill is assumed as the basis for the cost estimates, the geosynthetics quantity has been increased by 10% to account for perimeter run-out areas, anchor trenches, overlap, waste, etc.
- Installation of the liner system components (i.e., soil and geosynthetics) will take place during the typical construction season.

Cost Estimate for Groundwater Impact Assessment

An approximate cost estimate for preparation of a Groundwater Impact Assessment for a new (greenfield) landfill proposed in Illinois is summarized below. The costs are presented on a per acre basis for work related to field investigation and data evaluation, while the costs for GIA landfill modeling are presented as an approximate total cost for a landfill development project of approximately 100 acres.

Item	Per Acre Cost	Total Cost for 100-acre Landfill
Field Investigation	*$2,000-$3,000*	*$200,000 - $300,000*
Data Evaluation/Hydrogeo Report	*$1,000-$3,000*	*$100,000 - $300,000*
GIA Modeling	*N/A*	*$20,000 - $30,000*
Total GIA Cost:	***N/A***	***$400,000 - $500,000***

So for a 100-acre landfill, the total cost for the GIA would be approximately $400,000 to $500,000.

The cost estimates are based on recent project experience with landfill developments and associated permit applications. Refer to the attached Table 2 for details and further assumptions used in developing the cost estimates.

Summary

Assuming an average cost for the GIA of $450,000, the per-acre and total cost for the development of a 100-acre landfill with the three liner systems under consideration are approximately:

Liner Cross Section	Per Acre Cost	Total Cost for 100-acre Landfill
5-foot Recompacted Soil Liner	***$94,201***	***$9,420,100***
Single Composite Liner System	***$79,883***	***$7,988,300***
Double Composite Liner System	***$147,924***	***$14,792,400***

We hope that this information meets your needs. If you have any questions or comments, please contact us at the phone numbers or email addresses below.

Thank you,

Earth Tech, Inc.

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attachment

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Liner System		Means Code/Source	Location	Estimated Quantity	Unit	Unit Price	Estimated Cost	Remark
5' Thick Recompacted Soil Liner								
Clay Purchased and Delivered		project experience		806,667	cy	$6.00	$4,840,000	@$6.00/cy
Clay, Loading onto Trucks		02315-400-0250	On Landfill	806,667	cy	$1.31	$1,056,733	1.5cy cap. Backhoe
Clay Hauling fm Stockpile 1/8M RT	12. cy	02320-200-0310	On Landfill	806,667	cy	$2.00	$1,613,333	12 cy per load (est cost based on 1/4M)
Clay, Spreading		02315-505-0010	On Landfill	806,667	cy	$1.32	$1,064,800	Spread by Dozer
Compacting Clay		02315-300-5600	On Landfill	806,667	cy	$0.49	$395,267	Sheep Foot, 6" lift, 2 pass
						Total	**$8,970,133**	
						Total/acre	**$89,701.33**	

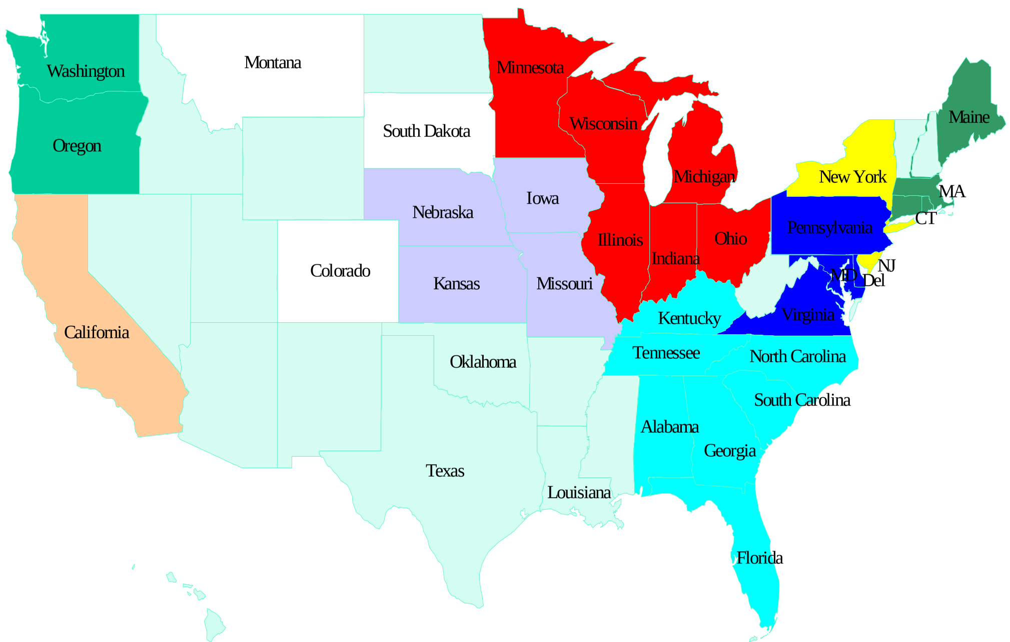
Liner System		Means Code/Source	Location	Quantity	Unit	Unit Price	Estimated Cost	Remark
3' Clay Layer w/Geomembrane								
Clay Purchased and Delivered		project experience		484,000	cy	$6.00	$2,904,000	@$6.00/cy
Clay, Loading onto Trucks		02315-400-0250	On Landfill	484,000	cy	$1.31	$634,040	1.5cy cap. Backhoe
Clay Hauling fm Stockpile 1/8M RT	12. cy	02320-200-0310	On Landfill	484,000	cy	$2.00	$968,000	12 cy per load (est cost based on 1/4M)
Clay, Spreading		02315-505-0010	On Landfill	484,000	cy	$1.32	$638,880	Spread by Dozer
Compacting Clay		02315-300-5600	On Landfill	484,000	cy	$0.49	$237,160	Sheep Foot, 6" lift, 2 pass
Geomembrane 60 mil		project experience		4,791,600	sf	$0.45	$2,156,220	Material and Installation
						Total	**$7,538,300**	
						Total/acre	**$75,383.00**	

Liner System		Means Code/Source	Location	Quantity	Unit	Unit Price	Estimated Cost	Remark
3' Clay Layer Double Composite System								
Clay Purchased and Delivered		project experience		484,000	cy	$6.00	$2,904,000	@$6.00/cy
Clay, Loading onto Trucks		02315-400-0250	On Landfill	484,000	cy	$1.31	$634,040	1.5cy cap. Backhoe
Clay Hauling fm Stockpile 1/8M RT	12. cy	02320-200-0310	On Landfill	484,000	cy	$2.00	$968,000	12 cy per load (est cost based on 1/4M)
Clay, Spreading		02315-505-0010	On Landfill	484,000	cy	$1.32	$638,880	Spread by Dozer
Compacting Clay		02315-300-5600	On Landfill	484,000	cy	$0.49	$237,160	Sheep Foot, 6" lift, 2 pass
Geomembrane 60 mil		project experience		4,791,600	sf	$0.45	$2,156,220	Material and Installation
Geosynthetic Drainage Layer		project experience		4,791,600	sf	$0.45	$2,156,220	Material and Installation
GCL		project experience		4,791,600	sf	$0.52	$2,491,632	Material and Installation
Geomembrane 60 mil		project experience		4,791,600	sf	$0.45	$2,156,220	Material and Installation
						Total	**$14,342,372**	
						Total/acre	**$143,423.72**	

Surface Area of Landfill	100	acres
Cost of Delivered Clay	$6.00	/cy
Recompacted Soil Liner Clay Layer	5	feet
Composite Liner System Clay Layer	3	feet

Item	Source				Per Acre Cost Estimate	Total Cost Estimate for 100-acre Landfill	Remark
Field Investigation	project experience				$2,000 to $3,000	$200,000 to $300,000	
Pre-Field Activities							Sub-item included
Hydrogeo Field Investigation							Sub-item included
Subcontractors							Sub-item included
Data Evaluation/Hydrogeo Report	project experience				$1,000 to $3,000	$100,000 to $300,000	
Hydrogeo Data Evaluation							Sub-item included
Hydrogeo Report Preparation							Sub-item included
Hydrogeo Graphics and Logs							Sub-item included
Geotech Labs							Sub-item included
Groundwater Monitoring Program							Sub-item included
GIA Modeling	project experience				N/A	$20,000 to $30,000	
					Total	$400,000 to $500,000	

Map of States Selected



States with names shown are those selected.
Patterned states are those not selected.
Colors represent different USEPA regions.

Earth Tech. Revision 0

December 2002

No.	State	Minimum Technical Requirement (MTR) for Liner Design	Exception to MTR. Requirement to Increase Design or Allow Less Stringent Design	Explanation of Exceptions
1.	Alabama	A composite liner consists of a minimum of 2-foot compacted clay having a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec and a 40-mil FML unless FML consists of HDPE geomembrane which requires 60-mil.	Allow less stringent design.	The alternate design shall ensure that certain concentration values in groundwater will not be exceeded in the first saturated zone at the relevant point of compliance. The relevant point of compliance shall be no more than 150 meters from the waste management unit boundary and shall be located on land owned by the owner of the landfill unit. According to ADEM, alternative has been approved for substituting one foot of clay for GCL. The hydraulic conductivity of the remaining one foot compacted clay can be $1x10^{-5}$ cm/sec, instead of $1x10^{-7}$ cm/sec.
2.	California	A composite liner consists of a minimum of 2-foot compacted clay having a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec and a 40-mil FML or at least 60-mil thick for HDPE. A 5-foot separation above the highest anticipated elevation of underlying ground water. When natural geologic materials do not satisfy this requirement, a liner with a hydraulic conductivity of not more than $1x10^{-6}$ cm/sec should be used.	Allow less stringent design.	MTR is for Class II landfills defined as waste management units for designated waste. For a Class III landfill, defined as landfills for nonhazardous solid waste, the minimum thickness of the clay liner is 1 foot.
3.	Colorado	The liner system shall be one of the following: a. Natural lithology with recompaction - a minimum 20 feet in thickness with a maximum in-situ hydraulic conductivity of $1x10^{-6}$ cm/sec. The upper 12-in is recompacted to achieve a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec. b. Soil liner – at least 3-foot compacted with a	Allow less stringent design.	Based on waste type and site specific technical information, alternative designs include, but are not limited to the following: 1. GCL 2. Natural lithology without recompaction 3. Soil admixtures 4. Geomembranes 5. Polymers

No.	State	Minimum Technical Requirement (MTR) for Liner Design	Exception to MTR. Requirement to Increase Design or Allow Less Stringent Design	Explanation of Exceptions
		maximum hydraulic conductivity of $1x10^{-7}$ cm/sec. c. Composite liner - a minimum of 2-foot compacted clay having a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec and a 30-mil FML or at least 60-mil thick for HDPE.		6. Variations of design components
4.	Connecticut	The liner system shall consist of a protective cover, a leachate collection system, a primary liner, a leachate leak detection zone, a secondary liner and a subbase. a. The subbase of the liner system shall be at least five feet above the maximum high water table and five feet above the surface of bedrock. b. The protective cover of the liner system shall have recompacted permeability greater than $1x10^{-4}$ cm/sec and at least 12 inches thick. c. The liner system shall be a dual synthetic liner system consisting of 12 inches of granular earthen filter material, underlain by geotextile, underlain by 12 inches of granular free-draining material or equivalent synthetic drainage structures containing a leachate collection system, underlain by a FML, underlain by 12 inches of granular earthen material, underlain by 12 inches of granular free-draining material or equivalent synthetic drainage structures containing a leachate detection system, underlain by a FML, underlain by compacted native soil.	Allow less stringent design.	The state has been promoting Resource Recovery Facilities (RRF) rather than landfills. Currently, there are 35 active landfills in the state. Most of them are small (6 – 7 acres). Only 2 – 3 large landfills (60± acres). Last landfill above 60 acres was permitted in 1998 for RRF ash. The liner requirements were written primarily for ash landfills and also applied to MSW landfills. RRF and MSW need to go through a dual approval process (water and waste). When seeking approval from the water department for groundwater discharge, the site is assumed without a liner system. Therefore, the alternative liner designs allow more flexibility. The followings are some of approved alternative liner designs: ▪ If the 5 foot subbase meets the permeability requirement of $1x10^{-7}$ cm/sec, it can be considered as the secondary compacted soil. ▪ Geonet can be used to replace the leachate collection piping and granular drainage blanket.
5.	Delaware	The liner system shall be one of the following: a. A composite liner at least 5 feet above the seasonal high water table in the upper most aquifer and consisting	Requirement to increase design.	More stringent designs will be required where deemed necessary by the Department for the protection of ground water resources.

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		of a minimum of 2 feet compacted clay having a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec and a 45-mil FML. b. A natural liner at least 5 feet thick recompacted having a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec. c. A double liner system separated by a drainage layer: the primary liner shall be a synthetic liner at least 30 mils thick and a secondary liner may be either synthetic (30-mil FML) or natural (5-foot natural liner). The drainage layer consists of at least 12 inches of soil having a hydraulic conductivity greater than $1 x 10^{-2}$ cm/sec.		
6.	Florida	The liner system shall be one of the following: a. A composite liner consists of a 60-mil HDPE geomembrane liner and a lower component, the thickness of which varies in relation to the hydraulic conductivity (*k*) and maximum design hydraulic head (MDHH): 1 inch MDHH: $k \leq 1x10^{-7}$ cm/sec, 24-in min. $k \leq 5x10^{-8}$ cm/sec, 12-in min. $k \leq 1x10^{-8}$ cm/sec, 12-in min. 6 inches MDHH: $k \leq 1x10^{-7}$ cm/sec, 30-in min. $k \leq 5x10^{-8}$ cm/sec, 18-in min. $k \leq 1x10^{-8}$ cm/sec, 12-in min. 12 inches MDHH:	Requirement to increase design.	More stringent standards may be necessary due to site-specific conditions and types of wastes to be disposed.

No.	State	Minimum Technical Requirement (MTR) for Liner Design	Exception to MTR. Requirement to Increase Design or Allow Less Stringent Design	Explanation of Exceptions
		$k \leq 1x10^{-7}$ cm/sec, 36-in min. $k \leq 5x10^{-8}$ cm/sec, 24-in min. $k \leq 1x10^{-8}$ cm/sec, 12-in min. b. A double liner system consists of upper and lower 60-mil HDPE geomembranes. The lower geomembrane shall be placed directly on a sub-base at least 6 inches thick with a maximum hydraulic conductivity of $1x10^{-5}$ cm/sec. GCL with a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec can be used to substitute for the 6-in sub-base soil. The leak detection system has a minimum hydraulic conductivity of 10 cm/sec.		
7.	Georgia	A composite liner consisting of a 30-mil FML and a minimum of 2-foot compacted clay having a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec. If FML is HDPE, it shall be at least 60 mils thick. At least 5 feet separation between the synthetic liner and the seasonal high water table in the upper most aquifer is required.	Allow less stringent design.	Dependent on that whether the landfill is located in an area of higher pollution susceptibility as defined by Hydrologic Atlas #20 (a Pollution Susceptibility Map of Georgia), or in a significant ground water recharge area as designated by Atlas #18. If not, the liner system may be designed as long as such design ensures that the concentration values listed in Table 1 of 391-3-3-.07(1)(d) will not be exceeded in the upper aquifer at the relevant point of compliance. The relevant point of compliance is defined as no more than 150 meters from the waste management unit boundary and located on land owned by the owner of the MSWLF unit.
8.	Illinois	The liner system shall be one of the following: a. A minimum 5-foot compacted clay with a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec. b. A composite liner consists of 3-foot compacted clay having a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec and a geomembrane no less than 60 mils in thickness.	Requirement to increase design.	The minimum technical design is assessed for groundwater impact using a contaminant transport model that requires the actual geologic and hydrogeologic conditions be characterized. The mathematical model must demonstrate that the minimum design can protect groundwater such that the concentration of any chemical constituent will not exceed the background value at a point located 100 feet

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				from the waste boundary within 100 years of closure of the facility. If this cannot be demonstrated, the design must be increased to a level that will ensure that the concentration of any chemical constituent will not exceed the background value at a point located 100 feet from the waste boundary within 100 years of closure of the facility.
9.	Indiana	A composite liner consists of a minimum of 3-foot compacted soil with a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec, and a geomembrane, Geomembrane may be 30 mils unless when HDPE is used, geomembrane must be 60 mils. This composite liner system requires a separation of 10 feet of nonaquifer material between the liner and the uppermost aquifer. At all sump areas, at a minimum, at liner areas within 25 feet lateral to the center of each sump, starting from the subgrade and extending upward, the liner must include the following components: a. A minimum of 2 feet of compacted soil having a hydraulic conductivity of $1x10^{-6}$ cm/sec or less; b. A leak detection zone; c. A minimum of 3 feet of compacted soil having a hydraulic conductivity of $1x10^{-7}$ cm/sec or less; d. A geomembrane; e. A GCL; f. A geomembrane; g. A drainage layer; and h. A protective cover.	Requirement to increase design.	In the portions of the landfill unit with less than 10 feet of vertical from the aquifer of significance, then the sump area liner cross section (described at left) must be used. Alternatively, the 10-foot separation can be constructed.
10.	Iowa	A composite liner consists of a minimum of 2-foot compacted	Allow less stringent	Alternatives are based on that the design of the liner

No.	State	Minimum Technical Requirement (MTR) for Liner Design	Exception to MTR. Requirement to Increase Design or Allow Less Stringent Design	Explanation of Exceptions
		clay having a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec and a 30-mil FML or at least 60-mil thick for HDPE.	design.	system is equivalent to the soil liner requirements, longevity and protection of the groundwater, or the specific type of waste to be disposed. A liner system has soil liner only has been approved. The soil liner can be 4 feet of recompacted clay or in-situ material meeting the alternative design requirements.
11.	Kansas	General MSW landfills: A composite liner consists of a minimum 30-mil geomembrane and at least a 2-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. Geomembrane components consisting of HDPE shall be at least 60-mil thick. Small landfills: A minimum of 2-foot compacted clay with a maximum hydraulic conductivity of $1x10^{-6}$ cm/sec, or in-situ material or an alternative, approved constructed liner meeting the demonstration standard for groundwater modeling or the liner performance standard. The in-situ material liner below the bottom of the landfill prior to encountering groundwater shall meet: (i) Has a permeability equivalent to 2 feet of $1x10^{-6}$ cm/sec material; (ii) Within the equivalently permeable layer, has no soil layer or stratum with a permeability greater than $1x10^{-4}$ cm/sec and with groundwater to flow laterally off the owner's property; and (iii) Shows consistency in all boring data.	Allow less stringent design.	Alternative designs shall demonstrate that certain concentration values will not be exceeded in the uppermost aquifer at the point of compliance which shall be within 150 meters of the edge of the planned unit boundary and on the owner's or operator's property and shall be at least 15.24 meters from the property boundary. GCL to substitute for one foot of compacted clay has been approved. Small landfills are exempted from the composite liner requirements. Small landfill criteria are : (1) Receives and disposes of less than 20 tons per day based on an annual average; (2) There is no evidence of groundwater contamination; (3) In an area with less than or equal to 25 inches of annual precipitation (averaged over a minimum 30-year period); and (4) The community utilizing the landfill has no practicable waste management alternative. The

No.	State	Minimum Technical Requirement (MTR) for Liner Design	Exception to MTR. Requirement to Increase Design or Allow Less Stringent Design	Explanation of Exceptions
				closest MSWLF is more than 75 miles away.
12.	Kentucky	A double composite liner system includes: 1. Primary Liner System: A composite liner consisting of 3-foot compacted clay having a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec and 60-mil geomembrane having a hydraulic conductivity less than $1x10^{-12}$ cm/sec. 2. Secondary Liner system: a) A composite liner consisting of 1 foot compacted clay having hydraulic conductivity of $1x10^{-7}$ cm/sec, 60-mil geomembrane having a hydraulic conductivity less than $1x10^{-12}$ cm/sec, 1 foot drainage layer having a hydraulic conductivity of $1x10^{-3}$ cm/sec, and a filter fabric; or b) A naturally occurring material above the uppermost aquifer with a minimum thickness of 20 feet with a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec.	Allow less stringent design.	Less stringent design for the bottom slope in the range of 10 - 25%, a single composite liner system is allowed. According to the Kentucky DEP, except fir one landfill that was built with a double composite liner system, all MSW landfills in Kentucky have been built using this option. Alternatives also allow using GCL. When GCL is used in addition to the composite liner system, the compacted clay is not required to meet the permeability requirement in the field and needs to demonstrate that it is capable of meeting hydraulic conductivity of $1x10^{-7}$ cm/sec in laboratory testing. A 4-foot separation between the liner system and the uppermost aquifer is required. If this condition is not met, an underdrain system is required.
13.	Louisiana	A composite liner consists of 3-foot -having a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec and a FML at least 30 mils thick or a HDPE geomembrane no less than 60 mils.	Requirement to increase design.	Based on the site geologic conditions, additional protection layer may be required to protect groundwater which is a major source of drinking water (found only in rare cases). Approximately 60% of the MSW landfills permitted under these regs have used alternative designs: using GCL to substitute for 1 foot or 2 feet (if the GCL has a geomembrane bonded to it) of compacted clay.
14.	Maine	A composite liner consists of a 60-mil HDPE geomembrane liner and a minimum of 2-foot compacted clay layer (CCL) having a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec	Requirement to increase design.	Improvement allowances are required when time of travel to sensitive receptors from the bottom of the landfill and leachate pond liner systems is less than 6

No.	State	Minimum Technical Requirement (MTR) for Liner Design	Exception to MTR. Requirement to Increase Design or Allow Less Stringent Design	Explanation of Exceptions
		and containing a minimum of 35% fines.		years. A GCL may substitute for up to 12" of CCL.
15.	Maryland	A composite liner consists of a synthetic membrane liner and a minimum of 1 foot compacted clay or other natural material having a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec. The synthetic membrane has a combined minimum thickness of 50 mils for unreinforced, or has a single reinforced membrane with a minimum thickness of 30 mils and a maximum hydraulic conductivity of $1x10^{-10}$ cm/sec. Placed over a prepared subbase with a minimum thickness of 2 feet and a maximum hydraulic conductivity of $1x10^{-5}$ cm/sec.	Requirement to increase design.	The MTR listed on the website has not been updated since the state program was approved. The liner design requires to compliance with the Subtitle D requirements and an alternative liner design can be approved if it meets the performance standards using the Subtitle D methods (HELP and Multi-Media). About 20 MSW landfills are currently active. Since the geologic and hydrogeologic conditions vary in the state, the liner system at each landfill was approved based on the site-specific conditions.
16.	Massachusetts	A composite liner consists of two components: the upper component must be a minimum 30-mil FML and the lower component must be at least a 2-foot layer of compacted low permeability soil/admixture with a hydraulic conductivity of no more than $1 x 10^{-7}$ cm/sec. FML components consisting of HDPE shall be at least 60-mil thick. The subgrade shall be sufficient thickness to ensure a minimum of 4 feet separation between the top of bedrock or the maximum high ground water table and the bottom of the lowest low permeability layer.	Requirement to increase design.	A double composite liner system is required under Final Interim Guidance on Double Liner Requirements for all Landfill Authorizations to Construct (ATC) Issued After December 20, 2000. This interim guidance is to be used for determining double liner requirements until the solid waste regulations (310 CMR 19) are revised to incorporate the following new requirements: ▪ For any area where the slope of the liner will be less steep than 4H:1V, a double composite liner is required. Option 1 – Double composite liner: Primary liner: FML/GCL Leak detection: geonet or 12" 10^{-2} cm/sec material Secondary liner: FML/2 feet CCL

No.	State	Minimum Technical Requirement (MTR) for Liner Design	Exception to MTR. Requirement to Increase Design or Allow Less Stringent Design	Explanation of Exceptions
				Option 2 – Alternative double composite liner: Primary liner: FML/GCL Leak detection: geonet or 12” 10^{-2} cm/sec material Secondary liner: FML/GCL/1 foot CCL ▪ For any area where the slope will be steeper than or equal to 4H:1V: Preferred Option – Modified double composite: Primary liner: FML/GCL Leak detection: geonet or 12” 10^{-2} cm/sec material Secondary liner: FML/1 foot CCL Acceptable Options: The following double liner design options are also acceptable: - Primary liner is a single element, secondary liner is composite: Primary liner: FML Leak detection: geonet or 12” 10^{-2} cm/sec material Secondary liner: FML/2 feet CCL - Primary liner is a single element, secondary liner is composite: Primary liner: FML Leak detection: geonet or 12” 10^{-2} cm/sec material Secondary liner: FML/GCL/1 foot CCL
17.	Michigan	All MSW landfills shall be constructed with a composite liner. A composite liner consists of two components: 1) The upper component must be a minimum 30-mil FML. FML components consisting of HDPE shall be at	No exception	The default thickness is 10 feet for the natural soil barrier having a maximum permeability of 1 x 10^{-7} cm/sec. If the natural soil barrier has a maximum permeability of 1 x 10^{-6} cm/sec, the required thickness

No.	State	Minimum Technical Requirement (MTR) for Liner Design	Exception to MTR. Requirement to Increase Design or Allow Less Stringent Design	Explanation of Exceptions
		least 60-mil thick. 2) The lower component may consist of any of the following soil layers: i) Compacted soil at least 2 feet thick with a hydraulic conductivity of no more than 1 x 10^{-7} cm/sec. ii) A bentonite geocomposite liner. iii) An alternative soil layer that is approved under the rules. New units and lateral extensions at existing disposal areas that have not received waste before Oct. 9, 1995 shall be designed in accordance with the leakage control criteria: 1) A monitorable unit which is located over a natural soil barrier and is in compliance with R 299.4422(2). A natural soil barrier may meet any of the following geologic conditions: i) Has a maximum demonstrated permeability of 1 x 10^{-7} cm/sec. ii) Has a thickness and permeability sufficient to prevent the migration of leakage from the unit to the uppermost aquifer for a time period as defined in R 299.4422(2)(b). iii) Underlain by an uppermost aquifer that is sufficiently artesian to prevent the vertical migration of contaminants from the site to the uppermost aquifer by advection or dispersion. iv) Any combination of hydrogeology and innovative design. 2) Designed with a double liner system in compliance		permeability of 1 x 10^{-6} cm/sec, the required thickness is 100 feet. In most north and west areas of the state where bedrock surface is relatively high, a double composite liner system is generally used. No alternative liner has been approved. The alternative layer as stated in the regulation was intended for future new geosynthetic materials.

No.	State	Minimum Technical Requirement (MTR) for Liner Design	Exception to MTR. Requirement to Increase Design or Allow Less Stringent Design	Explanation of Exceptions
		with R 299.4422(3): i) A primary composite liner. On the sidelope greater than or equal to 20% and 5 feet vertically about the toe, the soil component is optional. ii) A secondary collection system or leak detection system. iii) A secondary composite liner or any of the following alternative systems: a. The soil components can be a natural soil barrier has an equivalent combination of permeability and thickness as 2 feet of $1x10^{-7}$ cm/sec compacted soil. b. A natural soil barrier underlain by an uppermost aquifer that is sufficiently artesian to prevent the vertical migration of contaminations from the site to the uppermost aquifer by advection or dispersion. c. An alternative system approved by the Director.		
18.	Minnesota	The liner system shall be one of the following: a. A composite liner consists of a synthetic membrane liner and a minimum of 2-foot compacted clay having a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec. The synthetic membrane must be at least 60 mils for unreinforced or 30 mils for reinforced. b. A natural soil barrier must be at least 4 feet thick and recompacted.	Allow less stringent design	An alternative liner system may be approved based on its ability to control leachate migration, meet performance standards, and protect human health and the environment. Liner system Option b can be approved based on groundwater modeling results. Alternative liner design has been approved for only sideslopes using GCL to substitute for 1 foot of compacted clay.

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19.	Missouri	A composite liner consists of 2-foot compacted clay having a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec and a minimum 30-mil thick geomembrane. Geomembrane components consisting of HDPE shall be at least 60-mil.	Minimal Exceptions	One landfill was approved to use bentonite mixing with clay in order to achieve hydraulic conductivity of $1x10^{-7}$ cm/sec.
20.	Montana	A composite liner consists of 2-foot compacted clay having a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec and a FML at least 30 mils thick or a HDPE geomembrane at least 60 mils.	Allow less stringent design.	The barrier layer may include, but is not limited to the following alternatives based on the hydrogeologic characteristics, the climatic factors of the area, and the barrier layer design factors: (a) Compacted soil liner (b) GCL (c) Soil admixtures (d) Geomembrane (e) Polymers (f) Natural lithology when the uppermost soil layer of the landfill base is recompacted to achieve a minimum final thickness of 12 inches with a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec (g) Variations or combinations of the above design components A barrier layer is not required that has a department-approved no migration petition (six landfills have been approved). If the landfill base liner system is not covered within one winter season, a compacted clay layer is not allowed due to free and thaws effect.
21.	New Jersey	A composite liner consists of two components: the upper component must be a minimum 30-mil FM) and the lower	Requirement to Increase Design	Only one of the 12 MSW landfills was built with a single composite liner system. Other landfills were

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		component must be at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. FML components consisting of HDPE shall be at least 60-mil thick.		constructed with a double composite liner system: ▪ Primary 60-mil HDPE geomembrane liner ▪ Primary GCL ▪ Leak detection layer ▪ Secondary 60-mil HDPE geomembrane liner ▪ Secondary GCL A double composite liner system was used in these landfills because of site-specific hydrogeology (were built within a drinking water aquifer).
22.	Nebraska	A composite liner consists of two components: the upper component must be a minimum 30-mil FML and the lower component must be at least a 2-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. FML components consisting of HDPE shall be at least 60-mil thick. When approving the design, the Department will consider the hydrogeologic characteristics of the facility and the surrounding land, the climatic characteristics of the area, the volume and type of waste to be deposited, and the volume and physical and chemical characteristics of the leachate.	Allow less stringent design.	In accordance with a design approved by the Department, alternate designs shall ensure that the concentration values listed in the Rule will not be exceeded in the uppermost aquifer at the relevant point of compliance. The relevant point of compliance shall be located at the waste management unit boundary. A request may be made for the establishment of an alternate relevant point of compliance. The alternate relevant point of compliance shall be no more than 150 meters from the waste management unit boundary and shall be located on land owned by the owner of the solid waste disposal area. An alternative design which is commonly used consists of the following components: ▪ 60-mil HDPE geomembrane liner ▪ GCL ▪ 24-inch compacted soil to achieve a minimum 95% standard Proctor (ASTM D698) maximum dry density.

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23.	New York	On all bottom areas where the landfill slope is less than or equal to 25 percent, the liner system must consist of a double composite liner separated by a secondary leachate collection and removal system. On all side slope areas where the landfill slope is greater than 25 percent the liner system need only consist of a primary leachate collection and removal system above the uppermost geomembrane liner and a lower composite liner separated by a secondary leachate collection and removal system. (1) A composite liner must consist of two components, an upper geomembrane liner placed directly above a low permeability soil layer. Each composite liner is considered a single liner. (2) The double composite liner system must include a primary leachate collection and removal system consisting of a 24-inch granular soil layer with a leachate collection pipe network. The primary leachate collection and removal system lies above the primary (upper) composite liner. The primary composite liner consists of a 60-mil geomembrane that directly overlays an 18-inch thick low permeability soil layer. The primary composite liner lies above the secondary leachate collection and removal system. The secondary leachate collection and removal system lies above the secondary (lower) composite liner which consists of a 60-mil geomembrane that directly overlays a 24-inch thick low permeability soil layer. A. Primary composite liner: The soil component of the primary composite liner must be a minimum compacted thickness of 18 inches. The top 6-inches (minimum compacted thickness) directly below and in contact with the upper geomembrane	Requirement to Increase Design	No alternative designs. GCL may be used as extra layer. Single composite liners are allowed for C & D and ash monofill landfills.

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		liner must have a maximum remolded coefficient of permeability of 1×10^{-7} cm/sec. A GCL may be substituted for the top six-inch portion of the low permeability soil layer in the primary composite liner. The lower 12 inch soil layer (minimum compacted thickness), shall be specified as a structural fill layer to assure adequate separation of the primary composite liner from the secondary leachate collection and removal system and must be placed without damaging any geosynthetic or secondary leachate collection and removal system components below the primary composite liner. The soil material particles must be able to pass a one-inch screen. B. Secondary composite liner: The soil component of the secondary composite liner must be at least 24 inches in compacted thickness and must have a maximum remolded coefficient of permeability of 1×10^{-7} cm/sec throughout its thickness and must be directly overlain by and in contact with a geomembrane. The soil material particles must be able to pass a one-inch screen.		
24.	North Carolina	The standard composite liner utilizes a CCL. The composite liner consists of a geomembrane liner installed above and in direct and uniform contact with a CCL with a minimum thickness of 24 inches and a permeability of no more than 1×10^{-7} cm/sec. HDPE geomembrane liners shall have a minimum thickness of 60 mils. The minimum thickness of any geomembrane approved by the Division shall be greater than 30 mils.	Allow Less Stringent Design	An alternative base liner system other than those outlined in the Rule may be approved by the Division if it is demonstrated through a site-specific, two-phase modeling approach that the alternative liner design meets the following criteria: the rate of leakage through the alternative liner system will be less than or equal to the standard composite liner system, and the design will ensure that the concentration values listed in the Rule will not be exceeded in the uppermost aquifer at the relevant point of compliance. The

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				aquifer at the relevant point of compliance. The relevant point of compliance shall be established no more than 250 feet from a waste boundary, and shall be at least 50 feet within the facility property boundary. However, based on experience and knowledge of the state geology, the following two alternative liner designs can generally be approved without performing modeling: 1. A GCL alternative composite liner is one liner that consists of three components: a geomembrane liner installed above and in uniform contact with a GCL overlying a CCL with a minimum thickness of 18-inches and a permeability of no more than 1 x 10^{-5} cm/sec. 2. A two-geomembrane alternative composite liner consists of three components: two geomembrane liners each with an overlying leachate drainage system, and a CCL with a minimum thickness of 12-inches and a permeability of no more than 1 x 10^{-5} cm/sec overlain by the lower membrane liner.
25.	Ohio	A composite liner consists of a recompacted soil liner (RSL) having a maximum permeability of 1 x 10^{-7}cm/sec and a FML. The RSL shall be at least: 5 feet thick, unless the director approves an alternate thickness to be no less than 3 feet based on the result of calculations outlined in the Rule; or 3 feet thick with a GCL, unless the director approves an alternate thickness for the RSL based on the results of calculations outlined in the Rule. FML shall be 60-mil HDPE	Allow less stringent design.	Variance requests must demonstrate to the Director that the design is no less protective of human health and the environment than the designs specified in the Rule. Variances are not commonly requested.

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		or other materials having a minimum thickness of 40-mil.		
26.	Oklahoma	A composite liner where the upper component is a geomembrane liner and the lower component is a reconstructed clay liner at least 2 feet thick and shall have a hydraulic conductivity that is no greater than 1×10^{-7} cm/sec. If the geomembrane is not to be exposed to weather or sunlight for longer than 3 months, the nominal thickness of the geomembrane shall be 60 mils for HDPE and 30 mils for all other types of geomembranes, but if the geomembrane is to be exposed to weather or sunlight for longer than 3 months, the nominal thickness of the geomembrane shall be 60 mils for HDPE and 45 mils for all other types of geomembranes. A thicker geomembrane (60 to 100 mils) may be required to resist various stresses.	Minimal exceptions.	An alternative design may be proposed that ensures the concentration values listed in the Rule will not be exceeded in the uppermost aquifer at the relevant point of compliance. Although an alternative liner design can be proposed, about 40 landfills in the state have all been constructed with the MTR.
27.	Oregon	Comply with landfill design criteria in 40 CFR, Part 258, Subpart D (i.e., Subtitle D). Except as otherwise provided in the Rule, MSW landfill design must be in conformance with the design requirements of this rule. The Subtitle D standard design for a composite liner consists of an upper geomembrane liner and a lower CCL. (Hydraulic conductivity of CCL to be a maximum of 1×10^{-7} cm/sec, and the a minimum 2-feet thick.) The permittee has the option of constructing a landfill containment system which either conforms to the standard design defined in 40 CFR 258.40(a)(2), or a performance based alternative liner design (ALD) approved by the Department.	Requirement to increase design	When an application is submitted, the Department shall evaluate the need to provide protection to groundwater in addition to the requirements of 40 CFR, Part 258, Subpart D. The Department shall also evaluate whether the specific conditions at the site require an enhanced ability to monitor potential threats to groundwater in addition to the requirements of 40 CFR, Part 258, Subpart E. The Department may require a secondary leachate collection system, and/or leak detection system, or other design providing equivalent protection to the environment. The state has a wet part (west side of state) and an arid part (east side of state) due to rain shadow of Cascade Mountains. The larger regional landfills have chosen

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		To obtain an ALD approval, the permittee must demonstrate that the ALD will satisfy the performance standard in 40 CFR 258.40(a)(1) which requires the design to "…ensure that the concentration values listed in the Rule….will not be exceeded in the uppermost aquifer at the relevant point of compliance….", and the policies and specific requirements of Oregon's Groundwater Quality Protection Rules (i.e., prevent a leachate release exceeding the statistical background concentrations at the relevant point of compliance). To facilitate Department review and approval of an ALD demonstration, the permittee must submit a work plan. An ALD demonstration gets approved by the Department when the results from implementing the approved workplan demonstrate that an ALD adequately protects groundwater quality throughout the operating and post-closure period. Based on experiences with past ALD demonstrations, the Department has issued a policy to streamline the review process for ALD and siting combinations that are inherently protective of the environment. Past ALD demonstrations show that lower leakage rates occur if a GCL is substituted for the CCL component of the standard composite liner. The Department believes that the ALD demonstration process should be simplified for such ALD's when proposed in combination with a favorable site location and secondary leak detection/leachate collection system. The policy statement is as follows: The Department exempts the following liner design from the conventional ALD		to locate on the arid side of the state due to the fact that ODEQ frequently implements a general exception requiring additional groundwater protection based on environmental factors. This exception is more commonly applied to the wet side of the state. The general practice has been for the significant MSW landfills to implement a third liner layer (i.e., geomembrane) and leak detection system beneath the Subtitle D liner system. This has resulted because owners: know ODEQ may not approve lesser requirements on the west side of the state; and know ODEQ may require additional protection on the wet side of the state. For landfills on the arid side of the state, a hybrid of the third liner concept has been implemented where a third liner layer (i.e., geomembrane) and leak detection system is placed in portions of the site beneath the Subtitle D liner system (i.e., under leachate collection areas). For landfills on both the east and west sides of the state, alternatives using a GCL in lieu of the CCL have been demonstrated and used. The ALD demonstration may be omitted for GCL use based on adherence to Policy Rules (as described under the MTR column). Other alternatives may also be proposed for approval consideration.

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		demonstration: an alternative composite liner design comprised of a minimum 60-mil thick HDPE geomembrane, underlain by a minimum 0.6-cm thick GCL with a hydraulic conductivity of no more than 3 x 10^{-9} cm/sec. This exemption applies only at facilities where it is technically feasible to make this liner substitution, and where site characteristics and facility design meet one of the following conditions: site precipitation is less than or equal to 15-in per year, depth to groundwater is 100-ft or more, and the ALD is underlain by at least a partial secondary leak detection/leachate collection system; or the ALD is underlain by a continuous secondary leak detection/leachate collection system. The current ALD demonstration process is HELP or MULTIMED-model based. The Department is considering whether to accept other approaches. Accordingly, this policy may be modified in the future to accommodate other ALD demonstration methods.		Although not specifically discussed with an ODEQ representative at this time, past first-hand project experience in the State of Oregon has resulted in successful demonstration and approval of an alternative to the CCL hydraulic conductivity specification of the composite liner requirement (i.e., 1 x 10^{-6} cm/sec in lieu of 1 x 10^{-7} cm/sec).
28.	Pennsylvania	A liner system shall consist of the following elements: (1) Subbase, which is the prepared layer of soil or earthen materials upon which the remainder of the liner system is constructed. (2) Secondary liner, which is a continuous layer of synthetic materials or remolded clay placed on the subbase. (3) Leachate detection zone, which is the prepared layer placed on top of the secondary liner and upon which the primary liner is placed, and in which a leachate detection system is located. (4) Primary liner, which is a continuous layer of synthetic materials placed on the leachate detection	Allow less stringent design.	Unless alternative design requirements to meet the performance standards (MTR) as part of the permit under § 271.231 (relating to equivalency review procedure), the liner shall meet: a. Geosynthetic (primary or secondary liner): 30-mil FML, HDPE shall be at least 60-mil. b. Natural & Remolded Clay (secondary liner, composite component): 2 feet, >=90% maximum dry density when using Standard Proctor method, 30% min. fines by weight pass #200 sieve, and no coarse fragments greater than ¾ inch.

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		zone. (5) Protective cover and leachate collection zone, which is a prepared layer placed over the primary liner in which a leachate collection system is located. Either the primary or the secondary liner shall be constructed as a composite liner. General Limitations: (a) The bottom of the subbase of the liner system cannot be in contact with the seasonal high water table or perched water table without the use of groundwater pumping systems. Drainage systems may be utilized to prevent contact. (b) At least 8-feet shall be maintained between the bottom of the subbase of the liner system and the regional groundwater table in an unconfined aquifer. The regional groundwater table may not be artificially lowered. (c) In a confined aquifer, at least 8-feet shall be maintained between the bottom of the subbase of the liner system and the top of the confining layer or the shallowest level below the bottom of the subbase where groundwater occurs as a result of upward leakage from natural or preexisting causes. Subbase: (1) Be at least 6-inches thick and compacted. (2) Be no more permeable than 1 x 10^{-5} cm/sec, based on testing unless the clay component of a composite liner is designed and constructed directly above the		c. Sodium bentonite & bentonite like materials (secondary liner, composite component): 1 foot, >=90% maximum dry density when using Standard Proctor method, 8% min. powdered sodium bentonite or manufacturer's recommendations whichever is greater, no coarse fragments greater than ¾ inch., and no organic matter. d. GCL (composite component): minimum of ¾ pound of powered or granular sodium bentonite per square foot.

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		subbase. Secondary Liner: (1) Be no more permeable than 1×10^{-7} cm/sec based on testing. (2) If the operator does not design a composite primary liner, the operator shall design a composite secondary liner which has an upper component made of manufactured geosynthetic liner that meets the requirements independently of the composite component and a composite component made of earthen material that meets the requirements independently of the upper component, except that the composite component may be no more permeable than 1×10^{-7} cm/sec based on testing. (3) Use of a composite secondary liner does not relieve the operator of responsibility for a separate primary liner. (4) 2-feet thick natural and remolded clay may function as the secondary liner or composite component. (5) 1-foot thick sodium bentonite and bentonite-like materials may function as the secondary liner or composite component. (6) GCL may function as the composite component. (7) Geosynthetic functioning as the secondary liner shall be at least 30-mil minimum or 60-mil if HDPE. Leachate Detection Zone: (1) Be at least 12-inches thick. (2) Create a flow zone between the secondary liner and		

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		the primary liner equal to or more permeable than 1×10^{-2} cm/sec based on testing. (3) Contain a perforated piping system capable of detecting and intercepting liquid within the leachate detection zone and conveying the liquid to a collection sump. The minimum diameter of the perforated pipe shall be 4-inches with a wall thickness of Schedule 80 or greater. Primary Liner: (1) Be no more permeable than 1×10^{-7} cm/sec based on testing. (2) If the operator does not design a composite secondary liner, the operator shall design a composite primary liner which has an upper component made of manufactured geosynthetic liner that meets the requirements independently of the composite component and a composite component made of earthen material that meets the requirements independently of the upper component, except that the composite component may be no more permeable than 1×10^{-7} cm/sec based on testing. (3) Use of a composite primary liner does not relieve the operator of responsibility for a separate secondary liner. (4) 2-feet thick natural and remolded clay may function as the composite component. (5) 1-foot thick sodium bentonite and bentonite-like materials may function as the composite component.		

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		(6) GCL may function as the composite component. Geosynthetic functioning as the primary liner shall be at least 30 mil minimum or 60 mil if HDPE.		
29.	South Carolina	Comply with landfill design criteria in 40 CFR, Part 258, Subpart D (i.e., Subtitle D). Except as otherwise provided in the Rule, MSW landfill design must be in conformance with the design requirements of this rule. The Subtitle D standard design for a composite liner consists of an upper geomembrane liner and a lower CCL. (Hydraulic conductivity of CCL to be a maximum of 1 x 10^{-7} cm/sec, and the CCL to be minimum 2-ft thick.)	Allow less stringent design.	An alternative liner system may be approved by the Department if the applicant can demonstrate compliance with the design criteria in the Rule. Approval of an alternative liner design is reviewed on a case-by-case basis.
30.	South Dakota	A composite liner system where the upper component is a FML and the lower component is a soil liner having a 2-foot compacted thickness and having a recompacted maximum coefficient of permeability of 1 x 10^{-7} cm/sec. The FML must, at a minimum, be compatible with leachate, have a 60-mil thickness, and have a life expectancy longer than the life of the facility.	Allow less stringent design.	An alternative liner system may be approved by the Secretary if the applicant can demonstrate compliance with the design criteria in the Rule and the design ensures that the concentration values of the Rule are not exceeded at the relevant point of compliance Because of the geologic and hydrogeologic conditions (Aquifer is generally more than 100 feet below and in-situ soil is highly impermeable) in the majority of the State, most landfills were constructed with only a 2-foot CCL. A site was approved with no liner since the aquifer is more than 150 feet below the landfill bottom and in-situ unoxidized soil has hydraulic conductivity of 10^{-9} cm/sec.
31.	Tennessee	Liner must be a composite liner consisting of two components. The upper component must consist of a minimum 30-mil FML and the lower component must	Allow less stringent design.	Alternate liner designs may be used provided that it is demonstrated to the satisfaction of the Commissioner that the liner design provides equivalent or superior

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		consist of at least a 2-foot layer of compacted soil with a hydraulic conductivity of no more than 1 x 10^{-7} cm/sec. FML components consisting of HDPE shall be at least 60-mil thick. Underlying the liners shall be a geologic buffer which shall have: (1) a maximum hydraulic conductivity of 1 x 10^{-5} cm/sec and measures at least 10-feet from the bottom of the liner to the seasonal high water table of the uppermost unconfined aquifer or the top of the formation of a confined aquifer, or (2) have a maximum hydraulic conductivity of 1 x 10^{-6} cm/sec and measures not less than 5-feet from the bottom of the liner to the seasonal high water table of the uppermost unconfined aquifer or the top of the formation of a confined aquifer, or (3) other equivalent or superior protection as defined in the Rule Admixtures and special construction techniques may be used to improve the properties of the compacted soil component of the composite liner provided that: (1) In no case shall the liner thickness be less than 2-feet (2) The modified liner shall achieve equivalent or superior performance to requirements of the minimum performance standard in the Rule		performance to the minimum performance standard in the Rule. The Commissioner shall consider factors when approving a design. GCL can used to substitute for the CCL. The thickness of the CCL which can be replaced by GCL is based on the HELP model results and the site specific geologic and hydro-geologic conditions.
32.	Texas	Constructed with one of the two following provisions approved by the executive director:	Allow less stringent design.	Alternate designs may be authorized by the executive director if a demonstration is provided by computerized

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		(1) A design that ensures that the concentration values listed in the Rule will not be exceeded in the uppermost aquifer at the relevant point of compliance as specified in the Rule; or (2) A composite liner consisting of two components: the upper component must be a minimum 30-mil FML and the lower component must be at least a 2-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. FML components consisting of HDPE shall be at least 60-mil thick.		design modeling (HELP and Multi-Media models) that shows that the maximum contaminant levels detailed in the Rule will not be exceeded at the point of compliance. Alternative liner designs have been approved include: ▪ GCL to substitute for 2 feet CCL ▪ 60-mil HDPE geomembrane liner only (Modeling was performed) ▪ Natural soil liner (4' min. or 3" + 1" protective soil. Soil to meet: maximum permeability of 1×10^{-7} cm/sec, LL $\geq$ 30, PI $\geq$ 15, percent passing #200 sieve $\geq$ 30%, and 100% passing 1-inch).
33.	Virginia	A composite liner system having a lower liner consisting of at least a 2-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec and an upper component consisting of a minimum 30-mil FML. If HDPE is used as the upper component FML, it shall be at least 60-mil thick.	Allow less stringent design.	May submit a petition to allow for an alternate design. The director may grant a variance to the composite liner system design if it is demonstrated to the satisfaction of the director that the proposed alternate liner system design will ensure that the concentration values listed in the Rule will not be exceeded in the uppermost aquifer at the waste management unit boundary. Most commonly approved alternative liner design is to use GCL replacing 2-foot compacted soil.
34.	Washington	For nonarid landfills, a composite liner consisting of two parts: the upper component must be a minimum of 60-mil thickness HDPE geomembrane. The lower component must be at least a 2-foot thick layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec.		Equivalent liner designs and liner materials may be used for nonarid landfills provided a demonstration during the permitting process can be made that the liner is equivalent to the composite liner design.

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		Thinner geomembranes of other than HDPE may be used provided that a demonstration can be made that the alternative has equivalent factors under conditions of construction and use. Minimum thickness of geomembranes other than HDPE shall be 30-mils. For arid landfills (precipitation less than 12 inches), a design that ensures that the maximum contaminant levels listed in the Rule will not be exceeded in the hydrostratigraphic unit(s) identified in the hydrogeologic characterization/ report at the relevant point of compliance as specified during the permitting process in the Rule. The jurisdictional health department shall consider factors when approving a design that complies with the arid landfill design of the Rule.		An alternative liner design of using GCL to substitute for the 2-foot CCL was approved for nonarid landfills in the past. However, the Department is in the process of changing this alternative by requiring an equivalency demonstration based on diffusion rather than requiring a performance based modeling (Refer to Dr. Gary Fosse and Dr. Shackleford recent publications regarding "Transit Time Design for Diffusion Through Composite Liner" and "Predicting Leakage Through Composite Liner"). In this case, the alternative liner design may requires FML + GCL + 2' compacted soil with a maximum hydraulic conductivity of 1×10^{-5} cm/sec or 1×10^{-6} cm/sec. For arid landfills, the Department allows using GCL to substitute for the 2-foot CCL.
35.	Wisconsin	A composite liner consisting of two components; the upper component shall consist of a nominal 60-mil or thicker geomembrane liner with no thickness measurements falling below the minimum industry accepted manufacturing tolerances, and the lower component shall consist of a minimum 4-foot thick layer of compacted clay having a saturated hydraulic conductivity of 1×10^{-7}cm/sec or less.	No exceptions.	The Department has not allowed any substantial variations from the MSW landfill liner requirements. A few older landfills still have active cells which meet the requirement of 5 feet of compacted clay in the previous code since 1970s. Alternative liner designs were approved for some industrial waste and utility ash landfills and consisted of a compacted clay liner only or GCL to substitute for the compacted clay component.