Section 7: Detailed Design

7.1 Introduction

Detailed design phase

Fundamental design assumptions and criteria established during conceptual design should be reevaluated and refined at the outset of the detailed design stage. At this point, additional site characterization data, materials testing results, input from the Department and other reviewing agencies, permit requirements, and other available information should be incorporated into the design.

Regulatory references

Mandatory design standards and performance criteria are specified in 40 CFR 258 and OAR 340 Division 94. The design approach should also reflect current technologies, and conventional engineering principals and practices. Requirements for detailed design plans and specifications are described in OAR 340-93-140.

How to respond

Submit the following design documents to the Department for approval prior to construction, consisting of:

- detailed plans and specifications, stamped by a qualified professional engineer with current registration in Oregon
- a design report that describe the technologies and engineering analyses associated with the proposed design

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Design plans and specifications

Base design plans and specifications on the results of Phase I and Phase II site characterization, geotechnical studies, and conceptual design analyses and reporting.

Design report

Prepare a design report that includes the following information:

- executive summary, conclusions, recommendations
- design basis, main assumptions, design criteria, and site constraints
- descriptions of key landfill components and their design functions
- a written explanation of the detailed design drawings and specifications
- a demonstration that landfill components will function as designed
- results of design-related materials testing
- preliminary specifications for construction materials, and
- engineering analyses and calculations used to develop the design

Format

To facilitate the Department's review, design reports, design plans and specifications and other related documents should have the same organizational format used in this guidance document. Design documents should be sufficiently detailed to enable the Department to determine whether mandatory standards and performance criteria have been achieved. Specifications should follow the standard format adopted by the Construction Specifications Institute.

In this section

This section provides guidance on preparing detailed design plans and specifications for the following environmental control systems:

- liner system
  - soil liner component
  - geomembrane component
- primary leachate collection and removal system
- secondary leachate collection and removal system
- leachate treatment and storage impoundments
- leachate holding tanks and conveyance pipelines
- leachate treatment process
- final cover system
- surface water control system, and
- landfill gas control system

7.2 Liner System

Performance criteria

Landfill liners are designed to protect the environment by preventing the release of leachate and landfill gas. New municipal solid waste landfill units and lateral expansions of existing landfill units must be equipped with either a composite liner, or a site-specific alternative design that meets the environmental performance criteria. Unless the Department approves an alternative design, liner systems must include:
- a soil liner component and
- a geomembrane liner component

These components are discussed in the following sections.

Reference: Minimum design standards for liner systems are specified in 40 CFR 258.2, 40 CFR 258.40(b), and 258.40(a)(1). Associated performance criteria are contained in the Department's groundwater protection rules [OAR 340-40-020(1),(2),(3)].

Proposing an alternative design

An alternative design proposal should be discussed with Department staff, before the development of formal design details. At this point, the Department will consider, from a technical and environmental standpoint, whether the proposal is viable. The Department will not approve alternative liner designs unless a convincing demonstration is made that the alternative design meets both the environmental performance requirements and the no-groundwater-degradation policy. Alternative design proposals will be subject to the opportunity for public comment.

Reference: See the Alternative Design discussion in Section 5: Conceptual Design of Landfill Facilities

Design document content

The design documents should address technical considerations such as
- performance criteria
- construction details (anchoring, penetrations)
- material properties
- dimensions
- bottom and sidewall slopes
- site operations (particularly the cell filling sequence and configuration),
- interface friction properties of liner system components, and
- subgrade conditions such as groundwater levels and soil properties

7.3 Liner System -- Soil Liner Component

Soil characteristics

Soils have a wide range of physical characteristics that are relevant to liner construction. These characteristics, described below, effect the soil's potential to meet the specified permeability of 1 x 10^{-7}.

Characteristic	Description
Soil plasticity	The soil plasticity index (PI) should be greater than 10 percent. However, soils with very high PI (above 30 percent), are cohesive, sticky and difficult to work with in the field. When high PI soils are too dry, they may form clods that are difficult to break down during compaction. Perferential flow paths may form around the clods, increasing the liner's permeability. Large soil particles or rock fragments can also form perferential flow paths.
Soil density and moisture	A soil's maximum density corresponds to the optimum moisture content, the minimum permeability to a moisture content wet of optimum. Wet soils, however, have less shear strength and more potential for desiccation cracking. When specifying moisture content, consider shear strength and other engineering properties. Typically, the permeability criterion can be achieved at moisture values of 1 to 7 percent above optimum.

Liner construction

Soil liners should be constructed in a series of compacted lifts. To specify lift thickness consider soil characteristics, compaction equipment, foundation characteristics, compaction requirements and liner permeability. The compactor must reach the lower portions of the lift to establish good, homogeneous bonding between lifts.

Soil test methods

Use the following test methods to characterize prospective liner soils:

- grain size distribution (ASTM D-422)
- Atterberg limits (ASTM D-4318), and
- moisture/density relationships by standard or modified Proctors (ASTM D-698 or ASTM D-1557), whichever is appropriate for the compaction equipment the foundation characteristics

Design criteria: soil liner

Design the soil liner to meet the following criteria:

- maximum saturated hydraulic conductivity (permeability) -- 1 x 10^{-7} cm/sec
- minimum compacted thickness -- least two feet
- Atterberg limits -- plasticity index ³ 10%;
- percent fines -- ³ 50% passing a #200 sieve;
- percent coarse material -- 10% retained on a #4 sieve;
- maximum particle size including clods -- 1 - 2 inches.

Recommended design procedures

Design the soil liner component by following the procedures below.

Step	Action
1	Specify performance objectives and material properties
2	Specify Unified Soil Classification, percent clay content (by hydrometer analysis to the 2 micron particle size) and the additional soil properties in the design criteria
3	Establish liner dimensions including thickness and surface area
4	Prepare appropriate design details, including details of connections between existing and new sections of the liner
5	For bentonite amended soils, specify the bentonite application rate as a percentage of the original dry weight of the soil, and mixing techniques
6	Specify construction requirements for the soil test pad the full-scale liner and associated earthwork
7	Specify Construction Quality Control (CQC) and Construction Quality Assurance (CQA) requirements

Reference: Also refer to the construction requirements in Sections 8.3, 8.4, and 8.5.

7.4 Liner System -- Geomembrane Liner Component

Design criteria: geomembrane liner

Design the geomembrane component of the landfill liner to meet the following criteria:

- HDPE geomembranes of at least 60 mils thick (or at least 30 mil thick for other materials) should be installed in direct and uniform contact with the underlying soil liner
- the geomembrane should be chemically compatible with leachate, landfill gas, and other expected environmental conditions within the landfill
- the geomembrane should be physically compatible with the proposed subgrade and backfill properties
- the geomembrane should be capable of withstanding the anticipated short-term and long-term stresses due to facility construction and operation.
- the number of pipe penetrations through the geomembrane should be minimized to the extent possible
- the geomembrane's friction properties should be compatible with other components of the liner system to minimize mechanical stresses on any component

Design approach

A systematic approach to design will enhance the geomembrane's performance, reliability and compatibility with other landfill components.

Recommended design procedures

Design the geomembrane liner component by following the procedures below. Where listed, refer to the pages in Section 7.13 (Appendix of Engineering Analyses and Calculations) for additional details.

Step	Action	Ref. pg.
1	Specify performance criteria and material properties for geomembranes and associated geosynthetics	---
2	Perform a geomembrane design analysis to determine acceptable geomembrane properties	7-25
3	Analyze the liner system's stability in side-slope areas	7-26
4	Analyze geomembrane runout or anchor trench requirements and prepare design details	---
5	Prepare design details for sumps, pipe penetrations, mechanical attachments to structures, etc.	---

Step	Action	Ref. pg.
6	Specify Construction Quality Control (CQC) and Construction Quality Assurance (CQA) requirements	---

Geomembrane specifications

Identify the geomembrane's function and specify desired properties for:
- the geomembrane to perform its intended function
- construction survivability, and
- in-service durability (i.e., resistance to temperature variations, UV radiations, leachate, mechanical stress)

Testing and acceptance

Establish minimum requirements for testing and acceptance of geomembrane conformance, including:
- sampling frequency
- sample size
- sampling technique
- conformance testing procedures
- acceptance criteria, and
- rejection procedures

7.5 Primary Leachate Collection and Removal System

Performance criteria

The primary leachate collection and removal system (LCRS) must be designed to function automatically, continuously, and as efficiently as possible within practical limits. The LCRS should maintain a leachate depth of less than 30-cm above the liner.

Reference: 40 CFR 258.40(a)(2)

Design criteria

Design the primary leachate collection and removal system to meet the following criteria:

- granular drainage layer percent fines -- < 5% passing No. 200 sieve.
- granular drainage layer hydraulic conductivity -- 1 x 10^{-2} cm/sec.
- granular drainage material should consist of carbonate-free, rounded gravel or non-angular rock.
- leachate collection pipe -- minimum 6-inch diameter, schedule 80 or equivalent strength pipe.
- minimum slopes for collection pipes -- 1% after predicted settlement; comply with OAR 340-52-030 for sewer pipelines (enough slope to maintain scouring velocity).
- minimum slopes for leachate drainage layer -- 2% after foundation settlement.
- manhole/cleanout spacing -- Should be compatible with available cleanout equipment and meet recommendations (not minimums) of OAR 340-52-030 for sewer pipes. At a minimum, provide cleanouts at both ends of all leachate collection pipes and sweep bends to accommodate cleanout equipment.

Recommended design procedures

Design the leachate collection and removal system (LCRS) by following the procedure below. Where listed, refer to the pages in Section 7.13 (Appendix of Engineering Analyses and Calculations) for additional details.

Step	Action	Ref. pg.
1	Prepare scaled drawings of the leachate collection system layout and construction details	---
2	Specify properties, characteristics and performance criteria of granular drainage layers, including Unified Soil Classification, grain size distribution, maximum particle size, maximum percent passing No. 200 sieve, thickness, and hydraulic conductivity at anticipated field density	---

Step	Action	Ref. pg.
3	Specify properties, characteristics and performance criteria of geosynthetic drainage layers, including polymer type, transmissivity and evidence of chemical compatibility. Analyze requirements for geosynthetic drainage material to determine allowable properties	7-25, 7-26, 7-28
4	Specify properties and characteristics of any granular filter layers, including Unified Soil Classification, grain size distribution and thickness	---
5	Specify properties and characteristics of any geosynthetic layers used for filtration or for liner protection. By analysis, determine allowable properties for protection or filtration layers	7-26, 7-28
6	Describe leachate collection pipe configuration, dimensions and properties, and analyze pipe loading and structural strength	7-31
7	Identify minimum slope specifications for drainage layers and collection pipes	---
8	Prepare leachate collection sump capacity and design details	---
9	Prepare manhole/cleanout design details, describe cleanout equipment capability and procedures, and analyze manhole-foundation design requirements	7-31
10	Identify the location and minimum spacing of manhole/cleanouts	---
11	Conduct a filtration analysis to evaluate the primary LCRS's clogging potential	7-31
12	Conduct an analysis of primary LCRS performance	7-30

7.6 Secondary Leachate Collection and Removal System

Need for secondary system

Under certain circumstances (see OAR 340-94-060(6)), the Department may require a secondary leachate collection and removal system (LCRS) to provide for additional groundwater protection and/or enhanced monitoring.

Design criteria

Design the secondary LCRS to detect and collect leachate at locations of maximum leak probability (e.g., liner penetrations, leachate collection sumps and leachate drain lines). Consider the following criteria:

- locate the secondary LCRS
  - beneath areas of maximum leak probability;
  - directly below and parallel to the liner system; and
  - above or hydraulically isolated from the seasonal-high water table to prevent groundwater intrusion into the secondary LCRS and potentially erroneous monitoring results.
- granular drainage layer percent fines -- < 5% passing No. 200 sieve.
- granular drainage layer hydraulic conductivity -- 1 cm/sec (at field density).
- granular drainage layer physical properties -- non-angular rock or rounded gravel free of carbonate material
- geosynthetic drainage layer transmissivity -- 5×10^{-4} m^2/s.
- minimum slope specifications for drainage layer and collection pipes -- pipes should meet recommendations (not minimums) of OAR 340-52-030 for sewer pipelines. Drainage layer should slope at least 2% (after settlement)
- manhole/cleanout location and spacing should not exceed capabilities of available equipment

Recommended design procedures

Design the secondary leachate collection and removal system (LCRS) by following the procedure below. Where listed, refer to the pages in Section 7.13 (Appendix of Engineering Analyses and Calculations) for additional details.

Step	Action	Ref. pg.
1	Prepare scaled drawings of the secondary leachate collection and removal system layout and construction details	---
2	Describe the secondary LCRS lining system, including its physical properties and dimensions	---

Step	Action	Ref. pg.
3	Specify granular drainage layer properties and performance criteria, including Unified Soil Classification, grain size distribution, maximum particle size, maximum percent passing No. 200 sieve, thickness, and hydraulic conductivity at anticipated field density	---
4	Specify geosynthetic drainage layer properties, and performance criteria, including polymer type and transmissivity. Determine allowable properties for geosynthetic drainage material should be determined by analysis	7-25, 7-26
5	Specify granular filter layer properties and performance criteria, including Unified Soil Classification, grain size distribution and thickness. Granular filter material must be free of carbonate material	---
6	Specify geosynthetic protective or filter layer properties. Determine allowable properties for geosynthetic by analysis	7-25
7	Describe leachate collection pipe configuration, dimensions and properties. Determine allowable properties by a structural stability analysis	7-31
8	Identify minimum slope specifications for drainage layers and collection pipes	---
9	Prepare leachate collection sump capacity and design details	---
10	Prepare manhole/cleanout design and operation details, including cleanout equipment capabilities and operating procedures. Analyze foundation requirements for manholes.	7-31
11	Identify manhole/cleanout configuration and spacing	---
12	Analyze the clogging potential within secondary LCRS components	7-31
13	Analyze the collection efficiency of the secondary LCRS	7-30

7.7 Leachate Treatment and Storage Impoundments

Performance criteria

Environmental safeguards for leachate treatment and storage impoundments should be comparable to or more extensive than what is required for a Subtitle D landfill cell. For minimum standards on location, design, construction, and monitoring see OAR 340-94-060(3).

Design Criteria

Design leachate treatment and storage impoundments to meet the following criteria:

- impoundment liners equal or exceed the landfill liner design
- the leak detection system underlies the impoundment liner to account for the substantial liquid depths within such impoundments
- impoundments have sufficient freeboard to contain and prevent overflow due to the 24-hour, 25-year storm
- available storage capacity reflects adopted leachate management practices and seasonal operating restrictions

Recommended design procedures

Design the leachate treatment and storage system by following the procedures below. Where listed, refer to the pages in Section 7.13 (Appendix of Engineering Analyses and Calculations) for additional details.

Step	Action	Ref. pg.
1	Calculate required storage capacity, account for leachate flow projections and the impoundment's internal water budget	7-31
2	Incorporate landfill cell design procedures	---
3	Design the leak detection system, incorporate all applicable steps outlined in Subsection 7.6 for secondary leachate collection and removal systems	---
4	Design leachate impoundments using landfill-cell equivalent detail and engineering analysis	---
5	Use applicable information previously developed for landfill cell design analyses	---

7.8 Leachate Holding Tanks and Conveyance Pipelines

Design criteria: holding tanks

Design leachate holding tanks to be:

- watertight
- composed of landfill-leachate compatible materials
- located on a flat, stable foundation, and
- sized to support the LCRS and leachate management practices

Design criteria: conveyance pipelines

Design conveyance pipelines to be:

- composed of landfill-leachate compatible materials
- consistent with the Departments' guidelines for sewer pipelines
- watertight and
- capable of withstanding in-service conditions, physical loads, stresses

Recommended design procedures

Design leachate holding tanks to meet the same operational considerations as impoundments. Design conveyance pipelines according to the guidelines for sewer pipelines.

References: OAR 340-060(3); OAR 340-52-020, Appendix A

7.9 Leachate Treatment Process

Performance criteria

Design the leachate treatment and disposal system to achieve effluent quality (leachate strength) objectives as appropriate for direct discharge or for pretreatment followed by discharge to another treatment facility.

Designing the system

The design of a leachate treatment and disposal system should include the following main stages:

Stage	Description
A feasibility study	Evaluate treatment and disposal alternatives and identify preferred method
Conceptual design	Prepare Conceptual Design (Engineering) Report including conceptual design plans and specifications for the selected alternative
Detailed design	Prepare detailed design plans and specifications and the Design Report

Selecting a design

Leachate composition and flow rates are highly variable and subject to numerous, site-specific physical and environmental influences. Select treatment technologies which can be easily modified to accommodate substantial changes in hydraulic loading and leachate strength.

Treatability studies

If possible, conduct treatability studies on site-specific leachate before committing to a particular leachate treatment process or technology. Treatment process staging may be necessary to accommodate variations in leachate chemistry and flow rates. Staging involves adding or deleting treatment processes or changing capacity of existing processes as future conditions warrant.

Design criteria

Establish leachate treatment goals and design criteria (e.g., effluent quality, treatment efficiency) consistent with final disposal requirements and raw leachate characteristics.

Recommended design procedures

Design the leachate treatment process based on the results of the site characterization studies, a feasibility study, and the conceptual design report. Re-evaluate the following critical design parameters established during conceptual design:

Design parameter	Evaluation criteria
Leachate characteristics	additional testing may be needed to assess the leachate's variability and treatability
Site geotechnical conditions	additional, localized geotechnical testing may be required to augment site-wide investigations
Leachate flow projections (hydraulic loading)	accuracy
Storage capacity and detention times	accuracy
Treatment efficiency forecasts	accuracy
The adaptability of proposed leachate treatment technologies	ability to accommodate short-term and long-term variations in leachate characteristics and treatment requirements

7.10 Final Cover System

Performance criteria

The final cover system should minimize water infiltration and erosion. Other important design issues include landfill gas containment and control, settlement, erosion, long-term maintenance requirements, and slope stability. Landfills that undergo remedial action to alleviate groundwater contamination, may be required to meet more stringent design criteria for the final cover.

References: 40 CFR 258.60(a) and OAR 340-94-120

Alternative designs

EPA allows approved state permitting programs, like Oregon's, flexibility in interpreting Subtitle D cover design requirements. Accordingly, the Department may consider alternative designs provided that critical performance criteria (e.g., minimal infiltration) are met. In the State's arid regions, for example, a properly designed soil cover may perform as well as a geomembrane.

Design criteria

Design the final cover system to meet the following criteria:
- minimum slopes of 2% and maximum slopes of 30%
- accommodate anticipated settlements
- contain landfill gas and enhance gas collection and recovery efforts
- minimize erosion
- minimize surface water infiltration
- promote efficient surface water drainage and runoff
- maintain stability on side slopes, and
- enhance site aesthetics

Design procedures

Design the final cover system by following the procedure below. Where listed, refer to the pages in Section 7.13 (Appendix of Engineering Analyses and Calculations) for additional details.

Step	Action	Ref. pg.
1	Prepare typical cross-sections of the cover system design for top and side slope	----
2	Use the HELP Model to predict infiltration	7-25
3	Analyze slope stability	7-26, 7-27
4	Analyze potential settlement	7-28

5	Describe each layer of the cover system, including: • foundation layer • low permeability layer • drainage layer • protective layer • topsoil layer • vegetative layer	---

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Foundation layer

The foundation layer will serve as a base for either a low-permeability soil layer, or a geomembrane layer. The foundation layer must support and protect the cover during and after the construction phase.

Specify appropriate material properties, thickness, and configuration.

Low Permeability Layer

Design the low permeability layer to minimize moisture infiltration, to enhance landfill gas containment and control, and to accommodate site specific physical and environmental conditions.

Reference: Section 6.2 of this guidance provides detailed information on designing geomembrane and low-permeability soil layers

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Drainage layer

Design the drainage layer to minimize infiltration, leachate generation, slope stability problems, erosion, and to enhance access for maintenance equipment.

Design procedures: drainage layer

Design the drainage layer of the final cover system by following the procedures below. Where listed, refer to the pages in Section 7.13 (Appendix of Engineering Analyses and Calculations) for additional details.

Step	Action	Ref. pg.
1	Specify properties, and performance criteria of granular drainage layers, including Unified Soil Classification, grain size distribution, maximum particle size, maximum percent passing No. 200 sieve, thickness and hydraulic conductivity	---
2	Specify properties, and performance criteria of geosynthetic drainage layers, including polymer type and transmissivity	7-25
3	Identify properties of granular filter layers, including Unified Soil Classification, grain size distribution and thickness;	---

4	Specify properties of geosynthetics used for protective or filter layers. Determine allowable properties by analysis	7-28
5	Analyze filter layer performance	7-31
6	Specify configuration, dimensions and properties of the collection pipe system. Analyze structural parameters.	7-31
7	Develop exit drain design details	---
8	Analyze drainage layer performance	7-30

Protective layer

An additional soil layer may be used to protect low-permeability layers from physical or environmental damage.

Design of protective layer

Specify the protective layer's properties and dimensions, including Unified Soil Classification, grain size distribution, thickness, hydraulic conductivity and maximum particle size (if placed directly on a geomembrane layer). Design the protective layer to:

- provide adequate rooting depth and soil moisture storage for selected vegetation
- protect the low-permeability layer against root penetration, freezing, drying and desiccation, and
- protect geosynthetic layers from puncture and other physical damage

Topsoil layer

The primary function of the topsoil layer is to provide an optimal growing medium for desirable vegetation. Topsoil may be amended with woodwaste, sewage sludge, or compost if applied appropriately at agronomic rates. Soil amendments should not cause odors, air-born contaminants or surface water quality problems.

Design criteria: topsoil layer

Specify top soil characteristics based on a thorough analysis of vegetation alternatives and fertilizer requirements, such as:

- thickness
- U.S.D.A. textural classification
- Soil Taxonomy
- pH
- organic content
- salinity
- nutrient content, and
- carbon to nitrogen ratio

If the topsoil layer will function as the protective layer, follow procedures for the design of the protective layer

Note: For additional information on soil properties and enhancement techniques, contact the County Agent of the Oregon State University Extension Service

Vegetative layer

The vegetative layer's main functions are to:
- minimize erosion and long-term maintenance, and
- maximize evapotranspiration

Design criteria: vegetative layer

The vegetative layer should be compatible with other cover-system components and easy to maintain. Plant shallow-rooted, locally adapted perennial plants that:
- resist drought and temperature extremes
- thrive in low nutrient soil with minimum nutrient addition
- establish dense growth to minimize cover soil erosion (limit is no more than 2 tons/acre/year), and
- survive and function with little or no maintenance

Reference: Refer to the Page 7-33 in Section 7.13 (Appendix of Engineering Analyses and Calculations) for additional details.

Alternative to vegetative layer

A vegetative layer may be incompatible with site climatic conditions or end use plan. If an alternative layer is planned, assess soil erosion, long-term maintenance requirements, and compatibility with other cover system components. The specified material should:
- accommodate settlement without compromising function
- maintain positive slopes to promote surface drainage off the cover
- be stable and erosion resistant during extreme precipitation and/or wind, and
- limit soil erosion to no more than 2 tons/acre/year

Reference: Refer to the Page 7-33 in Section 7.13 (Appendix of Engineering Analyses and Calculations) for additional details.

Typical cover system design

A typical final cover system design meets the thickness, slope, and specifications listed in the table below.

Layer	Construction material	Thickness	Slope	Specifications

Layer	Construction material	Thickness	Slope	Specifications
Top layer	vegetation	---	---	persistent, drought resistant, adapted to local conditions, shallow-rooted
	on soil	$\geq$ 12 inches	$\geq$ 2%	erosion rate < 2 tons/acre/year
Drainage layer	Soil (sand and gravel mixes)	$\geq$ 12 inches	$\geq$ 2%	SP (USCS) soil, K > 10^{-2} cm/sec
	geosynthetic	variable	$\geq$ 2%	performance equivalent to soil, hydraulic transmissivity > $3x10^{-5}$ m^2/s
Low-permeability layer	geomembrane (HDPE)	$\geq$ 60 mils	$\geq$ 2%	other types of FMLs should be at least 20 mils in thickness
	on low-permeability soil	$\geq$ 24 inches	$\geq$ 2%	in place K < 10^{-6} cm/sec

7.11 Surface Water Control System

Precipitation data

Select appropriate precipitation data for design analyses.

Reference: Refer to the Page 7-32 in Section 7.13 (Appendix of Engineering Analyses and Calculations) for additional details.

Design criteria

Design the surface water control system to meet the following criteria:
- prevent run-on flow onto active or inactive portions of the landfill (assuming peak discharge from the 25-year storm)
- collect and control run-off from active and inactive portions of the landfill (assuming a 24-hour, 25-year storm)
- comply with the provisions of the storm water discharge (NPDES) permit and the Clean Water Act
- control sediment transport and remove suspended solids as necessary to comply with the NPDES permit conditions
- collect and contain leachate contaminated stormwater that accumulates in active fill areas
- temporarily store excess run-off from peak flows until it can be discharged at a lower, controlled rate
- minimize site erosion
- protect the integrity and effectiveness of the landfill cover system, and
- minimize post-closure maintenance requirements

Design Procedures

Design the surface water control system for both the active landfill operation and post-closure phases by following the procedure below.

Step	Action
1	Define drainage basin boundaries
2	Identify potentially sensitive features, such as wetlands, fish migratory streams
3	Develop site grading plans for active and closed landfill scenarios
4	Develop design storm hydrographs and calculate peak flow volumes and velocities
5	Select and size appropriate control-system components, including ditches, culverts, and detention basins to safely pass peak flows
6	Specify permanent and temporary erosion control measures

Step	Action
7	Specify permanent and temporary siltation control measures, and
8	Perform applicable analyses and calculations Reference: Refer to the Page 7-32 in Section 7.13 (Appendix of Engineering Analyses and Calculations) for additional details.

7.12 Landfill Gas Control System

Designing the system

Design the landfill gas control system to accommodate a wide range of operational and environmental variables, withstand harsh physical/ environmental conditions, and function as long as needed.

Appropriate landfill gas control system technologies are:

- flexible operationally
- easy to construct and modify
- durable (physically and chemically)
- easy to monitor, and
- easy to maintain and repair

Design criteria

Design the landfill gas control system to:

- handle the maximum gas flow rate predicted for the landfill
- accommodate variability in gas generation, composition, and other operational parameters
- expand as needed to collect gas from future cells, and
- meet the applicable criteria in the table below

If designing...	then meet the following criteria:
an active control system	• extraction well boreholes should be at least 24 inches in diameter • construct extraction well casings and collection laterals and headers of PVC, HDPE or stainless steel • provide 100% blower standby (backup) capability • equip flare systems with flame arresters to prevent accidental ignition in the discharge piping system • equip flare units with automatic ignition systems and alarms • at sites with a high risk of off-site gas migration, install alarm systems with auto-dial-phone capabilities to contact response personnel 24-hours-a-day, 7-days-a-week • design perimeter extraction wells should be designed to provide 100-percent overlap of influence between adjacent wells (i.e., radii of influence of adjacent wells should completely overlap)
a passive control system	use only in combination with geomembrane cover and liner systems

Recommended design procedures

Establish the overall design basis by re-evaluating conceptual design criteria, landfill gas test data, and site characterization data. Incorporate the latest available engineering data and gas test data and following the design procedure below.

Step	Action
1	Determine the landfill's gas generation potential. Various modeling techniques may be used to predict approximate peak and total landfill gas production
2	Define the main operating functions of the landfill gas control system (i.e., landfill gas migration control, odor or air-emissions control, energy recovery, or multi-use)
3	Establish performance criteria, construction materials properties, equipment layout, and equipment types and characteristics. Design construction details (e.g., well or collection-trench depths and spacings and perimeter setbacks, header pipe sizes and configuration) to accommodate site-specific conditions
4	Prepare a facilities plan that depicts the following system components: • extraction well and/or collection trench locations and spacings • locations of adjustment valves and sampling ports • configuration of collection header piping • condensate drain locations • layout of mechanical equipment complex (i.e., blowers, flares, electrical panels) • locations of gas monitoring probes
5	Prepare design details that describe proposed materials and equipment for the major control system components (i.e., well casings, collection piping, granular materials, valves, blowers, flares) and typical design details for the following: • extraction wells • valves and sampling ports • condensate drains, sumps, pumps, storage tanks and associated equipment • mechanical equipment complex (blowers, flares, condensers, electrical panels, alarms, etc.), and • well or piping penetrations through the cover or liner systems

7.13 Appendix of Engineering Analyses and Calculations

Design report supporting information

As applicable, describe the assumptions, technical rationale, references, and factors of safety used for each engineering analysis or calculation. Incorporate relevant analyses and calculations into the Design Report.

Soil balance calculations

Calculate quantities of specialized and general-purpose soils:
- to construct and operate each phase of landfill development
- for phased closure and final closure construction
- available at the identified borrow source, and
- to be imported over the life of the site

Water balance analysis (HELP model)

Use the latest version of U.S. EPA's Hydrologic Evaluation of Landfill Performance (HELP) Model to estimate:
- water percolation through each barrier layer
- lateral drainage from each drainage layer, and
- hydraulic head build-up in each drainage layer

Model input should consist of site-specific climatological data, if available, and site-specific geotechnical and design data. Assume landfill operational status ? development plan and engineering design plans. Provide all input assumptions and the complete model output in the Design Report.

Use of geosynthetics

Geosynthetics such as geomembranes, geotextiles, geonets, geogrids and geocomposites have many possible applications in landfill design and construction. Non-structural materials such as geomembranes and geonets should not be subjected to significant physical stresses. Other liner or cover components must be designed to protect non-structural materials from physical stresses.

Note: For methods to evaluate interface friction and shear stresses of layered geosynthetic components see Stability Analyses on page 7-26.

Selecting a geosynthetic

Select geosynthetics by matching intended functions with compatible physical properties. Manufacturers' specifications are usually derived from laboratory tests which do not account or field conditions. Adjust for differences between laboratory and in-situ conditions by either:

- customizing laboratory and field tests to model field conditions, or
- using partial factors of safety to account for differences between laboratory tests and field conditions

Perform a "design by function" analysis to select the appropriate geosynthetic material, or establish material properties by following the procedure below.

Step	Action
1	Evaluate the geosynthetic layer and the materials above and below
2	Specify a design factor of safety that reflects the potential consequences of the geosynthetic's failure
3	Describe the geosynthetic's primary function(s) and other critical functions
4	Calculate the numerical value for each geosynthetic property in question (as appropriate for the geosynthetic's intended function)
5	Specify testing requirements for selecting a geosynthetic product
6	Determine the partial factors of safety needed to compensate for differences between laboratory testing and the field conditions
7	Specify the minimum allowable properties for a product in a particular application

Reference: The suggested "design by function" approach to designing with geosynthetics is summarized in pages 61-62 of R. M. Koerner's Designing With Geosynthetics, 2nd Edition, Prentice-Hall Publ. Co., Englewood Cliffs, NJ, 1990, 652 pgs

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Stability analyses: parameters

Analyze the stability of all waste containment structures. Consider facilities design, construction and operation, and site characteristics (e.g., naturally unstable or seismically affected areas). Seismic impact zones, as defined in 40 CFR 258.14, exist at most locations in Oregon. Use appropriate testing and analysis to determine the following parameters:

- strength of soils and solid waste materials
- effective angles of internal friction for soils and solid waste
- friction angles of adjoining layer interfaces
- density of soils and solid waste, and
- pore water pressure in soils

Stability analyses: scenarios

Analyze the following scenarios using appropriate factors of safety:

- Potential rotational failure of the soil mass beneath the liner system
- Potential rotational failure of any containment dike, or other engineered structures
- Potential sliding failure of the liner system along the plane of the side slope
- The general slope stability and liner system stability along the plane of the liner system (assume active landfill operations and worst-case site development conditions
- Potential sliding failure or the cover system side slopes, assuming maximum pore water pressure in the drainage layer or cover soils over a geomembrane

Factors of safety

Suggested factor of safety (FS) values are shown in the table below. Actual values reflect engineering analyses site geotechnical and environmental characteristics, construction materials, operational procedures and risk factors.

Consequences of Slope Failure	**Uncertainty of Strength Measurements**	
	Small[1]	Large[2]
No imminent danger to human life or major environmental impact if slope fails:	1.25 (1.2)[*]	1.5 (1.3)
Imminent danger to human life or major environmental impact if slope fails:	1.5 (1.3)	2.0 or greater (1.7 or greater)

[1] Strength measurements are most reliable when the soil conditions are uniform and high quality test data are available

[2] Strength measurements are most uncertain when the soil conditions are complex and test data are inconsistent and incomplete

[*] Numbers without parentheses apply for static conditions and those within parentheses apply to seismic conditions.

Modified from: U.S. EPA, (1993), "Technical Manual for Solid Waste Disposal Facility Criteria - 40 CFR Part 258," November 1993.

Settlement

Settlement may involve a landfill cell, geologic units beneath the cell, or both. The amount of settlement depends on the characteristics of the solid waste and the underlying geological units.

Settlement analysis

Calculate for each landfill cell:

- the total consolidation of underlying geological units
- the total waste settlement
- differential settlement beneath the flattest sections of the liner system and maximum differential settlement beneath the liner footprint
- maximum differential settlement of the cover system
- slope allowance required to compensate for differential settlement of leachate drainage layers and collection pipes, and
- final cover slope allowances required to compensate for estimated differential settlement

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Settlement tolerances

Post-settlement slopes for leachate collection systems and cover systems should meet original design criteria

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Geotextile filter analysis

A geotextile filter should provide adequate cross-plane permeability and soil retention. Therefore, the geotextile's void spaces need to be compatible with adjoining materials. Analyze geotextile filters following the table below.

Step	Action
1	Specify a design factor of safety and calculate: • the required flow rate through the geotextile filter, and • the apparent opening size of the geotextile from the soil gradation
2	Specify appropriate geotextile testing (e.g., apparent opening size, permittivity)
3	Determine allowable flow rate. Use partial factors of safety to account for soil clogging, creep reduction of void spaces, and biological clogging
4	Consider other critical properties including: • chemical compatibility with landfill contaminants • survivability (during packaging, transportation, handling, and installation), and • ultraviolet-light resistance

Step	Action
5	Specify a particular geotextile product, or specify the required properties (e.g., apparent opening size and permittivity)

Geomembrane liner system

The geomembrane must have appropriate physical properties to withstand physical and environmental stresses during construction and long-term use. Analyze the critical design parameters following the procedure below

Step	Action
1	Calculate and specify a design factor of safety for construction and operation related stresses (i.e., tensile, shear, impact, and puncture stresses). Stress sources include anchorage, geomembrane weight, waste-weight, foundation subsidence, waste settlement, construction equipment operation, and contact subgrade and backfill materials (e.g., drainage layers)
2	Specify geomembrane testing procedures for critical properties (e.g., tensile strength, seam strength, tear resistance, puncture resistance, impact resistance, geomembrane friction, etc.). Use partial factors of safety to account for discrepancies between laboratory tests and field conditions
3	Consider other critical properties including: • chemical compatibility with leachate and gas • survivability during packaging, transportation, handling, and installation • ultraviolet light resistance, and • coefficient of thermal expansion (required slack in the geomembrane and acceptable temperature ranges for installation)
4	Specify a particular geomembrane product, or the minimum allowable geomembrane properties

Primary LCRS performance evaluation

Design the primary leachate collection and removal system (LCRS) using redundant features and conservative factors of safety to enhance its reliability. Evaluate critical design parameters using the following assumptions and analysis:

- Precipitation impinging directly on the drainage layer; the drainage layer is saturated; precipitation equals the wettest month’s average rainfall. Calculate the hydraulic head for these conditions. The hydraulic head should not exceed 12 inches [30-cm] or the thickness of the drainage layer at any point in the LCRS, and
- All leachate collection pipes fail with the final cover is in place; surface water infiltration enters the drainage layer at a rate equal to the HELP Model estimate; the drainage layer is saturated; precipitation equals the wettest monthly total. Calculate hydraulic head for these conditions. The hydraulic head should not exceed 12 inches [30-cm] or the thickness of the drainage layer at any point in the LCRS.

Secondary LCRS performance evaluation

Evaluate the performance of the proposed secondary LCRS design by calculating the following:

- Leakage detection sensitivity: ". . . the smallest primary liner leakage rate which can be detected."
- Leakage collection efficiency: the ratio of the leakage collected at the secondary LCRS sump divided by the leakage entering the secondary LCRS and
- Leak detection time: the time required for leachate to travel from the point of entering the secondary LCRS to a collection sump

References: Background Document: Bottom Liner Performance in Double-Lined Landfills and Surface Impoundments, EPA/530-SW-87-013, U.S.EPA, 1987, 301 pgs.
Background Document: Proposed Liner and Leak Detection Rule, EPA 530-SW-87-015, U.S.EPA, 1987, 526 pgs.

Cover system drainage layer performance

Evaluate drainage layer performance and reliability by using the HELP Model or other appropriate method(s) to calculate the maximum hydraulic head buildup within this layer.

LCRS filtration analysis

Demonstrate that the conveyance systems for the primary, and secondary LCRSs and the final cover drainage system are designed to prevent clogging. Use analysis and calculations to show that:

- geotextile filter layers will adequately retain solids and pass liquids (see page 7-28), and
- granular filter layers will adequately retain solids and pass liquids (use analytical methods on pages 19 - 20 of Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments, U.S. EPA, EPA/530-SW-89-047, July 1989, and page 7-68 of Lining of Waste Containment and Other Impoundment Facilities, U.S. EPA, EPA/600/2-88/052, September 1989, or other appropriate techniques.

Structural stability of leachate pipes

Generate structural calculations to show that leachate collection pipes will withstand:

- static and dynamic loading from construction equipment;
- maximum potential loading from vehicular traffic;
- maximum static loading from the completed landfill; and
- stresses from long-term differential consolidation of the landfill foundation.

Manhole foundation bearing capacity

Calculate the bearing capacity of manhole foundations. Demonstrate that the bearing capacity will support anticipated loads without damaging the liner system. Consider differential-settlement induced down-drag forces that may occur where compressible waste and rigid manholes meet.

Leachate storage capacity

Calculate the storage capacity of the leachate impoundment, accounting for all in puts and outputs. Demonstrate that leachate storage impoundments or holding tanks will provide:

- adequate storage capacity for the maximum leachate flows; assume the leachate collection system maintains less than 12 inches [30-cm] of leachate depth
- adequate storage capacity to manage leachate as planned and to satisfy any seasonal limitations, and
- sufficient freeboard to contain leachate and prevent overflows, assuming a 24-hour, 25-year storm

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Leachate treatment and disposal

Calculate the efficiency of the proposed treatment system considering the following factors:

- design criteria, including regulatory requirements;
- availability of representative leachate for testing;
- untreated (influent) leachate characteristics, (i.e., quantity and quality);
- temporal and spatial variability of leachate characteristics;
- method(s) of leachate disposal;
- periodic design modifications (certain treatment processes may be phased in to accommodate variable leachate quality and hydraulic loading);
- proposed unit treatment processes and associated technologies;
- potential temperature variations in leachate and ambient air;
- nutrient addition requirements (e.g., phosphorous and/or nitrogen addition may be required to enhance biological treatment.

Surface water control

Evaluate the effectiveness of the surface water control system for conditions throughout the landfill's development and operation. Use a 24-hour, 25-year or more severe storm if extreme impacts could result from control system failure.

Obtain storm recurrence information from the Weather Bureau's Technical Paper 40, Rainfall Frequency Atlas of the United States for Durations for 30 Minutes to 100 Years. Alternatively, analyze local meteorological data to estimate storm intensity. Use the Rational Method, the Soil Conservation Service (SCS) method (i.e., Urban Hydrology for Small Watersheds, SCS Technical Release #55, June 1986 (TR-55)) or other recognized methods to estimate design-storm-related peak flows.

Demonstrate by analysis, that:

- Diversion and conveyance structures (e.g., berms and channels) are designed to divert all stormwater run-on away from the landfill footprint (assume peak discharge from the 25-year storm). Use standard analytical methods recommended by the US Dept. of Transportation (Federal Highway Administration), the US Army Corps of Engineers, the US Dept. of Agriculture (Soil Conservation Services) or other appropriate engineering methods.
- Sedimentation and detention facilities will retain peak runoff flows from the 25-year storm , trap sediment effectively, and comply with the facility's NPDES permit. Use the SCS methods (TR-55) to develop inflow hydrographs for sedimentation/detention structures.
- Active landfill cells have adequate capacity to contain stormwater and leachate during a 24-hour, 25-year storm.

Post-closure surface water control

Analyze requirements for post-closure surface water runoff control. Assuming 24-hour, 25-year storm conditions, demonstrate that:

- culvert and drainage channel cross-sections and slopes will pass design-storm-generated flow volumes
- surface water control facilities will minimize runoff velocities and related energy, and erosion of the landfill cover and drainage channels
- all drainage channels will convey flow at or below the maximum permissible (mean) velocities. Select the proper channel section for the appropriate hydraulic condition, and
- site maintenance will be minimized.

Note: Use standard engineering methods and procedures such as described in the Engineering Field Manual for Conservation Practice, U.S. Soil Conservation Service, 1984; SCS Engineering Handbook #5; Open Channel Hydraulics, V. T. Chow, 1959; Handbook of Hydraulics, 3d. edition, King, 1939; or other published references and specifications.

Cover soil erosion

Use the U.S.D.A. Universal Soil Loss Equation to estimate the erosion loss from the proposed final cover system. U.S. EPA guidance recommends a maximum soil loss of < 2 tons/acre/day. Values for the Universal Soil Loss Equation parameters can be obtained from the U.S. Soil Conservation Service's (SCS) Technical Guidance Document available at local SCS offices.

Landfill gas control system

Calculate or estimate the following design parameters:

- landfill gas production (peak and total production over the life of the landfill)
- gas well spacings and depths
- individual extraction-well flow rates
- system-wide collection efficiency
- maximum allowable headloss criterion
- minimum allowable vacuum pressure at the remotest extraction well.
- headloss from wells to the blower
- total accumulative flow rate within the collection pipes and headers
- required sizes for collection pipes and vacuum-motor-blowers, and flare units (if applicable)
- requirements for blower backup capabilities, and phased expansion of the mechanical equipment complex (i.e., blowers, flares, etc.) disposal or recovery systems and the collection system.

7.14 Additional Resources

Landfill technologies, design, and construction practices

Draft Technical Manual for Solid Waste Disposal Facility Criteria - 40 CFR Part 258, U.S.EPA, April 1992.

Seminars - Requirements for Hazardous Waste Landfill Design, Construction and Closure, CERI-88-33; U.S.EPA; Center for Environmental Research Information, Cincinnati, OH 45268, 1988.

Lining of Waste Containment and Other Impoundment Facilities, EPA/600/2-88/052, U.S.EPA, Risk Reduction Engineering Laboratory, Cincinnati, OH 45268, September 1988.

Design, Construction, and Evaluation of Clay Liners for Waste Management Facilities, EPA/530/SW-86/007F, U.S.EPA, Office of Solid Waste and Emergency Response, Washington, DC 20460, November 1988.

Designing with geosynthetics

Koerner, Robert M., Designing With Geosynthetics, 2nd Edition, Prentice-Hall Publ. Co., Englewood Cliffs, NJ, 1990, 652 pgs.

Landfill cover systems

Seminars-Design and Construction of RCRA/CERCLA Final Covers, CERI 90-50, U.S.EPA, Office of Research and Development, Washington, DC 20460, 1990.

Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments, EPA/530-SW-89-047, U.S.EPA, Office of Solid Waste and Emergency Response, Washington, DC 20460, July 1989.

Proceedings of the 4th GRI Seminar on the topic of Landfill Closures: Geosynthetics, Interface Friction and New Developments, Geosynthetic Research Institute, Philadelphia, PA 19104, December 1990, 260 pgs.

Leachate treatment

Thornton, Richard J., and Blanc, Fredrick C., Leachate Treatment by Coagulation and Precipitation, proceedings of the American Society of Civil Engineers, Vol. 99, No. EE4, August 1973.

Chian, E. S. K., and De Walle, F. B., 1976, Sanitary Landfill Leachates and their Treatment, ASCE Environmental Engineering Division, No. EE2.

Chian, E. S. K., and De Walle, F. B., 1977, Evaluation of Leachate Treatment, Vols. I and II, Washington, DC: U.S. EPA, EPA-600/2-77-186.

Boyle, W. C., and Ham, R. K., 1974, Treatability of Leachate from Sanitary Landfills, Journal of Water Poll. Control Federation, Vol. 46, No. 5.

De Walle, F. B., and Chian E. S. K., 1977, Leachate Treatment by Biological and Physical-Chemical Methods, Proceedings of the Third Annual Solid Waste Research Symposium, U.S. EPA, March 14-16, 1977.

Robinson, H. D., and Maris, P. J., 1985, The Treatment of Leachates from Domestic Waste in Landfill Sites, Journal of Water Poll. Control Federation, January 1985, pp. 30-38.

Nelson, P. O., and Storhaug, R., 1985, Treatment of Leachate in Aerated Lagoons, Lab-Scale Study, Oslo, Norway, Norwegian Institute for Water Research, Report No. 0-84022.

Landfill gas control

EMCON Associates, 1980, Methane Generation and Recovery from Landfills, Ann Arbor Science, Ann Arbor, Michigan, p. 139.

Ham, R. K., et al., 1979, Recovery, Processing, and Utilization of Gas from Sanitary Landfills, Cincinnati, OH: U.S. EPA 600/2-79-001.
