TCEQ REGULATORY GUIDANCE
Waste Permits Division
RG-494 ● Revised March 2017

Guidance for Requesting a Water Balance (WB) Alternative Final Cover for a Municipal Solid Waste Landfill

Contents

1. Introduction

This guidance document is for owners and operators of municipal solid waste (MSW) landfills who are considering a water balance (WB) alternative final cover system (cover).

2. Applicability

This guidance is applicable to a landfill that has a synthetic membrane–compacted clay composite liner requirement as part of its permit and/or proposed permit application.

Pursuant to Title 30, Texas Administrative Code (30 TAC) Section 330.457(d), an alternative final cover design may be approved if it meets both of the following performance standards:

- Achieves an equivalent reduction in infiltration as the clay-rich soil cover layer specified in 30 TAC Section 330.457(a)(1) or (2).
- Provides equivalent protection from wind and water erosion as the erosion layer specified in 30 TAC Section 330.457(a)(3).

3. WB Cover Overview

In general, a WB cover limits percolation through the cover by use of silty and clayey soils to store water and sustain vegetation until the water is removed by evapotranspiration. A WB cover requires soil that can provide adequate water-holding capacity, supply moisture and nutrients to plants, and maintain long term slope stability and erosion resistance. As calculated by the Universal Soil Loss Equation, erosion of a WB cover should be less than or equal to 3 tons per acre per year. Total thickness of a WB cover, including the erosion layer, should not be less than two feet, which is the minimum required soil thickness of the synthetic membrane–compacted clay composite cover system. It is recommended that WB covers using high plasticity clay as the storage layer be overlain with a minimum one-foot thick erosion layer to reduce the potential for desiccation cracking in the storage layer. This recommendation is consistent with TCEQ final cover rules for Type IV landfills and pre-Subtitle D landfills. Healthy vegetation is essential to minimize erosion. The design of a WB cover should take into consideration site-specific soil, meteorological, and vegetation information.

4. Design and Permitting Options for WB Covers

This guidance discusses four options for the design and permitting of WB covers. Each option is considered to have equal merit in terms of the equivalency demonstration required in 30 TAC Section 330.457(d).

4.1. Option 1 – Statewide Design Table

Option 1 involves using procedures discussed in *Geoclimatic Design of Water Balance Covers for Municipal Solid Waste Landfills in Texas* (Khire 2016). This report documents the delineation and mapping of geoclimatic regions, region-specific analyses of candidate WB cover soils, performance modeling, and regional WB cover designs. The assumptions and model inputs discussed in the report are specific to that project. Selected charts depicting project results and the final cover design table are included in Section 10 (Attachment B: Statewide Design Table) of this publication.

Under Option 1, the applicant first determines the geoclimatic region in which the landfill facility is located. The geoclimatic regions are depicted in Figure 1 in Section 10. The storage layer thickness can then be determined from Table 3 in Section 10, which relates hydraulic conductivity to storage layer thickness.

The application should include information listed in Table 2 in Section 9 (Attachment A: Water Balance cover Guidance Summary Table) under the heading "General Requirements."

4.2. Option 2 – Cover Performance Verification

Option 2 involves site-specific field-scale testing using cover performance verification test plots to confirm the WB cover's design and performance.

Lysimeter test plots are effective in measuring the amount of percolation through cover soils. These test plots are the preferred method of evaluating WB cover performance when coupled with *in situ* soil instrumentation and laboratory testing of soils. Design aspects and construction considerations of lysimeter test plots have been documented by Benson et al. (1999) and Albright et al. (2010), and these publications may serve as references for lysimeter design and construction. Instrumentation used to monitor test plots should be capable of continuous data collection, and test plots should be configured to represent the area of the landfill cover with the greatest water-storage demand.

The application should include a WB cover design that has been modeled to allow less than or equal to 4 mm percolation in a year through the cover using site-specific soil, vegetation, and weather data. After approval, the applicant would construct the test plot concurrently with the installation of the initial section of the landfill's final cover.

The verification procedure should demonstrate the WB cover's performance under the precipitation conditions used in the modeling. The application should contain a plan for artificial moisture loading if natural weather patterns do not produce the necessary precipitation as follows:

- If modeling involved the 20-year weather data procedure, then years 1 and 2 should simulate the average annual precipitation, and year 3 should simulate the 95th percentile precipitation conditions.
- If the modeling involved the 30-year weather data procedure, then years 1, 2, and 3 should simulate the three consecutive years that resulted in the peak percolation.

The test plot should be installed, maintained, and monitored to allow for collection of data to determine whether the actual performance (e.g. moisture patterns and percolation through the cover) is adequate. The test plot should be designed to assess compliance with the less than or equal to 4 mm percolation limit. The permit application should detail the soil monitoring equipment, methods used, and how the methods will confirm the function of the WB cover. Careful consideration should be given to selection of monitoring equipment and methods to reduce the uncertainty in modeled estimates, which might be larger than required cover performance. The monitoring equipment and methods should include at least the following data:

- Continuous moisture content
- Basal percolation
- Soil temperature
- Weather data

Soil moisture and basal percolation should be collected using automatic data-acquisition systems to provide essentially continuous records.

The test plot should be constructed concurrently with the construction of the initial section of landfill WB cover during closure or partial closure. The initial section of landfill cover containing the test plot should be limited to less than or equal to 10 acres. At least one lysimeter should be installed within the test plot, and each lysimeter should have dimensions of at least 30 feet by 30 feet. At least three clusters of soil probes should be installed with the lysimeter, with one of the clusters upslope, one within, and one downslope of the lysimeter. Each probe cluster should consist of at least three probes with duplicate sensors located in the upper, middle, and lower portions of the cover soil with vertical spacing no greater than 1 foot. The probes should be capable of continuous measurement of soil moisture. Alternative monitoring equipment and methods will be considered.

The test plot should be operated, maintained, and monitored for a minimum of three years after vegetation is established. In all cases, data gathering from the test plot should begin no later than six months after construction.

During the cover evaluation period, the applicant should prepare and submit an annual report documenting the results of all the monitoring and discussing the performance of the cover system. The report should include:

- Soil data
- Vegetation data
- Weather data
- Soil moisture retention curves
- Basal percolation
- Observed erosion and any cover repairs
- Observations and recommendations of the project engineer

Data collected from a test plot may be suitable for use at other facilities with similar weather and soil data. Applicants intending to use such data at multiple sites should discuss this possibility with the MSW Permits Section prior to implementation in order to ensure agreement on the applicability of the data.

The measured percolation listed in Table 1 serves as a guide when evaluating test plot results annually.

Table 1: Measured Percolation

Measured Percolation	Evaluation
≤ 8 mm	Satisfactory: remainder of the landfill can be installed pursuant to the WB cover construction quality control plan (CQCP)[a].
> 8 mm and ≤12 mm	• Requires a permit modification with revised modeling and cover design for the remainder of the landfill. • Upon approval, the cover can be installed pursuant to the approved WB cover CQCP.
> 12 mm	• Requires a permit modification with revised modeling, WB cover design, and test plot design. Upon approval, an initial phase of cover may be constructed that includes a test plot for cover-performance verification. • WB cover beyond the maximum of 10 acres should not be constructed until satisfactory performance has been successfully demonstrated.

a. See Section 6 of this publication for details about the CQCP.

4.3. Option 3 – Model Calibration

Option 3 involves constructing and monitoring one or more test plots to obtain site-specific field-collected data; the data are used to calibrate the model employed in the WB cover design process.

Prior to designing and constructing a test plot, the TCEQ strongly recommends that facilities proposing model calibration coordinate with the MSW Permits Section to ensure that the calibration study sufficiently addresses the recommendations in this guidance. Test plot design parameters for discussion include:

- Test plot size and location.
- Monitoring instrumentation and parameters.
- Data-gathering procedures.

If a test plot will be located on property covered by an MSW permit, then prior authorization from the TCEQ would be required. If a test plot will be located on property not covered by an MSW permit, a detailed work plan should be submitted for agency review to ensure agreement on the data acquisition requirements and methods.

The application for a field-scale WB test plot should address the information discussed in this section and the items noted in the General Requirements and Model Requirements Sections under Option 3 in Table 2 of Attachment A, Section 9 of this publication to include the following:

- Detailed design plans and construction specifications of the test plot.
- Construction quality assurance procedures.
- Operating and monitoring procedures.

Test plots should be operated for at least three years after vegetation has been established to design parameters in order to minimize the impact of the initial moisture of the cover soils and to incorporate a variety of weather conditions at the site. The length of time between test plot construction and initiation of data collection may be shortened if the modeled cover design does not rely on vegetation. Using data collected from the test plot, the model is run to predict the performance of the proposed WB cover, and a revised WB cover is designed.

In order to calibrate the water balance model, input parameters should be adjusted within an appropriate range until the model-predicted soil water contents and soil water storages closely match the field data for the duration of the monitoring period. For a model to be considered calibrated, the model must demonstrate that:

- Model-predicted soil water contents and soil water storages do not show a consistent bias (over-prediction or under-prediction of the parameter throughout the modeling period).
- Maximum and minimum soil water storages predicted by the model are within 5 percent of the field values.

To assess the model calibration results, the sensitivity of the input parameters on the predicted soil water storages, water contents, surface runoff, evapotranspiration, and cumulative percolation should be reported in the form of time series plots.

Provided the data collected from the test plot can be successfully used to calibrate the model and design the WB cover, a permit modification application should be submitted requesting authorization for the WB cover. The application should address the requirements of 30 TAC Section 305.70 and include the information in Attachment A, Section 9 of this publication.

Calibration test plot data may be suitable for use at other facilities with similar climatological and soil conditions. Applicants intending to use data from a calibration test plot at multiple sites should discuss this possibility with the MSW Permits Section in advance to ensure agreement on the applicability of the data at other sites.

Initial calibration efforts will likely yield valuable information about proper monitoring methods, monitoring instrument types and numbers, size of test plots, and length of monitoring period. The use of this information in the development of subsequent focused model calibration projects is encouraged.

Test plots for model calibration should be installed, maintained, and monitored to ensure the collection of accurate data to ensure that the WB cover model can be properly calibrated. Test plots should be configured to represent the area of the landfill cover with the greatest water-storage demand and monitored with instrumentation capable of continuous data collection.

The following information should be generated from test plot monitoring to define the adequacy of site-specific parameters used in the model to predict the performance of the WB cover:

- Continuous moisture content with depth.
- Soil temperature.
- Percolation.

Site-specific parameters to be collected include, but are not limited to:

- Root depth and density.
- Leaf-area index.
- Plant water intake.
- Initial moisture content.
- *In situ* soil geotechnical and hydraulic properties (density, porosity, saturated and unsaturated hydraulic conductivity, and water retention curves).
- Moisture content.
- Moisture retention profiles.
- Adequate number of moisture sensor nests.
- Adequate vertical spacing of moisture sensor nests (not greater than 1 foot) within each nest.
- Duplicate moisture sensors at each depth within each nest.
- Parameters or criteria for runoff.

In addition to site-specific field data, the following meteorological parameters should be collected on-site contemporaneously with test-plot monitoring:

- Precipitation.
- Pan evaporation (obtain from local weather-reporting stations).
- Air temperature.
- Solar radiation (obtain from local weather-reporting station).
- Wind speed.
- Relative humidity.
- Cloud cover.
- Dew point (calculated).

Sources of soil cover material should be evaluated with a test plot. A field-scale lysimeter may be included in the calibration test plot for a better understanding of potential percolation from the WB cover.

4.4. Option 4 – Landfills in Arid Areas

Option 4 is available only for landfills having less than or equal to 25 inches of average annual precipitation as defined by 30 TAC Subsection 330.5(b)(1)(D). Option 4 involves site-specific modeling, but does not require construction and monitoring of a test plot. For meteorological data, the nearest weather station to the landfill with at least the most recent 30 years of precipitation data should be used to determine the average annual precipitation for the period.

A landfill with less than or equal to 25 inches average annual precipitation would be expected to use site-specific parameters including soil properties, vegetation, and climate and weather data in the design and modeling of the WB cover. However, the design of the WB cover for such sites may be based solely on successful numerical modeling, provided the model is an accepted and proven numerical unsaturated flow model.

The application should contain the information specified in Option 2 with the exception of design drawings and operational specifications for a test plot.

5. Modeling Guidelines for Options 2, 3, and 4

The selected computer model for options 2, 3, or 4 should integrate soil, meteorological, and vegetation data, and the effects on hydrology and soil-water balance, to predict the performance of the proposed WB cover. The computer model should:

- Simulate unsaturated flow.
- Include a surface boundary simulating soil-atmosphere interactions (precipitation, infiltration, evaporation, and runoff).
- Include adequate models for saturated and unsaturated hydraulic behavior.
- Model root water uptake (also known as transpiration).
- Integrate climate data.

Various computer programs for alternative cover modeling are described in Interstate Technology and Regulatory Council (ITRC) (2003). The UNSAT-H (Version 3.0) model has been the primary computer model used in WB cover equivalency demonstrations. If using a computer program other than UNSAT_H, the basis for its selection should be explained. The selected model default values should only be used if they are representative of site-specific conditions.

The model should be run to simulate the performance of the proposed WB cover as designed. The results of each year's model simulation should be summarized in a table that lists the values for the following parameters:

- Precipitation (P).
- Potential evapotranspiration (PET).
- P/PET ratio.
- Model-estimated "actual" evaporation and transpiration.
- Runoff as a percent of total precipitation.
- Storage.
- Percolation through the WB cover.
- Total mass balance error for the year.

The lower flux boundary should be the bottom surface of the WB cover. The mass balance error should be added proportionately to the percolation, surface runoff, and evapotranspiration. The results should also be presented graphically, showing the model-estimated storage requirement plotted by year, and the calculated available storage capacity for the WB cover.

The effective water storage capacity of the cover soil should not be less than the modeled capacity. The annual percentage runoff generated by the model is expected to be less than 10 percent of total water applied (precipitation and irrigation). Higher modeled runoff amounts may be acceptable if hourly rainfall data have been shown to support rainfall application rates and the hydraulic properties of the surface soil layer are representative of *in situ* soils. If irrigation is proposed to establish and sustain plant growth or to simulate precipitation, the water impingement due to the irrigation should be accounted for in the model. If the site receives snow or ice, the model input needs to be adjusted to account for moisture from snow and ice melt.

For sites where model calibration is indicated, site-specific soil parameters and field-study generated data should be used. A detailed discussion of the calibration process, input values, and output results should be provided. Model calibration should include considerations for hysteresis. Care should be taken to model only representative conditions, any model input data that are not based on field monitoring results and parameters should be identified, and the rationale for their use discussed.

5.1. Recognized Modeling Scenarios

MSW Permits Section has recognized two modeling scenarios, the 20-year approach and the 30-year approach.

5.1.1. 20-Year Weather Data Approach

Step 1. Select a weather reporting station nearest to the landfill that has at least 50 years of continuous monthly precipitation data. From the precipitation data, calculate the mean (average precipitation year) and 95th percentile (wet precipitation year) annual precipitation values.

Step 2. Select a weather reporting station nearest to the landfill that has at least 20 years of high quality continuous data for precipitation, maximum and minimum air temperature, average relative humidity (or dew point), average wind speed, and total solar radiation. This may or may not be the same weather station selected in Step 1. The most recent 20-year period for which complete weather data is available should be used.

Step 3. Select an average precipitation year and wet precipitation year from the data set chosen in Step 2 that either equal or are slightly higher than the average and wet precipitation years calculated from the 50-year precipitation data set.

Step 4. Run the model using the selected average precipitation year and the 95th percentile year from the data set chosen in Step 2. The modeling should simulate 20 consecutive average precipitation years, followed by one 95th percentile year.

5.1.2. 30-Year Weather Data Approach

This approach requires the most recent 30 years of high-quality continuous data for precipitation, maximum and minimum air temperature, average relative humidity (or dew point), average wind speed, and total solar radiation. Not all weather stations have a complete set of data; therefore, this approach may not be practicable. Assuming the data is available, each of the consecutive 30 years of weather data is input to the model.

5.2. Soil Considerations

The WB cover soils should be modeled using input data representative of the properties and characteristics of the soil that will be used in the WB cover throughout the soil profile. The soil should be compatible with, and support the growth of, the plants proposed for use in the WB cover, which includes achieving the required root depth, root density, and plant surface coverage so the percolation and erosion are adequately controlled. Sampling and laboratory testing should characterize the engineering, hydraulic, and agronomic properties of the soils to be used in the WB cover. The laboratory testing should be performed on undisturbed *in situ* soil and reconstructed, recompacted soil samples. At a minimum, results of the following tests should be reported for candidate soils and used to determine if the soils need to be amended before use in the WB cover:

- Unified Soil Classification System (USCS) classification.
- Bulk density.
- Maximum dry density obtained according to standard proctor tests.
- Compaction percentage.

- Soil water retention curve.
- Saturated hydraulic conductivity at proposed soil placement conditions.
- Nutrients (nitrogen, phosphorus, potassium, micronutrients).
- Other characteristics (e.g., organic matter, sodium adsorption ratio).

Generally, the upper six to twelve inches of the soil profile should be conducive to plant growth. If soil amendments are necessary, then the soil-amendment process should be fully described and addressed in the WB cover CQCP[b]. The amended soil should be retested to ensure target soil conditions have been met. Include a map that shows the soil-borrow sources and the test-sample locations.

The soil water characteristic curves should be defined using experimental data obtained for a wide range of suction values. The following information should be provided:

- Trend of the moisture retention curve, as defined using established models (e.g. the van Genuchten model), including the actual data points obtained in the laboratory testing program.
- Hydraulic conductivity function, predicted using the moisture retention curve and the measured saturated hydraulic conductivity.

5.3. Vegetation Considerations

If the WB cover is designed with reliance on vegetation for moisture transpiration, documentation should be provided that the proposed plants can achieve the modeled root depths, root densities, and percent coverage. The vegetation selection(s) should include a site-specific analysis and recommendation by a vegetation expert (such as an agricultural extension service agent, range scientist, or botanist) with supporting documentation from peer-reviewed published sources that are readily available. Each plant type should be discussed with data on its suitability for the landfill location and the proposed soil types. The vegetation analysis should take into account that the soil may not have all the properties of a natural or *in situ* soil, and the WB cover CQCP should include a program of amending the soil (with compost, fertilizer, etc.) as necessary to support plant growth.

If the WB cover is designed without reliance on vegetation for moisture transpiration, then the plants proposed for erosion control and the target percent coverage should be specified to meet the less than or equal to 3 tons per acre-year standard. The publications of the United States Department of Agriculture's (USDA) on local and county soil and vegetation types may provide such information.

b. See Section 6 of this publication for details about the CQCP.

6. Construction Quality Control Plan (CQCP) Considerations for All WB Covers

Construction quality control specifications should allow verification that the WB cover is constructed consistent with the conditions, parameters, and assumptions used in the modeling and design effort. The parameters, conditions, and assumptions used to demonstrate equivalency of the WB cover should be translated into the following and recorded in the CQCP:

- Material specifications.
- Construction quality control testing specifications and procedures.

If construction of the WB cover includes a test plot, the CQCP should contain detailed construction quality control procedures for the test plot as well as the rest of the WB cover to be installed. Specifications documented in the CQCP should include:

- Soil density and hydraulic conductivity.
- Construction methods to achieve the design density and hydraulic conductivity.
- Moisture content.
- All proposed soil types (USCS tests).
- Vegetation and how it will be established, evaluated, and maintained.
- Provisions for initial irrigation, fertilization, and seeding as needed to establish and maintain robust vegetation with desired root density and depth.
- Tests and testing frequency for verifying design conditions.

6.1. CQCP Tests and Testing Frequencies

- Borrow-source testing should be performed for USCS classification at a frequency of at least one test per 20,000 cubic yards.
- Hydraulic conductivity testing of borrow source soil should be performed using large diameter (greater than or equal to 6 inches) samples at a minimum frequency of every 20,000 cubic yards.
- Constructed soil cover should be tested for field density and moisture content at a frequency of at least two tests per acre per lift.
- Moisture contents of constructed soil cover should be in the dry of optimum region.
- Undisturbed constructed soil cover samples should be collected in 3-inch or greater diameter thin-wall tubes at a frequency of at least one test per 2.5 acres per lift and tested in the laboratory for moisture content, dry unit weight, and saturated hydraulic conductivity.

6.2. CQCP Soils and Vegetation

The CQCP should specify how soils will be evaluated for agronomic properties, how soils will be amended, and if vegetation will be fertilized or irrigated and, if so, under what circumstances. Methods and procedures should be specified for assessing the vegetation and for determining whether it has been established in accordance with the design specifications. The CQCP should include test procedures and frequencies for assessing the viability of the vegetation and quantifying the percent vegetation, including root depth and density if vegetation was used in the WB cover design model. Vegetation measurement methods for the plant types proposed should be accepted or approved by the USDA, Texas Department of Agriculture, or similar government entities.

WB cover construction methods must ensure that the as-built soil density is adequate for sufficient vegetation growth, for maintaining design values for unsaturated hydraulic conductivity, and for minimizing the development of cracks, macro features, and differential settlement.

6.3. CQCP and Out-Of-Specification Situations

The CQCP should include specifications for equipment weight and traffic on the cover, and procedures for identifying and correcting out-of-specification situations or damage. The CQCP should outline a procedure that describes the required actions and documentation when out-of-specification situations occur.

6.4. Final Cover System Evaluation Report (FCSER) and Engineer Certification

The CQCP should state that a FCSER with engineer certification will be submitted for each section of WB cover that is constructed. The FCSER should provide the following information:

- Completed report forms required by the TCEQ.
- Summary of construction activities.
- Drawings showing sample and test locations.
- Field and laboratory test results.
- Instructions to limit equipment weight and traffic on the cover, and procedures for identifying and correcting out-of-specification compaction and other situations or damage.
- As-built drawings (including cover elevation and thickness of the soil layers).
- Vegetation details for erosion control purposes; the plants proposed for erosion control and the target percent coverage.
- Description of any construction problems and how they were resolved.
- Statement of compliance with the MSW rules and the WB cover CQCP.
- Signature and seal of a licensed professional engineer.

7. Vegetation Establishment Report for All WB Covers

The application should specify that a vegetation establishment report will be submitted semi-annually until the vegetation is established to design conditions.

The report should describe the type and quantity of vegetation established and the overall percentage of coverage. Vegetation root structure (depth and density) should be evaluated and documented if vegetation inputs were used in the WB cover design model.

If the vegetation or root structure do not meet specifications, then corrective action may be necessary to improve vegetation.

8. Closure Plan and Post-Closure Care Plan Considerations for All WB Covers

The facility's closure plan should describe each type of final cover system, including the proposed WB alternative final cover system, and the parts of the landfill that may be covered with each type (for example, Subtitle D areas, pre–Subtitle D areas, side slopes, and top dome surfaces). The closure plan should include the WB cover CQCP.

The post-closure care plan for the facility should document the post-closure inspection, maintenance, and reporting requirements associated with the alternative final cover design. Post-closure care cost estimates should include the cost of long-term maintenance of vegetation, which may include reseeding, fertilizing, irrigating, and restoring cover that has been eroded or damaged.

9. Attachment A: Water Balance Cover Guidance Summary Table

For easy reference, Table 2 summarizes the four options and informational requirements for the design and permitting of WB covers discussed above.

Table 2: Water Balance Cover Guidance Summary

Description	Option 1	Option 2	Option 3	Option 4
Applicability				
Existing or proposed landfills that have a synthetic geomembrane-compacted clay composite liner	X	X	X	X
May be submitted as part of a new permit or permit amendment application or as a permit modification application under 30 TAC Subsection 305.70(k)(10).	X	X	X (two permit modifications required)	X
Can be utilized by landfills:	Statewide	Statewide	Statewide	Only in areas with <25″ average annual precipitation (most recent 30 years data)
Criteria				
Modeled percolation ≤4 mm/yr	X	X	X	X
Measured Percolation ≤8 mm/yr		Satisfactory		
Measured Percolation >8 mm/yr & ≤12 mm/yr		Revised design & modeling via new permit modification		

Description	Option 1	Option 2	Option 3	Option 4
Measured Percolation >12 mm in any year		• New design & modeling via new permit modification • New test plot evaluation of revised cover design		
Minimum of 18″ of storage layer thickness	X	X	X	X
Minimum of 6″ of erosion layer or 12” of erosion layer with high plasticity clay storage layer	X	X	X	X
General Requirements				
Site specific modeling		X	X	X
Performance verification test plot		X • ≤10 acres of final cover • Minimum of one lysimeter • Minimum of three clusters of soil probes • Minimum 30′ x 30′ test plot • Annual reports		
Model calibration test plot			X 1st Permit Modification: • Detailed design plans • CQCP for test plot and operating procedures	

Description	Option 1	Option 2	Option 3	Option 4
Test Plot Duration		Minimum 3 years after vegetation establishment	Minimum 3 years after vegetation establishment	
Detailed drawings of the test plot		X	X	
Site specific weather data		X	X	X
Site specific soil data	X	X	X	X
Site specific vegetation data		Optional, if available	Optional, if available	Optional, if available
Borrow source characterization - Borrow and test location map, soil tests (listed in Section 6.1 with frequency of no less than every 20,000 cy	X	X	X	X
Narrative, test results and calculations explaining the estimated target as-built saturated hydraulic conductivity	X			
Minimum thickness of the storage layer as determined from Table 3 in Attachment B	X			
Description & detailed drawings of the final cover design that include design details for the proposed WB cover, along with details of the standard cover system and any other alternative final cover approved for the facility, and details of tie-ins between all of the cover systems, as applicable	X	X	X	X
WB cover CQCP – See Section 6 of this publication for details	X	X	X	X

Description	Option 1	Option 2	Option 3	Option 4
Soil loss ≤3 tons/acre/year calculations	X	X	X	X
Slope stability evaluations	X	X	X	X
Closure and Post-Closure Care Plan	X	X	X	X
Financial Assurance	For the most expensive final cover option in the facility permit	For the most expensive final cover option in the facility permit	For the most expensive final cover option in the facility permit	For the most expensive final cover option in the facility permit
Calculations & narrative demonstrating that the design meets the two criteria in 30 TAC Section M330.457(d)	X	X	X	X
Semi-Annual Vegetation Establishment Reports	X (until vegetation reaches design coverage	X (until vegetation reaches design coverage)	X (until vegetation reaches design coverage)	X (until vegetation reaches design coverage)
Model Requirements				
If a computer model, besides UNSAT-H is used, basis for selecting the model		X	X	X
User's guide for models besides UNSAT-H		X	X	X
Version of the program		X	X	X
Detailed description of the specific options selected		X	X	X
All model assumptions		X	X	X
Input data, range of values for each input, and justification with respect to site-specific conditions		X	X	X

Description	Option 1	Option 2	Option 3	Option 4
Model input and output files		X	X	X
Sensitivity analyses of any variables for which a site-specific value cannot be determined		X	X	X
Summary table of the model results for each year listing: Precipitation, PET, P/PET ratio, model-estimated "actual" evaporation and transpiration, runoff as percent of total precipitation, storage, percolation, total mass balance error for each year		X	X	X
Narrative explaining the results, scenarios modeled, the sensitivity analyses performed, the worst case scenarios and how it was determined		X	X	X

10. Attachment B: Statewide Design Table

The following map, charts, and table are extracted from “Geoclimatic Design of Water Balance Covers for Municipal Solid Waste Landfills in Texas” authored by Dr. Milind V. Khire. The entire report may be viewed at <txswana.org/images/downloads/Water_Balance/txswana_water_balance_covers_khire_uncc_final_report.pdf>.

Figure 1: Map Showing Geoclimatic Regions (Figure 7 in the Khire report)

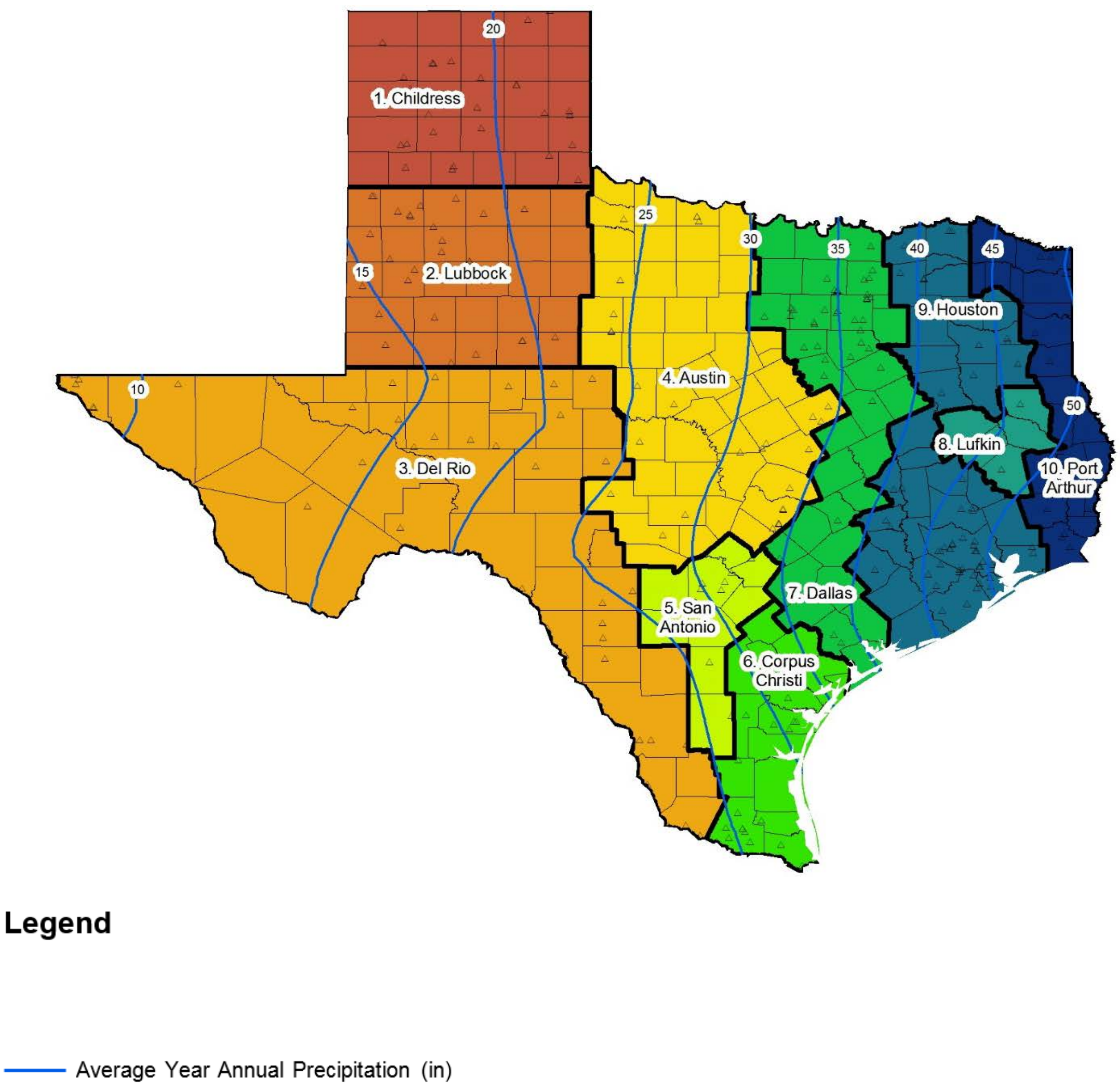

Figure 2: Peak annual percolation predicted by UNSAT-H vs. thickness of storage layer for in-service storage layer hydraulic conductivity of 10^{-6} cm/s (Figure 18 in the Khire report).

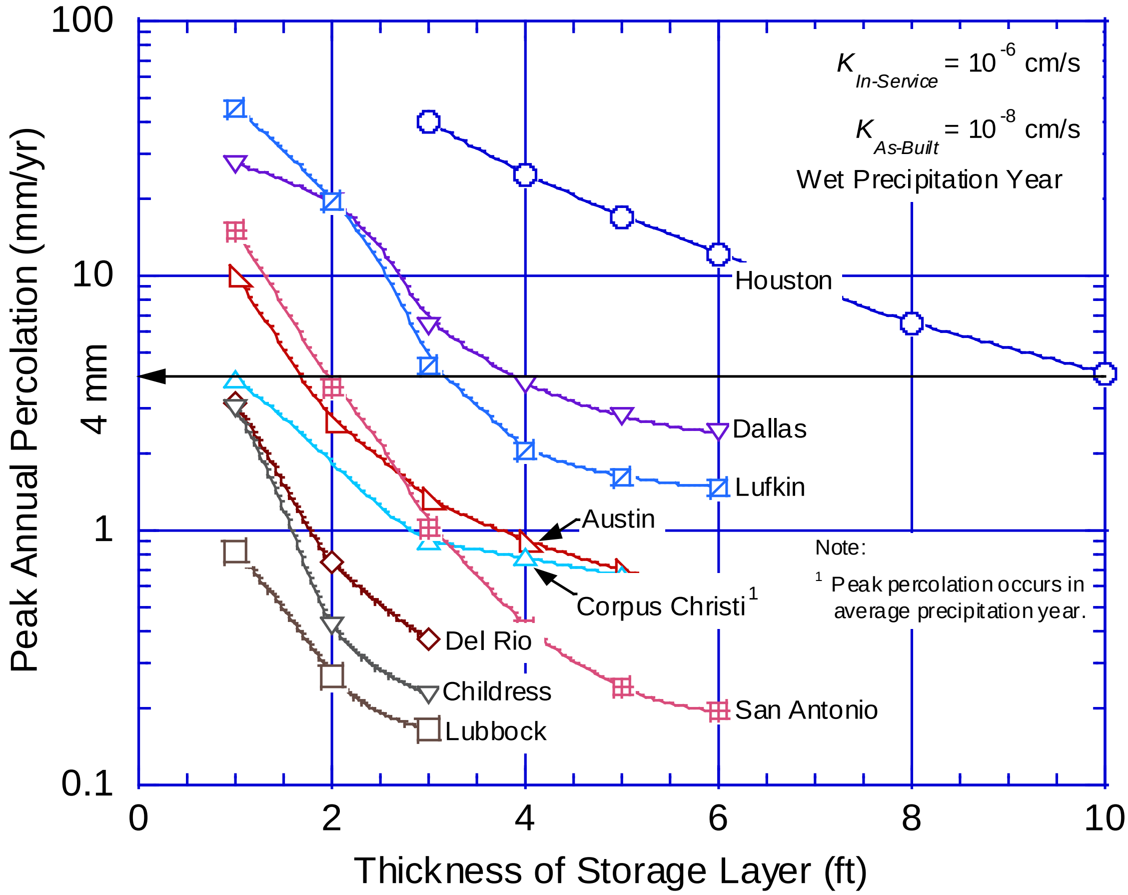

Figure 3: Peak annual percolation predicted by UNSAT-H vs. thickness of storage layer for in-service storage layer hydraulic conductivity of 5×10^{-6} cm/s (Figure 19 in the Khire report).

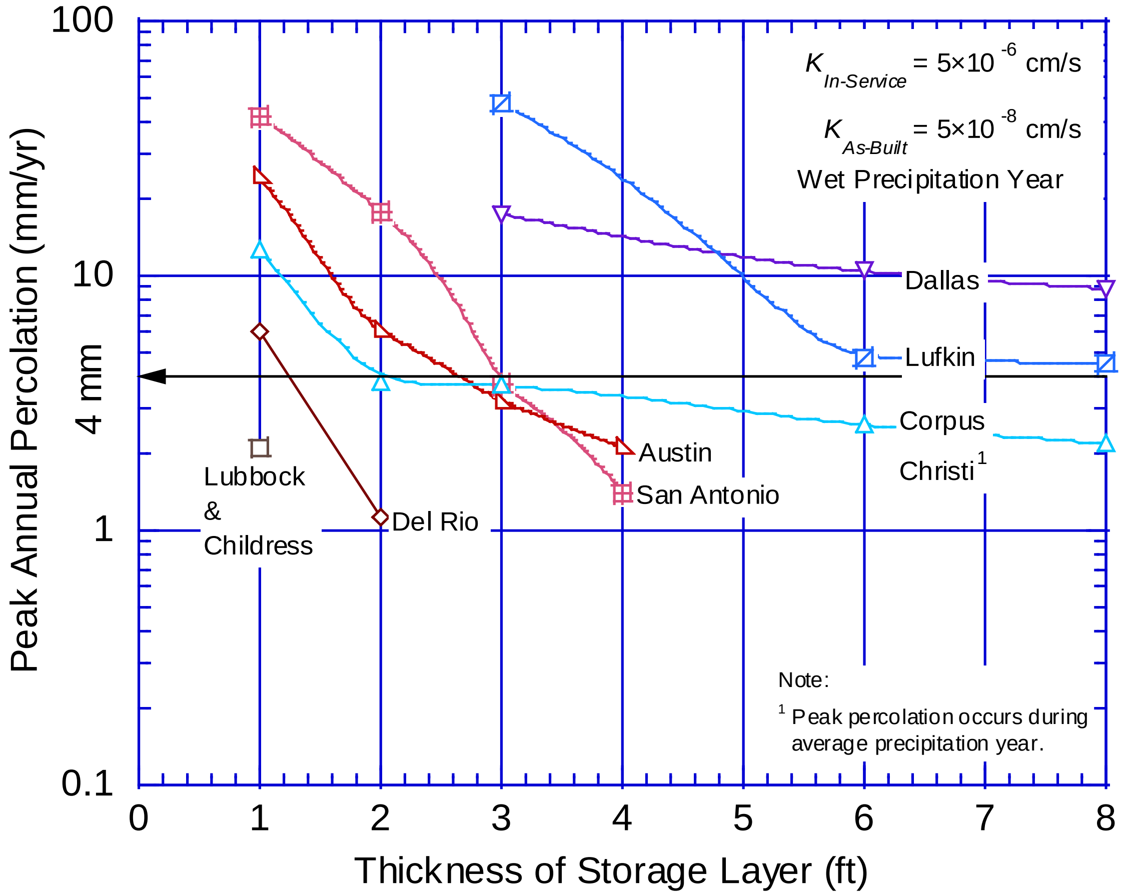

Figure 4: Peak annual percolation predicted by UNSAT-H vs. thickness of storage layer for in-service storage layer hydraulic conductivity of 10^{-5} cm/s (Figure 20 in the Khire report).

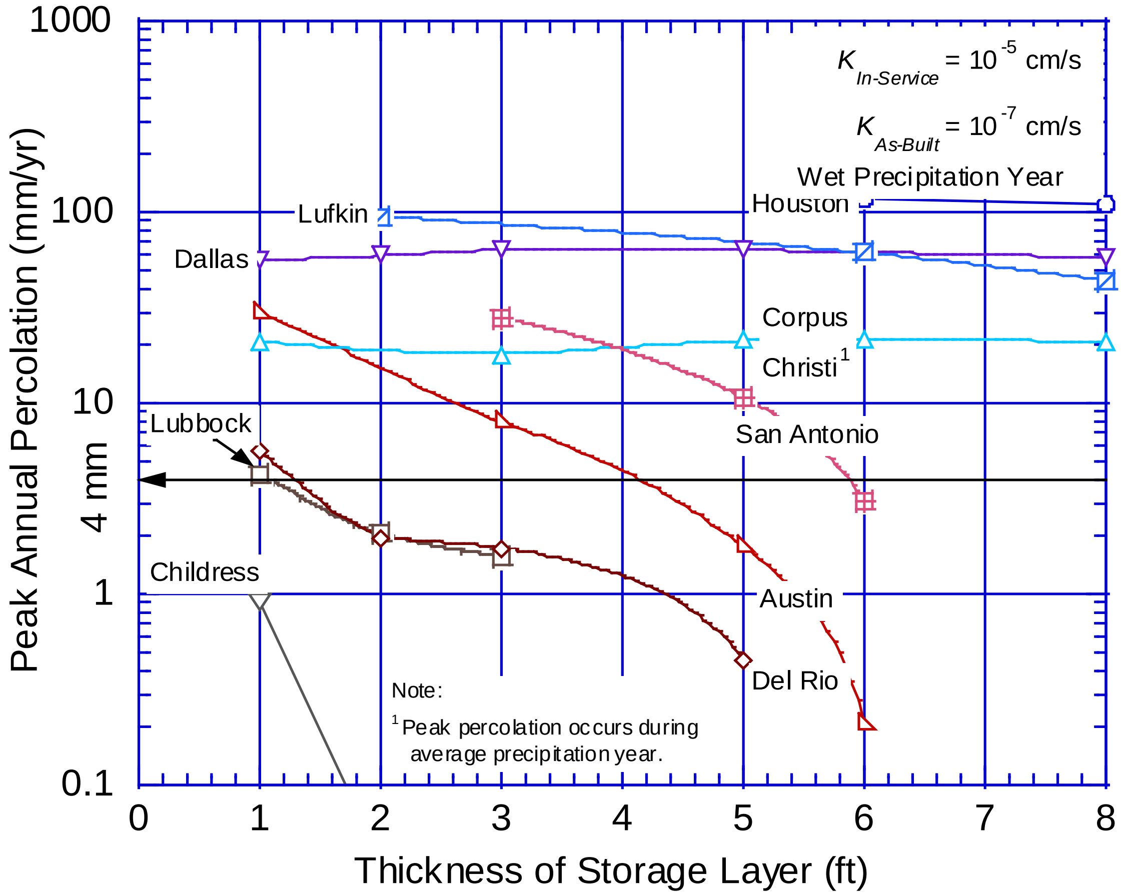

Table 3: Summary of minimum storage-layer thicknesses required to meet TCEQ criterion of 4 mm peak percolation (Table 8 in the Khire report).

Geoclimatic Region	$K_{As\text{-}Built}$ (cm/sec)	$K_{In\text{-}Service}$ (cm/sec)	Minimum Storage Layer Thickness for Bare Ground (ft)[c]
1-Childress	1.00E-08	1.00E-06	1 ft 0 in
	5.00E-08	5.00E-06	1 ft 0 in
	1.00E-07	1.00E-05	1 ft 0 in
	4.50E-07	4.50E-05	1 ft 7 in
	5.40E-05	2.70E-04	5 ft 8 in
2-Lubbock	1.00E-08	1.00E-06	1 ft 0 in
	5.00E-08	5.00E-06	1 ft 0 in
	1.00E-07	1.00E-05	1 ft 0 in
	4.50E-07	4.50E-05	10 ft+[d]
3-Del Rio	1.00E-08	1.00E-06	1 ft 0 in
	5.00E-08	5.00E-06	1 ft 3 in
	1.00E-07	1.00E-05	1 ft 7 in
	4.50E-07	4.50E-05	1 ft 10 in
	5.40E-05	2.70E-04	6 ft 2 in
4-Austin	1.00E-08	1.00E-06	1 ft 8 in
	5.00E-08	5.00E-06	2 ft 7 in
	1.00E-07	1.00E-05	3 ft 11 in
5-San Antonio	1.00E-08	1.00E-06	1 ft 11 in
	5.00E-08	5.00E-06	2 ft 11 in
	1.00E-07	1.00E-05	5 ft 10 in
6-Corpus Christi	1.00E-08	1.00E-06	1 ft 7 in
	5.00E-08	5.00E-06	2 ft 6 in
7-Dallas	1.00E-08	1.00E-06	3 ft 10 in
	5.00E-08	5.00E-06	8 ft+[d]
8-Lufkin	1.00E-08	1.00E-06	3 ft 1 in
	5.00E-08	5.00E-06	6 ft 0 in
9-Houston	1.00E-08	1.00E-06	10 ft 0 in
	5.00E-08	5.00E-06	10 ft+[d]

c. Thickness of vegetative layer needs to be 6 inches or greater.

d. Unable to meet criteria for up to the specified thickness.

11. References

Albright, W.H., et al. 2004. Field water balance of landfill final covers. *Journal of Environmental Quality* 33: 2317–32. In Desert Research Institute (DRI) Alternative Cover Assessment Program (ACAP) Refereed Articles. Available at <www.dri.edu/images/stories/research/programs/acap/acap-publications/1.pdf>.

Albright, William H., Craig H. Benson, W. Joseph Waugh. 2010. *Water Balance Covers for Waste Containment: Principles and Practice.* Reston, VA: ASCE Press.

Benson, Craig H., et al. 1999. *Test Section Installation Instructions.* Alternative Cover Assessment Program, Environmental Geotechnics Report No. 99-3. University of Wisconsin–Madison. In DRI ACAP Project Reports. Available at <www.dri.edu/images/stories/research/programs/acap/acap-publications/dri-acap-test-section-installation-details.pdf>.

Fayer, M.J. 2000. *UNSAT-H version 3.0: Unsaturated Soil Water and Heat Flow Model: Theory, User Manual, and Examples.* PNNL-13249. Pacific Northwest National Laboratory, Richland, WA. Prepared for the United States Department of Energy. In PPNL Publications. Available at <www.pnl.gov/main/publications/external/technical_reports/PNNL-13249.pdf>.

Hauser, Victor L., and Dianna M. Gimon. 2004. *Evaluating Evapotranspiration (ET) Landfill Cover Performance Using Hydrologic Models.* Mitretek Systems San Antonio, Texas: Prepared for Air Force Center for Environmental Excellence, Brooks City-Base. Available at <http://www.mvcitizens.org/projects/web-landfill/files/MVCC-30c-USAF-Evapotranspiration-2004.pdf>.

ITRC, Alternative Landfill Technologies Team. 2003, *Technical and Regulatory Guidance for Design, Installation, and Monitoring of Alternative Final Landfill Covers.* Washington D.C.: Interstate Technology and Regulatory Council. Available at <www.itrcweb.org/GuidanceDocuments/ALT-2.pdf>.

Khire, M.V., 2016, *Geoclimatic Design of Water Balance Covers for Municipal Solid Waste Landfills in Texas.* University of North Carolina at Charlotte. Available at <txswana.org/images/downloads/Water_Balance/txswana_water_balance_covers_khire_uncc_final_report.pdf>.