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

Waste Permits Division

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TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

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Prepared by
Waste Permits Division

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1.0 Introduction

This guide is for owners and operators of municipal solid waste (MSW) landfills who are considering a water balance (WB) or evapotranspiration (ET) alternative final cover system. This guidance is only applicable to a landfill that has a geomembrane-compacted clay composite liner required in the facility's existing permit. A landfill without such a requirement in its permit may use this guidance as written, or may seek an alternative maximum percolation rate for equivalency demonstration purposes. Any requests for alternative maximum percolation rates will be evaluated on a case-by-case basis.

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

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

These requirements are intended to ensure compliance with federal criteria in Title 40, Code of Federal Regulations, Section 258.60(b).

A WB final cover is one type of alternative final cover design. WB final covers are also commonly referred to as *ET covers* or *unsaturated soil covers*. In general, WB final covers rely on finer textured soils to store water and sustain vegetation until the water is removed by evapotranspiration. In contrast, a conventional final cover system consists of a layer of compacted clay-rich soil, a geomembrane layer, a drainage layer, and a layer of topsoil designed to minimize percolation of water into the waste. A WB final cover requires healthy vegetation and soil with adequate unsaturated hydraulic properties that can supply plant nutrients and ensure adequate water-holding capacity and slope stability over the long term. The design of a WB final cover should take into account site-specific conditions including climax plant community, climate, and the properties of the soil proposed for constructing the cover system.

WB covers are generally designed by one of two methods. One approach is to model and design the cover system without reliance on vegetation for moisture transpiration, relying solely on evaporation and storage in the soil layer(s). The second method is to rely on vegetation to aid in the removal of moisture from the soil layer(s). The values selected for percentage vegetative cover, root penetration, and root density in the modeling effort directly affect the conservativeness of the designed WB cover.

1.1 Climatological Partitioning of the State

Texas is a large state with widely varying climatological characteristics, ranging from arid in the west to humid in the east. The MSW Permitting Program has used the 25-inch average annual precipitation line as defined by 30 TAC 330.5(b)(1)(D) to delineate areas of the state defined as arid. This approach originated from federal provisions adopted as part of the Subtitle D requirements. Those parts of the state west of the 25-inch average annual precipitation line have been deemed arid for the purpose of allowing alternative landfill designs (“arid exempt landfills”). Consistent with this approach, the level of information needed to support the design and modeling of WB final covers for landfill sites in Texas will depend on their average annual precipitation. Data from the closest weather station to the facility with at least the most recent 30 years of precipitation reporting should be acquired and used to determine the average annual precipitation for the period.

1.2 Overview of Equivalency Demonstration

The selected computer model input parameters and their values that are used in the WB final cover design and equivalency demonstration should represent site-specific conditions (including climate, vegetation, and soil conditions). Construction quality assurance and control specifications should ensure that the WB cover is constructed and maintained as designed and modeled, including the design soil and vegetation conditions.

One recognized approach would be for a WB cover modeling and design process to demonstrate that the percolation at the bottom of the WB final cover is ≤ 4 mm for each of the years during the 30-year period of record. During cover performance verification testing, ≤ 8 mm in a year of measured percolation is recognized as satisfactory cover performance. Measured percolation of > 8 mm and ≤ 12 mm in a year may require additional modeling and a revised cover design for the remainder of the landfill. Measured percolation above 12 mm in a year likewise, may require additional modeling and a revised cover design for the remainder of the landfill. Additionally, these facilities may require retesting for percolation and soil moisture profiles.

To meet the soil erosion criterion in 30 TAC 330.457(d)(2), the TCEQ considers it reasonable to demonstrate that soil loss is ≤ 3 tons/acre/year, as calculated using the Universal Soil Loss Equation (TNRCC 1993).

1.3 Options for WB Final Cover Authorization

A landfill site with 25 inches or less 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 final cover. However, the design and modeling of the WB final cover for such sites may be based solely on numerical modeling, without calibration of the model, provided the model is an approved and proven numerical unsaturated flow model. To obtain authorization of this WB final cover, the facility should submit to the MSW Permits Section for review and approval a permit modification application under 30 TAC 305.70(k)(10) containing the WB final cover design, a WB final cover construction quality control plan (CQCP), and a satisfactory demonstration of equivalency utilizing site-specific soil, vegetation, and weather conditions as discussed in detail in later sections of this document.

A landfill site that receives greater than 25 inches of average annual precipitation, likewise, will be expected to provide site-specific soil, vegetation, climate and weather data for use in the design and modeling of the WB final cover. In addition, such sites would be expected to employ one of the following two options for demonstrating the designed cover system's performance: (1) a pre-construction design option (*model calibration option*); or (2) a post-construction design verification option (*cover performance verification option*).

Under the model calibration option, a facility will design a WB cover and then construct one or more calibration test plots in order to obtain site-specific field-collected data with which to calibrate the model. Each test plot shall be of an approved design, including size, location, and monitoring instrumentation for collection of model calibration data. The model calibration option is discussed in Section 2.0: the calibration test plot, in Section 2.1.

Under the cover performance verification option, a facility will design a WB cover and then verify the design and performance of the constructed WB final cover through site-specific field-scale testing (using a cover performance verification test plot). A preferred method of field verification of the WB final cover performance is the incorporation and monitoring of field-scale lysimetry coupled with *in situ* soil instrumentation and laboratory testing of soil samples within the constructed WB cover. Lysimeter test plots have been proven effective in measuring the amount of percolation through cover soils. Design aspects and construction considerations of lysimeter test plots have been documented by Benson et al. (1999) and Albright et al. (2010). The cover performance verification option is discussed in Section 3.0; the cover verification test plot, in Section 3.1.

Both the calibration and the cover performance verification test plots should be monitored with instrumentation capable of continuous data collection. Monitoring of test plots solely with discrete sampling has not been considered adequate. Test plots should be configured so as to represent the area of the landfill cover with the greatest water-storage demand.

2.0 Model Calibration Option

A facility proposing model calibration should coordinate with the MSW Permits Section in designing and establishing the field calibration test plots(s), monitoring parameters, and data-gathering procedures to ensure that the calibration study sufficiently addresses the recommendations in this guidance. If a test plot is to be located on property covered by an MSW permit, then the permittee should submit a permit modification request containing a detailed work plan for agency approval prior to constructing the test plot. If a test plot is to be located on property not covered by an MSW permit, a detailed work plan should be submitted for agency review and comment to ensure agreement on the data acquisition requirements and methods.

For a site opting for a calibrated WB cover model using a test plot located at a permitted landfill facility, two permit modifications would typically be required. In the first permit modification, the information for a field-scale WB test plot at the facility should include:

- detailed design plans
- construction quality assurance procedures
- operating procedures

The purpose of the test plot is to provide data with which to calibrate the model used in the initial WB cover design process. 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 weather conditions with a variety of patterns at the site. The length of time between test plot construction and initiation of data collection could possibly be shortened somewhat if the modeled cover design does not rely on vegetation. Using the data collected from the test plot, the applicant would rerun the analyses to predict the performance of the proposed WB cover model and prepare a revised cover design. General informational and operational requirements for model calibration test plots are detailed in Section 2.1.

In order to calibrate the water balance model, its 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. All of the following criteria should be met for a model to be considered calibrated.

- The model-predicted soil water contents and soil water storages should not show a consistent bias (over-prediction or under-prediction of the parameter throughout the modeling period).
- The maximum and minimum soil water storages predicted by the model should be within 5 percent of the field values.
- The timings associated with the increases and decreases in soil water storage predicted by the model should be within one week of the timings observed in the field.

In order 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, the applicant should submit a permit modification request for the WB final cover to be installed at the facility. The submission should include:

- a detailed report of the construction and operation of the test area
- data derived from the testing
- modeling procedures and input and output information
- discussion of changes made to the WB cover
- final cover design
- WB final cover CQCP

Calibration test plot data may be suitable for use at other facilities with similar climatological and soil conditions. Persons intending to utilize calibration test plot data at multiple sites should discuss this proposal with the TCEQ in advance in order to ensure agreement on the applicability of the data.

It is also likely that initial calibration efforts will yield valuable information as to proper monitoring methods, monitoring instrument types and numbers, size of test plots, and length of monitoring period. The agency encourages the use of this information in the development of subsequent focused calibration projects.

2.1 Calibration Test Plot

For model calibration, a test plot should be installed, maintained, and monitored to allow for the collection of data with which the WB final cover model may be properly calibrated. This test plot should be able to generate, at a minimum, the following information in order 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

The site-specific parameters to be evaluated should include, but are not limited to:

- root depth and density
- leaf-area index (LAI)
- plant water intake
- initial moisture content
- *in situ* soil geotechnical and hydraulic properties (density, porosity, saturated and unsaturated hydraulic conductivity, water retention curves)
- moisture content
  - moisture retention profiles
  - an adequate number of moisture sensor nests
  - adequate vertical spacing of the moisture sensors (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 (obtainable from local weather-reporting stations)
- air temperature
- solar radiation (obtainable from local weather-reporting station)
- wind speed
- relative humidity
- cloud cover
- dew point (calculated)

All candidate borrow sources for soil cover materials should be evaluated with a test plot prior to model calibration. A field-scale lysimeter may be included in the calibration test plot for a better understanding of potential percolation from the WB cover.

3.0 Cover Performance Verification Option

For a site proposing to verify the performance of the WB final cover system design using a test plot, typically one permit modification will be required. The permit modification application would be expected to include a final cover design that has been modeled to allow ≤ 4 mm percolation in a year through the cover using site-specific soil, vegetation, and weather data. The application would also contain a WB final-cover CQCP that includes all methods proposed for field-verifying that the final cover is performing as designed. After TCEQ approval of the WB final cover, the applicant will construct a cover performance verification test plot in concert with the installation of the initial section of the landfill's final cover. Monitoring equipment for the test plot should include at least one lysimeter and three clusters of soil moisture probes. The TCEQ will consider alternative monitoring equipment and methods in the future should such equipment and test methods become available. General informational and operational requirements for cover performance verification test plots are detailed in Section 3.1.

The cover performance verification test plot should be monitored for a minimum of three years after vegetation is fully established to design standards. An objective of the verification procedure should be to demonstrate the WB cover's performance under the precipitation conditions derived from the 30-year historical records that resulted in the maximum modeled percolation or storage. The TCEQ recommends that the application contain a contingency plan for artificial moisture loading to be implemented in year three of the test period, in the event the natural weather patterns in years one and two do not produce the necessary conditions. The time between test-plot construction and initiation of data collection could possibly be shortened somewhat if the modeled cover design does not rely on vegetation. For a site proposing the cover performance verification option, the TCEQ authorization will contain a condition requiring that the WB final cover be revised to reduce percolation, should the results of the verification testing indicate that the WB final cover is failing to perform as designed after establishment of vegetation. Additionally, a site with an approved alternative final cover will be required to maintain financial assurance for the cost of closure of the clay-geomembrane composite cover specified in the permit until the WB final cover has been successfully demonstrated. The financial assurance should continue to reflect the cost of the clay-geomembrane composite cover, and any reduction in the amount of required financial assurance would be based on a reduced landfill area requiring closure.

Cover performance verification test plot data may be suitable for use at other facilities with similar climatological and soil conditions. Persons intending to use such data at multiple sites should discuss this proposal with the TCEQ in advance in order to ensure agreement on the applicability of the data.

3.1 Cover Performance Verification Test Plot

For verification of WB final cover performance, a 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 for final cover performance verification should be designed to assess compliance with the ≤ 4 mm percolation limit. The permit modification application should detail the soil monitoring equipment and methods to be used and how those methods will confirm the function of the WB final cover system. Care should be taken to select monitoring equipment and methods so as to reduce the uncertainty in modeled estimates, which might be larger than required cover performance. At a minimum, the monitoring equipment and methods should provide 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 cover performance verification test plot should be operated, maintained, and monitored for a minimum of three years after vegetation is established. For WB cover designs that do not depend on vegetation for meeting the ≤ 4 mm percolation criterion, the test period may begin with the installation of the test plot. In all cases, data gathering from the test plot should begin no later than six months after construction.

The cover performance verification test plot should be constructed concurrently with the construction of the initial section of landfill final cover during closure or partial closure. The initial section of landfill cover containing the test plot should be limited to ≤ 10 acres. At least one lysimeter should be installed within the test plot, and each lysimeter should have dimensions of not less than 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. The actual design aspects of the lysimeter and soil probes should be determined site specifically and should be developed by engineers with experience in lysimeter design, construction, and monitoring.

During the cover evaluation period, the applicant should prepare and submit an annual report documenting the results of all monitoring performed and demonstrating that the cover system is functioning as designed. The report should document the following:

- soil data
- vegetation data
- weather data
- soil moisture retention curves
- basal percolation
- observations and recommendations of the project engineer

The TCEQ will review and evaluate the annual reports to determine if the WB final cover is meeting performance equivalency requirements and providing adequate protection from wind and water erosion.

Generally, if the measurements and results of the lysimeter and the soil moisture sensors indicate that the cover is allowing ≤ 8 mm percolation in a year, the cover may be viewed as successful and the remainder of the WB final cover can be installed pursuant to the WB final cover CQCP. If > 8 and ≤ 12 mm percolation in a year is measured, then the remaining WB final cover will be redesigned using data from the test plot, and the new design submitted to the TCEQ for permit modification. Upon approval, the remainder of the cover can be installed pursuant to the approved WB final cover CQCP. If > 12 mm percolation in a year is measured, then the remaining WB final cover will be redesigned, and the new design submitted to the TCEQ for permit modification. Upon approval, an initial phase of cover may be constructed that includes a new test plot for cover-performance verification in the same manner as the original test plot. Additional WB final cover beyond the initial maximum of 10 acres that includes the test plot should not be constructed until the TCEQ has determined that the initial phase of WB cover has been successfully demonstrated.

4.0 Modeling and Model Calibration

The UNSAT-H model has been the primary model used in WB cover equivalency demonstration applications received by the TCEQ to date. This model, and other unsaturated flow models, may be considered effective in the design process for these cover systems provided that the input data (e.g., soil properties, weather patterns) are representative of actual physical conditions.

The selected computer program should integrate soil, plant, and climate variables, and their effect on hydrology and soil water balance, to predict the performance of the proposed WB final cover system. The program 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 (transpiration)
- integrate climate data

Various computer programs for alternative cover modeling are described in ITRC (2003). The basis for selecting a computer program (including the version of the program and how it is appropriate for the WB final cover) should be explained, as well as which specific options in the program were selected.

All model assumptions, options, and input data should be identified and justified with respect to the site-specific conditions. Input data should be explained in relation to:

- general options
- hysteresis options
- heat flow options (if selected)
- vapor flow options (if selected)
- soil hydraulic properties
- surface node bounding values
- initial conditions
- plant parameters
- potential evapotranspiration (PET) partitioning (if selected)

For each of the input data, the available range of values should be specified, and the validity of the values chosen should be justified. Soil borrow-source laboratory-derived parameters should be used.

The model default values should not be used unless they are representative of site-specific conditions. For example, the values used in the UNSAT-H model for *a*, *b*, and *c* in the root-growth equation should be site specific. The permittee should document how each parameter input into the model is determined and how it is representative of site-specific conditions. For models other than UNSAT-H, applicants should provide a copy of the user’s guide.

The model should be run to simulate the performance of the proposed WB cover system as designed over the 30-year period represented by the meteorological data set. The lower flux boundary should be the bottom surface of the WB cover. Sensitivity analyses of any variables should be included for which a site-specific value cannot be determined.

Summarize the results of each model run in a table which lists the quantities for each year of the run for the following parameters:

- precipitation (P)
- 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 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 ET cover. The model input and output files should also be provided.

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.

A discussion should be included in the application explaining the modeler’s understanding of the model, the results for the scenarios modeled, the sensitivity analyses performed, and the worst-case scenario and how it was determined.

For sites where model calibration is indicated, site-specific soil parameters and field-study generated empirical 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 and any model input data that are not based on field monitoring results and parameters should be identified and the rationale for their use discussed.

5.0 Description of Proposed Final Cover Design

The WB final cover design should be fully described, including the number of layers; the thickness, function, and properties of each layer; and the vegetation. A summary should be presented of the results of the model, the calculations used to determine that the WB final cover design meets the two criteria in 30 TAC 330.457(d), and how the proposed WB cover meets the two criteria. Drawings should be provided of the proposed WB final cover that include design details for the proposed WB final cover system, 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.

The following site conditions should be characterized in a detailed discussion of the potential for the proposed WB cover to function successfully at the site:

- climate
- existing and proposed vegetation
- growing seasons
- distribution of precipitation through the year
- types of soils available
- moisture retention curves of the candidate soils
- compaction characteristics
- capability of the soils to sustain native and non-native plants

Soils used in the evaluation should be demonstrated to be available locally. Laboratory tests should be performed on the local soil to determine its suitability. Details of the recommended soil tests are discussed in Section 6.0 below. Before commencing construction, field and laboratory tests should be performed on the materials that will be used to ensure that the material properties conform to the design specifications. If the properties differ from those modeled, then a revised demonstration should be submitted for review and approval.

6.0 Soil

The WB cover soils should be modeled using input data that represent 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. The engineering, hydraulic, and agronomic properties of the soils to be used in the WB final cover should be characterized by sampling and laboratory testing. 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:

- 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)

This information should be evaluated to determine if the soils will need to be amended before use in the WB cover. Generally, at least the upper foot of the soil profile should be conducive to plant growth. If soil amendments are necessary, then the soil amendment process needs to be fully described and addressed in the WB final cover CQCP and the amended soil should be tested for the properties described above. A map should be included 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 trend of the moisture retention curve, as defined using well established models (e.g., Van Genutchen), should be presented, including the actual data points obtained in the laboratory testing program. The hydraulic conductivity function predicted using the moisture retention curve and the measured saturated hydraulic conductivity should also be provided.

7.0 Vegetation

If the WB cover is designed with reliance on vegetation for moisture transpiration, an adequate explanation of which plants are suitable for the site-specific soil types, root depths, root densities, percent coverage, and climatic conditions should be included. The vegetation selections 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. The documentation should describe each plant type, with data on seasonality, succession, rooting characteristics (depth, density, and spread), leaf area index, and suitability for the soil types proposed and for the location of the site. 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. The U.S. Department of Agriculture's publications on local and county soil and vegetation types are excellent starting points for such information.

The modeled root depth and root density should be consistent with the climate and the selected vegetation. The cover soil should be thick enough for the design root depth and density. Model inputs should reflect bare ground of at least 15 percent, and use a low estimate of the maximum leaf area index for the selected vegetation. The use of a percent bare ground > 15 would add conservatism in the cover design and would better account for periods when vegetation establishment proves difficult. The maximum leaf area index should be determined for the plant community that will develop on the cover assuming fair vegetation quality.

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 final cover CQCP should include a program of amending the soil (with organic matter, fertilizer, etc.) to meet the conditions assumed in the vegetation analysis. Documentation should be provided demonstrating that the specific plants chosen will grow in the site-specific climate and soil conditions proposed for the WB cover. A range of vegetation scenarios (e.g., *near term*—what is seeded by design; *long term*—an established plant community that may differ from what was seeded) should be modeled. For example, it is not sufficient to list 15 different plant types without correlating them to the site-specific climate and soil conditions for the WB cover. Some plants cannot survive and grow as predicted by the model in all areas.

The plant species chosen should have a root depth that is expected to develop within the soil layers of the WB final cover. If the root depth and density of the selected vegetation cannot be verified, the root depth used in the model should be based on the minimum root depth to compensate for the uncertainty of actual root depth that may be accomplished at the site.

8.0 Climate and Weather

Precipitation and other climate data needed to define the site's potential evapotranspiration should be characterized using a 30-year daily meteorological data set that includes daily precipitation, humidity, air temperature, solar radiation, and wind speed. Data should be obtained from a location that is representative of the site. If more than one weather station's data are to be used in determining precipitation values for the site, then the rationale for the use of data from multiple weather stations, and how site precipitation values were determined, should be discussed. The locations of all weather stations from which meteorological data were obtained in relation to the location of the landfill site should be shown on a scaled map.

The model results should not identify runoff on days with no precipitation. Surface runoff should not begin until the rainfall or snowmelt rate exceeds the soil-infiltration rate or the surface soil becomes saturated.

9.0 Final Cover Construction Quality Control Plan

Construction quality assurance and quality control (QA/QC) requirements should verify 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 final cover system should be translated into material specifications, and construction QA/QC testing specifications and procedures, and documented in the WB final cover CQCP. The WB final cover CQCP should also include all construction QA/QC requirements and specifications proposed to ensure that the WB cover is constructed and maintained as designed. For a facility employing a final cover performance verification test plot in the first section of WB cover installed, the CQCP should contain detailed QA/QC procedures for constructing and monitoring the test plot as well as QA/QC for the rest of the WB cover to be installed. Specifications should be included for:

- soil density and hydraulic conductivity
- construction methods to achieve the design density and hydraulic conductivity
- moisture content
- all proposed soil types (USCS tests)
- vegetation employed and how it will be established, evaluated, and maintained
- provisions for initial irrigation, fertilization, and seeding as needed to establish and maintain good condition, and desired root density and depth
- tests and test frequencies for verifying design conditions

Borrow-source testing should be performed for USCS classification at a frequency of at least one test per 1,000 cubic yards. Hydraulic conductivity testing should be performed using large block samples at a minimum frequency of one test per lift and one test per 10,000 cubic yards of placed material.

Slope stability evaluations should be supplied. The WB final cover 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, root density, and plant coverage. Standard or widely accepted vegetation measurement methods for the plant types proposed, which are accepted by the USDA or similar government authorities, are acceptable.

WB cover construction methods must ensure that the soil *in situ* 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. The CQCP should include instructions to limit equipment weight and traffic on the cover, and procedures for identifying and correcting over-compaction and other out-of-specification situations or damage.

10.0 Final Cover System Evaluation Report and Certification

The WB final cover CQCP should specify that a final cover system evaluation report (FCSER) and certification will be submitted for each section of WB cover that is constructed, and identify the information to be reported, including:

- completed report forms required by the TCEQ
- a summary of construction activities
- drawings showing sample and test locations
- field and laboratory test results
- as-built drawings (including cover elevation and thickness of the soil layers)
- vegetation details (plant mix, method of planting)
- description of construction problems and how they were resolved
- statement of compliance with the MSW rules and the WB final cover CQCP

The FCSER should be signed and sealed by a professional engineer licensed in Texas.

11.0 Vegetation Establishment Report

The WB final cover CQCP should specify that a vegetation establishment report will be submitted semi-annually during the cover vegetation start-up period, indicating the type and quantity of vegetation that has become established, the percent vegetative cover, and vegetative root structure (depth and density). If the type or quantity of vegetation or root structure does not meet specifications, then corrective action will be necessary to improve the vegetation and be consistent with the WB final cover as designed for the equivalency demonstration.

12.0 Closure Plan and Post-Closure Plan

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

The post-closure care plan for the facility must 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, and irrigating, and restoring cover that has been eroded or damaged (for example, by burrowing of animals).

13.0 References

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