ALTERNATIVE FINAL COVER SYSTEM DEMONSTRATION

GEOSYNTEC CONSULTANTS

COMPUTATION COVER SHEET

Client: TVA **Project:** KIF Gypsum Disposal Facility **Project/Proposal #:** GR3731 **Task #:** 06

TITLE OF COMPUTATIONS ALTERNATIVE FINAL COVER SYSTEM DEMONSTRATION

COMPUTATIONS BY:
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May 11, 2006 DATE

APPROVAL NOTES:

REVISIONS (Number and initial all revisions)

NO.	SHEET	DATE	BY	CHECKED BY	APPROVAL

Written by: Sowmya Bulusu **Date:** 04/11/06 **Reviewed by:** Basak Gulec **Date:** 04/27/06

Client: TVA **Project:** Kingston Fossil Plant Gypsum Disposal Facility **Project/Proposal No.:** GR3731 **Task No.:** 06

ALTERNATIVE FINAL COVER SYSTEM DEMONSTRATION

PURPOSE OF ANALYSES

The purpose of the analyses presented in this calculation package is to demonstrate the equivalency of an alternative final cover system for Kingston Fossil Plant Gypsum disposal facility (herein referred as KIF Gypsum disposal facility) to the prescribed final cover system meeting minimum technical requirements of Tennessee Department of Environment and Conservation (TDEC) Chapter 1200-1-7 [TDEC, 2005].

INTRODUCTION

Waste placement activities in the disposal area will be followed by the construction of a final cover system. The proposed alternative final cover consists of (from top to bottom):

- a 12-inch thick vegetative layer;
- a geocomposite drainage layer, consisting of a High-Density PolyEthylene (HDPE) geonet with geotextile filters heat bonded to both sides of the geonet;
- a 40-mil thick linear HDPE geomembrane; and
- a 12-inch thick compacted soil layer.

Regulations that describe the minimum technical requirements for final cover system at Class I and Class II facilities are included in Chapter 1200-1-7 of "*Rules of TDEC, Division of Solid Waste Management*" [TDEC, 2005]. According to this rule, the final cover system should consist of (from top to bottom):

- a vegetative layer at least 12 inches in thickness; and
- a compacted soil layer below it, at least 24 inches in thickness with permeability no greater than 1×10^{-7} cm/sec.

The details of the prescribed and proposed alternative final cover systems are shown in Figure 1.

DEMONSTRATION OF EQUIVALENCY OF THE PROPOSED FINAL COVER SYSTEM

According to Rule 1200-1-7, the Department may approve alternative final cover designs if determined by the staff to meet or exceed the minimum standards. The performances of the prescribed and alternative final cover systems are compared in terms of the infiltration through the final cover. The vegetative layer of the proposed final cover system (12-in thickness) is consistent with the Regulation 1200-1-7 prescribed vegetative layer and therefore it will not be discussed further.

In the proposed alternative final cover system, the upper component of the composite infiltration barrier system is a geomembrane, below which is a 12-inch thick layer of compacted soil. In addition, the proposed alternative final cover has a geocomposite drainage layer that is placed above the geomembrane to reduce the hydraulic head on the infiltration barrier.

METHOD OF ANALYSIS

Comparison of hydraulic performances of the alternative and prescribed final cover systems is carried out using the Hydrologic Evaluation of Landfill Performance (HELP) model, Version 3.07, developed by the U.S. Environmental Protection Agency (USEPA) [Schroeder et al., 1994 a, b]. The HELP program is a quasi two-dimensional hydrologic model of water movement across, into, through, and out of landfills. The program accepts climatologic, soil, and design data, and uses a solution technique that accounts for the effects of surface storage, runoff, infiltration, percolation, evaporation, soil moisture storage, and lateral drainage.

PARAMETERS USED IN HELP MODEL ANALYSIS

Climatic Data

- The mean monthly precipitation data was obtained from the National Climatic Data Center CDROM "*NCDC SUMMARY OF THE DAY*" published by EarthInfo Inc. [EarthInfo, 2005]. Daily precipitation data between 1948 and 2005 for the closest weather station to the site (i.e., Kingston, Weather Station ID: 404871) were averaged to obtain the normal mean monthly precipitation data. The precipitation was modeled in the HELP program using the synthetic daily weather generation option for Knoxville, Tennessee (over a 100-year modelling period) in conjunction with the calculated normal mean monthly precipitation data.
- The temperature, relative humidity, and solar radiation were modeled for Knoxville, Tennessee using the synthetic daily weather generation over a 100-year modeling period.
- The evaporative zone depth was selected as 12 in. from HELP default values, since the thickness of the vegetative cover soil for the prescribed and alternative final cover systems is 12 in.

Layer Material Properties

Final Cover System Data

The material properties used to represent the different components of the final cover are presented in Table 1. The final cover system was assumed to be vegetated with good stand of grass and runoff was allowed.

The analyzed drainage path is the length between the drainage benches on the final cover, i.e., 90 feet, at a slope of 33.3% (3 horizontal: 1 vertical).

Table 1. Layer Material Properties for Prescriptive and Proposed Alternative Final Cover System

Cover	Component	Thickness	HELP Material Texture #	Type / Classification	Total Porosity	Field Capacity	Wilting Point	Saturated Hydraulic Conductivity, k (cm/s)
Prescribed	Vegetative Cover(1)	12-inch	12	CL	0.471	0.342	0.210	4.2×10^{-5}
	Compacted Clay Layer	24-inch	16	Barrier Soil	0.427	0.418	0.367	1×10^{-7}
Alternative	Vegetative Cover(1)	12-inch	12	CL	0.471	0.342	0.210	4.2×10^{-5}
	Geocomposite(3) Drainage Layer	200-mil	20	Drainage Net	0.850	0.01	0.005	4.17 (3)
	Geomembrane (2)	40-mil	35	GM	0.000	0.000	0.000	2×10^{-13}
	Compacted Soil Layer(1)	12-inch	26	CL	0.445	0.393	0.277	1.9×10^{-6}

Notes:

(1) It was assumed that soils obtained from the on-site borrow areas would be used as vegetative cover and compacted soil layers. Information on the on-site potential borrow soils was obtained from the report titled "*Report of Geotechnical Investigation*" prepared by MACTEC in April 2006 [MACTEC, 2006]. Three types of soil s were identified during MACTEC [2006] subsurface explorations and laboratory testing. These soils were classified as MH, CH, and CL based on the Unified Soil Classification System (USCS). In the HELP analysis, CL and compacted CL were used for the vegetative cover and the compacted soil layer, respectively. HELP's default hydraulic conductivities were used for these layers. The default hydraulic conductivities were within the range of hydraulic conductivities obtained from laboratory testing (i.e., 2.8×10^{-5} cm/s to 6.7×10^{-8} cm/s) for MH, CH, and CL soil samples [MACTEC, 2006].

(2) Geomembrane was assumed to contain one hole per acre assuming good placement quality can be achieved through third-party CQA testing. The hole size was assumed to be 0.16 in^2, as recommended for these types of calculations by Giroud and Bonaparte [1989].

(3) The geocomposite drainage layer hydraulic conductivity value was estimated using a procedure described in the Attachment 1 of this calculation package.

RESULTS

The results of the HELP Model analyses are summarized in Table 2. The HELP model output files are included in Attachment 2.

Table 2. Infiltration rate comparison for the prescribed and alternative final cover systems.

Final Cover System	Average Annual Infiltration (in/day)	Peak Daily Infiltration (in/day)	Head on the top of the geomembrane (in) (peak daily)	
			Average	Maximum
Prescribed	3.20×10^{-3}	5.10×10^{-3}	12	12
Alternative	6.03×10^{-9}	9.09×10^{-8}	0.021	0.040

The results of these analyses (Attachment 2) show that less infiltration would occur through the proposed alternative final cover system than through the prescribed (i.e., compacted clay) final cover system.

In order to ensure that the synthetic component of the proposed final cover system will perform as analyzed, it is presented that, the synthetic component of the final cover will be constructed in accordance with the Material Specifications and Construction Quality Assurance and Quality Control (QA/QC) plan presented as part of this permit application.

CONCLUSION

Based on the analyses above, less infiltration would occur through the proposed alternative final cover system than for the prescribed (i.e., compacted clay) final cover system. The head in the final cover protection layer will also be less for the alternative final cover system compared to the prescribed one. Therefore, the alternative final cover system is considered superior to the prescribed final cover system.

REFERENCES

EarthInfo Inc., *NCDC Summary of the Day, Reference Manual*, EarthInfo Inc., 2005.

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GRI-GC8, "*Determination of the Allowable Flow Rate of a Drainage Geocomposite*", Standard Guide, Geosynthetic Research Institute, April, 2001.

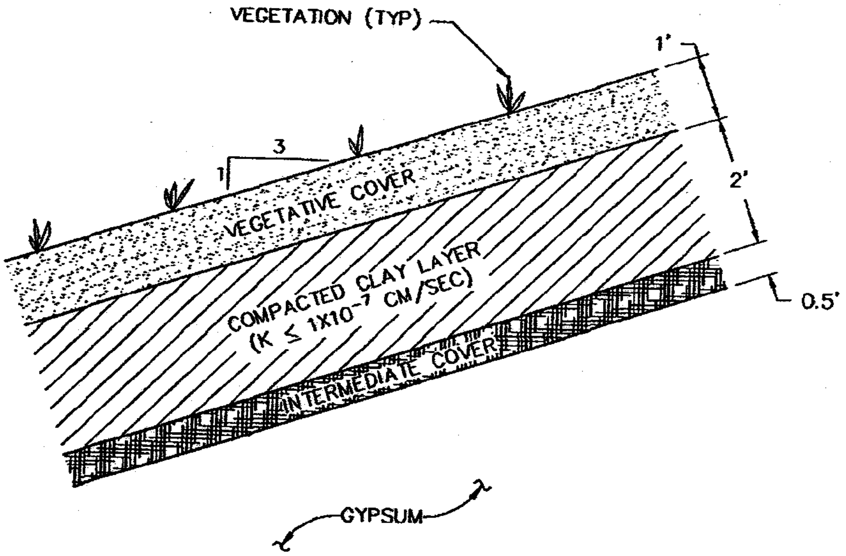
Koerner, R.M., "*Designing with Geosynthetics*", Third Edition, Prentice Hall, pp. 302 – 304, 1998.

MACTEC, "*Report of Geotechnical Investigation*", Prepared for Tennessee Valley Authority by MACTEC Engineering and Consulting, Inc., Project 3043051064.02, April 2006.

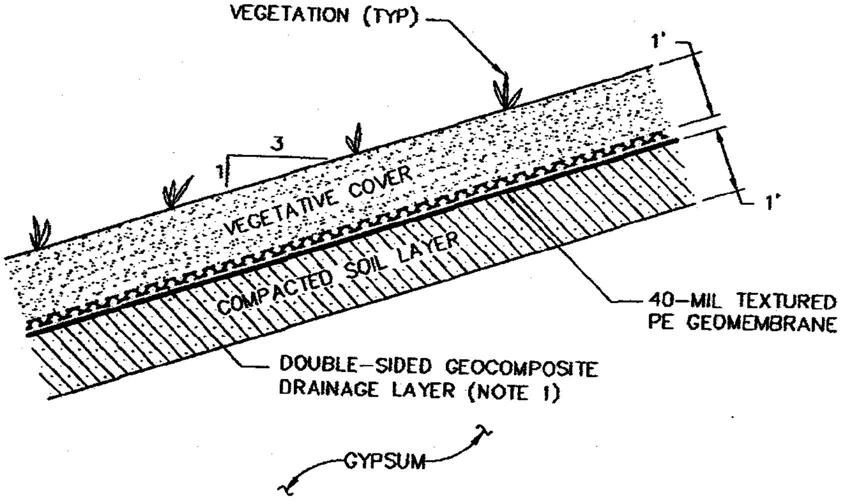
Schroeder, P. R., Lloyd, C. M., and Zappi, P. A., "*The Hydraulic Evaluation of Landfill Performance (HELP) Model, User's Guide for Version 3*", U.S. Environmental Protection Agency, Office of Research d Development Washington, D.C., Report No. EPA/600/R094/168a, 1994 a.

Schroeder, P. R., Dozier, T. S., Zappi, P. A., McEnroe, B. M., Sjostrom, J. W., and Peyton, R. L., "*The Hydraulic Evaluation of Landfill Performance (HELP) Model, Engineering documentation for Version 3*", U.S. Environmental Protection Agency, Office of Research and Development Washington, D.C., Report No. EPA/600/R094/168b, 1994 b.

TDEC, "*Rules of Tennessee Department of Environment and Conservation, Chapter 1200-1-7 – Solid Waste Processing and Disposal*", Division of Solid Waste Management, January 2005.



(a) Prescribed Final Cover System



(b) Proposed Alternative Final Cover System

Figure 1. Details of Prescribed and Alternative Final Cover Systems

Written by: Sowmya Bulusu **Date:** 04/11/06 **Reviewed by:** Basak Gulec **Date:** 04/27/06

Client: TVA **Project:** TVA Kingston Fossil Plant Landfill **Project/Proposal No.:** GR3731 **Task No.:** 06

ATTACHMENT 1

DRAINAGE LAYER HYDRAULIC CONDUCTIVITY DESIGN VALUES

Written by: Sowmya Bulusu Date: 04/11/06 Reviewed by: Basak Gulec Date: 04/27/06

Client: TVA Project: TVA Kingston Fossil Plant Landfill Project/Proposal No.: GR3731 Task No.: 06

Drainage Layer Hydraulic Conductivity Design Values

For geocomposite drainage layer (Alternative Final Cover System)

The hydraulic conductivity of a geocomposite drainage layer is related to the hydraulic transmissivity (θ) and the thickness of the geocomposite drainage layer (t) as follows:

$$k = \frac{\theta}{t} \qquad (1)$$

where:

k = hydraulic conductivity (cm/sec);
θ = hydraulic transmissivity (cm^2/sec); and
t = drainage layer thickness (cm).

The following equations proposed by Giroud et al. [2000] are used to estimate an appropriate transmissivity design value for the geocomposite drainage layer.

$$\theta_{LTIS} = \frac{\theta_{measured}}{\Pi(RF)} = \frac{\theta_{measured}}{RF_{IMCO} \times RF_{IMIN} \times RF_{CR} \times RF_{IN} \times RF_{CD} \times RF_{PC} \times RF_{CC} \times RF_{BC}} \qquad (2)$$

where:

θ_{LTIS} = long-term-in-soil hydraulic transmissivity of the geocomposite;
$\theta_{measured}$ = value of hydraulic transmissivity measured in laboratory tests;
$\Pi(RF)$ = product of all reduction factors;
RF_{IMCO} = reduction factor for immediate compression, i.e. decrease of hydraulic transmissivity due to compression of the transmissive core immediately following the application of stress;
RF_{IMIN} = reduction factor for immediate intrusion, i.e. decrease of hydraulic transmissivity due to geotextile intrusion into the transmissive core immediately following the application of stress;
RF_{CR} = reduction factor for creep, i.e. time-dependent hydraulic transmissivity reduction due to creep of the transmissive core under the applied stress;
RF_{IN} = reduction factor for delayed intrusion, i.e. decrease of hydraulic transmissivity over time due to geotextile intrusion into the transmissive core resulting from time-dependent deformation of the

geotextile;

RF_{CD} = reduction factor for chemical degradation, i.e. decrease of hydraulic transmissivity due to chemical degradation of the polymeric compound(s) used to make the geocomposite;

RF_{PC} = reduction factor for particulate clogging, i.e. decrease of hydraulic transmissivity due to clogging by particles migrating into the transmissive core;

RF_{CC} = reduction factor for chemical clogging, i.e. decrease of hydraulic transmissivity due to chemical clogging of the transmissive core;

RF_{BC} = reduction factor for biological clogging, i.e. decrease of hydraulic transmissivity due to biological clogging of the transmissive core;

θ_{design} = geocomposite transmissivity appropriate for use in design; and

FS = factor of safety to account for all possible uncertainties.

An overall factor of safety 1.5 is applied to the drainage layer transmissivity value. Therefore, θ_{design} can be calculated as follows:

$$\theta_{design} = \frac{\theta_{LTIS}}{FS} \qquad (3)$$

where:

θ_{design} = geocomposite transmissivity appropriate for use in design; and

FS = overall factor of safety to account for all possible uncertainties.

The selection of each reduction factor was based on certain mechanisms that reduce the flow capacity of the geocomposite layer due to thickness reduction caused by applied stresses, and hydraulic conductivity reduction caused by clogging. Recommendations on the selection of these reduction factors were obtained from several sources available in the technical literature [Giroud et al, 2000; GRI-GC8, 2001; and Koerner, 1998]. Reduction factors incorporated for the alternative final cover are discussed as follows:

The final cover system experiences a low confining pressure and is designed to function for a long time. Immediate compression, immediate intrusion, chemical degradation, and chemical clogging will be negligible for the proposed final cover and therefore a RF of 1 was assumed for these factors. Creep, delayed intrusion, and particulate clogging were assumed to happen to a small degree ($RF_{CR} = RF_{IN} = RF_{PC} = 1.1$); some biological clogging were also assumed to occur ($RF_{BC} = 1.2$). The overall factor of safety was assumed equal to 1.5.

Table 1. Reduction Factors for Geocomposite Drainage Layer

Reduction Factors			
		Range of Values	Alternative Final Cover
RF_{IMCO} =	Reduction factor for immediate compression	1.0 (1)	1.0
RF_{IMIN} =	Reduction factor for immediate intrusion	1.0 (1)	1.0
RF_{CD} =	Reduction factor for chemical degradation	1.2	1.0
RF_{CC} =	Reduction factor for chemical clogging	1.0-1.2 (1)	1.0
RF_{CR} =	Reduction factor for creep	1.1-1.4 (1)	1.1
RF_{IN} =	Reduction factor for delayed intrusion	1.0-1.2 (1)	1.1
RF_{PC} =	Reduction factor for particulate clogging	1.2	1.1
RF_{BC} =	Reduction factor for biological clogging	1.2-1.5 (1)	1.2
	Overall Reduction Factors =	**Π (RF)**	**1.6**
FS =	Factor of safety to account for all possible uncertainties		1.5

Range of published values.

For this project, a bi-planar geocomposite drainage layer with an assumed thickness of 200 mils (i.e., 0.20 inches) and a measured hydraulic transmissivity ($\theta_{measured}$) of 5.08 x 10^{-4} m^2/sec was considered. A geocomposite product with these properties is a standard commercially available product. Based on the reduction factors described above, θ_{design} and k_{design} values were calculated based on the $\theta_{measured}$ using Equations (1) through (3). The corresponding k_{design} values are presented in Table 2.

Table 2. Design Hydraulic Conductivity for Geocomposite Drainage Layer

Operation Condition	$\theta_{measured}$ (m^2/s)	Π (RF)	θ_{LTIS} (m^2/s)	FS	θ_{design} (m^2/s)	t (mm)	k_{design} (cm/s)
Alternative Final Cover	5.08E-04	1.6	3.18E-04	1.5	2.12E-04	5.08	4.17

Written by: Sowmya Bulusu Date: 04/11/06 Reviewed by: Basak Gulec Date: 04/27/06

Client: TVA Project: TVA Kingston Fossil Plant Landfill Project/Proposal No.: GR3731 Task No.: 06

ATTACHMENT 2

HELP RUNS

Written by: Sowmya Bulusu **Date:** 04/11/06 **Reviewed by:** Basak Gulec **Date:** 04/27/06

Client: TVA **Project:** TVA Kingston Fossil Plant Landfill **Project/Proposal No.:** GR3731 **Task No.:** 06

PRESCRIBED FINAL COVER SYSTEM

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                DEVELOPED BY ENVIRONMENTAL LABORATORY                     **
**                  USAE WATERWAYS EXPERIMENT STATION                       **
**              FOR USEPA RISK REDUCTION ENGINEERING LABORATORY             **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:      C:\HELP\TVA_1.D4
TEMPERATURE DATA FILE:        C:\HELP\TVA_1.D7
SOLAR RADIATION DATA FILE:    C:\HELP\TVA_1.D13
EVAPOTRANSPIRATION DATA:      C:\HELP\TVA_1.D11
SOIL AND DESIGN DATA FILE:    C:\HELP\TVA.D10
OUTPUT DATA FILE:             C:\HELP\TVA.OUT


TIME:  12:21       DATE:    5/ 5/2006


******************************************************************************

    TITLE:  TVA Kingston Fossil Plant Landfill

******************************************************************************


    NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
             COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                   LAYER  1
                                   --------

                       TYPE 1 - VERTICAL PERCOLATION LAYER
                           MATERIAL TEXTURE NUMBER  12
           THICKNESS                   =     12.00    INCHES
           POROSITY                    =      0.4710 VOL/VOL
           FIELD CAPACITY              =      0.3420 VOL/VOL
           WILTING POINT               =      0.2100 VOL/VOL
           INITIAL SOIL WATER CONTENT  =      0.4209 VOL/VOL
           EFFECTIVE SAT. HYD. COND.   =  0.419999997000E-04 CM/SEC
        NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  5.00
                  FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.
```

```
                                LAYER  2
                                --------

                     TYPE 3 - BARRIER SOIL LINER
                     MATERIAL TEXTURE NUMBER  16
    THICKNESS                      =      24.00    INCHES
    POROSITY                       =       0.4270  VOL/VOL
    FIELD CAPACITY                 =       0.4180  VOL/VOL
    WILTING POINT                  =       0.3670  VOL/VOL
    INITIAL SOIL WATER CONTENT     =       0.4270  VOL/VOL
    EFFECTIVE SAT. HYD. COND.      =   0.100000001000E-06 CM/SEC


                GENERAL DESIGN AND EVAPORATIVE ZONE DATA
                ----------------------------------------

  NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
           SOIL DATA BASE USING SOIL TEXTURE #12 WITH A
           GOOD STAND OF GRASS, A SURFACE SLOPE OF 33.%
           AND A SLOPE LENGTH OF   90. FEET.

  SCS RUNOFF CURVE NUMBER              =      85.30
  FRACTION OF AREA ALLOWING RUNOFF     =     100.0    PERCENT
  AREA PROJECTED ON HORIZONTAL PLANE   =      1.000   ACRES
  EVAPORATIVE ZONE DEPTH               =     12.0     INCHES
  INITIAL WATER IN EVAPORATIVE ZONE    =      5.050   INCHES
  UPPER LIMIT OF EVAPORATIVE STORAGE   =      5.652   INCHES
  LOWER LIMIT OF EVAPORATIVE STORAGE   =      2.520   INCHES
  INITIAL SNOW WATER                   =      0.000   INCHES
  INITIAL WATER IN LAYER MATERIALS     =     15.298   INCHES
  TOTAL INITIAL WATER                  =     15.298   INCHES
  TOTAL SUBSURFACE INFLOW              =      0.00    INCHES/YEAR


                EVAPOTRANSPIRATION AND WEATHER DATA
                -----------------------------------

  NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
           KNOXVILLE            TENNESSEE

       STATION LATITUDE                          =  35.49 DEGREES
       MAXIMUM LEAF AREA INDEX                   =   4.50
       START OF GROWING SEASON (JULIAN DATE)     =     85
       END OF GROWING SEASON (JULIAN DATE)       =    307
       EVAPORATIVE ZONE DEPTH                    =  12.0  INCHES
       AVERAGE ANNUAL WIND SPEED                 =   7.10 MPH
       AVERAGE 1ST QUARTER RELATIVE HUMIDITY     =  68.00 %
       AVERAGE 2ND QUARTER RELATIVE HUMIDITY     =  69.00 %
       AVERAGE 3RD QUARTER RELATIVE HUMIDITY     =  76.00 %
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```
          AVERAGE 4TH QUARTER RELATIVE HUMIDITY  =  72.00 %


        NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
                 COEFFICIENTS FOR    KNOXVILLE          TENNESSEE

                 NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

     JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
     -------      -------      -------      -------      -------      -------
       5.28         4.94         5.67         4.32         4.56         4.00
       4.72         3.50         3.78         2.88         4.55         5.48


        NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
                 COEFFICIENTS FOR    KNOXVILLE          TENNESSEE

              NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

     JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
     -------      -------      -------      -------      -------      -------
      35.40        40.30        49.80        59.10        67.10        73.50
      77.20        76.50        70.30        60.20        50.30        38.40


        NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
                 COEFFICIENTS FOR    KNOXVILLE          TENNESSEE
                   AND STATION LATITUDE  =  35.49 DEGREES


*******************************************************************************

        AVERAGE MONTHLY VALUES IN INCHES FOR YEARS    1 THROUGH  100
------------------------------------------------------------------------------

                          JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                          -------  -------  -------  -------  -------  -------
  PRECIPITATION
  -------------

    TOTALS                  4.90     5.10     5.40     4.25     4.94     3.89
                            4.90     3.64     4.24     2.86     4.49     5.63

    STD. DEVIATIONS         2.19     2.35     2.54     2.05     2.10     1.80
                            2.25     1.51     2.29     1.75     2.33     3.09

  RUNOFF
  ------

    TOTALS                 3.659    4.094    2.718    0.999    0.563    0.223
                           0.295    0.124    0.570    0.606    2.492    4.138

    STD. DEVIATIONS        2.455    2.374    2.353    1.350    1.086    0.531
                           0.536    0.357    0.995    1.023    2.170    2.888
```

```
EVAPOTRANSPIRATION
------------------
  TOTALS                      1.009     1.415     2.937     3.819     5.148     4.070
                              4.243     3.787     2.764     1.440     1.083     0.874

  STD. DEVIATIONS             0.261     0.349     0.277     0.667     1.035     1.493
                              1.549     1.231     0.957     0.334     0.150     0.173

PERCOLATION/LEAKAGE THROUGH LAYER  2
------------------------------------
  TOTALS                      0.1499    0.1347    0.1467    0.1314    0.0897    0.0331
                              0.0367    0.0307    0.0425    0.0928    0.1282    0.1518

  STD. DEVIATIONS             0.0083    0.0084    0.0057    0.0077    0.0374    0.0377
                              0.0379    0.0367    0.0437    0.0578    0.0383    0.0115

-------------------------------------------------------------------------------
            AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-------------------------------------------------------------------------------

DAILY AVERAGE HEAD ON TOP OF LAYER  2
-------------------------------------
  AVERAGES                   10.1261    9.6411    9.3980    6.9105    3.3748    1.1266
                              1.1828    0.8844    1.9264    4.9000    8.7509   10.8001

  STD. DEVIATIONS             1.8815    2.0931    1.2863    1.8024    2.4958    1.7182
                              1.6779    1.4301    2.4567    3.8209    3.3481    1.4147

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     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH  100
-------------------------------------------------------------------------------
                                       INCHES            CU. FEET     PERCENT
                                  -------------------  ------------  ---------
PRECIPITATION                      54.24    (   7.873)   196891.6     100.00

RUNOFF                             20.479   (  6.4228)    74340.14     37.757

EVAPOTRANSPIRATION                 32.588   (  3.0575)   118293.12     60.080

PERCOLATION/LEAKAGE THROUGH         1.16835 (  0.15528)     4241.115     2.15404
  LAYER  2

AVERAGE HEAD ON TOP                 5.752 (    0.939)
  OF LAYER  2

CHANGE IN WATER STORAGE             0.005   (  1.2363)        17.20      0.009

*******************************************************************************

*******************************************************************************
```

```
                 PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
  ------------------------------------------------------------------------
                                                 (INCHES)      (CU. FT.)
                                                ----------   -------------
    PRECIPITATION                                  5.13        18621.900

    RUNOFF                                         5.047       18321.5332

    PERCOLATION/LEAKAGE THROUGH LAYER  2           0.005102       18.52133

    AVERAGE HEAD ON TOP OF LAYER  2               12.000

    SNOW WATER                                     7.25        26300.9785

    MAXIMUM VEG. SOIL WATER (VOL/VOL)                    0.4710

    MINIMUM VEG. SOIL WATER (VOL/VOL)                    0.2100

***************************************************************************




***************************************************************************

                FINAL WATER STORAGE AT END OF YEAR  100
  ----------------------------------------------------------------------
                LAYER        (INCHES)      (VOL/VOL)
                -----        --------      ---------
                  1            5.5243         0.4604

                  2           10.2480         0.4270

               SNOW WATER      0.000

***************************************************************************
***************************************************************************
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Written by: Sowmya Bulusu **Date:** 04/11/06 **Reviewed by:** Basak Gulec **Date:** 04/27/06

Client: TVA **Project:** TVA Kingston Fossil Plant Landfill **Project/Proposal No.:** GR3731 **Task No.:** 06

ALTERNATIVE FINAL COVER SYSTEM

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**                                                                       **
**                                                                       **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE            **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)             **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                **
**                    USAE WATERWAYS EXPERIMENT STATION                  **
**              FOR USEPA RISK REDUCTION ENGINEERING LABORATORY          **
**                                                                       **
**                                                                       **
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PRECIPITATION DATA FILE:      C:\HELP\TVA_1.D4
TEMPERATURE DATA FILE:        C:\HELP\TVA_1.D7
SOLAR RADIATION DATA FILE:    C:\HELP\TVA_1.D13
EVAPOTRANSPIRATION DATA:      C:\HELP\TVA_1.D11
SOIL AND DESIGN DATA FILE:    C:\HELP\TVA-ALT.D10
OUTPUT DATA FILE:             C:\HELP\TVA-ALT.OUT


TIME:  12:33     DATE:   5/ 5/2006


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    TITLE:  TVA Kingston Fossil Plant Landfill - Alternative final cover

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    NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
             COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                  LAYER  1
                                  --------

                       TYPE 1 - VERTICAL PERCOLATION LAYER
                          MATERIAL TEXTURE NUMBER  12
          THICKNESS                  =     12.00   INCHES
          POROSITY                   =      0.4710 VOL/VOL
          FIELD CAPACITY             =      0.3420 VOL/VOL
          WILTING POINT              =      0.2100 VOL/VOL
          INITIAL SOIL WATER CONTENT =      0.3008 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.419999997000E-04 CM/SEC
        NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  5.00
                 FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.
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                           LAYER  2
                          --------

               TYPE 2 - LATERAL DRAINAGE LAYER
                 MATERIAL TEXTURE NUMBER 200
THICKNESS                    =      0.20   INCHES
POROSITY                     =      0.8500 VOL/VOL
FIELD CAPACITY               =      0.0100 VOL/VOL
WILTING POINT                =      0.0050 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.0100 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =   4.17000008000      CM/SEC
SLOPE                        =     33.30   PERCENT
DRAINAGE LENGTH              =     90.0    FEET


                           LAYER  3
                          --------

               TYPE 4 - FLEXIBLE MEMBRANE LINER
                 MATERIAL TEXTURE NUMBER  35
THICKNESS                    =      0.04   INCHES
POROSITY                     =      0.0000 VOL/VOL
FIELD CAPACITY               =      0.0000 VOL/VOL
WILTING POINT                =      0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.0000 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.199999996000E-12 CM/SEC
FML PINHOLE DENSITY          =      0.00   HOLES/ACRE
FML INSTALLATION DEFECTS     =      1.00   HOLES/ACRE
FML PLACEMENT QUALITY        =  3 - GOOD


                           LAYER  4
                          --------

                TYPE 3 - BARRIER SOIL LINER
                 MATERIAL TEXTURE NUMBER  26
THICKNESS                    =     12.00   INCHES
POROSITY                     =      0.4450 VOL/VOL
FIELD CAPACITY               =      0.3930 VOL/VOL
WILTING POINT                =      0.2770 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.4450 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.190000003000E-05 CM/SEC


          GENERAL DESIGN AND EVAPORATIVE ZONE DATA
          ----------------------------------------

NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
         SOIL DATA BASE USING SOIL TEXTURE #12 WITH A
         FAIR STAND OF GRASS, A SURFACE SLOPE OF 33.%
         AND A SLOPE LENGTH OF   90. FEET.
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```
SCS RUNOFF CURVE NUMBER                   =    89.30
FRACTION OF AREA ALLOWING RUNOFF          =   100.0     PERCENT
AREA PROJECTED ON HORIZONTAL PLANE        =     1.000   ACRES
EVAPORATIVE ZONE DEPTH                    =    12.0     INCHES
INITIAL WATER IN EVAPORATIVE ZONE         =     3.609   INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE        =     5.652   INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE        =     2.520   INCHES
INITIAL SNOW WATER                        =     0.000   INCHES
INITIAL WATER IN LAYER MATERIALS          =     8.951   INCHES
TOTAL INITIAL WATER                       =     8.951   INCHES
TOTAL SUBSURFACE INFLOW                   =     0.00    INCHES/YEAR


                   EVAPOTRANSPIRATION AND WEATHER DATA
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 NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
          KNOXVILLE             TENNESSEE

     STATION LATITUDE                             =  35.49 DEGREES
     MAXIMUM LEAF AREA INDEX                      =   4.50
     START OF GROWING SEASON (JULIAN DATE)        =    85
     END OF GROWING SEASON (JULIAN DATE)          =   307
     EVAPORATIVE ZONE DEPTH                       =  12.0  INCHES
     AVERAGE ANNUAL WIND SPEED                    =   7.10 MPH
     AVERAGE 1ST QUARTER RELATIVE HUMIDITY        =  68.00 %
     AVERAGE 2ND QUARTER RELATIVE HUMIDITY        =  69.00 %
     AVERAGE 3RD QUARTER RELATIVE HUMIDITY        =  76.00 %
     AVERAGE 4TH QUARTER RELATIVE HUMIDITY        =  72.00 %


 NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
          COEFFICIENTS FOR    KNOXVILLE           TENNESSEE

          NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
-------     -------     -------     -------     -------     -------
  5.28        4.94        5.67        4.32        4.56        4.00
  4.72        3.50        3.78        2.88        4.55        5.48


 NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
          COEFFICIENTS FOR    KNOXVILLE           TENNESSEE

     NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
-------     -------     -------     -------     -------     -------
 35.40       40.30       49.80       59.10       67.10       73.50
 77.20       76.50       70.30       60.20       50.30       38.40
 NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
```

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                 COEFFICIENTS FOR     KNOXVILLE          TENNESSEE
                  AND STATION LATITUDE  =  35.49 DEGREES


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          AVERAGE MONTHLY VALUES IN INCHES FOR YEARS     1 THROUGH  100
-------------------------------------------------------------------------------

                         JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                         -------  -------  -------  -------  -------  -------
 PRECIPITATION
 -------------
   TOTALS                  4.90     5.10     5.40     4.25     4.94     3.89
                           4.90     3.64     4.24     2.86     4.49     5.63

   STD. DEVIATIONS         2.19     2.35     2.54     2.05     2.10     1.80
                           2.25     1.51     2.29     1.75     2.33     3.09

 RUNOFF
 ------
   TOTALS                 1.117    1.550    0.766    0.364    0.497    0.326
                          0.495    0.222    0.599    0.285    0.713    1.168

   STD. DEVIATIONS        1.294    1.655    0.925    0.564    0.647    0.413
                          0.562    0.304    0.717    0.461    0.770    1.390

 EVAPOTRANSPIRATION
 ------------------
   TOTALS                 1.018    1.423    2.945    3.598    4.200    3.642
                          3.933    3.474    2.653    1.438    1.131    0.893

   STD. DEVIATIONS        0.265    0.351    0.281    0.833    1.191    1.301
                          1.398    1.092    0.951    0.377    0.152    0.183

 LATERAL DRAINAGE COLLECTED FROM LAYER  2
 ----------------------------------------
   TOTALS                2.6383   2.6616   2.1160   0.7999   0.4166   0.1633
                         0.2278   0.1278   0.5230   0.7721   2.1893   3.1477

   STD. DEVIATIONS       1.5492   1.3948   1.5094   0.9652   0.6595   0.3879
                         0.4102   0.3223   0.8198   0.8974   1.4411   1.7064

 PERCOLATION/LEAKAGE THROUGH LAYER  4
 ------------------------------------
   TOTALS                0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

   STD. DEVIATIONS       0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000


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             AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
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   DAILY AVERAGE HEAD ON TOP OF LAYER  3
   ---------------------------------------
     AVERAGES              0.0015   0.0016   0.0012   0.0005   0.0002   0.0001
                           0.0001   0.0001   0.0003   0.0004   0.0013   0.0018

     STD. DEVIATIONS       0.0009   0.0009   0.0009   0.0006   0.0004   0.0002
                           0.0002   0.0002   0.0005   0.0005   0.0009   0.0010

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    AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH  100
---------------------------------------------------------------------------

                                      INCHES           CU. FEET     PERCENT
                                 ------------------  ------------  ---------
 PRECIPITATION                    54.24   (   7.873)    196891.6    100.00

 RUNOFF                            8.103  (  3.0361)     29414.05    14.939

 EVAPOTRANSPIRATION               30.348  (  2.7853)    110161.85    55.951

 LATERAL DRAINAGE COLLECTED       15.78332 (  4.15610)    57293.441  29.09898
   FROM LAYER  2

 PERCOLATION/LEAKAGE THROUGH       0.00000 (  0.00000)        0.008   0.00000
   LAYER  4

 AVERAGE HEAD ON TOP               0.001 (   0.000)
   OF LAYER  3

 CHANGE IN WATER STORAGE           0.006  (  1.3447)         22.24     0.011
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              PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
  ----------------------------------------------------------------------
                                                 (INCHES)    (CU. FT.)
                                                ----------  -------------
     PRECIPITATION                                 5.13       18621.900

     RUNOFF                                        3.817      13856.2451

     DRAINAGE COLLECTED FROM LAYER  2              0.97077     3523.87769

     PERCOLATION/LEAKAGE THROUGH LAYER  4          0.000000       0.00033

     AVERAGE HEAD ON TOP OF LAYER  3               0.021
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    MAXIMUM HEAD ON TOP OF LAYER  3              0.040

    LOCATION OF MAXIMUM HEAD IN LAYER  2
           (DISTANCE FROM DRAIN)                 0.0 FEET

    SNOW WATER                                   7.25          26300.9785


    MAXIMUM VEG. SOIL WATER (VOL/VOL)                    0.4567

    MINIMUM VEG. SOIL WATER (VOL/VOL)                    0.2100

     ***  Maximum heads are computed using McEnroe's equations.  ***

          Reference:  Maximum Saturated Depth over Landfill Liner
                      by Bruce M. McEnroe, University of Kansas
                      ASCE Journal of Environmental Engineering
                      Vol. 119, No. 2, March 1993, pp. 262-270.

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                 FINAL WATER STORAGE AT END OF YEAR  100
    ----------------------------------------------------------------------
                 LAYER         (INCHES)       (VOL/VOL)
                 -----         --------       ---------
                   1            4.2219         0.3518

                   2            0.0020         0.0100

                   3            0.0000         0.0000

                   4            5.3400         0.4450

               SNOW WATER       0.000

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