INTRODUCTION

The Colorado Department of Public Health and the Environment (CDPHE) Guidelines on Individual Sewage Disposal Systems (Guidelines) and Tri-County Health Department's ISDS Regulation I-96 allow use of the water balance method to size evapotranspiration beds. This guidance document has been prepared to assist engineers and regulators in understanding and applying the water balance method to the design and review of evapotranspiration systems.

The guidance document presents the water balance design method in a spreadsheet format and explains the development of the spreadsheet and how to use it.

The Hydrologic Evaluation of Landfill Performance (HELP) Model (1) was used to obtain evapotranspiration, precipitation, and runoff data to input into the water balance spreadsheet. HELP is a water-routing model for determining water balances.

Figure 2.0, in the Appendix illustrates the relationships between the input and output data, the HELP Model, and the water balance spreadsheet.

CONCEPT OF THE WATER BALANCE METHOD

A water balance accounts for water entering the bed, water leaving the bed, and water storage within the bed. Sources of water into the bed include septic tank effluent and infiltration of rainwater and snowmelt. Water leaves the bed by absorption into soils, evaporation, and transpiration. Water is stored in the pore spaces (voids) in the gravel, sand, and topsoil within the bed. **A water balance uses the equation: INITIAL WATER (or WATER FROM PREVIOUS MONTH) + WATER IN - WATER OUT = WATER IN STORAGE.** An evapotranspiration bed must provide sufficient storage capacity under all anticipated conditions, therefore, the Guidelines and Regulation I-96 require that ET beds be sized to store all water during those months where WATER IN is greater than WATER OUT.

Water is stored within the void spaces between the soil particles in the bed. Figure 1.1 illustrates that soils consist of a solid phase, a water phase and an air phase. Water and air occupy the pore spaces (voids). The void phase is referred to as porosity.

Figure 1.2 indicates that for a 1 cubic foot sample of ET bed sand, that approximately 0.44 cubic foot consists of void space, if the sample were completely dried in an oven, to completely remove the "water phase", such that all void space were occupied entirely by air. The 0.44 cubic foot was determined from the HELP model default porosity for the default material texture 4, which corresponds to the ET bed sand. The HELP model inputs and outputs are discussed later in this document.

Figure 1.3 indicates that the ET sand in a bed will always have some minimum moisture content. The HELP model determines that this minimum moisture content would be 0.28 cubic feet in the 1 cubic foot sample. The remaining amount of void space ("air phase") would be 0.44 minus 0.28 = 0.16 cubic feet is available for storing effluent and precipitation infiltration.

Figure 1.4 illustrates the relationship between total porosity (total void), specific yield and specific retention. ET sand meeting the requirements of the Guidelines and Regulation I-96 would correspond to the "Fine Sand", with an effective size between 1/8 mm and 1/4 mm. The figure indicates a porosity of approximately 44%, which agrees closely with that determined from the HELP model default soil porosity. Values for specific yield and specific retention are not determined in Figure 1.4.

A water balance method for sizing an ET bed requires the following information:

1. Monthly evapotranspiration rate (determined from evaporative zone depth, maximum leaf area index, growing season, solar radiation, annual average wind speed, relative humidities)

   Monthly pan evaporation may also be used, however, these values **overestimate actual evapotranspiration,** which occurs from an ET bed.

Evapotranspiration is highly dependent upon temperature, leaf area, growing season, relative humidity, solar radiation, and capillary movement of water within evapotranspiration beds.

2. Monthly precipitation and runoff (includes snowmelt and rain)

Precipitation from snow and rain vary significantly from month to month, year to year, and by geographic location. The amount of precipitation which runs off the ground surface and which infiltrates is dependent on types of soil and ground slope.

3. Monthly quantity of septic tank effluent entering the bed

The amount of septic tank effluent entering the bed is dictated by Regulation I-96 and the Guidelines.

4. Quantity of effluent absorbed

The amount of absorption (loading rate or long term acceptance rate) into soils can be estimated based on hydraulic conductivity values for various soils types and loading rates for septic tank effluent from literature values.

5. Soil void space in sand media (porosity)

Soil characteristics are known from research.

6. Initial water (moisture) content in bed

Initial water can also be thought of as water which always remains in the bed, even during the hottest driest months. Figure 1.3 illustrates this concept. In Figure 1.4, this water is called "specific retention".

SOURCES OF DATA FOR USE IN THE HELP MODEL AND WATER BALANCE SPREADSHEET

The HELP model provides default weather and soils data for Denver, Colorado Springs, Pueblo, and Grand Junction, in Colorado. Default historical precipitation data are only available for Denver and Grand Junction, and HELP only provides five years of default precipitation data for these two cities (years 1974-1978 in most cases). The user must consider if these five years are representative. Synthetic precipitation data are available for Denver, Pueblo, Grand Junction and Colorado Springs. If the site for the ET bed is not near these cities, other sources of data will be required.

For locations outside Denver, Colorado Springs, Pueblo, and Grand Junction, information is available in publications or on diskette from the National Climatic Data Center (NCDC), NOAA, Federal Building, Asheville, North Carolina, 28801, (704) 271-4800; Fax (704) 271-4876. Climate data are also available from Hydrosphere Data Products, 1002 Walnut, Suite 200, Boulder, CO 80302 (800) 949-4937. Local weather information may also be available from local weather stations.

The HELP model also provides default values for a wide range of soil types within and adjacent to ET systems. The soils data are not as geographically dependent as the weather data, however, the engineer should be aware of local soils characteristics which may deviate from HELP default parameters.

USE OF HELP MODEL TO CALCULATE ET, PRECIPITATION AND RUNOFF

What is the HELP Model and Why is it Being Used?

The HELP (1) computer program is a two dimensional hydrologic model which performs water balance analyses of landfills. Although an ET bed is obviously not a landfill, the author of this document believes that the processes are sufficiently similar for the HELP model to be applied to determine the necessary data to input into the water balance sizing spreadsheet for ET beds.

The HELP Model is used primarily because it models evapotranspiration from an ET bed more realistically than relying on measurements or calculations of pan or lake evaporation.

NOAA provides monthly estimates of "pan evaporation" for Denver, computed from meterological measurements, using a form of the Penman Equation. NOAA also provides measured class A pan evaporation data, for other stations, however, this data is only available for April through October. The annual amount of evaporation determined from the Penman equation, for Denver is 65.68 inches, which is much more than from the HELP Model.

Table 1 below illustrates the difference between estimates of pan evaporation data from NOAA and evapotranspiration (in an actual ET bed) determined from the HELP Model.

TABLE 1
COMPARISON BETWEEN NOAA EVAPORATION AND HELP EVAPOTRANSPIRATION
DENVER, COLORADO

MONTH	PAN EVAP. NOAA (inches)	HELP EVAPOTRANSPIRATION (inches)	DIFFERENCE (inches)
January	2.20	0.58	1.62
February	2.33	0.55	1.78
March	3.83	0.85	2.98
April	5.70	1.48	4.22
May	7.43	2.48	4.95
June	8.96	4.93	4.03
July	9.80	8.35	1.45
August	9.13	2.80	6.33
September	6.59	3.89	2.70
October	4.78	2.21	2.57
November	2.69	0.84	1.85
December	2.24	0.70	1.54
TOTAL	**65.68**	**29.66**	**36.02**

The HELP model calculates actual evapotranspiration rates from weather data (solar radiation, temperature, relative humidity, etc), which are then used in the water balance spreadsheet. Due to the large difference between the NOAA evaporation data and the HELP Model data, direct input of the NOAA evaporation data into the spreadsheet is not recommended.

Figure 2.0 illustrates the relationship between the data inputs and outputs to and from the HELP model and the water balance spreadsheet. The HELP model calculates monthly evapotranspiration, precipitation, and runoff from the weather and soils data, which are then input into the spreadsheet, along with trial bed size, soils absorption rate, wastewater (septic tank effluent) flow, and initial water content. The spreadsheet then provides an evaluation of the trial bed size, and will be explained in detail later in this report.

A 50 year analysis was run using the HELP Model to obtain precipitation, runoff and evapotranpsiration data to use in the water balance spreadsheet. A copy of the printout is included in the Appendix, titled "evapotranspration bed 3 bedroom, 50 years". For a detailed explanation of how to use the HELP model, it is recommended that the model, user's guide, and engineering documentation be obtained from EPA and reviewed. This report will briefly discuss the inputs into and outputs provided from the 50 year run of the HELP model.

The HELP model layers are illustrated on Figure 1.0, which is taken from Diagram 7 of Tri-County Health Department Regulation I-96. The layers are described below and in the printout in the Appendix.

Layer 1 consists of the 4" topsoil layer, and is designated a by the user as a "vertical percolation layer", in model terminology. Material texture

10 was selected from the model's default soils menu, since it most closely represents topsoil in the Denver area. Selection of this default texture resulted in the indicated values for porosity, field capacity, wilting point, initial soil water content, and effective saturated hydraulic conductivity. The user may also input his/her own soils values, if desired.

Layer 2 consists of the sand media used in the ET bed, and is designated by the user as a "lateral drainage layer", in model terminology. The HELP default texture number 4 most closely represents the sand used in ET beds. A thickness of 24" was input, even though this layer averages 27" in depth. The user must also specify the amount of subsurface inflow into this layer. In this case, "subsurface inflow" is the yearly amount of septic tank influent entering into the bed. The subsurface inflow of 65 inches/year was calculated by multiplying the average daily flow (450 gallons) x 365 days/year = 164,250 gallons/year. This number was divided by 7.48 gallons/cubic foot, to obtain the volume in cubic feet (21,958). The volume in cubic feet was divided by the bed area (4000 square feet) and multiplied by 12 inches/foot, to obtain the subsurface inflow in inches (65).

The model offers the option of collecting or recirculating the "leachate" (subsurface inflow). In this case, "leachate" is actually septic tank effluent combined with precipitation infiltration, and is not collected, therefore, the user must specify "recirculate", in the model input. One-hundred percent of the leachate (65 inches/year) is recirculated from this layer into layer 3 (the native soils beneath the ET bed). The model requests the drainage length (6 feet was selected, since a six foot distance separates the influent piping).

As it did for layer 1, the model determines porosity, field capacity, wilting point, initial water, and saturated hydraulic conductivity for this default soil. These values are indicated in the printout.

Layer 3 consists of the native soil into which the bed is excavated, and is designated a "barrier layer" in model terminology. HELP default texture number 0 was selected, to represent a clay material. A thickness of 48 inches was selected, even though, in reality, this layer is much deeper. The values for porosity, field capacity, wilting point and initial soil water content are determined from the HELP model. The allowable soil absorption rate of 0.1 gallons/sqft/day was converted to (4.7 x 10 e-6 cm/sec) and input directly rather than using the MODEL's default value. One hundred percent of the "leachate" or septic tank effluent is recirculated into this layer from layer 2.

As indicated in the HELP printout for each layer, the model calculates an initial soil water content, by running a one year simulation. This value for layer 2 is used in the spreadsheet, and will be discussed in more detail later in this report.

General Design and Evaporative Zone Data:

The user input values consisted of surface slope (5%), area (bed size = 4000 square feet or 0.092 acres), vegetative cover (a fair stand of grass is assumed), a slope length of 25 feet, the percentage of area allowing runoff (100%), and an evaporative zone depth (28"). The slope length was selected assuming a 50 foot wide bed, with a center crown and a 5% slope away from the crown. The model then determines remaining parameters indicted in the HELP printout in the Appendix.

Evapotranspiration and Weather Data:

The default data were taken from the model for Denver Colorado, and the precipitation, temperature, and solar radiation were synthetically generated for 50 years by the model.

The model also accepts data from other sources (NOAA, Climedata, etc.), to be input.

HELP Model Output:

The model gives the following output <u>for all 50 years of the analysis:</u>

Under the title "EVAPOTRANSPIRATION AND WEATHER DATA", the model provides values for maximum leaf area index, start and end of growing season, average annual wind speed, average relative humidity values for all four quarters, normal mean monthly precipitation values, and mean monthly temperature values.

The section of model output, titled "MONTHLY TOTALS (IN INCHES) YEAR #" gives monthly precipitation, runoff, evapotranspiration, subsurface inflow into layer 2 (the sand media layer), amount of drainage collected from layer 2 and recirculated into layer 3, and percolation through layer 3.

The second portion of the model output, titled "MONTHLY SUMMARIES FOR DAILY HEADS (INCHES), consists of "average daily head on layer 3", along with the standard deviation. For year 1, the model indicates that "bed" would be continually ponded with approximately 6" of water.

The third section of HELP model output, titled "ANNUAL TOTALS FOR YEAR #, gives yearly summaries for each of the 50 years of the data given in the first section, in addition to a water balance accounting, indicating: Change in Water Storage, Soil Water at Start and End of Year, Snow Water at Start and End of Year, and the Annual Water Budget Balance.

Toward the end of the printout, the model gives the above indicated output in average values for the entire 50 years of the simulation, along with standard deviations. It is worthwhile noting that the average change in water storage is nearly zero. This indicates that the water in storage does not change from the beginning to the end of the year. This feature is incorporated into the spreadsheet calculations.

Data from the HELP Model for precipitation, runoff, evapotranspiration, and change in water storage are used in the water balance spreadsheet, as will be discussed later in this document. HELP output used in the spreadsheet are indicated with a star in the HELP printout.

The model also gives peak daily values for the 50 years. The peak head is 12.22 inches, indicating that the bed should still be able retain all water, without surfacing. The peak daily precipitation value, on the last page of the printout is used in Figures 4.1-4.3 of the spreadsheet.

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WATER BALANCE SPREADSHEET

The spreadsheet was developed utilizing Microsoft Excel, and is intended for use as a guideline for sizing evapotranspiration (ET) beds with the water balance method. **The spreadsheet was prepared using the water balance equation for each month: INITIAL WATER or WATER FROM PREVIOUS MONTH + WATER IN - WATER OUT = WATER IN STORAGE.**

As depicted in Figure 2.0, the HELP model is utilized to obtain monthly evapotranspiration, precipitation, runoff, and intitial soil water content.

In Figure 2A, NOAA evaporation and precipitation data were input directly into these spreadsheets, only for the purpose of comparing bed sizes evaluated with HELP ET values and NOAA pan evaporation values.

In Figures 2.1-2.3, 3.1-3.3, and 4.1-4.3, the HELP Model was utilized to obtain the following information used in the spreadsheet:

- monthly precipitation and evapotranspiration values
- amount of precipitation runoff
- void space within the bed (for sand media)
- initial soil water content

The information in the spreadsheets is described in detail below. The page numbers below refer to the page in the spreadsheet. The upper left corner headings of the spreadsheets in the Appendix indicate the number of bedrooms for the analysis, the upper middle headings indicate the precipitation, runoff, and evapotranspiration values used, and the upper right indicates the soil absorption rate. The lower left corner of the footings indicate the file name.

SPREADSHEET PAGE 1: USER INPUT PARAMETERS

The spreadsheet requires the user to input the following information:

1. Trial Bed Area (in square feet)

2. **Number of Bedrooms in the Home**

3. **Average Daily Flow per Bedroom (of septic tank effluent, in gallons):** The Guidelines and Regulation I-96 require 150 gallons per bedroom per day

4. **Allowable Soil Absorption Rate (in gallons/day/sq.ft) (from Table #10, Regulation I-96)**

5. **Monthly Precipitation Rate (in inches for Geographic Location of Bed)**

From HELP Model:

To estimate precipitation for spreadsheets in this document (Figures 2A, 2B, 2C, 2.1-2.3; 3.1-3.3; and 4.1-4.3), the default precipitation values in the HELP model for Denver, Colorado are used, together with the HELP model's synthetic weather generation coefficients, to simulate annual variations in precipitation. A 50 year simulation of precipitation was run using the HELP model. Average monthly precipitation values, in inches, obtained from the HELP model, were input into the spreadsheet.

The user is cautioned that variation in precipitation values between geographic areas within Colorado, and between wet and dry years and months needs to be considered. Because of this variation, the user is encouraged to use data which is most representative of the site, to run sensitivity analysis, or apply statistics, to assess the impact of using different precipitation or et values on the percent of bed storage utilized. Since the HELP default precipitation values are for only five years, the user should evaluate if that precipitation data is most appropriate.

If HELP is used to generate weather data, it provides standard deviations for the average values. Applying statistical probability, the user could calculate a confidence level that the precipitation value for that month would not be exceeded. The statistical approach will be discussed in more detail later in this document.

Direct Input of NOAA Data:
NOAA precipitation data could be input directly into the spreadsheet. A comparison between the HELP generated precipitation values and NOAA values indicates that the values are much more comparable than with evaporation/evapotranspiration values.

6. Runoff (amount of precipitation which runs off the ground surface, and does not infiltrate into the bed)

In the example spreadsheets, the runoff values obtained from the HELP model are input. HELP calculates runoff, based on several factors, such as ground slope, type of soil cover, length of slope, etc.

The spreadsheet calculates net infiltration by subtracting runoff from precipitation.

Runoff could also be estimated using other references (runoff coefficients from textbooks, urban drainage manuals, etc.), or runoff could be omitted for a more conservative design.

7. Monthly Evapotranspiration Rate (in inches/year) for Geographic Location of Bed

From the HELP Model:
In the spreadsheets shown as Figures 2.1-2.3, 3.1-3.3, 4.1-4.3, monthly evapotranspiration values are obtained from the HELP model, using default data for Denver, Colorado. A 50 year simulation was run, and the average monthly evapotranspiration values were calculated.

As previously illustrated in Table 1, evapotranspiration predicted by the HELP model is **not** equivalent to the pan or lake evaporation rates, and is significantly less that the lake evapotranspiration rate. For example, the HELP model predicts 29.6 inches of evapotranspiration, while the lake evaporation rate for the Denver area is 40 inches per year. The spreadsheets shown in the Appendix use the HELP model values.

Again, as with precipitation, the user is cautioned that evapotranspiration rates may vary significantly due to site specific micro-climates, and influences such as shading and whether the site is on a south or north facing slope.

Direct Input of NOAA Data:
In Figure 2A, NOAA evaporation data are input directly into the spreadsheets, only for comparison. Direct use of these values in the water balance spreadsheet is not recommended for design purposes.

8. Initial Water in Bed:
The initial water in the bed is expressed as: Volume of Water divided by Total Bed Volume (vol/vol). This value represents the **minimum** moisture content which can be achieved in the bed, recognizing that the sand within the bed will always retain a residual moisture content, even during the driest months, once the bed has been in operation. The value used in the spreadsheet is obtained from the HELP model, for layer 2 (ET Sand), and is equal to 0.2858 volume/volume. The HELP model initializes water content at steady state conditions within the bed, using the first year of climatological data. For a detailed explanation, refer to Section 3.6 of the HELP Model Engineering Documentation for Version 3. (1)

9. Total Bed Porosity:
Porosity is the volume of voids divided by the total volume of the bed and is taken from the HELP model as 0.437. In other words, 43.7% of the bed is available for storage of water, and the remaining 56.3% is occupied by solid soil particles. Figure 1.4, in the Appendix confirms that the pore volume from the HELP model is reasonable.

SPREADSHEET PAGE 1: OUTPUT

Percent Total Bed Storage Utilized:
This is the output which is used to evaluate if the bed is adequately sized. This output is depicted in Figure 2.0 (labeled "Final Output"). Values in excess of 100% would indicate that the bed is undersized, with surfacing of effluent and precipitation.

The values are shown on a month by month basis, on both this page and page 3 of the spreadsheet. They represent the percentage of total storage volume (porosity) occupied by water. For example, a value of 75% indicates that 75% of the available pore (void) space is occupied by water, while the remaining storage void space is occupied by air. Note that this value never drops below 65%, even during the driest month. This reflects that some residual soil water is always retained and that the bed never completely "dries out" under natural conditions.

SPREADSHEET PAGE 2: WATER AND EFFLUENT INTO AND OUT OF BED

This sheet accounts for water entering into, and leaving the bed. Water entering the bed comes from two sources: infiltration of precipitation (rainfall and snowmelt) and effluent from the septic tank. Water leaves the bed by evapotranspiration and absorption.

The information entered into the spreadsheet on page one is used to calculate precipitation and effluent amounts shown on this page in units of inches, gallons and cubic feet.

WATER INTO BED

Monthly Average Precipitation Infiltration Into Bed:
Values for "Monthly Average Precipitation Infiltration Into the Bed" are calculated by subtracting runoff from precipitation, and are expressed in units of inches, gallons and cubic feet. Gallons and cubic feet are calculated as follows:

Gallons: (inches of infiltration/12) x bed surface area (sq. ft.) x 7.48 gallons/cubic foot
Cubic Feet: (inches of infiltration/12) x bed surface area (sq.ft.)

Monthly Average Effluent Flow Into Bed:
"Average Monthly Effluent Into the Bed" is based on an average of 75 gallons/person/day x 2 persons per bedroom x # bedrooms. Average flow is allowed under the Guidelines and Regulation I-96. The effluent values are expressed as inches, gallons, and cubic feet, and are calculated as follows:

Inches: (((Flow (gallons/day) x # days in month))/7.48 gallons/cubic foot))/bed area (square feet)))x 12 inches/foot.

Gallons: Flow (gallons/day) x # days in month

Cubic Feet: Flow (gallons/day) x # days in month/7.48 gallons/cubic foot

WATER OUT OF BED

Water is removed from the bed by absorption of effluent into the soils and evapotranspiration.

Monthly Soil Absorption Rate:
Tri-County Health Department's Regulation I-96 allows maximum values of absorption as indicated in Table #10, as follows:

Maximum Percolation Rate (minutes per inch)	Maximum Absorption Rate (gal/sqft/day)
61-90	0.20
91-120	0.15
121+	0.10

Engineering judgement should also be applied in selecting the value, since the actual field absorption rate may be less than the maximum allowed. The allowable absorption value is input by the user on page 1, and is calculated in units of inches, gallons, and cubic feet, on page 2, as follows:

Inches: ((absorption rate (gal/sqft/day) x # days in month)/7.48 gallons/cubic foot)x 12 inches/foot

Gallons: absorption rate (gal/sqft/day) x # days in month x bed area (sq.ft)

Cubic Feet: (gallons/month)/7.48 gallons/cubic foot

Monthly NOAA Evaporation Rate (Figure 2A Only):
Monthly pan evaporation rates are taken from NOAA data for Denver, Colorado.

Monthly Evapotranspiration Rate (Figures 2.1-2.3, 3.1-3.3 and 4.1-4.3):
The monthly ET rate values from the HELP Model, input by the user into the spreadsheet on page one, are used on this page to calculate evapotranspiration rates, expressed in inches, gallons, and cubic feet as described above (for absorption).

SPREADSHEET PAGE 3: WATER STORAGE IN BED AT END OF MONTH

The output on this page described below is calculated from the previous two sheets of the spreadsheet.

Total Bed Volume (in cubic feet):
Bed Area (sq.ft.) x Average Bed Depth (ft). Based on Diagram 7 in Regulation I-96, an average bed depth of 27" is utilized.

Total Storage in Bed:
This represents the total storage in the bed **if no water were present, and all void space is occupied only with air.** This is illustrated in Figure 1.2, and is labeled "Void".

Vol/Vol = this is the porosity of the bed, from page 1.
Inches= Average Bed Depth (27") x porosity (.437)
Gallons= Total Bed Volume x porosity (.437) x 7.48 gals/cubic foot
Cubic Feet= Total Bed Volume (cubic feet) x porosity (.437)

Initial Water Content Within Bed:
This value is expressed in terms of Volume/Volume, gallons, cubic feet, and inches, from the value input on page one, which was obtained from the HELP model. This value may also be considered the minimum moisture content the bed ever reaches. This water is illustrated in Figure 1.3, and is indicated by "Water" on the drawing.

Volume/Volume (from HELP Model): This value is dimensionless. It could be cubic feet/cubic feet, cubic centimeter/cubic centimeter, gallon/gallon, etc. It is the volume of water divided by the total volume.

Gallons: Bed Total Volume (cubic feet) x Initial Water Content (0.2858 vol/vol) x 7.48 gallons/cubic foot

Cubic Feet: Bed Total Volume x Initial Water Content (0.2858 vol/vol)

Inches: Bed Depth (inches) x Initial Water Content (0.2858 vol/vol)

The "% Total Bed Storage" column in the spreadsheets represents the percentage of total storage volume occupied by water. At the initial water content value of 0.2858 vol/vol, it would be calculated as: % Total = (0.2858/0.437) x 100 = 65%.

Total Available Storage in Bed:
The represents the amount of storage within the bed available for storage of water, in units of inches, gallons, and cubic feet, after steady state moisture content conditions are reached. It is the volume of total void space minus the initial or steady state moisture content. The available storage would be: 0.437 vol/vol (total void space) - 0.2858 (water in bed) = 0.1512 vol/vol. This available storage is shown in Figure 1.3 as "Void for Storage", in the drawing of the cube. "Total available storage" is not used in the calculation of percent total storage utilized at the end of month. It is only included to illustrate that only a portion of the void space in the bed is available for storing effluent and precipitation infiltration.

The values on the bottom half of this page under the title **"WATER STORAGE IN BED AT END OF MONTH"** are calculated from the data on pages 1 and 2 using the following water balance equation:

WATER IN (precipitation infiltration + effluent) - WATER OUT (absorption + evapotranspiration) + INITIAL WATER OR WATER REMAINING (STORED) FROM PREVIOUS MONTH = WATER STORED IN BED (CURRENT MONTH)

For initial conditions, the soil water content is input in the formula, and is 0.2858 vol/vol. At that water content, 65% of the available storage (total void) within the bed is utilized. This value is obtained from the HELP Model, for layer 2 (indicated in HELP model printout with a star) which assumes the bed has operated for one year, and has achieved "steady-state" conditions.

The columns shown with bold borders, titled "Actual Storage" have been adjusted, since the spreadsheet does not allow water content in the bed to drop below the initial moisture content (.2858 vol/vol). Since the HELP Model indicates that water storage does not change from beginning to end of the year, the spreadsheet will not allow water (and percent of total storage) to drop below the initial moisture content (and percent of total storage), even during months where "water out" exceeds "water in". The spreadsheet contains a conditional formula which selects either the storage in the bed calculated with the water balance formula (INITIAL WATER (or WATER FROM PREVIOUS MONTH) + WATER IN - WATER OUT = WATER IN STORAGE), or the initial water content value, whichever value is greater.

The values obtained from the water balance equation above are divided by the total storage in the bed and multiplied by 100 to obtain the values in the far right column titled "Percent Total Storage Utilized". This column is duplicated on page 1 of the spreadsheet, to allow the user to evaluate the trial bed sizes without paging down in the spreadsheet.

RESULTS OF SPREADSHEET ANALYSIS

Figure 2A
Using Monthly Precipitation and Evaporation Values from NOAA Data

The NOAA evaporation data are used in the spreadsheet only to compare the difference between bed sizes from using pan evaporation values and HELP Model generated evapotranspiration values. Figure 2A shows the results of evaluating trial bed sizes using the evaporation and precipitation values from NOAA data.

As indicated in Figure 2A, a loading rate of 0.10, a trial bed size of only 3200 square feet resulted in 70% of the total bed storage capacity being utilized in December, allowing a 30% "margin of safety". The NOAA data are not recommended for evaluating bed sizes with the water balance spreadsheet, since they overestimate actual evapotranspiration.

Bed sizes were not evaluated using NOAA data for loading rates of 0.15 and 0.20 gal/sqft/day.

Figures 2.1-2.3
Using Average Precipitation, Runoff, and Evapotranspiration Values Calculated by HELP Model

Three trial bed sizes were evaluated using the maximum allowable design soil absorption rates from Tri-County Health Department's Regulation I-96, of 0.1, 0.15, and 0.20 gallons per square foot per day, and average flow for a three bedroom home. Copies of the analysis are included in the Appendix (Figures 2.1, 2.2, and 2.3).

The first analysis (Figure 2.1) using ET, precipitation, and runoff values from the HELP Model, uses a trial bed area of 4300 square feet, a soil absorption rate of 0.1 gallons/square foot/day, and average monthly values for precipitation, runoff and evapotranspiration obtained from the HELP model for Denver, Colorado. The output indicates that the maximum bed storage occurs in April and May, with 75% of the total bed storage utilized, providing a 25% "margin of safety". The initial thought would be to reduce the bed size such that 100% of total bed storage is utilized, however, the trial bed should not be considered oversized, since it is necessary to provide an acceptable margin of safety to allow for variations and uncertainty in the input parameters.

As shown in Figure 2.2, selection of a trial bed area of 2900 square feet with the loading rate of 0.15 gal/sqft/day resulted in a maximum percent of bed storage of 76% in April and May, allowing a 24% "margin of safety", to allow for variations in precipitation, runoff, and evapotranspiration.

As shown in Figure 2.3, selection of a trial bed area of 2200 square feet with a loading rate of 0.20 gal/sqft/day resulted in a maximum percent of available bed storage of 75% in April and May, providing a 25% "margin of safety".

Figures 3.1-3.3

Using 99% Confidence Levels from HELP Model

The HELP model output gives standard deviations for precipitation, runoff, and evapotranspiration, in the final pages of the printout (heading: AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1-50). Using principles of statistics, the user can utilize the standard deviations to calculate a confidence interval for the data utilized and for the bed area.

The standard deviations are used to calculate the upper limit for precipitation and runoff for a 99% confidence value, and a lower confidence limit for evapotranspiration. A lower limit is utilized for evapotranspiration, since ET would be lowest in periods of high precipitation (low solar radiation and temperature).

This means that we have a 99% level of confidence that the monthly precipitation and runoff values will not be exceeded. We also have a 99% level of confidence that the ET value will not be less than used. From a design standpoint, this is considered a very conservative approach. Consequently, it could be said that we have a 99% confidence level that bed sizes using these values are adequate.

Figure 3.0, titled "**STATISTICAL ANALYSIS OF PRECIPITATION, RUNOFF AND EVAPOTRANSPIRATION**" indicates 99% upper confidence limit values for precipitation and runoff, and a 99% lower confidence limit values for evapotranspiration.

The 99% Confidence Level values for precipitation, runoff and evapotranspiration are input into the spreadsheet (Figures 3.1-3.3), on page 1. The spreadsheet calculates net infiltration by subtracting runoff from precipitation. Trial bed sizes are evaluated for absorption values of 0.1, 0.15, and 0.20 gal/sqft/day, and the results are discussed below, with the results shown in Figures 3.1, 3.2, and 3.3.

As shown in Figure 3.1, selection of a 4400 square foot bed area, with a soil absorption rate of 0.1 gal/sqft/day, resulted in a maximum percent storage utilized of 90% in May.

As shown in Figure 3.2, selection of a 2950 square foot bed area, with a soils absorption rate of 0.15 gal/sqft/day resulted in a maximum percent storage utilized of 91% in May.

As shown in Figure 3.3, selection of a 2250 square foot bed area, with a soils absorption rate of 0.20 gal/sqft/day resulted in a maximum percent storage utilized of 86% in May.

A higher percentage of total storage can be utilized, with higher confidence in the input data.

Figures 4.1-4.3
Using 99% Confidence Level Values and Peak Daily Precipitation Value from HELP Model

The peak daily precipitation value must be considered, if adequate storage is to be provided to accommodate the peak storm event.

The HELP model indicates that the peak daily precipitation value is 2.49". A peak runoff of 1.143 inches corresponds to this storm event, resulting in a net daily peak infiltration into the bed of 1.35 inches. A daily peak infiltration of 1.35 inches would represent 11.5% (1.35"/11.72") of the total storage capacity in the bed.

As indicated in Figure 4.1, including the peak daily precipitation into the "worst case" month (in this case May), would require a 4700 square foot bed, based on an allowable absorption rate of 0.10 gal/sq.ft./day, and utilizing 100% of the total bed storage capacity.

Figure 4.2 indicates that a bed size of 3100 square feet would be necessary, with an allowable soils absorption rate of 0.15 gal/sqft/day, utilizing 99% of the total storage capacity in May.

Figure 4.3 indicates that a bed size of 2300 square feet would be necessary, with an allowable soils absorption rate of 0.20 gal/sqft/day, utilizing 100% of the total storage capacity in May.

All of the bed storage can be used since their is a high level of confidence in the input data.

COMPARISON OF ET BED SIZES USING AVERAGE NOAA VALUES WITH RESERVE, AVERAGE HELP MODEL VALUES WITH RESERVE, 99% UPPER CONFIDENCE LIMIT HELP VALUES WITH SMALL RESERVE, AND 99% CONFIDENCE LIMIT VALUES WITH PEAK DAILY PRECIPITATION VALUE AND NO RESERVE IN "WORST CASE MONTH"

Figure 5.0 in the Appendix summarizes the bed sizes obtained from each of methods above, for the allowable soil absorption rates of 0.10, 0.15, and 0.20 gal/sqft/day, for a three bedroom home and using the precipitation, runoff, and evapotranspiration values described. NOAA evaporation and precipitation values were only used to evaluate a trial bed size with an allowable soil absorption rate of 0.10 gal/sqft/day.

Comparing the values for an absorption rate of 0.10 gal/sq.ft./day indicates a 1500 square foot difference using average NOAA evaporation values with a 30% reserve and 99% confidence limit values with peak flow.

Comparing values for an absorption rate of 0.15 gal/sq.ft./day indicates a 200 square foot difference between average values and 99% level w/ Peak Daily precipitation.

Comparing values for an absorption rate of 0.20 gal/sq.ft./day, indicates a 100 square foot difference between average values and the 99% level w/ Peak Daily Precipitation.

Based on the spreadsheet analysis results summarized in Figure 5.0, it appears that the spreadsheet model is less sensitive to differences in precipitation and ET values where the soil absorption rates are greater.

USE OF HELP MODEL TO SIZE ET BEDS

It is worthwhile to ask the question: Can the HELP Model be used all by itself, to size ET beds, as an alternative to the spreadsheet?

The HELP model indicates that a 4000 square foot bed is adequate, for all conditions anticipated. The spreadsheet indicates that a 4300 square foot bed is acceptable for average conditions, with a 25% "safety factor". If a 99% confidence level is desired, a 4400 square foot bed is necessary. It a 99% confidence level and peak flow is included in the "worst case" month, a 4700 square foot bed is necessary. If the HELP model says a 4000 square foot bed is adequate, why use the larger beds from the spreadsheet?

To evaluate the sensitivity of the HELP model for bed sizes, HELP was run with bed sizes of 4000 square feet (0.092 acres, subsurface inflow of 65 inches/year); 4600 square feet (0.106 acres; subsurface inflow of 58 inches/year); and 5900 square feet (0.135 acres; subsurface inflow of 45 inches/year). The subsurface inflow values represent the septic tank effluent of 450 gallons/day, spread over the entire bed area.

The model output for average daily heads for the three beds for which the HELP model was run are shown in Table 2.

TABLE 2
MONTHLY AVERAGE DAILY HEADS FOR INDICATED BED SIZE
(in inches)

Month	4000 sq.ft	4600 sq.ft.	5900 sq.ft.
January	5.30	4.93	4.20
February	5.48	5.09	4.36
March	6.15	5.72	4.88
April	6.35	5.88	5.01
May	6.29	4.95	4.53
June	5.85	5.39	4.53
July	5.33	4.86	3.78
August	6.01	5.54	4.54
September	5.99	5.51	4.63
October	6.05	5.58	4.67
November	6.29	5.82	4.93
December	5.86	5.42	4.58

As Table 2 above indicates, the average daily heads decrease as the bed sizes increase, indicating that the model is somewhat sensitive to the changes in bed size. The smaller heads reflect that if the bed size and total storage are increased, more reserve storage is provided. The peak daily heads also decrease with increasing bed size. The 4000 square foot bed resulted in a peak head of 12.22 in., the 4600 sq.ft. bed resulted in a peak head of 11.52 in., and the 5900 square foot bed resulted in a peak head of 10.96 in.

The author believes that the HELP model precipitation, runoff, and et values are very useful to input into the spreadsheet and that the HELP model results provide a worthwhile check on the spreadsheet results, however, uncertainty remains with the HELP model in comparing different bed sizes. Using a 3000 square foot bed with the HELP model, **the HELP Model does not predict bed failure, however, the spreadsheet predicts that a 3800 square foot bed would fail (exceed storage capacity) during the month of May.**

Since the HELP model was developed for landfills, which are typically 10-100 times larger than ET beds, it may not be sufficiently "scaled" for use in sizing ET beds. It is also possible that the two dimensional aspect of the HELP Model makes it less applicable for determining bed areas than for evaluating water movement in a vertical dimension.

The HELP model is therefore not recommended for designing ET beds by itself, although the monthly values for ET, precipitation and runoff are applicable and are used in the spreadsheet analysis.

The methodology and equations used in the HELP model could be adapted to create a model which is scaled for ET beds, however, that is beyond the scope of this document.

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EVALUATION OF EXISTING ET BEDS

Under Tri-County Health Department's Regulation I-88, ET beds were sized using the following formula:

Area= (Design Flow x 237)/Lake Evaporation Rate (inches/year)

Design flow was 225 gallons per bedroom, and the 237 value was used as a conversion factor. This factor was found to be mathematically incorrect, and should have been 586. Use of the formula with the 237 conversion factor produced an ET rate of 0.17 gals/square foot/day, where the corrected formula with the 586 factor results in an ET rate of 0.07 gallons/day/square foot.

The formula with the 237 conversion factor resulted in the ET bed sizes shown in Table 3 below.

TABLE 3

Number of Bedrooms	Area (square feet)
2	2647
3	3971
4	5294

Reductions in the above areas were allowed for percolation rates between 61 and 90 minutes per inch, based on a credit for absorption.

In the spring of 1995, Tri-County Health Department field staff conducted a field survey of existing ET beds, to assess whether beds sized under the old formula were functioning properly. The spring of 1995 experienced abnormally high precipitation, consequently, the probability of a bed failure was higher, due to increased infiltration of precipitation. A total of 37 beds were inspected by field staff. Of those, only four were suspected to be failing, as evidenced by surfacing effluent. It was not possible to fully determine the cause of the failure of those beds. In addition, many of the beds did not have observation pipes, so the level of ponding within the beds could not be evaluated.

In addition to the survey, the Department is not aware of significant failure rates of ET beds, based on repair permits issued.

Since the water balance spreadsheet indicates that ET beds sized under the old formula are too small, it could be assumed that actual wastewater flows are less than design flows, or that soil absorption rates used in the spreadsheets are overly conservative, or a combination of both. It is also possible that periodic temporary failure of ET beds may be occurring during "wet periods", and that surfacing effluent may be visually indistinguishable from ponded precipitation runoff.

Figure 5.0 indicates that all sizes resulting from using HELP model evapotranspiration values in the water balance spreadsheet are larger than required under the old formula.

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REGULATORY ACCEPTANCE OF DESIGN

Use of NOAA evaporation rates are not recommended for use in the water balance spreadsheet, since they do not accurately estimate actual evapotranspiration. The bed size determined with NOAA evaporation rates is significantly smaller than currently operating ET beds, and is considered inadequately sized.

The above discussion presents three acceptable approaches to design using the water balance spreadsheet, beginning with the least conservative, and moving to the most conservative:

1) Design for average precipitation, runoff, and evapotranspiration values derived from the HELP model, but provide a "reserve capacity" of approximately 25% for the "worst case" months (typically April and May).

If average precipitation, runoff, and evapotranspiration values are used, it is recommended that all ET beds be sized such that no more than 75% of the available storage within the bed is utilized in the "worst-case" month(s), to allow for annual and monthly variations in precipitation, and evapotranspiration. An unusually wet month or year may result in the amount of available bed storage being exceeded, if sufficient "reserve space" is not provided.

2) Design for upper 99% confidence level values for precipitation and runoff, and lower 99% confidence level values for evapotranspiration and provide less (approximately 9%-14%) reserve capacity.

3) Design for upper 99% confidence values for precipitation and runoff, and lower 99% confidence values for evapotranspiration, and include peak daily flow in the "worst case" month, and utilize 100% of total bed storage capacity.

If 99% confidence level values are used, in conjunction with the peak daily flow in the worst case month, 100% of the bed capacity can be utilized.

The cost savings resulting from a less conservative design should be evaluated against the consequences of a bed failure, even if failure is temporary. In addition, it is recommended that the engineer consider how applicable the data are to the site where the bed was located.

The engineer must assess the quality of the data and determine which precipitation, runoff and ET values to use: average values from HELP model with "reserve capacity in "worst case" month(s); 99% confidence levels from HELP Model, with lesser reserve, or 99% confidence levels from HELP Model, with peak flow in the "worst case" month, based on professional judgement and experience.

The level of confidence in the data for the specific site should be carefully considered in determining how much "margin of safety" to provide in the form of percent of total storage utilized. Where their is less certainty in the data, greater reserve storage capacity should be provided in the bed. The additional cost associated with a more conservative design approach may more than offset the potential for a short term failure of the bed.

The spreadsheets can be provided, upon request, provided the user has the appropriate hardware and software (Microsoft Excel) to run it successfully, and sends a blank disc to:

Warren Brown
Tri-County Health Department
7000 E. Belleview
Suite 301
Englewood, Colorado 80111-1628

The file name for each of the spreadsheets (Figures 2A, 2.1-2.3, 3.1-3.3, and 4.1-4.3) is indicated in the lower left corner of each spreadsheet.

DISCLAIMER

Neither the Tri-County Health Department nor any of its agents or employees undertake or assume any liability to the owner of the property, design engineer, or system installation contractor, in the event of failure of a system sized using this guidance manual and the water balance spreadsheet. This information should only be used as a guide for the water balance methodology. Good engineering judgement is essential is selecting the various parameters which determine the system size.

REFERENCES

1. The Hydrologic Evaluation of Landfill Performance (HELP) Model, U.S. Environmental Protection Agency, Office of Research and Development, Washington DC 20460, EPA/600/R-94/168a, September 1994.