Visual HELP Laboratory Exercise: Recharge

Estimating Groundwater Recharge from Precipitation Using the Water Balance Method

Learning Objectives

After completion of this exercise you should be able to…

- Apply Visual HELP to obtain an estimate of a groundwater recharge rate from precipitation through the unsaturated zone;
- Understand the basic principals and limitations of the water balance method for estimating recharge from precipitation;
- Apply some of the many useful features of Visual HELP and the Weather Generator utility to actual projects.

Introduction

Visual HELP can be used to calculate a groundwater recharge rate from precipitation (rain or snow, or both) under the influence of site-specific soil properties, solar radiation, air temperature, wind speed, and vegetative properties. The HELP model (Schroeder, et al., 1994) predicts an infiltration rate under quasi two-dimensional influences through one or more uniform soil layers. Application of the HELP model (Schroeder, et al., 1994) has been done by contemporary groundwater practitioners to substantiate values of net recharge from precipitation obtained from historical studies for use in groundwater flow and contaminant transport models (see Abraham, B., et al., USAE Waterways Experimental Station, 1998).

In this exercise you will use the HELP model (Schroeder, et al., 1994) in Visual HELP to calculate the potential net recharge to groundwater from precipitation under site-specific soil, vegetative, and climatic conditions for a fictitious site near San Francisco, California using the water balance method. The water balance method calculates potential net recharge as a residual of all other water balance components and is expressed as:

$$R = P - D - ET_a - DW \qquad (1)$$

where,

R is potential net recharge, P is precipitation, D is net runoff, ET_a is actual evapotranspiration, and ΔW is the change in soil water storage.

Limitations of the Water Balance Method

In arid and semi-arid regions application of the water balance method is more difficult to apply than in humid regions because precipitation in these regions is only slightly larger than evapotranspiration. Therefore, small measurement errors in either of these two components of the water balance equation can cause large errors in recharge rate estimates (Simmers, I., et al., 1998; Lerner, D. et al., 1990). Care should therefore be taken when applying the water balance method in water scarce regions, and should be

used to calculate recharge events for one- to ten-day intervals to detect ephemeral recharge events common to these regions.

Note: All theoretical parts are italicized.

Terms and Notations

For this tutorial, the following terms and notations may be used:

type	- type in the given word or value
☞ , select	- click the left mouse button where indicated
√	- press the <Tab> key
↵	- press the <Enter> key
+	- click the left mouse button where indicated
☞☞	- double-click the left mouse button where indicated

The **bold faced type** indicates menu or window items to click or values to type in.

[….**]** denotes a button to click, either in a window, or in the side or bottom menu bars.

Background Information

Based on laboratory analysis of numerous soil samples collected at the site from split spoon and Shelby tube sampling, test pit soil profile descriptions, and a comprehensive vegetation survey, the following characterization of the unsaturated soil profile and vegetative cover was made:

1. The unsaturated zone exists to a depth of 10 feet, where the water table is encountered;
2. The ground surface is covered with an excellent stand of mature grass;
3. The root zone extends to a depth a 12 inches;
4. The soil is classified as a fine sandy loam;
5. Surface slope is 12 percent;
6. Leaf area index is 4;
7. Total Porosity: 0.48 (vol/vol)
8. Field Capacity: 0.25 (vol/vol)
9. Wilting point: 012 (vol/vol)
10. Initial soil water content: 0.28 (vol/vol)
11. Saturated hydraulic conductivity: 5.0×10^{-4} (cm/sec)

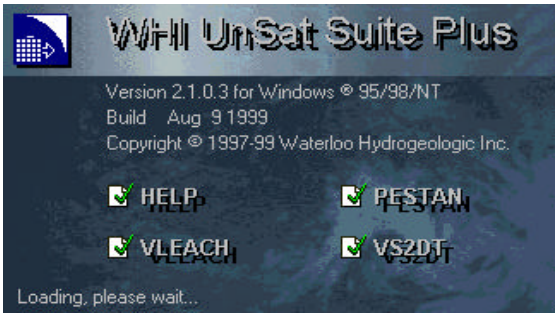
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Starting Visual HELP

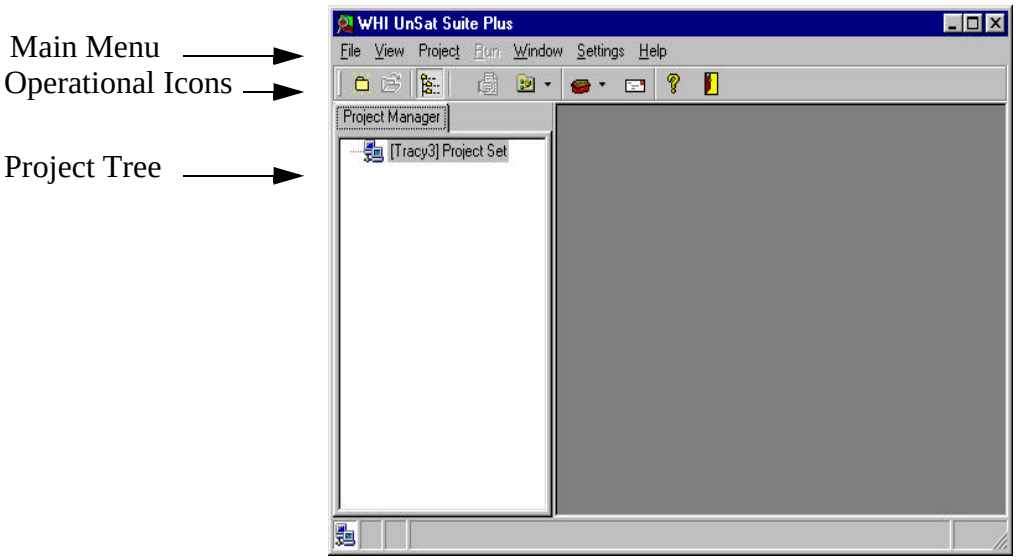
Visual HELP is a component of WHI UnSat Suite Plus package. To start WHI UnSat Suite Plus, click the following icon on your desktop.



An introductory screen will be displayed when you open WHI UnSat Suite



After the program is loaded, the main WHI UnSat Suite Plus window will appear on your display:



The WHI UnSat Suite Plus interface structure has been designed to help you navigate through the program with ease. The main menu is located at the top, similar to our other programs. The operational icons are located directly below the main menu items to allow quick access to additional options. The Project Tree View is located in the left part of the screen and shows the various ongoing projects, and their specific structure.

Creating a New Project

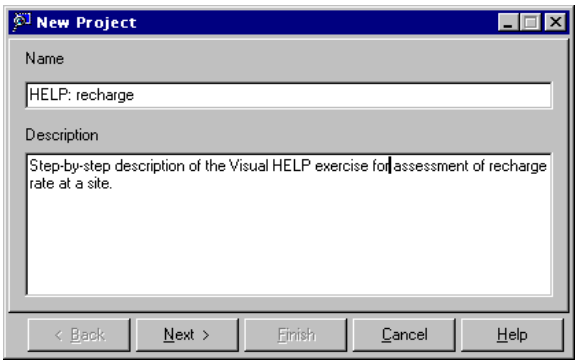
To create a new project, go the the **File Menu**,

☞ **New Project**, the **New Project** dialog box will open.

The **New Project** wizard will guide you through the steps required to setup a new Visual HELP project.

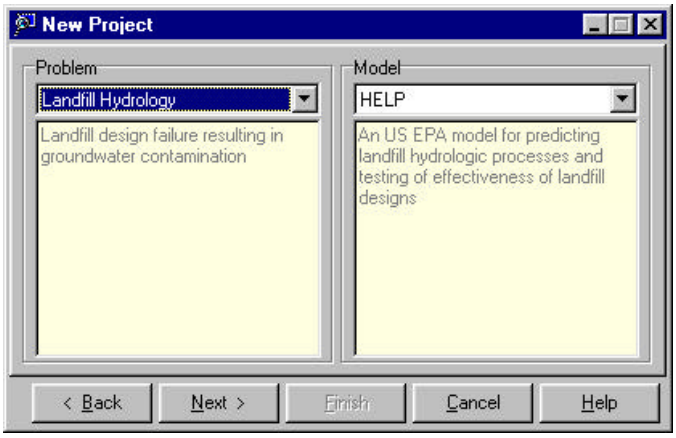
In the **Name** box type: **HELP: recharge**.

In the Description box type: **Step-by-step description of the Visual HELP exercise for assessment of recharge rate at a site.**



☞ **[Next],** to continue with your project setup. A **Problem/Model** dialog window will appear. This allows you to select which type of problem you are working on.

☞ **[Problem]** dropdown menu, select **Landfill Hydrology** from the drop down list. The problem list displays all the problem classes available with the WHI UnSat Suite Plus. Also notice that Visual HELP automatically recognizes the appropriate Problem class that should be used with the select Problem type.



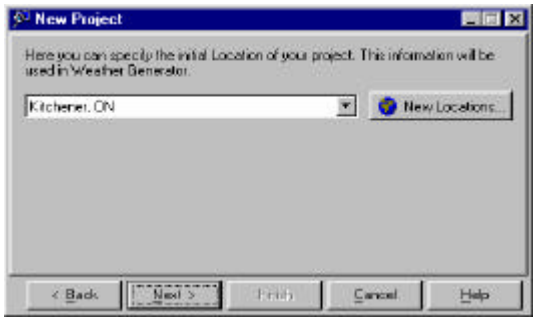
☞ **[Next]**

Once completed, the site location must be defined.

Selecting the Location

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We will now select the location of our project using the GIS - WHI Locator. The following dialog box should already appear on your screen.



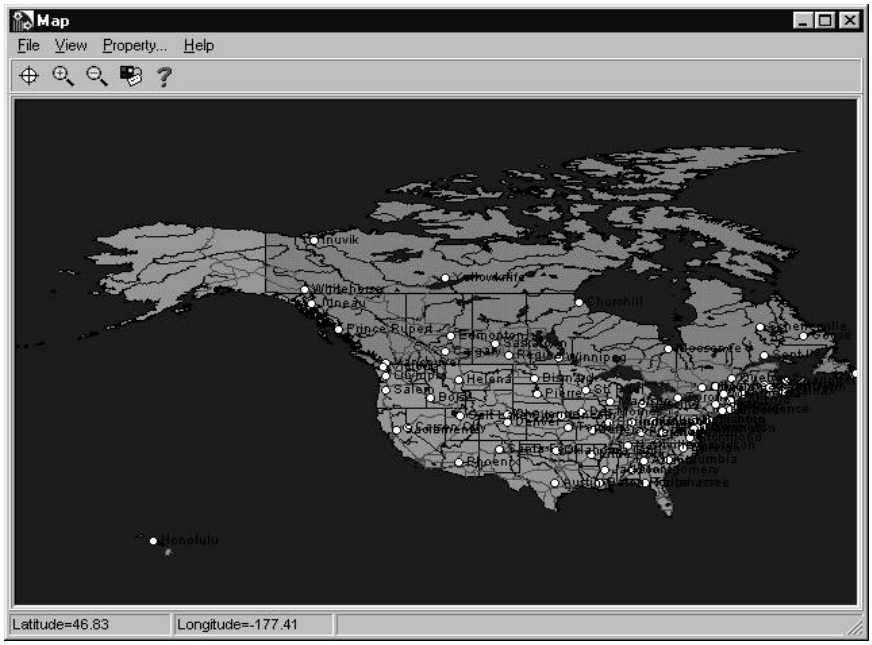
At this stage, the location list will only contain Kitchener, ON and Buffalo, NY by default. To add a new location,

☞ **[New Locations...]**

The following **Location Settings** dialog box will appear.



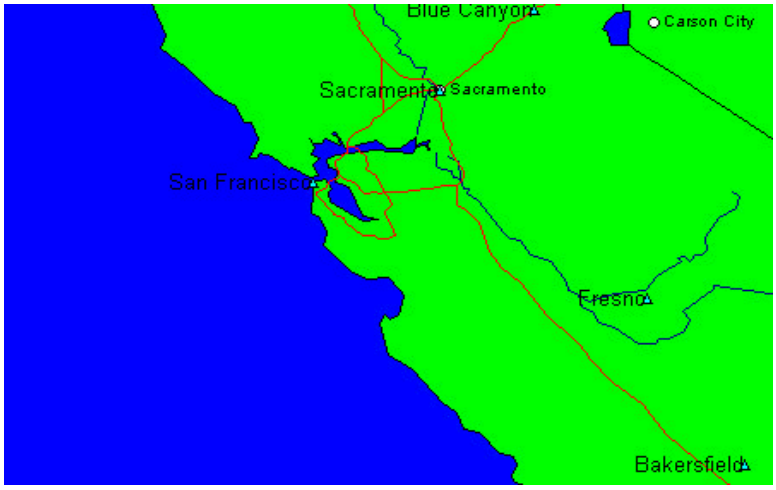
☞ **[Select Location..]** button**,** to enable the Site Locator, developed by WHI. As shown below, a map of USA, Canada, and Mexico appears on your display:.



Now lets select San Francisco as your site location.

☞  , to zoom into our location.

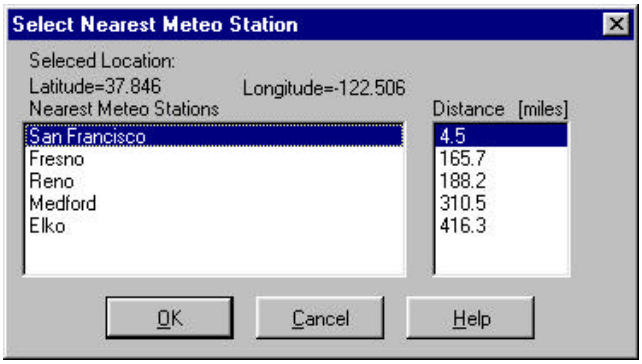
Move the mouse to the right of the region where the landfill project is located (the West Coast). The coordinates, seen in the bottom left of the screen, should read approximately Latitude: 41, Longitude:-127. Press the left mouse button and stretch a zoom rectangle to the bottom and right, release the button (approximate Latitude: 33, Longitude:-115). After one or two zooms, figure below should resemble your screen.



Next you will select San Francisco to set the longitude and latitude of the project location.

☞  , to activate the crosshairs.

Move the crosshair to the spot on the map where San Francisco is located and click to the north of it with the left mouse button. The dialog box showing the five nearest weather stations, including distance will appear.



Note: If you click directly on the city, it location will be forwarded to the database automatically. No nearest stations will show up.

In the "Select Nearest Meteo Station" dialog box,

☞ **[San Francisco],** as the nearest weather station.

☞ **[OK]**

The **Location Settings** dialog box will show the selected weather stations and coordinates of the location you have selected.

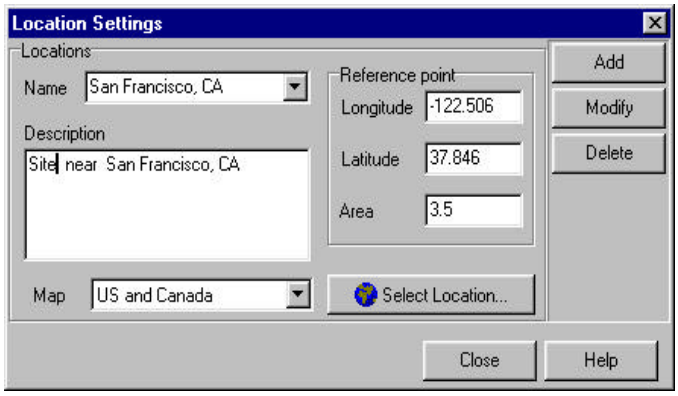
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Type: San Francisco, CA in the **Name** box.

Type: Site near San Francisco, in the **Description** text box.

Type: 1 , in the landfill area text box.

Finally, the **Location Settings** dialog box should appear as follows.



☞ **[Add],** to add the new location to the database.

☞ **[Close]**

While back in the **New Project**, select **San Francisco, CA** from the drop-down list.

☞ **[Next]**

Selecting Units

The next step is to define the units. This is completed in the "Select Input/Output Unit Templates" dialog box which allows you to define the units for both input and output. In addition, you may select the units used for the Weather Generator data and original DOS HELP output.

The Visual HELP Unit Converter was developed to maximize the flexibility for data input and output unit conversion. To show you the range of possibilities, just view the list of available units for hydraulic conductivity:



For this demo exercise we will specify that all input units will be in **Customary**, and output will be in **Customary (in)** units. The difference between two unit templates is that Length in **Customary** template is set in feet while in **Customary (in)** it is set in inches.

From the **Input** drop-down list,

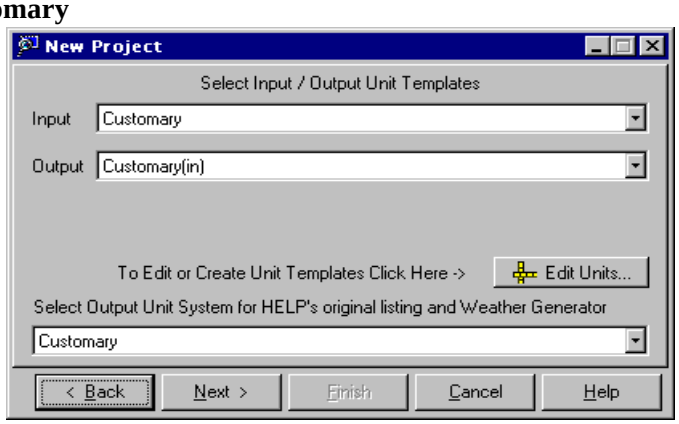
☞ **Customary**

From the **Output** drop-down list

☞ **Customary (in)**

From the **Select Output Unit System for original listing and Weather Generator** list box,

☞ **Customary**



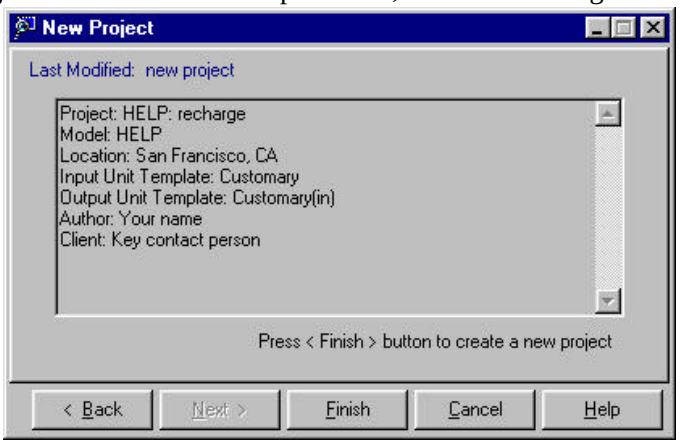
☞ **[Next]**

Assigning Authors and Clients

Visual HELP allows you to create and maintain your own database of project Authors and Clients for use in future projects. For this exercise we will use the default settings.

☞ **[Next]**

All the project information will be presented, as seen in the figure below.



☞ **[Finish]** to save the information as a project in the database and add it to the project tree.

After the project settings were specified, the **New Profile Wizard** will open.

Creating the Soil Profile

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The **New Profile Wizard**, which appears after you finish creating a project, is shown below:



In this dialog box you may select an already existing profile template or you can build a profile 'from scratch'. In this demonstration exercise we will use the later option.

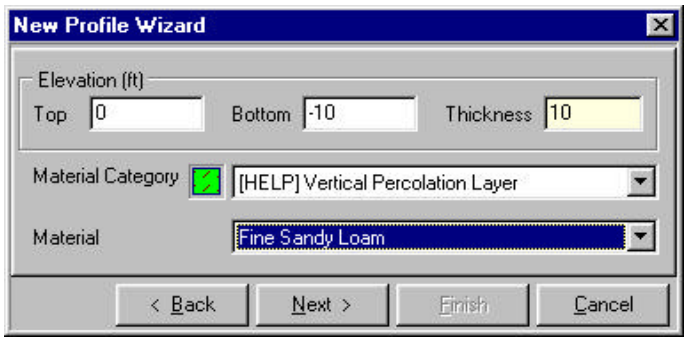
☞ **[create new profile]**

☞ **[Next]**

The dialog box with default profile parameters will appear. In this dialog box you may assign the parameters of the simulated profile. In your case the default profile thickness matches your profile characteristic.

☞ the drop-down arrow in the **Material** drop-down list box.

Select: **fine sandy loam**. In result of editing the **New Profile Wizard** window will look as follows:



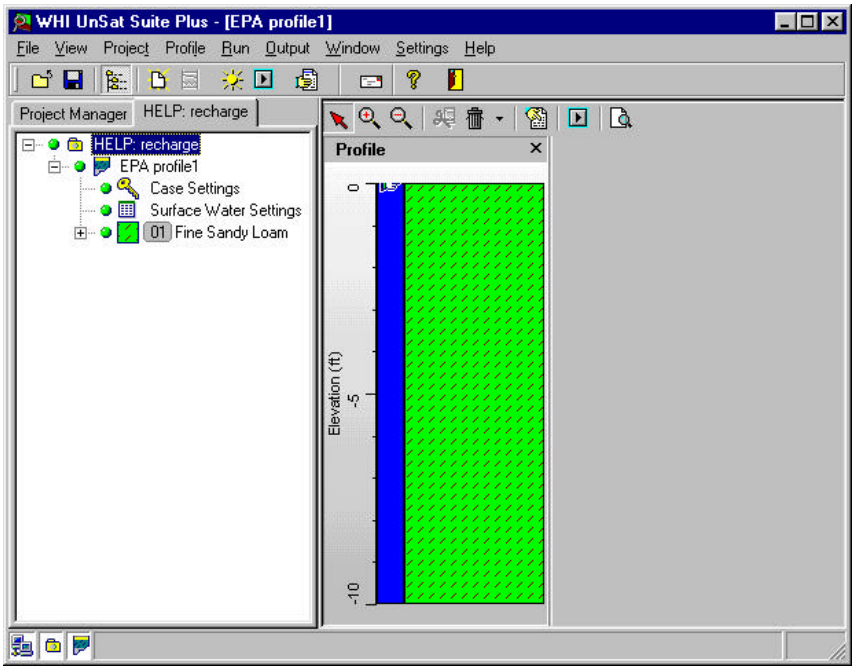
☞ **[Next]**

All the profile information will be presented:



☞ **[Finish]** to load the profile.

The new project details will be added to the project tree. This concludes creating a new project using Visual HELP. The following picture will appear on your display:



Editing Layer Parameters

To edit parameters of the Fine Sandy Loam layer,

☞ ☞ **Fine Sandy Loam,** in the Project Tree.

The **Profile Material Properties** dialogue box will appear. In this dialogue box, you can view and edit information about the layer including:

category, material texture, slope, top or bottom elevation, and thickness.

Under **Layer Specific**,

☞ **Slope** option button to enable surface runoff simulation.

Under **Layer Top**,

In the **Surface Slope (%)** text box:

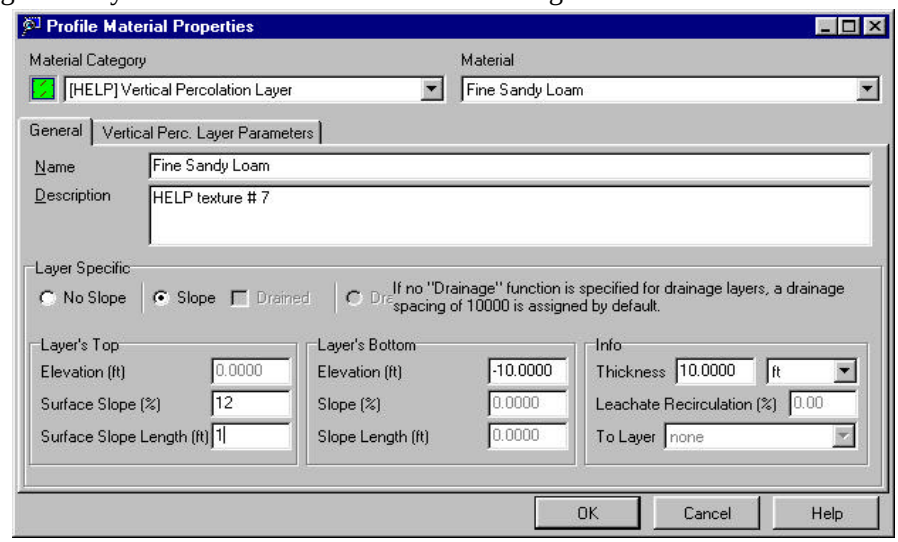
type: **12**

In the **Surface Slope Length (ft)** text box:

type: **1** (to set unit length of slope for this exercise)

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Finally, the dialog box on your screen should look like following:



☞ **Vertical Perc. layer Parameters** tab to edit the material properties of particular layer.

☞ **Value** beside **total porosity**

Type: 0.48

☞ **Value** beside **field capacity**

Type: 0.25

☞ **Value** beside **wilting point**

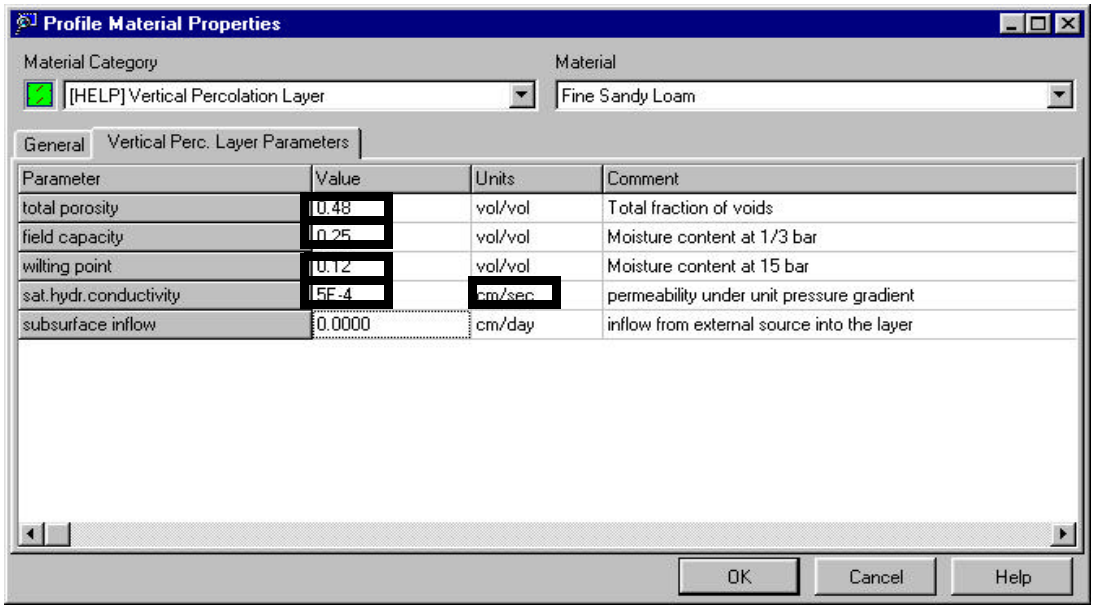
Type: 0.12

☞ **Units** beside the **sat. hydr. conductivity**, a drop-down list with available units will appear.

☞ **cm/sec**

Type: 5E-4, in the **Value** field.

The new **Vertical Perc. layer Parameters** tab will look like the figure below:



☞ **[OK]**

☞ **[-] ,**beside **Fine Sandy Loam** in the Project Tree.

Setting Initial Moisture Conditions & Runoff Parameters

Finally, you will now define your landfills moisture conditions and runoff parameters. This can be completed through the **Case Settings** and **Surface Water Settings** parameter groups located in the project tree.

Visual HELP gives you two options for setting the initial moisture storage and surface water on top of the soil. You may use:

- the model simulated values, or
- the user specified values.

For this specific exercise, the runoff curve number and initial moisture content will be calculated by Visual HELP. These settings, accessible through the **Case Settings** parameter group in the Project Tree are default and do not require yours intervention.

To edit additional parameters for the surface runoff simulation:

☞☞ **Surface Water Settings** from the Project Tree View.

To set the vegetation class,

☞ in the **Value** field, found beside the **Vegetation Class.** The drop down list of available types of the land cover will appear.

☞ **Excellent Stand of Grass:**



☞ **[OK]**

You have now have completed creating your specific profile.

Generating Weather Data

We will now create site specific weather data that will be considered when modeling your profile. As an added feature, Visual HELP also allows you to easily input historical daily data in NOAA and Canadian Climate Centre formats.

IMPORTANT: The HELP model requires three different types of meteorological data that must be provided as daily values:

- *Precipitation (rain or snow),*
- *Solar radiation, and*
- *Mean air temperature.*

In addition, HELP requires a set of parameters to simulate evapotranspiration that are constants for the duration of the simulation.

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HELP will then use this data to:

- *Calculate the volume of water flowing into the landfill, and simulate surface runoff, evaporation, vegetation growth and transpiration, and infiltration during warm periods; and*
- *simulate surface storage, snowmelt, runoff and infiltration during cold periods.*

For synthetic generation of daily values of precipitation, mean temperature, and solar radiation DOS HELP and Visual HELP version 1 included a Weather Generator developed by the Agricultural Research Service of the USDA (U.S. Department of Agriculture), as well as parameters for generating synthetic data for 139 U.S. cities. After Visual HELP 1.01 was released, WHI received requests from our clients worldwide to expand the area of Weather Generator application to other regions of the world.

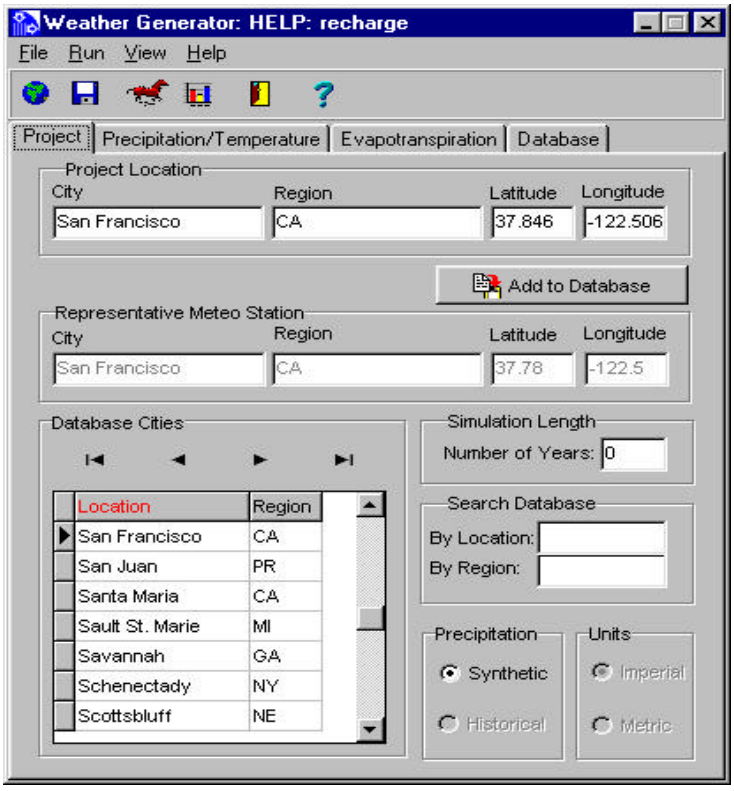
Trying to meet these requests, WHI developed a global database that includes more than 3000 stations and a GIS feature for searching the nearest stations globally for the Visual HELP version 2.1. If your landfill site is not located in our database, we recommend that you choose the closest city to your site and use the generated data for that location for your simulations. Visual HELP will search for the closest location of a given set of co-ordinates. This co-ordinate set can be entered as actual values or interactively with a map.

To import weather data not found in the database, you must modify the format of your data so that it meets the standards of Visual HELP. If you are in Canada, you can automatically import data in the format of the Canadian Climate Centre. Customers in the U.S.A. may automatically import data in the NOAA format. Visual HELP checks NOAA files for missing daily and monthly records and informs the user about the times, for which data are missing to make the correction process easy.

☞ **Run** from the main menu

☞ **Weather Generator**

After an introductory splash screen, the Weather Generator dialogue box will appear.



For this tutorial, you will be using data for the San Francisco weather station.

Parameters for San Francisco appear automatically in the text boxes throughout the **Weather Generator** dialogue boxes after it starts (if you have time, click **Precipitation/Temperature and Database** tabs to see the options to customize the weather parameters).

According to the exercise scenario, you have to edit values for evaporative zone depth and leaf area index.

☞ **Evapotranspiration** tab.

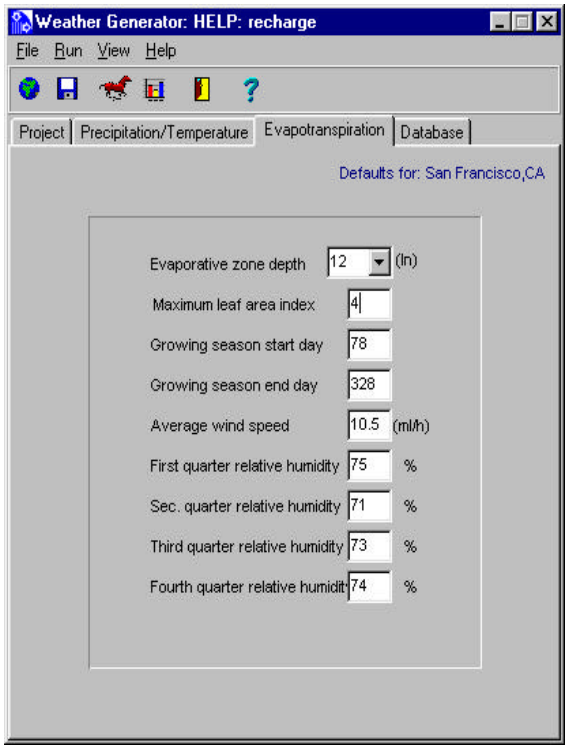
In the text box for **Evaporative zone depth**:

type: 12

In the text box for **Maximum leaf area index**:

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type: **4**



Let's generate weather data for our site for 100 years period.

☞ **Project** tab

☞ **Number of Years** text box,

Type: 100, to represent the number of years you wish to build daily weather data for.

To run the Weather Generator,

☞  ,on the **Weather Generator** toolbar. The Weather Generator will begin computations.

☞  ,to save the generated files

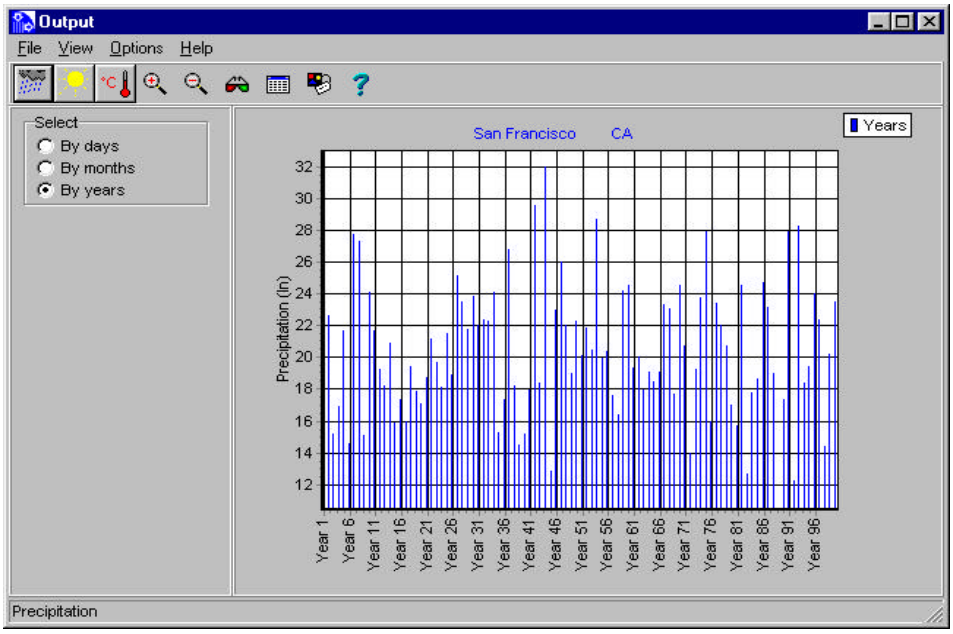
Viewing Weather Data

To view the results for the weather data you just generated,

☞  ,on the toolbar to view the **Output** dialogue box.

☞  ,on the toolbar to view generated precipitation values

By default annual totals will be presented, as shown below.

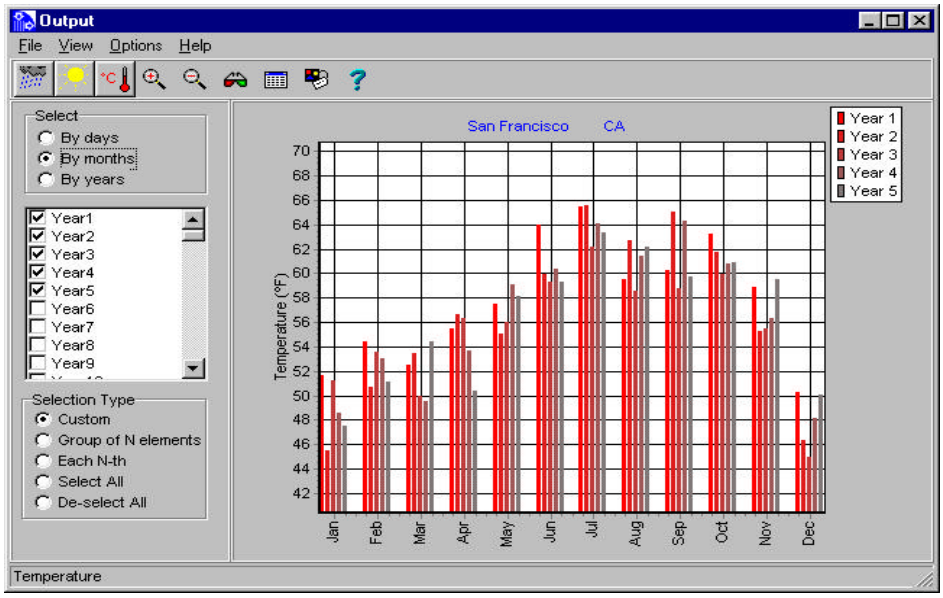


☞  ,to view the generated solar radiation data.

☞  ,to view the generated air temperature data.

☞ **By months** to view monthly outputs.

By default, monthly results for the first five years will be displayed:



☞  ,to view the generated raw data in table format.

☞  ,to close the table.

☞  ,to close the graphics.

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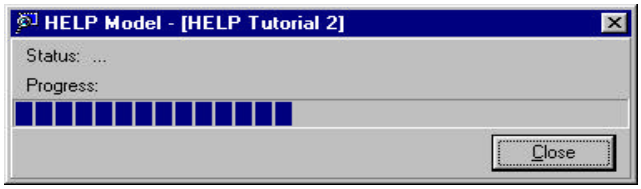
☞  ,to exit the Weather Generator.

You are now ready to run Visual HELP for 100 years using the unsaturated zone profile you created.

Running Visual HELP

☞  in the main toolbar to run the HELP simulation.

The program will collect input files and run the HELP model. A progression bar will appear showing you the status of your model run.

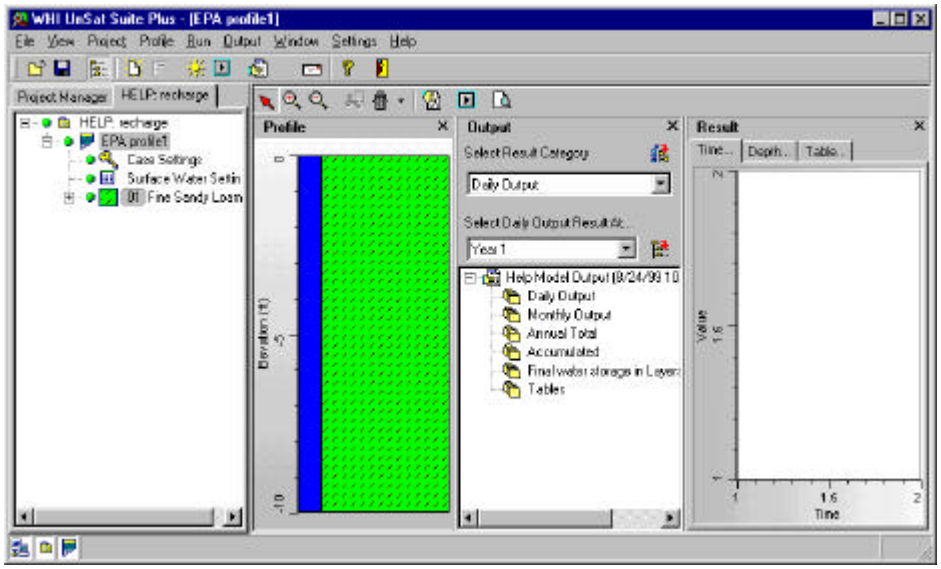


Viewing Results

Although you can easily view and print the original DOS HELP reports, we will only discuss graphical output using the Visual HELP interface.

Viewing the Output Graphs

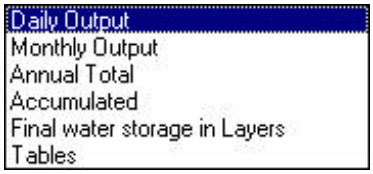
After the model has successfully run, Visual HELP will display the Output View and Result View windows.



☞  ,to enlarge the graphs viewing area

☞ **X** ,in the Profile View to close the window.

To select the output category, click the arrow in the **Select Result Category** drop-down listbox. The following list will appear:



You may select the category you wish to view, however for this exercise, we recommend viewing your results with an **Annual Total** category. This plot will show you the annual amounts of water that were drained during the simulation period and assess volumes of other water balance constituents.

☞ **Annual Total**

The result measures for the the **Annual Total** category will appear in the listbox below. To view all available result measures click the arrow in the drop-down listbox or

☞ **Select Annual Total Result at...** You will see: rate, volume, percent

Rate means the annual rate of the balance constituent, **volume** means the volume for the area represented by the profile, and **percent** means the percent of the amount of water entering the soil surface.

☞ **rate**



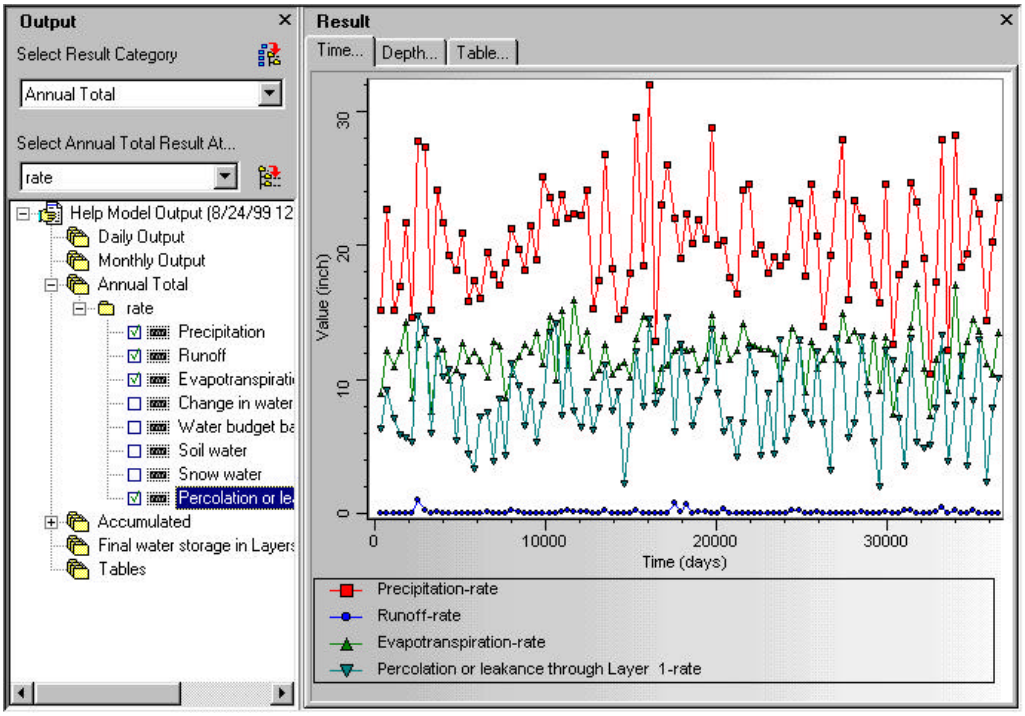
To view all the available results for this specific type of balance, click the icon to the right of the **Select Annual Total Result at...** box.

The list of available balance constituents will open in the Result Tree.

Click the check boxes beside the following variables: **Precipitation, Runoff, Evapotranspiration, Percolation or leakance through Layer 1** (percolation through the bottom).

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The graph of the variables will appear in the Result View window.



This plot illustrates the following:

- At the end of first year, approximately 6.3 inches of recharge (labeled as percolation in the time series plot) is predicted to reach the groundwater.
- Peak recharge is seen to occur in year 7 of the simulation with an annual recharge rate of approximately 14.8 inches for the year.
- Annual recharge can be as low as 2.0 in (year 81).
- A strong correlation exists between the amount of precipitation and recharge. This can be seen in the similar shapes of the precipitation and recharge plots over the 100-year simulation.
- The level of evapotranspiration activity affects the recharge rate. The recharge rate is higher when periods of high precipitation and low evapotranspiration activity correspond.
- Surface runoff does not play important role in profile water balance.

To get information about the principal proportion of the profile water balance constituents, lets examine the output data presented in **Accumulated** category.

From the top menu:

☞ **Output**

☞ **Clear Display Results**

☞ in the **Select Result Category** drop-down listbox.

☞ **Accumulated** from the appeared list:

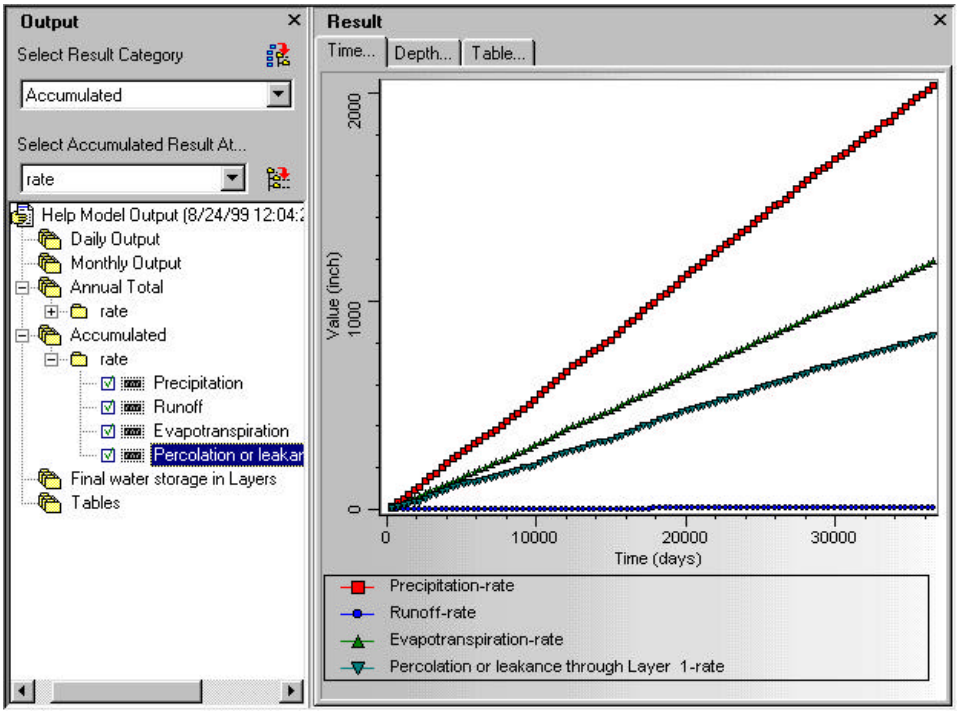
☞ in the **Select Annual Total Result at...** drop-down listbox.

☞ **rate**

To view all the available results for this specific type of balance, click the icon to the right of the **Select Annual Total Result at...** box.

The list of available balance constituents will open in the Result Tree.

Click the check boxes beside the following variables: **Precipitation, Runoff, Evapotranspiration, Percolation or leakance through Layer 1** (percolation through the bottom).



This plot illustrates that recharge is growing gradually totalling around 840 inches in 100 years.

. For specific values, the profile balance constituents may be viewed in table format.

Viewing Tables

To view Visual HELP tables,

☞ **Tables,** from the **Select Result Category** drop-down listbox.

☞ **Annual Totals rate**, from the **Select Table Result at..** lower listbox.

☞ **Add to Output Tree** icon to the right of the lower output listbox.

The table name **Annual Totals rate** will appear in the Output Tree.

Click the check boxes beside **Annual Totals rate.** The table editing dialog box will appear.

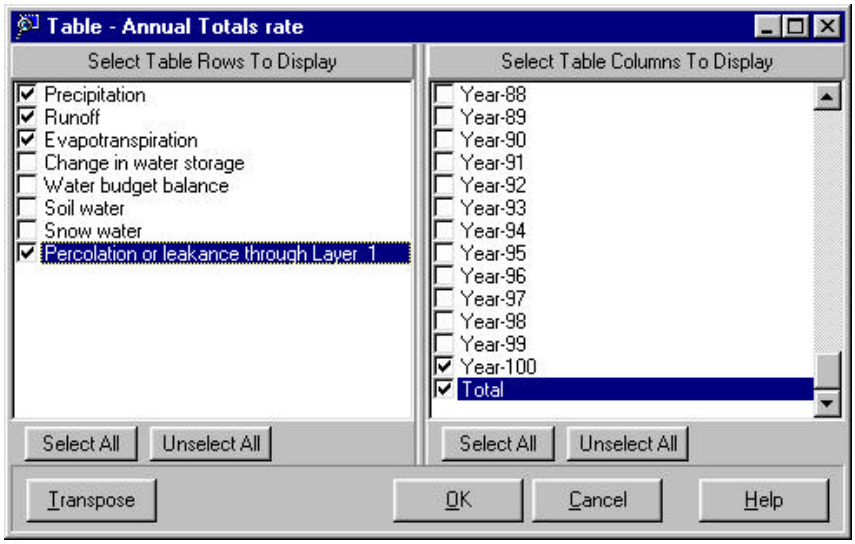
☞ **[Unselect All]** button below the left panel.

Click the check boxes beside the following variables: **Precipitation, Runoff, Evapotranspiration, Percolation or leakance through Layer 1**

☞ **[Unselect All]** button below the right panel.

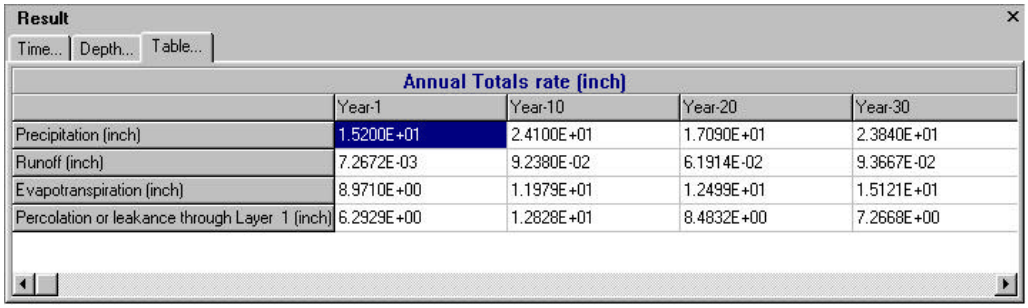
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Click the check boxes beside the following output times: **Year-1, Year-10, Year-20, Year-30, Year-50, Year-100 and Total.**



☞ **[OK]**

The table will appear in the Output Window:



Scroll to the end of the table to see the final values for accumulated volumes.

Precipitation **2034.6 in**

Runoff **8.56 in**

Evapotranspiration **1192.0 in**

Percolation or leakance through Layer 1 **834.78 in**

Because the values presented above are totals for the 100 year period, the average annual recharge will be equal to 8.34 inches at your project location. This number can be used for long term groundwater simulations. If you want to increase the level of detail in your groundwater model, you may use specific recharge values for individual years. To get these values, prepare the **Annual Totals rate** table for all years. To study the seasonal dynamics of the groundwater, you may use **Monthly** option of the output. These and other options are described in Visual HELP manual.

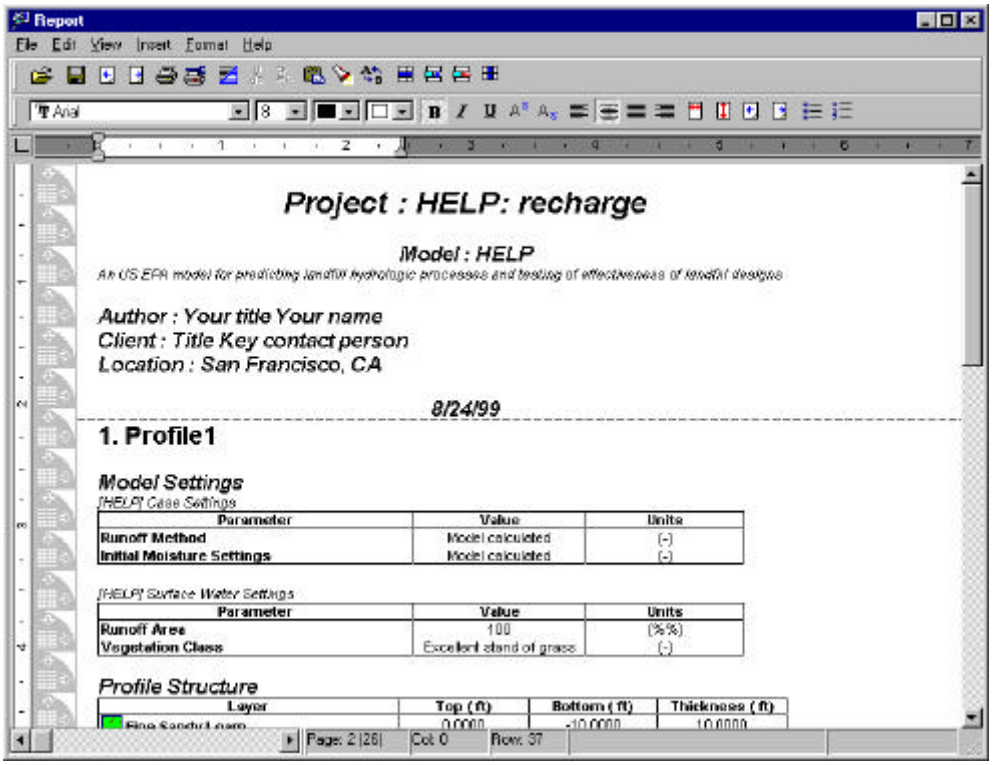
Finally, lets prepare the Visual HELP report.

Creating a Report

As an added feature of Visual HELP, we have developed a time saving, report generator that will help you prepare profession reports of the model simulation.

To create a report and add the project input data, click the  icon from the Operational Icons toolbar.

The Visual HELP Report Generator will display your report in a separate window.



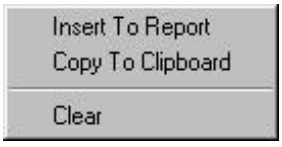
By default, the Report Generator lists all input data for your project. In the **Report** window you may edit the report, input your own text and add any type of graphics or table outputs produced by Visual HELP.

Note: The graphs and tables will be placed at the insertion point.

To add the table from the Result View to the report:

In the **Report** window scroll the cursor to the end of the report

<right click> the table in the Visual HELP Result View window. The following menu will appear:



☞ **Insert To Report**. The table will be inserted into the report.

To access the report (it will be hidden behind your actual Visual HELP window) in the main menu:

☞ **Project** and then select **[view report]** .

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The table may be larger than the Report window allows. In this case, the table will be automatically wrapped to improve the general appearance of the report. The report is fully customizeable and allows you to , insert a headers /footers, change fonts/ letters size, etc.

Once you are satisfied with your report, you may print the report and/or save it for future use.

This concludes the Visual HELP demonstration exercise. Close WHI UnSat Suite Plus by clicking  button in the top right corner.

We hope these instructions have provided you with a good understanding of the capabilities and tools Visual HELP offers for assessment of groundwater recharge. If you have time, we would encourage that you to go back and re-examine some of the other powerful features and analysis capabilities which were not covered by this demo exercise. If you have any questions about the functionality, capabilities, or features of this software, please do not hesitate to contact us.

Conclusions

1) When applied intelligently, the water balance method can be a useful methodology for estimating recharge to groundwater from precipitation.
2) The HELP model (Schroeder, P., et al., 1994) in Visual HELP has been successfully applied by contemporary groundwater practitioners to substantiate historical estimates of groundwater recharge using site-specific data.
3) The results of the 100-year simulation indicate a peak recharge rate of approximately 15-inches will be observed in year 7, and a low of approximately 2-inches is expected in year 81. Average recharge to groundwater will be 8.34-inches.

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