Estimation of Groundwater Recharge using VHELP

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GENERAL

Groundwater as a dependable source and its proximity to various users has led to indiscriminate extraction of this precious natural resource for agricultural, domestic and industrial uses. The rapid and uncontrolled use of groundwater has resulted in many problems. The intensive groundwater development has resulted in depletion in water levels, deterioration in water quality and availability of this resource. The development of groundwater resources in those areas therefore need to be regulated and augmented through suitable measures to provide sustainability. Since rainfall being the main source of recharge to groundwater, substantial volumes of surplus monsoon runoff that flows out into the sea has to be conserved and recharged to groundwater reservoir. The benefits result in terms of rise in water level and consequent increase in storage of the groundwater reservoir.

Ground water recharge is the process by which water percolates down the soil and reaches the water table, either by natural or artificial methods. Rainfall is the principal source for replenishment of moisture in the soil water system and recharge of ground water. Other sources include recharge from rivers, streams, irrigation water, etc. Artificial groundwater recharge (AGR) is a process by which the groundwater reservoir is augmented at a rate exceeding that obtaining under natural conditions or replenishment. Any man-made scheme or facility that adds water to an aquifer may be considered to be an artificial recharge system. The rainwater which is not harvested and stored mostly runs off the land surface and gets wasted without proper use. Where the rains are intense and continuous over some days, the runoff turns into flood inundating vast tracts of land and damages life and property. When the rainfall is scanty, part of it gets lost by interception by tree canopy, evaporation and runoff leaving very little of it for storage and future use. Although water is renewable, it is a finite commodity. Therefore rainwater harvesting (RWH) and storage becomes imperative in either case, for effective use by people, livestock and nature.

While in the urban areas rain water harvesting is practiced for drinking, domestic, gardening, and ground water recharge purposes; in rural areas it is undertaken more extensively for irrigation, dry land agriculture, horticulture, ground water recharge, domestic, livestock, inland fisheries, duck rearing and for multifarious other similar purposes. The sub-surface reservoirs are technically feasible alternatives for storing surplus monsoon runoff. The sub-surface storages have advantages of being free from the adverse effects like inundation of large surface area, loss of cultivable land, displacement of local population, evaporation losses and sensitivity to earthquakes. The recharging structures for groundwater are of small dimensions and cost effective, such as check dams, percolation tanks, surface spreading basins, pits, sub- surface dykes, etc. Figure 1 shows a schematic view of the groundwater system.

NATURAL AND INDUCED RECHARGE OF THE AQUIFER

Natural recharge is the groundwater replenishment from runoff or snowmelt, through seepage from the land surface. Induced natural recharge occurs when intensive exploitation of groundwater close to river results in depletion of ground water level. This phenomenon is well known in areas where river flows all the year: but it may also occur in semi-arid climates where depletion of the piezometric level of an aquifer underlying a temporary river creates the empty space in the aquifer which facilitates its recharge during floods.

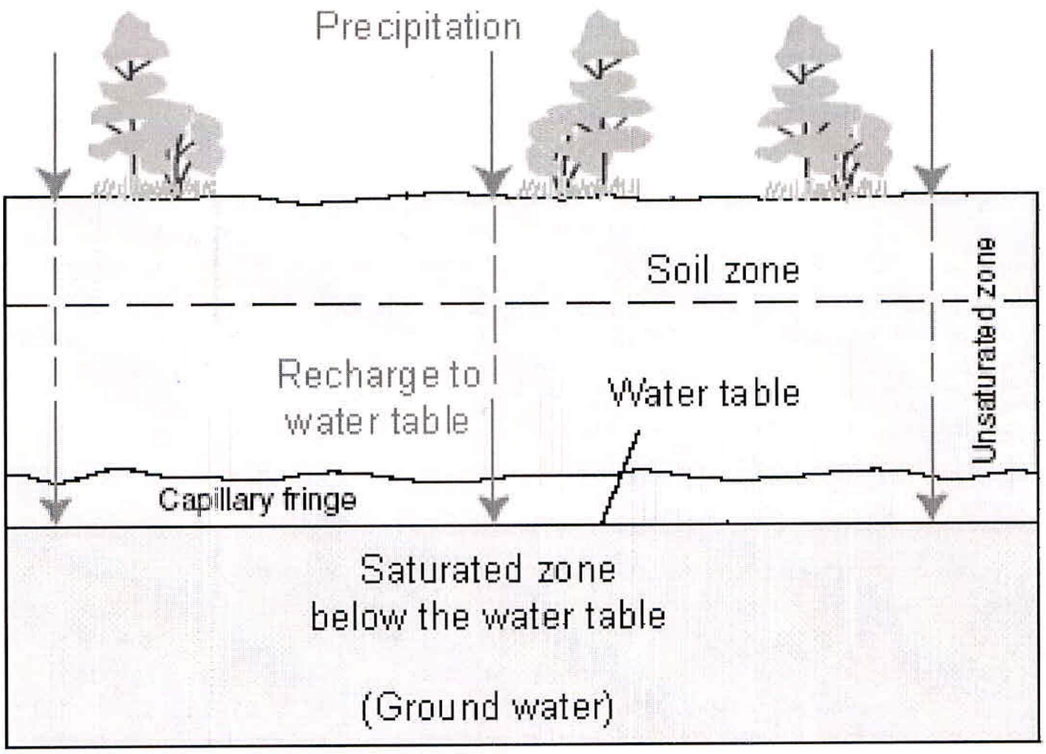

Fig. 1 Schematic view of the groundwater system

ARTIFICIAL RECHARGE TECHNIQUES

In order to use underground reservoir to store a significant volume of water – possibly of the same order of magnitude as the annual runoff –with the intent to use it at later stage, it is necessary to ascertain the potential storage capacity of the ground water reservoir as well as its suitability for being recharged by the surface water and for easily returning the stored water when needed. The ground water reservoir should present sufficient free space between ground surface and water table to accommodate and retain the water to be recharge for the period during which water is not needed.

This condition requires accurate and detailed hydro-geological investigations including geological mapping, geophysics and reconnaissance drilling, in order to determine the configuration and the storage capacity of the underground reservoir. Artificial recharge of aquifers can be achieved using following three different methods:

1. Surface Spreading
2. Watershed Management (Water Harvesting)
3. Recharge Wells.

The artificial recharge techniques vary widely similar to the variations in hydro-geological conditions. The direct technique of recharge is generally preferred over indirect methods with ensured water quality standards. Based on the experiments and R&D studies in the country on artificial recharge following techniques have been developed for augmenting the ground water:

1. **Direct surface techniques**
   - Flooding
   - Basins or percolation tanks
   - Stream augmentation
   - Ditch and furrow system
   - Over irrigation
2. **Direct sub surface techniques**
   - Injection wells or recharge wells
   - Recharge pits and shafts
   - Dug well recharge
   - Bore hole flooding
   - Natural openings, cavity fillings.
3. **Combination surface – sub-surface techniques**
   - Basin or percolation tanks with pit shaft or wells.
4. **Indirect Techniques**
   - Induced recharge from surface water source.
   - Aquifer modification.

Depending upon geomorphologic and physiographic conditions as well as conditions suitable for recharge, availability of source water the approach for water harvesting and artificial recharge can be used suiting to the environment. The suitability of an aquifer for recharging has been estimated from the following parameters;

- Surface material which has to be highly permeable so as to allow water to percolate easily.
- The unsaturated zone should present a high vertical permeability, and vertical flow of water should not be restrained by less permeable clayey layers.
- Depth to water level should not be less than 7 to 10m.
- Aquifer transmissivity should be high enough to allow water to move rapidly from the mound created under the recharge basin.

An adequate transmissivity for recharge is also a good indicator of the aquifer capacity to produce high well discharge and therefore easily to return the water stored.

ESTIMATION OF GROUNDWATER RECHARGE USING VISUAL HELP MODEL

The Hydrologic Evaluation of Landfill Performance (HELP) program, Versions 1, 2 and 3, was developed by the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, for the U.S. Environmental Protection Agency (EPA), Risk Reduction Engineering Laboratory, Cincinnati, OH, in response to needs in the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, better known as Superfund) as identified by the EPA Office of Solid Waste, Washington, DC.

HELP computer program is a quasi-two-dimensional hydrologic model of water movement across, into, through and out of landfills. The model accepts weather, soil and design data and uses solution techniques that account for surface storage, snowmelt, runoff, infiltration, vegetative growth, evapotranspiration, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geo-membrane or composite liners.

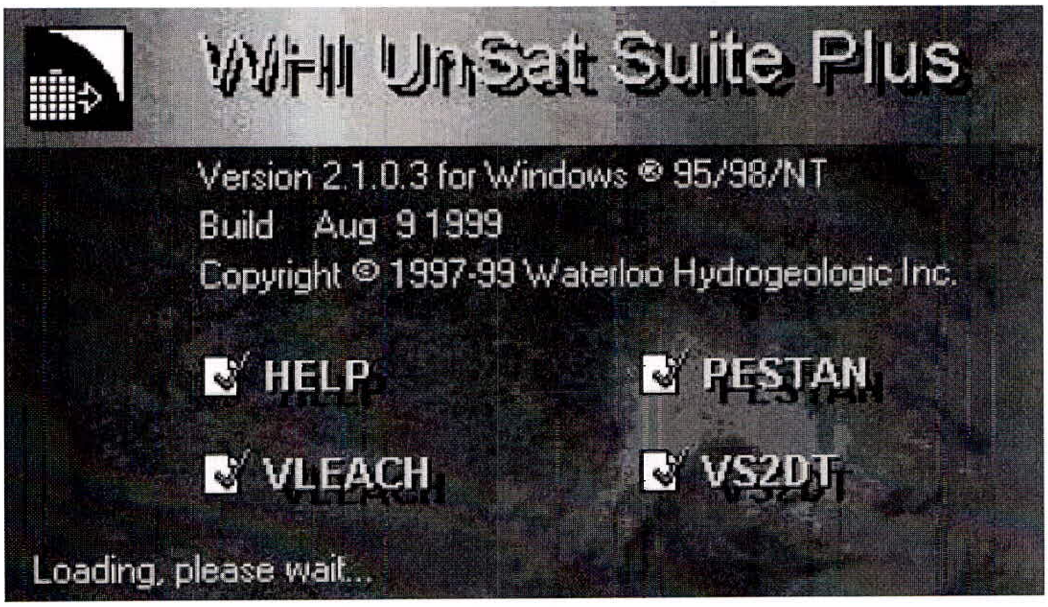

Fig. 2 Visual HELP Model

The program was developed to conduct water balance analyses of landfills, cover systems, and solid waste disposal facilities. As such, the model facilitates rapid estimation of the amounts of runoff, evapotranspiration, drainage, leachate collection, and liner leakage that may be expected to result from the operation of a wide variety of landfill designs.

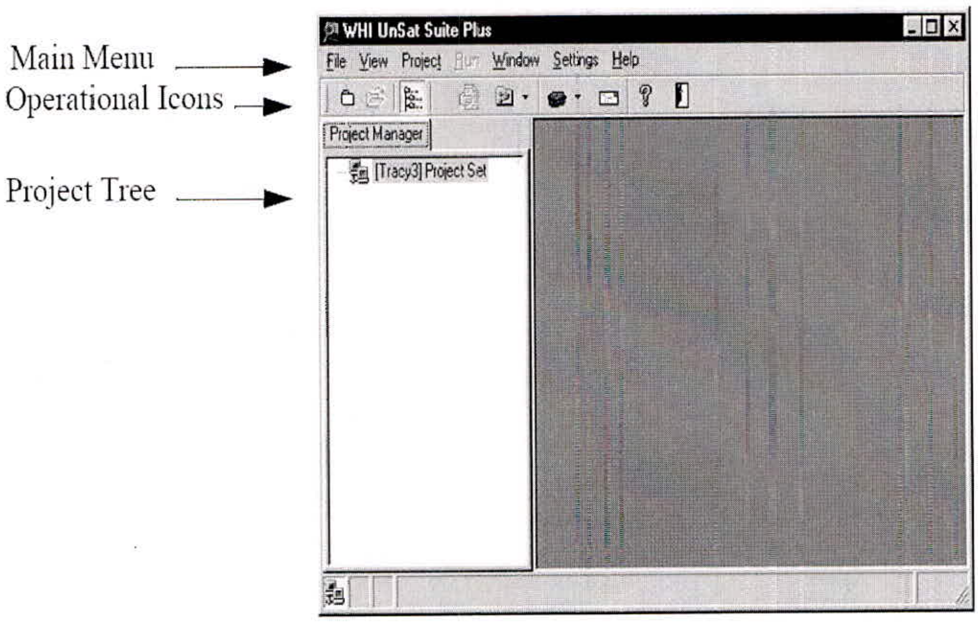

Fig. 3 Basic Structure of VHELP

The HELP model requires daily climatologic data, soil characteristics, and design specifications to perform the analysis. Daily rainfall data may be input by the user, generated stochastically, or taken from the model's historical data base. The model contains parameters for generating synthetic precipitation for a number of cities worldwide. Daily temperature and solar radiation data are generated stochastically or may be input by the user.

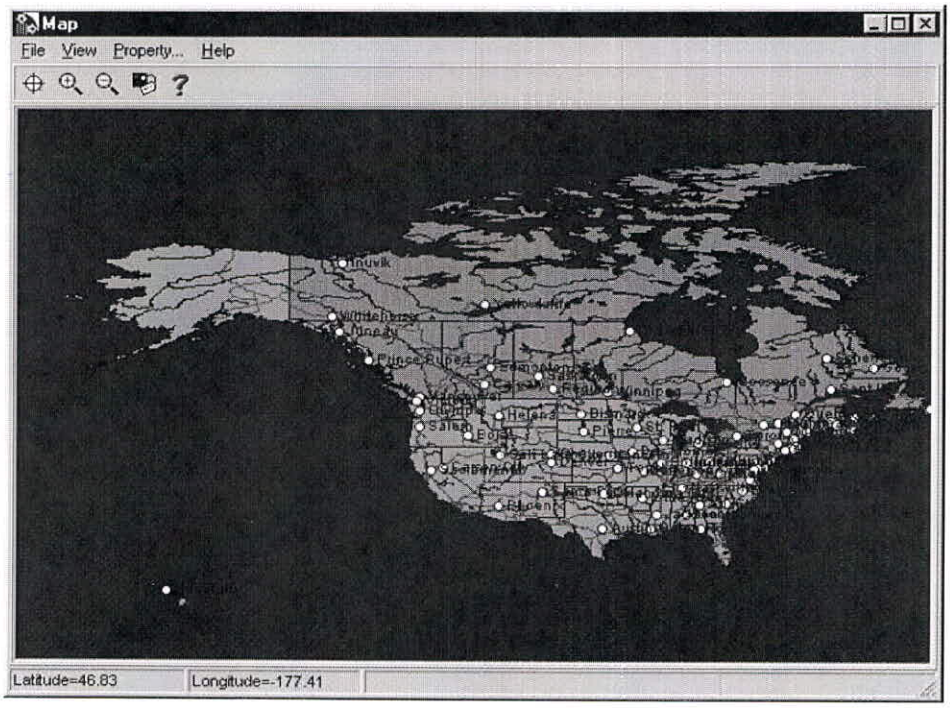

Fig. 4 Geographical selection of recharge site

Necessary soil data include porosity, field capacity, wilting point, saturated hydraulic conductivity, and Soil Conservation Service (SCS) runoff curve number for antecedent moisture condition II. The model contains default soil characteristics for 42 material types for use when measurements or site-specific estimates are not available. Design specifications include such things as the slope and maximum drainage distance for lateral drainage layers, layer thicknesses, leachate recirculation procedure, surface cover characteristics and information on any geo-membranes. Based on the soil profile data, soil profile can be defined in the VHELP as shown below.

There could be a no. of profile of different soil material like, sand, clay, sandy loam, etc. Figure 6 shows a definition sketch of a soil profile which can be designed or modified user-specified.

Under the soil profile general details, type of material, slope conditions, surface slope length, layer thickness, etc are required.

Once these details are defined, soil material properties needs to be given viz. total porosity, field capacity, wilting point, saturated hydraulic conductivity and subsurface inflow.

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 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 (Abraham, B., et al., USAE Waterways Experimental Station, 1998). The water balance method calculates potential net recharge as a residual of all other water balance components and is expressed as:

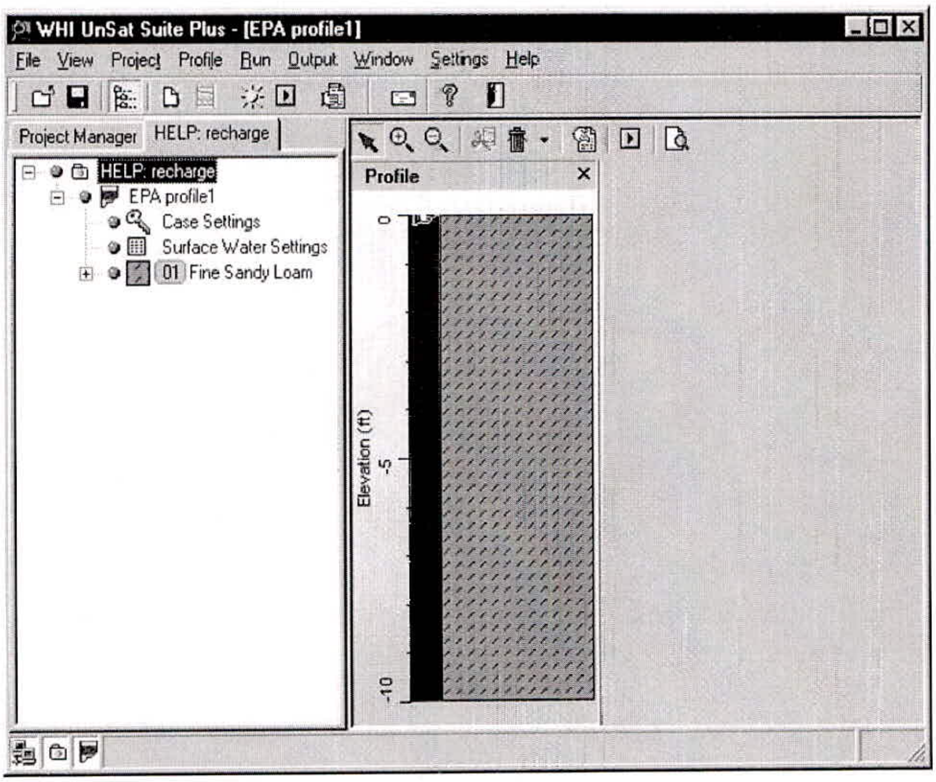

Fig. 5 Preparation of soil profile using VHELP

$$R = P - D - ETa - \Delta W \quad \ldots \quad (1)$$

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

Various data required for the estimation of groundwater recharge include total porosity, saturated hydraulic conductivity, soil texture, field capacity, wilting point, initial soil water content. The data required for vegetation include vegetation density, root zone depth and leaf area index (LAI). The meteorological data required by the HELP model are precipitation, minimum-maximum temperature, solar radiation, humidity and wind speed.

The HELP program incorporates a routine for generating daily values of precipitation, mean temperature, and solar radiation. This routine was developed by the USDA Agricultural Research Service (Richardson and Wright, 1984) based on a procedure described by Richardson (1981). The HELP user has the option of generating synthetic daily precipitation data rather than using default or user-specified historical data. Similarly, the HELP user has the option of generating synthetic daily mean temperature and solar radiation data rather than using user-specified historical data. The weather generator of HELP model generates data up to 100 years. Figure 9 shows the inbuilt weather generator of VHELP.

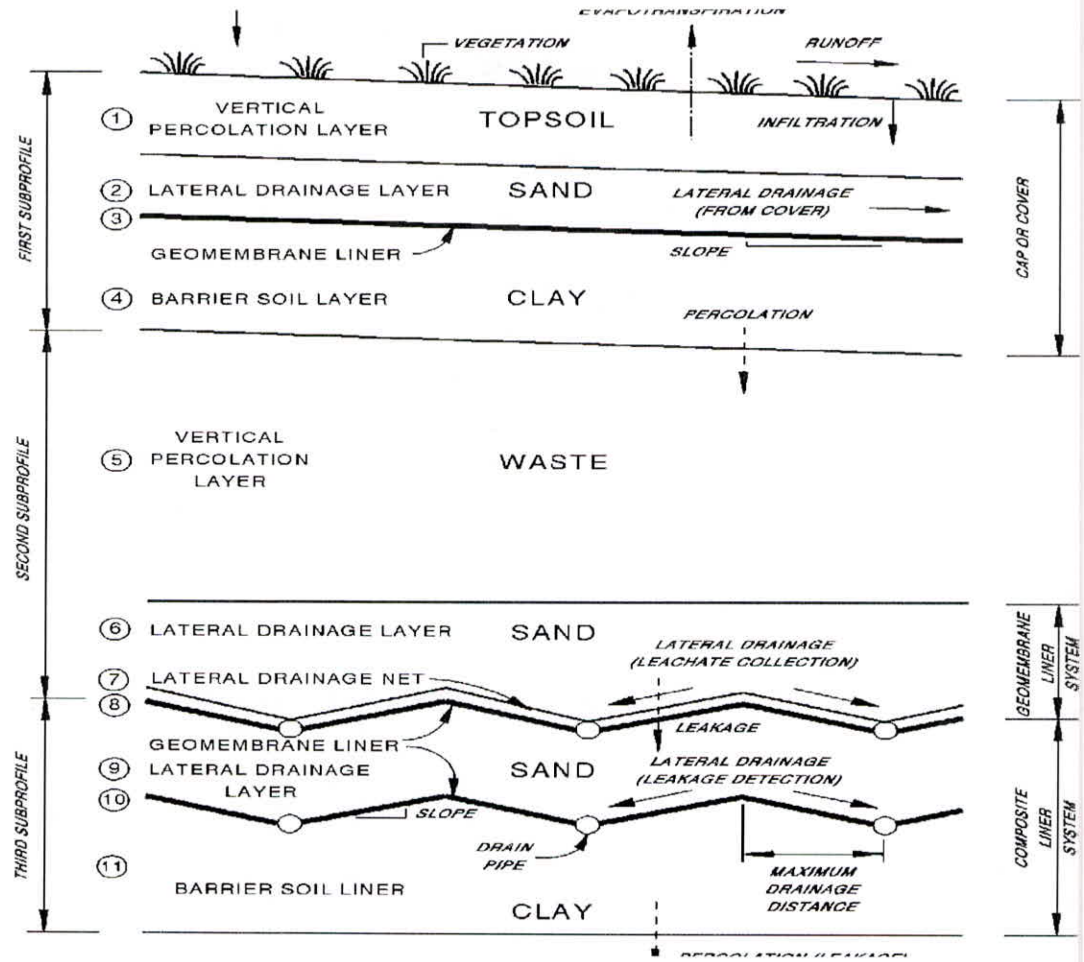

Fig. 6 Definition sketch of a soil profile using HELP model

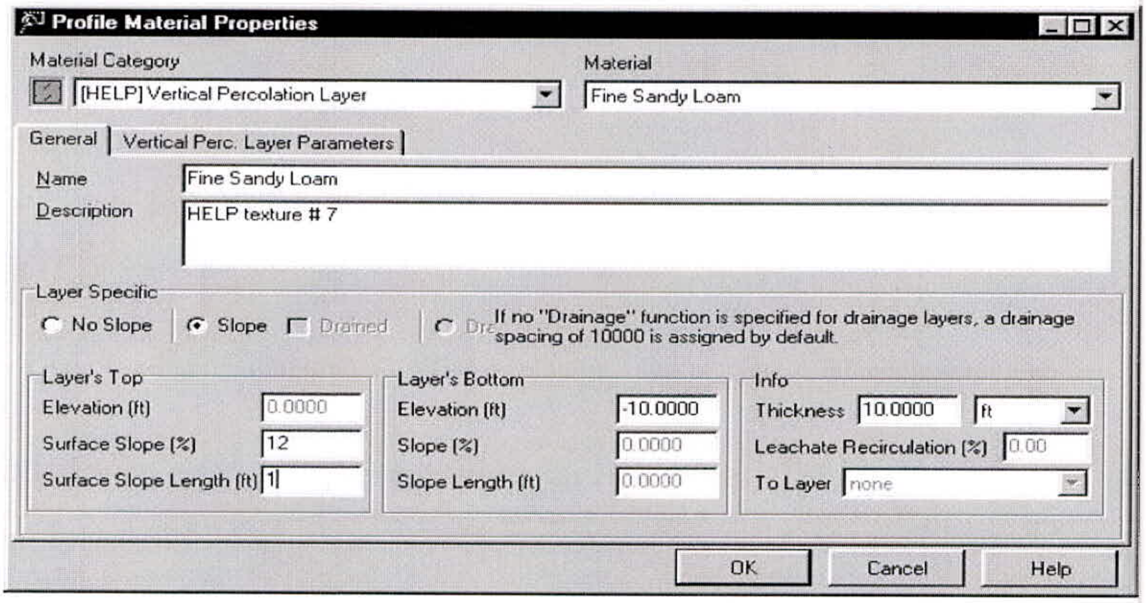

Fig. 7 Soil profile general properties

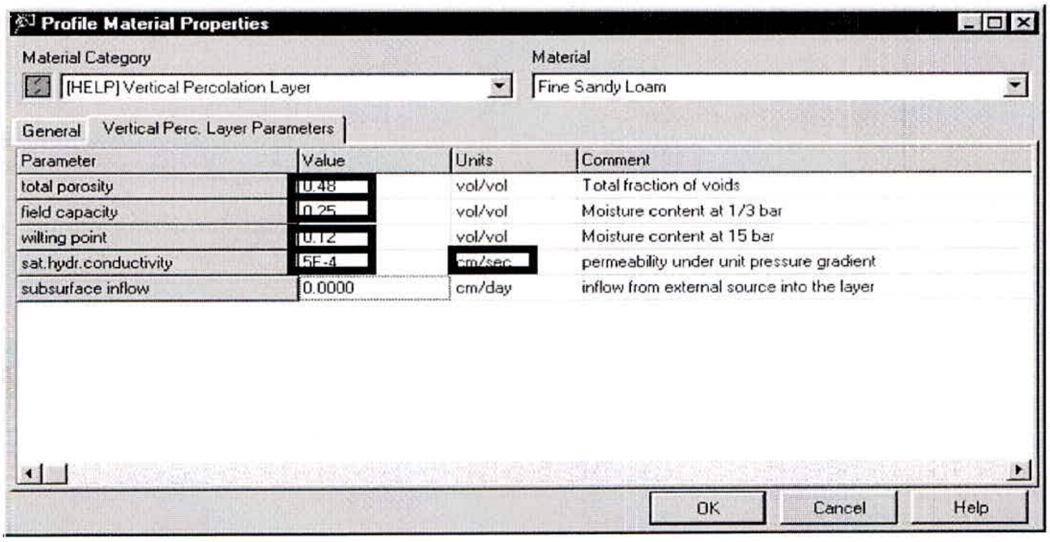

Fig. 8 Soil properties of vertical percolation layer

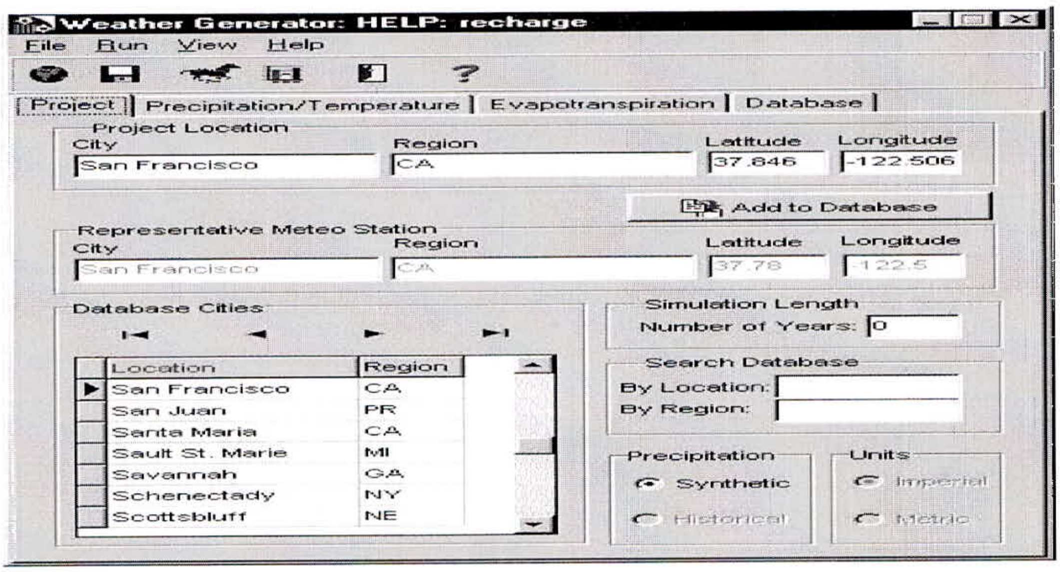

Fig. 9 Weather generator of HELP Model

The VHELP model also computes the evapotranspiration rate. When the weather data is imported or generated, the weather generator requires some root zone, vegetation and meteorological parameters to estimate the evapotranspiration. Various parameters required for the computation of evapotranspiration are shown in Figure 10.

Finally the VHELP model is run to get the outputs. It computes various components of the water balance. The HELP model gives the potential net recharge to groundwater. The recharge rates can be estimated on daily, monthly or annual basis. The results of the HELP model are in a water budget form which includes precipitation, runoff, evapotranspiration and percolation through soil layers. A view of the model outputs for the annual totals is given in Figure 11. Finally a report can be generated indicating model settings, profile structure and water budgeting.

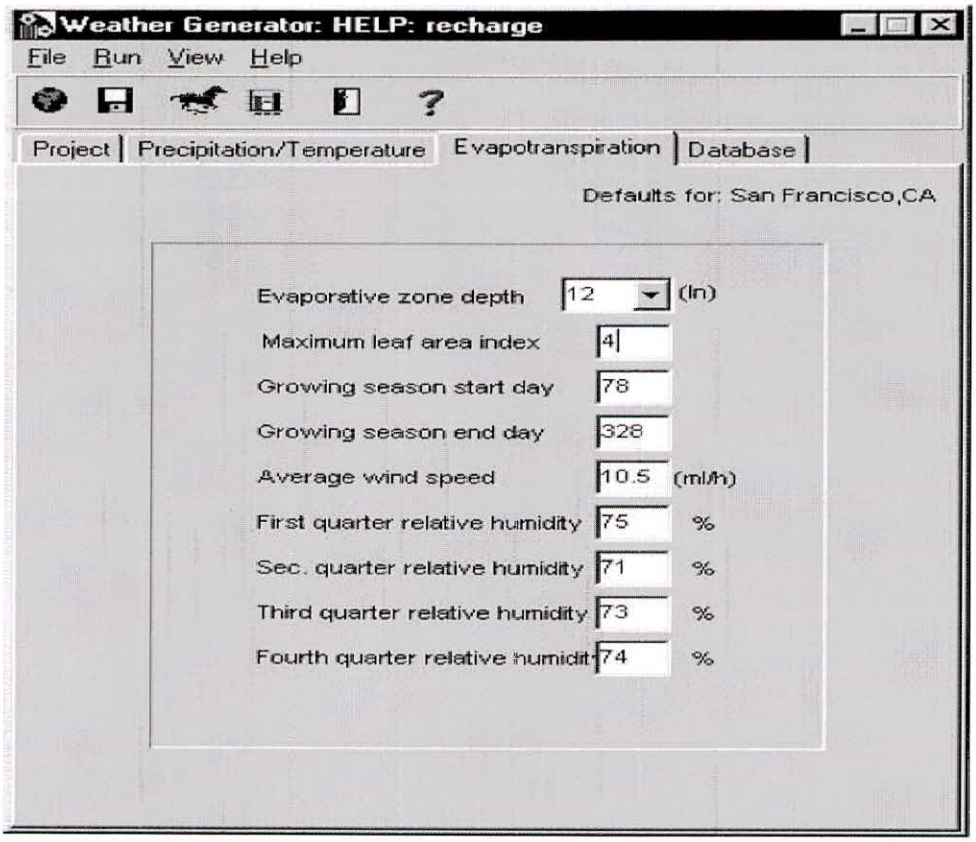

Fig. 10 Parameters for estimation of evapotranspiration

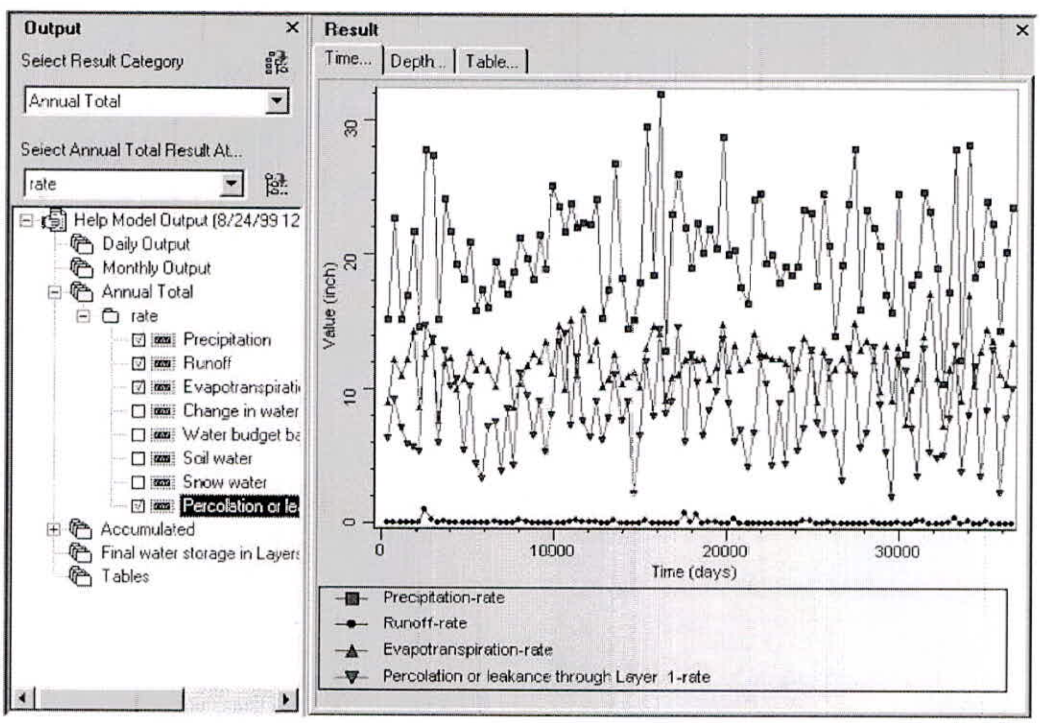

Fig. 11 Output results of VHELP

CONCLUSIONS

The water balance approach of HELP model can be a useful methodology, if applied properly, for estimating site-specific recharge to groundwater from precipitation. The HELP model has been successfully applied by contemporary groundwater practitioners to substantiate historical estimates of groundwater recharge using site-specific data.

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